مؤسسة دبي للمستقبل
DUBAI FUTURE FOUNDATION

أبحاث دبي للمستقبل
DUBAI FUTURE RESEARCH

In collaboration with

UNITED ARAB EMIRATES
MINISTRY OF ENERGY & INFRASTRUCTURE

UNITED ARAB EMIRATES
MINISTRY OF CLIMATE CHANGE
& ENVIRONMENT

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

HYDROGEN

FROM HYPE TO REALITY

DUBAIFUTURE.AE

v1.0

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1.

EXECUTIVE SUMMARY

Hydrogen is an energy carrier that is becoming increasingly capable of being produced cleanly, allowing for economic growth while minimising the impact on the environment. Our planet's climate is changing at an alarming rate, in large part due to anthropogenic, or human-induced, emissions. In an effort to scale back these emissions, countries around the world are adopting clean, renewable energy sources, which are becoming more cost-effective than their polluting counterparts in many places. However, existing renewables face limitations in what they can achieve, for example in supplying energy for industry, which is where hydrogen comes in. As the world strives to achieve net zero emissions, hydrogen will complement other low or zero carbon energy sources and become a key component of our planet's clean energy mix particularly by decarbonising hard-to-abate industries such as steel, cement, aviation, and shipping.

OPPORTUNITIES

Currently, hydrogen is primarily used for ammonia and methanol production, through chemical synthesis, and in oil refineries, where hydrogen is used to lower the sulphur content of fuel. Several new applications could emerge due to the increasing feasibility of producing low-carbon hydrogen:

Providing Access to Clean Energy

Utility providers can store energy generated from renewable sources in the form of hydrogen and export it to countries that lack renewable energy sources for consumption.

Minimising Carbon Emissions in Heavy Industries

Both ‘blue hydrogen’, that is, hydrogen produced with natural gas using carbon capture, and ‘green hydrogen’, produced through electrolysis with electricity from renewable sources, can play a key role in minimising the carbon footprint of high-polluting heavy industries such as cement and steel production. It is challenging for solar and wind to deliver the required heat for such industries.

Energy Storage for Renewables

Utility providers can rely on hydrogen as a means of storing energy to back up intermittent renewable sources such as solar, with the added benefit of transportability. It offers a degree of reliability and stability that renewables lack. Although batteries are the preferred energy storage medium for power grids, storing energy in hydrogen does have advantages, primarily the cost of bulk energy storage over extended periods of time, but also its ease of transportation compared to batteries.

Heavy Goods Transport

Existing fuel cell technology already enables hydrogen to power a large range of vehicle types, currently being most economical for heavier, lower-range vehicles such as forklifts and heavy goods vehicles. Development of the hydrogen economy will allow a wider range of vehicles to become economically competitive with both battery electric alternatives and internal combustion engines.

Other Applications

Other future applications being explored include the decarbonisation of the aviation and maritime industries through the use of hydrogen fuel cells, ammonia, and green-hydrogen-based synthetic fuels.

CHALLENGES

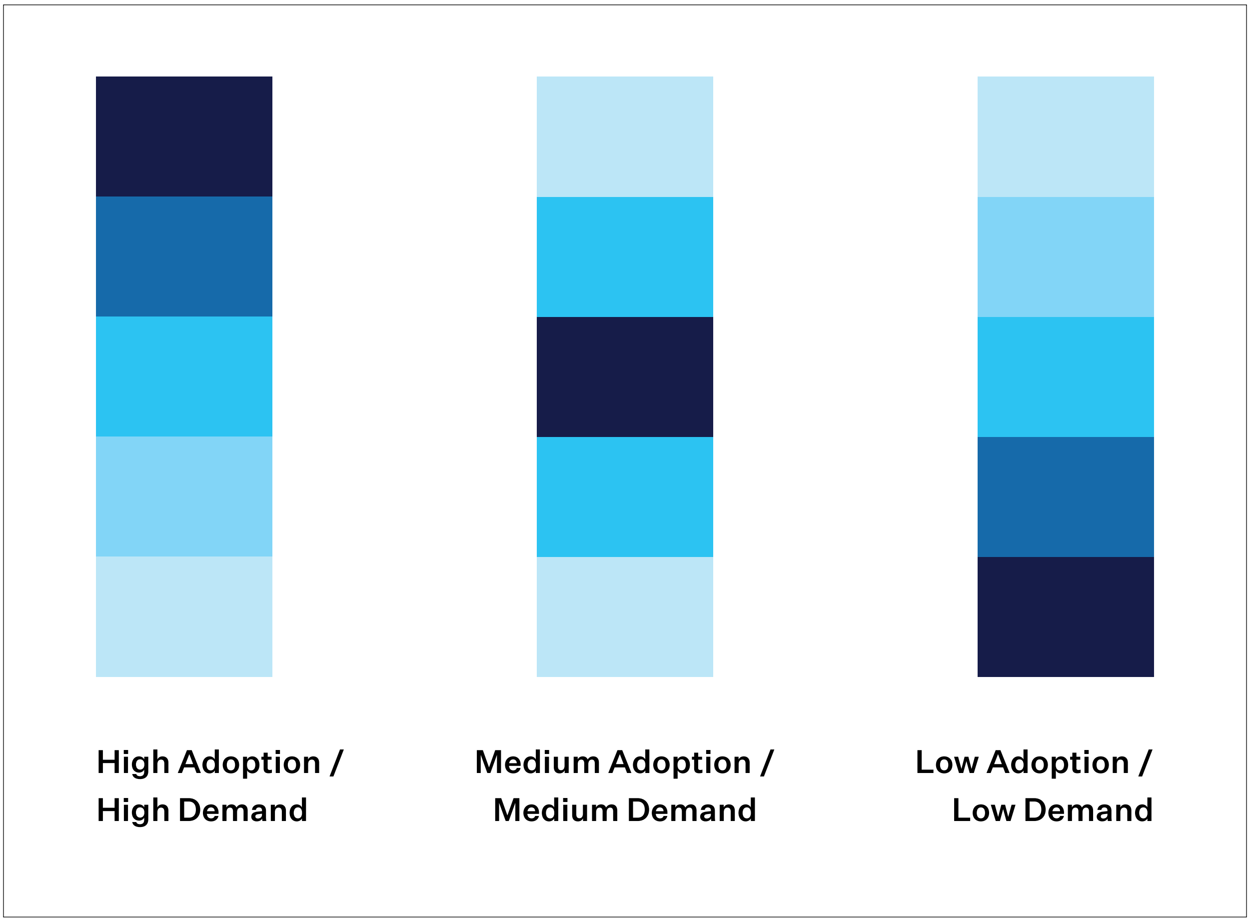
Although hydrogen's energy by mass, or specific energy, is impressively high, its energy by volume, or energy density, is relatively low, especially when compared to hydrocarbons such as petrol and diesel. This is less of a concern for stationary applications, but it poses challenges when the hydrogen needs to be transported for export or when hydrogen is used to power vehicles. Existing solutions to the energy density problem include compression and liquefaction. However, such methods are inefficient and consume a significant amount of energy. Emerging solutions include chemical storage of hydrogen in the form of hydrides (Bimbo, 2019), the hydrogenation of organic molecules for use as liquid organic hydrogen carriers (Sampson, 2020), and the use of ammonia as a hydrogen carrier. Other challenges include safety concerns and sustainability of green hydrogen production, which will need to be addressed for hydrogen to become a truly scalable alternative to fossil fuels.

THE FUTURE UAE HYDROGEN ECONOMY

In developing a framework for understanding the potential of a UAE hydrogen economy, this report combines data modelling with a scenario approach to categorise, estimate, and evaluate possible outcomes:

International Energy Market Scenarios

These scenarios are constructed from baseline assumptions incorporated into a quantitative model for international hydrogen demand and pricing. The three domestic market and four export sector scenarios are each considered within three international energy market scenarios:



Variables that affect the outcome include carbon pricing, net zero commitments, and hydrogen uptake itself.

Domestic Demand Strategies

In crafting a hydrogen sector strategy, the UAE has a range of options for managing the sector and directing the domestic market. Examples of successful industrial policies elsewhere offer big picture insights into cultivating new industrial sectors.

This report covers three alternative approaches for the UAE's domestic hydrogen market, bundling policies together to optimise their effectiveness:

The Walled Garden

A maximal approach to develop a large and secure local market.

Balanced Costs & Benefits

A balanced approach maintaining some of the elements of The Walled Garden at a smaller scale while reducing the level of coordination.

Export Only

A hands-off approach minimising the role of government in managing domestic demand.

Export Sector Development Strategies

The strategic pathways for the export sector involve metrics modelled quantitatively, including determining target volumes for production, selecting which types of hydrogen to produce, establishing investment levels to meet production targets, and anticipating end markets for UAE-produced hydrogen. Based on those metrics, different forecast models for economic, environmental, and social impacts on UAE have been prepared. The strategies also include the external-facing policy adaptations necessary to enable the strategies to succeed:

Producer & Hub

Seeking to maximise the UAE's global market share and developing as an innovation centre for the industry.

Regional Coordination

Establishing a region-wide hydrogen cluster rather than engaging in potentially destructive intra-Gulf Cooperation Council (GCC) competition.

Producer

Harnessing the UAE's resources, relationships, and location to develop an internationally competitive hydrogen sector on the same scale as GCC neighbours.

Low-hanging Fruit

Seeking to minimise the UAE's exposure to downside risk by limiting investment in the hydrogen sector, while seizing opportunities where they exist.

RECOMMENDATIONS

It must be acknowledged that a long-term recommendation will be sensitive to land availability, logistical constraints, and financial implications for supporting domestic demand. Hence, a detailed techno-economic assessment is required before recommending a specific strategic pathway at this stage. In a future where such constraints are overcome, the highest potential benefit to the UAE in the global hydrogen economy of the future would come from building a strong export market for locally produced hydrogen, which is described as the 'Producer & Hub' export sector development strategy in this report. The strategy is possible under either high or medium international and domestic hydrogen demand. The 'Producer & Hub' strategy could add up to AED 32 billion annually to Dubai's GDP by 2050, create over 120,000 jobs between now and 2050, and offset CO_2 emissions equivalent to 84 days per year of the UAE's crude oil production by 2050.

Add Up to AED 32 Billion

annually to Dubai's GDP by 2050

Create 120,000+ Jobs

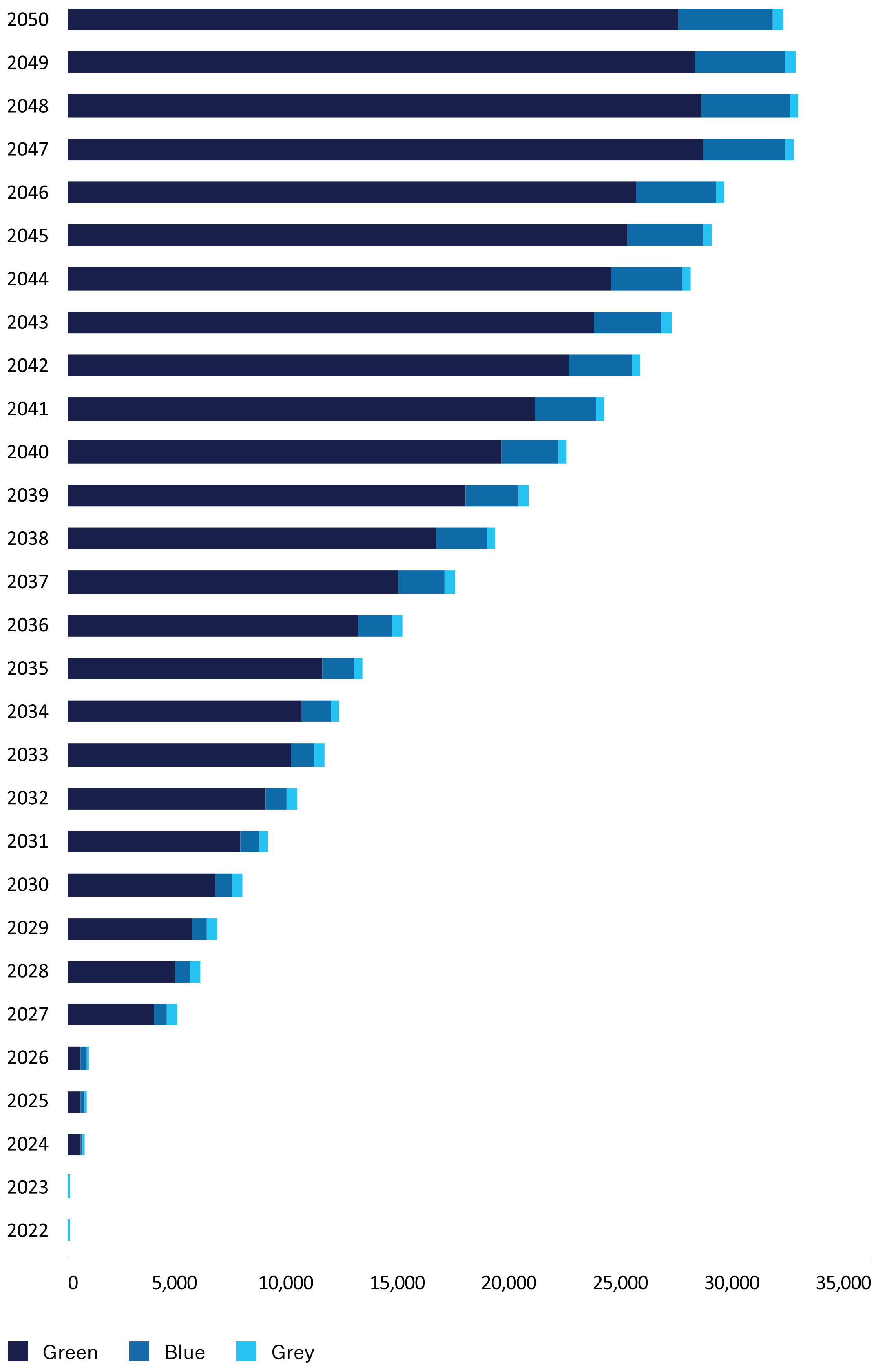
between now and 2050

Offset CO_2 Emissions 84 Days

per year of the UAE's crude oil production by 2050

Economic Impact on Dubai

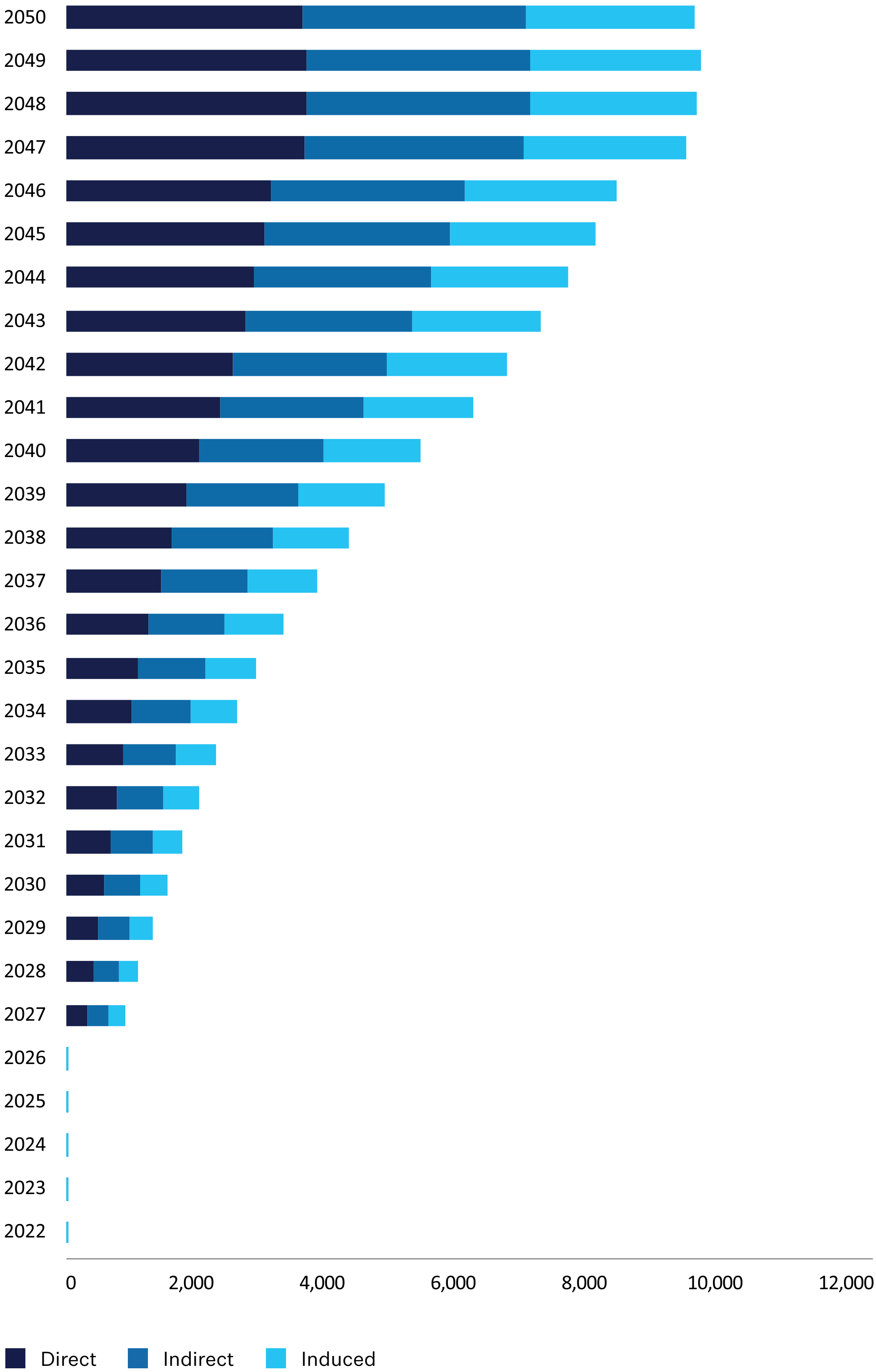
Figure 1. Dubai: Contribution to GDP (Direct + Indirect + Induced) (AED mm)



Source: Dubai Future Foundation

Social Impact on Dubai

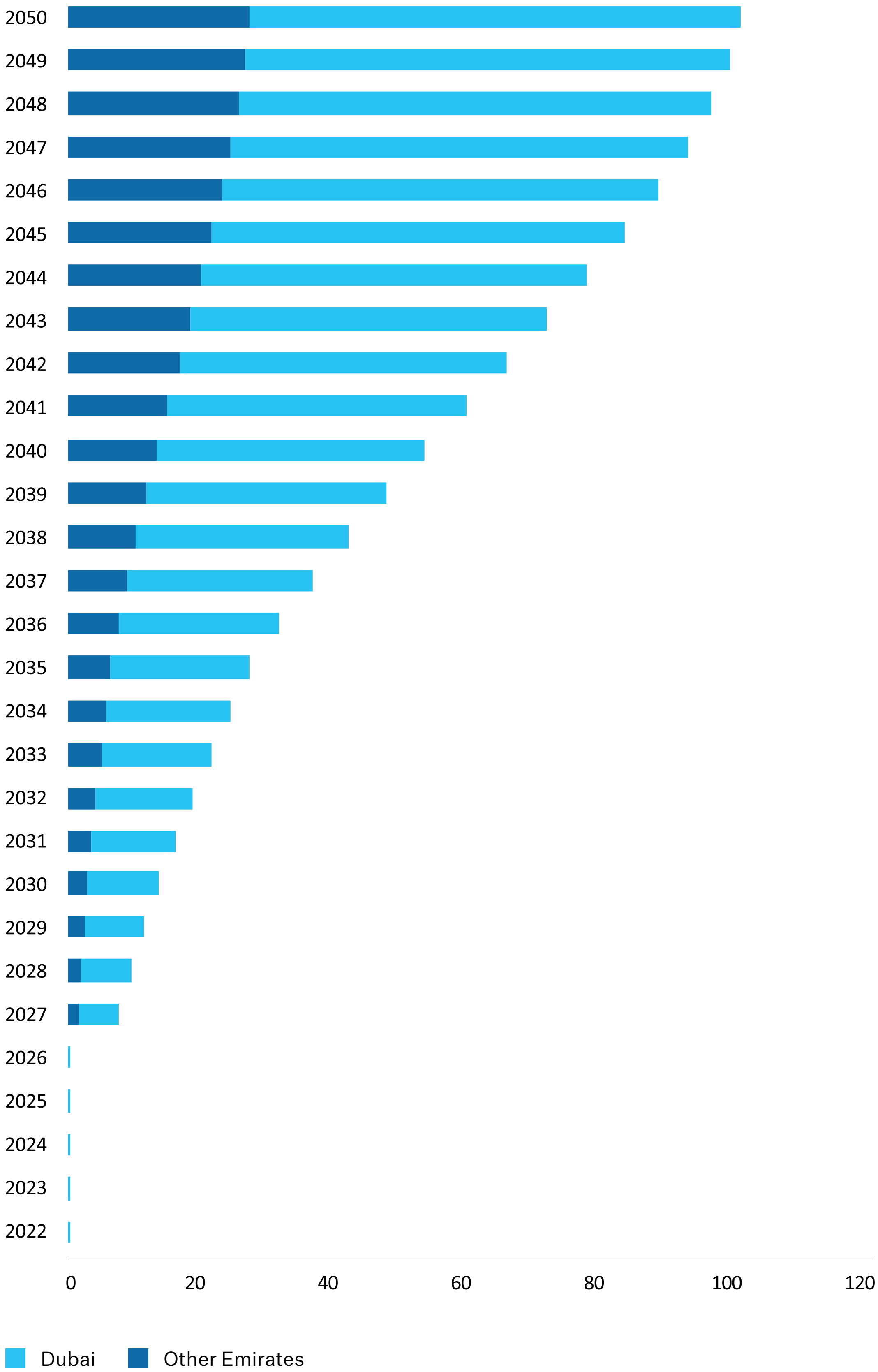
Figure 2. Dubai: Jobs Created Each Year (FTE)



Source: Dubai Future Foundation

Environmental Impact on the UAE

Figure 3. Days per Year of UAE Crude Oil Production's CO_2 Impact Offset by H2



Source: Dubai Future Foundation

Dubai Future Foundation, its partners, and expert contributors, have developed the following **short- to medium-term recommendations** in order to enable this strategic pathway to be followed:

1.
The development of proofs of concept by local authorities showcasing future use cases, including green-hydrogen-based synthetic fuels.

2.
The development of prototypes demonstrating the ability to overcome challenges, such as prototyping seawater electrolysers to overcome the freshwater scarcity challenge.

3.
Carrying out a pilot project demonstrating verification of clean hydrogen.

4.
The assessment and feasibility study of a jointly funded pipeline connecting GCC countries to Europe and East Asia for the export of hydrogen.

5.
The alignment of key government entities across the UAE to manage and coordinate the production and supply of blue and green hydrogen.

6.
Provision of financial incentives to hydrogen producers.

7.
The introduction of targeted measures to support hydrogen research and development (R&D) in the UAE.

8.
The conversion of up to 50% of all public fleets of heavy goods vehicles to hydrogen FCEVs (fuel cell electric vehicles) by 2050.

9.
The development of 100 hydrogen fuelling stations in the UAE by 2050.

2.

INTRODUCTION TO HYDROGEN

THE FIRST ELEMENT

Hydrogen is one of the most potent energy carriers available today, containing more energy by mass than fossil fuels. This energy is released when hydrogen combines with oxygen and the by-product could be nothing more than water vapour (depending on the method used), providing energy to help economies grow while minimising the negative impact on the environment. It is also the most abundant element, not only on our planet, but the entire universe. There are multiple methods of producing hydrogen cleanly, including a process known as electrolysis, which uses electricity to extract hydrogen molecules from water. As long as the electricity used comes from renewable sources such as solar power, the process has a minimal impact on the environment.

Hydrogen has the potential to become a significant part of the energy mix, alongside other renewables. According to some estimates, hydrogen could meet up to 24% of the world's energy needs by 2050 if strong and comprehensive policies are implemented to support it (IEA, 2019). However, approximately 95% of the hydrogen produced today is made using fossil fuels (IRENA, 2020a). As production is scaled up, it is essential to rely on clean production methods to reduce the impact on the climate.

Despite its significant potential, hydrogen has its limitations. First, its energy density – or energy by volume – is not as high as that of fossil fuels, and it requires more space. For example, if existing aircraft were to be adapted to use hydrogen, the aircraft would need to be reconfigured to accommodate larger fuel tanks, resulting in fewer seats for passengers and/or less cargo space. Second, hydrogen does not have the benefit of an existing fuelling infrastructure. In terms of cars, for example, battery electric vehicles (BEVs) can often be charged at their owners' homes, while fuel cell electric vehicles (FCEVs), which are powered by hydrogen, require entirely new networks of hydrogen filling stations, similar to existing petrol stations. The lack of existing hydrogen infrastructure allows early movers to define standards, select technologies, and capture an oversize share of the early market as other economies catch up. Other challenges, including the storage and transportation of hydrogen, sustainability, and safety concerns are addressed later in this report, together with ways of overcoming such challenges and emerging trends that reveal the true potential of hydrogen as the fuel of the future.

A BRIEF HISTORY

Science fiction author Jules Verne imagined the hydrogen economy as early as 1874 in his book *The Mysterious Island*. He described a world where:

> *Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.*

What was once imagined is now being transformed into reality. In the 1950s, NASA began developing hydrogen fuel cells for use in space. The following two decades saw the Apollo missions to the moon relying on hydrogen fuel cells as a power source.The concept of a hydrogen economy began attracting significant attention in the 1990s as scientific evidence continued to accumulate on the impact of anthropogenic greenhouse gases (GHGs) as drivers of climate change. Anthropogenic GHGs are introduced to our planet's atmosphere by human activity, predominantly through carbon dioxide emissions from the production and use of fossil fuels, though also from carbon dioxide, methane, and nitrogen dioxide generated by agriculture and land use change such as deforestation.

This realisation initiated a first wave of proposed hydrogen solutions and applications which largely proved impractical and prohibitively expensive at the time. Since then, however, hydrogen and fuel cell technologies have advanced significantly, thanks to increased R&D funding. In parallel, other renewable energy sources have become cheaper. In fact, in some parts of the world, renewables are now more cost-effective than traditional fossil fuels (IEA, 2020).

The policy landscape has also transformed over the years, enabling new clean energy alternatives through climate change policies. The Paris Agreement of 2015 has played a central enabling role towards a greener energy future. A combination of promising technical, economic, and policy factors now suggests that there is real potential for hydrogen to be used more broadly, among other low-carbon energy sources, particularly for the decarbonisation of industry sectors such as transport, energy storage and generation, green fertilisers, and steel production.

Another new development is pressure from activist shareholders for firms to disclose climate vulnerabilities and develop decarbonisation plans. Some hedge funds and insurers are ditching entire sectors – such as coal – because of the perceived climate risk (Partridge, 2020). Although hydrogen and fuel cell technologies remain relatively expensive, compared to other energy generation and storage technologies, initial implementation projects have demonstrated the potential to drive economies of scale, resulting in a step change in costs and opening a pathway for hydrogen and fuel cell technology deployment. In fact, industries powered by 'green' – or renewables-derived – hydrogen are already gaining significant momentum globally, and even some of the largest oil and gas companies, including Shell and BP, are developing hydrogen projects (Mathis and Rathi, 2020). This second wave of hydrogen implementation is unlike the one from over a decade ago. This time, hydrogen is better positioned to stay.

3.

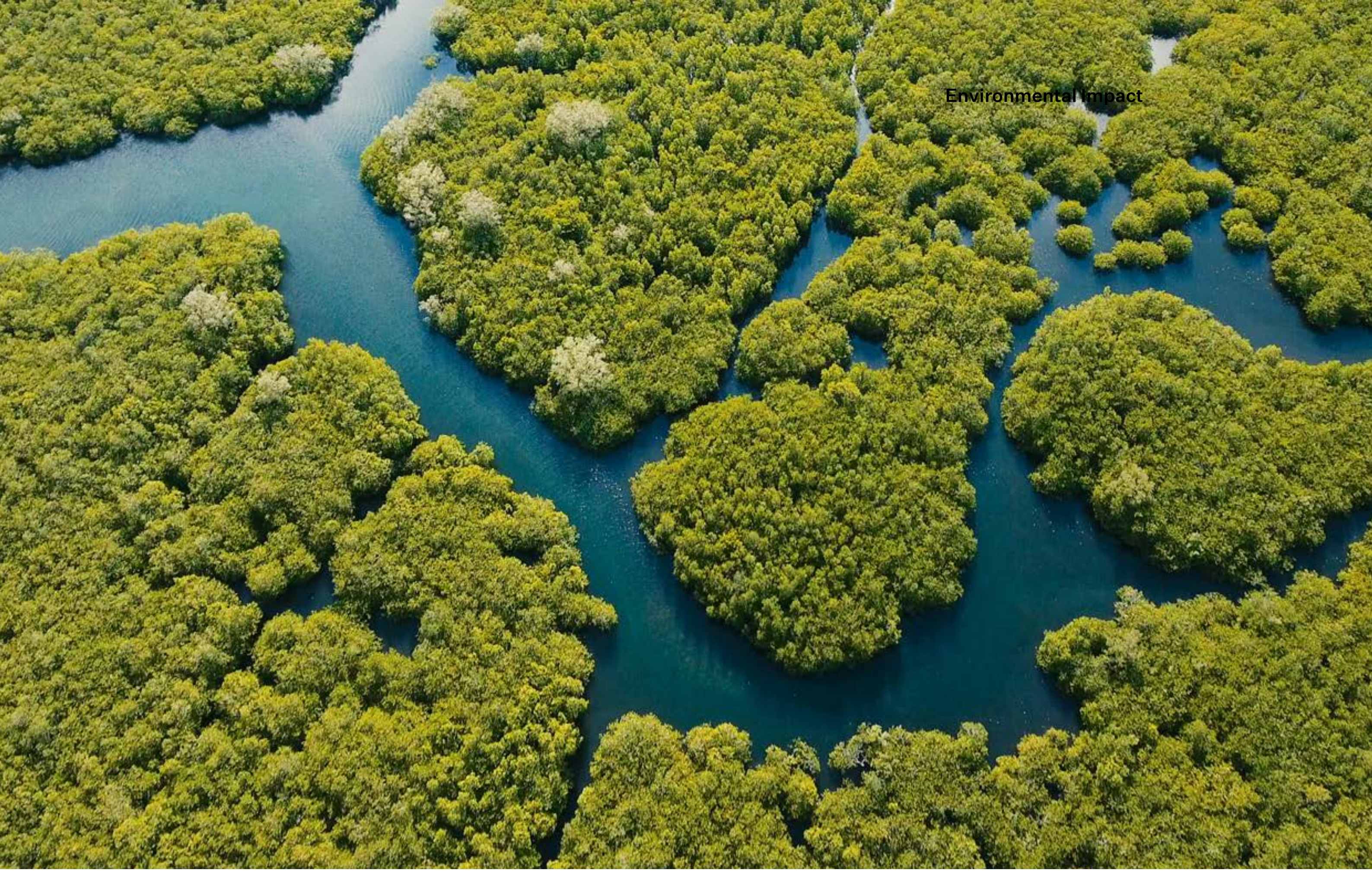
ENVIRONMENTAL IMPACT

CLIMATE CHANGE

The United Nations Intergovernmental Panel on Climate Change (IPCC) defines climate change as ‘a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer’. Climate change is also a natural phenomenon. Over the last 650,000 years there have been seven cycles of glacial advance and retreat (ibid.). However, there is now compelling evidence that current climate change is the result of rapid anthropogenic, or human-induced, emissions which have been creating a significant alteration in GHG levels in the atmosphere since the first Industrial Revolution. Our planet’s average surface temperature has risen by around 1C since the late 19th Century (NASA, n.d.). Anthropogenic climate change has also been observed through several global climate change indicators in addition to the global average surface temperature, including ocean heat content (OHC), sea levels, and the mass balance of ice covers.

AN IMMINENT THREAT

Climate change is set to have a devastating impact on our planet. It poses risks for multiple sectors including human health, food and water security, economic growth, energy, infrastructure, and the environment. Agriculture, crop yields, forestry, and grasslands are heavily dependent on, and influenced by, temperature and precipitation patterns in order to thrive, and climate change is altering these patterns. According to the World Meteorological Organization (WMO), climate-related disasters constitute one of the major drivers of the rise in global hunger, which remains a major concern, with one in nine people in the world suffering from hunger as of 2018. Due to climate change, drought and flood events may become more frequent, and severe dry conditions may increase the magnitude and frequency of wildfires. Climate change is also affecting our oceans as part of an interlinked series of environmental threats. It is causing increased ocean stratification, acidification, and deoxygenation, which are in turn leading to drastic changes in the ecosystem and biodiversity. Climate change is a global issue and the Middle East and North Africa (MENA) region is not immune. In fact, on 11 July 2018 the UAE National Centre of Meteorology (NCM) recorded the highest temperature ever, 51.1C, in Mezeira, Abu Dhabi.



OUR COMMITMENT

Signatories to the Paris Agreement are pursuing efforts to limit the global temperature rise to 1.5°C above pre-industrial levels. However, even if the unconditional commitments made as of late 2020 under the Paris Agreement are met, the global average temperature is still expected to rise by 3.2°C (UNEP, 2019). Unless global GHG emissions fall by 7.6% each year between 2020 and 2030, the world will be unable to deliver on the temperature goal of 1.5°C. This needs concerted collective action. The UAE was one of the first countries in the region to ratify the Paris Agreement, committing the global community to pursue efforts to mitigate GHG emissions.

The UAE submitted its second Nationally Determined Contribution (NDC) in 2020, pledging a reduction in GHG emissions by 23.5% compared to business as usual for the year 2030, with an absolute emission reduction of about 70 million tonnes.

The UAE also pledged to increase installed clean power capacity to 14 gigawatts (GW) and to plant 30 million mangrove seedlings to enhance carbon sinks and to serve as natural barriers against sea level rise.

The UAE is now making an accelerated effort to decouple its economic growth from environmental impact. To chart the nation's new development path and present its united ambition and determination, UAE Vision 2021 was launched with the primary objective of ranking the UAE among the best countries in the world by the year 2021. Through the Green Economy for Sustainable Development initiative of 2012, the UAE expressed its determination to enhance both the competitiveness and sustainability of its development and to preserve its environment for future generations, with the ambition of becoming a global hub and a successful model for sustainable development. The resolution also helps improve the nation's capacity to adapt to the adverse effects of climate change while shifting towards a cleaner and greener environment.

The UAE considers the transition to a climate-resilient green economy to be a promising opportunity for economic diversification while positioning the country as a global leader in renewable energy and green innovation. The National Climate Change Plan 2050 was adopted by the UAE Cabinet in June 2017 with the aim of consolidating the UAE's climate action under a single framework and identifying the strategic priorities that cover both mitigation and adaptation. The UAE National Energy Plan 2050 was also adopted in 2017, setting a target of increasing the share of clean energy in the country's installed power capacity to 50% by 2050.

Furthermore, in October 2021, the UAE announced its Net Zero 2050 Strategic Initiative, with plans to invest AED 600 billion in clean and renewable energy sources in the next three decades.

HYDROGEN AND CLIMATE ACTION

The energy sector is responsible for the majority of the world's GHG emissions, which is why technology and policy interventions in this sector will constitute an important part of the global effort to combat climate change. Consuming hydrogen for energy is clean, which is why hydrogen can play an important role in minimising the energy sector's emissions, as long as the hydrogen is produced using low-GHG emitting methods. Hydrogen also represents a cost-effective solution for the decarbonisation of sectors such as transport and heavy industry.

Countries around the world are actively pursuing green economies and relying on hydrogen in different ways in their efforts to tackle climate change. For instance, Australia, currently the world's largest coal exporter, is focusing on the production side, aspiring to become the leading exporter of hydrogen. Meanwhile, Japan is focusing on the consumption side by adopting hydrogen to reduce its dependence on fossil fuels.

In the UAE, the energy sector accounts for over 85% of the country's GHG emissions and efforts are being made to integrate hydrogen into the economy as a major energy carrier for transportation, industrial use, and electricity generation. The UAE, and specifically the Mohammed bin Rashid Al Maktoum Solar Park in Dubai, is home to the region's first solar-powered green hydrogen project, which was commissioned in May 2021 by Dubai Electricity and Water Authority (DEWA).

This project is aligned with the vision of His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of the UAE and Ruler of Dubai, to identify new energy resources and provide sustainable power as part of a balanced approach that prioritises the environment.

The Green Hydrogen project will demonstrate how green electrification can help decarbonise the economy and advance the vision of Sheikh Mohammed bin Rashid Al Maktoum to generate 75% of Dubai's total power output from clean energy sources by 2050. Other initiatives in the UAE include the Abu Dhabi National Oil Company's (ADNOC) plans to expand its hydrogen production (Saadi, 2021) and Mubadala's plans to accelerate green hydrogen capabilities in Abu Dhabi alongside Siemens (Mubadala, 2021).

The combination of relative abundance and the universal availability of fossil fuel energy technology has locked in an economic advantage for conventional energy sources in purely financial terms. The failure to price the impact of carbon emissions into fossil fuel sales is a quintessential case of failing to place a cost on externalities. A series of evolving international agreements has attempted to rectify this failure through voluntary emission reduction targets for developed economies as well as market mechanisms to incentivise carbon reduction. These include both national-level and private sector carbon offset credits, through which countries or organisations sponsoring projects reducing overall carbon emissions elsewhere can generate revenue, with a UN-administered system introduced under the Kyoto Protocol. The development of a low-carbon/green hydrogen sector could serve as both a mechanism to meet climate goals and as potential means of revenue generation through tradeable credits.

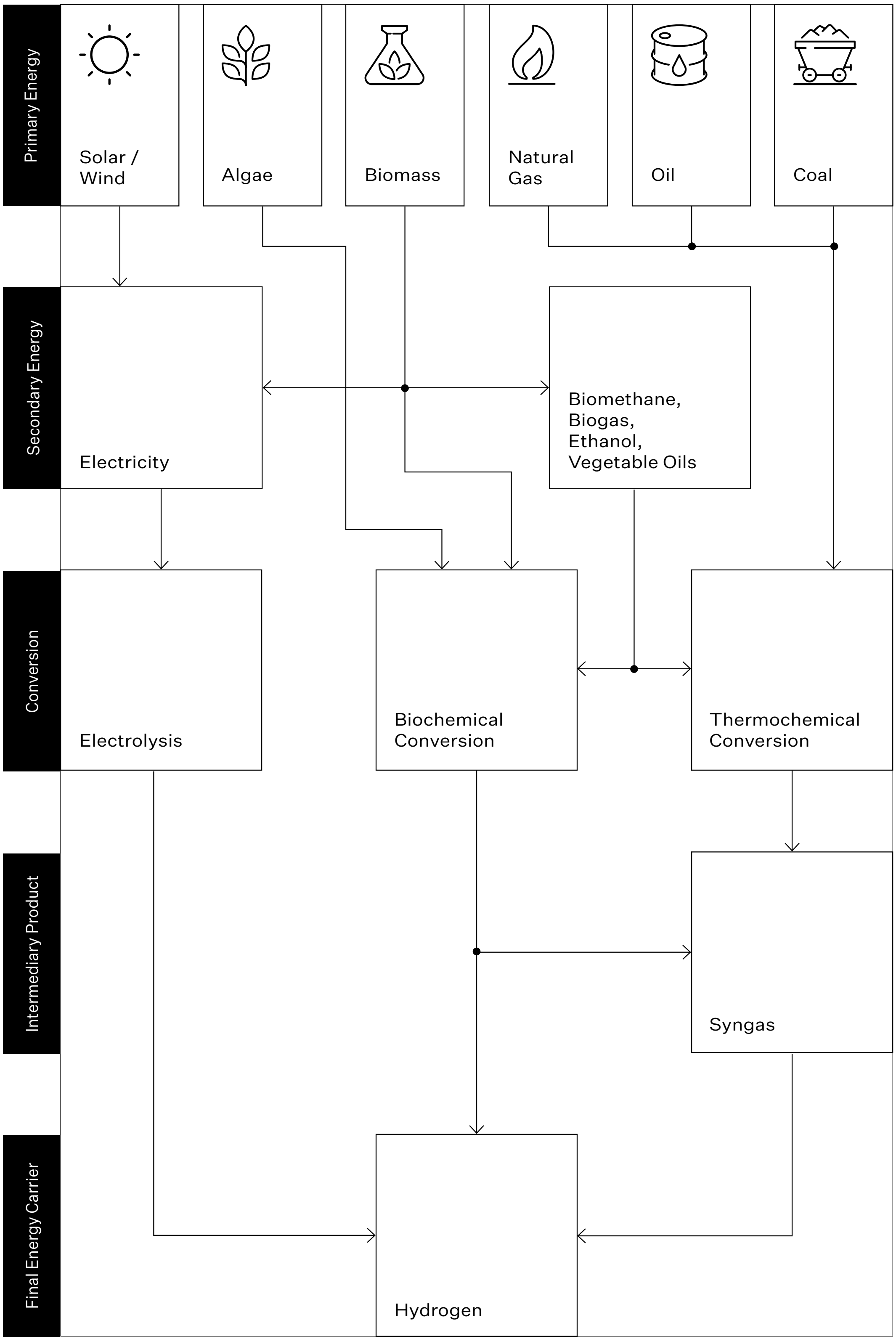
4.

HUES OF HYDROGEN

Although abundant, very little hydrogen exists on our planet in its natural form, which is why hydrogen needs to be produced by extracting it from other molecules.

There are multiple methods that can be used to produce the same element of hydrogen. Each method is commonly referred to by a colour that represents the production process. Most of the hydrogen produced today is created through the reforming of fossil fuels, a process that produces a reaction between natural gas or coal and steam and is often characterised as ‘grey hydrogen’. This process can be coupled with CCUS, where the CO2 generated is captured and used or stored underground. The hydrogen produced from this method is referred to as ‘blue hydrogen’. Hydrogen can also be produced through electrolysis using electricity generated by renewable energy sources such as wind and solar or from biogas obtained from biomass. The hydrogen produced from these methods is referred to as ‘green hydrogen’ (Shell, n.d.). Hydrogen production from hydrocarbons represents an important stepping stone for the transition towards blue and green hydrogen.

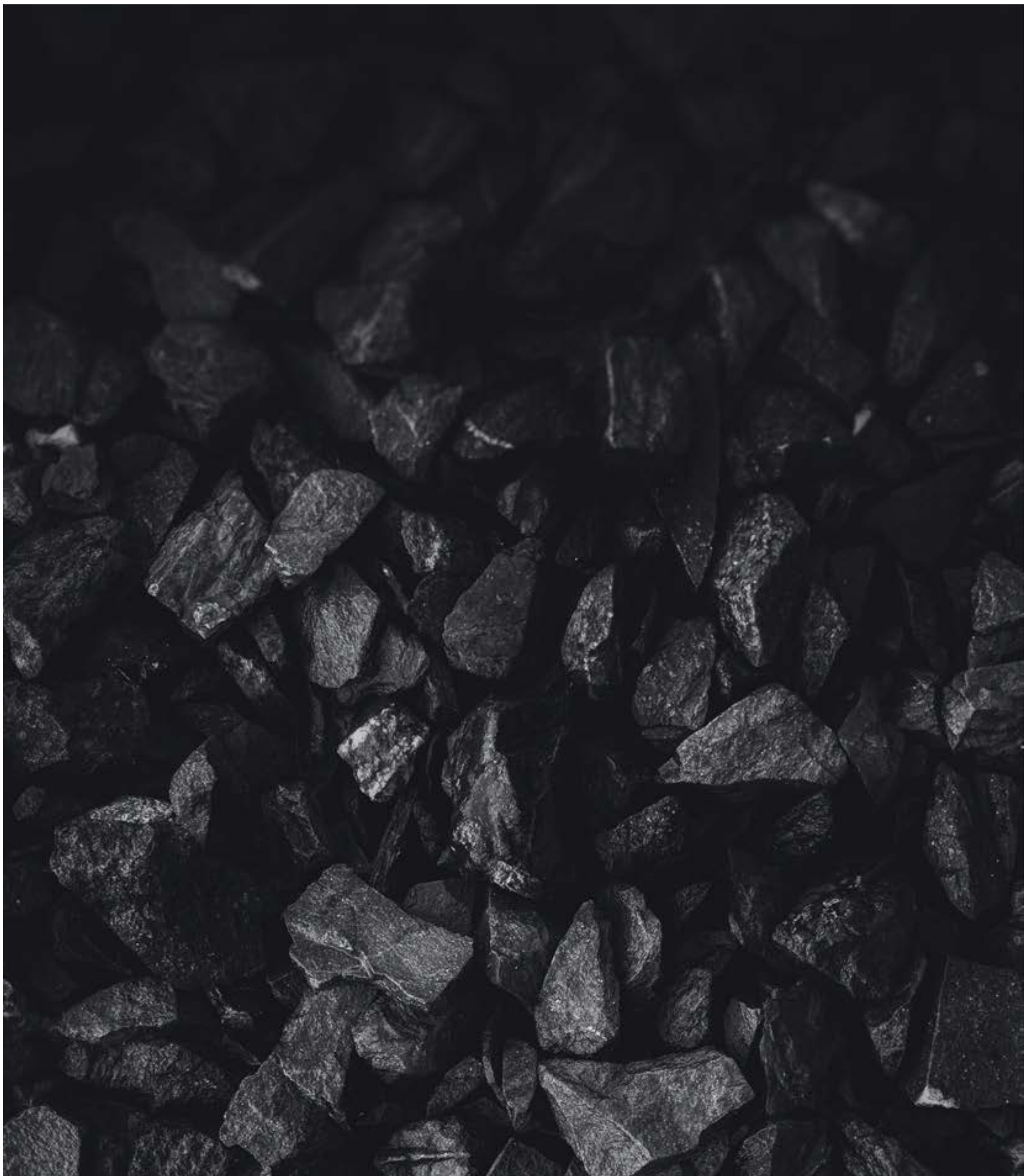
Figure 4. Hydrogen Production Methods



Source: Shell

GREY HYDROGEN

Grey hydrogen is produced from fossil fuels, typically natural gas or coal, which are reformed to release the hydrogen from their hydrocarbon molecules, a process that results in carbon dioxide being released into the atmosphere. In the case of natural gas, it contains methane that is used to produce hydrogen with thermal reforming processes, such as steam–methane reformation and partial oxidation. In the case of coal, gasification is used to produce hydrogen as well as power, liquid fuels, and other chemicals. Hydrogen is produced by reacting coal with oxygen and steam under high pressures and temperatures to form synthesis gas, or ‘syngas’, a mixture consisting primarily of carbon monoxide and hydrogen. This is then processed with steam to produce hydrogen and carbon dioxide, from which hydrogen is removed by a separation system.



BLUE HYDROGEN

Grey hydrogen becomes blue hydrogen when the CO_2 emissions are captured and sequestered via CCUS technology, minimising the impact on the environment.

The UAE is home to the Al Reyadah CCUS plant, which is the world's first fully commercial iron and steel industry CO_2 capture plant, and the Middle-East's first commercial-scale CO_2 plant. The UAE can build on this experience and expertise to use CCUS to produce blue hydrogen.

TURQUOISE HYDROGEN

Turquoise hydrogen is produced by a process known as methane pyrolysis, which, like grey and blue hydrogen, involves methane. Methane pyrolysis, however, relies on heat produced with electricity rather than through the combustion of fossil fuels (Canestrini, 2021). This method also produces hydrogen and carbon as outputs, but the carbon is produced in solid form, avoiding emissions to the atmosphere.

GREEN HYDROGEN

Green hydrogen is typically produced via electrolysis of water in which the electricity required to drive the process comes from renewable energy sources such as wind and solar. Water electrolysis is a well-established electrochemical process using equipment known as electrolysers in which electricity applied between two electrodes immersed in water separates water into hydrogen and oxygen (Kolodziejczyk, 2019).

Green hydrogen can also be produced through steam–methane reforming of biomethane or the gasification of biofuels. While these methods produce carbon dioxide, they may be considered ‘green’ or carbon-neutral because the released carbon dioxide was previously absorbed from the atmosphere, being used by plants or microorganisms to generate biomass. It can also be argued, however, that they should not be considered green because carbon dioxide is still released into the atmosphere. The more appropriate term might be net zero carbon emissions hydrogen. Although green hydrogen can also be directly produced as a result of microbial activity (OEERE, n.d.), this is currently a niche option.

The definitions of green, blue, and grey hydrogen often overlap and there is ongoing debate globally to formalise, regulate, and develop a 'guarantee of origin' scheme for hydrogen. Generally, any hydrogen produced without the release of carbon dioxide or produced from net zero carbon sources is considered green hydrogen.

A key pilot project demonstrating the production of green hydrogen was undertaken in Dubai by the Dubai Electricity and Water Authority (DEWA). This is the first megawatt-scale green hydrogen pilot project in the MENA region to produce hydrogen through solar power generation. The project is another example of successful government and private sector collaboration.

The green hydrogen facility tests and showcases an integrated megawatt-scale plant to produce green hydrogen using renewable energy. The green hydrogen electrolysis production site is operational since May 2021.

YELLOW HYDROGEN

Yellow hydrogen refers to hydrogen extracted from water using electrolysis, similar to green hydrogen. The only difference is that the electricity source used is nuclear energy instead of renewables.

5.

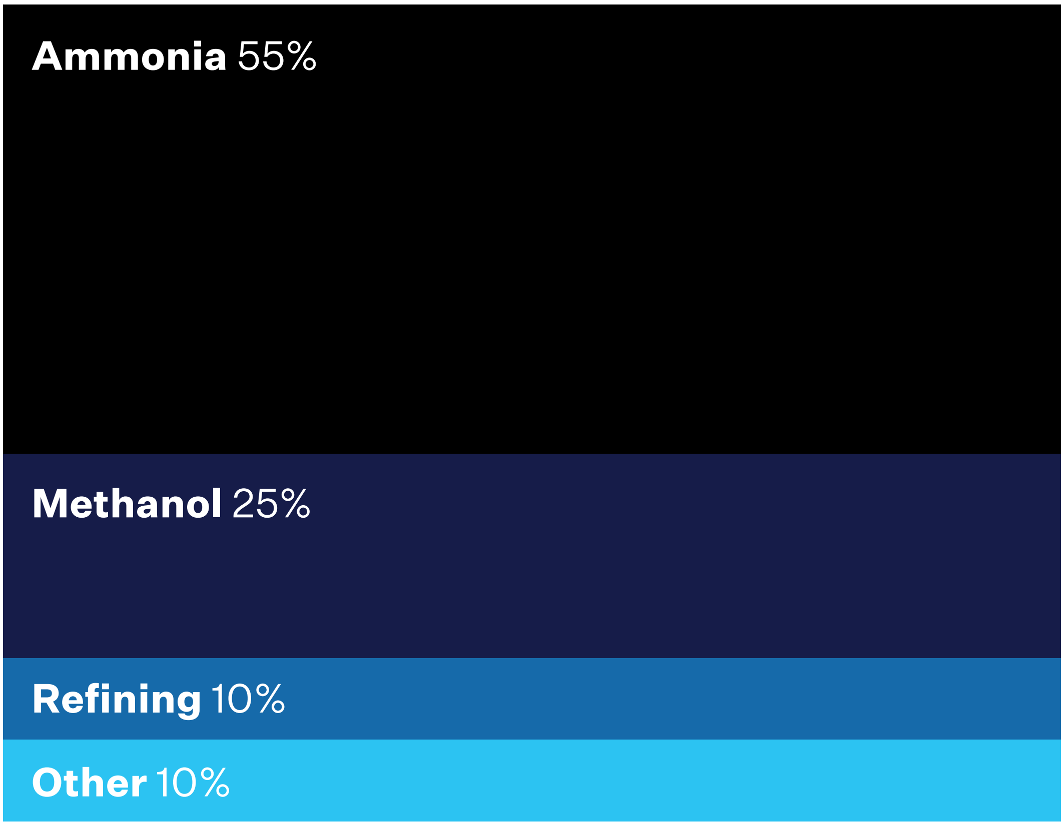
HYDROGEN APPLICATIONS TODAY

Hydrogen use today is dominated by industrial applications, primarily the production of ammonia, oil refinery processing, and methanol production. It is also already used to a limited extent for energy, in applications seen as having major future potential such as electricity generation, fuel cells, and transportation (US Department of Energy, 2001).

PRIMARY APPLICATIONS

Hydrogen is primarily used for ammonia and methanol production, through chemical synthesis, and in oil refineries, where hydrogen is used to lower the sulphur content of fuel. About 55% of the hydrogen produced around the world is used for ammonia synthesis, 25% in refineries, and approximately 10% for methanol production. Other applications account for the other 10% of global hydrogen production (Forsythe, 2020).

Figure 5. Hydrogen Usage



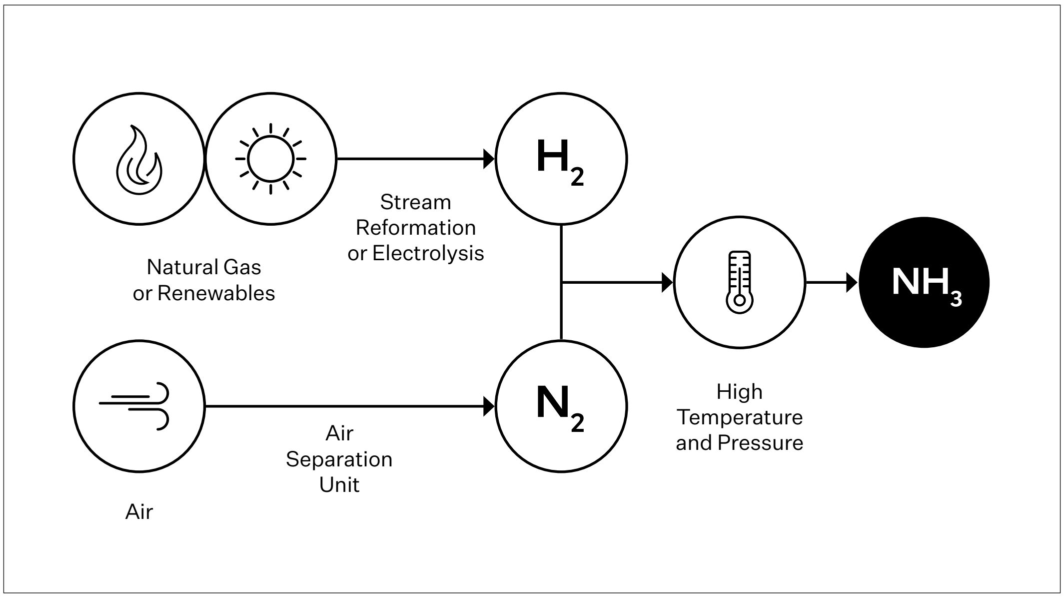
Sources: Dubai Future Foundation, Hydrogen Europe

Ammonia

At present, almost 90% of ammonia is used for fertiliser production. Due to its high energy of evaporation, ammonia is also used in refrigeration plants as an ozone-friendly and inexpensively produced refrigerant named R-717 (Drägerwerk, 2021). Ammonia can potentially be used as a storage compound for hydrogen (Ghavam *et al.*, 2021).

Ammonia (NH3) is primarily produced today using the established Haber–Bosch process, which combines hydrogen and nitrogen by synthesis.

Figure 6. Ammonia Production



Sources: Dubai Future Foundation, American Association for the Advancement of Science

Oil Refining

Oil refining, the process of converting crude oil into various end-user products such as transport fuels and petrochemical feedstocks, is one of the largest uses of hydrogen today. Hydrogen is used in hydrotreatment, which removes impurities such as sulphur. This application is set to grow as regulations for sulphur content tighten. Today, refineries remove around 70% of naturally occurring sulphur from crude oils. Due to rising concerns about air quality, there is regulatory pressure to further lower the sulphur content in refined products (IEA, 2019).

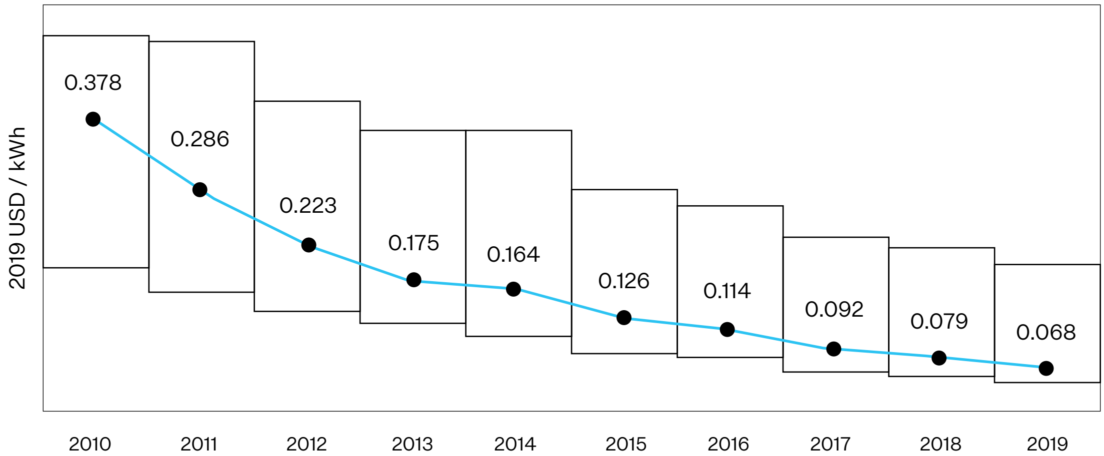
6.

HYDROGEN APPLICATIONS OF THE FUTURE

While the world is still far from achieving its climate goals, it has come a long way with renewable energy sources such as wind and solar. Solar photovoltaic (PV) costs have fallen globally by 82% between 2010 and 2019 (IRENA, 2020b), based on the levelised cost of electricity (LCOE). The LCOE takes into account not only upfront project costs, but also the costs of electricity generation over the life of a project. In fact, according to the IEA, 'solar projects now offer some of the lowest cost electricity ever seen' (IEA, 2020).

Solar photovoltaic costs fell globally by 82% between 2010 and 2019, based on the levelised cost of electricity.

Figure 7. Solar PV Levelised Cost of Electricity and Annual Ranges



Source: IRENA

The UAE has been setting world records for the cheapest solar power in recent years. In 2015, the record was set at a cost of 5.6 US cents per kWh, and later in 2016 at 2.99 US cents per kWh, both in Dubai. The latest record was set in 2020 with a bid of just 1.35 US cents per kWh in Abu Dhabi for the 2GW Al Dhafra project (Crider, 2020).

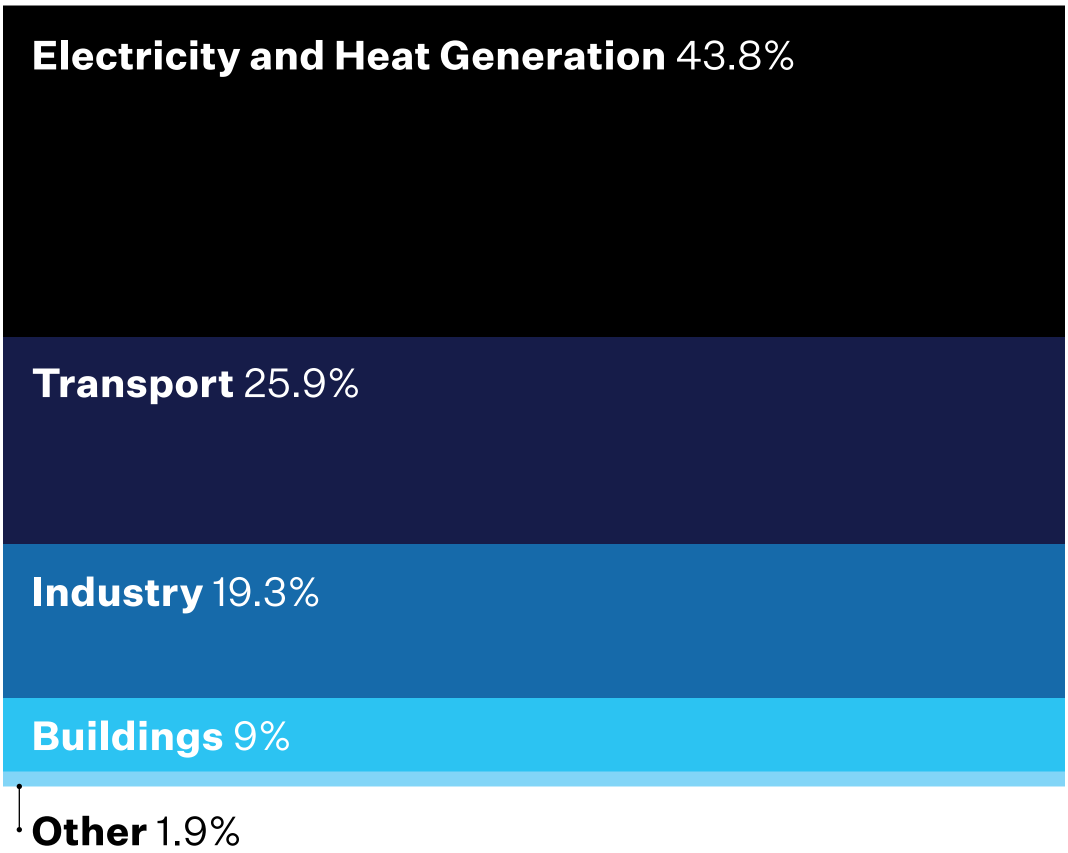
Wind and concentrated solar power (CSP) costs have fallen dramatically as well. In Dubai, the 700MW Solar CSP plant achieved an LCOE of 7.3 US cents per kWh. However, while it is increasingly realistic to imagine an energy mix dominated by renewables in the near future, there remain a number of gaps left by solar and wind and hydrogen will play an essential role in filling them.

The latest record was set in 2020 with a bid of just 1.35 US cents per kWh in Abu Dhabi for the 2GW Al Dhafra project.

DECARBONISING HEAVY INDUSTRIES

Hydrogen will play a particular role in decarbonising high-polluting heavy industries such as cement and steel production. Solar and wind struggle to deliver the required heat for such industries, while hydrogen burns at very high temperatures, making it a realistic, clean alternative to fossil fuels (Mathis and Rathi, 2020). In steel production, for example, which accounts for some 7–9% of global CO_2 emissions (World Steel Association, 2017), there are multiple ways in which green hydrogen can be used. For example, it can provide an alternative injection material to pulverised coal injection (PCI), which reduces emissions by up to 20%, or be used as an alternative reductant to produce direct reduced iron (DRI), which enables near carbon-neutral steel production, as long as the electricity used comes from renewables (Hoffmann et al., 2021).

Figure 8. Industry Accounts for a Fifth of the World's Annual CO_2 Emissions



Sources: Bloomberg, International Energy Agency

AVIATION AND MARITIME

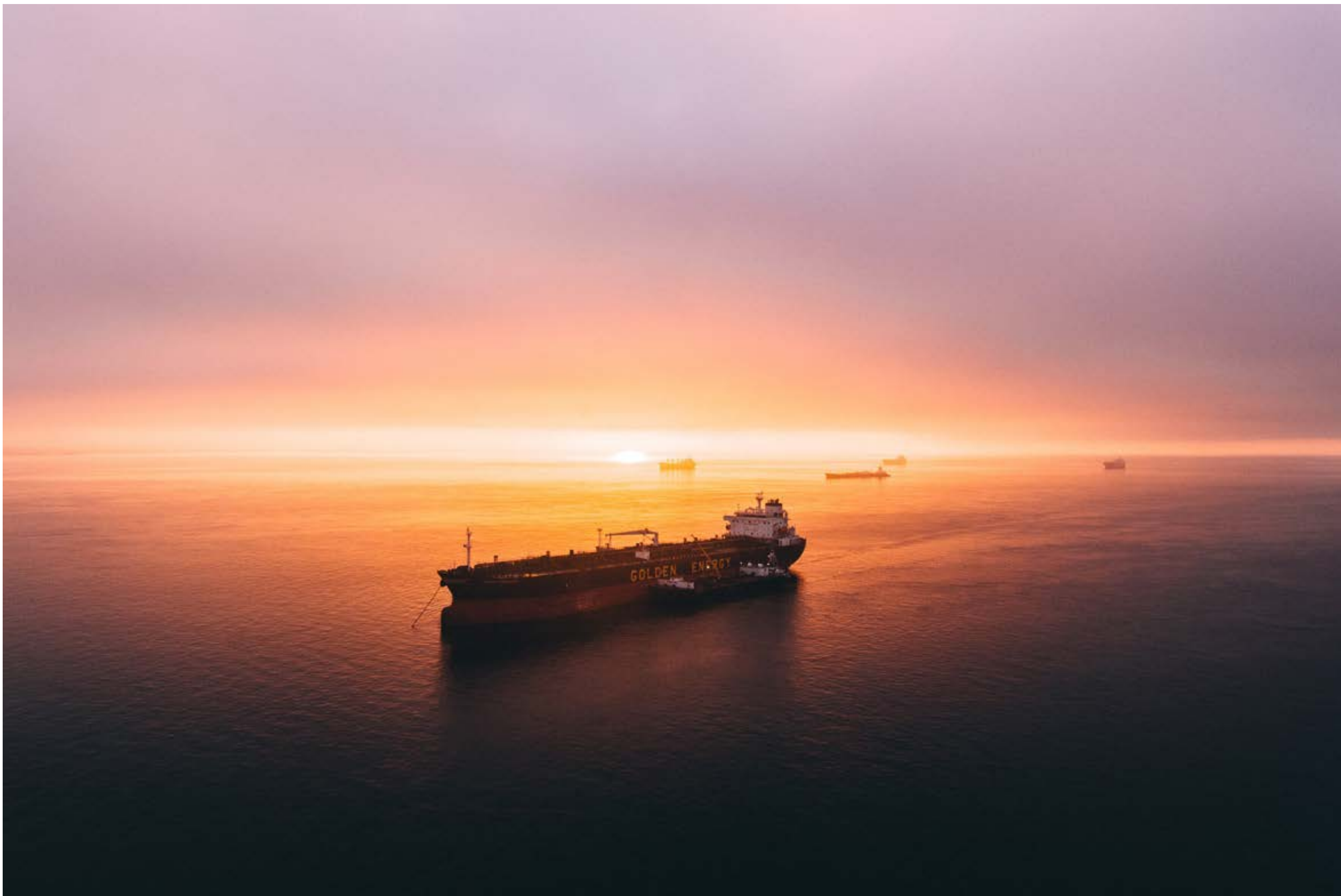
Due to its high energy by mass, hydrogen will also play a vital role in decarbonising industries where weight is a critical factor. Hydrogen has been the fuel of choice for rockets and the space industry for several decades and industries such as aviation and shipping now have the potential to switch to hydrogen-based fuels to lessen their impact on climate change.

Hydrogen is a particularly promising solution for aviation because it serves as a clean alternative to kerosene-based jet fuel, while weighing considerably less, excluding containment vessels. In fact, hydrogen's energy by mass is three times higher than traditional jet fuel (Airbus, 2020). However, it faces technical limitations such as the large amount of space taken up by hydrogen tanks, the weight of such tanks, high production costs, and the lack of infrastructure at airports.

Hydrogen can be used in fuel cells to produce electricity for propellers in smaller aircraft, or it can be used to power large jet engines. Airbus, for example, has announced that it may have its first hydrogen-fuelled passenger planes in service by 2035 (BBC News, 2020). One study estimates up to 40% of flights in Europe becoming hydrogen-powered by 2050 (O'Callaghan, 2019).

Hydrogen can also help reduce aviation emissions through synthetic fuels. Green hydrogen can be combined with captured carbon dioxide to produce synthetic jet fuel. Although consuming the synthetic jet fuel produces emissions, if the captured carbon dioxide used in producing the synthetic jet fuel is sourced from direct air capture (DAC) plants, the process becomes a net zero emissions loop.

Similarly, hydrogen can play a vital role in decarbonising the shipping industry, through fuel cells, combustion, or green-hydrogen-based ammonia. In considering low-carbon fuels for ships, ammonia is often preferred over hydrogen because of its high energy density, proven technology, ease and economy of storage, and an existing global distribution network.



EXPORTING SOLAR RESOURCES

The UAE and the Middle East benefit from excellent solar resources and declining solar PV costs, which the region has begun to take advantage of by developing large-scale solar parks. Solar energy can be converted and stored in the form of green hydrogen, which can be converted into liquid form and exported to other countries for clean electricity generation. Brunei and Japan have demonstrated this possibility recently by creating the world's first supply chain of internationally traded hydrogen.

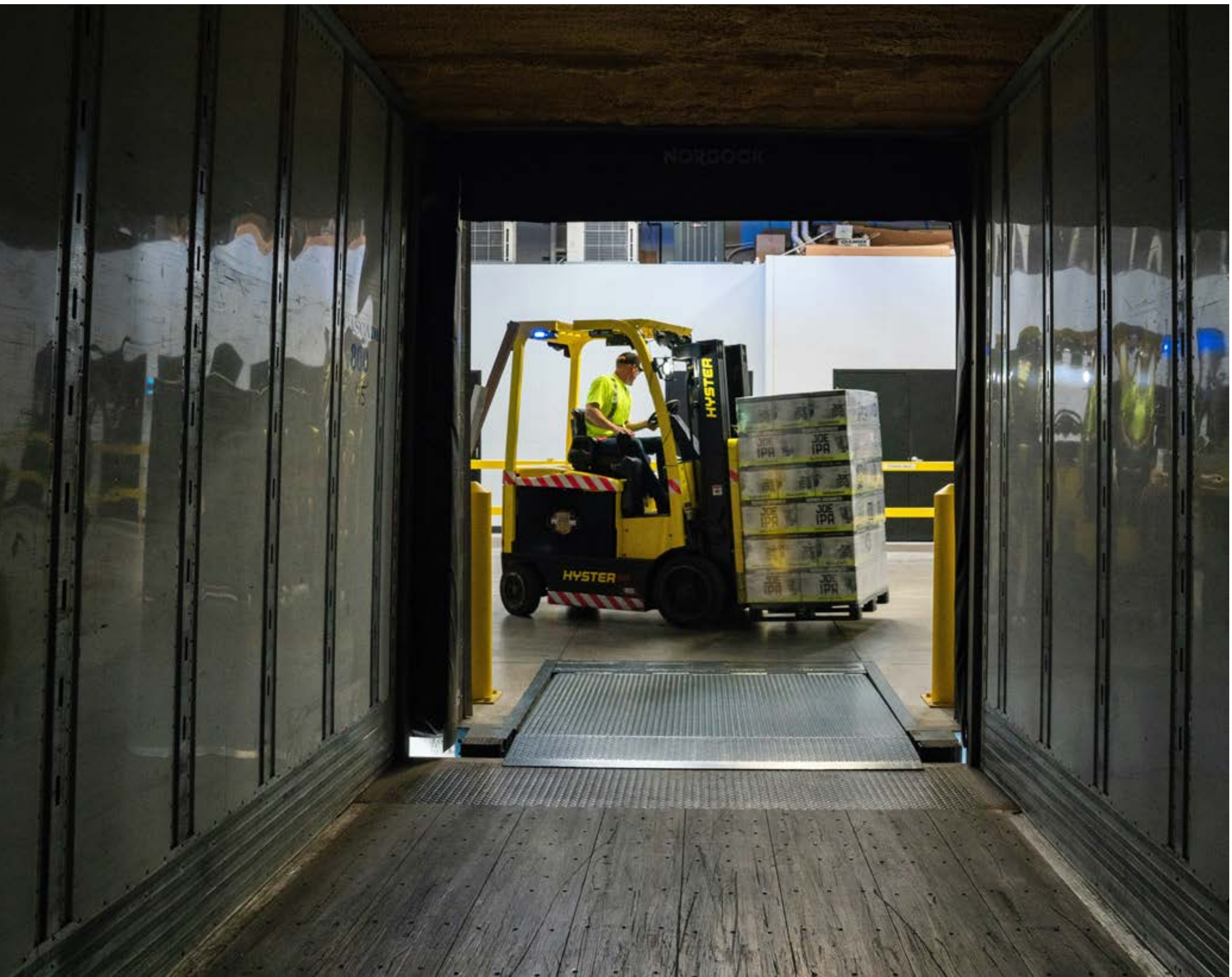
Instead of energy-intensive cryogenic liquefaction, they are relying on a hydrogenation reaction using toluene to create methylcyclohexane (MCH), which is liquid at ambient temperature and pressure, allowing existing facilities to be used for storage and transport. The hydrogen is extracted in Japan and used for electricity generation, then the toluene is transported back to Brunei for reuse in the hydrogenation process (Kumagai, 2020). Australia, the world's largest coal exporter, is also in discussions with Japan, aspiring to become the leading exporter of hydrogen.

ENERGY STORAGE AND ELECTRICITY GENERATION

Solar and wind-based electricity sources are intermittent in nature. Although battery storage is often the preferred method of storing energy from such intermittent sources for use when needed, hydrogen can act as an alternative medium, with the added benefit of transportability, providing the much-needed reliability and stability that renewables lack. For example, utility providers or relevant authorities can produce green hydrogen from excess solar power when there is a surplus and then released as the process is reversed to provide electricity during renewable generation’s downtime.

HEAVY GOODS TRANSPORT

Existing fuel cell technology already powers a large range of vehicle types, being most economical for heavy, lower-range vehicles such as forklifts and heavy goods vehicles. Development of the hydrogen economy will allow them to become economically competitive with both battery electric vehicles and internal combustion engines.



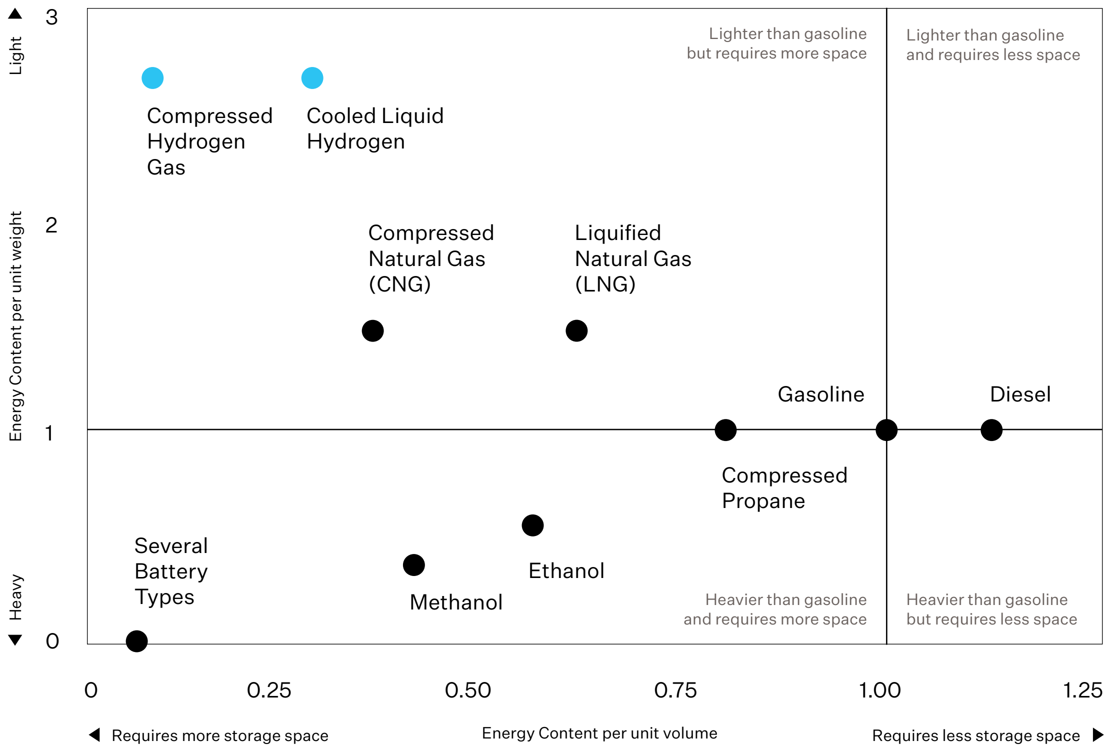
7.

OVERCOMING CHALLENGES

TRANSPORTING HYDROGEN

The energy content per unit of weight of hydrogen, also known as specific energy, is significantly higher than that of most other fuels. However, hydrogen possesses a naturally low level of energy density, or energy per unit of volume. For stationary applications such as energy storage for an electrical grid, energy density is less of a concern as hydrogen can be stored in large volumes underground in salt caverns or in depleted oil and gas fields (Bimbo, 2019). However, in terms of transporting hydrogen, whether for export or as a fuel, large storage vessels become impractical and hydrogen is therefore often compressed or liquified to increase its energy density.

Figure 9. Energy Density Comparison of Several Transportation Fuels (Indexed to Gasoline = 1)



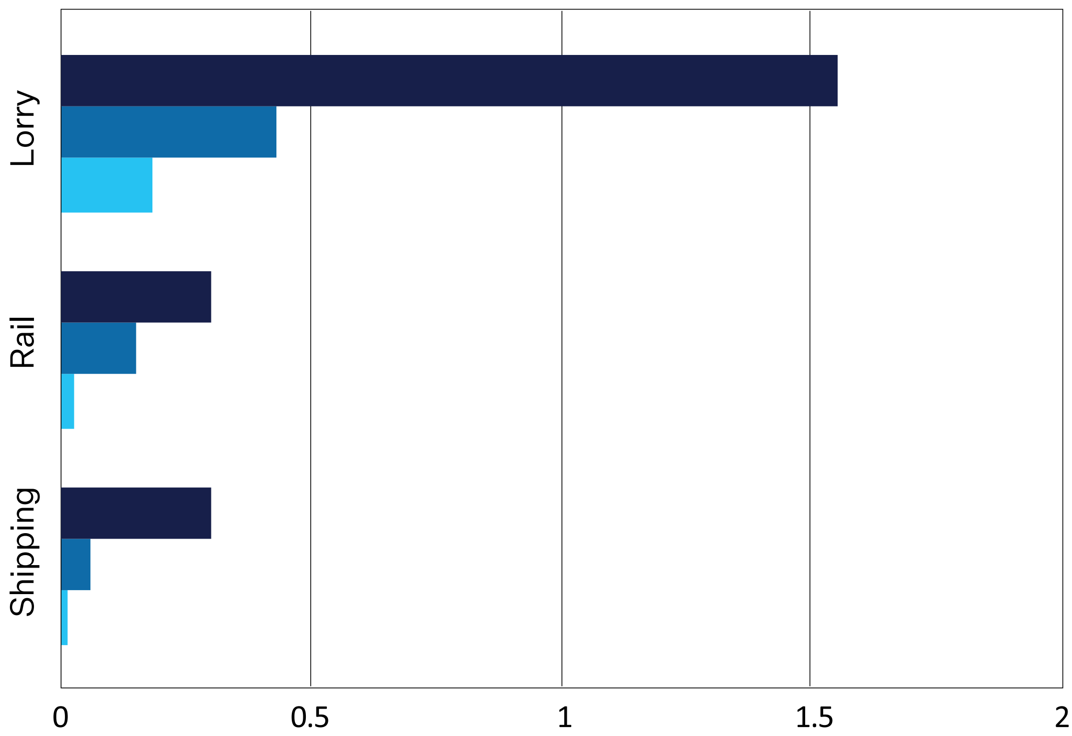
Source: U.S. Energy Information Administration

Such methods for increasing hydrogen's energy density are far from efficient, however, and transporting hydrogen remains a challenge. The liquefying process consumes 40% of the energy in the hydrogen and the compression process wastes about 20% (US Department of Energy, 2001). Other challenges include the need for safe storage tanks, which, in the case of compressed hydrogen gas, need to be capable of storing hydrogen at 5,000 psi and would weigh an estimated 65 times as much as the hydrogen they can contain (ibid.).

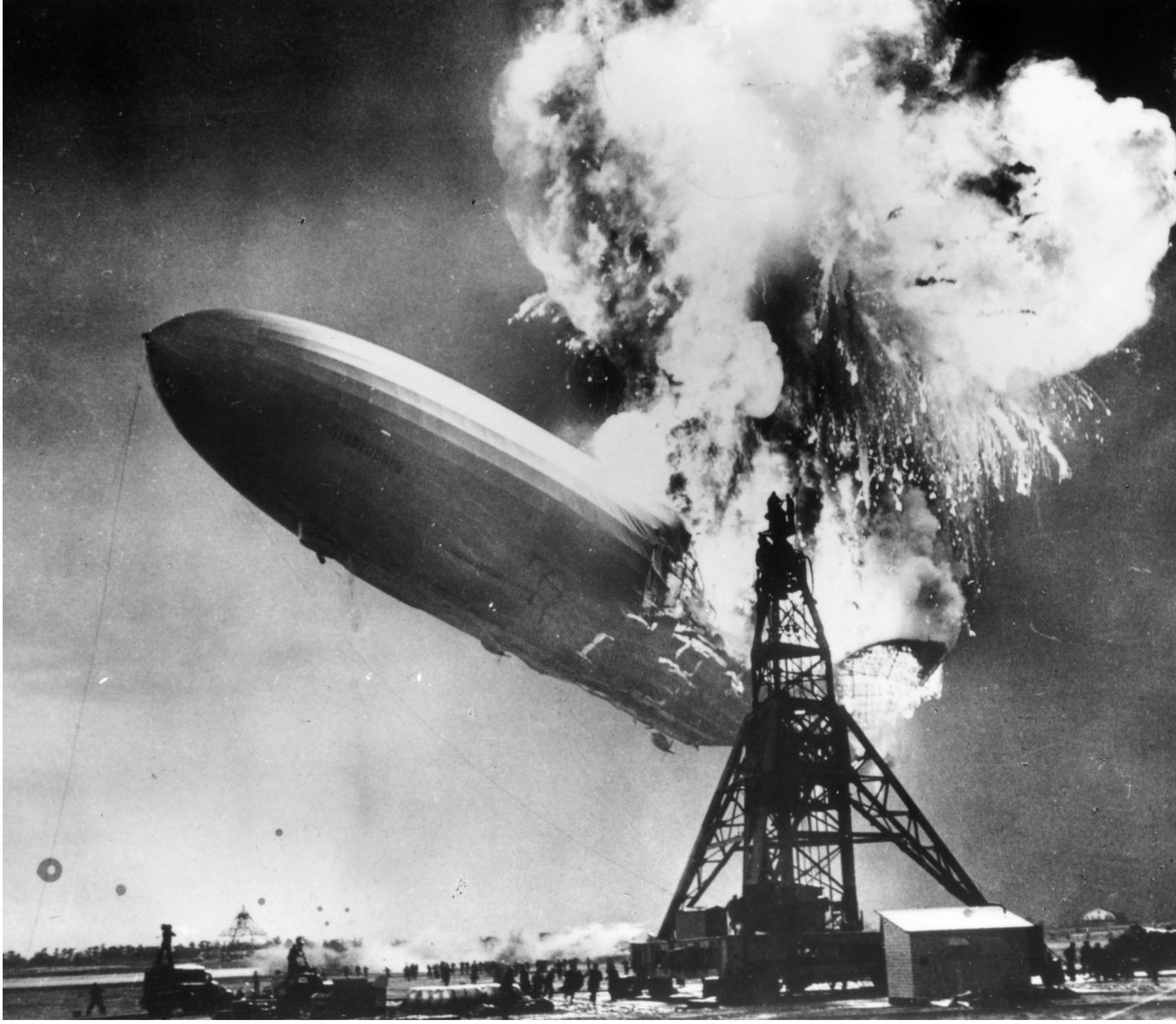
This challenge remains an area of opportunity for further research and development and there are several novel solutions being tested and implemented worldwide, including the chemical storage of hydrogen in the form of hydrides (Bimbo, 2019), the hydrogenation of organic molecules for use as liquid organic hydrogen carriers (Sampson, 2020), and the use of ammonia as a hydrogen carrier. Ammonia is easier to store and transport than compressed hydrogen gas or liquid hydrogen and contains 50% more hydrogen by volume than liquid hydrogen (The Royal Society, 2020).

Ammonia is easier to store and transport than compressed hydrogen gas or liquid hydrogen and contains 50% more hydrogen by volume than liquid hydrogen.

Figure 10. Estimated Costs for Transport of Hydrogen and Ammonia by Lorry, Rail, and Ship



Source: Royal Society



SAFETY

A discussion of hydrogen would not be complete without mentioning the ubiquitous imagery of the Hindenburg: this was a tragedy that formed an indelible mark on the popular understanding of hydrogen in aviation. The disaster is far more complicated than it appears but does indeed highlight the dangerous properties of hydrogen, which are summarised as follows:

> *In common with methane and propane, [hydrogen] is odourless, colourless and tasteless and although non-toxic and non-carcinogenic can act as an asphyxiant. With regard to the present discussion, however, the more important hazards of hydrogen are its ready flammability, a frequently invisible, high temperature flame and its eagerness to burn or form explosive mixtures with air.*
> (Ricci *et al.*, 2006)

This highlights legitimate concerns for public safety and the risks associated with producing and using hydrogen. The issues associated with hydrogen have been known to science for decades and have been addressed accordingly, as is illustrated in the following excerpt:

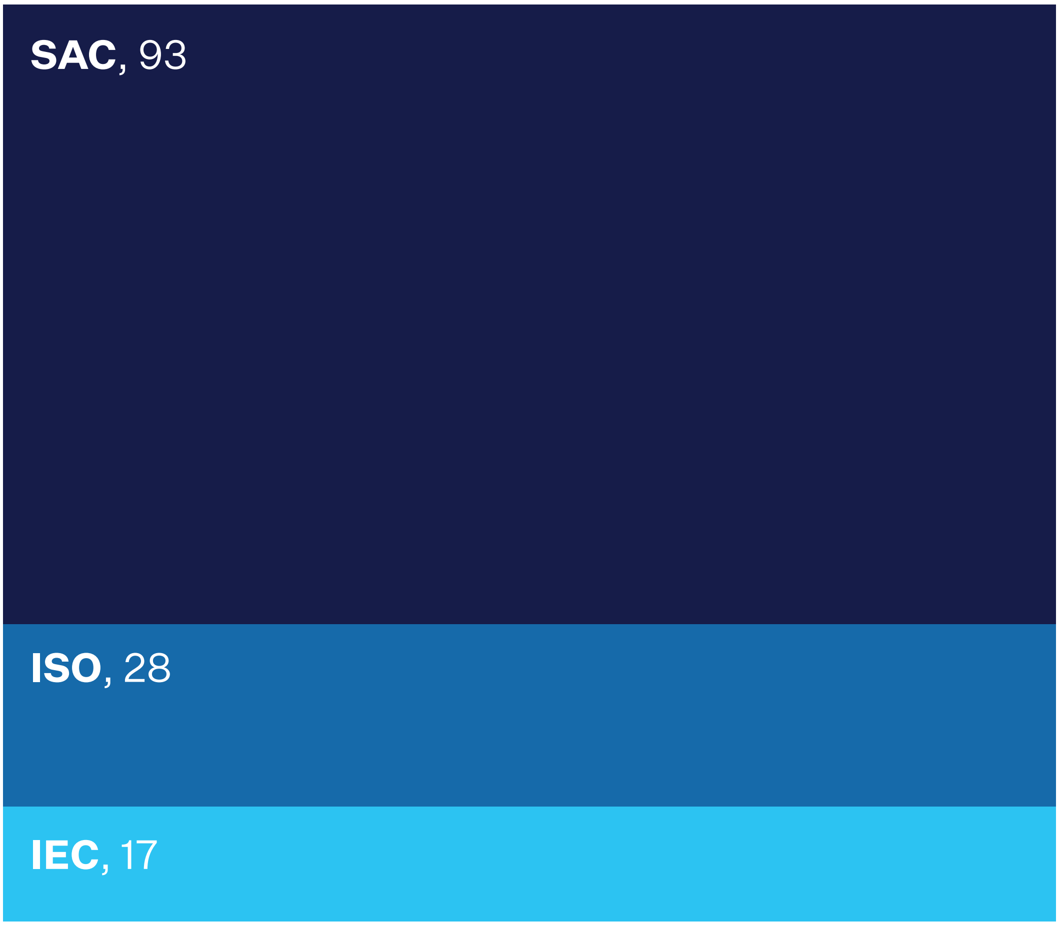
> *The likelihood of the devastating effects of a hydrogen detonation occurring is, however, heavily dependent on the physical environment of the release. Many of the controlling influences are already well known and a lot of work focused on anticipated hydrogen economy installation and applications is current underway or planned. Consequently, provided that the risk from detonation is recognised, understood and respected, it should not prove to be a major factor in the risk profile for hydrogen.* (ibid.)

Additionally, this is reinforced in the emphasis on the 'significant financial resources have been spent on hydrogen energy research and development globally' (Kolodziejczyk and Wee-Liat, 2019) since 2008 in order to improve safety practices and technological advancement. Resources have been specifically dedicated to improving fuel cell design and transportation – a leading concern for safety (Forsythe, 2019; Tae, 2021).

CERTIFICATION AND STANDARDS

As an emerging technology, the fuel hydrogen production sector – especially for blue or green hydrogen – is subject to an incomplete patchwork of safety, quality, and technical standards. For instance, the certifying bodies across major potential export markets – the Standardization Administration of China, the global Switzerland-based International Organization for Standardization (ISO), and the EU's International Electrotechnical Commission (IEC) – vary dramatically in the number and detail of their standards for hydrogen and hydrogen technology, with China implementing 93 separate standards for the industry, the ISO 28, and IEC 17.

Figure 11. Number of Chinese, ISO and IEC Hydrogen Standards



Source: China National Institute of Standardization

While many of these standards delineate technical specifications for consumer equipment, some are crucial to hydrogen exporters. Chinese SAC standard GB/T 37244-2018 specifies purity requirements for hydrogen used in fuel cell vehicles, with ammonia contamination limited to one part per 10 million and overall purity set at 99.97%. EU standards are still being formulated, but Italian manufacturers are lobbying for a 99.999% hydrogen purity requirement (HyLaw, n.d.).

In addition to purity standards, safety standards have an impact on hydrogen producers and transporters. The US Department of Energy, partly responding to safety concerns raised by the 2019 hydrogen explosion at the hydrogen fuelling site at Santa Clara, is formulating guidelines and requirements for hydrogen fuel, including potentially the addition of odorants and colourants to assist in identifying fuel leaks.

The European Union has convened a hydrogen safety panel to develop and propose standards for hydrogen and fuel cell projects, while the ISO has 15 hydrogen-related standards under development through ISO/TC 197, the technical committee on hydrogen technologies (the UAE is not represented in either body as member or observer). These standards will determine market access for key economies and may effectively serve as non-tariff barriers to keep sub-standard hydrogen fuel from entering national markets.

As decarbonisation gains in importance for consumers of fuel hydrogen, green energy certifications will increase in importance for market access. The European Union has already issued two directives on promotion of renewable energy sources – RED I and RED II – with requirements for energy producers to provide guarantees of origin (GO) certificates documenting the renewable or low-carbon source of that energy. Through the CertifHy process, this certification system is being applied to blue and green hydrogen. Any blue and green hydrogen producers in the UAE should ensure they are able to comply with the certification requirements because without appropriate GOs their hydrogen will not receive emissions reduction credit and would risk incurring extra charges or exclusion from the EU market.

8.

HYDROGEN STRATEGIES GLOBALLY

The economic, technological, and ecological potential of hydrogen as an energy source has been broadly accepted by a range of national governments and major corporations. While the sector – especially green hydrogen production from renewables – remains largely notional, with the few existing facilities primarily serving research or demonstration functions, a number of significant international economies have developed detailed and ambitious plans for large-scale hydrogen production. These economies will be the major players and the UAE's potential competitors in a global hydrogen economy where a competitive trading market is set to emerge in the near to medium term. The potential markets are covered in detail below.

GCC countries have great export potential

Figure 12. Green Hydrogen Production, Domestic Consumption, and Export Potential

Source: Strategy& (PwC)

The list below is not exhaustive but summarises the publicly announced plans of countries most relevant to development of the UAE's hydrogen sector.

SAUDI ARABIA

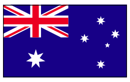
Recognising the vulnerability associated with its economic reliance on oil exports, Saudi Arabia has opted to leverage its experience in the global energy trade to assertively move into both blue and green hydrogen production. It benefits from advantageous production conditions, encompassing some of the most favourable locations for wind and solar energy as well as holding the world's fifth largest domestic natural gas reserves and extensive energy infrastructure and trading relationships.

Saudi Arabia has already begun its hydrogen transition. In September 2020, Saudi Aramco executed the first international shipment of blue hydrogen, delivering 40 tons of blue ammonia by tanker to Japan from production facilities in the Arabian Gulf. This pilot project is part of a larger Saudi–Japanese partnership to develop ecologically acceptable energy sources to feed a decarbonising but still energy-intensive Japanese economy.

The planned city of Neom along the Red Sea coast in north-western Saudi Arabia is the cornerstone of the Saudi green hydrogen strategy. The $500 billion project to construct a 170km long urban environment in an empty desert area incorporates hydrogen power as a major fuel source for transportation and infrastructure, and includes a 4GW green hydrogen production site, the Helios Green Fuels Project, designed to produce around 240,000 tons of hydrogen per year with first production planned for 2025 (MEED, 2021).

Neom also benefits from its location, with optimal sites for renewable energy untethered to existing oil infrastructure. With Neom, Saudi Arabia would start to shift the centre of its export energy production from the Arabian Gulf to the Red Sea, reducing shipping distances to Europe by 2,000 nautical miles (nm) (The Motorship, 2021).

As ambitious as Saudi plans are, construction on the Helios Green Fuels Projects has not yet begun and the entire Neom project remains in the planning stages. While Saudi Arabia has great potential, its strategy remains vulnerable to sudden shifts in economic or political conditions. Furthermore, depending on the speed of the development and growth of Neom, domestic hydrogen demand may undercut the country's export capability, as has been the case with the development of its natural gas resources.



AUSTRALIA

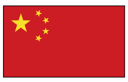
Due to the vast, arid expanse of its desert regions, Australia has some of the most advantageous locations for green energy production in the world, while also benefiting from a technologically advanced energy- and resource-extraction economy, leaving it well placed to quickly develop a green hydrogen sector. Australia has domestic natural gas deposits for viable blue hydrogen, but their location offshore from Australia's sparsely populated and underdeveloped north-west coast makes blue hydrogen production less attractive economically due to high cost and lack of infrastructure.

Australia published its National Hydrogen Strategy in 2019, anticipating a study-and-scale-up period until 2025 prior to commercial hydrogen production and export. Like Saudi Arabia, Australia's low production costs make developing a large-scale export industry attractive. Optimum locations for green hydrogen production are abundant across Australia, but most projects are concentrated in the north-west, far from Australia's population centres but closer to key export markets in Asia.

Australia has actively partnered with Japan and, to a lesser extent, South Korea to jointly develop Australian hydrogen potential to fill anticipated Japanese and Korean demand.

The largest single green hydrogen project in the world is located in north-western Australia. The Asia Renewable Energy Hub is based in Pilbara, a designated region within the state of Western Australia over five times larger in area than the UAE (510,000 km^2 vs 83,600 km^2) with no major cities and a population of less than 70,000. The Asia Renewable Energy Hub has a planned capacity of 26GW with a potential output of 1.75 million tons of hydrogen per year for conversion to green ammonia for shipment to Asian buyers. Additional export-oriented projects include the Murchison Renewable Hydrogen Project, also in Western Australia (5GW, approximately 300,000 tons of hydrogen), Pacific Solar Hydrogen in Queensland (3.6GW, 200,000 tons), and H2-Hub Gladstone, also in Queensland (3GW, 160,000 tons). Smaller projects in New South Wales are in development largely to address domestic demand.

Australian hydrogen production enjoys strong support from the federal government as well as state governments, matching national priorities for decarbonisation and economic diversification away from China-bound exports and regional development. Projects remain largely in planning stages, still pending government approval and final financing, with the Asia Renewable Energy Hub having to revise its plans following an initial rejection. Australia is unlikely to abandon its hydrogen strategy, but may also find that initial plans and timelines were unduly optimistic.



CHINA

China’s hydrogen strategy, focusing extensively on consumption of hydrogen fuel and its use as a replacement for fossil fuels for the domestic sector, differs from those of Saudi Arabia and Australia.

While hydrogen production is a priority in China's approach, greater emphasis is placed on the development and roll-out of hydrogen fuel cell technology and the integration of hydrogen fuel into heavy industry. China's considerable hydrogen production potential, especially in producing green hydrogen in Xinjiang, Tibet, and Inner Mongolia, will struggle to keep up with projected domestic demand, most likely leaving a hydrogen deficit at least for the short to medium term.

China was an early proponent of the potential of hydrogen. Plans on developing hydrogen and fuel-cell related technologies were included in its national Science and Technology Development outline (2006–2020) and integrated into its national energy technology plan issued in 2016. Hydrogen continues to feature in China's strategic economic planning. By 2050, hydrogen is expected to make up 10% of total energy supply, with an estimated demand of 60 million tons, representing an annual outlay of over 1 trillion RMB ($154 billion) (Integral, 2020). China has plans to deploy hydrogen across its economy. In the transport sector, it has a target of over 10,000 fuelling stations in a nationwide network, 5.2 million fuel-cell cars sold per year, and 5.5 million fuel-cell batteries produced annually. In addition to national-level targets, provincial policies also emphasise the development of hydrogen with dedicated industrial zones for hydrogen products, 17 of which constitute a cluster around Shanghai. China seeks to profit from international markets for hydrogen products rather than hydrogen fuel itself.

The largest Chinese production site, the Beijing Jingneng Power Company's plant in Inner Mongolia, is scheduled to be the first green gigawatt-scale electrolyser plant to come online, with an estimated operational start in 2021. Eventually set to operate at 5GW with a production potential of approximately 500,000 tons of hydrogen per year, its success would mark the start of a new hydrogen economy and establish China as an early leader. Despite the scale of this green project, China plans to continue production of grey and brown hydrogen through the medium term to address expected demand.

China has demonstrated its ability to follow through on ambitious development projects and has committed significant political capital to the success of its hydrogen sector. Furthermore, the size and position of the Chinese economy allows it to influence other important players, such as Japan and South Korea, both Asian neighbours seeking to stay technologically relevant and large exporters breaking into the Chinese market. Early success for China would put pressure on Dubai to move rapidly on its own hydrogen strategy as well as increasing the likelihood of a large-scale global shift towards hydrogen as an energy carrier.

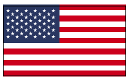
EUROPEAN UNION

The European Union, like China, is aggressively pursuing a shift towards hydrogen as a major carbon-neutral fuel alternative for transportation and, especially, for industry. It differs from China largely in having relatively disadvantageous characteristics for hydrogen production. The EU is a major importer of conventional fuels, with a particular reliance on natural gas imports from Russia and the former Soviet Union. Blue hydrogen production would require additional gas imports to serve as feedstock, undercutting the benefits of local hydrogen production. In terms of green hydrogen production, most of the continent is relatively unfavourable to renewable energy compared to the UAE. While wind and solar have played an increasing role in electricity generation, the regional climate limits their growth. Meanwhile, domestic energy demand, especially in the context of increasing pressure on carbon-emitting fuels, incentivises direct use of renewable energy rather than conversion into green hydrogen.
As such, the EU recognises that it will need to import hydrogen to meet the demand created by its decarbonisation plans (FCH, n.d.).

To meet its import needs, the EU has identified North Africa and Ukraine as production partners. While there is an economic rationale for these selections, Algeria, in particular, has optimum conditions for green and blue hydrogen production. It currently serves as a major natural gas supplier to the EU, with pipeline infrastructure connecting its fields to EU markets. Similarly, the solar conditions in Algeria have the potential to make it one of the lowest-cost producers of green hydrogen in the world, with scale-up and transportation facilitated by existing gas infrastructure. Ukraine does not have the green hydrogen potential of Algeria, but it could become a significant producer of blue hydrogen through the exploitation of offshore fields and shale gas deposits. However, despite the identification of these potential sources for EU hydrogen imports, there is cause for scepticism as to whether they will be able to fulfil that role. Large-scale hydrogen projects have not been undertaken by either Algeria or Ukraine and both countries would require substantial investments to develop their hydrogen sectors and modernise infrastructure ahead of any large-scale exports to the EU. Their selection stems more from EU political priorities in the region, which would benefit considerably from stabilisation and economic growth at its periphery, rather than the practical feasibility of Algeria and Ukraine supplying the EU market.

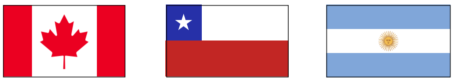
EU adoption of hydrogen technology is subject to the same political uncertainties as elsewhere, but decarbonisation is a priority broadly shared by political leaders across the EU ideological spectrum, and the extent of planning and funding at both EU and national levels implies a firm commitment to the technology. Successful EU hydrogen adoption will likewise create pressures on regional neighbours and other developed economies to follow suit or risk technological irrelevance, while also reducing the costs of imposing carbon pricing as low-carbon technology and green hydrogen costs decline. Extension of hydrogen to developing countries could be hastened by incorporating the technology into EU international development strategies.

Successful adoption in both the EU and China would likely to be sufficient to force a global shift even if other major economies lagged or resisted the hydrogen transition.



UNITED STATES

Recently, the US announced a target to lower the cost of production of clean hydrogen to $1 per kg by 2030 (NS Energy, 2021). However, due to simple geography, even with rapid hydrogen technology uptake, the United States is unlikely to be a significant market for UAE hydrogen. It will most likely meet most of its hydrogen demand from domestic production and the balance through imports from regionally optimal producers in the Americas, notably Canada, Chile, and Argentina. The US contains several regions that are optimal for green hydrogen production as well as sufficient natural gas deposits for blue hydrogen production.



CANADA, CHILE, AND ARGENTINA

In the Western hemisphere, the most significant potential market for fuel hydrogen is the United States. Other major economies in the Americas are relatively less developed technologically and economically (Brazil, Mexico) or contain abundant domestic hydrogen production potential (Canada). Chile and Canada both have introduced hydrogen production strategies to capitalise on their positional advantage, but these are unlikely to have an impact on Dubai’s strategic and economic environment. The cost of transport and limitations on early-stage production are set to ensure that their production will be geared towards the US market.

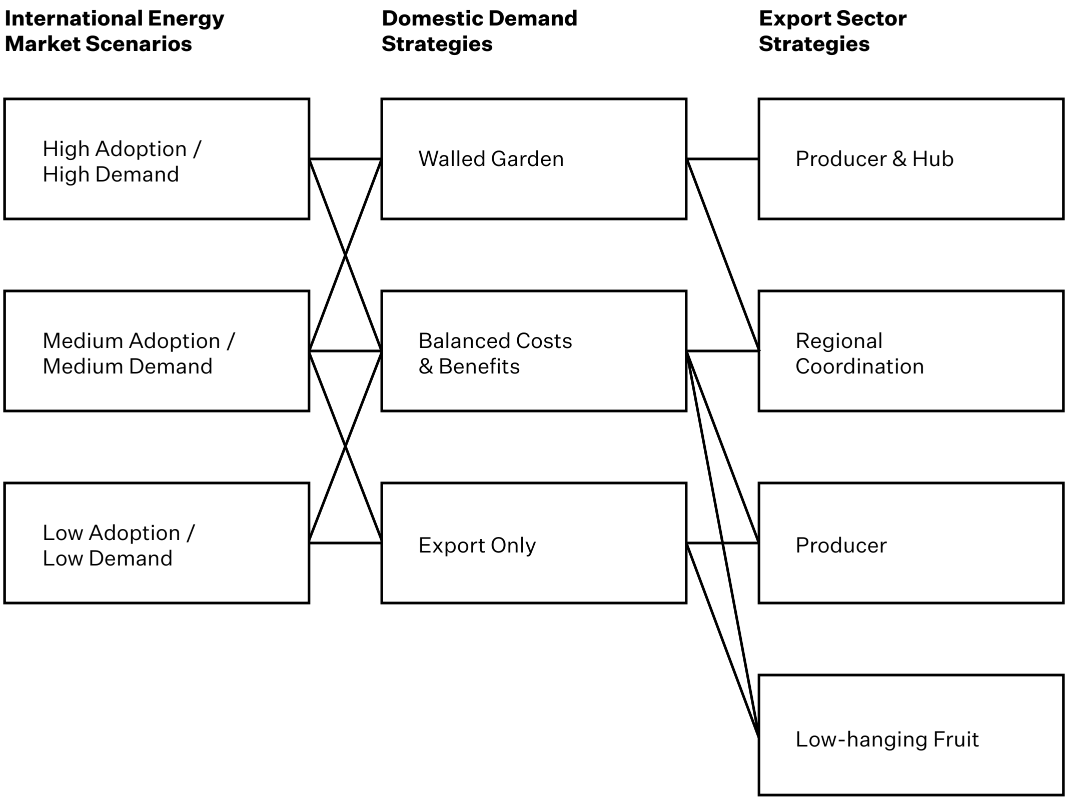
9.

FUTURE OF HYDROGEN FOR THE UAE

To understand the potential of hydrogen production and trade for the UAE, this report combines data modelling with a scenario approach to categorise, estimate, and evaluate possible outcomes. The framework consists of three layers: the first represents different scenarios for the world economy; the second shows different policy approaches in the UAE's domestic hydrogen sector; and the third shows different policy approaches for the UAE's hydrogen export strategy. The two upper layers therefore set the international and domestic context and conditions for the investments and policy initiatives that make up the UAE's export strategy, which will be critical in determining the country's role in a future global hydrogen economy.

Lines represent affinities between scenarios and strategies. Strategies are optimised for anticipated market conditions, with certain market conditions being conducive to certain strategies while others dramatically reduce the likelihood of achieving strategy objectives.

Figure 13. Hydrogen Adoption and Demand Scenarios



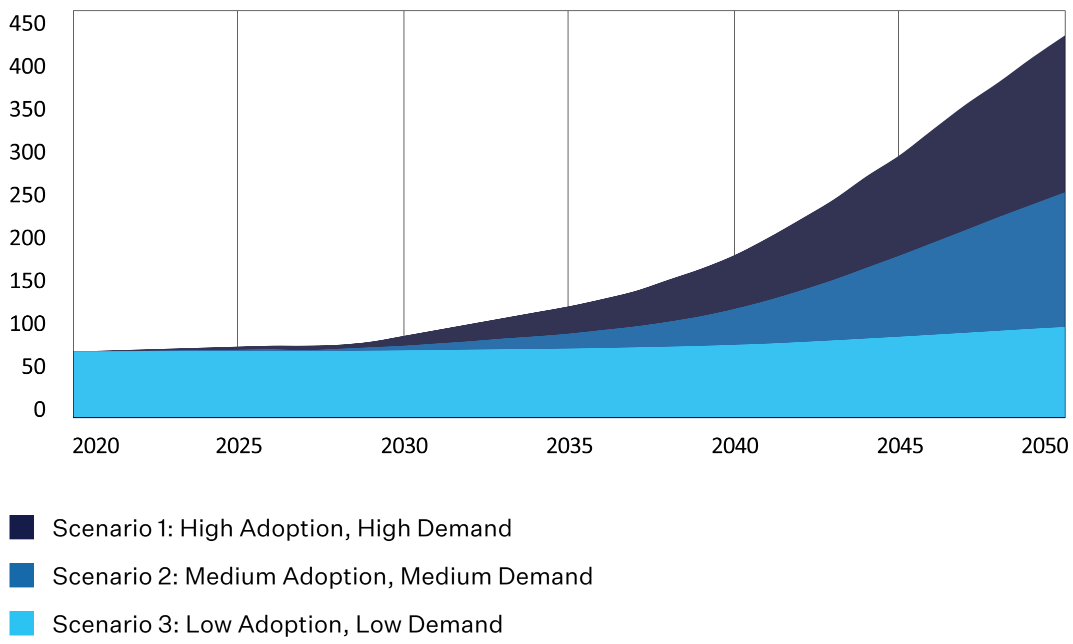
INTERNATIONAL ENERGY MARKET SCENARIOS

These scenarios describe the evolution of the international energy market in terms of its uptake of hydrogen. Those market conditions are exogenous to the economy of the UAE and minimally influenced by diplomatic or political action carried out by the UAE. They consist of baseline assumptions incorporated into the quantitative model regarding international hydrogen demand and pricing. The three scenarios represent a pessimistic, a moderate, and an optimistic future for hydrogen adoption. There are too many unknowns to accurately assign precise probabilities to each scenario and the UAE cannot wait for the situation to clarify before crafting its own policy. As is often the case, decision makers will have to operate with incomplete information in determining what they consider the most likely trajectory for the international hydrogen economy.

Optimising a strategy for managing the emergence of a hydrogen energy sector represents a formidable challenge. New technologies represent a discontinuity from existing models and trends, characterised by non-linear effects for price and output. Efficiencies will depend on the extent of adoption, scale of investment, and breadth of interoperability. There are also uncertainties around the success of R&D efforts and achievement of economic targets. Perfect clarity around future developments is impossible and assumptions must be made regarding the future economic context in which the UAE's hydrogen strategies will play out.

An effective hydrogen strategy will depend on building on Dubai and the UAE's position as an international financial, trade, and logistics hub, adapting their positional advantage to the particular needs of the emerging hydrogen energy economy. Economic benefits to the UAE will depend on exporting hydrogen to the international market, including hydrogen produced in the UAE and potentially in GCC partner economies. Energy exports, however, are just a single facet of the potential gains from the hydrogen sector – strategic policy choices may also allow the UAE to benefit from hydrogen infrastructure development, financing, and R&D. However, all of these gains will depend on successfully adapting to the international economic environment and fostering mutually beneficial relationships with neighbouring producers, energy importers, and hydrogen technology leaders.

Figure 14. Global H2 Demand by Market Scenario



Source: Dubai Future Foundation

In order to clarify the choices facing the UAE in responding to the maturing of the global hydrogen energy industry, three possible scenarios trajectories for the global industry are presented below:

High Adoption, High Demand

In this scenario, breakthroughs in hydrogen technology, both in production and in application, together with coordinated global efforts to decarbonise, produce a rapid acceleration of hydrogen adoption in the short to medium term, reconfiguring global energy markets around hydrogen energy sources. Representing the most optimistic scenario based on projections from the Hydrogen Council (Bauer, 2021), this involves not only the fulfilment of existing national strategies but accompanying adoption by consumers and private industry. Either to address climate change concerns or to seize on long-term economic efficiencies, public utilities and governments at every level accelerate investments in hydrogen infrastructure, with those developments driving changes in consumer choices in a virtuous circle. Through integration with renewable electricity infrastructure, hydrogen energy becomes a globally significant strategic commodity and large-scale phase out of fossil fuel consumption becomes feasible. As the global hydrogen economy emerges, any volume of exports can be absorbed.

Medium Adoption, Medium Demand

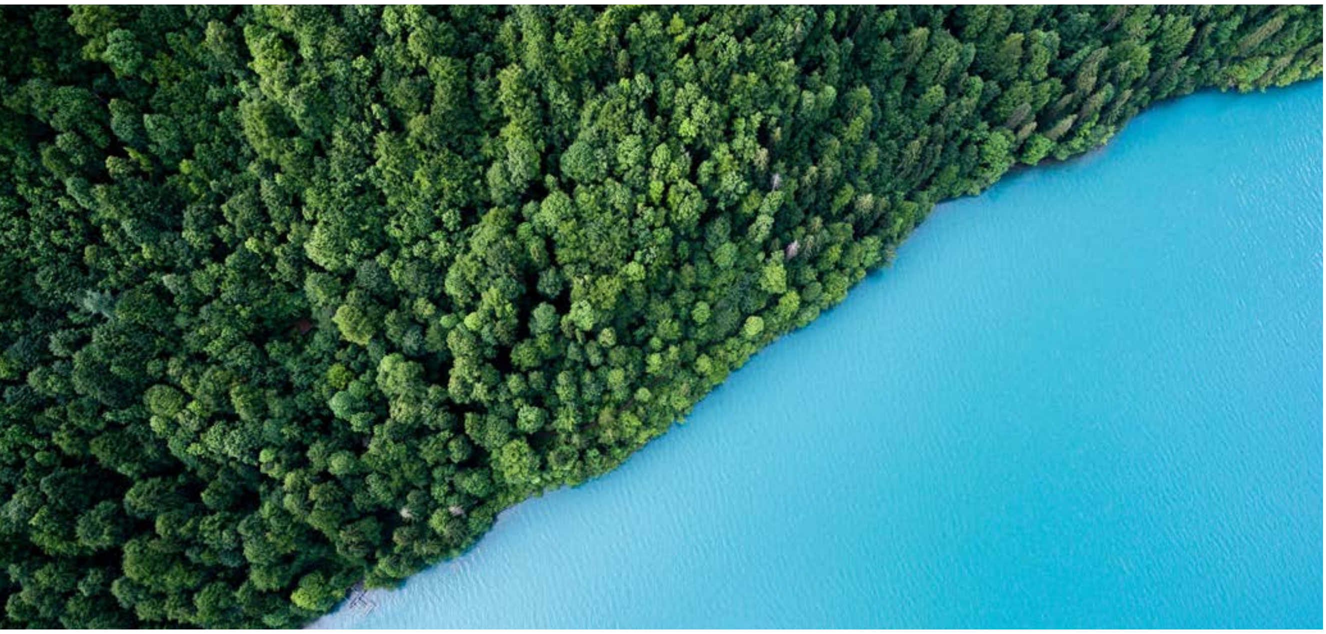
This scenario assumes that most of the existing national hydrogen strategies proceed apace, technological breakthroughs produce increased efficiencies, global carbon policy develops favourably for hydrogen, and adoption of hydrogen technology occurs at anticipated rates, facilitated by government incentives in major markets. National governments fulfil their targets for the purchase of fuel cell vehicles, while mandates for manufacturers and incentives for consumers dramatically increase private-sector sales. Heavy industry responds to decarbonisation pressure by investing in hydrogen as a heat and power source for industrial processes while cities and regions gradually shift to a hydrogen-based heating infrastructure. Hydrogen represents a competitive means of energy storage for solar and wind renewables. Hydrogen matures as a major global energy source, although fossil fuels still play a significant role while other alternative technologies compete in tandem. As hydrogen becomes a cost-effective fuel, the global market absorbs increasing quantities.

Low Adoption, Low Demand

This scenario reflects the fact that, while many major economies, including global heavyweights such as China, Japan, and the European Union, have developed and begun to implement hydrogen strategies with the twin goals of decarbonising their economies and fostering new energy technology, the global energy sector has yet to cross an inflection point beyond which the success of hydrogen is inevitable. Political, economic, and technological challenges, both within and external to the hydrogen industry, may delay adoption or undermine the economic viability of hydrogen as an energy source. In this scenario, hydrogen remains a niche fuel and an experimental technology with other energy sources – traditional and/or other alternatives – dominating the international market.

VARIABLES – DRIVERS OF GLOBAL DEMAND

The actual course of the hydrogen economy will depend on policy decisions on a few key areas of the energy markets:



Carbon Pricing

As the impact of climate change becomes visible and the evidence for anthropogenic global warming mounts, international organisations and governments in leading economies face increasing pressure to control carbon emissions and stabilise global temperatures. While existing international agreements have relied on developed countries voluntarily setting targets for emissions reductions, they have also introduced some basic elements of a global carbon emissions price. Through the flexible mechanisms embedded in the Kyoto Protocol, countries could exchange carbon emissions credits, with a net emitter offsetting its carbon footprint through carbon reduction credits purchased by supporting projects based in another country. These have included reforestation, emission reduction in existing activities, and the replacement of polluting industries with lower-emission technology.

Some national governments have adopted emissions trading programmes that cap carbon emissions at specified levels and allow industries to trade in emissions credits. Such programmes attempt to introduce limits on overall carbon emissions through market mechanisms that dynamically price emissions. An international market has also developed for private sector carbon offsets whereby companies or organisations fund carbon mitigation projects to help meet their targets for emission reductions.

Some national governments have adopted emissions trading programmes that cap carbon emissions at specified levels and allow industries to trade in emissions credits.

Net Zero Commitments

Currently 28 countries have announced plans to achieve net zero carbon emissions in the medium term. Of these, 2 – Suriname and Bhutan, both with unique ecological and demographic characteristics – have achieved net zero emissions, 6 have embedded their plans in national law and 6 more have proposed legislation to that effect, with the remaining 14 still developing plans to meet their announced targets. The countries involved include economic superpowers such as China, the EU, and Japan and major developed economies such as South Korea and Canada. While China gives itself until 2060, most net zero commitments have a 2050 deadline and a few are even more ambitious. If even half of these states treat their commitments seriously, their actions will validate more aggressive projections for hydrogen technology adoption as an essential near- to mid-term economically and technologically viable clean energy source. In addition to producing competitive pressure on countries yet to commit to net zero plans – the lack of a US plan being a particularly glaring omission – the large-scale adoption of hydrogen energy to enable net zero goals creates a strategic imperative to adopt new technology or face energy obsolescence.

Public Hydrogen R&D

Environmental concerns and technological adaptation goals will determine global levels of hydrogen fuel demand, but whatever the appetite for hydrogen fuel adoption, successful uptake will depend on technological innovation at all stages of the hydrogen economy, including more efficient electrolysers, cheaper solar power for green hydrogen production, effective techniques for safe and economical hydrogen transportation (especially across long distances), and pioneering new applications for hydrogen fuel, not only as a replacement for fossil fuel technology but for possibly novel consumer and industrial uses as well. While the pace of innovation is difficult to predict due to non-linear impacts of breakthrough technologies and the uncertainties inherent in R&D, progress depends on growing R&D funding.

Publicly funded R&D is an essential element in the maturation of hydrogen technology. The private sector specialises in technology that can be easily commercialised as it is already close to maturity and in iterative innovation of technologies already integrated into businesses' production chains. Basic research and other loss-making upstream innovation thus rely on public funding. While the level of R&D announced in national-level hydrogen strategies is sufficient to progress the sector, reversals to commitments are possible. These can be triggered by a variety of causes – sudden economic downturn, financial crisis, change in political leadership, or changes in energy economics.

Public R&D funding for hydrogen has collapsed before. The sudden fall of oil prices together with the global financial crisis in 2008–9 led to lower hydrogen-related R&D, marked by moderate initial cuts followed by a particularly steep drop in 2011, largely stemming from US budget policy. Dubai has traditionally relied on foreign research for technological innovation and would be unable to unilaterally mitigate a steep decline in global hydrogen-related R&D. Although geo-political or economic shocks could drive such a decline it is less likely today than a decade ago given the commitments made by governments and investments made by governments and companies.

Whatever the appetite for hydrogen fuel adoption, successful uptake will depend on technological innovation at all stages of the hydrogen economy.

Hydrogen Uptake Planning

National strategies include ambitious targets for the purchase and introduction of hydrogen technology across numerous sectors and economies. Hydrogen fuel has been integrated into EU, Chinese, South Korean, and Japanese plans for developing renewable green electricity, decarbonising heavy industry, providing heat and power to homes and public buildings, and replacing fossil fuels in transportation from trains and heavy goods vehicles to passenger cars. South Korea is already experimenting with urban-scale rollout in the development and redevelopment of towns and cities, and China continues to aggressively introduce EVs into its public transportation fleets. Multiple major economies have set ambitious targets in the millions for FCEVs in the medium term. The realisation of a future hydrogen energy economy depends on the successful fulfilment of these plans with outcomes strong enough to continue the momentum of hydrogen adoption.

The global spread of hydrogen sector planning helps reduce the risk of failure by avoiding reliance on a single source of demand, but aggressive commitments to new technologies – and hydrogen specifically – have failed to materialise into practical change at significant scale. For example, in 2004 California rolled out an initiative to develop a 'Hydrogen Highway' of state-wide refuelling stations and continues to offer a rebate of up to $7,000 for the purchase of hydrogen fuel cell vehicles. The governor at the time, the former actor Arnold Schwarzenegger, launched the programme by using a special hydrogen-fuelled Hummer H2H as his personal vehicle, investing substantial political capital into the programme. To date – over 16 years after the Hydrogen Highway launched – only 44 fuelling stations have been built across all of California and the number of hydrogen-powered consumer vehicles is estimated at less than 8,000. Following the 2008 global financial crisis, hydrogen risked becoming an orphan technology in California, despite its enthusiastic early leadership and substantial investment in the sector. Today, government commitments are more plentiful, although implementation has been limited. Dubai's hydrogen export sector will therefore depend on foreign governments following through on their commitments to the rollout of hydrogen in their own economies – both through public sector purchases and incentives for private purchasers – with political backsliding presenting a risk to international hydrogen demand.

> Dubai's hydrogen export sector will depend on foreign governments following through on their commitments to the rollout of hydrogen in their own economies.

DOMESTIC HYDROGEN DEMAND STRATEGIES

The middle layer strategies describe potential policy choices for the adoption, promotion, and organisation of the hydrogen economy within the UAE. Unlike international energy market scenarios, these are outcomes of policy decisions which the UAE government controls. They are derived from case studies in successful industrial policy elsewhere (particularly Asia) and are best understood as bundles of incentives, investments, and reforms related to the hydrogen production sector which enable and promote its development. The range of options within each strategy is too great to incorporate into the model; rather they should be thought of as means to increase the possibility of successful outcomes for the hydrogen export sector development strategies.

The successful development of new industries has historically been aided by government-led industrial policy in the domestic market to accelerate technological development and adoption, promote investment, reduce uncertainties around market growth, and overcome operational challenges. Though the best-known examples are derived from East Asian states – cars and consumer electronics in Japan and Korea, and more recently IT systems in China – successful examples can be found around the world, including the European cultivation of Airbus as a commercial aviation giant. However, costly failures are equally common and carry the risk of locking in resources for uncompetitive industries with serious negative consequences for the rest of the economy.

The middle layer strategies describe potential policy choices for the adoption, promotion, and organisation of the hydrogen economy within the UAE.

In crafting a hydrogen sector strategy, the UAE has a range of options on managing the sector and directing the domestic market. The example of successful policies elsewhere offers some big picture insights on cultivating new industrial sectors:

1.
Growth of new industries creates complex dependencies and policies must therefore be bundled appropriately to be effective.

2.
Especially in open economies, domestic industrial policy must align with international competitiveness strategies.

3.
Policy implementation and execution requires highly skilled and well-resourced public agencies, with coordination across different levels of government and ministries.

4.
Appropriate strategies optimally executed particularly benefit second movers, which can learn from early adapters and leverage policy to quickly close technological gaps and advance to become sector leaders.

The key policy levers to consider include:

- Demand management through credible targets and incentives.
- Public sector infrastructure investment and equipment purchases.
- Coordination between local producers and consumers.
- Regulatory flexibility and standard setting.

DEMAND MANAGEMENT

The principal tool for local industrial policy consists of establishing credible targets for output in strategic industries, supported by economic incentives to align private sector and consumer behaviour. Dubai can shape its hydrogen sector by setting production goals for different types of hydrogen – typically blue or green – and uses of hydrogen – such as in industry or transport – matched to specific deadlines and milestones. Government support for an emerging sector produces a strong signal to investors and entrepreneurs that the target technology will eventually deliver returns, with early entrants able to secure a dominant position. Production targets and development strategies have served as the basis of economic recovery in Europe following the Second World War, the rise of Japan and new Asian Tiger economies, and China's emergence as an economic superpower (China is unusual only in its willingness to directly call its targets 'five year plans'). A major decision point for Dubai's promotion of domestic hydrogen technology is its willingness to announce a target for local hydrogen use. A local hydrogen technology plan sends a clear signal to firms and investors, while the lack of a plan sends an equally strong message.

Incentives may extend beyond producers and investors to consumers, whether households or businesses. Many Western governments, for example, offered rebates and tax incentives for the installation of rooftop solar panels. In order to be effective, incentives must be carefully calibrated to market conditions to tilt enough consumers to form a base for the sector. Poorly managed incentive programmes may incur significant costs without delivering durable benefits.

PUBLIC SECTOR INVESTMENT AND PURCHASES

Governments may also directly cultivate domestic markets for infant industries by committing a portion of public sector procurement and investment towards the target industry. The public sector is a major consumer of a wide range of goods and services and a significant player in any economy. Much of its spending is predictable, with requirements and patterns that repeat year after year for essential activities. This is spending which would occur anyway, so selecting products from target industries over conventional alternatives represents an effective way of creating durable demand for the emerging sector, even if initial purchases incur a premium as the industry continues to scale up and innovate.

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CONSUMER/PRODUCER COORDINATION

Dubai can also support local hydrogen production through coordination with customers, such as large-scale business operations, small businesses and households, and local and international research institutions. Innovation and technological change occur rapidly in emerging industries, with a need for producers to collect requirements from consumers, educate the private sector on adopting new technologies, and remain up to date with breakthroughs in hydrogen research. Emerging firms frequently lack the resources to effectively conduct these activities individually and those that do treat findings as proprietary knowledge to be leveraged against industry rivals. By coordinating these functions through an industry association or public–private group, Dubai can deploy resources more effectively. An industry group can serve as a vehicle for members to share market intelligence and for the government of Dubai to secure national-level (and not firm-specific) licences for IP. It can also provide universal access to patents and research conducted within the Emirate. Participating firms can benefit from faster adoption of hydrogen technology locally, reduced firm-level R&D costs, and improved international competitiveness.

An industry group can serve as a vehicle for members to share market intelligence and for the government of Dubai to secure national-level licences for IP. It can also provide universal access to patents and research conducted within the Emirate.

REGULATORY AND STANDARDS POLICY

From a regulatory perspective, Dubai has two priorities: 1) creating a favourable environment for local hydrogen production; and 2) ensuring that local standards, to the greatest extent possible, reflect standards in leading export markets. Dubai is already famous for its simplified regulatory environment for business in general, with the UAE ranking 16th out of 190 global economies in the World Bank's Doing Business index, which identifies the main weaknesses in the business environment as Trading Across Borders (92nd), Resolving Insolvency (80th), Getting Credit (48th), and Paying Taxes (30th). Through a local hydrogen strategy, Dubai may address the financial barriers to business incubation and through an export strategy (independently or in coordination with Abu Dhabi) may reduce the impact of cross-border trading. The use of Free Economic Zones may also serve to help certain businesses associated with the local hydrogen sector operate more efficiently.

Public policy directed towards aligning local standards with those of key export markets will also incentivise Dubai's hydrogen value chain players to develop their internal processes to create energy products suitable for direct sales abroad. As discussed above, quality and safety regulations for hydrogen energy are currently in their infancy – some countries have purity standards for fuel cell and industrial hydrogen with specifications for maximum impurity levels, but these vary considerably. Safety standards represent a major unresolved issue, given hydrogen's flammability. An explosion at a hydrogen facility in California in 2019 forced the temporary closure of the San Francisco Bay Area hydrogen distribution system, with shortages in hydrogen fuel availability lasting months, significantly affecting hydrogen technology adoption in the state. Creating effective safety standards for consumer hydrogen use and securing their international recognition would represent a major advantage for Dubai's hydrogen sector.

Below, we present three alternative approaches for the UAE's domestic hydrogen market, bundling policies together to optimise their effectiveness. Costs, risks, and overall economic impact vary substantially between the three approaches and not all are compatible with every hydrogen sector export strategy presented in this report. Furthermore, the success of hydrogen in the UAE cannot be detached from the evolution of the global hydrogen economy – pessimistic assumptions regarding international demand or the global regulatory environment effectively foreclose more aggressive approaches for both domestic and export hydrogen sectors in the UAE. Care should also be taken to align hydrogen sector development strategies with other strategic goals for the UAE. In addition to the economic and environmental impact of a robust hydrogen sector, the emergence of this new industry in the UAE will affect the employment profile of the economy, demand for high-skill labour and services, and the UAE's network of international relationships.

The success of hydrogen in the UAE cannot be detached from the evolution of the global hydrogen economy – pessimistic assumptions regarding international demand or the global regulatory environment effectively foreclose more aggressive approaches for both domestic and export hydrogen sectors in the UAE.

The Walled Garden Scenario

A maximal approach to the domestic sector would be to develop a large and secure local market – a ‘walled garden’ – for locally produced hydrogen through public sector investment and mandates or incentives for private sector hydrogen adoption. The local market would serve as the main source of reliable and secure demand for hydrogen production, reducing risks for investors. In addition to the financial advantage of a captive domestic market, hydrogen production and associated industries (distribution, infrastructure, etc.) would benefit from having an environment in which to experiment with different operational models as well as new practices, technologies, and processes that have longer time horizons and lower revenue pressures than they would face if mainly exposed to competitive international markets. This provides an opportunity and incentive for innovation, with successful developments later introduced to export markets to boost efficiency and competitiveness.

A standard free market model would risk destructive competition within the UAE and too broad dispersal of incentives. Instead, two or three producers should work closely with the government to coordinate the growth of the sector and develop plans to meet production and adoption targets, while still subject to price discipline through some competition on global markets. The UAE should create trade associations to link the hydrogen sector with consumers of energy to facilitate market research and customer outreach.

An aggressive industrial policy for local hydrogen demand in the UAE will have the greatest impact on accelerating the growth of the hydrogen sector and incubating the export industry. This will involve a greater commitment of resources, not only in financial terms but also in planning and managing the development of the local market.

Balanced Costs and Benefits Scenario

A balanced approach maintains some of the elements of the walled garden at a smaller scale, reducing the level of coordination without abandoning it entirely. This avoids the use of aggressive economic strategies in places new to government-coordinated strategic planning that are often costly and difficult to implement. In addition to the direct costs incurred through public infrastructure investments and purchases, favourable financing incurs an opportunity cost and coordination between industry and government creates friction as new working arrangements disrupt old patterns and government capacity improves to fill its role. This comes at the increased risk of slippage for timelines, reduced protection for the industry, and lower government influence on corporate planning.

Nonetheless, a smaller local market would offer some buffer to international competitive pressure and allow for innovation and experimentation, with a greater need for private sector initiative. A looser organisation of the sector reduces the cost of economic management – a general association of major UAE producers with some incentives for innovation sharing could be enforced through shared competitiveness anxiety. Trade associations should still be sponsored and encouraged to facilitate hydrogen technology adoption, market research, and customer outreach.

A balanced approach offers benefits for the industry and enables optimal outcomes, but achievement depends to a greater extent on corporate leadership than government guidance. The commitment of resources is lower with an increased risk of falling behind international competitors.

Export-only Sector

An alternative to active strategic intervention in the local hydrogen fuel market is a ‘hands-off’, export-only approach. Targets for hydrogen adoption may still be issued but formulated as guidelines for voluntary adoption by the private sector. Instead of actively working to partner producers with potential consumers of fuel hydrogen, the UAE may opt to allow the local energy market to develop its own equilibrium, relying on the profit motive of producers to incentivise them to undertake hydrogen promotion.

Likewise, hydrogen producers would be encouraged to self-organise and determine the extent of resource and knowledge pooling within the sector. Public sector hydrogen adoption through infrastructure investment and equipment purchases would be entirely price-sensitive, relying on producer cost reduction to offer superior economic performance to conventional alternatives. Incentives would be limited to certification without benefits, a largely symbolic measure unless it could be linked with benefits from international programmes. Producers would largely rely on cost advantages on the global market to realise returns, with increased profit pressure during the vulnerable early period of the industry. Support could still be offered through export strategy mechanisms, but for domestic demand the UAE would take a ‘hands-off’ approach.

The export-only alternative requires minimal additional expenditure of effort and resources beyond the development strategy adopted. While this minimises costs, it removes a buffer for the infant industry and effectively eliminates the ability for the government to incentivise or enforce its hydrogen-related targets.

Forgoing industrial policy for the domestic hydrogen sector allows the government to minimise its expenditures and allows the sector to develop based on market conditions. However, this includes the possibility that the sector does not develop at all as rival producers move aggressively to capture market share while the UAE's hydrogen production industry remains immature and proves unable to make up for its late entry. However, any export sector that develops will be profitable from its early stages, avoiding the possibility of creating an industry dependent on long-term support.

HYDROGEN EXPORT SECTOR DEVELOPMENT STRATEGIES

The bottom layer consists of strategies for the UAE's hydrogen export sector. These strategies involve metrics modelled quantitatively, including determining target volumes for production, selecting hues of hydrogen to produce, establishing investment levels to meet production targets, and anticipating end markets for UAE-produced hydrogen. Based on those metrics, different forecast models for the economic, environment, and social impact on the UAE have been prepared. The strategies also include the external-facing policy adaptations necessary to enable the strategies to succeed.

For the UAE, the greatest potential benefits from the global hydrogen economy stem from the export potential among major overseas markets. As the technology remains immature and the penetration of hydrogen technology into key applications – industrial heat and power, electricity generation, and transportation – remains minimal, considerable uncertainties remain regarding the direction of the global energy economy, including the speed at which hydrogen technology progresses, the growth of the hydrogen market to 2050, and the extent to which conventional energy sources are displaced. The drivers of global hydrogen development and uptake are largely beyond the ability of the UAE to determine (though it may be able to influence them through international collaboration), but the international hydrogen economy will serve as the environment in which the UAE's hydrogen sector must operate. This study has discussed three possible scenarios for the international hydrogen economy in the sections above.

The sections below envision potential futures for the UAE's hydrogen export sector and strategies to realise those visions. The range of strategies partly reflects the scenarios described for the global hydrogen economy. For example, the Minimal Strategy described below is appropriate for a low uptake/low demand international market, minimising economic exposure to the hydrogen economy, similarly pairing with a low-priority domestic policy for hydrogen production. More ambitious export sector strategies will depend for their success on a minimum of a maturing global hydrogen scenario and offer greater potential upside in terms of economic resilience, technology development, and ecological rebalancing.

Below, the study describes and projects the impacts of four different hydrogen export development strategies for Dubai.

Producer & Hub Strategy

A rapidly decarbonising and therefore increasingly hydrogen-reliant global economy creates the opportunity to pursue an ambitious hydrogen export promotion strategy with the goal of emerging as a leader. This would mean capturing not only a disproportionate share of the international market but developing allied industries and becoming a research and innovation centre. While a strictly producer strategy would position the UAE to capture a share of global hydrogen export revenue, the producer & hub strategy would seek to maximise the UAE's global market share – including substantial near-term exports to Asia – and to develop the country as an innovation centre for the industry.

This strategy requires an assertive approach to maximise production in the near term in order to outcompete other early entrants and create a durable market advantage. Benefits accrue for the UAE not only through hydrogen export earnings, but the ability to link the hydrogen sector to the UAE's technology ecosystem and, vitally, its financial services sector, creating an exchange for hydrogen-linked financial assets and derivatives. With such an approach, the UAE's role as a magnet for talent and a creator of high-skill employment would be significantly enhanced, but such a strategy would require substantially more early investment than a producer-only strategy, with correspondingly greater exposure to volatility or to sub-par global adoption of hydrogen technology.

Producer Strategy

The UAE enjoys significant advantages in hydrogen production – abundant access to solar and wind power, natural gas reservoirs appropriate for blue hydrogen, established energy infrastructure and trading partnerships. With a maturing global hydrogen industry, it could parlay those advantages through a producer strategy to become a competitive hydrogen exporter, developing a new high-tech, high-skill sector within its domestic economy while also leading the shift towards sustainable energy resources. This strategy harnesses the UAE's resources, relationships, and location to develop an internationally competitive hydrogen sector on the same scale as GCC neighbours.

Under such a strategy investments are spaced out over time in order to optimise capacity and costs against export revenues, with an emphasis placed on markets that can be accessed most economically, notably the EU and energy-poor MENA countries. The combination of hydrogen types is optimised for economic performance (both through export revenues and carbon offsets), with blue hydrogen preponderant in the short to medium term and a gradual shift to green hydrogen in the long term. While this strategy contains greater risk than the minimal approach, an emphasis on economic viability will allow the UAE to capture a segment of international hydrogen markets, creating a high-tech sector to complement its services- and trade-based economy.

Regional Coordination Strategy

The UAE's advantages in hydrogen production are shared by its neighbours, with the GCC representing one of the most suitable regions for the economical production of both blue and green hydrogen. Several major regional economies – such as Oman and Saudi Arabia – are already developing their own hydrogen sectors and are further along than the UAE. Qatar is a major natural gas exporter, accounting for the overwhelming majority of the UAE's gas imports. In anything short of a high uptake/ high demand scenario, the UAE's GCC neighbours would constitute formidable competition for the global export market and even in optimal conditions rivals for regional leadership in financing, hydrogen-related services, and innovation.

However, if the UAE is willing to cooperate in hydrogen sector development through the GCC, there is great potential in establishing a region-wide hydrogen cluster rather than engaging in potentially destructive intra-GCC competition. Such a producer cluster could co-exist with the UAE developing within it as a hub for allied industries and research. For the UAE alone, developing sufficient capacity to move international markets through a producer strategy without a hub element would require upfront investments large enough to risk the long-term economic future of the country. By collectively organising production the GCC as a whole could achieve a dominant hydrogen position, similar (though not quite as strong) to its position in international oil markets. Investment in hydrogen projects can be made jointly through institutions such as Gulf Investment Corporation, which is equally owned by the governments of the six-member GCC states. Spreading out investment through multiple economies would reduce risks to individual members, while coordinating infrastructure and facility development would allow investment and operation to function more efficiently, with less risk and duplication. While the UAE would need to cede some of its policy independence for the sake of GCC coordination, its infrastructure, sophisticated financial markets, and existing advantages as a regional talent magnet would allow it to nonetheless capture some of the benefits of serving as a hydrogen hub.

Low-hanging Fruit

While the development of hydrogen technology as an alternative fuel source has attracted significant attention and major economies have introduced plans for hydrogen energy promotion, studies of the topic have presented a range of possible outcomes, including scenarios in which hydrogen fails to develop as expected and national plans are delayed or abandoned. Entry into the sector will come at significant cost and investments will be exposed to risk from international markets. Even in best case scenarios, it will take years or decades to achieve economic benefits. A minimal ‘low-hanging fruit’ strategy seeks to minimise the UAE’s exposure to downside risk by limiting investment in the hydrogen sector while seizing opportunities to benefit from its success through energy services and infrastructure that can be developed or adapted quickly and cheaply.

If hydrogen remains a niche fuel, the UAE could still come out ahead on those services and through infrastructure deals while economies that bet heavily on hydrogen absorb significant losses. However, by limiting risk, the UAE would also limit its share of any gains from hydrogen exports, missing an opportunity to deepen and diversify its economy while neighbours and competitors benefit from a once-in-a-century technological shift.

10.

CONCLUSION AND RECOMMENDATIONS

The extent to which the future hydrogen economy will grow in the UAE will depend largely on external factors outside its control. Different levels of future international hydrogen adoption and demand will provide different contexts for the domestic demand and export sector pathways followed by Dubai and the UAE.

However, many of the trends suggest the external factors will drive growth in hydrogen. Due to the drop in green and blue hydrogen production costs, the hydrogen economy is set to expand beyond its main existing markets for ammonia production, methanol production, and oil refining. The challenges mentioned in this report will need to be overcome, but hydrogen is showing promise as a solution to decarbonise several hard-to-abate industries, such as iron, steel, and cement production and the aviation and maritime industries. In addition to its role in the reduction of carbon emissions, hydrogen may also play an important role in energy storage due to superior transportability compared to batteries.

Many governments have set targets for hydrogen use and made significant investments in R&D and pilot programmes. All of these factors suggest that it is more likely than not that hydrogen will grow rapidly as a source of low-carbon energy. While some risk remains, there is also a major opportunity for the UAE to secure first-mover advantage.

A long-term recommendation will be sensitive to several factors, such as land availability, logistical constraints, and financial implications for supporting domestic demand. A detailed techno-economic assessment is required before recommending a specific strategic pathway at this stage. In a future where such constraints are overcome, the highest potential benefit to the UAE in the global hydrogen economy of the future would come from building a strong export market for locally produced hydrogen, which is described as the ‘Producer & Hub’ export sector development strategy in this report. The strategy is possible under either high or medium international and domestic hydrogen demand.

The ‘Producer & Hub’ strategy could add up to AED 32 billion annually to Dubai’s GDP by 2050, create over 120,000 jobs between now and 2050, and offset CO_2 emissions equivalent to 84 days per year of the UAE’s crude oil production by 2050.

Add Up to AED 32 Billion

annually to Dubai’s GDP by 2050

Create 120,000+ Jobs

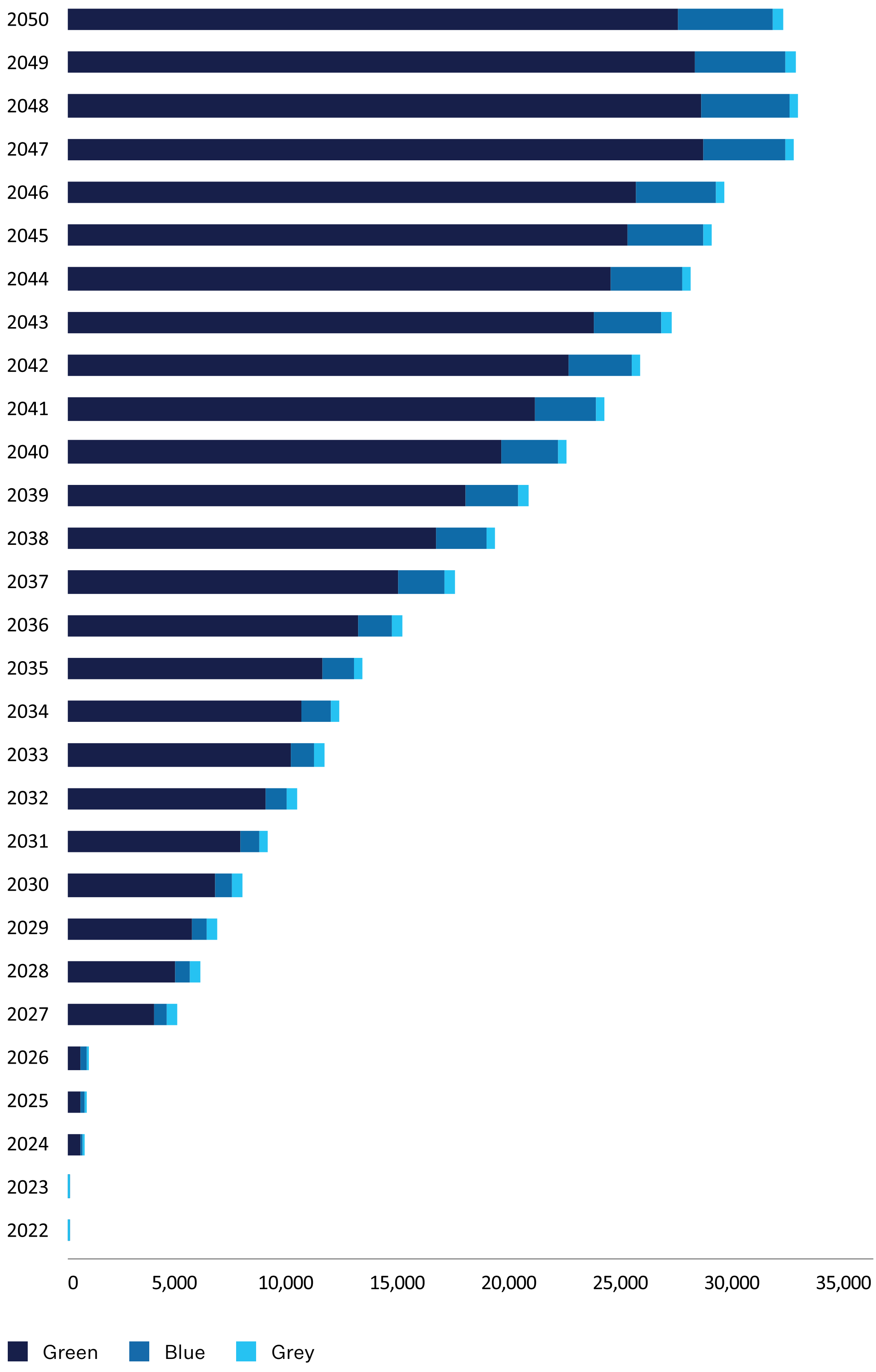
between now and 2050

Offset CO_2 Emissions 84 Days

per year of the UAE’s crude oil production by 2050

Economic Impact on Dubai

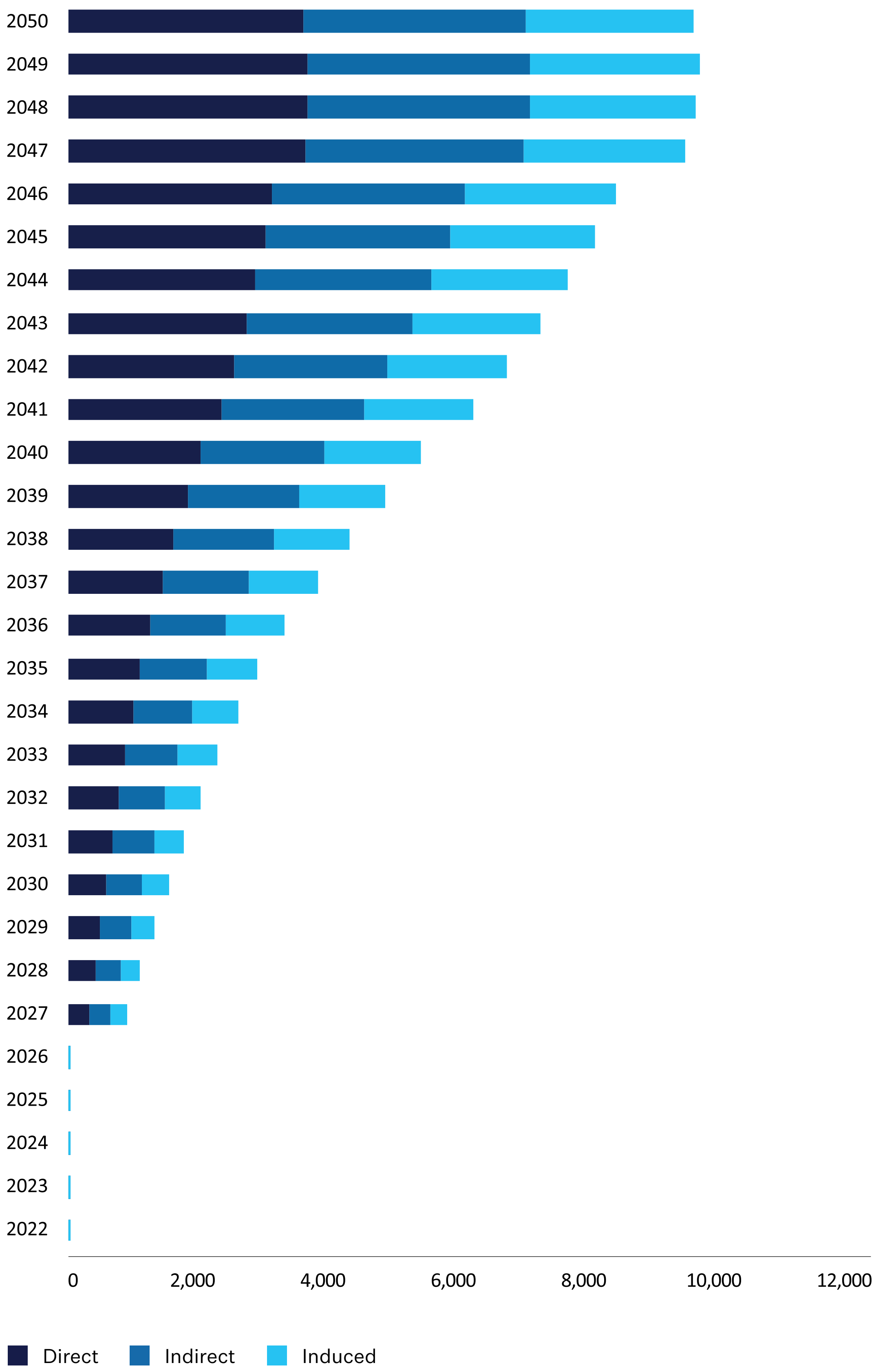
Figure 15. Dubai: Contribution to GDP (Direct + Indirect + Induced) (AED mm)



Source: Dubai Future Foundation

Social Impact on Dubai

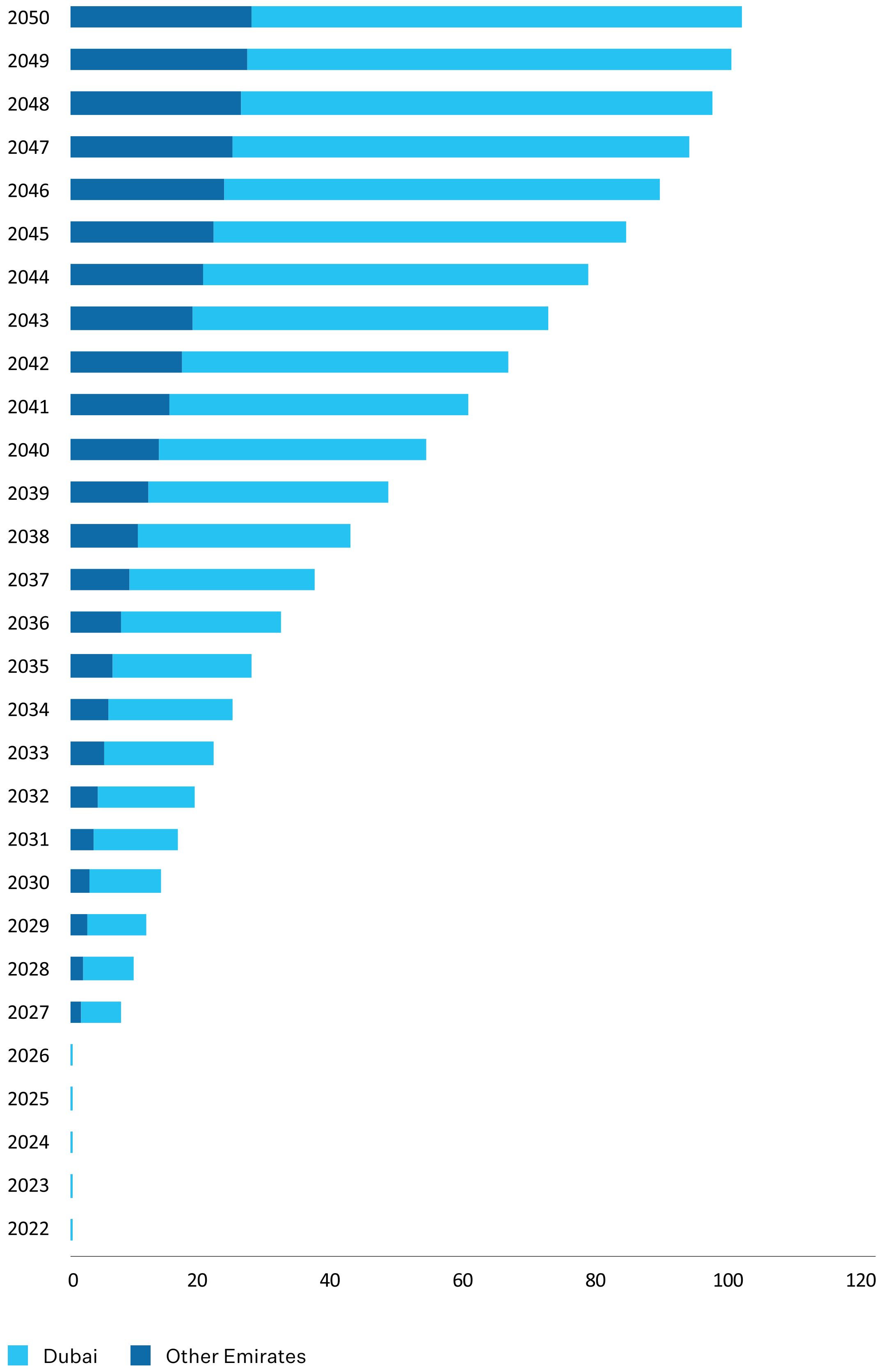
Figure 16. Dubai: Jobs Created Each Year (FTE)



Source: Dubai Future Foundation

Environmental Impact on the UAE

Figure 17. Days per Year of UAE Crude Oil Production's CO_2 Impact Offset by H2



Source: Dubai Future Foundation

Dubai Future Foundation, its partners, and expert contributors, have developed the following **short- to medium-term recommendations** in order to enable this strategic pathway to be followed:

1. **The development of proofs of concept showcasing future use cases, including green-hydrogen-based synthetic fuels.** Such synthetic fuels can be produced cleanly, which would significantly reduce the environmental impact of road transportation vehicles, aeroplanes, and ships. These fuels can be produced in a way that is compatible with existing engines, which means the environmental benefit can come at little or no additional cost to the owners, depending on the cost of the synthetic fuel.

2. **The development of prototypes demonstrating the ability to overcome challenges, such as prototyping seawater electrolysers to overcome the freshwater scarcity challenge.** Stanford University and University of Houston are currently developing such prototypes, but the objective would be to prove their commercial viability and scalability in addition to verifying the technology.

3. **Carrying out a pilot project demonstrating verification of clean hydrogen.** Given that the primary benefit of hydrogen is its ability to tackle climate change, importing countries will most likely insist on importing cleanly produced hydrogen. There is no way to physically differentiate cleanly produced hydrogen from grey hydrogen, but technologies such as blockchain can be used to verify the production source of the hydrogen being imported.

4. **The assessment and feasibility study of a jointly funded pipeline connecting GCC countries to Europe and East Asia for the export of hydrogen.** GCC countries have the potential to produce green, blue, and yellow (nuclear energy-derived) hydrogen at scale, with significant ability to export clean hydrogen to countries lacking the required resources. The project could be jointly funded by GCC countries.

5. **The alignment of key government entities across the UAE to manage and coordinate the production and supply of blue and green hydrogen.** Coordinated competition will ensure efficient allocation of resources at a national level.

6. **Provision of financial incentives to hydrogen producers.** Incentives such as public ownership stakes, direct grants, and long-term contracts from public bodies for hydrogen purchases would accelerate the development of a future hydrogen economy in the UAE.

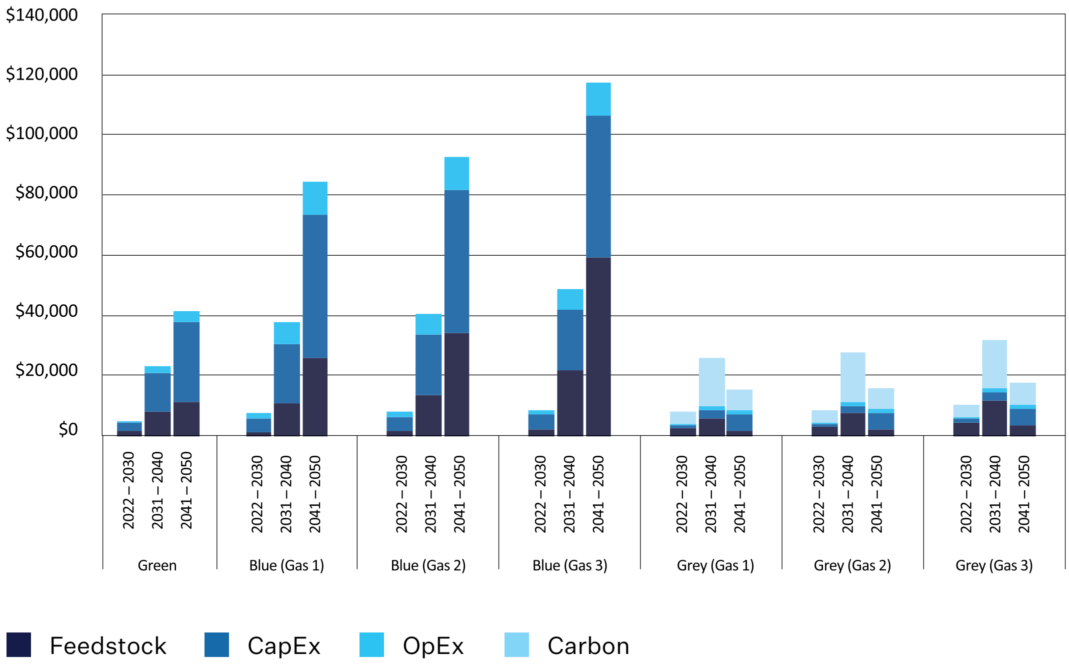
7. **The introduction of targeted measures to support hydrogen research and development (R&D) in the UAE.** Research can be encouraged through the identification and communication of hydrogen R&D opportunities among the relevant institutions and other stakeholders in the country, and the facilitation of collaborative R&D pooling.

8. **The conversion of up to 50% of all public fleets of heavy goods vehicles to hydrogen FCEVs (fuel cell electric vehicles) by 2050.** The public sector is a major consumer of a wide range of goods and services and a significant player in any economy. This is spending which would occur anyway, so selecting products from target industries over conventional alternatives represents an effective way to create durable demand for the emerging sector.

9. **The development of 100 hydrogen fuelling stations in the UAE by 2050.** In addition to being a basic need for hydrogen FCEV vehicles, the significant development of hydrogen infrastructure in the country would produce a strong signal to investors and entrepreneurs that investment in hydrogen will eventually deliver returns.

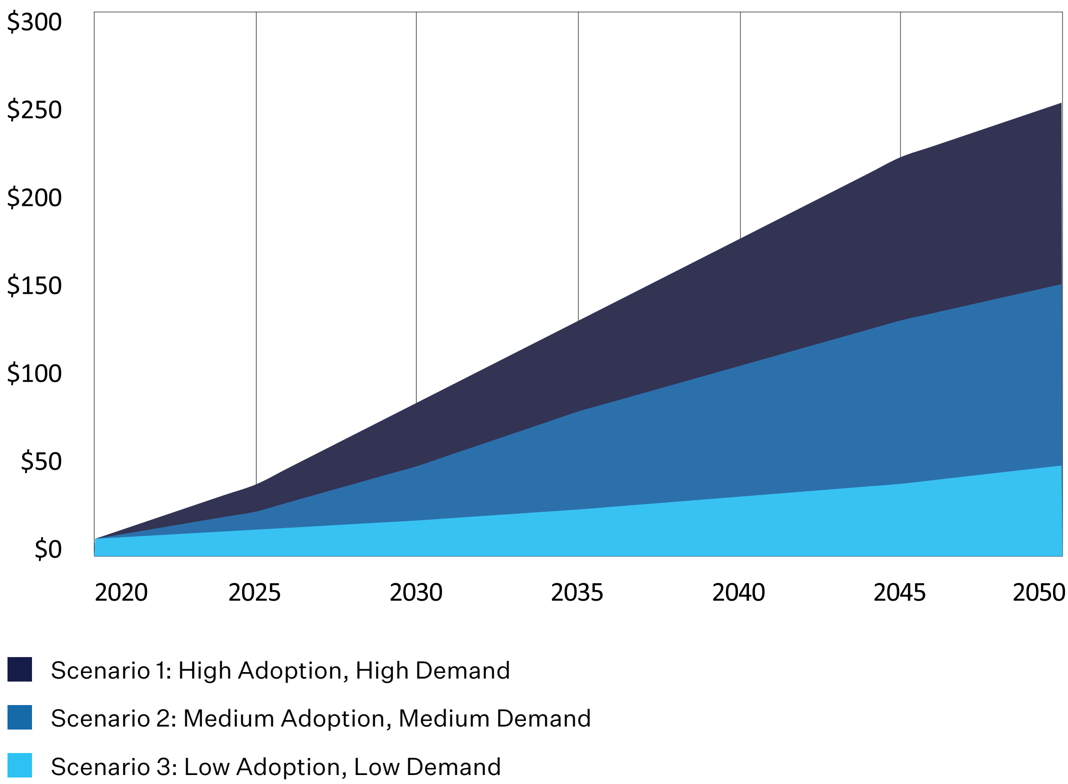
APPENDIX: IMPACT ANALYSIS ASSUMPTIONS

Figure 18. UAE Production Costs by Hydrogen Colour, 2022–2050: Market Scenario 2 (USD mm)



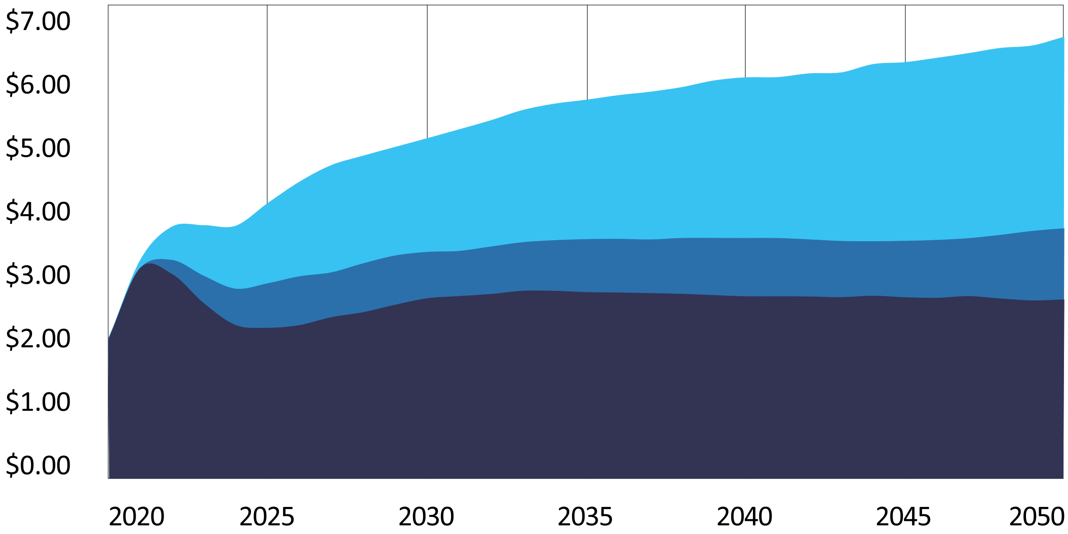
Source: Dubai Future Foundation

Figure 19. Projections of Carbon Price by Market Scenario (USD per ton CO_2)



Source: Dubai Future Foundation

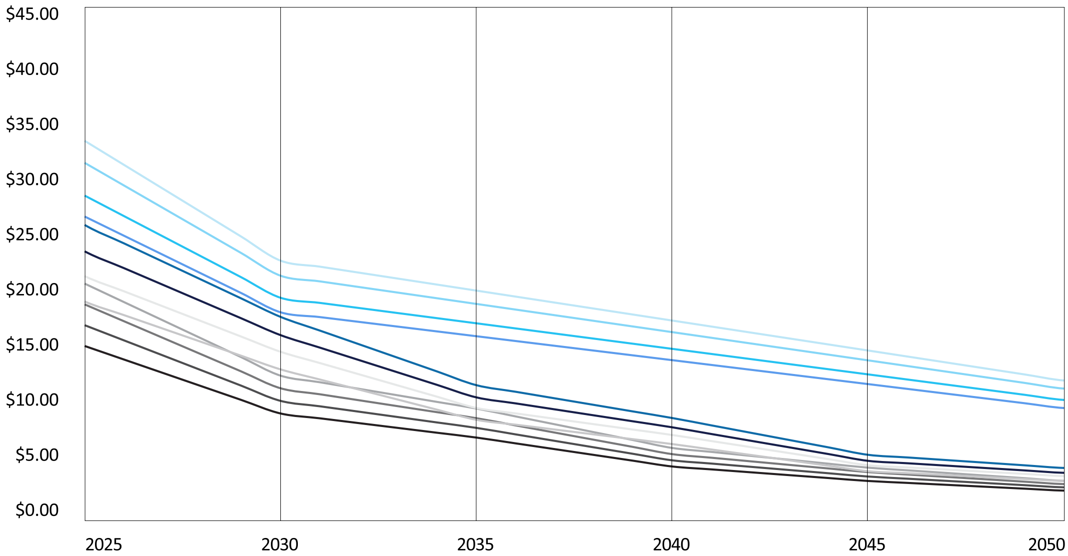
Figure 20. Projected Natural Gas Price (Henry Hub, USD / MMBtu, 2020 dollars)
US Energy Information Administration estimates



- Scenario 1: Low price of natural gas (due to high oil and gas supply)
- Scenario 2: Reference case
- Scenario 3: High price of natural has (due to low oil and gas supply)

Source: Dubai Future Foundation

Figure 21. Price of Local Green Electricity to Power Local Hydrogen Production (projected 2025–2050)



MS1/SS1 MS1/SS2 MS1/SS3 MS1/SS4 MS2/SS1 MS2/SS2
MS2/SS3 MS2/SS4 MS3/SS1 MS3/SS2 MS3/SS3 MS3/SS4

Source: Dubai Future Foundation

Figure 22. Projected UAE Hydrogen Sales Prices by Colour (USD/kg H2, UAE FOB)

Market Scenario	Colour	2020	2035	2050
Fast	Green	2.87	1.64	0.90
Fast	Blue	2.32	1.74	1.48
Fast	Grey	1.32	1.48	1.37
Moderate	Green	3.32	1.85	1.16
Moderate	Blue	2.53	1.99	1.80
Moderate	Grey	1.43	1.58	1.69
Slow	Green	4.21	2.27	1.48
Slow	Blue	2.64	2.32	2.32
Slow	Grey	1.53	1.69	2.22

Source: Dubai Future Foundation

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ABOUT DFF

Launched by His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of the UAE and Ruler of Dubai, the Dubai Future Foundation was established in 2016 to play a pivotal role in shaping the future of Dubai, as well as to collectively imagine, inspire and design the city's future in collaboration with the government and private entities within various industries.

Mandated in positioning Dubai as a hub for innovation and a leading city of the future, the foundation's main areas of focus are Future Foresight and Imagination, Content and Knowledge Dissemination, Capacity Building, Future Design and Acceleration, and Future Experiences.

DFF builds bridges between government and the private sector, innovators, startups, talents, and industry experts, and creates an innovative ecosystem that enables innovations to take shape, promotes global dialogues, builds partnerships, and cultivates disruptive mindsets.

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