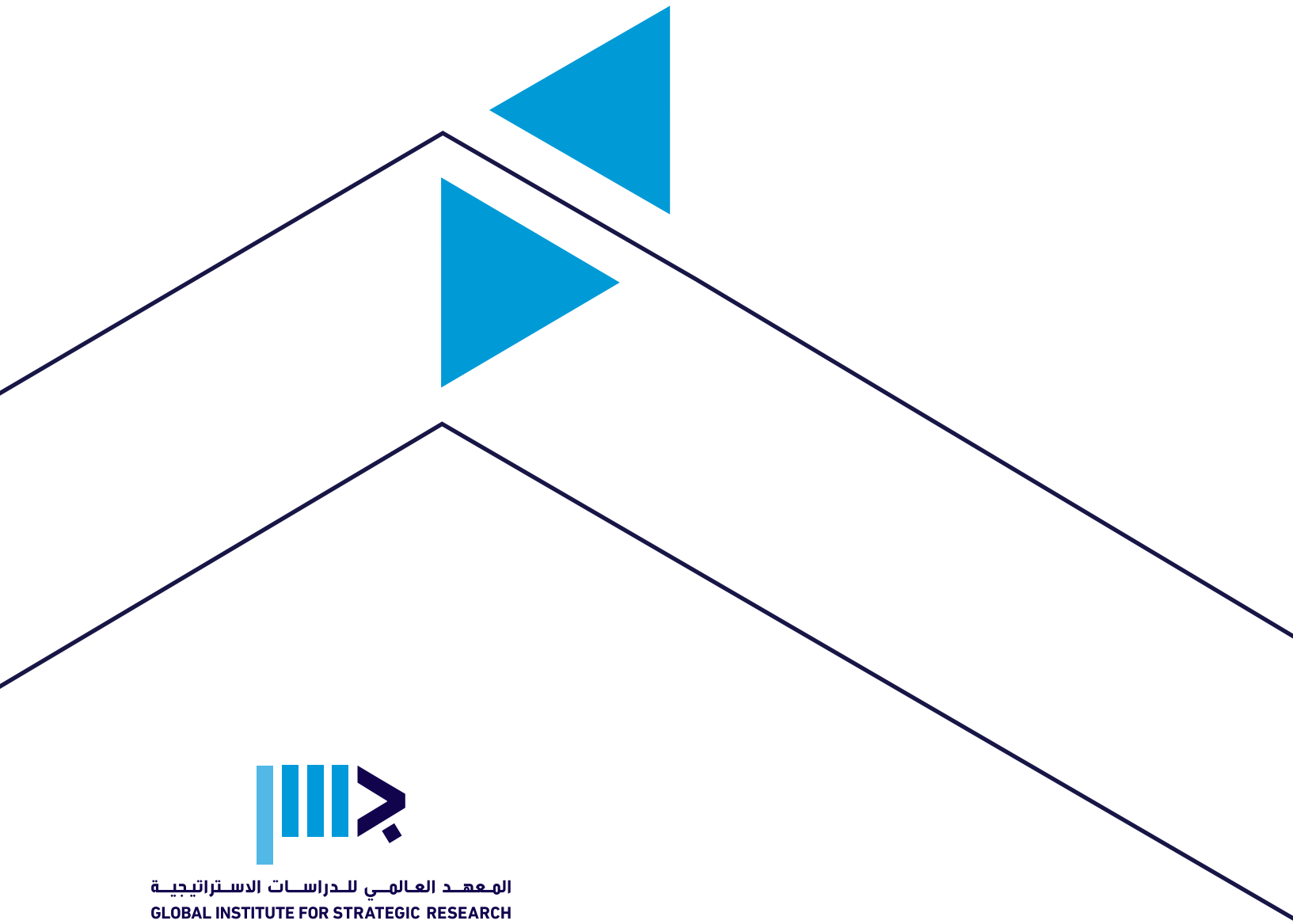
# DECARBONIZING ARAB ECONOMIES

## Accelerating Energy Transition by Hydrogen Exports and Economic Diversification



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GLOBAL INSTITUTE FOR STRATEGIC RESEARCH

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## Accelerating Energy Transition by Hydrogen Exports and Economic Diversification

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# Executive Summary

Arab countries have made great progress in planning large hydrogen projects. The last meeting of the UN Conference of the Parties on Climate Change (COP27) in Egypt and the preparation of the coming one in Abu Dhabi (COP28) have had a highly stimulating effect: Egypt is now ranked as the largest destination for foreign direct investment in hydrogen mega projects, and Abu Dhabi has tripled its plans in the field of renewable energy in the run-up to COP28. The planned hydrogen projects in Arab countries have reached a volume comparable to those in OECD countries. Qatar is moving in a somewhat different direction as it concentrates on prolonging its success with LNG exports.

The focus of most green hydrogen projects in the region is on exports, mainly to Europe. There is not yet much coordination of these export plans. A considerable risk exists that Arab countries will compete with each other for technology partners, finances, capacity of equipment producers, and export contracts. There is no OPEC equivalent for hydrogen, and it is improbable that it will be created.

It is expected that the largest consumer of green hydrogen in Europe will be the heavy industry, which is otherwise difficult to decarbonize. Estimates of European imports of green hydrogen assume that half of the European green hydrogen needs will be met by imports, while the other half will come from production in Europe itself (mainly Southern Europe). These projections assume that existing basic industries will remain in Europe.

The shift toward a hydrogen economy, however, can lead to a far-reaching change in comparative advantages. Production costs of heavy industry depend to a large extent on energy costs. "Green hydrogen" (and derivatives) will be more expensive in Europe than in regions with more solar and wind energy, and exports from these regions will suffer from high transport costs, which can be up to three times higher than the production costs of green hydrogen because hydrogen is much more difficult to transport than oil.

This can lead to a situation in which parts of heavy industry in Europe can no longer compete internationally and may have to relocate – with a double impact on the plans of Arab countries. On the one hand, it could reduce the scope of hydrogen sales in Europe; however, it can create enormous opportunities for the further diversification of Arab economies by hosting more such industries near the sources of cheap renewable energy. Such a shift would contribute simultaneously to the decarbonization of the world economy and to a more balanced international distribution of industrial activity and a more equal division of labor between the MENA region and Europe.

# KEY MESSAGES

- Most industrialized countries plan to phase out fossil fuel energy and have started a transition process to net-zero emissions.

- Egypt, which hosted COP27 in 2022, is now ranked as the largest destination for foreign direct investment in hydrogen mega projects, and Abu Dhabi, the host of COP28, has tripled the amount the country plans to invest in renewable energy projects and is focused on Japan and other Asian countries with an increasing use of hydrogen.

- The planned hydrogen projects in Arab countries have reached a volume comparable to those in OECD countries. Qatar is moving in a somewhat different direction as it concentrates on prolonging its success with LNG exports.

- GCC countries are busy with roadmaps to expand their hydrogen activities and become less dependent on the export of oil and gas. Saudi Arabia, Oman, and the UAE are pursuing ambitious plans in the global shift toward renewable energy and green hydrogen. The North African countries Egypt and Morocco, which harbor few fossil energy deposits, have already a long record of exploring alternatives to fossil fuels.

- The Gulf region is expected to become a top global producer of green and blue hydrogen, ammonia, and other derivatives. North African countries less blessed with oil and gas reserves could improve their balance of payments by increasing their own renewable energy production for local consumption and become important exporters.

- For oil-producing countries, the expansion of renewable energy could be an important step in the planned diversification of their economies to become less dependent on oil and gas. The focus of most green hydrogen projects in the region is on exports, mainly to Europe.

- A considerable risk exists that Arab countries will compete with each other for technology partners, finances, capacity of equipment producers, and export contracts. There is no OPEC equivalent for hydrogen, and it is improbable that it will be created. These simultaneous and interacting international races will lead to shifts in international competitiveness, a different division of labor not only in the energy sector, the rise or decline of heavy industries in several countries, changes in international trade routes, and new geopolitical tensions.

- A gradual shift toward a larger share of renewable energy in world energy consumption to reduce worldwide greenhouse gas emissions is an obvious threat to fossil fuel producers in the MENA region.

- Arab states would benefit from the "hydrogen revolution" not only by finding a renewable replacement for their oil and gas exports, but they will have new opportunities to expand in domestic industries in which they already have a considerable capacity. This will not only fundamentally change the world energy sector, but it will also have a profound impact on the location of the energy-intensive heavy industry.

- The entire world will gain from this double shift. Global emissions of greenhouse gasses will thereby decline. Arab industries will be powered by more green energy and Europe will eliminate its largest CO2 emitters. It can create enormous opportunities for the further diversification of Arab economies by hosting more such industries near the sources of cheap renewable energy.

- Such a shift would contribute simultaneously to the decarbonization of the world economy and to a more balanced international distribution of industrial activity and a more equal division of labor between the MENA region and Europe.

# 1. Introduction: Acceleration of the Energy Transition

While writing this manuscript, the world experienced the hottest days ever since temperatures were measured. June and July 2023 were already the hottest months in world history. The Daily Tribune in Bahrain warned that "Seven Arab countries are expected to be exposed to an unprecedented rise in temperatures within days, sometimes reaching 50 degrees Celsius."[1] The heat wave has caused an enormous demand for natural gas to power air conditioning, but it has also triggered additional concerns about climate change.

The International Panel on Climate Change (IPCC) has recently warned that present efforts will not be sufficient to limit global warming to 1.5°C.[2] Most industrialized countries plan to phase out fossil fuel energy and have started a transition process to net-zero emissions. Sultan Al Jaber, president of the COP28 UN climate summit to be held in November 2023 in the United Arab Emirates (and CEO of the UAE's national oil and gas company, ADNOC), has recently laid out his plan of action for the summit. Commitments to phase down the use of fossil fuels and to "double energy efficiency, triple renewable energy capacity to 11,000 GW globally, and double hydrogen production to 180 million tons a year by 2030 will be put to governments at COP28, and are expected to be agreed."[3]

The annual COP meetings seem to have a strong stimulating effect on the plans of host countries. Egypt, which hosted COP27 in 2022, is now ranked as the largest destination for foreign direct investment in hydrogen mega projects, and Abu Dhabi, the host of COP28, has tripled the amount the country plans to invest in renewable energy projects.

The Gulf region is expected to become a top global producer of green and blue hydrogen, ammonia, and other derivatives.[4] The countries of the Gulf Cooperation Council (GCC) already expected in 2021 that they could create a hydrogen industry worth US$ 200 billion by 2050, which would produce 1000 gigaton of green hydrogen annually and create 1 million new jobs.[5] North African countries less blessed with oil and gas reserves could improve their balance of payments by increasing their own renewable energy production for local consumption and become important exporters.

# 2. Three Races

There are actually three simultaneous and interacting international races going on: a race to produce more "green" hydrogen from renewable energy and to conclude early trade agreements between importers and exporters, a race between the major producers for more efficient and cheaper equipment to produce green hydrogen, and finally a race to secure access to sufficient supplies of rare metals needed for such equipment. The outcome of these three races will lead to shifts in international competitiveness, a different division of labor not only in the energy sector, the rise or decline of heavy industries in several countries, changes in international trade routes, and new geopolitical tensions.

Europe was the frontrunner in the field of renewable energy. The generous subsidies that the United States introduced with the "Inflation Reduction Act" and the large-scale investments in renewable energy in China have threatened this position and stimulated additional European efforts to switch to a "green" energy system as part of Europe's Green Deal. How can Arab countries situate themselves in this new constellation and benefit from a world economy that is less based on fossil fuels?

# 3. Renewable Energy From Arab Countries

Oil and gas-producing countries have profited from high prices in the past two years, and oil and gas will still be needed for decades to come. This is why major international oil companies are quite reluctant to invest in renewable energy. So why do (and should) the Gulf countries, which harbor approximately one-third of the world's oil reserves and one-fifth of natural gas reserves, also invest in green hydrogen, which could reduce the worldwide demand for oil and gas? There are several reasons:

- The oil and gas reserves of the region are large but finite. Even before these reserves are depleted, falling costs of renewable energy can make a green hydrogen production more economically viable.[6]
- There is a strong worldwide push toward decarbonization and the growing demand for clean energy sources creates new economic opportunities.
- Reducing the carbon footprint by increasing the use of clean energy will also improve the international competitiveness of subsidiary industries.
- The geographical location of the region and its climate can make it a powerhouse for a future hydrogen economy. Existing infrastructure makes GCC economies "excellent hydrogen first movers."[7]
- Harnessing the region's vast opportunities for solar and wind power can help desert regions contribute more to economic development.
- A strong position in the world hydrogen market would allow GCC countries "to maintain economic and political power even in a decarbonized world."[8]

Individual Arab countries have taken up this challenge in a different way. *MEED Middle East Business Intelligence* recently published an overview of planned expenditures on green hydrogen projects in the Middle East, with a total value of approximately US$ 150 billion (see Table 1 below). If you compare these figures with the planned expenditures elsewhere in the world (and take the different size of populations into account), these investments do not remain behind those in highly industrialized nations. Of course, figures on planned investments everywhere must be interpreted with great caution until the investments are actually commissioned.

**Table 1: Value of Green Hydrogen Projects in billion US$**[9]

These are the frontrunners:

| | MEED Overview |
|---|---|
| Egypt | 63.8 billion |
| Oman | 48.9 billion |
| Morocco | 16.85 billion |
| Saudi Arabia | 10.5 billion |
| United Arab Emirates | 10.28 billion |

Algeria, Bahrain, Kuwait, and Qatar have other priorities.

Since the MEED review, the planned amounts have increased. Egypt's portfolio of green hydrogen projects now reaches US$ 83 billion.[10] The United Arab Emirates (UAE) have recently tripled their planned expenditures on renewable energy and focused on Japan and other Asian countries with an increasing use of hydrogen.[11] GCC countries are busy with roadmaps to expand their hydrogen activities and become less dependent on the export of oil and gas. Saudi Arabia, Oman, and the UAE are pursuing ambitious plans.[12] The North African countries Egypt and Morocco, which harbor few fossil energy deposits, have already a long record of exploring alternatives to fossil fuels.

## 3.1. Egypt

Egypt's Minister of Electricity and Renewable Energy announced during the UN Conference of the Parties on Climate Change (COP27) in 2022 that Egypt would be able to produce the cheapest green hydrogen in the world and aims eventually at 8 percent of global hydrogen exports.[13] At COP27, the country signed eight framework agreements with industrial partners to develop green hydrogen and ammonia projects, including agreements with the Norwegian company Scatec, the Danish shipping firm Maersk, France's EDF Renewables, and the Emirati renewable energy company Masdar.[14] After the launch of the Global Ammonia Technology Roadmap at COP26, Egypt was the first country to apply the global roadmap at the national level and will provide a blueprint for other countries.[15] Large scale investments in 17 green hydrogen projects accounted for 97% of Egypt's inbound capital investment in 2022.[16]

Egypt expects that it can produce green hydrogen from 2025 on for $2.7 per kg and that this would decrease to $1.7 in 2050. The production of green hydrogen could create 100,000 jobs and contribute more than $10 billion to the country's GDP by 2025 (which seems overoptimistic). In 2035, Egypt wants to produce 42% of its energy from renewable resources.[17] To speed up this transition, the Egyptian cabinet in May 2023 approved "a package of incentives for green hydrogen projects. The incentive will include a host of tax exemptions, including on VAT and customs duties, and regulatory exemptions, including on import and export registry. The Bill will also allow officials to grant so-called 'golden licenses' to certain projects – effectively giving their developers land allocation, building permits, and management approval in a single step."[18] Such a conducive regulatory environment may be the reason why several Gulf states have also invested in Egypt's green hydrogen projects.

## 3.2. Morocco

Morocco belongs to the countries in the world where hydrogen in the future will be especially cheap.[19] The kingdom plans to be responsible for about 4% of the worldwide production of green energy in the future. By 2030, it wants to cover 52% of its own energy needs with renewable energy.[20] In October 2022, Morocco signed a "green partnership" agreement for closer cooperation on energy with the EU.[21]

Morocco has the largest solar energy power station in the world, which does not work on photovoltaics, but concentrates sunlight with many mirrors to heat water and let steam drive large turbines to produce electricity. The most prominent reason for Morocco's relatively large percentage of renewable energy is that the country hardly has any fossil energy deposits. Morocco therefore needs more green electricity to replace the remaining imports of coal.

The electricity from solar and wind energy will also be used for direct export to Britain: It is planned that the *Xlinks Morocco-UK Power Project* will use a surface area of 1,500 $km^2$ to produce green electricity and transport it via a 3,800 km long submarine cable to England, which would be enough to deliver electricity to 7 million households in Britain by 2030.[22]

## 3.3. Saudi Arabia

To enable the large-scale adoption of green hydrogen, Saudi Arabia plans to build the largest green hydrogen plant in the world in Neom, producing 600 tons of green hydrogen in the form of ammonia daily from 2026 onwards.[23] Furthermore, Saudi Arabia plans to produce 4 million tons of clean hydrogen and become the world's largest exporter of hydrogen by 2030. This will be "blue" hydrogen with 27 million tons of $CO_2$ captured for use in the chemical industry.[24] In 2020, the country sent the first shipment of hydrogen to Japan in the form of 40 tons of high-grade blue ammonia to be used for zero-carbon power generation.[25] The Saudi Green Initiative foresees an energy mix in 2030, in which 50% of the country's energy consumption will consist of renewable energy.[26] The world's largest company, Saudi Arabia's state oil company Aramco, plans to produce hydrogen-powered vehicles.[27]

## 3.4. United Arab Emirates

With planned investments of US$ 54 billion in the coming seven years, "the United Arab Emirates (UAE) is positioning itself to be a major player in the global shift toward renewable energy and green hydrogen."[28] UAE's vice president and ruler of Dubai has recently announced that the UAE will triple its investment in renewable energy and wants to serve as a model of sustainable development in the Middle East. According to the UAE's Minister of Energy, the UAE plans to produce 1.4 million metric tons of hydrogen in two hydrogen oases by 2031 and will increase that amount to 15 million metric tons, produced in five hydrogen oases, by 2050. The country plans to achieve 32% of its total production from clean energy (renewables and nuclear).[29]

## 3.5. Oman[30]

Oman aims to produce at least 1 million tons of renewable hydrogen a year by 2030, up to 3.75 million tons by 2040 – and up to 8.5 million tons by 2050, which would be greater than the current total hydrogen demand in Europe. The 2040 hydrogen target would represent 80% of Oman's current LNG exports in energy-equivalent terms, while achieving the 2050 target would almost double this percentage.

Based on IEA analysis of the current global project pipeline, Oman is on track to become the sixth largest exporter of hydrogen globally and the largest in the Middle East by 2030.

Oman is implementing concrete measures to achieve its ambitious targets. An independent entity, Hydrogen Oman (HYDROM), established in 2022, will lead and manage its hydrogen strategy. So far, 1,500 square kilometers of land has been put aside for development by 2030 – and up to 40 times more land has been identified for potential production in the long term. Six projects have already been allocated land for renewable hydrogen in the country's first auction process.[31]

## 3.6. Other Countries

Other countries in the region have been less actively looking for alternatives to fossil fuels, partly because they have recently been very successful with their exports of natural gas. This is the case for Algeria and Qatar, both of which could considerably step up their share in the EU's gas imports because of the decline of Russia's exports to Europe.[32]

*Algeria* could in principle be able to meet about 40% of Europe's need for green hydrogen.[33] Being Africa's most important exporting country of natural gas, its government has been somewhat less interested in renewable energy than its neighboring Morocco. The German gas company VNG will cooperate with the state company Sonatrach in developing Algeria's green hydrogen potential.[34]

*Qatar* saw a tremendous increase in its income from liquid natural gas. Qatar has hitherto left it mostly to the importing countries to reduce the emissions that come free in the use of natural gas by carbon capture (CCS), but it does capture 5 million tons $CO_2$ annually from an LNG facility[35] and has ambitious plans to expand carbon capture and storage to collect over 11 million tons of $CO_2$ per year in 2035.[36] 'Blue ammonia' will become an important export product. The Qatar Investment Authority is also considering investing in a green hydrogen and ammonia project in Egypt's Suez Canal Zone[37], and Qatar is increasing the share of solar energy in the domestic grid at a fast pace. Since 2022, Qatar has generated 800 MW of renewable energy and plans to expand this to more than 3 GW in the future.[38] The electrification of the process of liquifying natural gas must ensure that the country's LNG exports are relatively clean.

*Kuwait* intends to reduce the ecological footprint of fossil fuels by increasing carbon capture in Kuwait itself, because the injection of $CO_2$ into oil reservoirs would assist in pumping out the remaining oil.[39]

*Bahrain* formulated a National Renewable Energy Action Plan in 2017, but this was not very ambitious (5 percent of domestic energy consumption from renewables in 2025 and 10 percent by 2035). Since then, Bahrain has made significant strides in the development of solar energy. Bahrain is the least resource-rich country in the GCC. However, Bahrain might still "position itself as a key exporter of green hydrogen in the future".[40]

Two other countries are at an early stage of exploring their potential to produce green hydrogen:

*Tunisia* started in early 2022 to develop a national strategy for green hydrogen, which is expected to be ready by 2024.[41] While Tunisia has the necessary assets to produce green hydrogen at competitive costs and to become a supplier of Europe in the short and medium run, it would perhaps make more sense to export electricity directly from Tunisia to Italy, given the relatively short distance.[42]

*Mauritania* has a similar potential for renewable energy as Morocco, but it lacks the infrastructure. The country had developed a plan, together with the German project developer *Conjuncta* and *Infinity Power Holding* (a joint venture of companies from Egypt and the UAE), to produce 8 million tons of green hydrogen in the future.[43]

# 4. Potential Green Hydrogen Exports

For oil-producing countries, the expansion of renewable energy could be an important step in the planned diversification of their economies to become less dependent on oil and gas.

Estimated potential for green hydrogen exports by Arab states (in million tons)

| | 2030 | 2040 | 2050 |
|---|---|---|---|
| Algeria[44] | | 1 | |
| Egypt | 4[45] | | 10[46] |
| Mauritania[42] | | | 8 |
| Morocco[47] | 0.3 | 1 | 3 |
| Oman[48] | 1 | 3.75 | 8.5 |
| Saudi Arabia[49] | 4 | | |
| Tunisia[50] | | | 5.5-6 |
| UAE[51] | | | |

The Economic and Social Commission for Western Asia (ESCWA) of the United Nations mentions in its latest report on "Potential hydrogen developments in the Arab region" of June 2023 the growing export opportunities, especially to Europe, which will not be able to produce sufficient green hydrogen itself.[52] The European Commission assumes that the EU will produce about 10 million tons of green hydrogen itself by 2030, but that it will have to import roughly the same amount.[53]

The reductions in imports from Russia have redirected energy supplies from the Middle East to Europe to compensate for the shortfalls. European countries have thus become even more important customers for fossil fuels from the Middle East, especially for liquefied natural gas (LNG).

The focus of most hydrogen projects in Arab countries is on exports. There is not yet much coordination of these export plans.[54] There is no OPEC equivalent for hydrogen, and it is improbable that it will be created because of the strong international competition from all continents to produce and export green hydrogen.

A considerable risk exists that Arab countries will compete with each other for technology partners, equipment producers' capacity, export contracts, and finances. It is estimated that the capacity to produce

one million tons of green hydrogen would cost $25 billion.[55] An estimate of the capacity of international equipment producers for electrolysis is provided by the International Energy Agency.[56] "Electrolysis technologies have not yet reached the commercial viability required to realistically meet long-term net-zero emission targets. Scaling up these technologies and concomitant reduction in production costs will take time and require large financial resources."[57] Geopolitical tensions could also lead to important setbacks in the MENA region if European and American technology partners do not maintain access to rare metals, for which China still has a monopoly, which are necessary for green electricity production and electrolysis.

Although European countries will try to spread their imports over many countries, countries in North Africa and the Middle East will be preferred suppliers. This is not, in the first place, a question of geographical distance, but of the potential mode of transport. The mode of transport rather than the cost of local production of hydrogen is the decisive factor for the competitiveness of supplies from a country on European markets. The cost of transport can be three times the cost of production in some cases.

# 5. Crucial Costs of Transport

The Hydrogen Council[58] (an international association of companies in the sector) and the international consulting firm McKinsey forecast that in 2050, approximately 400 million tons of "clean" hydrogen and derivates (such as ammonia and methanol) will be traded across international borders every year.[59] A well-known expert, the founder of BloombergNEF, who specializes in the analysis of trends in the energy sector, recently criticized that report, pointing out that high transport costs will probably hinder such an expansion of cross-border trade in hydrogen.[60] Only if transports occur through pipelines will high volumes of hydrogen be traded.

If hydrogen is to be shipped, there is a choice between six different modalities, each with its own advantages and disadvantages:

- Hydrogen gas could be *compressed* at approximately 250 bar, which would be relatively easy, but the compressed hydrogen would still be very voluminous. For the transport of the same amount of energy as with LNG, seven times as many ships would have to sail, which would hardly be profitable.

- Hydrogen gas could be *liquefied by cooling* it to -253°C. The resulting volume would still be larger than the amount of LNG with the same energy content. Cooling the hydrogen (and keeping it cool throughout the transport process) would cost much energy and could only be done in special containers that would not become brittle at such low temperatures.

- Hydrogen can be *transformed into ammonia* by combining hydrogen with nitrogen. This is a promising way to transport hydrogen over large distances because ammonia could also be used directly in the fertilizer production and as a shipping fuel.[61] However, ammonia is a dangerous product that must be handled with great care.[62]

- Hydrogen could be made to interact with CO2 to *produce methanol*, which could be used as shipping fuel as well, which would not require major changes in the design of engines. However, it would be considerably more expensive than the transformation into ammonia, so much so that for larger ships, according to Liebreich, the costs would be comparable to that of a small nuclear reactor for the propulsion of the ship.[63]

- Hydrogen can be dissolved into a "liquid organic hydrogen carrier" (LOHC), which is a diesel-like substance that can be transported under atmospheric pressure and temperature. Hydrogen could be recovered at the destination, with the LOHC sent back for reuse. However, dissolving hydrogen will create much heat where you do not need it, and the recovery requires much heat (and thus energy), which makes it costly. Nevertheless, the use of LOHC for hydrogen export is discussed in Qatar.[64]

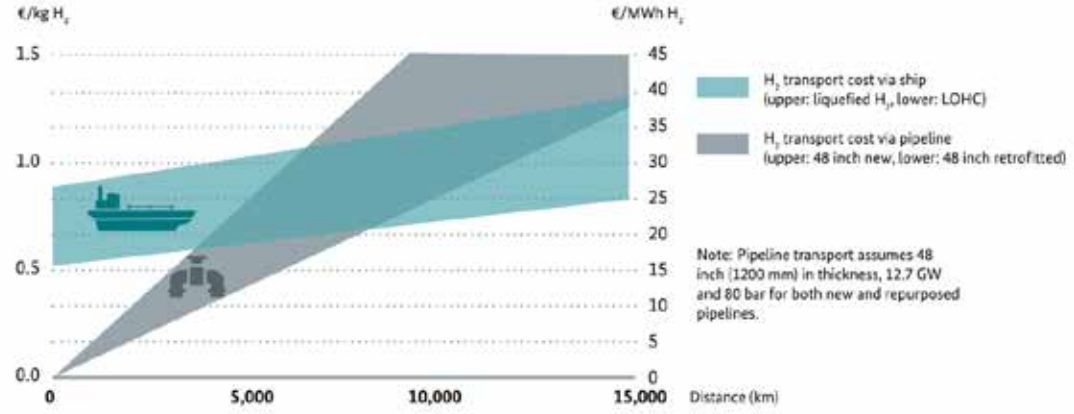
- A type of *hydrogen powder* could be made by combining hydrogen with other elements (for example, kalium compounds), which are as easy to transport as washing powder. By adding water to the powder, hydrogen could be released again.[65] However, this transformation is quite expensive.

All these modalities will probably be used, although they require that at both ends of the transport chain, specific facilities exist to handle and transform hydrogen before departure and then recover it at the point of destination. Purpose-built ships have to be available for transport. The choice for a specific modality would then depend on the facilities in the ports of departure and arrival with the options that these make available for a specific route.

All these modalities come at considerable costs, which are often higher than the production costs of hydrogen in countries with favorable climates for low-cost electricity generation. The International Energy Agency has recently compared the costs of different types of transport.[66]

The figure below, prepared by Guidehouse consultancy, also provides a cost comparison of shipping and pipeline hydrogen transport routes.[67]

**Figure 10: Cost comparison of shipping and pipeline hydrogen transport routes.**




Source: Guidehouse / European Hydrogen Backbone (2021)

It illustrates that up to about 5000 km, it would be cheaper to import hydrogen via pipelines – where they exist – rather than by ship. On the other hand, pipelines require an enormous upfront investment and entail security risks (as the Nord Stream pipeline has demonstrated), whereas transport by ship is much more flexible and better suited for low-volume transport.

Three natural gas pipelines actually connect North Africa (Algeria) with Europe: the almost 3500 km long Trans-Mediterranean (TransMed) pipeline via Tunisia to Italy and the Medgaz and Maghreb-Europe pipelines to Spain, which are connected to the Spanish and Portuguese networks of gas pipelines. They could be refitted for hydrogen transport.[68] Spain, Portugal, and France agreed in early 2023 to build a dedicated undersea hydrogen pipeline from the Iberian Peninsula to France. An extension of the pipeline to Germany is also planned.

While hydrogen from North Africa can be supplied to Europe via pipelines in the future, discussions about deliveries from the Gulf to Europe have up to now focused on transport by ship. Exploration of shipping options has been subsidized by the EU, but they would not be the most efficient solution for bulk transport (compared to pipelines).[69]

A study conducted in June 2023 has shown the feasibility of a pipeline that would link the Gulf region and Egypt to Europe, starting in the 2030s. It could transport 2.5 million tons of hydrogen annually. By adding more pipelines of the same nature, the transport capacity can be scaled up. It is unclear whether this project has come in place of the EastMed pipeline, which was planned by Greece, Cyprus, and Israel to connect offshore gas reserves from the Levantine Basin to Greece and Bulgaria, but was abandoned when it proved politically controversial.[70]

# 6. Europe's Demand For Green Hydrogen

Expectations regarding Europe's future demand for hydrogen vary widely. In 2019, the "Hydrogen Roadmap Europe" foresaw that the needed hydrogen in 2050 would be for industry (39%), transport (30%), heating and power for buildings (26%), and power generation (5%).[71]

Demand might be lower than expected in 2019 for three reasons:

- Demand for heating and buildings can be lower because more and more heating is done by electrical appliances. Study after study has shown that the use of hydrogen for heating would be very inefficient (with only a few exceptions).[72]

- Road transport was the largest expected market when discussions on the large-scale use of hydrogen started in the 1990s. However, the market for emission-free vehicles is now dominated by electrical cars. Even heavy trucks are more often driven by batteries rather than hydrogen. Hydrogen cars, though, might get a second chance once the raw materials for batteries become scarce.[73] Aviation and shipping certainly will be very large consumers of hydrogen or its derivatives.

- The most important reason for lower-than-expected demand could be that heavy industry may not remain competitive in many European countries. The steel production is forecast to become the largest consumer of industrial hydrogen in Europe by 2040.[74] In countries that have neither iron ore deposits nor cheap green energy, it will eventually not be possible to produce steel without permanent subsidies and protection against foreign competitors.

There has been a very interesting study in the Netherlands on how a fossil fuel-free Dutch industry might look at the end of the 2030s.[75] The results of this study could also be highly relevant for other European countries:

A large part of heavy industry in the Netherlands (and Europe) benefitted from the extensive Dutch natural gas reserves in the north of the country and the deliveries of relatively cheap Russian gas. Now that an end has come to both (in the Netherlands because of the earthquakes caused by decades of gas extraction, and for Russian gas because of the war in Ukraine), the basic rationale for the location of heavy industry has changed. If most of the energy has to come from alternative sources, such as sunlight and wind, other regions are much better off. According to this study, the industries in question are raw iron, aluminum, and zinc, the production of ammonia, methanol, and synthetic fuel, and parts of the basic chemical industry.

Initiatives for a change in the international division of labor may first come from countries with abundant raw materials and good chances of being top green hydrogen producers. A good example is Australia, which is the world's largest iron ore exporter, but also has excellent conditions (and concrete plans)

for large-scale green hydrogen production. Critics stress that it is somewhat strange that Australia first exports most of its iron ore and then starts to export green energy to process this ore elsewhere. The Green Metal Strategy acknowledges Australia's incredible potential to introduce zero-emission steel production based on its iron ore and renewable energy resources. Currently, Western Australia's mining and mineral industries function under a 'dig and ship' model, missing the opportunity to operate under a 'dig-process-manufacture-deliver' system.[76] If Australia starts to process only 18% of its iron ore itself, it would have a steel industry of the size of this industry in Japan.[77] Similar ideas are probably discussed in Brazil, which is expected to be Latin America's largest green hydrogen producer in the future[78] and has enormous mineral deposits, and in Chili, which aims to become one of the world's three largest exporters of hydrogen[79] and is the world's largest exporter of copper.

Even if the natural endowment is only cheap green energy, countries with high solar and wind energy can have a comparative advantage because energy sometimes accounts for more than 35% of the production costs of heavy industry.[80] Therefore, at least some Arab countries may have a good chance to expand their industry in these sectors. "Some key Arab hydrocarbon-producing countries have large industrial parks or clusters where low-carbon hydrogen projects can be located at lower costs than green field sites. Substantial shares of hydrogen production could be consumed locally by industries in these parks. (...) The development of a low-carbon hydrogen industry could help achieve economic diversification away from hydrocarbons."[81]

# 7. Economic Diversification in the Arab Countries

The development of a hydrogen industry in itself will already make a great contribution to economic diversification. However, diversification does not have to stop there. The worldwide switch to renewable energy sources could entail a much broader diversification of Arab economies because it could trigger a considerable expansion of energy-intensive basic industries with a potential large spin-off in other industrial sectors.

During the past decades, many Arab countries have already made great strides in this direction. The most diversified of the Gulf countries is the UAE, which has "managed to significantly reduce reliance on the hydrocarbons sector for GDP growth and government income."[82] Whereas the oil sector accounted for 46.9% of GDP in 1980, its share declined to 16.74% in 2019. In Saudi Arabia, the stress on diversification has oscillated with oil and gas prices. Interest was strong with low prices, but ebbed somewhat when prices were high. Now, "the lion's share of Vision 2030 entails a large transition from the current state of the economy toward non-oil manufacturing."[83] Egypt's and Morocco's economies are already quite diversified.

## 7.1. Steel Industry

Egypt is Africa's largest steel producer[84] and has three iron ore mines; however, the country is still a net importer of steel.[85] Local green steel production could easily be taken up.[86] Saudi Arabia, which also exports iron ore,[87] produces almost as much steel as Egypt. Algeria, the UAE, Oman, and Morocco also have a steel industry, albeit somewhat smaller. However, Algeria harbors "one of the world's most important iron ore deposits."[88] The UAE is an exporter of iron ore,[89] and the Abu Dhabi National Energy Company (TAQA) will produce green hydrogen that will be used to manufacture green steel in partnership with Emirates Steel.[90] Oman exports even more iron ore than the UAE or Saudi Arabia.[91] Morocco, too, has considerable iron ore deposits.[92]

The steel industry in the region already has considerable experience with DRI technology, for which hydrogen can be used to extract raw iron from iron ore, since "the region's sector is dominated by direct reduced iron-electric arc furnace (DRI-EAF) technology, which releases lower emissions than the increasingly obsolete coal-fueled blast furnace and basic oxygen furnace (BF-BOF) process used in 71% of global crude steel production in 2021."[93] The region has an established supply of DR-grade iron ore, and its iron ore pelletizing plants are among the world's largest. In Saudi Arabia, for example, steel making "is dominated by the SABIC-owned steel producer Saudi Iron and Steel Company (Hadeed), with a crude steel production capacity of 6 million tons. Hadeed's DRI capacity stands at almost 5 million tons. (...) Although Hadeed has extensive experience using the DRI-EAF process of steelmaking, its current

energy usage for its operation and plant needs is still carbon intensive because of the use of natural gas and electricity generated from fossil fuels."[94]

## 7.2. Fertilizer Industry

One of the industries that will be affected by the changes to 'clean' energy is the fertilizer industry, for which ammonia is the most important ingredient. The world's largest ammonia factory is actually built in Qatar, although it is 'blue' ammonia and not 'green ammonia,' because it is made from natural gas with carbon capture and storage.[95] Qatar is already an important exporter. Oman will build a green ammonia plant of about the same size as the new factory in Qatar. Its entire production will be shipped to South Korea.[96] The International Energy Agency (IEA) published a global ammonia technology roadmap[97] in October 2021, which identified green hydrogen as the key to decarbonizing nitrogen fertilizer production. Egypt was the first country to translate this into a national ammonia roadmap in cooperation with the European Bank for Reconstruction and Development.[98]

## 7.3. Synthetic Kerosine

Another increasingly important market is the market for synthetic kerosine. Bio-kerosine, which is actually added in small quantities to traditional kerosine, will not be available in sufficient quantities to keep track with the expected growth of world aviation. The Gulf states would be very suitable for the production of synthetic kerosine from green hydrogen and $CO_2$ captured from the air (or initially from processing fossil fuel). The UAE's Ministry of Energy and Infrastructure together with the World Economic Forum and the Clean Skies for Tomorrow coalition, published a Roadmap "Fueling the Aviation Energy Transition in the UAE."[99] The world now consumes 300 million tons of kerosine every year. In the long run, these would have to be replaced by emission-free fuels or fuels with "net-zero" emissions – a colossal future market. The UAE's state company "Masdar has teamed up with national carrier Etihad Airways, Siemens Energy, TotalEnergies, and others to develop green hydrogen for use in sustainable aviation fuels."[100]

## 7.4. Basic Chemicals

The Gulf states already have a prominent position in basic chemicals. The revenues of their chemical industry increased to more than $60 billion in 2021.[101] The "same year saw the rise of announcements within green hydrogen, green hydrogen-based ammonia, and renewable energy segments in the GCC of many promising projects in collaboration with international partners."[102] Egypt also heavily invests in oil refineries and the petrochemical industry.[103]

One might ask why Arab states have not reached an even more prominent position in these sectors, given that they have had the cheapest energy sources already for decades. The simple answer is low transportation costs. Their cheap oil and gas could easily be shipped or pumped elsewhere for fuel production. With transportation costs considerably higher for hydrogen and most derivatives than for oil and gas, Arab states gain an important proximity advantage, which makes them attractive for energy-intensive industries. However, several Arab states have the additional advantage that they already have the necessary experience and relevant infrastructure to make good use of green hydrogen, and the oil exporting states also have the financial means to finance the creation of the necessary capacity to do so.

The UN Economic and Social Commission for Western Asia sees a great potential for the export of hydrogen from Arab countries to Europe, but questions whether it might be enough to satisfy Europe's and Asia's import needs.[104] Europe, however, certainly does not want to limit its hydrogen imports to imports from the MENA region, although this would be the cheapest source. The EU and individual European countries have concluded a myriad of agreements to explore green hydrogen imports from all over the world – including Australia, Namibia, Chile, and Uruguay, because Europe would not like to become too dependent on imports from any one region.[105] Given the strong international competition between hydrogen exporters, Arab countries run the risk of producing too much hydrogen for exports, mainly to Europe, all the more so if large parts of the European energy-consuming heavy industry move elsewhere. This can be another reason to consider a much larger use in their own industries, building on the natural advantages of the region.

# 8. Double Shift

As a result, Arab states would benefit from the "hydrogen revolution" not only by finding a replacement for their oil and gas exports, which are threatened eventually by the necessary decarbonization of the world economy. This shift will also have a considerable impact on other energy-intensive economic sectors. Given that the transport of energy becomes more expensive, Arab countries will have a new comparative advantage. They will have new opportunities to expand in industries in which they already have a considerable capacity. This growth will not so much come from foreign companies but from the growth of domestic industries, while European companies in these fields will move into less energy-intensive sectors. The entire world will gain from this double shift. Global emissions of greenhouse gasses will thereby decline. Arab industries will be powered by more green energy and Europe will eliminate its largest $CO_2$ emitters. The international division of labor will become somewhat more balanced.

# 9. Conclusion

A gradual shift toward a larger share of renewable energy in world energy consumption to reduce worldwide greenhouse gas emissions is an obvious threat to fossil fuel producers in the MENA region. However, Arab countries are also well placed to benefit from the shift toward renewable energy because of the presence of abundant sunlight and wind. This shift will not only fundamentally change the world energy sector, but it will also have a profound impact on the location of the energy-intensive heavy industry. While oil and gas still flow from producing countries to the locations of consumption, some heavy industry in the future may concentrate in countries where renewable energy is the cheapest. A decisive factor is that oil and gas can be transported relatively easily, while the transport of intermittent energies derived from the sun and wind is quite expensive. This shift provides additional comparative advantage to Arab countries and can greatly boost their efforts to further diversify their economies.

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# 11. Recommendations

1. Improve the coordination of plans for the export of renewable energy by Arab countries (as suggested in the study Hydrogen. From Hype to Reality (p. 84) by the Dubai Future Foundation).

2. Regularly update detailed roadmaps to achieve Net-Zero Emissions by 2050. Do not follow present shareholder driven short-term policies of the biggest private oil and gas companies to slow down their investments in clean energy.

3. Elaborate specific scenarios for different levels of demand for green and blue hydrogen at different costs of transport as a background for robust policy decisions.

4. Apply a comprehensive risk assessment framework to assess the risks of specific hydrogen supply chains (as described on p. 357-360 in https://iea.blob.core.windows.net/assets/d1ec36e9-fb41-466b-b265-45b0e7a4af36/EnergyTechnologyPerspectives2023.pdf). Diversify material input and design to reduce risks.

5. Analyze the reasons why exports of blue ammonia do not flourish as planned (The Canadian firm Nutrien cancelled a planned $2 billion construction of a blue ammonia factory, although it had assured an offtake of 40% in a letter of intent with Mitsubishi. (https://www.hydrogeninsight.com/production/worlds-largest-blue-hydrogen-based-ammonia-project-shelved-due-to-increased-costs-and-lack-of-market/2-1-1499569); Saudi Arabia, too, struggles to find buyers for its blue ammonia (https://www.hydrogeninsight.com/production/saudi-aramco-struggling-to-find-buyers-for-its-blue-hydrogen-due-to-high-costs/2-1-1449004)

6. Facilitate the expansion of domestic industries that could contribute to the construction of a renewable energy infrastructure and industries that assure the offtake of renewable energy especially in areas of international competition. Explore opportunities for subsidiary industries which could contribute to or benefit from the expansion of these industries.

7. Identify international companies that consider new locations of production as an alternative to present locations with high energy costs.

8. Develop geological surveys to identify domestic critical material resources that could support the development of renewable energy.

# 12. Future Research Agenda

1. What are the consequences (challenges and opportunities) for Arab countries of the subsidy race between the United States and Europe in the field of renewable energy?

2. Do Egypt's large scale renewable energy projects (in addition to other mega-projects) contribute to the country's high inflation rate and can this lead to public unrest?

3. How large are European exports of different branches of heavy industry that will become less competitive as a result of relatively high energy prices, and where do these exports go?

4. How does the competitive position of Arab countries in different sectors of heavy industry compare to that of Australia, the United States, and Brazil, countries with a similar combination of a large potential of renewable energy and relevant mineral deposits?

5. How would Arab green hydrogen projects be affected by geopolitical tensions that would restrict exports of critical materials from China to Western technology partners?

6. How can cooperation between MENA/GCC states and Europe (or Asia) in the field of hydrogen trade be embedded into a broader framework for economic cooperation?

7. What are the main obstacles that hinder the realization of large hydrogen projects in Arab countries and how can these be overcome?

8. What are the selection criteria of international energy companies to participate in hydrogen projects in specific Arab countries but not in others?

9. What is the network of bilateral cooperation agreements between Arab countries and countries in Europe and Asia? How do the agreements differ from each other? Why are some agreements concluded with the EU as a whole, with individual EU member states, between port authorities, or between companies?

10. How would a successful completion of a gas pipeline from Nigeria to either Morocco or Algeria alter the situation of LNG exporting Arab countries? (see https://www.gem.wiki/Nigeria-Morocco_Gas_Pipeline; https://intellinews.com/niger-coup-threatens-nigeria-morocco-30bcm-gas-pipeline-project-286426/)

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## DECLARATION OF COMPETING INTEREST

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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