

The Potential Role of Hydrogen and Natural Gas in Energy Transition Strategies in Arab Countries

الدور المحتمل للهيدروجين والغاز الطبيعي في استراتيجيات التحول الطاقوي في الدول العربية

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Abstract:

This study examines the evolving hydrogen sector in Arab countries within the context of energy transition strategies, emphasizing the interplay with the natural gas industry. It analyzes current developments, future prospects, and recent policy decisions regarding sustainable hydrogen production. Additionally, it highlights the potential synergies between natural gas and hydrogen, leveraging existing infrastructure and expertise. The study underscores the pivotal role of both hydrogen and natural gas in diversifying energy sources, addressing environmental challenges, and fostering economic growth through export opportunities, aligning with the Sustainable Development Plan for 2030.

Keywords :Renewable energy, Natural Gas, Hydrogen, Energy transition, Arab countries

Jel Classification Codes :Q43; Q48

Abstract in Arabic:

تتناول هذه الدراسة تطور قطاع الهيدروجين في البلدان العربية في سياق استراتيجيات التحول الطاقوي، مع التركيز على التفاعل مع صناعة الغاز الطبيعي. وتحلل التطورات الحالية والآفاق المستقبلية وقرارات السياسة الأخيرة المتعلقة بإنتاج الهيدروجين المستدام. بالإضافة إلى ذلك، فإنها تسلط الضوء على أوجه التآزر المحتملة بين الغاز الطبيعي والهيدروجين، والاستفادة من البنية التحتية والخبرة الحالية. وتؤكد الدراسة على الدور المحوري لكل من الهيدروجين والغاز الطبيعي في تنويع مصادر الطاقة، ومواجهة التحديات البيئية، وتعزيز النمو الاقتصادي من خلال فرص التصدير للدول العربية، بما يتماشى مع خطة التنمية المستدامة لعام 2030.

كلمات مفتاحية: الطاقة المتجددة، الغاز الطبيعي، الهيدروجين، التحول الطاقوي، الدول العربية

تصنيفات JEL: Q43 ; Q48

Introduction:

The economy of the Arab region heavily relies on fossil fuels as a source of energy, raw materials, economic growth, and export revenues. This situation not only has direct negative impacts on the climate but also poses a serious

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threat to the region's economy. Therefore, addressing environmental and economic vulnerabilities is imperative, as the situation will worsen without swift measures towards energy transition.

Diversifying the energy mix is a key aspect of energy transition. In addition to accelerating the adoption of renewable energy and electrification in relevant sectors, exploring alternative energy sources, including hydrogen production, usage, and exportation, is necessary to ensure a fair and sustainable transition in the energy sector.

Hydrogen can play an effective role in the energy transition process within the framework of international efforts to reduce greenhouse gas emissions, improve air quality, and create a low-carbon energy future leading to carbon neutrality. Hydrogen is a safe and clean energy source that does not produce any carbon dioxide emissions when combusted. Moreover, it is versatile, applicable in fuel cells for vehicles, as a heat source in residential sectors, or as a raw material in the industrial sector.

Developing and utilizing low-carbon hydrogen, whether blue or green, in the Arab region can play a significant role as part of a suite of clean energy solutions. It can leverage the region's natural gas resources and expanding renewable energy potentials. In the long term, transitioning to a hydrogen economy can ensure that Arab countries do not excessively rely on a few selected energy sources, thus making them more resilient and less vulnerable to supply shocks in the energy sector.

Hence, this paper seeks to address the following questions:

- What is the significance and role of hydrogen within energy transition strategies and future renewable energy mix in Arab countries?

In exploring the significance and role of hydrogen within energy transition strategies in Arab countries, several key sub-questions arise:

1. What are the current initiatives and policies regarding hydrogen adoption and integration into energy transition strategies in Arab countries?
2. How can Arab countries leverage their existing natural gas resources and renewable energy potentials to develop and utilize low-carbon hydrogen (both blue and green) effectively?
3. What are the economic, environmental, and geopolitical implications of transitioning towards a hydrogen economy in Arab countries, and how can potential challenges be mitigated?

Based on the examination of energy transition strategies in Arab countries, the following hypothesis is proposed:

- Arab countries can leverage natural gas and renewables to produce low-carbon hydrogen, fostering energy diversification and economic growth

Research Methodology:

This study employs a combination of qualitative and quantitative research methods to investigate the integration of hydrogen into energy transition strategies in Arab countries. Qualitative analysis involves reviewing policy documents, governmental initiatives, and expert opinions to understand the regulatory landscape and identify key challenges and opportunities. Quantitative analysis includes data collection on energy consumption, production, and emissions to assess the potential impact of hydrogen adoption. Additionally, case studies and comparative analysis will be utilized to provide insights into successful hydrogen implementation strategies from other regions.

Literature Review:

Several studies highlight the potential of hydrogen as a game-changer in Arab countries' energy transition. Jacobson et al. (2017) emphasize the crucial role of renewable energy, including hydrogen, in mitigating global warming. Their research underscores the synergistic effects of integrated systems incorporating hydrogen for a sustainable future. Similarly, a study by Al-Saidi et al. (2023) explores the nexus between renewable energy and carbon emissions, specifically focusing on the significance of hydrogen energy. They conclude that green hydrogen production using renewable sources can significantly contribute to achieving Goal 7 of the UN's Sustainable Development Goals – affordable and clean energy.

However, challenges remain, as highlighted by various researchers. The high cost of green hydrogen production compared to traditional fuels is a major concern, as emphasized by Fattoum et al. (2023) in their study on the prospect of green hydrogen in Saudi Arabia. Additionally, extensive infrastructure development is required for storage, transportation, and utilization, as identified by The International Renewable Energy Agency (IRENA) in their 2021 report on green hydrogen.

Also, structural adjustments in key sectors of the economy are necessary to create the appropriate conditions for hydrogen to play its role as the energy of the future, as Bravo Melgarejo. S (2021) demonstrates in his study on the role of hydrogen in the energy transition through challenges related to hydrogen's deployment in the transport sector and the use of hydrogen-based storage in the electricity market.

Natural gas, though not a zero-carbon solution, presents potential benefits as a transition fuel. The Oxford Institute for Energy Studies (2021)

acknowledges its cleaner emissions compared to coal and oil, making it a preferable option during the initial stages of energy transition. However, they also emphasize the importance of carbon capture and storage technologies to mitigate the environmental impact of natural gas throughout its lifecycle.

1. Hydrogen production, transportation, and storage are not novel endeavors;

Indeed, significant quantities of hydrogen have been produced and utilized for decades, primarily serving as a raw material in industries such as ammonia and methanol production. However, the increasing global momentum arises from a recontextualization of hydrogen as a clean energy source upon which future energy systems are predicated. Notably, hydrogen combustion yields no carbon dioxide emissions, thereby holding promise for realizing a global carbon-neutral economy.

1.1 Hydrogen Production:

Pure hydrogen can be produced through various methods, although natural hydrogen extraction sites, both terrestrial and marine, remain limited. Currently, natural hydrogen is only extracted at a single location, the Borakibougou Basin in Mali, West Africa, where the Canadian company Hydroma operates a pilot project. Globally, all consumed hydrogen is presently produced utilizing sophisticated technological processes (KETI, 2020).

While hydrogen holds immense promise as a clean energy carrier in the Arab world's energy transition, significant challenges remain. According to the International Renewable Energy Agency (IRENA), global hydrogen production in 2022 stood at around 75 million tonnes per year (MtH₂/yr) as pure hydrogen and an additional 45 MtH₂/yr as part of a mix of gases. This translates to approximately 3% of global final energy demand, equivalent to the annual energy consumption of Germany. Notably, around 70% of the energy required for dedicated hydrogen production in 2022 still relied on natural gas, with coal also contributing significantly, particularly in China, which alone accounted for 90% of global coal consumption for hydrogen production (IRENA, 2023). As emphasized by Fattoum et al. (2023), the high cost of green hydrogen production compared to traditional fuels remains a significant hurdle. Additionally, extensive infrastructure development, as identified by IRENA (2021), is required for widespread adoption.

Natural gas, although not a perfect solution, offers potential as a bridge fuel. The Oxford Institute for Energy Studies (2021) acknowledges its cleaner

emissions compared to coal and oil, but stresses the importance of carbon capture and storage technologies, currently limited to a small fraction of global hydrogen production, to mitigate its environmental impact.

A nuanced approach that acknowledges the potential and limitations of both hydrogen and natural gas is crucial. While studies by Jacobson et al. (2017) and Al-Saidi et al. (2023) highlight the promise of green hydrogen for decarbonization and achieving sustainable development goals, overcoming cost and infrastructure hurdles remains essential. Arab nations like the UAE and Saudi Arabia, demonstrating leadership with ambitious green hydrogen plans, showcase the potential for a clean energy future. Ultimately, a balanced strategy that leverages the strengths of both hydrogen and natural gas, while addressing their limitations and investing in carbon capture technologies, is likely the key to a successful and sustainable energy transition in the Arab world.

Dominating the market but contributing to the problem, steam methane reforming (SMR) currently reigns supreme as the primary method for hydrogen production. This process, reliant on natural gas and high temperatures, churns out hydrogen but also generates significant carbon dioxide emissions. Gasification, another option, utilizes coal or biomass as feedstocks, further adding to the carbon footprint (Shell, 2017).

Electrolysis, however, offers a glimmer of hope for a cleaner future. This method employs electricity to split water into hydrogen and oxygen, but its environmental impact hinges critically on the source of the electricity used. Unfortunately, as of 2022, only around 1% of global pure hydrogen production comes from electrolysis powered by renewable energy sources, highlighting the urgent need for substantial investment in clean energy infrastructure (IRENA, 2023).

Some of the aforementioned technologies, particularly steam methane reforming, can be coupled with carbon capture and storage (CCS) or carbon capture, utilization, and storage (CCUS) facilities. In such cases, the produced hydrogen is termed "blue hydrogen." Conversely, hydrogen produced via electrolysis using electricity generated entirely from renewable energy sources is termed "green hydrogen" and is considered the preferable option for long-term carbon removal measures.

A number of terminologies are used to categorise hydrogen based on how it is produced, including sustainable or clean. Even more common is the use of colours. However, there are no agreed definitions for these terms, and they can obscure many different levels of potential emissions. These last estimated per kg of hydrogen produced can vary substantially depending on

several factors such as the technology used, the source of the electricity used in the production process and the carbon capture rate (IEA, 2023)

Despite the absence of recognized universal appellations and the fact that these color definitions may change from one country to another, the following classifications are generally used to describe the different types of hydrogen based on the primary energy source used in the production process (Arcos, J.M.M & Santos, D.M.F, 2023).

Black, brown and grey hydrogen : these three are the most polluting. Grey hydrogen is the most common form and is generated from natural gas (or methane) through a process called steam reforming. Grey hydrogen is generally used in the petrochemical industry and for ammonia production. GHG emissions of this process remain moderate compared to those of black or brown hydrogen, the least environmentally friendly hydrogen production method, using bituminous and lignite coal.

Blue hydrogen : is essentially the same as grey hydrogen, but the carbon generated from steam reforming is captured and stored underground through industrial carbon capture and storage (CCS). Therefore this hydrogen is described as low carbon (80-90% of the generated carbon is captured). Blue hydrogen is considered an alternative solution during the energy transition, as it still offers the possibility of consuming fossil fuels, but with a reduction in the carbon footprint.

Green hydrogen : Green hydrogen called clean hydrogen, renewable hydrogen or low-carbon hydrogen, is produced through a process called electrolysis by using clean electricity from surplus renewable energy sources. Green hydrogen is seen as the best way of harmonizing the intermittency of renewables. Green hydrogen only represents a small percentage of the total hydrogen production because of the high costs involved in its process. However, it has an excellent projection in the perspective of satisfying net-zero carbon plans.

Turquoise hydrogen : the production of this form of hydrogen is still in the experimental phase. It refers to a way of creating the element through a process called methane pyrolysis, which generates solid carbon.

Pink hydrogen : it is created through electrolysis of water powered by nuclear energy. This energy is also used in other ways to produce purple (violet) hydrogen and red hydrogen.

Yellow hydrogen : is produced with electrolysis using electricity from the energy grid. Carbon emissions vary significantly in time, depending on the grid's energy sources.

White hydrogen : White hydrogen or natural hydrogen refers to hydrogen that occurs naturally underground. Strategies and techniques for exploiting this hydrogen are still in the development phase.

1.2 Transportation and Storage:

Hydrogen production, transportation, and storage vary from one country to another in terms of technologies and primary sources utilized in production. The choice of technology is influenced by cost-related and non-cost-related factors. With increasing concerns about achieving climate targets by mid-century and SDG 7 by 2030, particularly in the transportation sector, technology selection will be significantly influenced by these drivers, policies, laws, and related systems (Shell, 2017).

Available data suggests that roughly 80% of hydrogen is utilized near its production sites, with the remaining 20% transported via trucks or pipelines. However, this is expected to change significantly in the coming decade as the hydrogen economy globalizes and interregional trade increases (IEA, 2019).

Several methods exist for hydrogen transportation, each with its own advantages and limitations :

- **Pipeline transportation:** Blending hydrogen with natural gas in existing pipelines or utilizing dedicated hydrogen pipelines remains the most cost-effective option for medium and long distances.
- **Liquid hydrogen:** While suitable for shipping pure hydrogen, this method requires significant energy for cryogenic liquefaction and transportation, impacting overall efficiency.
- **Ammonia:** Converting hydrogen into ammonia offers a versatile option for long-distance transportation at ambient temperatures. However, the conversion and re-gasification processes add complexity and potential energy losses.
- **Liquid organic hydrogen carriers (LOHCs):** This emerging technology utilizes organic liquids that reversibly bind with hydrogen, enabling easier transportation and storage at ambient conditions. However, LOHCs are still under development, and their feasibility requires further evaluation.

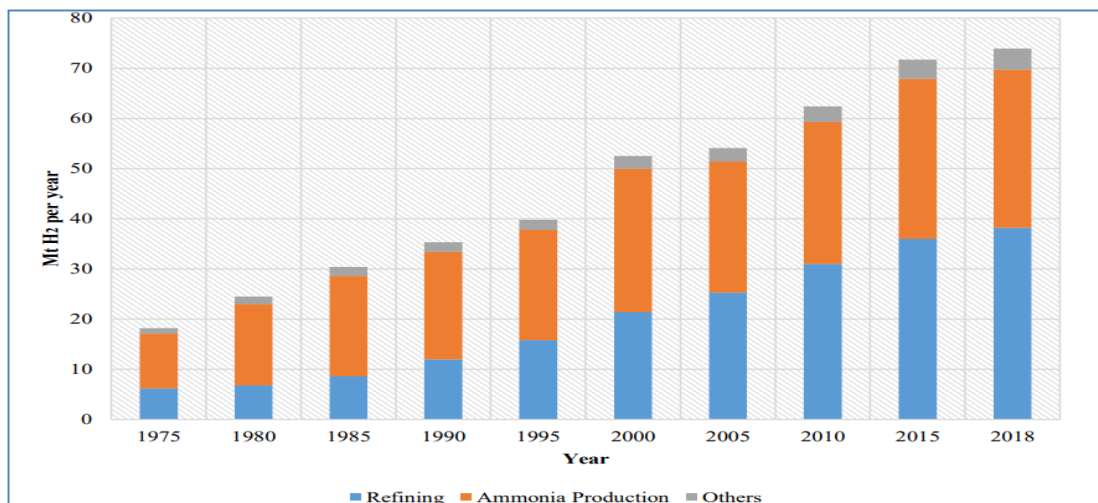
Pipelines represent the most cost-effective means for transporting hydrogen over medium and long distances. Large-scale hydrogen shipments over long international distances are preferably converted into ammonia or liquid organic forms. However, the costs associated with conversion and re-gasification may increase total expenses and compromise energy efficiency. Hydrogen storage primarily depends on the quantities to be stored, storage duration, movements within and outside storage, and geological conditions.

For small quantities stored for short periods, compressed tanks remain the preferred option, while larger quantities stored for longer durations are best stored within geological formations. Additionally, aquifers have been considered a potential storage option, but their suitability has yet to be confirmed, as they have not been used for pure hydrogen storage before (IEA, 2019).

1.3 Current Structure of Hydrogen Utilization:

Hydrogen is currently predominantly used in hydrocarbon and petrochemical industries, including ammonia production for fertilizers. It is also utilized in steel manufacturing, particularly for direct reduced iron. In 2021, oil refining and ammonia production accounted for over 80% of the total global hydrogen utilization.

Fig (1): illustrates the global distribution of major hydrogen utilization sectors

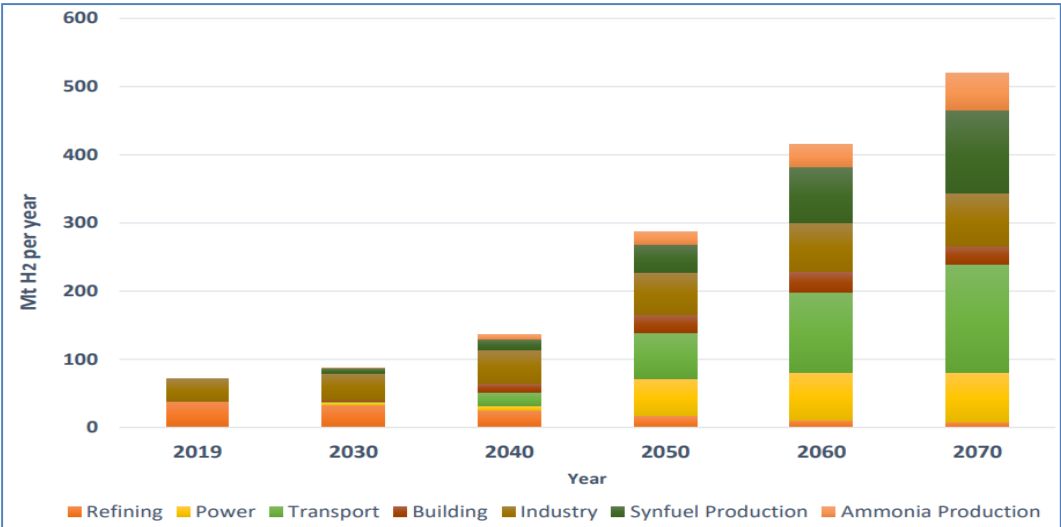


Source:(C Okonkwo, AL-BREIKI, BICER, & Al-ANSARI, 2021)

However, the landscape of hydrogen utilization is undergoing a significant transformation, extending beyond its traditional applications. One promising area of growth lies in **steel manufacturing**. The **direct reduced iron (DRI)** process, which utilizes hydrogen, offers a cleaner alternative to traditional blast furnace methods. Furthermore, hydrogen's potential extends to **hydrogenation processes**, where it can be combined with various feedstocks to create valuable products like **synthetic fuels, methanol, and even ammonia**. This opens doors for potential decarbonization in sectors

like transportation and power generation, offering exciting possibilities for a cleaner future.

Fig (2): Worldwide Hydrogen Demand Across Sectors from 2019 to 2070



Source:(C Okonkwo, AL-BREIKI, BICER, & Al-ANSARI, 2021)

2.Hydrogen Production, Utilization, and its Alignment with Sustainable Development Goals

The integration of low-carbon hydrogen into global economies is a crucial component of sustainable energy solutions and actions required to achieve carbon neutrality by 2050, a long-term goal adopted by several nations, organizations, and entities. The United Nations Sustainable Development Goals (SDGs) framework serves as a basis for identifying and classifying various sustainable development benefits of low-carbon hydrogen by examining its interrelation with these goals, as illustrated in Table (1).

Table (1): Low-Carbon Hydrogen and Its Relationship to the Sustainable Development Goals

Impact of Low-Carbon Hydrogen	Sustainable Development Goals
Introduction of clean hydrogen sources, especially in hard-to-abate sectors of the economy, has a clear positive impact on the health and well-being of local communities.	Goal 3: Ensure healthy lives and promote well-being for all at all ages.
Developing commercially viable and sustainable sources of additional seawater desalination capacity for hydrogen	Goal 6: Ensure availability and sustainable management of water and

production can also provide local communities with a water supply.	sanitation for all.
Low-carbon hydrogen production and use offers a new source of clean energy storage in the long term. The challenge is to increase low-carbon hydrogen production capacity over time and create sustainable and affordable markets for everyone.	Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all.
Developing a multi-billion dollar low-carbon industry in potential low-carbon hydrogen producing and consuming countries will provide long-term economic growth and job opportunities.	Goal 8: Promote inclusive and sustainable economic growth, full and productive employment and decent work for all.
The development of low-carbon hydrogen allows for innovation along the low-carbon hydrogen value chain and, in the long term, is likely to develop a flexible infrastructure for hydrogen production and consumption.	Goal 9: Industry, Innovation and Infrastructure.
The long-term use of low-carbon hydrogen in the transport sector helps to reduce traffic pollution and improve local environments in cities and communities.	Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable.
Low-carbon hydrogen is part of a mix of clean solutions and measures to address climate change mitigation, particularly in hard-to-abate sectors.	Goal 13: Take urgent action to combat climate change and its impacts.

Source :(ESCWA, 2022, p. 25)

From the table, we can infer that realizing the full impact of low-carbon hydrogen is likely to occur over a long period, with its cost expected to significantly decrease over the coming decades. The contribution of green hydrogen production will vary from one country to another, not solely due to limited availability of low-cost renewable energy resources and associated infrastructure, but also potentially due to the need to prioritize their use for clean electricity purposes in certain countries. Blue hydrogen production could serve as a quicker option for reducing greenhouse gas emissions and supporting long-term expansion of green hydrogen

production capacity. However, blue hydrogen production pathways are costly, albeit relatively less expensive than green hydrogen production.

3.National Policies and Strategies in the Hydrogen Sector and its Role in the Energy Transition

Several countries have expressed interest in hydrogen and the role it can play in the energy transition process. Some have begun preparing and developing visions, roadmaps, and strategies to determine the path towards achieving a hydrogen economy at the national level. These strategies aim to identify the best paths according to national priorities for providing hydrogen supplies through either domestic production or imports, and the applications in which hydrogen can be used. Additionally, some countries have studied investment opportunities in hydrogen production for export to potential markets, and have initiated preliminary agreements and understandings to secure their share in future international hydrogen trade.

The process of developing a national hydrogen strategy involves several stages, as illustrated in Table 3. Before formulating the strategy in its final form, it begins with research and development programs to understand the basic principles of technology and build the necessary knowledge base for dealing with hydrogen in terms of production and use. Subsequently, it transitions to the second stage, which is visioning, where the general framework and guidelines for pilot projects are set, usually formulated in partnership between governments and the private sector attracted by the expected growth prospects of hydrogen applications. The third step is the preparation of a roadmap, which includes a comprehensive plan with activities required to assess the potential of hydrogen and identify priority research areas and important application for the implementation of pilot projects. With the completion of the aforementioned three stages, the basic components for formulating the national strategy are ready, which will in turn establish clear policies and assess their compatibility with current energy policy

(OAPEC, 2021, pp. 74-75).

In the past few years (starting from 2018), the number of countries interested in hydrogen and its role in national energy policy has increased. Some of these countries have announced their national hydrogen strategies, while others are still in the process of developing their national strategies or roadmaps.

Table (2): Stages of Developing a National Hydrogen Strategy

1.R & D	2.Vision Document	3.Roadmap	4.National Strategy
- Understand the basic principles of technology - Building the necessary knowledge base to deal with hydrogen in terms of production and use	- Review final goals and objectives - Unifying viewpoints between the public and private sectors - Highlighting the advantages and added value of projects	- Determine the main goals - Review the required procedures - Establish an initial time frame to accelerate implementation	- Formulate main goals - Ensure consistency with national energy policy - Establish direct and supplementary procedures - Establish a time frame
Partnership between the public and private sectors	- Create a platform for exchanging information - Harmonizing visions between the two sides, a measure that will reduce investment risks during the first implementation of hydrogen projects		

Source :(OAPEC, 2021, p. 75)

According to the latest update, by the end of the first quarter of 2023, the number of countries that have announced their national hydrogen strategies reached 25 countries, in addition to the European Union, which announced the European Hydrogen Strategy in mid-2020. The list includes, as shown in Figure the majority of European countries such as Germany, France, Belgium, and the Netherlands. Also, countries in Asia and the Pacific such as Australia, Japan, and South Korea, in Africa like Namibia and South Africa, and in the Americas including Canada, Chile, and Colombia. From the Arab region, Algeria and Oman are included.

Table (3): Evolution of Hydrogen Plans and Strategies by Country 2023

The roadmap for hydrogen is being prepared	The roadmap for hydrogen has been prepared	The national hydrogen strategy is being prepared	The National Hydrogen Strategy was announced
Jordan Saudi Arabia New Zealand	Italy Russia China India United States of America Finland Ukraine The UAE Morocco	Brazil Egypt Jordan Mauritania Morocco Paraguay Sweden The UAE Tunisia Uzbekistan	Algeria, Spain, Portugal, Norway, Netherlands, Germany, France, Japan, Colombia, Czech Republic, Belgium, Luxembourg, Australia, Oman, Chile, South Korea, Canada, Denmark, United Kingdom, Hungary, Slovakia, Austria, Poland, South Africa, Namibia
3	9	10	25

Source :(OAPEC, 2023, p. 24)

Furthermore, the number of countries working to finalize their national hydrogen strategies reached 10. Additionally, a significant number of countries have either completed or are actively developing hydrogen roadmaps, totaling 12 countries. Thus, the total number of countries that have completed or are in the process of developing national hydrogen plans and strategies amounts to 47 countries.

Countries are increasingly turning to hydrogen production driven by the growing global demand for this resource. For instance, the European Union aims to increase its reliance on hydrogen to meet 14% of the energy demand in Europe by 2050. To this end, the European Commission announced a special support program in February 2023 to incentivize investments related to hydrogen use for energy generation and transportation (EU, 2020).

In the United States, the US Congress approved a \$369 billions support package in August 2022, comprising various tax incentives to support a

range of climate change-related projects, including infrastructure associated with hydrogen storage, transportation, and consumption. Meanwhile, the United Kingdom is betting on hydrogen to replace natural gas in heating and cooking sectors by 30% by 2030. For this reason, the UK is studying options to utilize the natural gas pipeline network for transporting and consuming hydrogen in the future. The British government plans to produce 10 gigawatts of electricity through hydrogen by 2030 as part of its efforts to reduce emissions and achieve carbon neutrality. Overall, the year 2022 witnessed approximately \$240 billions injected into over 680 global projects for hydrogen production, consumption, transportation, and storage, representing a 50% increase in investments in this sector compared to the previous year. This reflects the seriousness of gradually transitioning towards using this resource as a balanced part of the global energy mix (Nour El-Din, 2023).

At the same time, conflicts and energy wars that threatened fossil energy supply lines and raised prices in 2022 contributed to increased Western interest in hydrogen as an alternative energy source. Hydrogen production not only achieves clean energy transition goals but also allows countries to diversify energy sources and mitigate risks surrounding their supply chains.

4. Energy potential in Arab countries and prospects for hydrogen production within the framework of the energy transition

The current and future capabilities of the Arab region in renewable energy, in addition to its wealth of natural gas resources, constitute an important element for developing its capabilities to produce blue and green hydrogen. It is speculated that each Arab country or group of Arab countries may choose a different path to develop low-carbon hydrogen and integrate it into its economy. Hydrocarbon producers with large natural gas reserves may initially focus on blue hydrogen to develop their capabilities to produce low-carbon hydrogen at relatively competitive prices. However, countries that do not possess significant fossil fuel resources or have limited quantities may focus on developing green hydrogen. Some countries with significant gas reserves may decide to produce both blue and green hydrogen simultaneously.

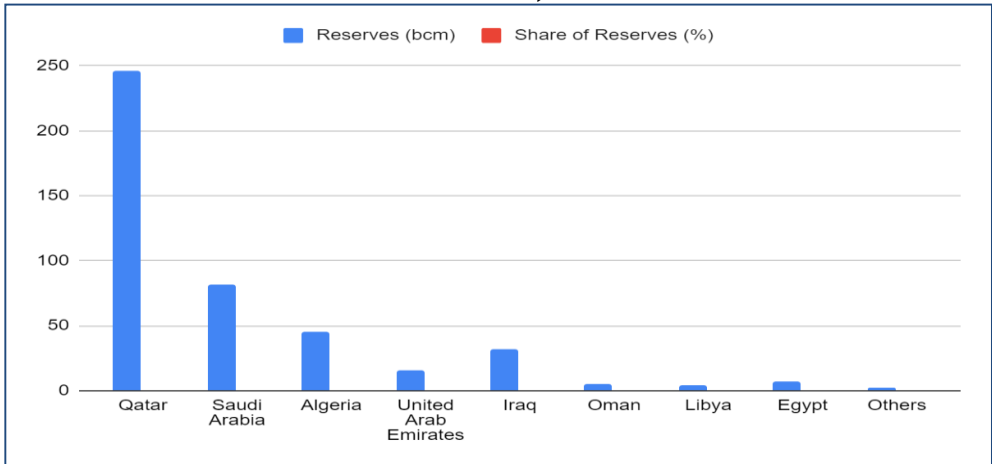
4.1 Natural Gas Resources and Their Potential for Hydrogen Production in Arab Countries :

Natural gas, as mentioned earlier, is essential for producing blue hydrogen. The Arab region encompasses an integrated and independent gas industry, including onshore and offshore discovered reserves, producing gas fields, gas transmission and distribution networks, gas processing, and purification

stations, as well as massive infrastructure for gas exports to regional and global markets. The Arab region is one of the largest global producers of natural gas and a major exporter of natural gas via pipelines and liquefied natural gas. Therefore, Arab countries can leverage this existing infrastructure to produce and transport natural gas for use in hydrogen production at investment costs that will be the lowest globally compared to other regions (Abdel Moati, 2015). Figure (3) illustrates the natural gas reserves in the Arab region.

Moreover, natural gas prices in Arab countries are among the lowest globally compared to other regions. Gas prices are one of the most significant factors influencing the cost of hydrogen production alongside capital and operational expenses. Consequently, hydrogen production utilizing natural gas in Arab countries would be highly competitive even when coupled with carbon capture, utilization, and storage processes. As illustrated in Table (4), the Arab region emerges as the least costly in gray or blue hydrogen production compared to other regions worldwide, with total costs amounting to less than 1 dollar per kilogram of gray hydrogen. With the implementation of carbon capture, utilization, and storage technology, the cost of blue hydrogen would rise to 1.5 dollars per kilogram. This is attributed to the reduced cost of natural gas production and the general decrease in operational expenses (OAPEC, 2021, p. 88).

Fig (3): Natural Gas Reserves in the Arab Region in 2023 (Billion Cubic Meters)



Source :(OAPEC, 2022)

Table (4) : The cost of producing one kilogram of hydrogen in the Arab region compared to other regions (dollars per kilogram).

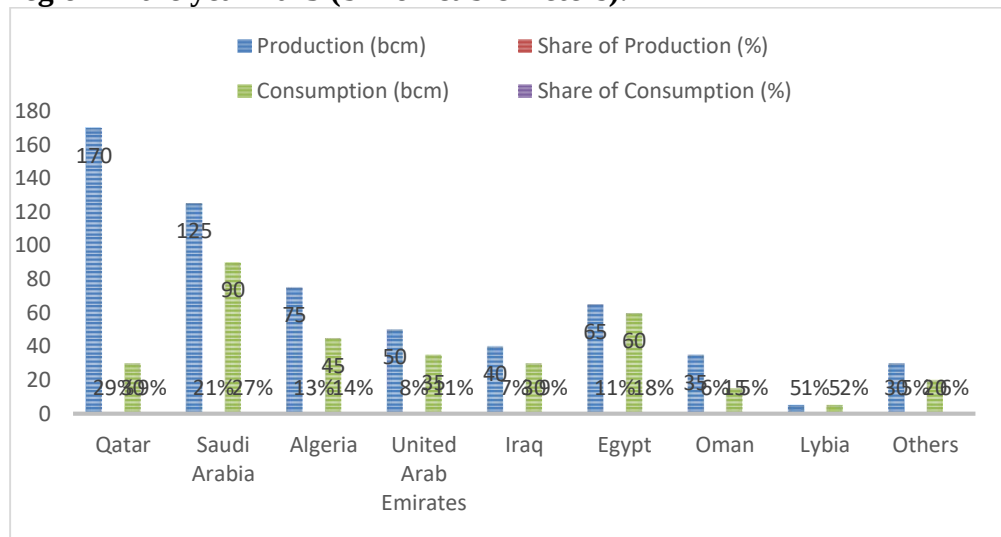
Region	Gray Hydrogen	Blue Hydrogen	Green Hydrogen
Arab Region	0.5 - 1.0	1.0 - 1.5	2.6 - 4.5
North America	1.0 - 2.0	2.0 - 3.0	3.5 - 5.0
Europe	2.0 - 4.0	3.0 - 5.0	4.0 - 8.0
Asia (excluding Arab Region)	1.5 - 3.0	2.5 - 4.0	4.0 - 7.0

Source : (IEA, 2019)

Therefore, the Arab region can potentially lead the world in blue hydrogen production, ensuring the continued development of its natural gas resources while considering international trends in carbon emissions reduction. This would accelerate the establishment of a hydrogen economy within the region, meeting demand across various sectors. Additionally, leveraging existing natural gas export networks from the region to European markets could transform the region into a global hydrogen supplier.

However, not every Arab country has the capacity to access this resource. Where natural gas is available, priority is typically given to electricity generation. Nonetheless, a very small group of Arab countries possess a surplus of natural gas, exporting it through cross-border pipelines or liquefied natural gas carriers. Furthermore, natural gas can also be utilized in blue hydrogen production for export after meeting domestic market demands. Figure 4 illustrates the fragile balance of natural gas in many Arab countries, where a high proportion of current production is either consumed domestically or simply insufficient to meet local needs (Abdel Moati, 2015).

Fig (4):The production and consumption of natural gas in the Arab region in the year 2023 (billion cubic meters).



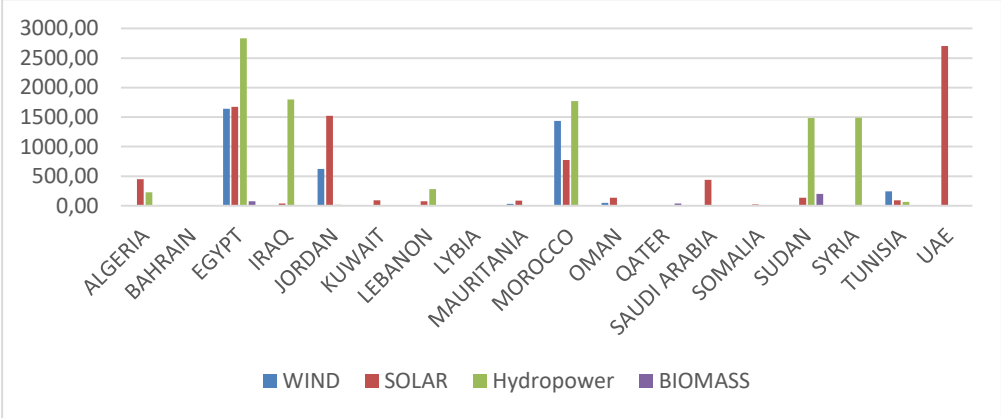
Source :(OAPEC, 2022)

Excluding Qatar, which will remain a principale source of gas regionally and globally, it is expected that the produced natural gas in most Arab countries will be primarily allocated to meet the growing domestic demand in the energy and industrial sectors. However, its utilization for gas will grow at a slower pace in the future compared to previous decades. Countries with substantial reserves of natural gas, such as the United Arab Emirates, Qatar, and Saudi Arabia, possess both renewable and non-renewable energy potentials that enable them to develop blue and green hydrogen. Excluding Qatar, which will remain a principale source of gas regionally and globally, it is expected that the produced natural gas in most Arab countries will be primarily allocated to meet the growing domestic demand in the energy and industrial sectors. (ESCWA, 2022, p. 34).

4.2 Renewable Energy Resources and Their Potential for Hydrogen Production in Arab Countries

Over the past decade, there has been a notable increase in the Arab region's capacity to generate combined renewable energy, rising from 1 gigawatt in 2010 to over 22 gigawatts in 2021 (OAPEC, 2022). However, the majority of the total combined renewable energy remains concentrated in a few countries, as illustrated in Figure (5). In 2021 alone, four countries (Jordan, the United Arab Emirates, Morocco, and Egypt) accounted for approximately 80% of the total variable renewable energy in the region.

Fig (5): Cumulative Capacities of Renewable Energy Production in the Arab Region in 2021 (megawatts)



Source :(OAEPEC, 2022)

According to the Arab Future Energy Index, issued by the Regional Center for Renewable Energy and Energy Efficiency in collaboration with the United Nations Development Program, it is expected that the Arab region's capacity for combined renewable energy production will reach approximately 180 gigawatts by 2030. These estimates are based on goals announced by various Arab countries regarding their plans for renewable energy production capacities and the targeted future share of renewable energy from their total energy production mix. These goals appear to be highly ambitious when compared to the current cumulative renewable energy capacity and its share in each country's energy production mix. However, the likelihood of surpassing renewable energy accounting for more than 30% of the total energy consumption mix by 2030 in most Arab countries remains distant, even with the ambitious development program(ESCWA, 2023, p. 7).

Therefore, it is expected that fossil fuels, especially natural gas, will continue to play a dominant role in the overall capacity of the Arab region to generate electricity in the coming years. Policy makers must make some decisions related to public energy policies to introduce new capacities for low-carbon hydrogen into their countries' economies for domestic purposes and/or to serve their exports. This includes allocating a portion or a significant portion of their future renewable energy generation capacity to produce green hydrogen. This applies to Arab countries that either do not possess natural gas resources or have limited access to this resource.

5. Current and planned developments in the Arab region regarding hydrogen production and export are as follows:

Hydrogen production and utilization in Arab countries are primarily driven by the requirements of oil refining, petrochemicals, and steel industries, which heavily rely on hydrogen. More than 90% of the total hydrogen produced in the Arab region is gray hydrogen. Large quantities of hydrogen are primarily consumed in the Gulf Cooperation Council (GCC) countries and the Arab Maghreb region. Currently, the GCC countries consume between 5 and 6 millions tons of hydrogen, with Saudi Arabia accounting for over 40% of the total consumption of the GCC countries(Nour El-Din, 2023).

Currently, only a very limited number of Arab countries are producing blue and green hydrogen and developing circular carbon economy as alternatives to help achieve the long-term goal of carbon neutrality. It is worth noting that most countries in the Arab region still face challenges in planning and implementing realistic programs for sustainable renewable energy. The integration of sufficient levels of renewable electricity generation remains an unrealized goal in this region; however, international focus on low-carbon hydrogen has led to the development of new initiatives for low-carbon hydrogen in the region.

Many Arab countries have been considered potential sources for low-carbon hydrogen production due to their significant potentials in solar and wind energy and the availability of vast land areas for renewable energy projects (OAPEC, 2023).

5.1 Projects and Proposed Plans for Hydrogen Production in Arab Countries

In recent years, several Arab countries have shown interest in studying opportunities for harnessing hydrogen and exploring the feasibility of implementing projects for hydrogen production and export, particularly in markets with clear strategies towards future hydrogen utilization.

Currently, six Arab countries are actively involved in developing low-carbon hydrogen production or planning for it, including blue and green hydrogen projects. These countries are Algeria, Egypt, and Morocco in North Africa, as well as Oman, the United Arab Emirates, and Saudi Arabia in the Gulf Cooperation Council (GCC) region. Additionally, other Arab countries with significant capabilities or working on developing their capacities for renewable energy and/or natural gas resources have also expressed interest in hydrogen development and are planning initiatives to develop low-carbon hydrogen production (OAPEC, 2023)

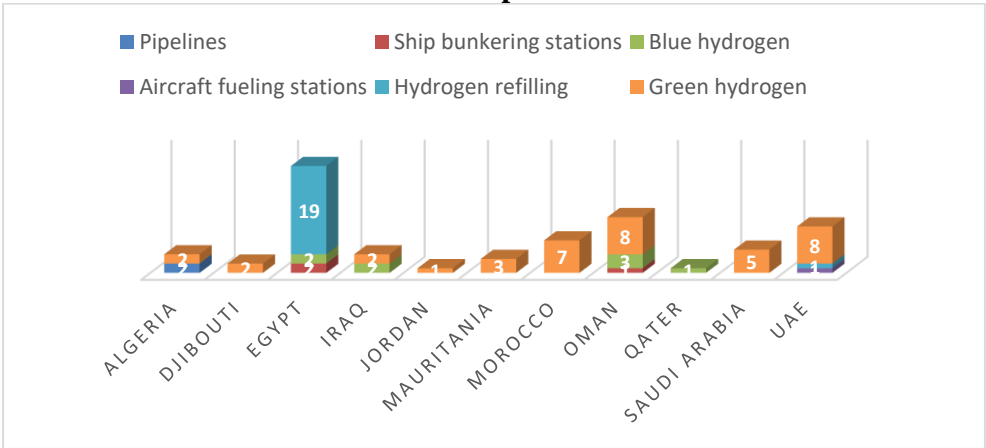
Table (5) : Objectives Set by Arab Countries Interested in Investing in Hydrogen and Ammonia Production and Export

Country	The objectives
Algeria	Production of 40 TWh by 2040, equivalent to 1 million tons when converted into hydrogen
Egypt	Producing 5 % of the global hydrogen market by 2040
Morocco	Production 4 TWh of Hydrogen for the local market, plus 10 TWh for export by 2030, will require 6 GW of renewable energy sources 4 % of the local hydrogen share market by 2030, according to the strategy of the Ministry of Sustainable Development
Oman	1-1.25 million tons 1-1.25 million tons of Green hydrogen production per year by 2030 3.25-3.75 million tons of Green hydrogen production per year by 2040 7.5-8.5 million tons of Green hydrogen production per year by 2050
Saudi Arabia	Production of 2.9 millions tons of Green and blue hydrogen per year by 2030 and 4 millions tons by 2035 Production of 11 millions tons of blue ammonia by 2030
United Arab Emirates	25 % of the global hydrogen market by 2030 Among the top 10 hydrogen producing countries in 2030

Source : (OAPEC, 2023, p. 25)

The nature of measures taken by these countries has varied, including the establishment of national hydrogen plans and the updating of national energy strategies to consider the potential future role of hydrogen. Additionally, some countries have focused on entering into preliminary agreements and understandings with leading international companies to directly invest in green and blue hydrogen production projects, as well as experimental projects to implement hydrogen usage in transportation. Overall, the number of announced hydrogen projects in Arab countries as of the end of March 2023 reached 77 projects. Egypt leads with 24 projects, the majority of which are for green hydrogen and green ammonia production, followed by the United Arab Emirates with 12 projects distributed among blue and green hydrogen production and hydrogen applications in transportation. The remaining projects range from 11 in Oman, 10 in Saudi Arabia, 7 in Morocco, to 4 in Algeria. Other countries, such as Iraq, Qatar, Jordan, and Djibouti, have also joined the list (see Figure 6).

Fig (6):Announced Projects for Hydrogen Production and Utilization in Arab Countries up to March 2023



Source : (OAPEC, 2023, p. 28)

In Egypt, the Cabinet approved in late 2022 the granting of eight licenses for hydrogen production, leveraging the available infrastructure primarily in the gas production and liquefaction sector. Notably, green hydrogen projects in Egypt have seen significant Emirati involvement through the company "Masdar," which signed an agreement with Egypt to implement projects capable of producing 480,000 tons of hydrogen annually. Currently, there are more than 24 projects for green hydrogen production and export across Egyptian regions, expected to benefit from existing gas export chains and facilities.

As for the United Arab Emirates (UAE), it aims to secure a quarter of the world's green hydrogen production alone, following the opening of the first green hydrogen production plant in the Middle East in November 2022. The UAE is striving to achieve its targeted hydrogen production volume through a series of agreements with global energy companies (Masdar, 2022).

Saudi Arabia relies on building the world's largest project for green hydrogen production, located in the city of Neom in the northern part of the Kingdom. The massive project is expected to utilize up to 4 gigawatts of solar and wind energy to produce approximately 600 metric tons of green hydrogen per day. Upon its operation by 2026, the entire production capacity of the field will be dedicated to export, under pre-signed contracts with foreign companies (Saudi Aramco, 2020).

5.2 Opportunities for exporting low-carbon hydrogen are emerging in the Arab region

New opportunities for exporting low-carbon hydrogen are emerging in the Arab region, partly due to the scarcity of local supplies, especially towards Europe, which will not suffice to meet the anticipated long-term demand for hydrogen. Industrialized countries like the European Union, South Korea, and Japan continue to focus on decarbonizing their economies. Among the available alternatives to achieve a clean energy consumption mix and fulfill their climate neutrality commitments by 2050, the introduction of low-carbon hydrogen, particularly in sectors where carbon electrification and emission reduction are challenging, is being pursued. However, forecasts for the planned consumption of low-carbon hydrogen or hydrogen-based ammonia indicate that local supplies in Europe will not be adequate to meet the expected long-term demand. Consequently, this opens the door to importing it from the Arab region and other places (ESCWA, 2022, p. 44).

The European Union's hydrogen strategy points to potential imports of low-carbon hydrogen from neighboring countries, particularly in Eastern Europe and countries around the South and East of the Mediterranean Sea. It specifically highlights North Africa and its geographical proximity, emphasizing that it could provide cost-competitive renewable hydrogen supplies. While the EU's strategy does not specify the methods of importing from North Africa, an initiative launched by European gas pipeline operators, known as the European Backbone for Hydrogen, suggests that hydrogen imports from North Africa, planned for 2040 or possibly earlier, will likely pass through Spain and Italy. This may include supplies of low-carbon hydrogen from Algeria, and possibly Tunisia, Libya, and Morocco (EU, 2020).

The Arab countries in the Middle East also represent another potential source of low-carbon hydrogen supply towards Europe and some Asian countries. There has been much discussion about a planned gas pipeline project in the Eastern Mediterranean to Southern Europe as a potential cross-border infrastructure for transporting renewable low-carbon hydrogen. However, the implementation of this ambitious gas pipeline project, which spans 2,000 kilometers, is not expected to materialize in the near future.

It is speculated that potential supplies of low-carbon hydrogen from the Middle East will be transported aboard specialized ships to Asia and Europe. Currently, there are no clearly defined projects aimed at exporting hydrogen gas from the Middle East, except for the NEOM Green Hydrogen project in Saudi Arabia. A trial export shipment of blue ammonia, which relies on hydrogen, was conducted from the industrial city of Jubail in Saudi Arabia. Due to the constraints imposed by the costs of transporting pure hydrogen over long distances, low-carbon hydrogen from the Middle East is predominantly shipped in the form of low-cost low-carbon ammonia (Saudi Aramco, 2020)

Finally, it is essential to address the issue of potential clean energy sources in the Arab region and their adequacy to produce low-carbon hydrogen in quantities that meet the expected demand for imports.

Conclusion:

The energy transition process necessitates structural changes in the energy system to gradually eliminate practices leading to greenhouse gas emissions, aiming for a carbon-free system. The electricity model based on expanding renewable energy power plants has proven to be highly costly, and achieving deep decarbonization will take a long time, especially in industries reliant on fossil fuels. Hence, attention has turned towards finding alternatives or supplements to renewable energy sources to achieve this goal, with hydrogen emerging as one such solution due to its suitability as a fuel and energy carrier, and its ability to be produced from renewable energy sources, facilitating integration and grid balance. Therefore, employing a hybrid model of electricity and hydrogen can overcome several reasonable challenges in the energy sector.

However, the study found that low-carbon hydrogen production economies still face several challenges, directly linked to various constraints, including technological limitations. Green hydrogen production is significantly more costly compared to blue hydrogen production. Blue hydrogen production has not yet widely developed, and both options are more expensive than natural gas production. Nevertheless, the low-carbon transitional blue hydrogen option can progress more rapidly than green hydrogen. In the long

term, it is expected that the cost gap between blue and green hydrogen production will significantly narrow, with the expected increase in green hydrogen production capacities.

Moreover, the study indicates that Arab countries with significant natural gas reserves, such as Qatar, Saudi Arabia, Algeria, and Libya, have renewable and non-renewable energy potentials enabling them to develop blue and green hydrogen. However, only a limited number of these countries have embarked on hydrogen production and circular carbon economy development as alternatives to aid in achieving the long-term goal of carbon neutrality. It is worth noting that most countries in the Arab region still face challenges in planning and implementing realistic sustainable renewable energy programs.

Furthermore, exporting low-carbon hydrogen presents opportunities for potential new producers in the Arab region and can provide incentives for fuel producers from Arab countries in the long run, especially with emerging opportunities in low-carbon hydrogen export, partly attributed to the scarcity of local low-carbon hydrogen supplies in Europe, which will not suffice to meet the long-term hydrogen demand.

Here are selected recommendations for Arab countries aiming to accelerate the development of low-carbon hydrogen on both local and global levels:

1. Accelerate local renewable energy projects to increase the share of renewable electricity in energy systems to ensure sufficient capacity to produce green hydrogen.
2. Mitigate risks by formulating low-carbon hydrogen strategies that reflect each country's carbon neutrality goals and commitments, renewable and non-renewable energy resources, financial strength, and/or access to financing sources. Governments can also reduce risks by implementing local initiatives to create demand for low-carbon hydrogen.
3. Enhance expertise in the oil and gas sectors and international partnerships with oil and gas companies; strengthen the current infrastructure in refining and shipping to expedite the transition to sustainable fuel and industrial materials production, thereby mitigating disruptions in local economies and jobs in the face of global strategies aimed at carbon removal and carbon border adjustment mechanisms.
4. Establish suitable legal and regulatory frameworks to incentivize local and international investors to invest in low-carbon hydrogen production; focus on decarbonizing sectors that are difficult to electrify while avoiding financially demanding and high-risk support cycles.

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