Poised to Lead: How the Middle East and North Africa Can Accelerate the Global Energy Transition

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CLEAN AIR TASK FORCE

Executive Summary

In August 2020, Clean Air Task Force (CATF) launched a project to explore the role that Middle Eastern and North African (MENA) nations could play in supplying decarbonized fuels to Europe and other regions that recognize the greenhouse gas benefits of decarbonized fuels. Large oil and gas exporting regions have the potential to become early suppliers to the zero-carbon fuel markets and to develop the infrastructure and operational know-how to help develop business models for national oil and gas companies that are appropriate for a decarbonized world. Decarbonized fuels, such as low-emission hydrogen (H_2) and ammonia (NH_3), will be needed to fill residual demand for low- and zero-carbon energy in hard-to-abate sectors and end-uses that are not amenable to electrification.

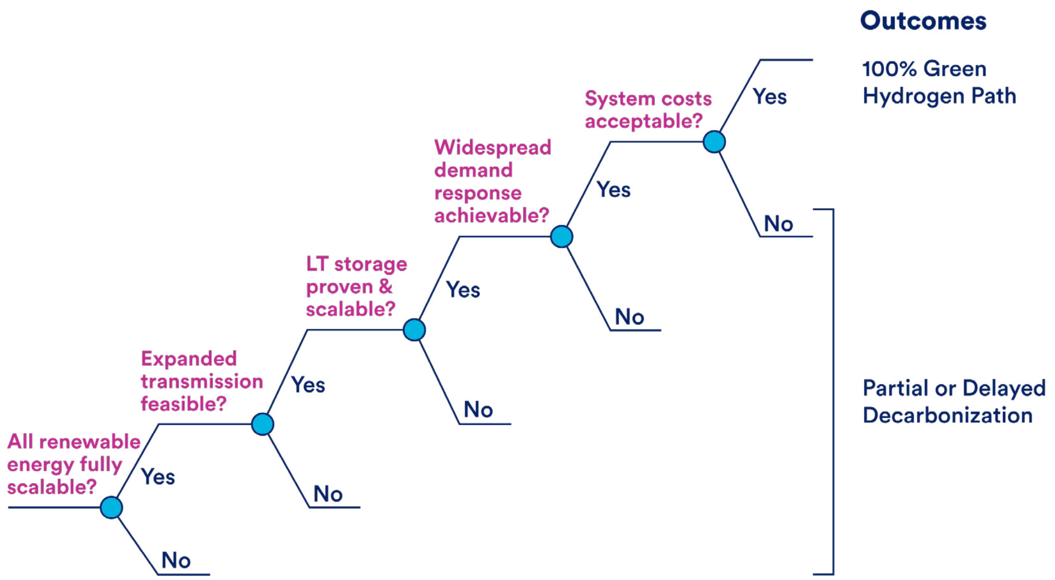
Historically, much of the focus on zero-carbon fuels production in the MENA region has been on the potential development of utility-scale photovoltaic projects, combined with electrolysis, to provide hydrogen to

Box 1: What Are Zero-Carbon Fuels?

Hydrogen and ammonia are carbon-free molecules that produce no carbon dioxide at the point of combustion. However, it is not enough to consider the emissions when the fuels are burned as is typically done with other fuels. As very little hydrogen is freely available in nature, it must be manufactured using other primary energy and materials, and that production process can result in significant greenhouse gas emissions. Here, we refer to fuels that are not only zero-carbon at the point of use, but that are also produced in ways that aim to minimize greenhouse gas emissions, resulting in very low CO_2-equivalent emissions across the value chain, including upstream and embodied emissions, and preventing leaks of hydrogen. Such production methods include hydrogen and ammonia produced by renewable or nuclear energy-fueled electrolyzers, or at natural gas-fed facilities that capture and use or store their carbon dioxide emissions (or other carbon byproducts), and source natural gas feedstocks from supply chains with low methane leak rates.

Figure 1: Robust Risk Management

The range of possible outcomes associated with these risk elements can be illustrated schematically.
If all five are resolved, a 100% variable renewable energy-centric path to full decarbonization would be successful.



European markets. Producing hydrogen and ammonia with renewable energy is often referred to as "green hydrogen". There has also been some focus on the conversion of natural gas (methane) to hydrogen in combination with carbon capture and storage, primarily for markets in Southeast Asia. This is often called "blue hydrogen".

There are very encouraging pathways for both production methods.

CATF analysis has found the potential for meaningful cost reductions in the use of electrolyzers as the technology scales in size and moves through the learning curve (see Box 3). The application of electrolyzers to scalable and firm zero-carbon options, such as superhot rock geothermal and advanced nuclear energy, will also benefit from such cost reductions. In the immediate term, the conversion of natural gas to hydrogen in a manner that minimizes methane leaks and substantially abates carbon dioxide emissions through carbon capture, utilization, and storage technology will likely be the lowest-cost option and play an important catalytic role in spurring development of the global zero-carbon fuels market. As is the case with hydrogen from electrolyzers, it should be noted that methane-sourced hydrogen with carbon capture and storage will also potentially see meaningful cost reductions with enhanced deployment.

CATF anticipates that natural gas-derived hydrogen will have particular salience in nations with significant hydrocarbon reserves and an interest in repurposing the existing uses of oil and gas for export to preserve the value of these resources. Effective decarbonization of industrial activity also enables the Gulf Cooperation Council (GCC) to maximize its future oil and gas production, and this includes many countries in the MENA region. Natural gas-derived hydrogen could also be attractive to oil-rich and gas-poor nations, such as Saudi Arabia, that seek to preserve their gas reserves for higher value-add products such as petrochemicals. A continued pathway for production and sale of MENA hydrocarbons could be opened if their conversion to hydrogen can be demonstrated as cost effective and environmental safeguards can be met: carbon capture, utilization, and storage must be demonstrated as environmentally sound, and upstream methane emissions associated with the production of natural gas must be cut to near zero.

Notably, MENA is also well-positioned to combine hydrogen delivery infrastructure with abundant sunlight to meet demand for hydrogen from renewable sources from regions that have lower solar/wind potential and more land use limitations constraining the build-out of renewable energy.

The initial phase of this project included an extensive set of interviews with key actors both within and outside the MENA region. The findings in this report are based largely on these interviews.

Top Level Findings

CATF's research identified five primary barriers to wide-scale production of zero-carbon fuels in MENA for export and use within the domestic economy. If the production of zero-carbon fuels, particularly hydrocarbon-derived low-emission hydrogen and ammonia, is to increase sufficiently to play a role in climate mitigation, concerted policy action will be needed to address each of the following impediments:

1. **Beyond current industrial users, there is currently no meaningful demand for zero-carbon fuels.**
2. **There is currently no economic incentive to build out carbon capture and storage infrastructure, or store carbon dioxide except for use in enhanced oil recovery projects.**
3. **There is currently no regulatory requirement to reduce carbon dioxide or methane emissions, nor is there a carbon price that would create an incentive to invest in these actions.**
4. **Procedures for analyzing the carbon dioxide and methane emissions from the production of various zero-carbon fuels and for certifying the resulting products do not exist. This is a major inhibitor, as a certification scheme will be required for an efficient commodity market.**
5. **There are challenges to financing the higher cost of capital and lower returns compared to the traditional fuel supply business.**

Production of zero-carbon fuels is proceeding piecemeal, and the present pace is such that the MENA region will miss a major opportunity to capitalize on production of low-emission hydrogen with natural gas. This, in turn, will make it more difficult and costly to reach net-zero goals. Moreover, decarbonization policies such as the EU CBAM, which puts a carbon price on some industrial imports, could drive the global demand for renewable and low-carbon hydrogen, and would therefore represent a market opportunity for the MENA regions. For the market to scale, the large industrial players who would invest in and operate the physical infrastructure to produce low-emission hydrogen must be able to construct a viable business plan that shows they will recover the capital invested in the project and produce a return commensurate with the risks. As applicable, they must also be able to recover the cost of capturing and disposing of the carbon dioxide. These markets will not develop without government intervention. Policies are needed to provide investor certainty and stimulate markets for zero-carbon fuels produced using low-carbon methods. This includes supportive policies in host (production) and buyer countries, as well as common frameworks for fuel certification. A single, workable, analytically transparent, and objective global fuel certification scheme is needed to give confidence to both sellers and buyers.

The remaining findings touch on a range of subjects and actors:

1. **The potential future cost of producing hydrogen via different pathways varies widely.**

We know that, at present, low-emission hydrogen production pathways yield an end-product that is significantly more expensive than its unabated hydrocarbon counterpart. It is imperative that hydrogen is produced in an environmentally sound manner, and the question of how far and how quickly the cost of low-emission hydrogen production techniques can be reduced is critically important. Many existing estimates rely on unrealistic or undocumented assumptions, and many studies look at only part of the system required to produce and transport zero-carbon fuels. A concerted effort to estimate the future cost for different zero-carbon fuel alternatives is critical to both the policy debate and to those organizations making investment decisions. One key finding of our preliminary work concerns the cost of infrastructure needed to support the export and delivery of hydrogen and its significance as a component of delivered cost. This element, especially, requires further study.

2. **Signals from the policy world (both in the EU and elsewhere) are conflicting and imprecise.**

In part because the global discussion over zero-carbon fuels is at a relatively early stage, policies establishing rules and standards for zero-carbon fuel production, transport, and use are still being defined. In particular, the EU methodology to determine and certify greenhouse gas emissions from low-carbon hydrogen will only be announced by end of 2024. Moreover, there is an unclear message from the EU on the long-term use of low-carbon hydrogen because it is officially for transition purposes and not to be used beyond 2050. These restrictions contribute to uncertainty for investors since long-term use is necessary to have an investment return for building infrastructure and installations. As a result, there is uncertainty about what requirements will need to be met in key markets. Until reasonable clarity can be achieved, it is unlikely that significant investment will result.

3. **Although we have uncovered a great deal of interest and activity in zero-carbon fuels within MENA, there is little regional coordination, and actions are mainly reactive and piecemeal rather than anticipatory.**
4. **Technical challenges associated with the more complex parts of the hydrogen value chain(s) remain uncertain but can be overcome by scaling technologies and additional projects.**

A number of technical challenges still need to be overcome to deliver zero-carbon fuels to market and effectively make use of the full suite of low-carbon production methods. The following challenges have been identified across the value chain. Additional technical challenges could be surfaced following a more in-depth analysis.

Production: There are technical challenges in producing zero-carbon fuels using low-carbon methods. In the case of renewable hydrogen, scaling remains a challenge, both in terms of increasing electrolyzer production capacity and increasing the pace of dedicated renewable capacity additions for electrolysis. In the case of fossil-based hydrogen produced with carbon capture and storage, the hydrogen production technology is mature and can be scaled without the hurdles currently faced by hydrogen generated with renewable energy. Moreover, MENA already has extensive gas networks in place to facilitate production. However, not all fossil-fuel production methods have been used extensively with carbon capture. While the manufacturing of low-carbon hydrogen using natural gas steam methane reforming (SMR) with carbon capture and storage is a proven technology, there is only limited experience fitting carbon capture and storage to autothermal reforming (ATR).

Transportation and Storage: Establishing a large-scale hydrogen market must be underpinned by an effective and cost-efficient system for storage and transport designed to connect supply sources to demand.

Converting hydrogen into a carrier for transportation purposes (liquid hydrogen, methylcyclohexane, ammonia) is another key challenge. Liquified hydrogen is a promising carrier to transport hydrogen from production facilities to end users. While there is mature hydrogen liquefaction know-how, the high costs associated with liquefaction remain a barrier.

In addition to the high costs associated with hydrogen liquefaction to -253 degrees Celsius, vessels must be designed and constructed for large-scale seaborne transportation. Ammonia, another promising hydrogen carrier and zero-carbon fuel, has a mature shipping supply chain, but it will also require scaling of vessels to satisfy future ammonia trade.

Conversion of Carriers: Decentralized ammonia cracking after transportation at the port of arrival or point of use remains at a low-technology readiness level (TRL). While ammonia can be used directly as fuel, other applications will require the hydrogen molecules to be liberated and distributed to end users.

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SECTION 1

Introduction: State of Energy and Climate in MENA

The Middle East and North Africa (MENA) region is a leading producer of hydrocarbon fuels. Led by countries with large hydrocarbon reserves such as Saudi Arabia, the United Arab Emirates (UAE), Qatar, Kuwait, Iraq, and Iran, MENA accounted for an estimated 16% of the world's energy supply in 2014, of which 50% was exported.[1] Annually, (2019) the Middle East exports roughly 6.6 million TJ (gross) of natural gas (4.6% of global production) and 36.7 million TJ (gross) of crude oil (19.3% of global production),[2] and is the largest seaborne crude oil export hub. Much of the oil is destined for countries in Asia, which are most reliant on oil imports. By 2025, Asia is expected to rely on imports to meet 81% of its total oil demand.[3] Europe also relies heavily on imported oil and gas, including, in recent years, imported oil from Iraq and Saudi Arabia,[4] and imported natural gas from Algeria and Qatar.[5]

Despite global efforts to reduce carbon dioxide emissions, to net-zero by around midcentury,[6] and to reduce new restrictions on bank lending to oil and gas projects,[7] demand for hydrocarbon fuels is expected

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1 William Avis, *The use of fossil fuels in the Middle East and North Africa*, Knowledge, Evidence and Learning for Development (K4D) (Feb. 21, 2020), https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/15165/763_Fossil_Fuel_Use_in_the_MENA_Region.pdf?sequence=1&isAllowed=y

2 *Middle East,* Int'l Energy Agency, https://www.iea.org/regions/middle-east (last visited Apr. 4, 2022); Data and Statistics, Int'l Energy Agency, https://www.iea.org/data-and-statistics/data-tables?country=WORLD&energy=Balances&year=2019 (last visited Apr. 11, 2022).

3 *Oil 2020: Analysis and Forecast to 2025,* Int'l Energy Agency 75 (2020), https://iea.blob.core.windows.net/assets/4884bbba-d393-48b8-a9e9-6c2e002efc55/Oil_2020.pdf

4 *From where do we import energy?,* Eurostat, https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2c.html#carouselControls?lang=en (last visited Apr. 8, 2022).

5 Julian Wettengel, *Germany and the EU remain heavily dependent on imported fossil fuels,* Clean Energy Wire (Mar. 14, 2022), https://www.cleanenergywire.org/factsheets/germanys-dependence-imported-fossil-fuels

6 United Nations Framework Convention on Climate Change (UNFCCC), Glasgow Climate Pact 17 (Nov. 13, 2021), https://unfccc.int/sites/default/files/resource/cop26_auv_2f_cover_decision.pdf

7 *Finance is leaving oil and gas,* Inst. for Energy Econ. and Fin. Analysis, https://ieefa.org/finance-exiting-oil-and-gas/ (last visited Apr. 5, 2022).

to remain strong in the near-term.[8] In fact, some leading producers in the MENA region have short- and medium-term plans that anticipate expanded domestic production.[9] Revenues from continued oil sales are expected to help finance domestic decarbonization.[10] Oil majors, likewise, anticipate growth in oil and gas demand from developing countries even as demand declines in developed nations.

Other countries in the region are positioned differently and are likely to make earlier shifts to alternative energy sources. For example, while Oman generates "up to 85% of its GDP from oil and gas, its fossil fuel reserves are dwindling and becoming increasingly costly to extract. In December 2020, the country published its **Oman Vision 2040** strategy, a plan to diversify the economy away from fossil fuels and increase investment in renewables."[11] Still others had more limited fossil resources to begin with (Bahrain, Jordan, Lebanon, Morocco, Syria, Yemen).

The picture for oil and gas demand over the longer term is less certain. Medium- and long-term forecasts for global oil and gas production and when/whether oil and gas demand will peak vary considerably and depend on the degree to which countries adopt and implement new policies consistent with net-zero emission pledges.[12] Some forecasts, based on continuation of current policy and technology trends, see continued oil and gas demand growth through 2050, driven by non-OECD Asia.[13] Scenarios assuming aggressive climate action see marked declines.

With world-class fossil resources at its disposal, the MENA region relies on hydrocarbons for nearly all its electricity production. However, this is set to change. At the end of 2017, the six members of the GCC had some 146 GW of installed power capacity produced largely with hydrocarbon fuels. As recently as 2018, renewable energy accounted for less than 1% of the GCC region's electricity production (867 megawatts, MW), concentrated in three countries: the UAE accounted for 68% of the total installed capacity, followed by Saudi Arabia (16%), and Kuwait (9%).[14] In 2016, $11 billion was invested in renewables across the MENA region compared to $1.2 billion in 2008, a nine-fold increase. Recent auctions resulted in world-record solar prices, including $17.8/MWh for the Sakaka project in Saudi Arabia and $24.2 and $29.9 /MWh in Abu Dhabi and Dubai, respectively. Morocco hosts the world's largest concentrated solar power (CSP) plant and leads the region in renewable capacity. Growth in renewable energy across the Middle East and North Africa region could reach 80 GW by 2030 if the region's ambitious climate targets are met.[15] Further, the UAE has started the first public nuclear electricity project (Barakah) with four reactors to provide 5.6 GW. ADNOC (Abu Dhabi National Oil Company) and ADQ's (Abu Dhabi Developmental Holding Company) recent stake in MASDAR aims to propel investment for 23GW of additional renewable power in the UAE. Unit 1 is operational, while the others are in the final stages of construction (Units 3 and 4) or fuel loading (Unit 2).[16]

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[8] Irina Slav, *Global Oil Demand Could Reach New Heights in 2022,* Business Insider (Dec. 28, 2021), https://markets.businessinsider.com/news/stocks/global-oil-demand-could-reach-new-heights-in-2022-1031068861

[9] *See* Alex Lawler & Hadeel Al Sayegh, *UAE says Q1 to see oil supply surplus, current shortage not unexpected,* Reuters (Nov. 15, 2021), https://www.reuters.com/business/energy/uae-energy-minister-says-current-oil-shortage-not-unexpected-2021-11-15/; *see also* Sara Schonhardt, *Saudi Arabia's climate plan relies on more oil,* E&E News (Nov. 8, 2021), https://www.eenews.net/articles/saudi-arabias-climate-plan-relies-on-more-oil/

[10] Sara Schonhardt, *Saudi Arabia's climate plan relies on more oil,* E&E News (Nov. 8, 2021), https://www.eenews.net/articles/saudi-arabias-climate-plan-relies-on-more-oil/

[11] Laura Paddison, *Oman plans to build world's largest green hydrogen plant,* The Guardian (May 27, 2021), https://www.theguardian.com/world/2021/may/27/oman-plans-to-build-worlds-largest-green-hydrogen-plant

[12] *World Energy Outlook 2021: Overview, Int'l Energy Agency* (Oct. 2021), https://www.iea.org/reports/world-energy-outlook-2021/overview; *Energy Outlook: Overview,* BP (Mar. 14, 2022), https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/overview.html

[13] Stephen Nalley & Angelina LaRose, *International Energy Outlook 2021* (IEO2021), U.S. Energy Info. Admin. (Oct. 6, 2021), https://www.eia.gov/outlooks/ieo/pdf/IEO2021_ReleasePresentation.pdf

[14] *See Middle East,* Int'l Energy Agency, https://www.iea.org/regions/middle-east (last visited Apr. 4, 2022).

[15] *Middle East & North Africa,* Int'l Renewable Energy Agency, https://www.irena.org/mena (last visited Apr. 5, 2022).

[16] *U.A.E. Nuclear Power Plant Reaches "First Criticality" in First for Arab World,* U.S.-U.A.E. Bus. Council (Aug. 3, 2020), http://usuaebusiness.org/u-a-e-nuclear-power-plant-reaches-first-criticality-in-first-for-arab-world/; Matt Fisher, UAE's Nuclear Power Journey Has Lessons for Newcomers as IAEA Restarts In-Person Reviews, Int'l Atomic Energy Agency (May 24, 2021), https://www.iaea.org/newscenter/news/uaes-nuclear-power-journey-has-lessons-for-newcomers-as-iaea-restarts-in-person-reviews

1.1 Energy Mix Presents Challenges and Opportunities in Meeting Climate Goals

In light of global efforts to cut emissions roughly in half by 2030 and reach carbon neutrality by 2050,[17] MENA's current energy production and resource mix presents clear challenges for decarbonization, but also opportunities. With a heavy reliance on unabated fossil energy production and consumption, the region has considerable work to do to lower its direct greenhouse gas emissions, including methane and carbon dioxide emissions associated with fossil fuel production.

On average, the Middle East region emitted 7.2 tonnes CO_2 per capita in 2019 – roughly 1.6 times the global average. However, these averages mask enormous variation related to fossil fuel production and consumption and national development characteristics. Driven by production and use of hydrocarbons, the six GCC countries have per capita CO_2 emissions ranging from 13.9 and 30.7 tonnes while Middle East countries outside the GCC have carbon intensities ranging from 0.3 to 7.0 tonnes of CO_2 per capita. North African countries have per capita CO_2 emissions of between 1.7 and 6.8 tonnes.[18]

While renewable energy presents a path to decarbonize domestic energy use, to the extent that the MENA region continues to rely on sales of unabated hydrocarbons, it risks losing market share in countries committed to deep decarbonization and carbon neutrality. A change in strategy is needed to take advantage of new market opportunities and retain market share in the supply of fuels over the medium- and long-term. An aggressive zero-carbon fuel strategy could help customers reliant on hydrocarbon fuels meet their climate mitigation goals and improve the viability of low-emission hydrogen over electrification for more applications. At the same time, production and use of zero-carbon fuels in lieu of unabated hydrocarbons will reduce the carbon footprint within the host countries.

MENA's extensive and low-cost energy resources, both fossil and renewables, along with its infrastructure (industrial base, fuel transportation, deep water ports), large potential geologic carbon storage capacity (including depleted oil and gas fields), capital resources, available land, supply chain, and engineering capacities, position the region to lead in the production of zero-carbon fuels seen as critical to replacing hydrocarbons in hard-to-decarbonize sectors. While the "winning" zero-carbon fuel technologies in MENA and globally are not yet clear and will depend on factors such as cost and demand, there is growing interest within MENA in the range of zero-carbon fuels technologies.
With burgeoning pilot and demonstration projects across the region, zero-carbon fuels are increasingly viewed as a central component of the region's future. However, with the relatively large number of players starting to engage with this new opportunity, the various forms of zero-carbon fuels being explored, and the uncertain future demand for the different resources and fuels, there is considerable uncertainty as to how the region will scale up technology to take full advantage of zero-carbon fuels markets.

Within the region, the answer could be different from one country to another considering differences in natural resource endowments. Countries like Morocco and Jordan, for example, that have more modest levels of domestic hydrocarbon production, may see the primary opportunity as renewable-energy-based electrolysis to support their trade balance. In contrast, the GCC countries may seek to lean more heavily on lower-cost steam methane reformation coupled with carbon management. Of note, the IEA finds both technologies will be needed to meet climate goals in the most cost-effective manner.[19]

As a vital part of the region's response to the global climate challenge, we believe there is an opportunity for MENA actors to work together to create world-class infrastructure and zero-carbon fuel export and import markets. Through regional collaboration, MENA

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17 Jeff Tollefson, *IPCC says limiting global warming to 1.5 °C will require drastic action,* Nature (Oct. 8, 2018), https://www.nature.com/articles/d41586-018-06876-2

18 *Middle East,* Int'l Energy Agency, https://www.iea.org/regions/middle-east (last visited Apr. 4, 2022).

19 IEA's Net Zero by 2050 report finds that low-carbon hydrogen will need to increase from 9 Mt in 2020 to 150 Mt in 2030 and 520 Mt in 2050. In 2030, they forecast 54% of this low-carbon hydrogen will be produced with renewables and 46% will come from hydrocarbons and carbon management. By 2050, the share from renewables will be higher (62%), but 38% will still be delivered through hydrocarbon-fuelled production with carbon management. Net Zero by 2050, Int'l Energy Agency (May 2021), https://www.iea.org/reports/net-zero-by-2050

countries could leverage early experience and capacity to develop technical and policy concepts that would build confidence in zero-carbon fuels coming from the region while informing critical policy debates elsewhere.

1.2 CATF Project to Explore Opportunities for Zero-Carbon Fuels in MENA

Nearly all countries will need zero-carbon fuels to fill residual demand for energy in sectors and end-uses that are not amenable to electrification. To date, the MENA region has been mainly viewed by Europeans as a potential location for siting utility-scale photovoltaic projects, whose output could be used to produce hydrogen through electrolysis. However, CATF engineering and economics analysis of other geographies led us to conclude that the land use and infrastructure challenges of this additional renewable energy build-out, and the potential for delay in making this hydrogen available, suggest that renewable energy-derived hydrogen should be supplemented by other options, especially hydrogen made from fossil fuels, with associated carbon capture and storage and measures to limit lifecycle methane emissions.[20]

CATF foresees that the hydrocarbon-derived low-emission hydrogen pathway will have particular salience in nations with significant hydrocarbon reserves and carbon dioxide injection/storage potential and an interest in preserving the value of those resources. This includes virtually all the MENA region. A continued pathway for production and sale of MENA hydrocarbons could be opened if hydrocarbon-derived low-emission hydrogen can be demonstrated to be cost effective and other environmental safeguards can be met. In particular, carbon capture and storage must be shown to be government regulated to ensure permanence, and upstream methane emissions associated with the production of natural gas must be cut to near zero.

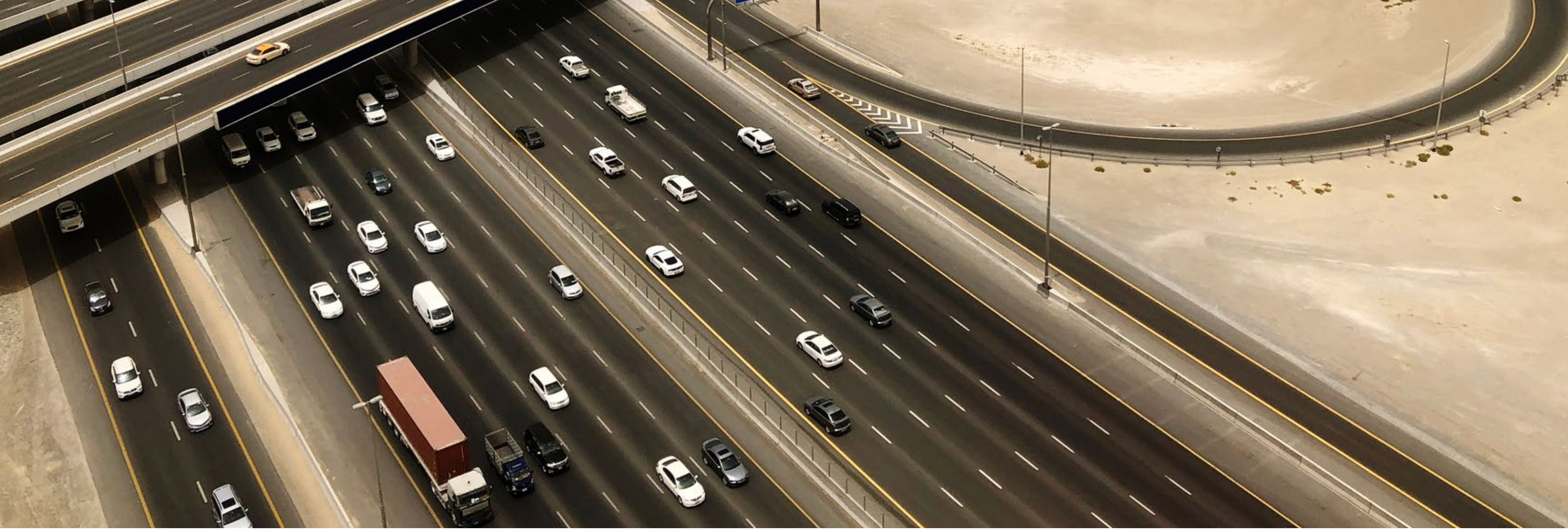
The development of carbon capture and storage in the MENA region can also make a key contribution towards accelerating the commercialization of the technology, which has been identified as vital to achieving global climate targets by organizations including the International Energy Agency and the International Panel on Climate Change. In addition to providing a source of zero-carbon fuels, carbon capture and storage will have an important role to play in decarbonizing hard-to-abate industries and the large-scale removal and storage of atmospheric CO_2; several examples of such applications are already operating or planned globally and in the MENA region (see Box 2). Scaling up zero-carbon fuel production will help establish economies of scale and regulatory frameworks for new CO_2 infrastructure, which can, in turn, support the wider decarbonization of the region and advance these technologies for global use.

1.3 Methodology to Assess Current State-of-Play for Zero-Carbon Fuels in MENA

To understand both the challenges and opportunities for zero-carbon fuel production in the MENA region, CATF conducted 38 structured interviews with experts in the export region and in key import markets, particularly Europe and Japan.

Most interviews from within the MENA region focused on gaining an in-depth perspective from government, industry, and academia in two countries: UAE and Saudi Arabia. These can be viewed as a good proxy for the major oil and gas producing members of the GCC, including UAE, Bahrain, Saudi Arabia, Oman, Qatar, and Kuwait, and to a lesser degree the other major oil and gas producers in the region: Iran and Iraq. Additional interviews were conducted with experts from Egypt, Kuwait, Morocco, and Turkey. Accordingly, while we reference the MENA region, given the breadth of the interviews, findings on the zero-carbon fuel opportunity for other countries in the Middle East region that are not major producers of oil and gas (e.g., Syria, Jordan, Lebanon, Yemen) and North Africa (Egypt, Algeria, Libya, and Tunisia) could be seen as preliminary. Information provided on the regional context, current state-of-play for the different technologies, barriers, and recommendations, draws extensively on the expert interviews. Additional information is taken from published information and data and informed by CATF technology experts.

[20] Mike Fowler, *We need "blue" hydrogen. And we need to get it right,* Clean Air Task Force (Sept. 3, 2021), https://www.catf.us/2021/09/we-need-blue-hydrogen-and-we-need-to-get-it-right/



SECTION 2

Experience with Zero-Carbon Fuels in MENA

The MENA region has experience with and/or is actively exploring the full range of technologies needed to advance production of zero-carbon fuels, including carbon capture, utilization, and storage, steam methane reformation, and electrolysis.

2.1 Experience with Carbon Management

The capacity to safely, permanently, and economically capture and store carbon dioxide is critical to facilitating production of low-carbon hydrogen and ammonia from the region's natural gas and oil resources as well as net-zero liquified natural gas (LNG). Some companies, such as Occidental Petroleum, see CO_2 storage as a possible new profit center (Saudi Aramco, ADNOC) and business model, making carbon management, including direct air capture, a central part of their future plans. As noted above, the MENA region is endowed with significant amounts of pore space for geological storage. In fact, the CO_2 storage capacity in the region is estimated to be capable of accepting 170 billion tonnes of CO_2.[21]

Experience in the region with CO_2 capture and storage centers on a few pioneer projects, summarized in Box 2.

To support further development of the carbon capture, utilization, and storage opportunity, countries in the MENA region have started to develop a regulatory framework for carbon management, covering factors such as how carbon dioxide is classified, ownership of subsurface pore space, liability for emissions post-closure, and requirements related to the capture, transport, and storage of carbon dioxide. For example, among the GCC countries, the regulatory framework needed to support investments in carbon capture, utilization, and storage technology is incipient (Table 1). All six countries already require environmental impact studies, and nearly all are instituting incentives and addressing liability during the post-closure period. However, there are also major gaps in the regulatory framework, contributing to uncertainty on the part of developers and buyers on the cost, environmental impact, and market value of carbon capture, utilization, and storage and hydrocarbon-derived zero-carbon fuels.

[21] Michael Godec et al., *Opportunities for Using Anthropogenic CO_2 for Enhanced Oil Recovery and CO_2 Storage,* 27 Energy & Fuels 4183 (2013).

Box 2: MENA Experience with Carbon Capture, Utilization, and Storage

Several countries within MENA have experience with carbon capture, utilization, and storage technology, demonstrating the technological capacity within the region.

Saudi Arabia has advanced enhanced oil recovery (EOR) projects, including Saudi Aramco's Uthmaniyah CO_2-EOR project. The region's expertise in CO_2 sub-surface oil and gas activities, including hydrocarbon injection for pressure maintenance, are expected to be directly relevant to CO_2 injection for sequestration and for EOR.

The UAE's Al Reyadah project includes capture, transport, and injection of up to 800,000 tonnes of CO_2 per year. Part of an overall master plan which could also create a CO_2 network and hub for managing future CO_2 supply and injection requirements in the UAE, the project captures carbon dioxide from the flue gas of an Emirates Steel production facility and injects the CO_2 for EOR in the Abu Dhabi National Oil Company's nearby oil fields.[22]

In 2019, Qatar's Energy Minister Said al-Kaabi announced plans to capture and sequester millions of tonnes of carbon dioxide from its LNG export facilities by 2025. Qatar currently has the capacity to capture 2.1 Mt per year of CO_2 from the Ras Laffan LNG plant for geologic sequestration, one of the first examples of dedicated sequestration in MENA.[23] As part of its plan to scale up carbon capture and storage, Qatar is looking both at carbon sequestration, which was framed as the nearer term option, as well as EOR, which QatarEnergy has been piloting in some of its oilfields. In January 2021, Qatar announced plans to build out capacity for carbon capture and storage to 7 million tons per year by 2030.[24] In February 2021, QatarEnergy announced final investment decision (FID) on the North Field East LNG Project, with a reference to carbon capture and storage being included in the design. While the amount of annual carbon capture was not disclosed, $200M of the estimated $28.75B project was for emissions reduction technology.[25]

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22 *Al Reyadah Carbon Capture, Use, and Storage (CCUS) Project,* Carbon Sequestration Leadership F., https://www.cslforum.org/cslf/Projects/AlReyadah (last visited Apr. 5, 2022).

23 *Global Status of CCS 2020,* Global CCS Inst., https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf (last visited Apr. 5, 2022).

24 Verity Ratcliffe, *Qatar Raises Carbon Capture Ambitions, Touting Green Credentials,* Bloomberg (Jan. 13, 2021), https://www.bloomberg.com/news/articles/2021-01-13/qatar-raises-carbon-capture-ambitions-touting-green-credentials

25 Katie McQue, *QP to spend $200 million on emissions reduction technology for LNG expansion project,* S&P Global (Jun. 30, 2021), https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/063021-qp-to-spend-200-million-on-emissions-reduction-technology-for-lng-expansion-project

Table 1: Status of the Regulatory Framework for Carbon Capture, Utilization, and Storage in GCC Countries

Source: Table is taken from the Masdar Institute which examined the GCC countries[26]

Regulatory Domain (X:MAJOR GAP; -:MINOR GAP; BLANK:NO GAP)	Bahrain	Kuwait	Oman	Qatar	KSA	UAE
CO_2 classification	X	X	X	X	X	X
Ownership of subsurface facility	–	X		X	X	–
Transboundary CO_2	X	X	X	X	X	X
Environmental impact study						
CO_2 impurity	X	X	X	X	X	X
CO_2 capture regulation	–	X		X	X	–
CO_2 transportation regulation	–	X		X	X	–
CO_2 storage regulation*	X	X	X	X	X	X
Liability during the post-closure period	–	–	X	–	–	–
Regulation for CCS with EOR	X	X	X	X	X	X
Incentives	–	–	X	–	–	–

2.2 Experience Using Hydrocarbons to Produce Synthetic Fuels, Including Zero-Carbon Fuels

The MENA region has experience and capacity to produce synthetic fuels, and coupled with its vast carbon storage potential, has the capability to lead in production of hydrocarbon-derived zero-carbon fuels. Initial projects demonstrate the potential and readiness to deliver ero-carbon fuels produced with fossil resources.

Led by Saudi Arabia, Qatar, and Iran, the MENA region produced 14% of the global ammonia supply in 2019 (20.5M tons),[27] with carbon dioxide emissions associated with that production estimated at 25.5 million tons. With efforts to reduce emissions from these existing sources of ammonia production (e.g., through carbon capture, utilization, and storage as described above), the MENA region is well-positioned to yield large volumes of decarbonized fuels. Likewise, established ammonia shipping routes[28] coupled with the expansive loading and receiving terminal network can support access to markets for low-carbon fuels and enable the MENA region to lead in trade of zero-carbon.

Major MENA players recognize this potential, having recently made public announcements of some of the world's first blue ammonia shipments. In 2020, Saudi Aramco announced a zero-carbon fuel value chain with Japan, alongside their first blue ammonia shipment. Forty tonnes of ammonia were shipped to Japan, with support from the Japanese Ministry of Economy, Trade, and Industry. The associated carbon dioxide was captured by Saudi Aramco and utilized both for methanol production at SABIC's Ibn-Sina facility and CO_2-EOR at Aramco's Uthmaniyah field.[29]

[26] I-Tsung Tsai, *CCS Regulation in Gulf Cooperation Council (GCC): Current Progress & Future Perspectives,* Masdar Inst. (May 2014).

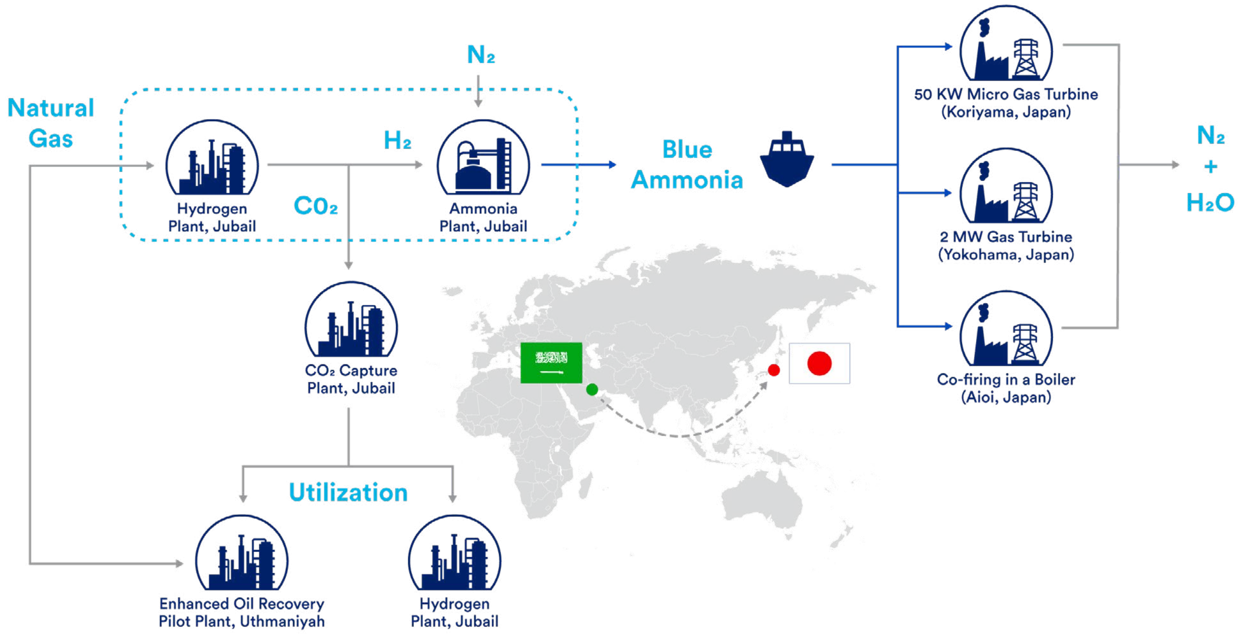
[27] Assuming 2.9 tons CO_2 / ton NH_3 produced.

[28] *Nitrogen Statistics and Information,* Nat'l Min. Info. Ctr., https://www.usgs.gov/centers/nmic/nitrogen-statistics-and-information (last visited Apr. 5, 2022).

[29] Joanna Sampson, *World First: Saudi Arabia Sends Blue Ammonia Shipment to Japan,* World-Energy (Sept. 30, 2020), https://www.world-energy.org/article/12799.html; *see also World's first blue ammonia shipment opens new route to a sustainable future,* Aramco (Sept. 27, 2020), https://www.aramco.com/en/news-media/news/2020/first-blue-ammonia-shipment

Figure 2: Saudi Arabia-Japan "Blue Ammonia" Supply Chain Demonstration[30]

Conceptual Flow Diagram of "Blue Ammonia" Supply Chain Demonstration (Duration: August 2020 – October 2020)



[30] *Conceptual Flow Diagram of "Blue Ammonia" Supply Chain Demonstration,* Aramco (Aug.-Oct. 2020), https://www.aramco.com/-/media/news/2020/sep/blue-ammonia-supply-chain-flow-diagram-web.pdf?la=en&hash=6FFE2FC0FF076E1BA65B957B1B22405BF817281A

[31] *World's first blue ammonia shipment opens new route to a sustainable future,* Aramco (Sept. 27, 2020), https://www.aramco.com/en/news-media/news/2020/first-blue-ammonia-shipment

> The use of hydrogen is expected to grow in the global energy system, and this world's first demonstration represents an exciting opportunity for Aramco to showcase the potential of hydrocarbons as a reliable and affordable source of low-carbon hydrogen and ammonia. This milestone also highlights a successful transnational, multi-industry partnership between Saudi Arabia and Japan. Multinational partnerships are key in realizing the Circular Carbon Economy, championed by the Saudi Arabian G20 Presidency. Aramco continues to work with various partners around the world, finding solutions through the deployment of breakthrough technologies to produce low-carbon energy and address the global climate challenge.[31]
>
> – Ahmad O. Al-Khowaiter, Aramco's Chief Technology Officer

The UAE has also staked out a leadership position, with East Asian counterparties, on natural gas-derived hydrogen with carbon capture and storage. In August 2021, ADNOC announced the sale of its first cargo of so-called "blue" ammonia to Japan for fertilizer production, leaving from the port of Ruwais. The carbon dioxide was to be transferred to – and reinjected into – underground reservoirs by the ADNOC Al carbon capture plant.[32] Additional shipments of natural gas-derived ammonia with carbon capture and storage have been sent to Japanese refinery Idemitsu for use in operations.[33] Separately, ADNOC and Fertiglobe sold low-carbon fuel demonstration cargos to customers in Japan and Korea.[34]

Dr. Sultan Ahmed Al Jaber, UAE Minister of Industry and Advanced Technology and ADNOC's group CEO said, "Today's announcement builds upon ADNOC's commitment to expanding the UAE's position as a regional leader in the production of hydrogen and its carrier fuels, meeting the needs of critical global export markets such as Japan. Through the expansion of our capabilities across the blue ammonia value chain, we look forward to furthering our legacy as one of the world's least carbon-intensive hydrocarbon producers and supporting industrial decarbonization with a competitive, low-carbon product portfolio."[35]

ADNOC, OCI, and Fertiglobe announced plans to expand their blue ammonia offering right next to Al Ruwais. This new blue ammonia facility's capacity will be up to one million tonnes per year. The FID is expected in 2022 for a plant start-up in 2025.[36] ADNOC's company-wide plan includes expanding CO_2 capture to 5 million tons per year by 2030.[37]

These early projects demonstrate the technical viability across the value chain – from production of hydrogen and ammonia with carbon capture, utilization, and storage, shipping, and fuel consumption, and recognize growth in export markets for hydrocarbon-derived zero-carbon fuels where off-takers are willing to pay a premium for the environmental attribute. Stakeholders emphasized that conventional fuel prices will not pay for carbon management, and that hydrocarbon-derived zero-carbon fuels will not be profitable unless buyers are willing to pay the cost premium for this added service; which a regulatory driver or target carbon price would make more attractive. This and other barriers to large-scale investment are discussed below.[38]

However, fuel costs vary by region considering economies of scale, infrastructure, and other factors. Industrial conventional hydrogen in the Middle East can cost as low as $0.90/kg, and adding carbon capture, utilization, and storage might raise the price by 35-50%, or about $0.50/kg, to $1.40/kg.[39] However, this does not include the cost of converting the hydrogen molecules to a suitable carrier for hydrogen transportation (and liberating the hydrogen molecules at the end user point), which further underscores the economic challenge that decarbonized hydrogen from the Middle East is not yet competitive with market prices for hydrogen or ammonia generated with unabated fossil fuels. With improved

[32] Richard Ewing, *ADNOC and Fertiglobe sell UAE's first cargo of blue ammonia to Japan's Itochu,* Indep. Commodity Intel. Servs. (Aug. 3, 2021), https://www.icis.com/explore/resources/news/2021/08/03/10669904/adnoc-and-fertiglobe-sell-uae-s-first-cargo-of-blue-ammonia-to-japan-s-itochu/

[33] *Adnoc Makes New Blue Ammonia Shipment to Japan,* World-Energy (Sept. 10, 2021), https://www.world-energy.org/article/20168.html

[34] Sanja Pekic, *Mitsui and GS join TA'ZIZ in blue ammonia project,* Offshore Energy (Nov. 16, 2021), https://www.offshore-energy.biz/mitsui-and-gs-join-taziz-in-blue-ammonia-project/

[35] Richard Ewing, *ADNOC and Fertiglobe sell UAE's first cargo of blue ammonia to Japan's Itochu,* Indep. Commodity Intel. Servs. (Aug. 3, 2021), https://www.icis.com/explore/resources/news/2021/08/03/10669904/adnoc-and-fertiglobe-sell-uae-s-first-cargo-of-blue-ammonia-to-japan-s-itochu/

[36] *Fertiglobe Joins TA'ZIZ as Partner in World-Scale Blue Ammonia Project in Ruwais in Abu Dhabi,* OCI, https://www.oci.nl/news/2021-oci-nv-7/ (last visited Apr. 5, 2022).

[37] *UAE's ADNOC, TotalEnergies sign agreement on CCS, hydrogen,* S&P Global (Dec. 5, 2021), https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/120521-uaes-adnoc-totalenergies-sign-agreement-on-ccs-hydrogen

[38] Sunita Satyapal, *2021 AMR Plenary Session,* U.S. DOE (Jun. 7, 2021), https://www.hydrogen.energy.gov/pdfs/review21/plenary5_satyapal_2021_o.pdf; *Reports / Case Studies,* Fuel Cell & Hydrogen Energy Ass'n, https://www.fchea.org/reports (last visited Apr. 5, 2022); The Future of Hydrogen, Int'l Energy Agency (Jun. 2019), https://www.iea.org/reports/the-future-of-hydrogen (U.S. specific numbers).

[39] *Hydrogen in the GCC,* Qamar Energy (Nov. 2020), https://www.rvo.nl/sites/default/files/2020/12/Hydrogen%20in%20the%20GCC.pdf

efficiencies of steam methane reformation and the possibility of lower future natural gas prices as demand starts to fall, the Chief Technology Officer at Saudi Aramco expects the cost of so-called "blue" hydrogen to come down to $1/kg. Existing fossil-based hydrogen in the region is produced for captive downstream industries, mainly for oil refining. Therefore, hydrogen from retrofitted steam methane reformers (SMR) are not likely to become available as ZCFs for export.

2.3 Demonstrations and Plans to Advance Zero-Carbon Fuels Produced with Renewables

In parallel, the MENA region is actively exploring opportunities to produce zero-carbon fuels with renewable energy. The UAE recently launched the first solar-driven, hydrogen-producing facility in the MENA region.[40] The public-private solar-powered electrolysis facility was demonstrated during Expo 2020 Dubai, which took place from October 1, 2021 until March 31, 2022.

The facility is testing and demonstrating how hydrogen can be produced with renewable energy on an industrial scale, stored, and deployed. In the pilot, photovoltaic electricity from the Mohammed bin Rashid Al Maktoum Solar Park is harnessed during the day to produce hydrogen using proton exchange membrane (PEM) electrolysis. At night, the hydrogen is converted into electricity to power the city with sustainable energy.[41]

Saudi Arabia is building one of the world's largest green hydrogen facilities. The NEOM plant will be powered by over four gigawatts of renewable energy from solar and wind. Once on-line by 2025, it is expected to produce 650 tons per day (0.2 Mt per year) of green hydrogen by electrolysis and more than 3,200 tons per day (1.2 Mt per year) of green ammonia. Other countries in MENA have taken early steps to produce zero-carbon fuels with renewable energy, including Bahrain,[42] Egypt,[43] Jordan,[44] Morocco,[45] Mauritania,[46] Oman,[47] and Tunisia.[48] Some of these projects are being developed to serve the European market. This information is summarized in Table 2.

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[40] *Under the patronage and presence of Ahmed bin Saeed Al Maktoum Dubai inaugurates Green Hydrogen project at Mohammed bin Rashid Al Maktoum Solar Park,* Dubai Elec. and Water Auth. (May 19, 2021), https://www.dewa.gov.ae/en/about-us/media-publications/latest-news/2021/05/green-hydrogen-project

[41] *Green Hydrogen Project: clean fuel from solar power in Dubai,* Siemens Energy, https://www.siemens-energy.com/mea/siemens-energy-in-middle-east/company/megaprojects/dewa-green-hydrogen-project.html (last visited Apr. 5, 2022); *Green hydrogen powers the way to a brighter future with new project,* Expo 2020 Dubai UAE (May 19, 2021), https://www.expo2020dubai.com/en/news/expo-siemens-energy-dewa-green-hydrogen

[42] *Bahrain to establish green hydrogen plant,* bizbahrain (Dec. 22, 2021), https://www.bizbahrain.com/bahrain-to-establish-green-hydrogen-plant/

[43] *Egypt: Minister – Egypt Plans to Incorporate Green Hydrogen,* allAfrica (Dec. 28, 2021), https://allafrica.com/stories/202112280085.html; *Siemens Energy supports Egypt to develop Green Hydrogen Industry,* Siemens Energy (Aug. 24, 2021), https://press.siemens-energy.com/mea/en/pressrelease/siemens-energy-supports-egypt-develop-green-hydrogen-industry

[44] *FFI partners with the Kingdom of Jordan on green hydrogen,* pv mag. (Nov. 4, 2021), https://www.pv-magazine-australia.com/press-releases/ffi-partners-with-the-kingdom-of-jordan-on-green-hydrogen/

[45] Anoop Menon, *Morocco's first green hydrogen project to start production in 2025,* ZAWYA (May 24, 2021), https://www.zawya.com/mena/en/business/story/Moroccos_first_green_hydrogen_project_to_start_production_in_2025-ZAWYA20210524060307/; Alba Sanz, *Morocco halts green hydrogen agreement with Germany,* Atalayer (May 31, 2021), https://atalayar.com/en/content/morocco-halts-green-hydrogen-agreement-germany

[46] *CWP developing a US$40 billion Green Hydrogen project in North Africa,* RenewAfrica (Jun. 2, 2021), https://www.arabianbusiness.com/industries/energy/463477-omans-oq-partners-plan-25-gigawatt-green-hydrogen-plant; Matthew Goosen, *Chariot Partners with Mauritania for Green Hydrogen Plan,* Energy Cap. & Power (Dec. 9, 2021), https://energycapitalpower.com/chariot-partners-with-mauritania-for-green-hydrogen-plan/

[47] Laura Paddison, *Oman plans to build world's largest green hydrogen plant,* The Guardian (May 27, 2021), https://www.theguardian.com/world/2021/may/27/oman-plans-to-build-worlds-largest-green-hydrogen-plant; *Oman's OQ and partners plan 25-gigawatt green hydrogen plant,* Arabian Bus. (May 18, 2021), https://www.arabianbusiness.com/industries/energy/463477-omans-oq-partners-plan-25-gigawatt-green-hydrogen-plant

[48] Rim Hana, *Tunisia-German donates of 30 million euros to develop green hydrogen,* Tunisie Numerique (Dec. 16, 2020), https://news-tunisia.tunisienumerique.com/tunisia-german-donate-of-30-million-euros-to-develop-green-hydrogen/

Table 2: Renewable-Based Hydrogen Projects Announced in MENA

Country	Project	Hydrogen produced and/or electrolyzer or RE capacity	Status	Off-taker	On-line year
UAE	Mohammed bin Rashid Al Maktoum Solar Park Expo 2020 Dubai demonstration project (solar)	20.5 kg H_2/hour; 1.25 MW renewable capacity	In demonstration	Electricity production for city	On-line
Saudi Arabia	NEOM plant (solar + wind)	0.2 Mt H_2 & 1.2 Mt ammonia per year; 4+ GW renewable capacity	Under construction		2025
Morocco	Power-to-X (wind and solar)	100 MW renewable capacity	Signed agreement (Germany) but currently stalled	At least a portion of the hydrogen would be exported to Germany	2025
Oman	Al Wusta (wind and solar)	1.8 Mt hydrogen and 10 Mt ammonia per year; 25 GW renewable capacity	Final investment decision expected in 2026; construction to begin in 2028	Most hydrogen/ ammonia to be exported to Europe and Asia	At full capacity in 2038
Egypt	Anticipates five pilot projects (wind and solar)	100-200 MW	MOU signed (Siemens)	Intended for export	
Mauritania	Project Nour green hydrogen plant (wind and solar)	Up to 10 GW	MOU signed, $9.5M for feasibility study (Chariot Ltd.)	Anticipates exports to Europe	
Mauritania	AMAN (wind and solar)	30 GW	MOU signed (CWP Global)		
Tunisia	Power-to-X		MOU signed (Germany)	At least a portion of the hydrogen would be exported to Germany	
Jordan	(solar and wind)		Framework agreement signed to conduct studies (FFI)	Intended for export	
Bahrain		4 MW	Announced		

Read more: UAE's Masdar signs deal for green hydrogen projects in Egypt, targets exports to Europe

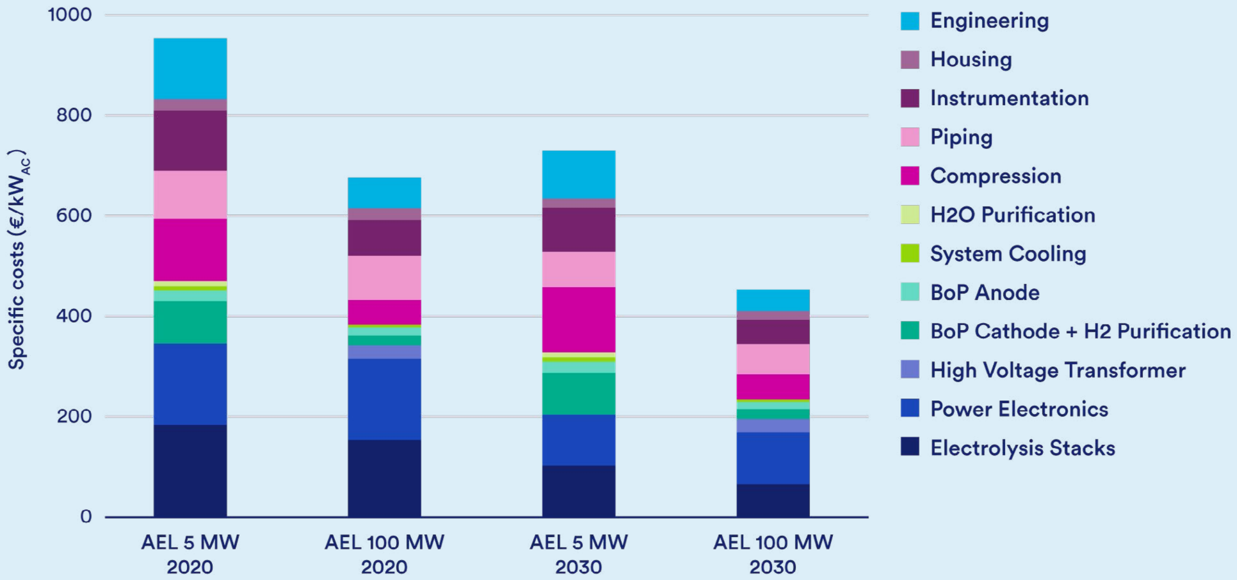
Box 3: Long-Term Potential of Electrolyzer Technology

A recent bottom-up study by the Fraunhofer Institute for Solar Energy Systems[49] commissioned by CATF found that system costs for electrolyzer technology (all the different system components) could be reduced by up to a third between 2020 and 2030. For example, the study found that large-scale 100 MW alkaline electrolyzer system costs can be reduced from 663 Euros per kW in 2020 to 444 Euros per kW in 2030. Notably, as shown in Figure 3, the electrolysis stacks are just one of several components driving the cost of electrolyzer systems. The study found that electrolysis stack costs of 65 Euros per kW are reachable by 2030.

How these costs translate to costs per kg of hydrogen produced depends on the price of zero-carbon electricity and how often the systems are used. As illustrated in Figure 4, assuming electricity costs of 50 Euros/kWh, the hydrogen production costs (Euros/kg) decrease strongly with rising annual full load hours. The cost curves for the MENA region would be more favorable than shown, given optimal conditions for renewable energy. Costs per kg of hydrogen production are most attractive when electrolyzers are used upwards of 3,000 hours per year, roughly equivalent to a renewable energy capacity factor of 34%.

A separate CATF analysis finds that to produce renewable hydrogen for $1.50/kg (€1.36/kg), it would be necessary to have either free renewable electricity available to run the electrolyzer at nearly 40% capacity factor (e.g., electricity that would otherwise be curtailed) or, if paying for dedicated electricity, it would need to cost no more than 1.8 cents USD/kWh (0.016 EUR/kWh) if it is available at 100% capacity factor.[50]

Figure 3: Specific Costs of 5 MW and 100 MW Next Generation AEL Systems (including mechanical compressors) for the Design Scenarios 2020 and 2030

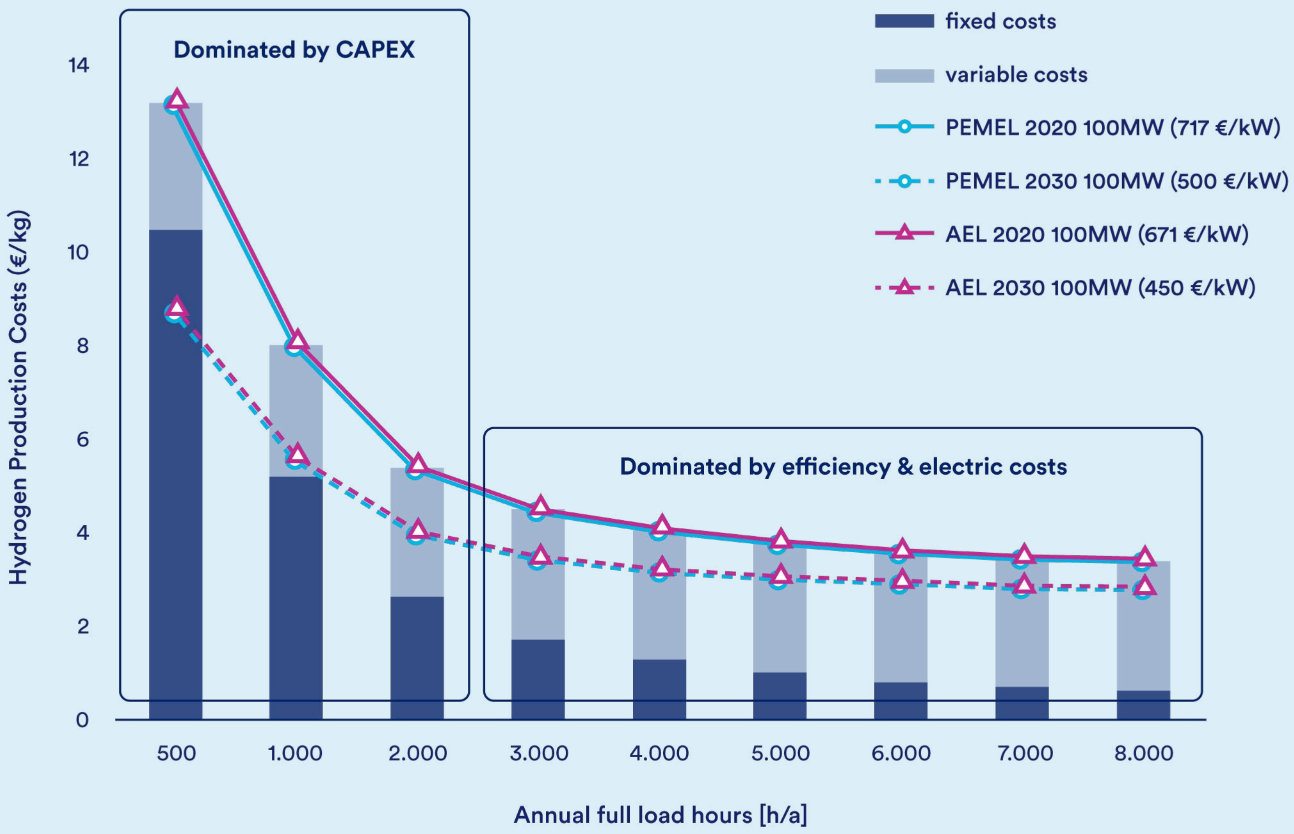


[49] Marius Holst et al., *Cost Forecast for Low Temperature Electrolysis – Technology Driven Bottom-Up Prognosis for PEM and Alkaline Water Electrolysis Systems,* Fraunhofer Institute for Solar Energy Systems ISE (Oct. 2021), https://www.ise.fraunhofer.de/content/dam/ise/de/documents/presseinformationen/2022/2021-11-17_CATF_Report_Electrolysis_final.pdf

[50] Mike Fowler, *Low-emission hydrogen for $1.50/kg Could Promote Significant Decarbonization. What Will It Take to Get There with Renewable Electricity?,* Clean Air Task Force (Apr. 27, 2021), https://www.catf.us/2021/04/clean-hydrogen-significant-decarbonization/

Costs for hydrogen produced with renewable energy are considerably higher than costs for hydrocarbon-derived ZCFs but are projected to decline: according to a report on hydrogen in the GCC by the Netherlands Enterprise Agency, green hydrogen costs are expected to fall from $3.5-7.5/kg (€3.2-6.8/kg)[51] in 2020 to $1.6-2.2/kg (€1.5-2.0/kg) by 2030.[52] However, Siemens Energy announced in March 2021 that it would begin using commercial wind projects to generate green hydrogen for just $1.50/kg (€1.36/kg) by 2025.[53] Europe's hydrogen demand is expected to increase from around 8 Mt/year and the EU Commission has recognized that Europe will not be able to produce its own hydrogen, highlighting the need for imports.

Figure 4: Hydrogen Production Cost (€/kg) Depending on Annual Full Load Hours (hours/year) and Electrolyzer Type and Cost

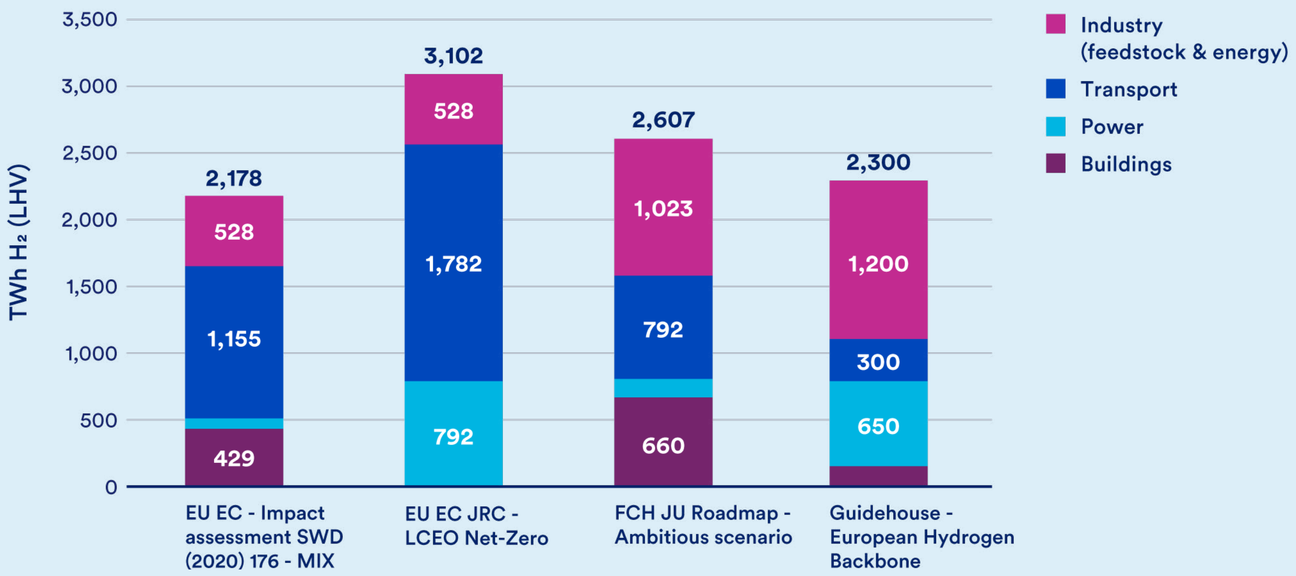


[51] Currency conversions are made using Oanda.com on March 23, 2022.

[52] *Hydrogen in the GCC,* Qamar Energy (Nov. 2020), https://www.rvo.nl/sites/default/files/2020/12/Hydrogen%20in%20the%20GCC.pdf

[53] Sergio Matalucci, *The Hydrogen Stream: Siemens targets $1.50/kg by 2025, BP and Saudi Aramco bet on blue hydrogen,* pv mag. (Mar. 26, 2021), https://www.pv-magazine.com/2021/03/26/the-hydrogen-stream-siemens-targets-1-50-kg-by-2025-bp-and-saudi-aramco-bet-on-blue-hydrogen/; Michael J. Coren, *The natural gas industry's risky bet on hydrogen,* Quartz (Dec. 29, 2021), https://www.msn.com/en-xl/money/tech-and-science/the-natural-gas-industrys-risky-bet-on-hydrogen/ar-AASeCri

Figure 5: Projections of Potential Hydrogen Demand in 2050 According to Four EU Decarbonization Studies



While it is unlikely that all the projects recently announced will come to fruition, the sheer number and scale of the proposed projects illustrate interest in the new marketplace for renewable, energy-derived hydrogen. Explanations for the growing interest in renewable hydrogen include greater certainty there will be sustained market demand and generous funding offered by European governments (particularly Germany) seeking to secure enough fuel to meet projected future demand. Considerations such as the amounts of space required for renewable electricity to produce green hydrogen, costs stemming from use of renewable resources with low-capacity factors, the relative inefficiency of electrolyzer technology, and the opportunity cost of using renewable energy for zero-carbon fuel exports instead of meeting domestic energy needs may be downplayed as countries seek to gain experience and a foothold in the new zero-carbon fuel marketplace. Moreover, issues such as water availability could become more important in the future given the already dry climate in much of the region and increasing risks of drought stemming from climate change.

2.4 Identifying and Overcoming Barriers to Deployment

The MENA region has made enormous progress in launching pilot projects and initiating planning to promote clean zero-carbon fuels. However, while there are clear demand signals for green hydrogen, several factors may prevent the region from moving to industrial scale production of zero-carbon fuel resources produced with natural gas.

The finance gap. There remains a sizable gap between the price paid for conventional hydrogen and the all-in cost of producing zero-carbon fuels, including sequestration costs and insurance for so-called "blue" hydrogen and dedicated renewable energy and electrolyzer technology for so-called "green" hydrogen. While there is a larger gap between the price paid for conventional hydrocarbons and zero-carbon fuels produced from renewable energy, there are already financial mechanisms for green hydrogen such as H2 Global[54] that can help fill the gap on a temporary basis.

[54] Andreas Franke, *Germany launches H2Global system to galvanize green hydrogen imports,* S&P Global (Mar. 17, 2021), https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/031721-germany-launches-h2global-system-to-galvanize-green-hydrogen-imports

For zero-carbon fuels produced with natural gas, the cost premium must, likewise, be addressed for projects with carbon capture, utilization, and storage to be bankable. Under both pathways, there is considerable uncertainty on how the costs will decline over time as efficiencies and capacity factors improve with changes in fuel prices, though stated goals have blue hydrogen declining to $1/kg in the next few decades and green hydrogen reaching $1.5-3/kg.

In developing countries, donor governments and institutions can play a role in supporting investments in blue hydrogen, but some may be reluctant to do so given new policies not to invest in fossil fuels (that may be ambiguous on blue hydrogen), and in reaction to signals on market demand, described below.

Inadequate market demand signals. The demand for low-emission hydrogen produced with fossil fuels is unclear in important markets for clean fuels like Europe. The European Council puts a particular focus on renewable hydrogen, viewing blue hydrogen as transitional until renewable-produced hydrogen becomes cost-competitive, around 2030. Many European country plans specify use of electrolyzers and renewable energy, though some East European countries and the Netherlands are interested in blue hydrogen, and large consumers such as the Port of Rotterdam expressed an intent to accept various production methods so long as the fuel is low carbon.[55] Notably, the European Commission recently approved a Delegated Regulation specifying emissions savings requirements (relative to conventional fossil fuel lifecycle emissions) applicable to hydrogen fuels.[56] These benchmarks have yet to be passed by the European Parliament. Moreover, it isn't clear how these new emissions savings requirements will drive interest in low-emission hydrogen from hydrocarbons given other European and national policy and financing preferences. If stakeholders believe there may be restrictions on hydrocarbon-derived low-emission hydrogen after 2030, this will put a damper on new supply given the risk that investments would not be recovered. Additional components of the European regulatory framework, such as a clear definition of low-carbon hydrogen, have yet to be developed. The key hydrogen accounting and certification methodology is not expected to be ready until 2024.[57]

An aspect of Europe's regulation that could increase demand for low-emission hydrogen from fossil fuels is the Carbon Border Adjustment Mechanism (CBAM). According to the Commision's proposal, starting in 2026, products such as iron, steel, and cement entering the European market will need to show they are subject to an equivalent carbon price or pay a price equivalent to what similar sources pay in Europe (adjusted for free allowances) for every tonne of carbon dioxide emitted. Use of zero-carbon fuels, whether produced with hydrocarbons with carbon capture and storage or other low-carbon energy sources, could substantially lower the GHG emissions per unit of product entering the EU and therefore reduce the CBAM payment.

Japan appears open to low-emission hydrogen, and especially clean ammonia, produced with fossil fuels. Government subsidies aim to expand demand and support technology, finance, and legal systems in countries with fossil resources to promote zero-carbon fuels. However, even here, a clearer sense of the market demand could be helpful to project developers in MENA.

Lack of common systems to measure and certify methane and carbon dioxide emissions associated with different fuel sources and types. Buyers and sellers in the marketplace need a common way to monitor, report, verify, and certify the lifecycle GHG emissions associated with delivered zero-carbon fuels. This should include, for example, systems to monitor, report, verify, and certify emissions from green electricity, methane emission rates in oil and gas production, and CCS carbon leak rates, and assign the resulting emissions to the delivered fuel. Such a mutually recognized lifecycle assessment and guarantee of origin system should enable buyers to know which fuels meet their requirements and sellers to know which markets will purchase their fuels.
The EU has indicated ISO methodologies in association

[55] Gregor Erbach & Liselotte Jensen, *EU hydrogen policy: Hydrogen as an energy carrier for a climate-neutral economy,* European Parliament (Apr. 2021), https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689332/EPRS_BRI(2021)689332_EN.pdf

[56] Rosa Oyarzabal & Lucas Falco, *The European Commission Approves the EU Criteria on Sustainable Hydrogen Activities,* Covington & Burling LLP (Apr. 22, 2021), https://www.insideenergyandenvironment.com/2021/04/the-european-commission-approves-the-eu-criteria-on-sustainable-hydrogen-activities/

[57] Low-carbon hydrogen has been included in the Gas Package proposal issued in December 2021. However, a Delegated Act with the hydrogen accounting and certification methodology will be released in 2024. While low-carbon hydrogen has been included in the Gas Package legislation, there is still uncertainty around the greenhouse gas emissions reduction methodology that will be applied to hydrogen.

with its emissions savings regulations for clean fuels and expects to issue a Delegated Act by the end of 2024 that specifies a methodology to determine greenhouse gases emissions from low-carbon hydrogen along with certification procedures. The Delegated Act is expected to align with the Renewable Energy Directive to define low-carbon hydrogen as reducing greenhouse gases by more than 70%. Other organizations are also working to define a standardized approach to assigning carbon emissions to different types of fuels (e.g., IPHE). A single, internationally accepted system will open markets and minimize costs for participants.

Regional policy gaps. MENA countries are still developing the national strategies and regulatory frameworks for carbon capture, utilization, and storage and clean fuels that are needed to deliver investment certainty and drive the long-term direction of the industry. Some countries are leading in developing national policies supporting technologies at a high level. For example, Saudi Arabia has adopted a program of a Circular Carbon Economy, and Morocco's green hydrogen development plan seeks to fulfill local demand for zero-carbon fuels while optimizing capacity for exports. Policies and strategies in other countries are under development (e.g., Qatar, Egypt), or viewed as being at an early stage (UAE). However, as shown in Table 1, even countries seen as leading in developing policies and pilots have considerable work to do to develop a comprehensive regulatory framework. This should include regulations to limit greenhouse gas emissions (i.e., direct carbon dioxide and methane emissions limits, fuel standards, and standards to minimize methane leakage).

Competition to deliver clean fuels. Whereas the competition to source hydrocarbons is limited to locations with economic supplies of hydrocarbon resources, the competition to source zero-carbon fuels encompasses a broader list of countries and fuel types. For example, countries able to produce excess, low-cost zero-carbon electricity can now enter the marketplace to deliver so-called "green" fuels. Some potential competitors capable of producing zero-carbon fuels with fossil fuels (e.g., Indonesia, Malaysia) are closer to important end markets (Japan, Korea, Singapore, China). Moreover, there is a longer list of fuel types that could qualify as zero-carbon or climate-beneficial fuels, not just low-emission hydrogen and ammonia, but also green or low-carbon methanol based on atmospheric CO_2, renewable diesel from biofuels, and zero-emission LNG. In the case of methanol, only when synthesized from climate-beneficial biomass or CO_2 from Direct Air Capture (DAC) and green or blue hydrogen, can it be considered a sustainable option. The costs of producing and delivering clean fuels are in flux and are affected by national characteristics – the cost of the original energy source and how those costs might decline over time, the availability of compatible national and international infrastructure, transportation distance and cost, etc. The added complexity in the marketplace makes it harder for investors to decide which fuel to produce or whether an investment is likely to be bankable.

SECTION 3

Policy Recommendations for MENA

Recognizing the strong resource potential and capacity across MENA to produce zero-carbon fuels with natural gas as well as renewable energy, efforts are needed to nurture both pathways. This includes promoting a level playing field so that the clean attributes of both fuels will be properly recognized.

Step up regional coordination in support of zero-carbon fuels. Given the growing competition globally in the production of low-emission hydrogen and ammonia, the MENA region should establish new channels for coordination and collaboration aimed at bringing together industry and policymakers to support regional leadership in these new markets. A critical goal of this collaboration is to ensure a transition to abated hydrocarbons in the context of a decarbonizing global economy by promoting fuel-neutral policies. There are opportunities to come together to support the national and international policy frameworks needed to enable new technologies and create a level playing field. There are also opportunities to collaborate on technology development to foster regional learning and leadership. Specific opportunities for regional coordination and collaboration are detailed below.

Collaborate on zero-carbon fuel technical pilots. With the first zero-carbon fuel projects coming on-line in the region, regional collaboration presents an opportunity to speed learning and uptake of this new technology, potentially lowering the cost and improving regional competitiveness. Technical collaboration could also lead to fruitful partnerships to make the best use of regional expertise and resources (e.g., pore space, port infrastructure, low-cost electricity). There could also be opportunities to share early experiences with methane mitigation to demonstrate and socialize the viability of best practices for leak detection and repair, and the contribution such measures can make to meeting emissions standards at the lowest cost.

Develop comprehensive domestic policy frameworks to support zero-carbon fuels. Governments could be doing more to proactively advance zero-carbon fuels, including development of policy roadmaps and goals for technology deployment. In addition, as noted above, governments in the MENA region have important gaps in the regulatory frameworks needed to deliver certainty to developers seeking to advance carbon capture, utilization, and sequestration (see Table 1).

Knowing the rules and requirements will allow investors to properly evaluate the costs of carbon management in the production of hydrocarbon-derived hydrogen. Likewise, rules are needed to ensure that methane pollution will be minimized and measured so that the process of producing the decarbonized fuel is defined and considered sufficient from a climate standpoint. These rules can benefit from regional collaboration, including assessment of pros and cons, and identification of best practices.

Develop model fuel-neutral, zero-carbon fuel government procurement policies. The MENA region could lead by example by defining fuel-neutral procurement policies that could serve as a template for both government and private sector entities. Rather than differentiating purchases based on the pathway used to produce the hydrogen, whether explicit or implicit in how regulations are defined, policymakers should consider regulatory designs (e.g., declining annual average CO_2 emissions for fuel purchases) that make use of comprehensive lifecycle assessments (discussed below) and promote continuous improvement in lifecycle CO_2 emissions per kilogram or joule of hydrogen produced. This would include encouraging continuous improvements in methane and carbon management as well as embodied emissions of energy equipment and avoiding "bright line" distinctions. Among other factors, the rate of decline in carbon dioxide emissions could consider the estimated cost per ton of CO_2 reduced, and how those costs compare to relevant international benchmarks. Such procurement policies could help drive fuel-neutral markets that would put different hydrogen production technologies on a level playing field, driving demand and premium pricing for all fuels that can be produced with relatively low lifecycle emissions.

Encourage international markets to adopt similar fuel-neutral, zero-carbon fuel mandates and policies. In parallel to adopting regional fuel-neutral, zero-carbon fuels procurement policies, MENA governments should encourage important international markets (e.g., European and Asian governments) to develop similar rules and guidelines. This would be important to create markets that are fuel-neutral so long as the hydrogen production is clean. To the extent that governments and industries adopt common approaches, this would open the marketplace to all producers while encouraging continuous improvement and early adoption of best practices.

Advocate for common systems to measure, certify, and track carbon dioxide and methane emissions associated with different sources and fuels. To support procurement policies and mandates, it will be essential for producers to use common and trusted methodologies to quantify methane and carbon dioxide emissions. Accordingly, MENA governments should advocate for a common global system to measure and certify these emissions that would include all important greenhouse gas emissions sources over the fuel lifecycle, including emissions from green electricity (including from manufacturing/infrastructure for renewables generation), methane emission rates in oil and gas production, carbon capture and storage carbon leak rates, and emissions associated with fuel transportation via LNG or other options, among others. The resulting certified methane and carbon dioxide emissions rates would then be attached to a given fuel producer and shipment. Standardized measurement and certification systems would build confidence in the accuracy and comparability of measurements used to determine which fuels meet procurement standards and requirements, supporting the use of a fuel-neutral, emissions-based approach and improving confidence in the environmental performance of different fuel producers. A guarantee of origin system would ensure that the emission rates are appropriately tracked as the fuels are shipped to market. Early efforts by MENA to adopt rigorous new methodologies and certifications addressing these issues would give the region a leg up in the global marketplace and could present opportunities for leadership in international climate forums.

Consider the role domestic and international carbon markets can play to jumpstart zero-carbon fuels investments. A number of regional stakeholders expressed interest in the role that carbon markets can play in helping to close the finance gap for low-emission hydrogen projects. This can take many forms, ranging from domestic carbon pricing (via a cap-and-trade program or carbon tax), to internal carbon pricing within energy companies, to use of Article 6 cooperative approaches, projects, and activities that involve the international transfer of mitigation outcomes in ways that prevent double counting, to use of voluntary offset markets. These programs help address the finance gap by raising the costs of unabated fossil fuel use or by valuing the emissions reductions achieved by mitigation measures. Regional energy modelling could be helpful in assessing which carbon pricing approaches and carbon price levels could be most effective in lowering greenhouse gases and driving technology investments considering the region's production and consumption of hydrocarbon fuels. And, in the meantime, recognizing that establishing a meaningful domestic carbon price can take years, it could make sense to lay the groundwork for carbon capture, utilization, and storage in the full range of offset markets. Currently, only the American Carbon Registry has a methodology for CCS-EOR projects in North America (currently under review), so there is considerable work to be done to define and socialize methodologies for other carbon capture, utilization, and storage scenarios. However, the rules and guidelines for Article 6 projects and activities agreed at COP26 in Glasgow set the stage for activities involving removals to potentially generate emissions reductions (and receive carbon price incentives) over a long crediting period, sending a promising signal on the inclusion of such projects.

Advocate for international financial institutions and donor governments to include hydrocarbon-derived zero-carbon fuels in their investment portfolios. Increasingly, donor governments and institutions that provide overseas development assistance to eligible developing countries are changing their policies to limit or eliminate investments in fossil fuels. These changes often do not directly address the treatment of investments aimed at reducing emissions from fossil fuel operations, whether through capturing, using, and storing released CO_2 or by reducing releases of methane. As hydrocarbon projects with the appropriate mitigation features can produce hydrogen and ammonia with emission rates similar to those produced with renewable energy, international financial, technology, and capacity support should help overcome barriers to electrolyzers and carbon capture, utilization, and storage on a comparable basis, considering the respective technology, investment, and other risks. MENA policymakers can be important advocates for establishing level playing fields in the delivery of international climate finance, particularly with respect to the institutions supporting climate investments within the region (e.g., Green Climate Fund, World Bank, IFC, EBRD, USAID, African Development Bank).

Assess and publicize co-benefits of zero-carbon fuels investments. To drive political support for zero-carbon fuel investments within the MENA region, it could be helpful to assess how such projects will advance national economic priorities such as higher rates of employment and education. Estimating and tracking job creation, and other relevant metrics on a project basis, could help justify domestic investment and win social support.

Use policy to implement, reward, and responsibly advance carbon management projects. The early deployment of carbon capture and storage projects will require supportive policies and rules designed to mitigate the additional costs of CO_2 capture and help de-risk the build-out of new CO_2 infrastructure. While the region's experience with CO_2 transport and storage activity for EOR provides a useful platform, future expansion will extend to dedicated storage sites which offer greater potential for scale up. New regulatory frameworks to ensure the safe, long-term storage of CO_2 – in the context of both EOR and dedicated storage – should be implemented, providing developers with criteria for site selection and permitting, monitoring requirements, and rules for long-term liability. Until global demand and price signals for low-carbon fuels are established, early carbon capture-based projects will face financial shortfalls which can be alleviated through near-term policy mechanisms such as contracts for difference (potentially based on a reference price for unabated hydrocarbons). The development of new CO_2 infrastructure would also benefit from financial support to maximize opportunities for economies of scale, as well to reduce project risks associated with pre-FID expenses such as site exploration and design studies.

Build capacity within government agencies to increase carbon capture and storage activity within the region. To help establish a regional capability to deploy carbon management infrastructure as rapidly as possible, international engagement and knowledge sharing can help build up necessary specialized technical and regulatory expertise within the relevant agencies. This will enable the regional governments to implement effective frameworks and guidance for CO_2 storage which are recognized as environmentally sound on a global level. This may extend to the creation of new agencies and legislative regimes for subsurface activity which are distinct from existing hydrocarbon extraction-based entities and protocols.

Educate private lenders and investors in the region about advanced energy and climate technologies. To improve the availability of funds on favorable terms, it may be helpful to educate lenders and investors new to the zero-carbon fuels space on advanced clean energy and climate technologies, successful business models, and differences between actual and perceived risks.

SECTION 4

Conclusion

With its heavy reliance on fossil fuel production, use, and sales, the MENA region faces clear challenges, but also opportunities, in decarbonizing its economy consistent with the goals of the Paris Agreement.

Near-term efforts to diversify its offerings to meet the future needs of the global fuels marketplace could help the region retain market share, continue to make use of its fossil fuel endowment, and meet domestic climate goals while contributing to the mitigation of greenhouse gas emissions from hard-to-abate sectors.

The MENA region has many of the key ingredients needed to be a world leader in the supply of zero-carbon fuels produced using low-carbon methods. This includes the availability of extensive and low-cost energy resources, both fossil and renewables, critical infrastructure (industrial base, fuel transportation, deep water ports), large potential geologic carbon storage capacity (including in depleted oil and gas fields), capital resources, available land, supply chain, and engineering capacities. Through regional collaboration, MENA countries could leverage early experience and capacity to develop technical and policy concepts that would build confidence in zero-carbon fuels coming from the region while informing critical policy debates elsewhere.

While the challenges to advancing zero-carbon fuels are real – especially on the demand-side, where there is uncertainty on how growing demand for zero-carbon fuels will translate to price premiums necessary to cover the incremental costs of hydrogen produced with renewable energy and natural gas with carbon capture and storage and methane management – there is a lot the region can be doing to proactively create a marketplace that values low-carbon attributes of both main production pathways. This includes technical collaborations, leadership on domestic policy frameworks and enabling environments, and advocacy to encourage a level playing field so that fuels will be judged by their lifecycle, carbon dioxide-equivalent attributes and not their production methods. Clean Air Task Force stands ready to support regional leaders to advance these critical climate solutions.