SPECIAL REPORT
SEIZING THE GREEN HYDROGEN OPPORTUNITY

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FOREWORD.

In the global race to achieve Net Zero by 2050, low carbon hydrogen has emerged as a so-called climate silver bullet.

In 2021, The International Renewable Energy Agency's (IRENA) World Energy Transitions Outlook estimated that hydrogen and its derivatives would account for 12% of final energy consumption by 2050 – however, key questions remain about the near and intermediate steps which must be taken along the way.

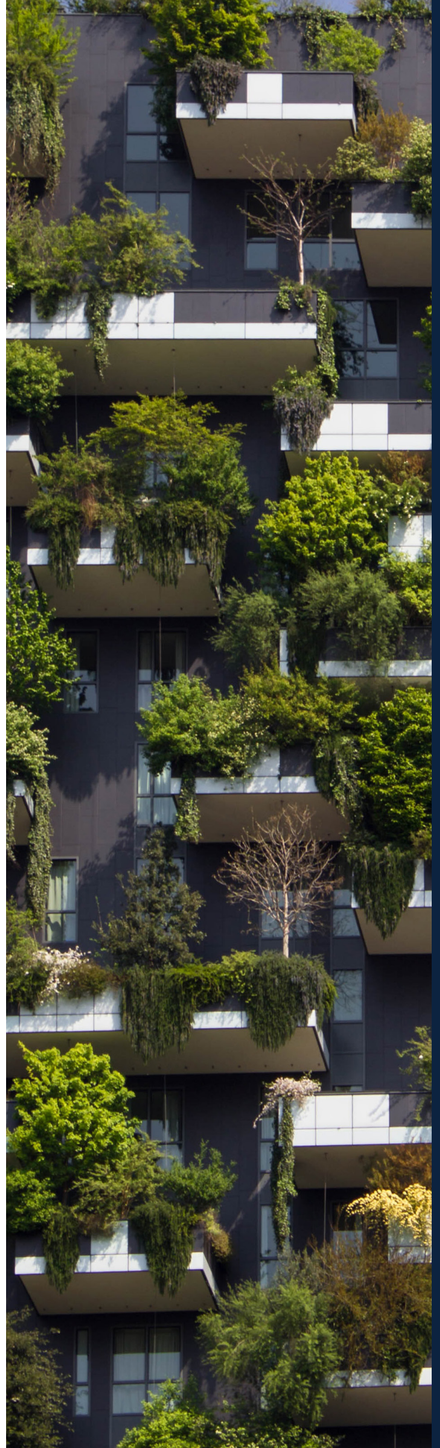
In this report we look at both the opportunities and challenges of green hydrogen as well as possible pathways for governments and corporates alike. We examine how investment in infrastructure and innovative technology will both be needed in equal abundance alongside policies that support the hydrogen adoption. Importantly, we also identify how public and private sector cooperation will be crucial if hydrogen is to become a 'fuel of the future'.

Drawing on our expertise as one of the largest banks in the region with a unique window into the UAE economy, we outline the decisive role that strategic financing will play in the shift to hydrogen. Specifically, we hone in on how smart investments if deployed properly can enable hydrogen to complement other technologies like renewable power, biofuels, or energy efficiency improvements especially across carbon intensive sectors such as heavy industry, maritime, and aviation. We consider exactly what it would mean if the world was to overcome production, distribution, and technical obstacles related to hydrogen making it a cost effective and scalable fuel.

Turning our attention to the UAE's commitment to green hydrogen, we explore the key projects across the country and provide projections for industries like transportation, logistics, utilities, and aviation. While it's true that nobody can fully predict how and where green hydrogen will be used, we hope that this report, through it's use cases, will help to frame the possibilities of hydrogen as an enabler of a future decarbonised energy system.

Shargiil Bashir
Group Chief Sustainability Officer, FAB

"As one of the largest banks in the region with a unique window into the UAE economy, we outline the decisive role that strategic financing will play in the shift to hydrogen."



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INTRODUCTION.

14GW
UAE's expected green energy capacity by 2030

Weather events in 2022, including record heat, fires, and drought in the US, Europe and China, unprecedented flooding in Pakistan, and the record melt of the Greenland ice sheet have underscored the importance of tackling climate change: for many people around the world, the threat is existential.

That danger is especially pronounced in the Middle East. In the Arabian Gulf there have been nine separate occasions since 2005 when the wet bulb temperature (heat combined with humidity) has exceeded the 35C threshold of human survivability. An MIT simulation found that if the current pace of greenhouse emissions remains constant, cities such as Abu Dhabi, Dubai and Doha will exceed this threshold several times a year by the end of the century.

Momentum towards net zero carbon emissions clearly must be maintained if the world is to have any chance of keeping increases in temperature to acceptable levels. Despite being exempted from the need to reduce emissions under the 1994 UN Framework Convention on Climate Change, the United Arab Emirates (UAE) has a long track record of climate leadership. In 2005, the UAE was one of the first major oil-producing countries to ratify the Kyoto Protocol. And in 2009, it became the permanent host of the International Renewable Energy Agency. In 2015, the UAE signed the Paris Agreement while in October 2021 it announced a net zero 2050 target: in both instances, it was the first country in the region to do so.

In order to achieve its ambitious 2050 net zero target, the UAE has identified a number of projects that will eliminate about one million tonnes of carbon dioxide equivalent annually. Most of these projects use proven technologies, some of which have already been extensively deployed in the UAE. For instance, the country's clean energy capacity, including nuclear, has already expanded from 13 MW in 2011 to 2.4 GW in 2020 and is expected to reach 14 GW by 2030.

Nevertheless, the UAE recognises that new technologies are required if the world is to meet the challenge of climate change. Chief among these is green hydrogen, which uses renewable energy sources to produce a potential fuel for heavy industry and transportation (as opposed to today's grey hydrogen, which utilises natural gas). Eventually other uses for hydrogen, such as domestic heating in cooler countries, may become viable.

The hurdles to industrialising the production of green hydrogen remain formidable but the potential opportunities presented by green hydrogen are enormous. Goldman Sachs (see **Figure 1** on green hydrogen production power demand) describes green hydrogen as "a once-in-a-generation opportunity" given its potential role for the utilities and energy industry, especially in Europe. The UAE has decisively embraced that opportunity.

In its quest to become a leader in green hydrogen production, the UAE has several significant advantages, most notably existing large-scale hydrogen and ammonia production facilities and access to competitive solar PV energy. Perhaps most important is the UAE's strong government support for green hydrogen, which should drive the development of a clear regulatory regime and ensure the provision of necessary infrastructure investment and broader financial support.

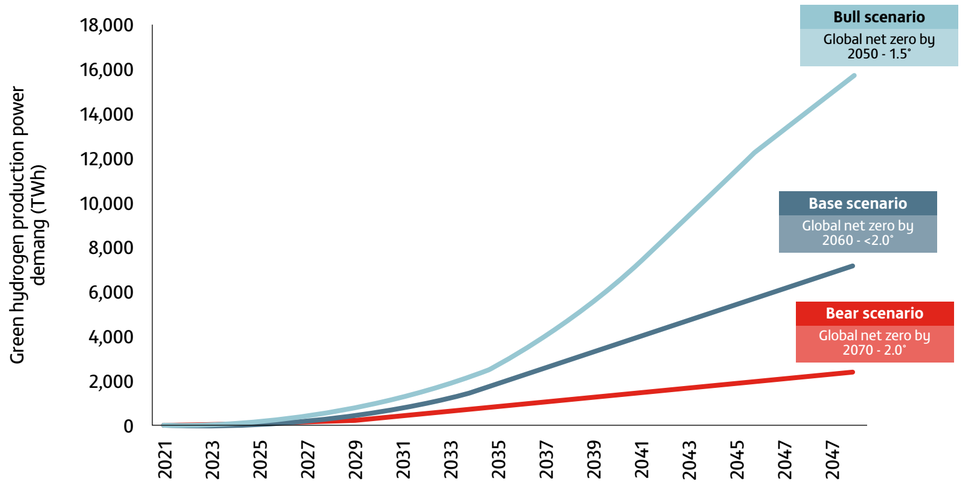
Green Hydrogen - Quick Take

Hydrogen emits only water when burned but creating it can be carbon intensive. Depending on production methods, hydrogen can be grey, blue, or green – and sometimes even pink, yellow or turquoise (*see infographic on next page*) However, green hydrogen is the only type produced in a climate-neutral manner making it critical to reach Net Zero by 2050.

"Momentum towards net zero carbon emissions clearly must be maintained if the world is to have any chance of keeping increases in temperature to acceptable levels."

Green hydrogen could be the next transformational driver of power demand growth
Green hydrogen production power demand (TWh) under our three GS hydrogen scenarios

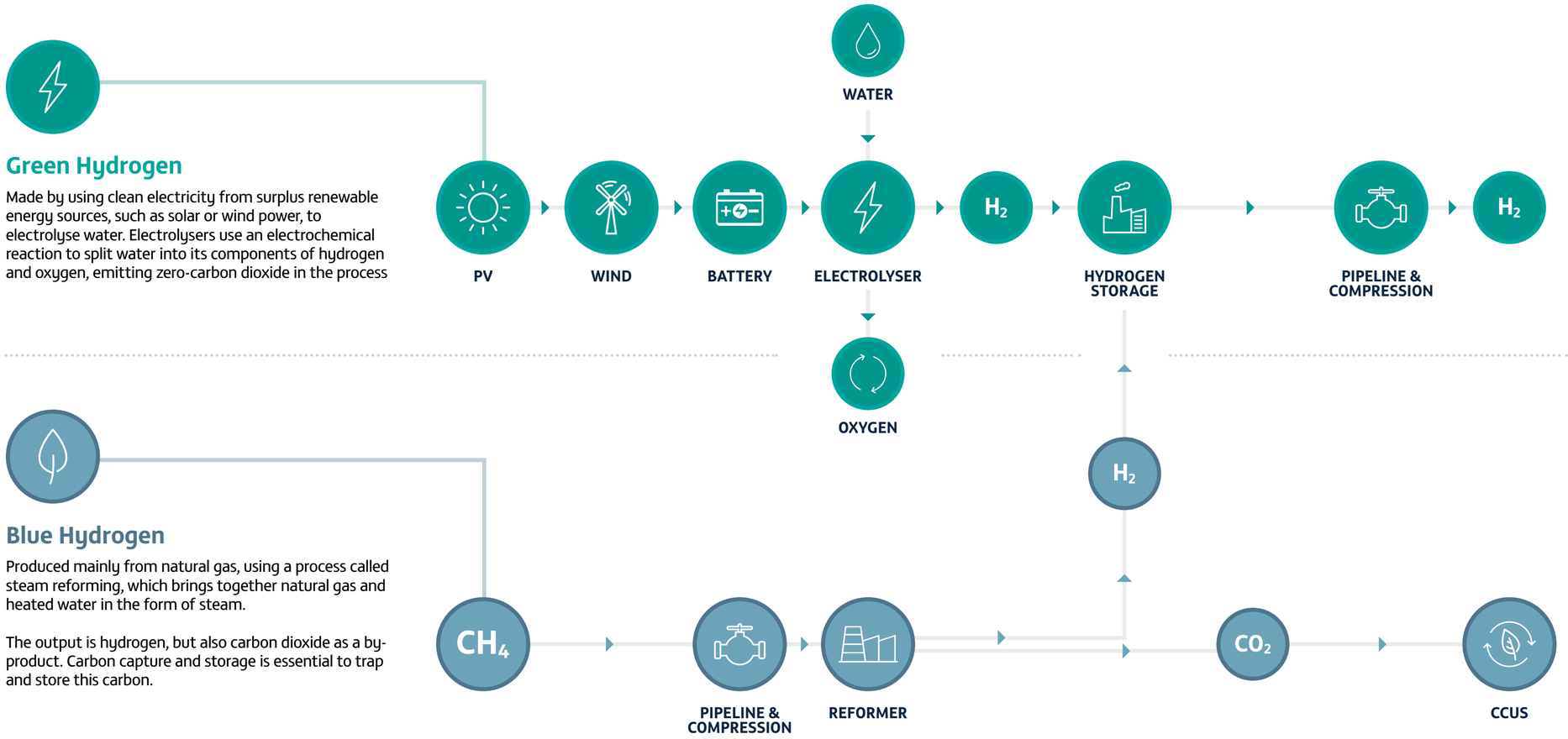
FIGURE 1



Source: Goldman Sachs Global Investment Research

The differences between the hydrogen colours

Source: Petrofac



Green Hydrogen

Made by using clean electricity from surplus renewable energy sources, such as solar or wind power, to electrolyse water. Electrolysers use an electrochemical reaction to split water into its components of hydrogen and oxygen, emitting zero-carbon dioxide in the process

Blue Hydrogen

Produced mainly from natural gas, using a process called steam reforming, which brings together natural gas and heated water in the form of steam.

The output is hydrogen, but also carbon dioxide as a by-product. Carbon capture and storage is essential to trap and store this carbon.

Grey Hydrogen

The most common form of hydrogen production. Grey hydrogen is created from natural gas, or methane, using steam methane reformation but without capturing the GHGs made in the process.

Pink Hydrogen

Generated through electrolysis powered by nuclear energy. Nuclear-produced hydrogen can also be referred to as purple hydrogen or red hydrogen.

In addition, the very high temperatures from nuclear reactors could be used in other hydrogen productions by producing steam for more efficient electrolysis or fossil gas-based steam methane reforming.

Yellow Hydrogen

Where electrolysis is achieved solely through solar power (unlike green which could use a combination of renewable energy sources such as wind or solar).

THE GREEN HYDROGEN OPPORTUNITY.

Hydrogen is the most abundant element in the universe and, combined with other elements, is widespread on Earth. It is essential to many industrial processes, including fertilizer production and removing sulphur from oil. But huge amounts of energy – usually from natural gas – are required to extract hydrogen. That has limited its potential applications.

The use of renewable energy to split water into hydrogen and oxygen – creating so-called green hydrogen – could change everything. Without the need for expensive natural gas, the power of hydrogen could be unleashed on the global economy. Crucially, this power comes at no cost to the environment: hydrogen emits only water when it is burned. By substituting it for fossil fuels, global CO2 emissions could be sharply cut.

"Green hydrogen is a key solution for hard to abate sectors, such as heavy industry or heavy transportation where electrification doesn't work well," explains James Humfrey, executive vice president, growth & industry, downstream industry, marketing & trading directorate at Abu Dhabi National Oil Company (ADNOC). Blue hydrogen (produced using natural gas but with carbon captured and stored) and purple hydrogen (also known as pink hydrogen, produced using nuclear power) use different technologies to achieve broadly the same result.

The UAE has decisively backed low carbon hydrogen as part of its 2050 net zero initiative. In November 2021, the government published a high-level Hydrogen Leadership Roadmap. It also announced ambitions to capture 25% of the low carbon hydrogen market by 2030.

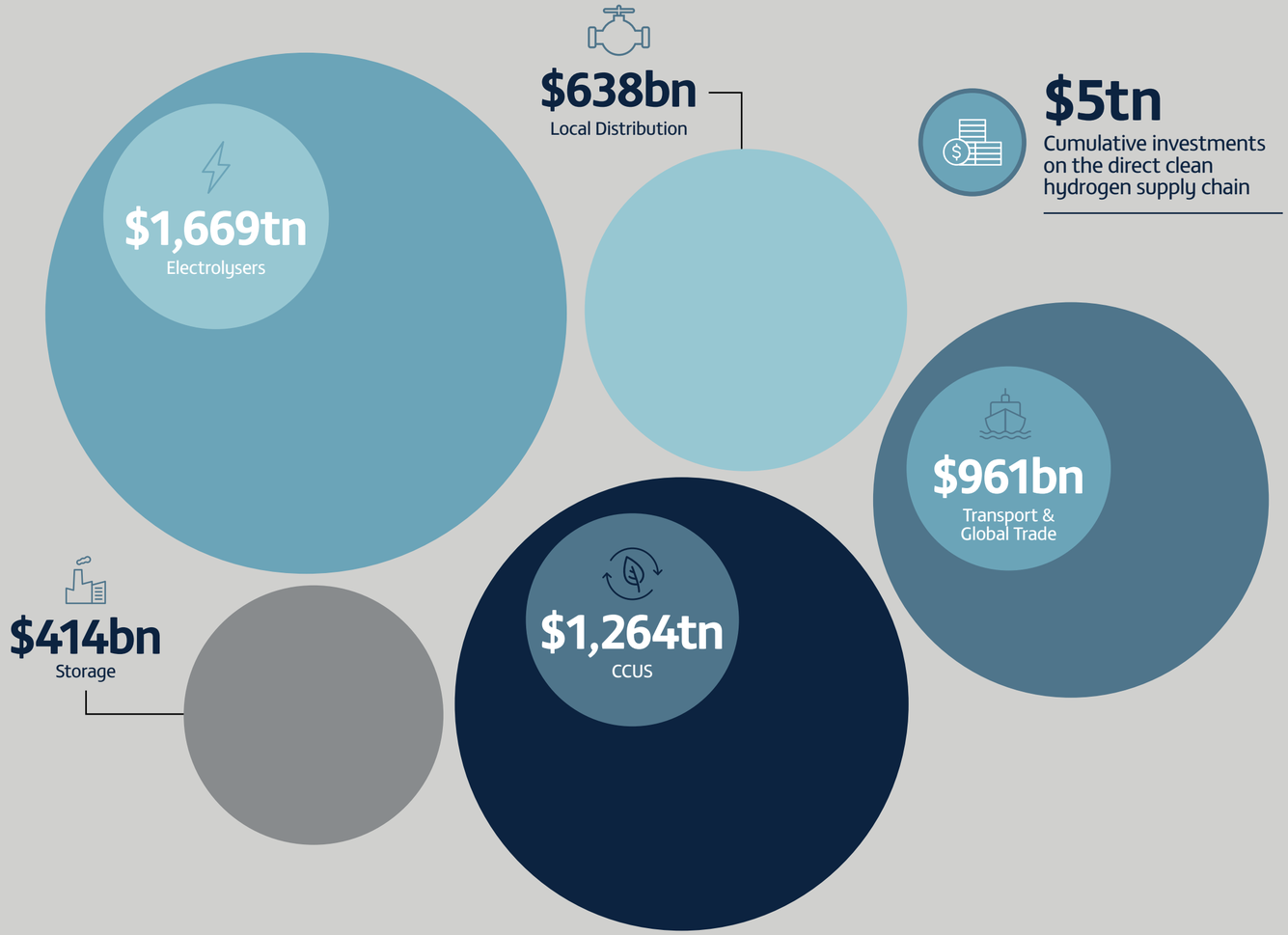
By then, Goldman Sachs (see **Figure 2**) believes the market for clean hydrogen generation could be worth $250 billion. For an economy valued at around $360 billion in 2020, the stakes are therefore extremely high.

"Green hydrogen is a key solution for hard to abate sectors, such as heavy industry or heavy transportation where electrification doesn't work well."

We estimate US$5tn of investments will be required in the global clean hydrogen supply chain to net zero
Investments required in the clean hydrogen supply chain for net zero

FIGURE 2

Source: Goldman Sachs Global Investment Research



TAKING A LEAD.

The dash for green hydrogen is not unique to the UAE. Goldman Sachs estimates that there are now more than 30 national hydrogen strategies which together would result in a 400-fold increase in clean hydrogen installed capacity this decade compared to 2020. These figures imply a 50-fold increase in the pace of annual average green hydrogen new builds.

Against this competitive backdrop, the UAE stands out for two key reasons. The first is that it has irrefutably tied its future economic success to low carbon hydrogen. Green hydrogen is seen as a catalyst for economic diversification as well as a route to net zero. The UAE's geopolitical and economic status is threatened by the global move away from hydrocarbons. Building low carbon hydrogen production capacity and creating a global supply chain mitigate these risks.

To this end, the Hydrogen Leadership Roadmap specifically aims to encourage exports of low carbon hydrogen (principally to Japan, South Korea, Germany, and India) and foster new hydrogen derivative opportunities such as low-carbon steel and sustainable kerosene (see **Etihad case study**).

The Roadmap commits the government to building value-add partnerships and strengthening government-to-government relationships: both UAE companies and the government have solid track records here. ADNOC, Masdar and BP signed a strategic agreement in September 2021 to develop clean hydrogen hubs in both the UK and the UAE, for instance. At government level, the UAE formed an energy partnership with Germany in 2017 and strengthened it further in September with an Energy Security and Industry Accelerator Agreement that includes hydrogen as a core focus. The UAE also committed to developing an international hydrogen supply chain with Japan in April 2021.

Such activity is happening beyond the UAE too. For instance, in Saudi Arabia, NEOM, Air Products and ACWA Power are building a $5 billion green hydrogen-based ammonia production facility. In Egypt, Masdar and Hassan Allam Utilities, are developing 4 GW green hydrogen plants, and in Oman, OQ, ACWA Power and Air Products, are investing in a renewable-powered green hydrogen-based ammonia production facility.

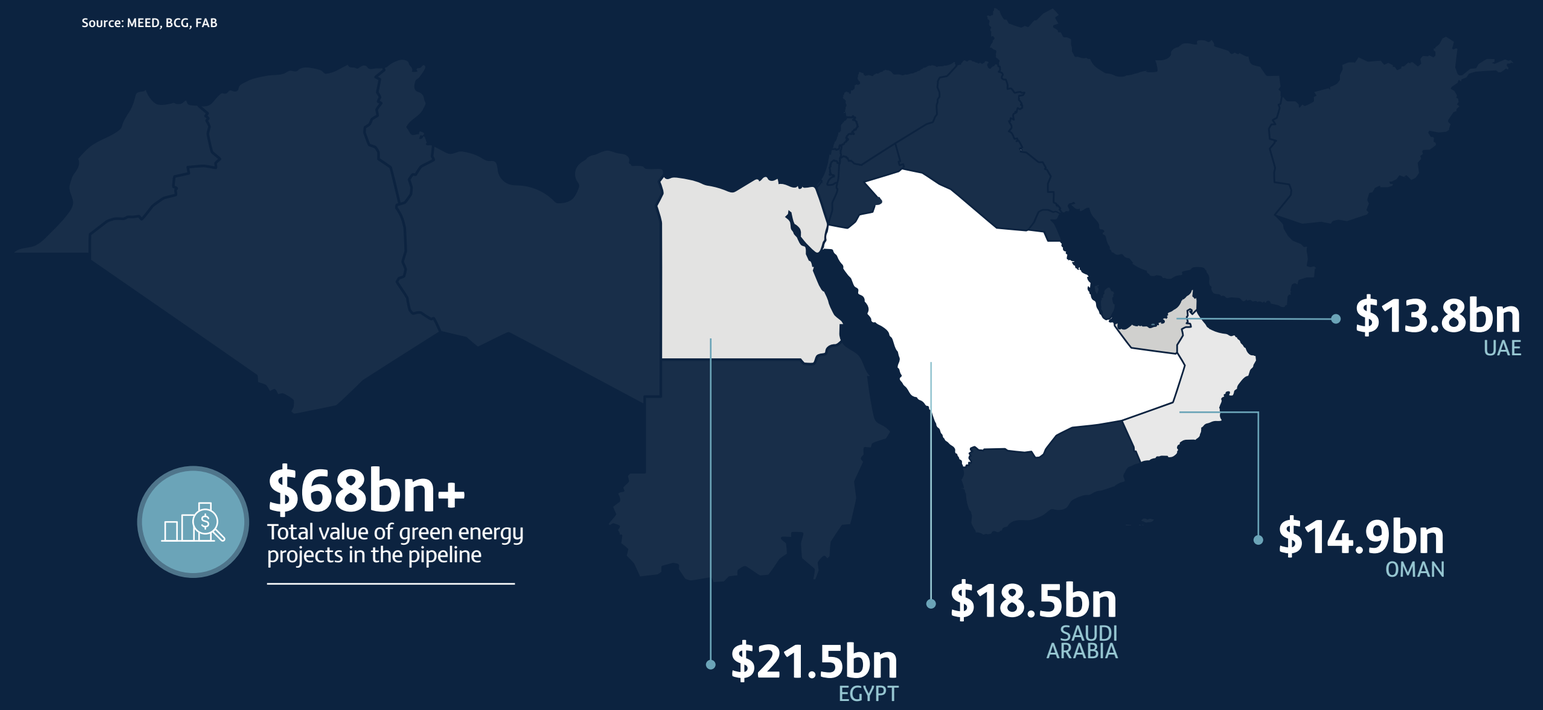
Yet, the UAE's bid for green hydrogen leadership benefits from several competitive advantages. "The country [has much of] the renewable energy capacity that is necessary," notes Shargiil Bashir, chief sustainability officer at First Abu Dhabi Bank. Moreover, that capacity is keenly priced. The Al Dhafra solar project achieved the world's lowest solar tariff (at below $0.0135 per kWh). The success of that project also demonstrates the UAE's ability to deliver large-scale projects, notes ADNOC's Humfrey.

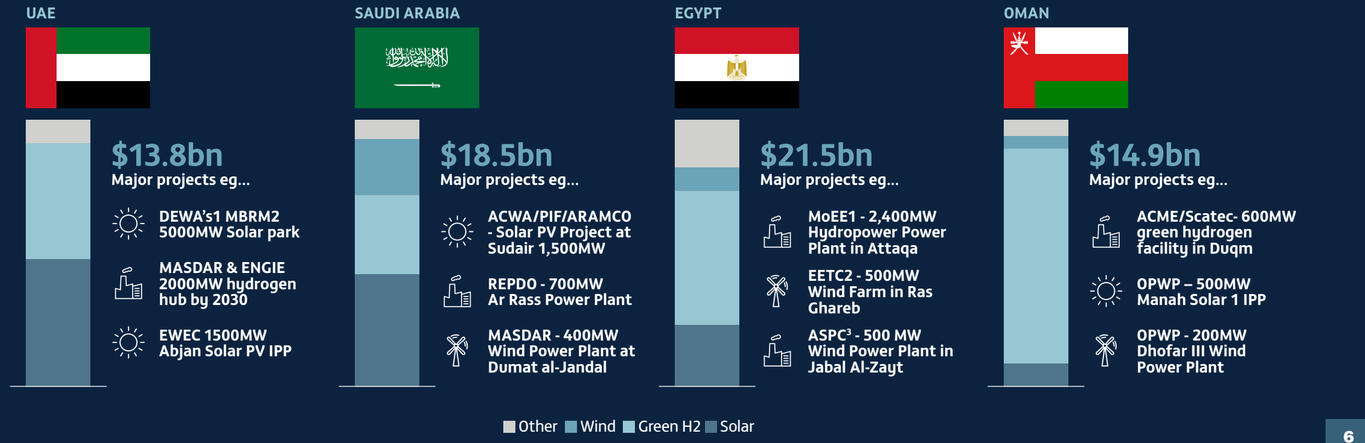
Making hydrogen takes enormous amounts of space and the UAE has large tracks of unused land, unlike rivals in Europe or much of Asia. Finally, the UAE is already geared up to export commodities. It has high quality infrastructure, plenty of transferable skills and established trade routes to, and relationships with, many large potential sources of demand in Europe and Asia, as well as being geographically central to both.

> "The country has much of the renewable energy capacity that is necessary."

2030 green energy project pipeline

Source: MEED, BCG, FAB





PRODUCTION BARRIERS ARE SIGNIFICANT.

The excitement around low carbon hydrogen is palpable, though the industry remains nascent. While green, blue and purple hydrogen have been proven viable in multiple pilots, and small-scale production is underway, large-scale production and adoption are some way off.

"We have yet to unlock the cost model for production and distribution of green hydrogen and there remain technical challenges to its widespread production and use," says Bashir.

Most of these challenges are not unique to the UAE but relate to the immaturity of electrolysis technology. One problem is that electrolysis modules are currently too big, according to Stephan Gobert, senior vice president of hydrogen, AMEA at France's ENGIE. "It's not possible to stack modules next to each other to produce a gigawatt scale facility, for example, because of the space and land required. A 500 MW capacity facility is, at the current time, 100 modules of 5 MW each."

Module size – and complexity – hampers the expansion of manufacturing capacity and keeps costs high. "Suppliers do not have the factory space to produce modules on the scale required," says Gobert. Moreover, most electrolysers are still built by hand: the process needs to be industrialised. Both of the two competing electrolyser technologies – pressurised and unpressurised – present health and safety hazards.

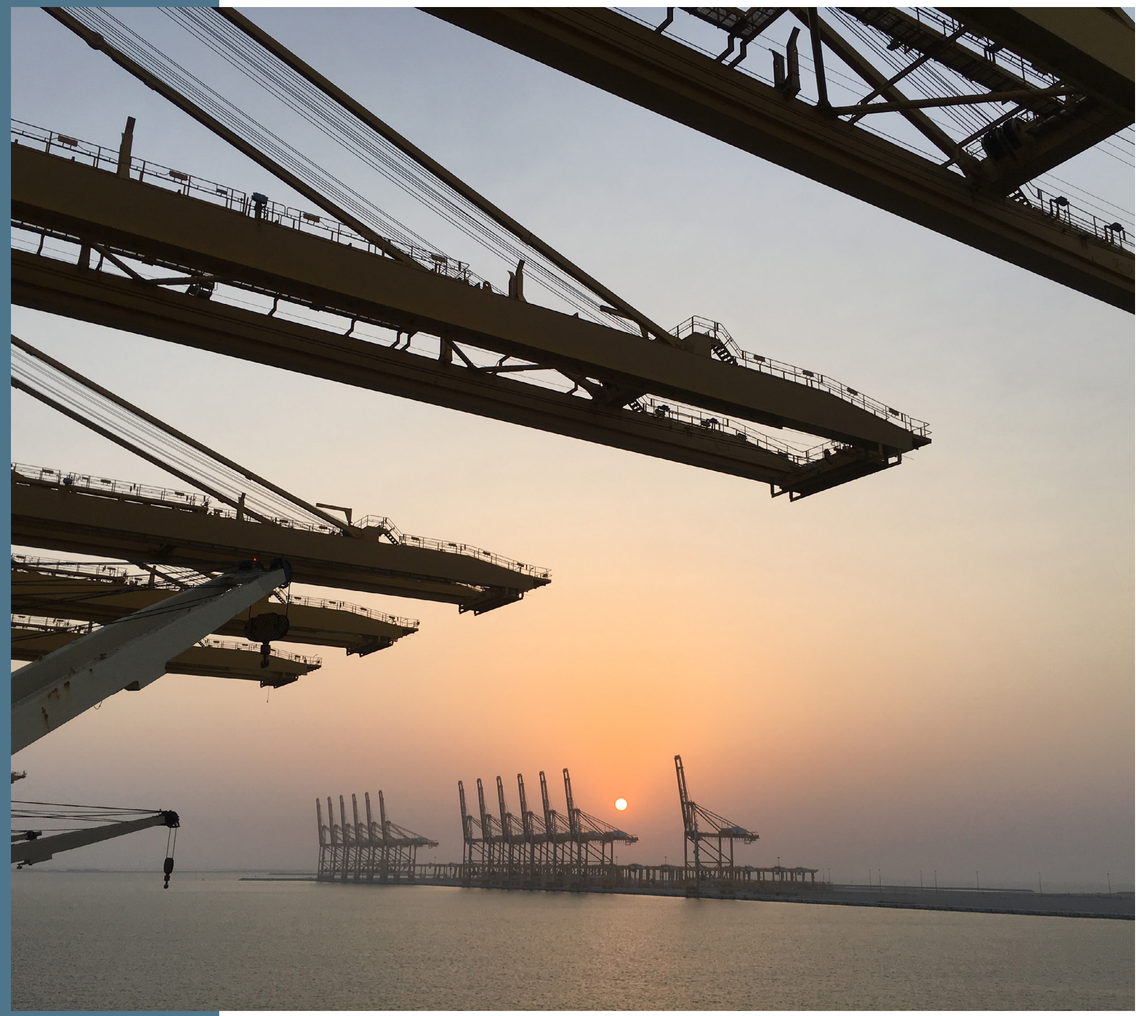
Vast space – even by UAE standards – is required around facilities given that hydrogen is extremely flammable, explosive and leaks easily.

Low carbon hydrogen is water intensive, which presents a particular problem for the UAE. "Every kilo of green hydrogen requires 80 litres of water as a feedstock, while every kilo of blue hydrogen requires 40 litres for cooling," says Mariam Alqubaisi, head of sustainability at Etihad.

However, Noel Aoun, executive director strategy at TAQA Group, says that desalination is the solution: "even with this additional cost, green hydrogen in the GCC remains extremely cost competitive".

80litres

The volume of water required as feedstock for every kilo of green hydrogen



DISTRIBUTION AND DEMAND ARE ALSO IMPORTANT.

Large-scale exports – one of the UAE's main hydrogen goals – will require major new infrastructure, both for transportation and to enable it to be used within those countries, explains Aoun. In the future, technologies such as liquid hydrogen and liquid organic hydrogen carrier technology (LOHC) could be used for exports. In March, ADNOC, Uniper, start-up Hydrogenious LOHC and Jera Americas announced plans to develop LOHC to transport hydrogen from the UAE to Germany.

But for now, ammonia is the only feasible way to transport hydrogen across continents, according to Humfrey at ADNOC. "In addition, ammonia will likely be used in the future for power, industrial processes relating to copper and steel, and potentially to fuel marine vessels," he notes. The first test delivery of ammonia from the UAE arrived in Germany in March.

Eventually, ammonia cracking – which converts ammonia back to hydrogen – could be used to create pure hydrogen to power trucks or heat homes in countries such as Germany, where the hydrogen strategy is as much as 80% reliant on imports.
As well as finding ways to transport hydrogen, it is also necessary to find offtakers. There are multiple potential use cases for green hydrogen. But each requires significant development and investment. "Technical trials are necessary," says Humfrey. For instance, in the coal-fired power market, ammonia can be used as a fuel, with a steadily increasing percentage displacing coal. "However, a lot of testing is still required to achieve that goal at scale," he adds.

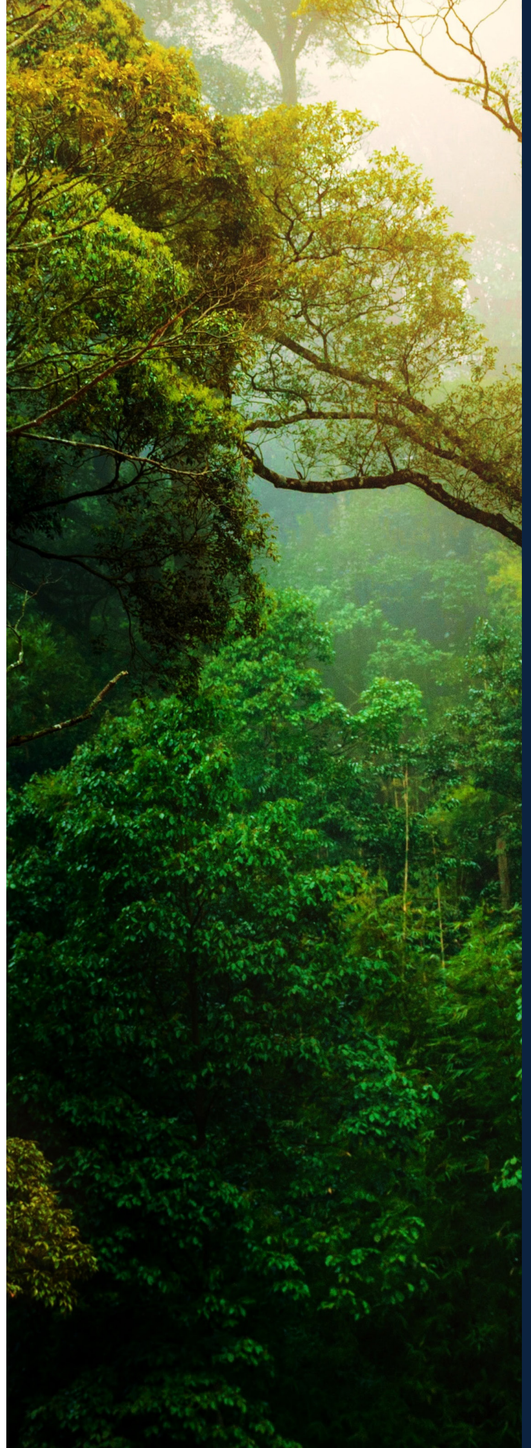
Domestically, it is also important to cultivate offtakers, and the government has been successful in encouraging national champions to investigate use cases.
For instance, UAE flag carrier Etihad is part of a project to use hydrogen for maritime and aviation fuel (see case study) while Emirates Global Aluminium signed an agreement with the Ministry of Energy & Infrastructure to join the UAE Hydrogen Leadership Initiative in September.

Indeed, the UAE already has several hydrogen projects in development. "Our first project is with ammonia producer Fertiglobe, a strategic partnership between Netherlands-based nitrogen producer OCI and ADNOC," explains Frederic Claux, managing director, thermal and supply, AMEA at France's ENGIE, which signed a $5 billion renewable energy and green hydrogen strategic alliance with Masdar in December 2021. Feasibility studies should be finished this year, with construction complete by the end of 2025.

The Fertiglobe project has two objectives. "The first is to decarbonise an existing ammonia plant that produces 600,000 tons of ammonia from grey hydrogen a year," says his colleague, Golbert. "The second objective is about timing: Fertiglobe aims to become the first green ammonia producer in the world so that it can better understand the potential market for fertilisers produced from green ammonia – which could be critical for exports to the European Union – for example, and the costs associated with decarbonised end products."

TAQA is also leading a number of initiatives and has signed memoranda with Emirates Steel, to decarbonise steel production, and with Abu Dhabi Ports, to export green ammonia. "Both are megaprojects and will have typical megaproject life cycles," says TAQA's Aoun. "The cost of green hydrogen remains high, so we need to learn more, and optimise costs before production becomes... feasible, bankable and has the right technical design."
Activity has also been brisk in neighbouring emirate Dubai. Petrolyn Chemie signed an agreement to build a $1 billion green hydrogen and ammonia production plant with Korea Electric Power Corporation, Samsung C&T and Korea Western Power in June. And Siemens Energy's solar-driven electrolysis hydrogen collaboration - a small-scale pilot project for testing purposes only - with DEWA (the state electricity and water company of Dubai) has been in operation since 2021.

$5bn
Value of ENGIE and Masdar's renewable energy and green hydrogen strategic alliance



A POTENTIAL GAME CHANGER.

The announcement that TAQA, Mubadala (Abu Dhabi's sovereign investment fund) and ADNOC will become shareholders in renewables company Masdar, making it one of the largest clean energy companies of its kind, is enormously important to the future of green hydrogen in the UAE.

The partnership between the three companies – which previously collaborated via the Abu Dhabi Hydrogen Alliance – will have a combined current, committed, and exclusive capacity of over 23 GW of renewable energy, with the expectation of reaching well over 50GW total capacity by 2030. Crucially, the partnership also brings the three companies' green hydrogen portfolios into Masdar.

ADNOC's Humfrey describes the move as "the obvious next step" given the scale of the UAE's ambitions. "Abu Dhabi has always been focused on a coherent approach to the energy transition and the changed shareholdings in Masdar (once regulatory approval is granted) will reflect that," he adds. Within Masdar, there will be two companies: one led by TAQA focused on power; and one led by ADNOC focused on green hydrogen. "The partnership with ADNOC and Mubadala in Masdar aims to leverage the key competitive strengths of each partner. We have expertise in solar photovoltaic and water desalination, which are critical for green hydrogen," says Aoun at TAQA.

"The partnership with ADNOC and Mubadala in Masdar aims to leverage the key competitive strengths of each partner."

MOMENTUM IS BUILDING.

The technological challenges relating to making green hydrogen are – slowly – being addressed. "Progress is being made," says Gobert at ENGIE. It has worked on the technology locally for over five years and has moved from megawatt to hundreds of megawatts-scale projects, such as its 150 MW project with Masdar. (For reference, nuclear plants or large-scale renewables might top a gigawatt).

However, ultimately the success of green hydrogen will largely be determined by price. The tragic events in Ukraine, and subsequent sanctions on Russia, have focused international attention on energy security and narrowed the gap between grey and green hydrogen prices, boosting its prospects. "A year ago, green hydrogen was three or four times more expensive than grey hydrogen," says ENGIE's Claux. "But today, given high gas prices in Europe, the picture has dramatically changed.

We believe that high gas prices will be sustained for at least a few years, which creates a major opportunity for green hydrogen." By 2030, green hydrogen might be ready to compete on price as the cost of renewable power (roughly 50% of the total cost) and electrolysers and other plant infrastructure (50%) falls steadily, notes Gobert.

As prices fall, there will be a tipping point, according to TAQA's Aoun: "Green hydrogen will go from extremely expensive to cheap very fast. At that point, demand will jump." Price parity may not be necessary: industrial users may be willing to pay a premium in order to meet their net zero objectives. Humfrey at ADNOC believes that recent corporate commitments to source green hydrogen to meet their net zero targets represent a breakthrough. "That demand will, in turn, unlock supply and capital – and that's very exciting."

For the foreseeable future, however, government support will be essential to make green hydrogen a key part of the global economy. "The development of renewable energy shows how important government support was in past decades," says First Abu Dhabi's Bashir. "Similar support will be necessary for green hydrogen." Aoun agrees that there is a requirement for subsidies and public-private partnerships given the tremendous amount of funding required by the energy transition.

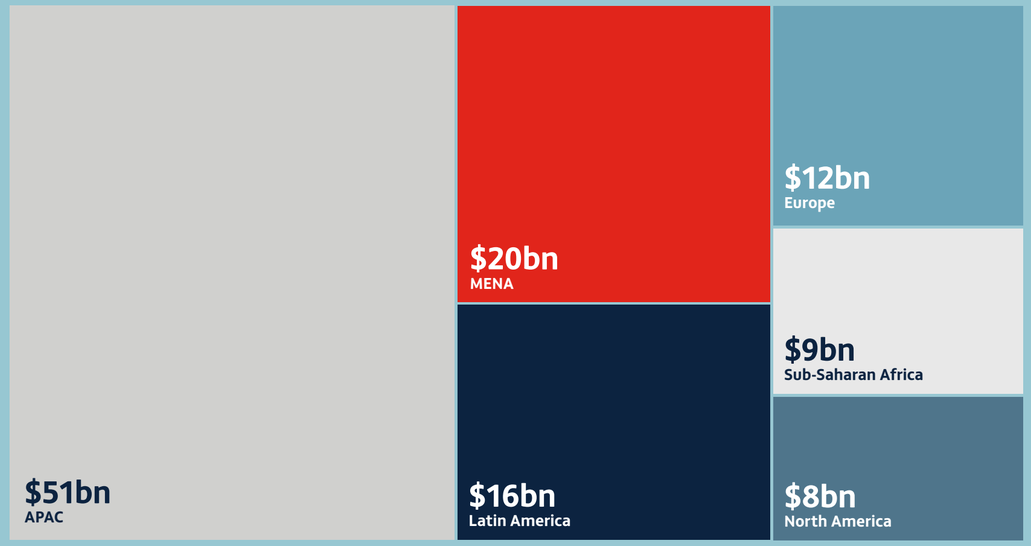
The Hydrogen Roadmap published in November 2021 was a landmark as a statement of intent for the UAE. Since then, Abu Dhabi's Department of Energy has been working with stakeholders across government and the private sector to define policies, regulations, standards and certifications for the hydrogen sector. The hope is that the next instalment of the Roadmap, due before the end of the year, will also provide greater clarity on how the investments necessary to make production scale green hydrogen a reality will be financed, further accelerating the UAE's bid for green hydrogen leadership.

150MW
The size of ENGIE and Masdar's project

Total value ($116bn) of green hydrogen projects in the financing stage globally

FIGURE 3

Source: IJ Global



134
Total number of green hydrogen projects in the financing stage

CASE STUDY

ETIHAD

THE NEED TO MAKE GREEN HYDROGEN COMPETITIVE WITH FOSSIL FUELS.

Etihad is the UAE's flag carrier and reflects the country's ambitions, including its net zero 2050 target. While aviation accounts for just over 2% of carbon emissions globally, they are high in the atmosphere, and together with other gases, have a significant impact. More to the point, airlines have had a free ride when it comes to polluting for 70 years, notes Mariam Alqubaisi, head of sustainability at Etihad: "They now have a responsibility to take decarbonisation seriously".

Abating carbon emissions is more difficult for aviation than for ground-based transport: while there have been electric plane trials, there is no prospect of long haul, large passenger electric commercial airlines in the foreseeable future because of battery weight and capacity limitations.Instead, Etihad has been among the earliest investors in sustainable aviation fuel. No alternative fuels are yet mature so Alqubaisi says Etihad is investing in a wide variety of technologies, encompassing "both low hanging fruit and projects that may not be commercial for many years".

One innovative project tackled fuel, food and water security by using oil from a salt-tolerant plant called Salicornia – grown on a fish and shrimp farm and effectively fertilised by their waste – as part of a mix for jet fuel. The biofuel project had the virtue of not compromising food production or water resources, which Etihad believes is important given the scarcity of water in the region. Etihad is also exploring waste to fuel (in line with the UAE's target to redirect over 75% of municipal solid waste away from landfill by 2025 and reduce methane emissions). "A third, and important, alternative fuel being explored is hydrogen," says Alqubaisi.

There are projects seeking to directly use hydrogen in fuel cells for flight – it is three times more energy rich than fossil fuels and has no emissions. But Etihad is currently focused on processing hydrogen to create a hydrocarbon (synthetic kerosene) from carbon dioxide captured and converted to carbon monoxide. While synthetic kerosene still results in carbon emissions, they are significantly lower than kerosene produced from fossil fuels.

Etihad is part of the Green Falcon project with Masdar and others, which is seeking to create green hydrogen as an energy agent for maritime and aviation use. "We expect the Green Falcon pilot to begin producing green hydrogen by the end of 2024 but full production is at least a decade away," explains Alqubaisi. "More importantly, before we get to that stage, we need to make green hydrogen competitive with fossil fuels from a price perspective."

Given the nature of Etihad's business, it is easier to start with blue hydrogen (which separates hydrogen from fossil fuels in a heat-intensive process and reforms it to produce kerosene for aviation) but captures the CO2 for storage rather than releasing it into the atmosphere. "Clearly, kerosene produced from blue hydrogen is more expensive than that made from fossil fuels. But it is cheaper than green hydrogen and therefore an easier first step," says Alqubaisi.

"We expect the Green Falcon pilot project to begin producing green hydrogen by the end of 2024."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