Decarbonising the Middle East's Hydrocarbon Business

A Report for the Japanese Institute of Middle Eastern Economies (JIME)

© 2021 Qamar Energy | www.qamarenergy.com | info@qamarenergy.com

Decarbonising the Middle East Hydrocarbon Business

The coronavirus pandemic has resulted dramatic changes to the global energy system. As world economies brace for the impact of the new Omicron variant on energy demand, several important questions arise for the future of the hydrocarbon business. In the Middle East, producers are grappling with the prospect of earlier peak oil demand, and shorter timelines to achieve crucial climate goals. Carbon border taxes in export markets, a global phase-out of funding for oil and gas projects, and the rise of competitive non-hydrocarbon technologies mean the region's social contract, based on revenues mainly from hydrocarbons, could be undermined. Energy transformation of the region's hydrocarbon business, therefore, has become the need of the hour, with some producers better prepared than others.

What will the decarbonisation of the Middle East's hydrocarbon business entail? Are major producers ready to tackle the challenges of an energy transformation? What are the new business models and strategies that can be adopted? And what role shall hydrogen, carbon capture and storage, and renewables play in the region's future energy mix?

EXECUTIVE SUMMARY

- Climate change policies and the need to save natural gas for export has prompted Middle East producers to embark on a decarbonisation drive, where renewable energy plays the leading role, followed more recently by new energy systems like hydrogen, batteries / electric vehicles, and more advanced CCUS.
- The leaders of energy transition in the region are undoubtedly the UAE and Saudi Arabia, while other OPEC+ producers have been slower to follow.
- Electrification, digitalisation, EVs, and an international focus away from domestic oil and gas production have become part of energy transformation strategies.
- Peak oil demand is now expected to occur sooner than previously forecast, or may have already passed. This has created additional pressure on Middle East producers to diversify away from oil and potential low oil rents.
- As the cleanest fuel among traditional hydrocarbons, natural gas enjoys its status as a destination fuel for a lower-carbon future in the region, although its role in the energy transition does require decarbonisation and the mitigating of methane emissions.
- Natural gas can replace crude and other polluting petroleum products used as feedstock in power generation, desalination, and an expanding petrochemical industry. In this way, it can boost economic growth and diversification, particularly in countries with large resources in the near-term.
- However, a longer-term renewables-led carbon-neutral future cannot materialise without aggressive movement on capturing and utilising/storing existing and near-term CO_2 emissions.
- Hydrogen will become a crucial carbon-free fuel or feedstock for hydrocarbon producers to maintain economic vitality through applications in the power, industry, and transportation sectors.
- Hydrocarbon producers can adopt one or a combination of 3 transformation strategies – Limited Transformation, Planned Transformation, and Policy-led Transformation – to support the region's energy transformation. However, to fully decarbonise, producers will have to adopt all 3. Currently, only the UAE has adopted all.

PEAK OIL DEMAND MAY HAVE COME CLOSER

Once a distant prospect expected to occur in the 2040s, the coronavirus pandemic has changed forecasts for peak oil demand dramatically. Growing pressures to decarbonise have now found a new accelerator – the largest decline in global oil use and energy-related carbon dioxide (CO_2) emissions in 2020 since World War II. According to the IEA, primary energy demand dropped ~4% in 2020, resulting in a drop of ~2 $GtCO_2e$ in energy-related carbon dioxide emissions (-5.8% from 2019 levels)[1]. Global emissions from only oil use dropped by ~10%, making up by far the largest share of emissions' reduction (1.1 $GtCO_2e$ from ~2 $GtCO_2e$ total), as lockdowns and mobility restrictions forced consumption for transportation fuels to a precipitous decline.

Although demand has recovered remarkably since the early days of the pandemic, the climate push to achieve the 2015 Paris Agreement's 1.5°C target has meant that CO_2 emissions will need netting out between 2044 and 2050[2], and total greenhouse gas (GHG) emissions between 2063 and 2068[3]. This puts the spotlight on oil, which is responsible for over 33% of CO_2 emissions from fuels[4], and already under threat of losing its near-monopoly in ground transport from electric vehicles (EVs), hydrogen fuel cell vehicles, new green public transport, and alternative and synthetic fuels, such as biodiesel and synthetic kerosene for heavy goods transport, shipping and aviation.

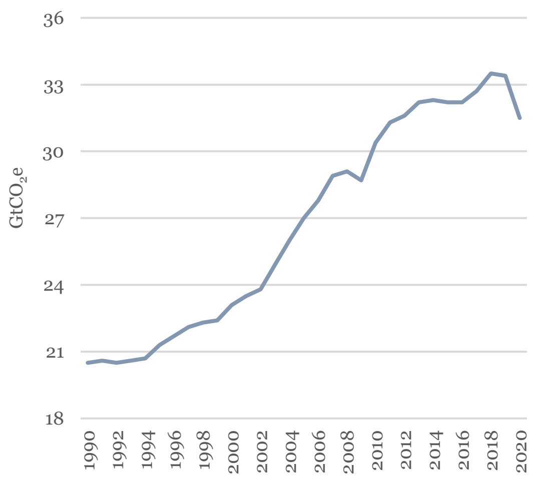


Figure 1 Global energy-related CO_2 emissions, 1990-2020[5]

The IEA's World Energy Outlook for 2021 suggests that the peak for oil demand would already have occurred in 2019 under its Announced Pledges[6], Sustainable Development[7], and Net-Zero Emissions by 2050[8] scenarios. Under the Stated Policies[9] scenario, oil demand peaks by 2030 and remains largely unchanged till 2050.

Other agencies also forecast peak oil demand to have already passed, with BP's Rapid Transition and Net Zero scenarios illustrating a peak in 2019. The Business-as-usual Scenario[10] meanwhile expects peak demand to occur in 2025, by when oil demand would have recovered to pre-pandemic levels, and then enter a gradual but steady decline out to 2050. DNV, meanwhile, in its Energy Transition Outlook for 2021, suggests that oil demand also peaked in 2019[11], a significant revision from its previous forecasts predicting peak oil demand in the early 2020s[12], ahead of other mainstream outlooks.

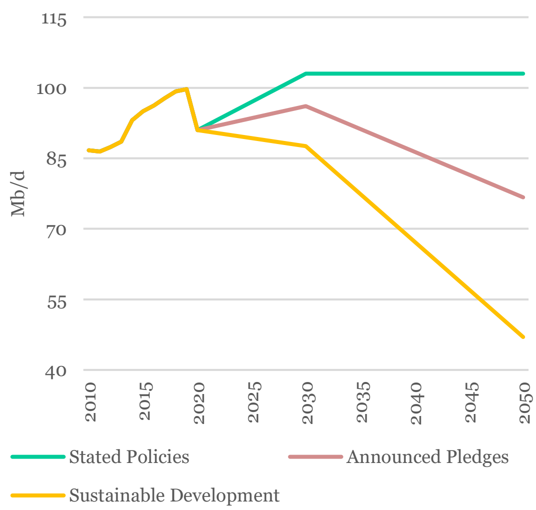


Figure 2 IEA WEO 2021 Peak Oil Demand Forecasts[13]

[1] IEA, "Global Energy Review: CO2 Emissions in 2020", March 2021, https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020
[2] With CO_2 emissions reduced by at least 50% from 2019 levels by 2030
[3] IPCC, "Mitigation Pathways Compatible with 1.5C in the Context of Sustainable Development", Table 2.4, Chapter 2, P119, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf
[4] https://ourworldindata.org/emissions-by-fuel
[5] IEA, "Global Energy Review: CO_2 Emissions in 2020", March 2021, https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020
[6] Announced Pledges Scenario (APS) assumes that all climate commitments made by governments around the world, including the Nationally Determined Contributions (NDCs) to the Paris Agreement, and longer-term net zero targets, are met in full and on time.
[7] The Sustainable Development Scenario (SDS) achieves key energy-related UN Sustainable Development Goals related universal energy access, and reaches global net zero emissions by 2070.
[8] The Net Zero Emissions by 2050 Scenario (NZE) sets out a narrow but achievable pathway for the global energy sector to achieve net zero CO_2 emissions by 2050.
[9] The Stated Policies Scenario (STEPS) reflects current policy settings based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.
[10] Comparable to the previous BP Evolving Transition Scenario
[11] DNV, Energy Transition Outlook 2021, https://eto.dnv.com/2021/highlights/energy-transition-outlook#eto-highlights
[12] S&P Global Platts, "Global oil demand, GHG emissions may already have peaked: DNV GL", https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/090820-global-oil-demand-ghg-emissions-may-already-have-peaked-dnv-gl
[13] IEA, World Energy Outlook 2021

Pandemic-linked behavioural shifts, such as remote working and reduced commuting have already been largely incorporated into daily lifestyles, and are expected to have a lasting effect on energy use, underpinning the revision to most peak demand forecasts. Faster uptake of electric vehicles, driven by declining battery costs and stronger policies, the transition to service-oriented economies, improving efficiency in sectors like construction and manufacturing, and higher electrification (driven by growing renewables uptake) will continue pressuring oil demand and consequent future supply.

NET ZERO FUTURES COULD RESULT IN DIMINISHED OIL EARNINGS

Estimates for world oil demand in low-carbon futures vary from agency to agency. For example, the IEA forecasts world oil demand to reach ~104 Mb/d by 2030 under the Stated Policies scenario, and 87.6 Mb/d under the Sustainable Development scenario. By 2050, this further decreases to 47 Mb/d[14]. BP forecasts oil demand to reach 98 Mb/d under its Business-as-usual scenario, but 89 Mb/d by 2030 and 47 Mb/d by 2050 under the Rapid Transition scenario[15]. Its more aggressive Net Zero scenario sees global oil demand declining to 24 Mb/d by 2050, while DNV sees world oil consumption reaching 80 Mb/d by 2030 and 45 Mb/d by 2050[16]. This decline in oil demand is the result of several trends, most importantly: improving vehicle engine efficiency, the rising penetration of electric vehicles (EVs), and the replacement of oil in industry, home heating and remaining power applications by natural gas and renewables.

Table 1 Oil demand forecasts under low-carbon futures (Mb/d)

Organisation	Scenario	Demand 2030	Demand 2050
IEA	Stated Policies	104	103
	Announced Pledges	96.1	87.6
	Sustainable Development	87.6	47
BP	Business-as-usual	98	89
	Rapid Transition	89	47
	Net Zero	87	24
DNV	ETO 2021	80	45

Under all these scenarios, the Organisation of Petroleum Exporting Countries (OPEC) and Russia remain the largest suppliers. Under the IEA's Net-Zero Emissions scenario, OPEC along with Russia will make up 61% of all supply by 2050, with OPEC on its own contributing 52%. This is a rise of 14% from its current share in world supply. Among OPEC members, Iraq, Iran and Kuwait will provide nearly 40% of all growth as new fields come online and production increases at existing fields.

However, production will largely decline from other world producers as decarbonisation efforts ramp up. Many large producers will also struggle to stem natural losses in output as fields age, fields with higher carbon footprints become less attractive, and operational complexities at heavy oil sands, sour fields, and deepwater assets become costlier to manageDespite a rising market share and even rising output in absolute terms, softer oil prices, will mean lower revenues for OPEC producers, particularly Middle East ones who rely on oil earnings to support their economies. According to Wood Mackenzie, oil prices under a net-zero future will range from US$ 40/b in 2030, to as low as US$ 10-18/b in 2050[17].

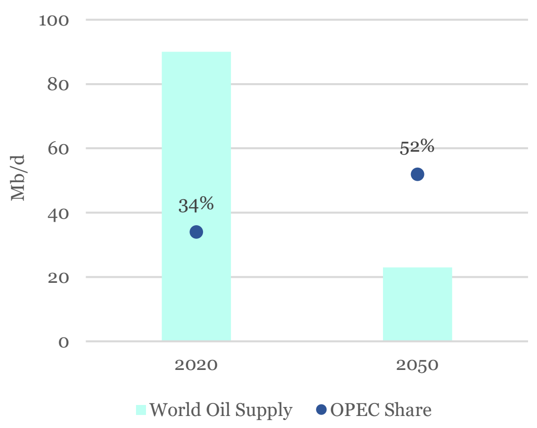


Figure 3 Projected share of OPEC production in world supply[18]

[14] IEA, World Energy Outlook 2021
[15] BP, Energy Outlook 2020
[16] DNV, Energy Transition Outlook 2021

[17] Reuters, "Oil to hit $40 by 2030 if climate goals are met -consultancy", https://www.reuters.com/business/energy/oil-hit-40-by-2030-if-climate-goals-are-met-consultancy-2021-04-15/
[18] IEA; Qamar Energy Research

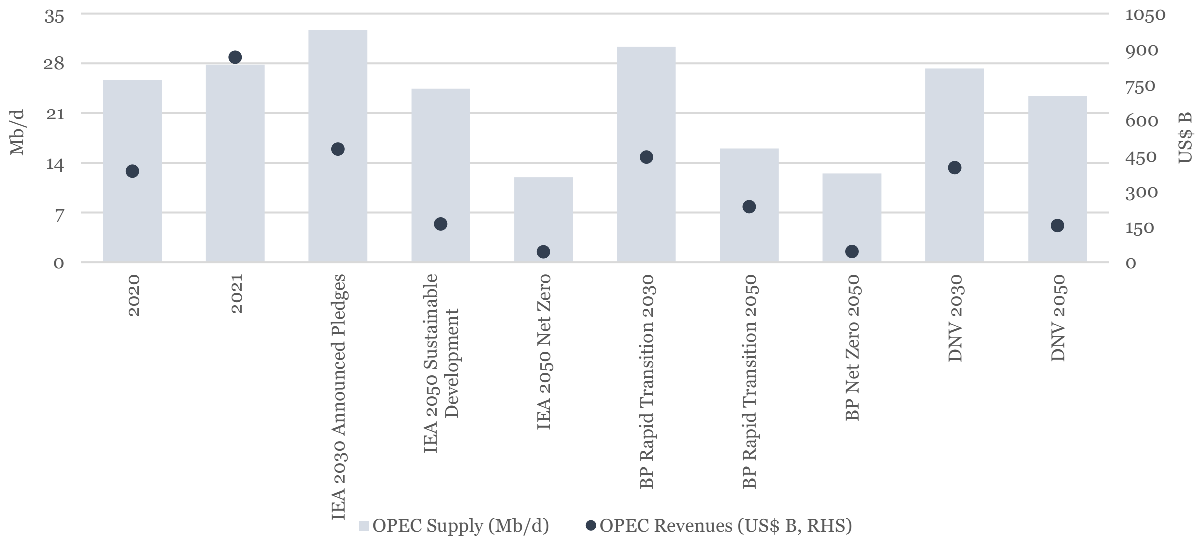


Figure 4 Projected OPEC revenues under low carbon / net zero futures[19]

Table 2 Projected OPEC revenues under low carbon / net zero futures[20]

	2020	2021	IEA 2030 Announced Pledges	IEA 2050 Sustainable Development	IEA 2050 Net Zero	BP Rapid Transition 2030	BP Rapid Transition 2050	BP Net Zero 2050	DNV 2030	DNV 2050
Oil Price (US$/b)[21]	41.0	85.0	40.0	18.0	10.0	40.0	40.0	10.0	40.0	18.0
Demand (Mb/d)	91.0	96.6	96.1	47.0	23.0	89.0	47.0	24.0	80.0	45.0
OPEC Supply (Mb/d)	25.7	27.8	32.7	24.4	12.0	30.3	16.0	12.48	27.28	23.4
OPEC Revenues (US$ B)	384.9	864.9	478.3	161.0	43.8	444.3	234.6	45.7	399.4	154.2

Figure 4 illustrates the revenues OPEC will earn under an increasingly decarbonised world. Even under scenarios that see only pledged climate goals met, oil revenues are less than half of those earned in 2021. Rising electrification and softer prices will force Middle East incumbents to adopt diversification strategies to wean off reliance on oil rents faster than concrete climate action. The Gulf Cooperation Council (GCC) countries are already leading the charge in this regard, with large OPEC producers like the UAE becoming the regional leader in economic diversification through the adoption of privatisation, low-carbon technologies, and renewable energy sources for power and transport.

THE LATER PEAK IN GAS DEMAND WILL MAKE IT INTEGRAL TO EARLY DECARBONISATION

Globally, climate change policies will most immediately and strongly reduce demand for fossil fuels like oil and coal, through efficiency and the adoption of non-fossil fuel technologies like electric vehicles, solar and wind power, biofuels, and hydrogen. Carbon border tariffs, proposed by the EU for implementation in 2023, would require Middle East countries to impose carbon prices within their own economies or

[19] IEA; Qamar Energy Research
[20] IEA; BP; DNV; Wood Mackenzie; Qamar Energy Research
[21] Prices from 2030 onwards are Wood Mackenzie forecasts

face higher costs for their carbon-intensive exports to the EU. These include raw materials like crude and NGLs, gas and LNG, refined oil products, petrochemicals, and other industrial products such as aluminium, steel, fertilisers and cement, that utilise crude oil, NGLs and/or gas as fuel and feedstock, necessitating a quicker transition to cleaner fuels.

As the cleanest fuel among traditional hydrocarbons, natural gas enjoys status as a destination fuel even in a regional low-carbon future, although its role in the energy transition does require ultimate decarbonisation and the mitigating of methane emissions. First, its global consumption is expected to peak much later than that of oil's, around 2040. Second, it can support the creation of the circular carbon economy by functioning as a background fuel for green technologies (renewable power sources, blue hydrogen, CCS). Third, it can help Middle East producers create a "carbon space" for exports from cost-competitive unconventional natural gas resources and increased flared gas capture in countries like Iraq. This can take the form of "carbon neutral" LNG, which has emissions already offset, or at least an emissions transparency mechanism, which requires suppliers to report their related emissions per cargo.

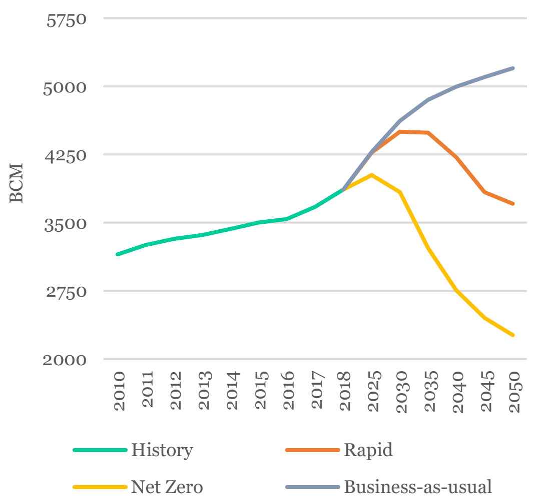


Figure 5 Peak natural gas demand forecasts[22]

Natural gas can replace crude and other polluting petroleum products used as feedstock in power generation, desalination, and an expanding petrochemical industry. In this way, it can boost economic growth and diversification, particularly in countries with large resources (Qatar, Saudi Arabia, UAE, Oman, Iran), and those with untapped potential (Iraq). While current higher gas prices might make it difficult to progress large new gas-intensive industries, the power and desalination sectors remain important offtakers, as do less gas-intensive industries.

Demand for gas in the Middle East is expected to remain strong till 2035, before the rate of growth enters a slowdown. Reduction in subsidies (for gas, liquid fuels, electricity and water), and improved collection of dues will encourage greater efficiency and less wasteful consumption by then, as will the uptake of alternative power generation, including renewable (mostly solar and wind), nuclear, and some coal, to diversify reliance on hydrocarbons.

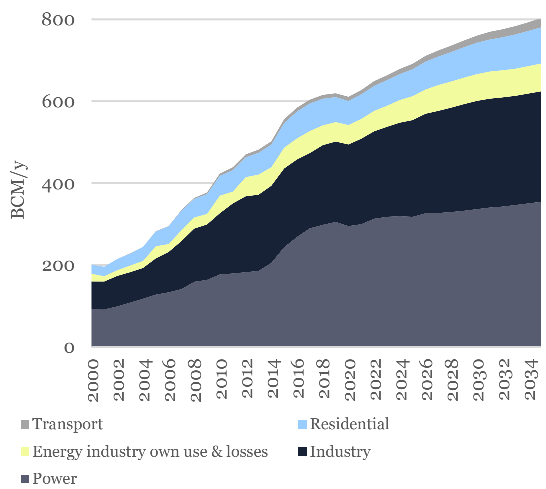


Figure 6 Middle East gas demand forecast[23]

Increasing gas production and associated gas capture will result in a sizeable natural gas surplus in the Middle East, led primarily by Qatar, the UAE, and Saudi Arabia. In Qatar, the North Field Expansion project will increase LNG production capacity to 126 Mtpa by 2027, while in Saudi Arabia, the Jafurah unconventional natural gas resource is expected to produce ~20 BCM/y. Saudi Aramco has already awarded US$ 10 B in contracts for Jafurah development. The UAE is accelerating US$ 20 B of natural gas projects, led in particular by the Dalma gas field in the Arabian Gulf, the Shah gas project, the Umm Shaif gas cap, and unconventional gas of the Diyab formation in the Ruwais concession, which will help the country in its bid to become self-sufficient in gas by 2030, with surplus to be exported via an expanded LNG business and/or used to produce blue hydrogen and in other petrochemical industries.

[22] BP, Energy Outlook 2020

[23] Qamar Energy Research

Oman's tight Khazzan field, operated by BP, has restored the Sultanate's LNG exports to capacity, and along with further development of the Ghazeer section of the field, Shell, Total[24], ENI and BP are working on other tight gas projects. With increased gas availability, Oman plans to debottleneck its existing 10.4 Mtpa of LNG facilities to add an additional 1 Mtpa by 2021. Kuwait meanwhile is targeting an initial 5 BCM by developing the deep, tight, sour Jurassic reservoirs in its north, while Bahrain is planning to undertake development on its 388 BCM GIIP unconventional offshore and 283-566 BCM in place deep, tight onshore discovery made in 2018.

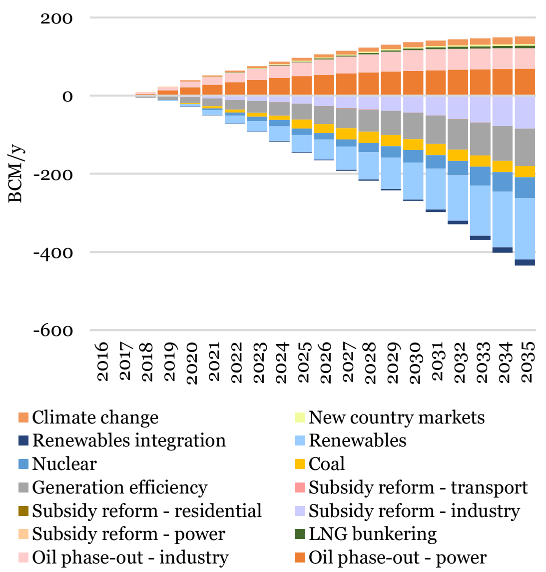


Figure 7 Increasing production will result in a significant gas surplus[25]

A surplus can offer several opportunities to the region's decarbonisation efforts. It can encourage faster phase-out of oil in power generation and industry, at least in the initial years, and can support the establishment of new regional and also extra-regional markets by pipeline. For example, natural gas development in the Kurdistan Region of Iraq (KRI) can support pipeline flows to not only Federal Iraq, but also potentially to southern Europe through Turkey, depending on pipeline costs, end-market prices and the strategic behaviour of competing suppliers.

Gas-fired power generation can become highly efficient, can be coupled with CCUS to eliminate nearly all carbon dioxide emissions, and can support the creation of new, lighter industry, and/or industries like hydrogen, that will require gas either to produce blue hydrogen, or to firm up renewables powering electrolysers for green hydrogen. Surpluses can also support EVs electricity demand, and can offer potential for extra-regional electricity exports, such as through the Gulf Cooperation Council Interconnection Authority link between the GCC countries and Iraq.

LONGER-TERM, RENEWABLES WILL DISPLACE NATURAL GAS IN A DECARBONISED ECONOMY

Renewables have gained real momentum in the region as drivers of the energy transformation. The cost of delivery and service of solar, wind, and other renewable energy has reached parity with conventional generation methods, due to improvements in performance and steady gains across on the learning curve. Higher gas prices in recent years and shortages have encouraged Middle East producers to explore alternative forms of generation, and solar has proven to be particularly viable. Solar power has set a series of world record low costs for both photovoltaic and concentrated solar power (CSP) in bids in Dubai, Abu Dhabi, Saudi Arabia, and Qatar (Table 3). Saudi Arabia has also achieved record low onshore wind bids. Other countries that have lagged behind in renewables uptake, such as Oman and Qatar, are now also moving ahead with large projects, with Qatar recording one of the lowest tariffs in the world for its solar project.

Table 3 Record-low solar bids in the Middle East in recent years[26]

Year	Location	Project	Capacity (MW)	Tariff (US¢/kWh)
2016	Dubai	MBR Phase-3	800	2.99
2016	Abu Dhabi	Sweihan	1170	2.42
2017	Abu Dhabi	Noor	1177	2.94

[24] Middle East Economic Survey (22nd March 2019), Volume 62 No. 12; https://www.worldoil.com/news/2019/4/8/total-strengthens-omans-natural-gas-sector

[25] Qamar Energy Research
[26] Qamar Energy Research

2018	Saudi Arabia	Sakaka	300	2.34
2018	Dubai	MBR Phase-4	250	2.40
2018	Egypt	Kom Ombo	200	2.79
2018	Jordan	Round 3 Solar PV Auction	50	2.48
2018	Egypt	West Nile	600	2.50
2019	Bahrain	Askar	125	3.91
2019	Dubai	MBR Phase-5	900	1.69
2020	Qatar	Al Kharsaah	800	1.57
2020	Saudi Arabia	Jeddah	300	1.61
2020	Abu Dhabi	Al Dhafra	2000	1.35
2021	Saudi Arabia	Sudair	1500	1.24
2021	Saudi Arabia	Al Shuaiba	600	1.04

Low renewable energy costs can enable large-scale adoption of solar PV, as is evidenced by the growing number of projects in the region and planned capacity additions. Early adopters can become exporters to other countries / regions, and can also become early movers in the green hydrogen space. Solar PV is relatively technically straightforward and quick to build, and should therefore achieve a significant share in the region's lowest-cost generation mix. This is even before considering its low carbon footprint and manageable local environmental impacts. PV has a good match to Middle East demand patterns, and can be coupled with CSP for night-time use, to achieve a high level of penetration in the power system without incurring large system integration costs.

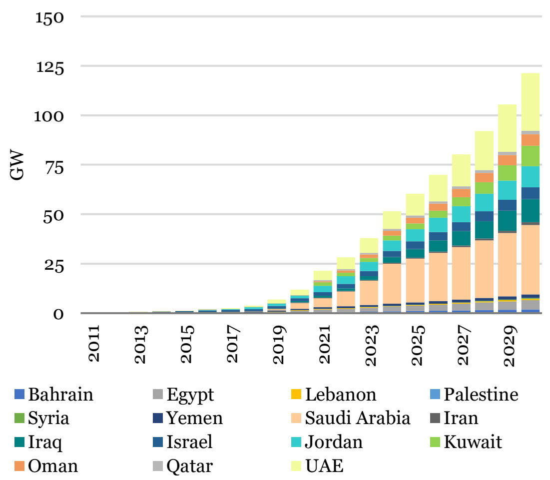


Figure 8 Installed and planned solar capacity in MENA[27]

Batteries can meet the limitations of timing and demand in the region, especially during the winter and summer seasons, as well as limitations at industrial sites that need continuous operations, such as cranes. Recent falls in li-ion battery costs makes them particularly suited to combination storage systems, such as with hydrogen and/or CSP, to give the lowest-cost solution to meet the intermittency of daily and seasonal supply-demand.

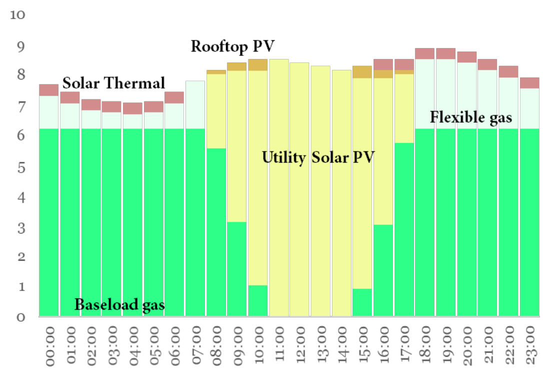


Figure 9 Example of Power Sector Flexibility in Winter in the MENA Region, Generation (GW)

[27] Qamar Energy Research

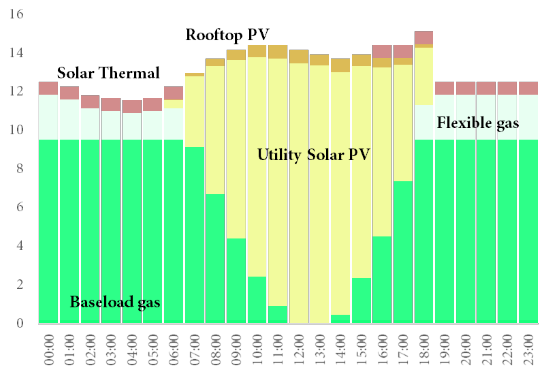


Figure 10 Example of Power Sector Flexibility in Summer in the MENA Region, Generation (GW)

Figure 9 and Figure 10 illustrate how combination storage solutions can address the intermittency of supply-demand during the winter and summer seasons in the region, particularly the GCC. Typically, peak demand occurs in the summer, in the daylight hours to the early evening. Solar power is ideally suited to meeting the daytime peak but not the early evening. Battery solutions, combined with thermal (e.g. CSP with molten salt) storage can be used for that early evening period. Other battery solutions, combined with increased energy efficiency to reduce the overall level of load, and in particular to shrink the peak and move it partly into periods with abundant solar generation, can reduce the size, cost, and O&M of storage systems. A combination of optimised solar, battery and demand management systems can displace significant amounts of gas consumption in the MENA region. Strong wind resources in areas such as Morocco, Egypt's Gulf of Suez, Jordan, north-western Saudi Arabia and south-eastern Oman can also contribute.

ACHIEVING A LOW-CARBON FUTURE REQUIRES STRONG ACTION ON CARBON CAPTURE

A renewables-led carbon-neutral future cannot materialise without aggressive movement on capturing and utilising/storing existing and near-term CO_2 emissions, as the majority of the global energy system is still fossil fuel-based and cannot be retrofitted to function on low-carbon technologies overnight. Renewable systems require flexible back-up in the form of fossil fuels, usually natural gas, to firm up grids and reduce intermittency in supply. Heavy industry needs reducing agents and high-temperature heat, which can be provided by gas or hydrogen. The transport sector is still overwhelmingly fossil-fuel driven, and even though electrification of light passenger vehicles has gained momentum, heavy transport, marine transport, and aviation, are all still fossil fuel-based, and will continue to require fuels such as biofuels, hydrogen, ammonia or synthetic hydrocarbons. These sectors require interim solutions to reduce emissions as they transition to carbon-neutral fuels and feedstock.

Potential emissions from combustion of known global fossil fuel reserves are estimated to be over 3200 $GtCO_2e$[28]. Achieving the Paris Agreement's 1.5°C climate target stipulates for an upper limit of only 460 $GtCO_2e$ emissions from fossil fuel reserves, nearly 86% lower than estimated emissions. The 2°C target stipulates a slightly higher carbon budget of 1200 $GtCO_2e$, but this still requires a reduction in emissions of at least 63%[29]. OPEC reserves would account for >600 GtCO2e emissions from its reserves, with other OPEC+ making up 100 $GtCO_2e$ of emissions. The remainder includes large quantities of coal and Canadian oil sands.

To achieve a 1.5°C future, other OPEC+ will have to have its emissions taken off entirely, or alternatively, all natural gas reserves emissions will have to be taken off. Current emissions are between 40-50 $GtCO_2e$ annually, meaning that emissions will bust the 1.5°C budget within 10 years. This adds significant pressure on large producers, particularly OPEC, to adopt mitigation strategies that can maintain the budget for longer while still maintaining a hydrocarbon business.

[28] BP Statistical Review of World Energy

[29] Qamar Energy Research

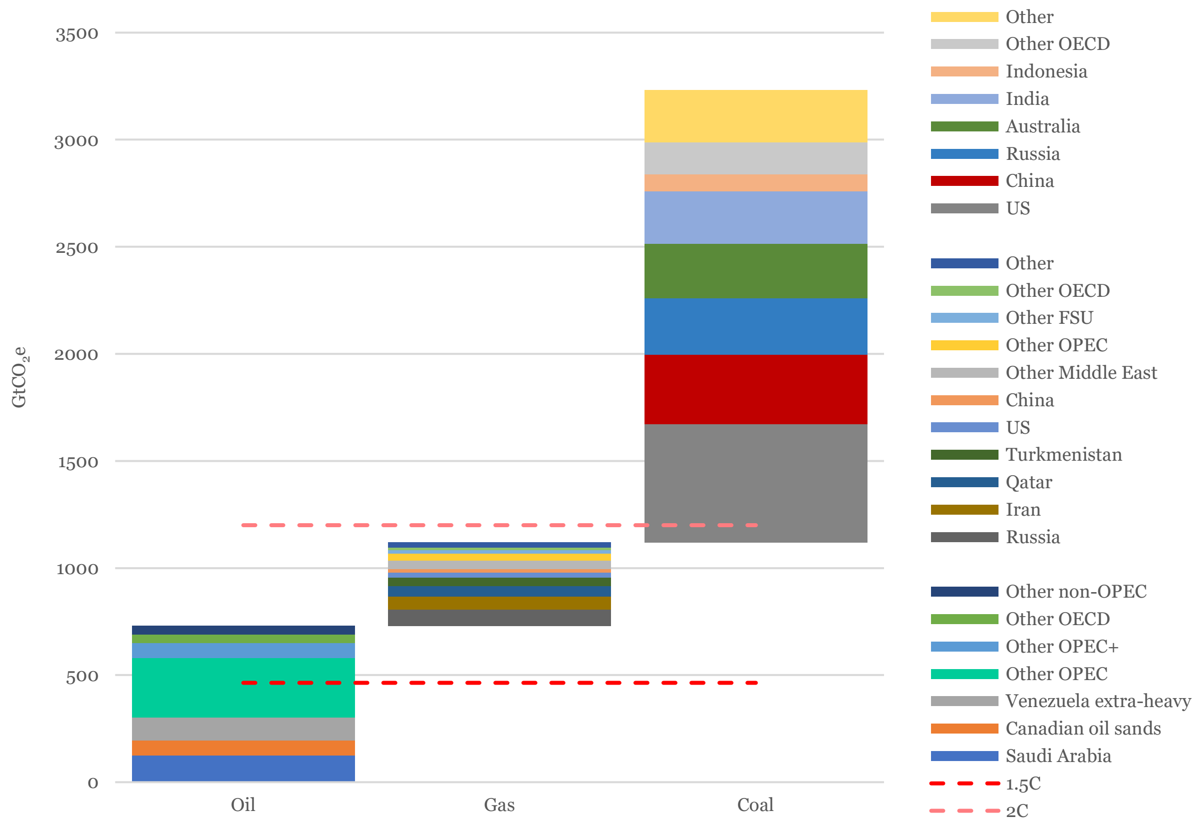
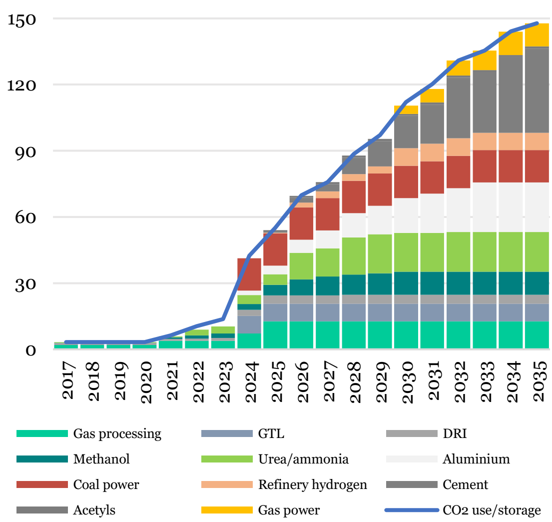


Figure 11 CO_2 emissions from fossil fuel reserves[30]

Several options exist for mitigating CO_2 emissions from fossil fuels. One, they can be embedded in petrochemicals to make long-lived products such as plastics. Two, they can be captured through CCUS systems, and then utilised for enhanced oil recovery at oil fields or permanently stored in geological formations or as solid minerals or long-lived products. Three, bioenergy can be coupled with CCUS to extract bioenergy from biomass and capture the resultant CO_2 for storage. Four, direct air capture (DAC) entails capturing CO_2 directly from the atmosphere, but this method requires significant scale-up and reduction in costs via manufacturing-type processes to become commercially viable.

The Middle East enjoys significant technical potential for capturing CO_2, thanks to its agreeable geology and terrain for storage, high public acceptance, relevant petroleum-related skills, and a limited number of large point emitters, that are located in close proximity to end-use sectors and offtakers. For example, industrial and oil plants in Saudi Arabia present a ready opportunity for CCUS and are often situated close to oilfields and/or depleted reservoirs. The UAE meanwhile enjoys a sophisticated, large-scale network of refining and petrochemical facilities, including the Ruwais ammonia plant, along its coastline (Dubai-Sharjah-Ras al-Khaimah Belt, and Abu Dhabi), which suggests strong future potential for CO_2 offtake (methanol and synthetic fuels' production).



[30] Qamar Energy Research; BP Statistical Review of World Energy

Figure 12 Middle East technical potential for captured CO_2, Mtpa[31]

CCUS potential can also encourage the development of combined CO_2 and hydrogen clusters. In the UAE, existing natural gas infrastructure can be utilised for processing, transportation, and storage of CO_2 and/or hydrogen, which can support the establishment of combined hubs in key industrial and port cities. Existing LNG export and import terminals can be modified/retrofitted to support international CO_2/hydrogen trade with key markets, while gas pipelines and salt domes can support transportation and storage.

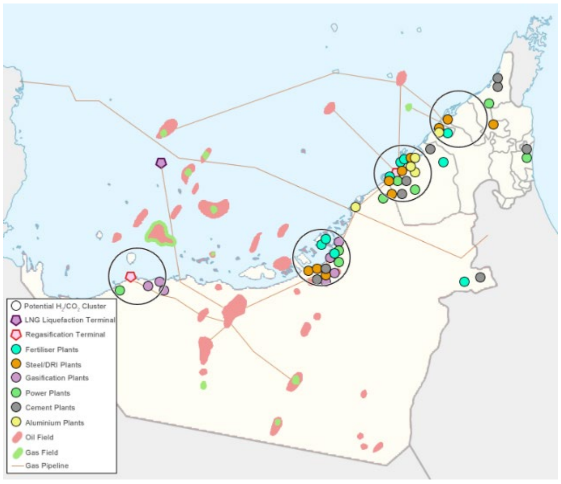


Figure 13 UAE Potential H_2/CO_2 Clusters[32]

HYDROGEN IS THE NEXT BIG OPPORTUNITY IN THE MIDDLE EAST'S DECARBONISATION DRIVE

Oil and gas production and export, along with associated industries such as petrochemicals, remain core pillars of the Middle East economy. Other vital businesses for the region include aviation and shipping, currently reliant on oil-based fuels. To maintain economic vitality, it is therefore essential that low-carbon ways are developed to use hydrocarbons, and new export industries are created. Hydrogen is a carbon-free fuel or feedstock. Low-carbon hydrogen represents a potential route to decarbonise domestic industry and to create new export streams, whether hydrogen directly, or hydrogen-derived industrial materials such as ammonia, plastics, synthetic fuels and steel.

CCUS capabilities, strong infrastructure, and a natural gas surplus are a natural fit for blue hydrogen potential in the Middle East, at least in the interim towards carbon-neutral hydrogen. Grey hydrogen from fossil fuels is already widely used in the region, but is currently not a widely traded commodity, and is also very polluting. Until the technical efficiency and capacity factor of green hydrogen production methods can be improved, natural gas coupled with CCUS will be the main form of production for low-carbon hydrogen.

The Middle East has the lowest cost of hydrogen production, unsurprisingly, due to the low cost of domestic natural gas and of CCUS. According to external sources including the International Gas Union, PwC and KAPSARC, current natural gas prices to industry in the region are within the range of US$ 2.15-3/MMBtu[33], among the lowest in the world. Even though the inclusion of CCUS would increase the cost of production for an industrial-level hydrogen facility by a factor of 1.5, the region could still boast one of the lowest costs for blue hydrogen production in the world. Adjusting the IEA's estimates to allow for gas prices, CCUS costs and reasonable cost reductions for economies of scale suggest an achievable production cost of ~ US$ 1.3/kg – almost the same cost of grey hydrogen production in some markets (e.g., U.S.) and cheaper than other key markets (EU, China, India). Existing well-established natural gas supply chains can contribute to further cost savings. Achievable sales prices to domestic or international customers would depend on the market structure and competition.

Initially, specific actions to scale-up blue hydrogen could include adapting oil refining, methanol, direct reduced iron and fertiliser production. There is some opportunity for ground transport, but likely shipping offers a larger and readier market. Gas-fired power plants can be adapted to run on a blend of hydrogen or ammonia for aluminium smelting; cement, and other industry could use hydrogen fuel; and steel plants using the Direct Reduced Iron (DRI) process could convert to hydrogen Industrial and port clusters, as discussed earlier, offer the potential for hydrogen and CCUS hubs. The UAE is home to the world's second-largest bunkering port, the Fujairah

[31] Qamar Energy Research
[32] Qamar Energy Research
[33] https://www.igu.org/resources/wholesale-price-survey-2020-edition/; https://www.kapsarc.org/file-download.php?i=69521; https://www.strategyand.pwc.com/m1/en/reports/securing-the-future-of-natural-gas-in-the-gcc.pdf; Qamar Energy Analysis

Terminal, which is planning to expand its oil storage by 42 Mbbl by 2022. ADNOC, the UAE national oil company, is planning to establish a new, up to 6 Mtpa LNG terminal there, which can also support the transformation of Fujairah as a hydrogen hub in the medium-term.

Hydrogen hubs can convert hydrogen to ammonia as the lowest-cost export option to Europe and Asia (Japan in particular), which are emerging as the key markets for low-carbon hydrogen and related materials. Middle East producers can avail significant near-term opportunities in these export markets, while simultaneously developing local applications of hydrogen such as transport and replacing grey hydrogen use domestically. However, these have to be assessed against two pre-requisites: the absence of low-carbon accounting standards and the current lack of a national carbon price or other incentives and requirements to use low-carbon hydrogen.

The Middle East will also play a leading role in green hydrogen production. All stakeholders involved in the hydrogen value chain in the region have also simultaneously embarked on green hydrogen production projects, recognising it as a critical feedstock for decarbonising the entire economy in the medium-term. On an international level, the cost of clean, green hydrogen is still 3-10 times higher than that of grey, while blue hydrogen is twice that of grey.

However, international partnerships to develop competencies and technology improvements can drive the cost of electrolysers for green hydrogen production down. The cost of hydrogen from electrolysis depends on the technology used and its efficiency, its costs (primarily capital, with operating costs less important), the cost of input electricity, the lifetime of the electrolyser, and its load factor (how much is used relative to maximum capacity).

Figure 14 shows the estimated costs achievable under typical Middle East conditions from electrolysis (assuming 100% load factors for the electrolysers) using solar PV, with or without battery storage, for the three main technology options (alkaline, polymer electrolyte membrane (PEM) and solid oxide electrolytic cell (SOEC)). Given the uncertainties, by 2050 the cost of hydrogen production from each option is very comparable and the choice will depend on the local situation, technological progress, and operational issues such as the ability to ramp up and down easily, and the potential use of waste heat by the solid oxide system.

Therefore low-carbon electrolytic hydrogen needs to be produced from renewables and/or other clean energy with high availability and low costs, possibly a combination of solar PV, off-peak nuclear, concentrated solar thermal power (CSP) and batteries. These play to the region's strengths.

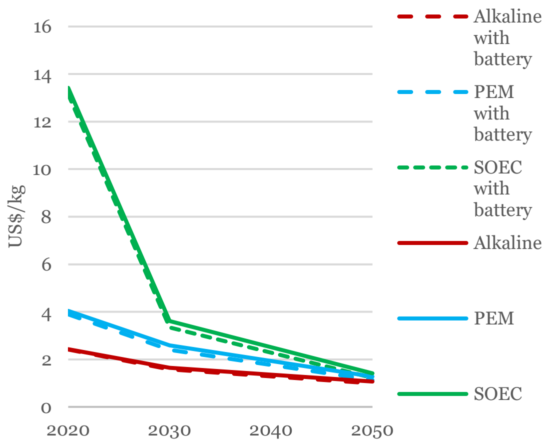


Figure 14 Green Hydrogen Production Costs in MENA[34]

To align with carbon legislations like an EU carbon border tariff, Middle East countries can utilise green hydrogen to produce decarbonised materials like "green steel" and "green ammonia" for export. Low levelised costs of electricity and high renewables potential could help the region become a leading international supplier of steel, chemicals and other hydrogen derivatives. These materials would be easier to transport globally than native hydrogen. An alternative approach, already explored by some players in the GCC, would be to export a fuel such as liquefied petroleum gas (LPG) or ammonia, which would be reformed into hydrogen in the destination market or used as blend stock, then receive back a shipment of carbon dioxide for storage.

In a conservative scenario[35], Middle East countries, particularly the GCC, could supply around 20 Mt of hydrogen and derivatives to European and East Asian markets by 2050 – equivalent to 10% of Europe and East Asia's market. This could generate

[34] Qamar Energy Research

[35] GCC countries will dedicate only 300-420 GW for hydrogen production from their RE capacity, powering 150-210 GW of electrolysis, potentially producing 50-70 Mt of H_2 per year by 2050

US$ 30-40 B in annual export revenues. In an aggressive scenario[36], the volume would increase up to 50 Mt by 2050, 30% of Europe and East Asia's market, reaching US$ 80-100 B in annual revenues.

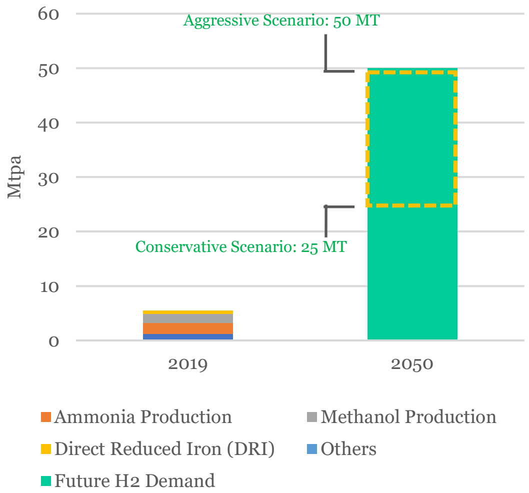


Figure 15 Current and future H_2 demand in GCC countries[37]

The strategies of the EU and some of its constituent member states, and of Japan, Singapore and South Korea, imply that despite domestic production, sizeable imports will be required to meet consumption targets. For instance, EU H_2 imports are forecast to reach 100 Mt by 2050 with Germany and Belgium importing 25 Mt each. Meanwhile, Japan is projected to import 85 Mt of ammonia. This provides the Middle East with lucrative export markets of the future.

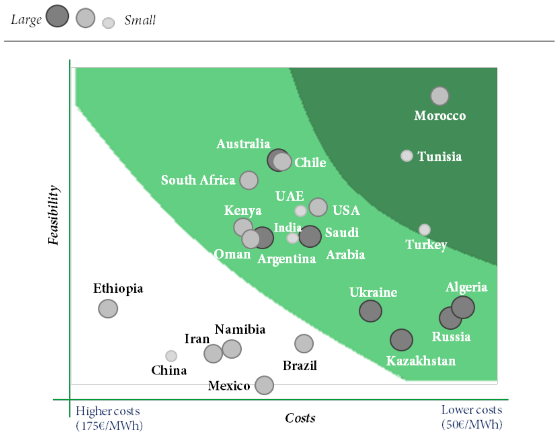


Figure 16 Green Hydrogen Export Potential by 2050[38]

The Middle East region, led by the UAE, Saudi Arabia, and Oman has been highly active since late 2020 in developing international partnerships and signing project deals for both blue and green hydrogen. Table 4 summarises selected key deals.

Table 4 Select high profile partnerships in recent past between MENA countries & International Players[39]

Country	Hydrogen R&D and Projects
UAE	• Partnership with Japan's Marubeni for establishing a hydrogen-based society targeting the water and electricity sector • Hydrogen bus pilot using green H_2 for Expo 2020 alongside Hyundai/Toyota • Development of hydrogen FCEVs with Toyota, Air Liquide • ADNOC and GS Energy to explore possibilities to grow Abu Dhabi's hydrogen economy and export position • First fuel ammonia cooperation deal with ADNOC and METI • Joint international hydrogen supply chain between METI and MoEI • ADNOC, INPEX Corp., JERA Co, JOGMEC to explore the commercial potential of blue ammonia production in the UAE • Masdar and Engie to develop a green hydrogen hub in the UAE, with at least 2 GW capacity by 2030

[36] GCC countries will dedicate 700-1,000 GW of RE capacity, powering 250-500 GW of electrolysis, potentially producing 80-100 Mt of H_2 per year by 2050
[37] The Conservative and Aggressive Scenarios are defined based on the level of renewable deployment that can be achieved in GCC countries. Under the Conservative Scenario, the GCC countries continue their renewables deployment in line with 2030 targets (~100-140 GW per decade), enabling them to dedicate this capacity for ~150-210 GW of electrolysis capacity to produce 50-70 MT of hydrogen per year by 2050. Under the Aggressive Scenario, GCC countries deploy a renewable capacity of 700-1,000 GW to power ~350-500 GW of electrolysis capacity, that can produce 80-100 MT of hydrogen per year by 2050. This scenario assumes that GCC countries can address a larger share of the market. Chile, for example, plans to deploy 300 GW for hydrogen production by 2050; since the GCC is ~3 times larger than Chile in surface area, it could deploy up to 3x Chile's capacity for hydrogen production.
[38] Qamar Energy Research
[39] Qamar Energy Research

	• ADNOC, TotalEnergies to cooperate on CCUS and hydrogen to help the UAE meet net-zero target by 2050 • JBIC has signed an MoU with ADNOC covering collaborations on decarbonisation, including hydrogen • ADNOC and Taqa to form global renewables and hydrogen venture with a generating capacity of 30 GW by 2030
Saudi Arabia	• Solar hydrogen demonstration plant in Riyadh's Solar Village within the scope of the joint program HYSOLAR • Saudi Green Hydrogen project, Neom Helios, developed by US Air Products shows the international recognition of the GCC as a potential green hydrogen hub • Aramco and Hyundai MoU with Saudi Aramco to accelerate hydrogen ecosystem expansion in the Korean and Saudi markets • Aramco and Hyundai OilBank Co. deal to export liquefied petroleum gas to South Korea and re-export CO_2 back to Saudi • ENEOS and Aramco MoU for the development of a CO_2-free hydrogen and ammonia supply chain
Oman	• Belgian firm DEME Concessions developing a 500 MW green hydrogen plant in the port of Duqm, Oman for export and green ammonia • EJAAD (an Omani membership-based collaborative platform backed by MoG, PDO) in efforts to create a national strategy for hydrogen • Sumitomo Corp. and ARA Petroleum launched a feasibility study on a hydrogen hybrid project through a local production and consumption model • Oman's OQ and Korea's Kogas Tech signed MoU to explore green hydrogen opportunities together

WHAT STRATEGIES ARE THE INCUMBENTS ADOPTING TO SUPPORT THE TRANSITION?

Major hydrocarbon producers have adopted either one, or a combination of the following three strategies to support the energy transformation. These are Strategy I: Limited Transformation; Strategy II: Planned Transformation, and; Strategy III: Policy-led Transformation. Each can be divided into sub-parts.

Table 5 Major MENA oil producers' strategies to support the energy transition[40]

Strategy	Sub-Strategies		MENA Producers undertaking Strategy	
Limited Transformation	Stick to legacy business	Typically adopted by producer NOCs with a heavy reliance on oil and gas rents for economic wellbeing. These companies stick to E&P, processing, and sales/distribution of oil and gas in domestic markets and beyond	Ministry of Oil, Iraq	●●●●
			National Oil Company, Libya	●●●●
			National Iranian Oil Company	●●●
			Sonatrach, Algeria	●●●
	Integrate technologies	Integrating oil and gas operations with low-carbon technologies to keep costs low while expanding resource base and exploiting new commercial opportunities (e.g. CCUS for EOR)	ADNOC	●●●
			Saudi Aramco	●●
			Petroleum Development Oman	●●●
			Kuwait Oil Company	●
	Commercial restructuring	Adoption of dual strategy by restructuring operations: decarbonise traditional operations while securing a dominant position in emerging energy sources (e.g. hydrogen)	ADNOC	●●●
			Saudi Aramco	●●
			Qatar Energy (Qatar Petroleum)	●●

[40] Qamar Energy Research

	Downstream focus	Integrating domestic and international refineries with petrochemical plants to secure offtake for future; create new oil and gas markets by geography (Asia) and sector (downstream)	ADNOC	●●
			Saudi Aramco	●●
			Kuwait Oil Company	●
	Internationalisation	Has some overlap with Downstream focus, but includes a broader scope: JVs with refineries, petrochemical plants, and storage terminals	ADNOC	●●●
			Saudi Aramco	●●●
	International diplomacy	International diplomatic engagement on climate and decarbonisation targets through OPEC+, COP26, Paris Agreement, other pledges	ADNOC	●●●
			Saudi Aramco	●●
Planned Transformation	High electrification	Integrate renewable generation and EOR, synthetic fuels, direct CO_2 capture, electricity marketing to battery vehicles into core business	Petroleum Development Oman	●
	Divestment	Managed divestment of hydrocarbon assets	~	
Policy-led Transformation	State-backed policies for energy diversification	Investment into clean tech and low-carbon energy sources, domestically and/or internationally through sovereign wealth funds	Mubadala	●●●●
			Saudi Public Investment Fund	●●●
			Qatar Investment Authority	●●

Under the Limited Transformation Strategy, Sticking to Legacy Business unsurprisingly features the Iraqi Ministry of Oil, the Libyan National Oil Company, the National Iranian Oil Company, and to an extent, Algeria's Sonatrach, who is struggling to stem declines at its ageing brownfields. These companies have not undertaken direct mandates to support the energy transition, and as such efforts have been recent, and limited to reduction of associated gas flaring from oilfields, an increase in power generation and efficiency (not always from natural gas in favour of crude/diesel), and a small renewables capacity. In the case of Iraq, renewables are yet to take off meaningfully, although its first-ever solar PV bid round for 755 MW saw competitive prices. TotalEnergies and Masdar have each committed to developing 1 GW and 2 GW of solar assets in the country, but Iraq remains focussed on strong oil sector growth, as does Iran, who has significant hydropower and large solar and wind potential, but is betting on the removal of US sanctions to escalate production and exports.

Other strategies under Limited Transformation, such as integrating low-carbon technologies and commercial restructuring feature oil producers like Aramco and Petroleum Development Oman, and also ADNOC, who has embarked on a dual strategy of decarbonising traditional operations while securing a dominant position in emerging energy sources. This is evident in the flurry of deals it has undertaken with regards to hydrogen and CCUS, and its plans for expanding carbon capture. The December 2021 for ADNOC alongside utility Taqa to take a stake in the renewable and green hydrogen businesses of state clean energy vehicle Masdar marked a more radical shift towards developing a low-carbon energy champion.

Saudi Arabia and Oman also follow suit, albeit a little behind the UAE, with their own hydrogen agendas and the integration of CCUS for EOR in their upstream operations. Internationalisation is best represented by ADNOC, Aramco, and to a certain extent the Kuwait Oil Company. These firms have entered high-profile joint ventures and partnerships with refineries and petrochemical firms in Asia (mainly India, Malaysia, Vietnam, and others) to expand their international footprint and secure future markets for their hydrocarbon business. Domestic refining and petrochemicals are also a keen focus for these companies, although ADNOC recently shelved plans to build the new 400 kb/d refinery near Ruwais due to unattractive market conditions.

Planned Transformation sees limited implementation so far among MENA producers, but there is an increasing trend of integrating renewable energy generation with EOR practices, as evidenced by Petroleum Development Oman's Miraah Solar Project, which utilises steam produced from solar power for injection into oilfields. Synthetic fuels, DAC, EVs are also growing in tandem with more traditional low-carbon energy forms, but are currently limited to an R&D phase.

Investment through sovereign wealth funds is best illustrated by the UAE / ADNOC, who has initiated new low-carbon in the country through CCUS, nuclear, renewable desalination efforts, and hydrogen through investment arms like Mubadala, ADIA, and ADQ. The country has also made major progress in low-cost solar power, batteries (Masdar), and establishing a regional Electrical Energy Storage Solutions Hub (EESSH). The UAE's international investment arms are responsible for new partnerships in hydrogen, and are also encouraging the restructuring of national energy and utility companies. Saudi Arabia's PIF and Qatar's Investment Authority also follow suit, but to a lesser degree.

ANNEX

Table 6 UAE & Saudi Arabia are leading the charge in climate goals[41]

Country	Climate Goals / Clean Energy Targets
UAE	• 20% power generation capacity from clean energy (11 GW of total 50 GW generating capacity) by 2024 • **2nd Paris Agreement NDC: GHG emissions reductions by 23.5% below BAU (310 Mt) by 2030 → absolute reduction of 70 Mt** • UAE National Energy Strategy 2050 to increase share of clean energy to 50% of capacity mix by 2050 • New ambitious **UAE Net Zero by 2050 Strategic Initiative → carbon neutrality by 2050**
Saudi Arabia	• 58.7 GW of renewable energy capacity by 2030 (40 GW solar PV, 16 GW wind, 2.7 GW solar CSP) • Saudi circular carbon economy programme / Saudi Green Initiative → **carbon neutrality by 2060, annual emissions reduction target 2030 revised >2x upward from previous target of 130 Mt** • Global methane pledge → **reduction of methane emissions by 30% from 2020 levels by 2030** • **Aramco net-zero carbon emissions by 2050**
Oman	• -2% reduction of GHG emissions on BAU by 2030 (-1.8 Mt) • National Energy Strategy to derive 20% of electricity from RE by 2027 through development of 2.66 GW of RE, and 30% by 2030 • Zero Routine Flaring by 2030
Qatar	• 20% of electricity from solar power by 2030 • Zero routine flaring by 2030 • Capture and storage of >7 Mtpa of CO2 from QP operations by 2030
Bahrain & Kuwait	• **Bahrain Net Zero by 2060 Initiative** • Bahrain target of 5% RE into mix by 2025 and 10% by 2035, under the National Renewable Energy Action Plan (NREAP) • Bahrain 6% reduction in energy consumption by 2025 under the National Energy Efficiency Action Plan (NEEAP) • Kuwait 4.32 GW of RE capacity by 2030 from current 70 MW
Iraq	• RE production to make up 20-30% of total power output by 2027 • 10 GW installed solar capacity by 2030 • Reduction of GHG emissions 14% below BAU emissions between 2020-2035

[41] Qamar Energy Research

Iran	• 5 GW of new renewable capacity by 2030 • GHG emissions reductions 4% on BAU by 2030, 8% on BAU by 2030 with end of sanctions and provision of finance • Allows for carbon credits