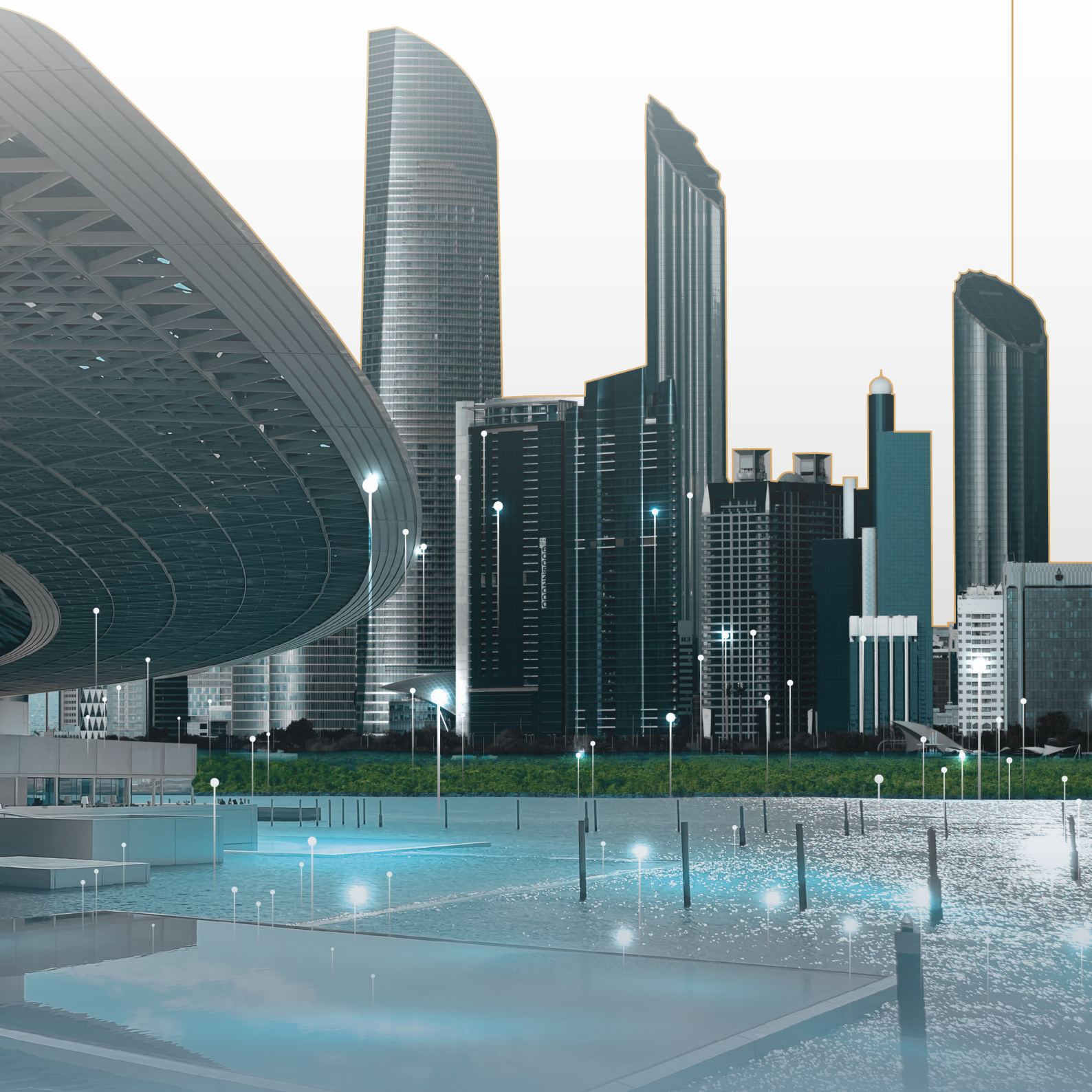
دائـــــرة الـــطـــاقـــة
DEPARTMENT OF ENERGY

2024 DOE Future Foresight Reports

The Future of Ammonia-Based Fuel and Ammonia for Energy Storage & Delivery



Executive Summary

The Abu Dhabi Department of Energy (DOE) is committed to proactively navigating the evolving landscape of the energy sector through a series of Future Foresight Reports. These reports published by DOE are designed to align with DOE's corporate strategy as well as influence it by anticipating future trends, scenarios and implications. By incorporating future foresight practices, DOE is positioning itself to anticipate challenges, leverage emerging technologies, and lead the way in sustainable energy development. The primary purpose of these reports is to systematically analyze potential future scenarios, technological advancements, policy shifts, and market dynamics that could impact the energy sector. By understanding and leveraging this future intelligence, DOE can make informed decisions that drive innovation, efficiency, and sustainability. The report series serves as a strategic tool to guide DOE in achieving its long-term goals, mitigating risks, and capitalizing on new opportunities.

The Abu Dhabi Department of Energy's Series of Future Foresight Reports exemplifies DoE's commitment to strategic planning, anticipating future opportunities and driving innovation. By leveraging foresight practices, DOE are not only preparing for the future but actively shaping it in alignment with our corporate strategy goals. These reports will serve as a cornerstone for decision-making, ensuring that the DOE remains at the forefront of the global energy transition, driving sustainable growth and securing a prosperous energy future for all.

This report titled 'The Future of Ammonia-Based Fuel and Ammonia for Energy Storage and Delivery,' explores the emerging ammonia economy, focusing on its role in hydrogen energy production, global trade, and the transition to sustainable ammonia technologies.

Contents

Overview

The Ammonia Economy, which is directly intertwined with the hydrogen economy, represents a long-term trend in the energy industry that has the potential to significantly transform it over a horizon of 10 years or more. The UAE emerges as a prospective leader in harnessing and exporting hydrogen energy to the global market, driven by the capacity to produce it at a relatively low cost and strong links with the global energy industry, with historically established supply chains to the European Union and Asia.

The UAE's vision for the ammonia industry is outlined in The National Hydrogen Strategy 2050 and The UAE Hydrogen Leadership Roadmap, demonstrating a relatively progressive approach. In the meantime, other countries in the MENA region are also actively formulating plans for the development of their respective ammonia capabilities.

The analysis of trends and forecasts in the global energy sector indicates three promising and interconnected areas for the development in this field: (1) Ammonia-based fuel for the transport industry and manufacturing, (2) Ammonia for energy storage and delivery, and (3) New generation of the ammonia production processes and technologies. The success of the first two directions hinges on such key factors as the establishment of global standards and regulatory frameworks. Additionally, the modernization of existing carbon-intensive ammonia production capacities is crucial, with a phased transition from grey to blue and ultimately to green ammonia production technologies. The UAE has already been launching projects addressing these aspects since 2021, creating favorable conditions for a rapid transition to ammonia-based fuels and engaging in hydrogen energy trade internationally.

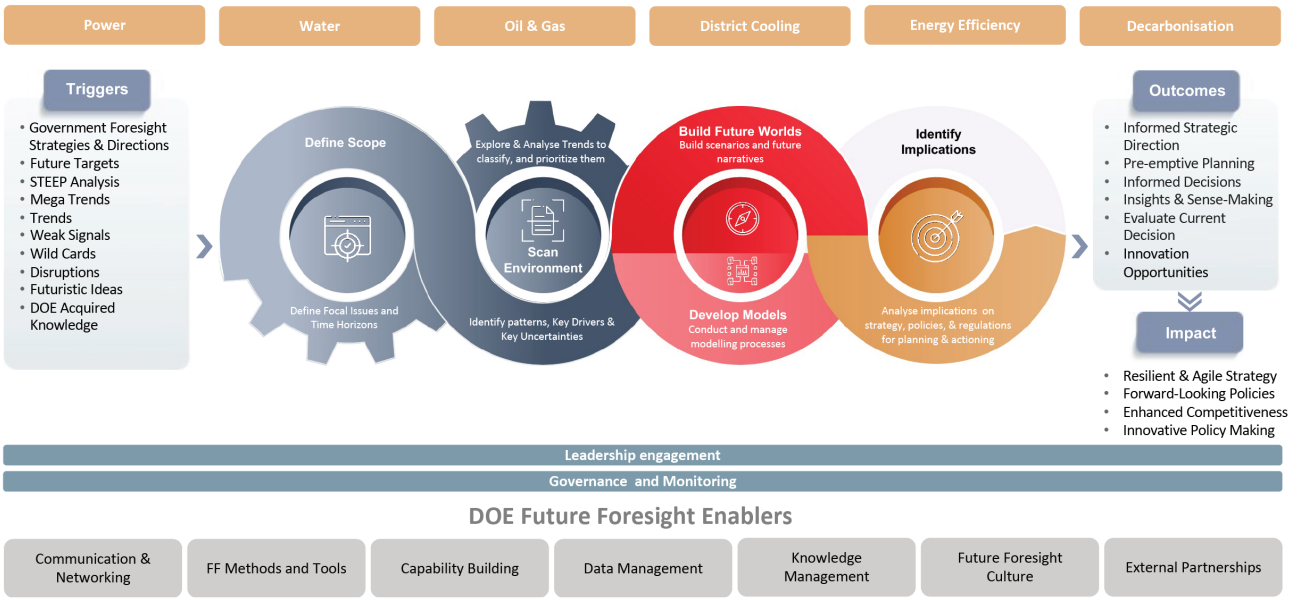
The main uncertainties in this industry are closely tied to the cost of renewable ammonia and the volume and localization of new renewable ammonia production capacity. To achieve the set ambition, efforts should encompass the UAE as a whole and extend to other regions. The economic efficiency of the country's ammonia production facilities and available capacity will play a crucial role in determining the focus on foreign and domestic markets. Strategic actions taken by the UAE in the short term can have a lasting impact on future developments, potentially positioning the UAE as a leader in the global hydrogen energy market.

Approach

The Future Foresight Framework aims to address UAE's leadership and the government's farsighted visions and aspirations for the development of Energy Efficiency technologies. This framework allows us to determine perspective directions for the development of the Ammonia Economy, and identify the goal and the necessary steps to achieve it.

The core operating model of the Future Foresight Framework is comprised of four key phases, which are:

The DOE Future Foresight Framework is illustrated below:



The framework is initiated by a set of triggers, from external and internal factors, such as government directions, strategies, and targets, as well as drivers of change (trends, megatrends, weak signals, and wild cards), knowledge from internal business intelligence and ideas, and disruptions affecting the development of the Ammonia Economy in the Abu Dhabi Emirate.

Along with the implementation of the framework model, DOE develops and acquires knowledge about the future that helps to achieve impact through the development of more resilient and agile strategies in plausible futures, and developing innovative and forward-looking energy policies and regulatory frameworks that support the Energy sector in the energy generation and usage optimization, while enhancing competitiveness.

The DOE Future Foresight model is supported by seven enablers that act as catalysts for effective implementation, which are considered an integral and important part of the framework execution. Key findings along the model's implementation are aligned with the DOE leadership to ensure the outcomes of the model contribute to improved decision-making, strategic planning, providing insights, and recognizing opportunities and threats. The framework, when implemented effectively, aims to lead to a positive impact for DOE in innovative policy-making, developing forward-looking policies and regulations, resilient and agile strategies, and improving competitiveness.

Current State

Ammonia, a chemical compound with widespread industrial applications, holds significance within the global energy transition as a viable low-carbon gaseous fuel. Currently, 183 Mt of ammonia is produced annually, more than 99% of this amount is generated from fossil fuels.[1] Carbon-free or green ammonia is produced from hydrogen through the process of water electrolysis based on renewable energy sources (solar, water, wind). Despite its commercial-scale production originating back to 1921, the quantity of renewable ammonia generated in 2021 remained below 0.02 Mt. However, trends indicate a shifting industrial production landscape towards an increasing reliance on carbon-free ammonia, primarily blue and green. Forecasts suggest that post-2025, it will assume a predominant role in all new global capacity developments.

Currently main uses of ammonia lie within the chemicals industry (fertilizers, pharmaceuticals, textiles, etc.), and less than 1% of produced ammonia is used for emerging applications, i.e. maritime fuel, stationary power fuel, and energy carrier. The promising uses of this compound are connected with hydrogen storage and transportation due to the large perspectives of replacement of fossil fuels by hydrogen fuel (fig.1). It is considered to be the most efficient and cheap hydrogen carrier for its long-term storage capacity as well as its use for long-distance transportation of renewable energy.

Ammonia Economy as a concept implies the use of renewable ammonia as a replacement for fossil fuels, being a hydrogen energy carrier and contributing to the switch of the ammonia industry and its customers from black and grey to renewable technologies.

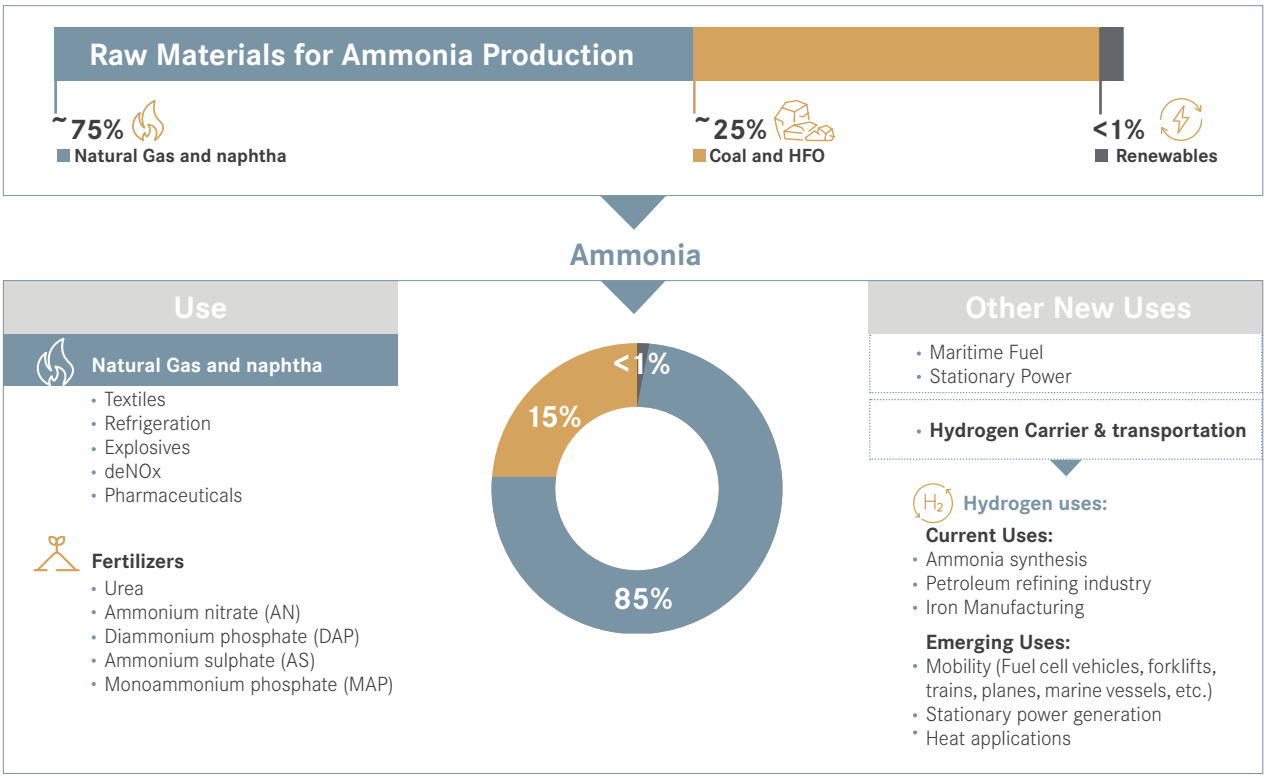


Figure 1: Global structure of ammonia production and applications
Source: Innovation Outlook Renewable ammonia, International Renewable Energy Agency

In UAE ammonia is currently produced in such industrial complexes as the Fertil Ruwais Complex and Dubi Chem plants. In 2009 UAE was selected to host the International Renewable Energy Agency and at that moment national agenda for renewables was created. The period until 2020-2021 reflects a time when the ammonia industry was not extensively examined and was part of broader ambitions related to the transition to a hydrogen economy. According to the UAE Hydrogen Leadership Roadmap, published in 2021, UAE starts its path to hydrogen leadership from a position of strength, with over seven projects underway, developments on the ground, and four test cargos of renewable energy sold. The UAE is currently implementing a large number of policies, plans, and initiatives to support and encourage the development of renewable energy sources, including ammonia-based renewable energy sources.

Table 1: UAE Initiatives for an Ammonia Economy

Strategic document	Legislative level	Initiative	Key players[1]	Implementation period
National Climate Change Plan of the UAE	Federal	One of three key goals is to manage greenhouse gas (GHG) emissions while sustaining economic growth.	MOCC	2017 - 2050
UAE Energy Strategy 2050	Federal	The goal for the first phase until 2030 is to triple the contribution of renewable energy and invest AED 150 to AED 200 billion by 2030. **At this phase, the strategy goals include:** • Triple the share of renewable energy by 2030. • Increase the installed clean energy capacities from 14.2 GW to 19.8 GW by 2030. • Surge the share of installed clean energy capacities in the total energy mix to 30% by 2030. • Increase the contribution of clean energy generation by 2030 to 32%.	MEI	2017-2050
UAE Environment Policy	Federal	Priorities of the Policy include limiting the impact of climate change, accelerating the efforts to conserve natural resources, and boosting air quality.	MOCC	From 2021
UAE National Hydrogen Strategy	Federal	The opportunity for the UAE in a hydrogen economy is in using renewable ammonia as a fuel in aluminum and chemical and fertilizers sectors and transport industry.	MEI	2023 - 2050
Abu Dhabi Climate Change Strategy	Regional	The goal is to achieve a 22% reduction in carbon emissions in the emirate of Abu Dhabi by 2027.	EAD	By 2027

Table 1: UAE initiatives for a Smart Grid and AI development

Strategic document	Legislative level	Initiative	Key players[1]	Implementation period
Environment Vision 2030 (Abu Dhabi)	Regional	One of the five prioritized objectives is the promotion of clean air and the reduction of noise pollution, aiming to contribute significantly to the creation of safe and healthy living conditions for the community	EAD	By 2030
UAE Net Zero 2050	Federal	The strategy aims to achieve net zero emissions by 2050. As an integral facet of the strategy implementation, substantial financial support is allocated to facilitate clean energy projects. The objective entails a significant augmentation of clean energy production capacity, encompassing solar and nuclear technologies, with a targeted attainment of 14 GW by 2030. This goal represents a substantial escalation from 100 megawatts recorded in 2015 and the 2.4 GW achieved in 2020.	MOCC	By 2050
National Water and Energy Demand Management Programme	Federal	Strategic orientation to reduce energy demand by 40% and increase renewable energy's contribution to the energy mix to 50%	MoEI	By 2050
UAE Hydrogen Leadership Roadmap	Federal	The roadmap sets the objective of securing a 25% market share for low-carbon hydrogen and its derivatives in key import markets by the year 2030. Notably, three out of the seven low-carbon hydrogen projects outlined in the plan are specifically oriented toward the production of blue or green ammonia.	MoEI	2021-2050

Source: UAE strategic planning documents

1 – MoEI - Ministry of Energy and Infrastructure; GCAA - General Civil Aviation Authority, MoIAT Ministry of Industry and Advanced Technology, MEI - Ministry of Energy and Infrastructure, MOCC - Ministry of Climate Change and Environment, EAD - Environment Agency – Abu Dhabi.

UAE actively increases the capacities of the ammonia production industry by new blue and green ammonia plants. For example, in 2021, Abu Dhabi Ports and Helios Industry embarked on the development of the UAE's renewable ammonia plant, boasting an annual capacity of 200,000 metric[2] tons. This project attracted an investment of $1 billion from Helios Industry. Concurrently, TAQA and Abu Dhabi Ports initiated the establishment of a 2-gigawatt green ammonia export facility[3], while ADNOC disclosed plans for the construction of new capacities for blue ammonia production.

Further contributing to the momentum in green ammonia initiatives, Brooge Renewable Energy announced in 2023 the successful completion of the feasibility study for its green ammonia project in Abu Dhabi, boasting a daily capacity of 1,950 metric tons[4]. These endeavors underscore the commitment and progress in positioning the UAE as a significant player in the green and blue ammonia market landscape.

Topic Relevance

The development of the ammonia economy in Abu Dhabi is an integral component of the UAE's pathway to achieving net zero emissions by 2050. Key stakeholders and businesses in the UAE are actively engaged in various stages of the hydrogen value chain.

As outlined in The National Hydrogen Strategy, the demand for hydrogen in the UAE is poised to experience an increase, potentially rising from 2.1 million metric tons per annum (mtpa) to approximately 10.1 mtpa between 2031 and 2050.[5] Leveraging its natural gas reserves, access to solar renewable energy, the advanced position in the global energy sector, and favorable conditions for sustainable and capital-intensive ventures, the UAE is poised to emerge as a global leader in low-carbon hydrogen. The Hydrogen Leadership Roadmap envisions capturing a 25% share of the global low-carbon hydrogen market, with a strategic focus on markets in Japan, South Korea, and Europe.

Looking ahead to the period between 2033 and 2040, the orientation extends beyond domestic usage, emphasizing the exportation of ammonia-based renewable energy from the UAE. Three notable projects driving this initiative include Taziz - Ruwais Chemical Hub (1 million metric tons per annum (mtpa) blue ammonia production), Abu Dhabi in Khalifa Industrial Zone (200,000 metric tons of ammonia and 40,000 metric tons of hydrogen annual production), and the collaborative efforts of TAQA & Abu Dhabi Ports. According to The National Hydrogen Strategy, export potential from the UAE is anticipated to reach 0.6 to 1.8 mtpa by 2031 in low and high export scenarios, with the prospect of surpassing these figures more than fourfold by 2050 (fig.2).

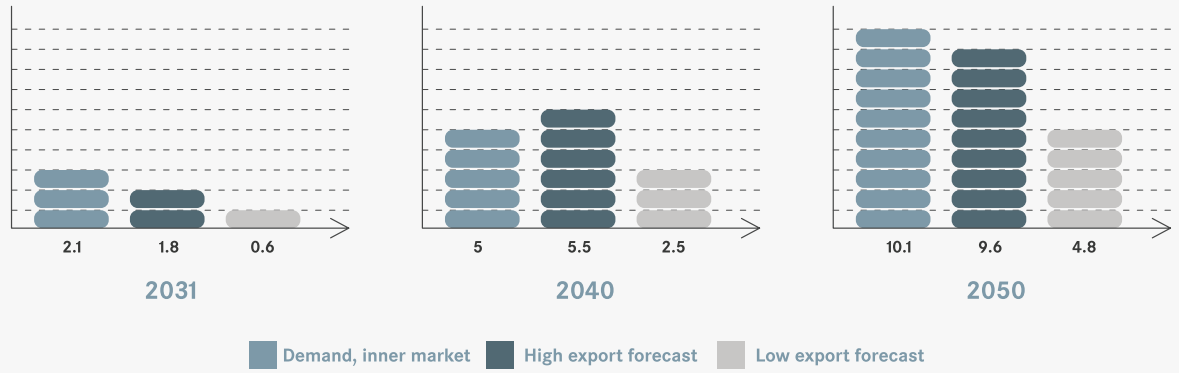


Figure 2: UAE Low Carbon Hydrogen Demand from 2031 to 2050 in mtpa (inner market), and export forecast in two scenarios

The ammonia economy in the UAE is poised to impact the reshaping of the energy industry. The development of ammonia production capacities not only aligns with the country's sustainable goals but also reinforces its leadership position in the global energy resources market.

Report Analysis

Define Scope

Certainly, outlining a high-level plan for the development of an Ammonia Economy in Abu Dhabi across short, medium, and long-term periods requires consideration of current initiatives, regional strategies, and planned projects. The following plan is primarily based on The National Hydrogen Strategy 2050 and The UAE's Hydrogen Leadership Roadmap and Abu Dhabi Department of Energy's Low-Carbon Hydrogen Policy and Regulatory Framework to Accelerate UAE's National Hydrogen Strategy.

Table 2: High-level plan for the development of the Ammonia Economy in Abu Dhabi

Less than 5 years	• Establishment of policy and regulatory framework, including a framework for CO2 emission reduction in hard-to-abate sectors. • Strengthening international collaborations, building on existing partnerships with countries like Japan, Germany, and the Netherlands. • Global recognition of certification schemes for renewable and low-carbon hydrogen and hydrogen derivatives. • Methodology for calculating GHG Emissions from ammonia production. • Establishment of a dedicated committee to support low-carbon hydrogen projects to streamline processes, offer guidance and coordinate efforts to accelerate the development and implementation of hydrogen initiatives. • Creation of pricing mechanisms to support the transition to renewable energy. • Launch of hydrogen Innovation fund. • Launch of new blue and green ammonia capacities, such as the project in Ruwais with one million metric tons per annum planned capacity. • Local specialized talent development. • State support measures for green hydrogen demand.
Between 5 and 10 years	• Launch of the hydrogen oasis in Abu Dhabi – Ruwais. • Surpassing a production capacity of 1.4 MTPA of low-carbon hydrogen and introducing new projects for the creation of renewable ammonia in Abu Dhabi. • Establishment of renewable hydrogen supply chains in domestic markets. • Start exporting renewable ammonia to international markets, particularly in Asia and Europe. • Launch of a new dedicated R&D hydrogen center. • Increasing solar capacities in the country, according to the forecasts, solar capacity is projected to surge by more than 600% to reach 7.3 gigawatts (GW) by 2030.

Table 2: High-level plan for the development of the Ammonia Economy in Abu Dhabi

More than 10 years	• Establishment of the UAE as a leading global producer and exporter of low-carbon hydrogen. • Growing maturity of the green and blue ammonia market with transparent roles of key market players both SMBs and large enterprises. • Reshaping the global energy sector and shifting to renewable energy in the areas where it can be used. • Launch new manufacturing capacities and extension production capacities to reach the target of 15 million metric tons per annum (MTPA) by 2050. • Establishment of an innovation hub for hydrogen in the UAE, serving as a focal point for research, development, and collaboration in hydrogen-related technologies.

Source: Sia Partners Analysis

Scan Environment

PESTEL Analysis

Abu Dhabi is one of the global centers of the emerging renewable hydrogen market. Its huge prospects for development in new energy markets relate to climatic and geographic advantages and strong support transition to renewable energy from the government. The government's commitment extends to the integration of major national enterprises in the development and reshaping processes within the hydrogen industry.

Table 3: PESTEL Analysis of Ammonia Economy in Abu Dhabi

Political	• Government support and investments in ammonia manufacturing. The importance of the Ammonia Economy development is highlighted in strategic UAE and Abu-Dhabi documents. • Essential role of projects in Abu-Dhabi in the realization of the UAE Hydrogen Leadership Roadmap and localization of hydrogen development oases in Abu Dhabi. • Support for R&D and investing in the creation of R&D centers for renewable hydrogen and hydrogen oases to accelerate the technologies and market development. • Ongoing regional developments in hydrogen and ammonia industry production. • Strategic alliances with other countries and plans for new cooperations.
Economical	• Favorable climate for producing cost-effective renewable ammonia. The UAE has three of the most expansive solar power plants on the global market. Solar capacity will be increased to 9.2 GW by 2025 and to 14.21 GW by 2031[6]. • The UAE energy enterprises are already integrated into the end-to-end value chain for hydrogen and ammonia. • Export potential is defined by the favorable geographic positioning of the UAE. • A large inner market for renewable energy with demand from aluminum, steel, aviation, and shipping industries. The UAE's industry sector with heavy-emitting segments contributes to around 46% of the total CO2 emissions[7]. • High prices for natural gas create an opportunity for development and partial replacement of fossil fuels by renewable ammonia. • Several projects to create new capacities of blue and green ammonia are under realization, for example, ADNOC Blue ammonia project[8] and the 2GW Green Hydrogen to Ammonia Project. • The UAE's big state-owned companies engage in hydrogen projects - TAQA, ADNOC, Masdar, Mubadala, EGA, Emirates Steel, Etihad Rail, etc[9].

Table 3: PESTEL analysis

Social	• The UAE workforce has sufficient skills across the energy sector and modern technological markets for sustainable development. • The UAE focuses on attracting expats from developed countries. Sustainability becomes an important factor taken into consideration by well-educated and qualified people when choosing a country to live in.
Technological	• Existing supply chain infrastructure and processes for energy resources storage and transportation (including export) are resilient and efficient. • According to The UAE National Hydrogen Strategy, grey hydrogen production technologies account for 95% of the current supply. Reprioritization of blue and green ammonia will require a respective shift in focus towards newer technologies. • The UAE is attractive for innovative SMEs and start-ups especially in tech for the energy sector, with the planned establishment of a Hydrogen Innovation Hub focused on key R&D priorities by 2025 will become an additional enabler of innovations. • Several R&D projects and initiatives are developed in partnership with local and global organizations, for example, Mubadala Investment Company (Mubadala)[10] and Siemens Energy work to drive investment and development of advanced technology, manufacture of equipment, green hydrogen, and synthetic fuel production.[11]
Environmental	• High priority of the renewable energy sector development. According to the UAE Energy Strategy 2050, it is planned to triple the capacity of renewable energy by 2030 which requires ambitious investment projects. • The Abu Dhabi Climate Change Strategy aims to reduce carbon emissions by 22% by 2027. Ammonia has immense potential to be used for the minimization of CO2 emissions in the marine transport sector, which contributes over 3% of the global carbon footprint[12] • Ammonia also can be used as a fuel in several processes of heavy industries, these industries represent 22% of global emissions [13] • UAE Environment Policy is oriented toward accelerating the efforts to conserve natural resources and boost air quality.
Legal	• Technical standards of production processes and Guarantees-of-origin certification schemes are under development in the global collaboration.

Source: Sia Partners Analysis

The Future Radar

The identified trends are intricately linked to technological and procedural facets of ammonia production and usage, as well as the ongoing evolution and incentivization of the renewable energy market.

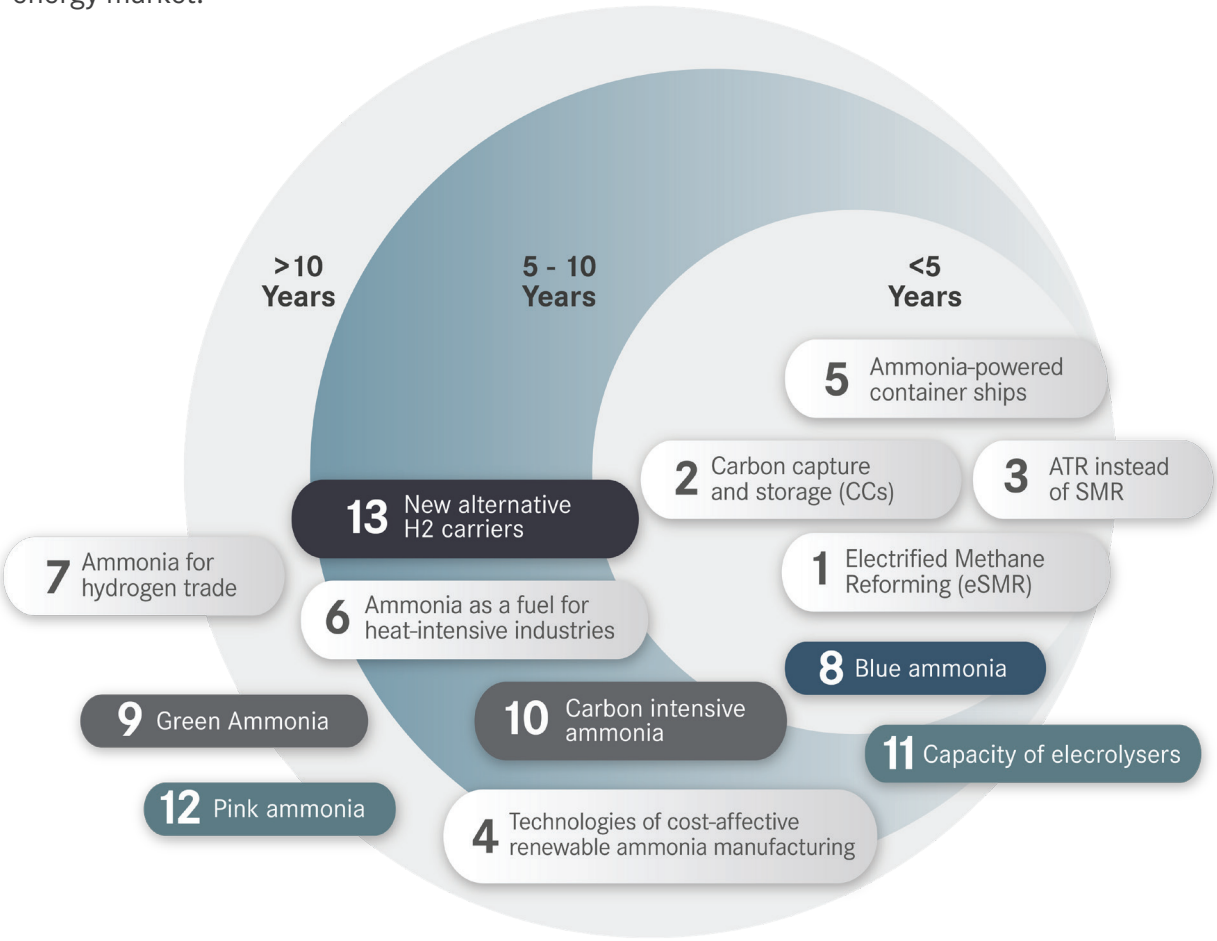


Figure 3: Future Radar with long-term (>10 years), medium-term (5-10 years), and short-term (<5 years) periods

Trends
Manifestation of a direction of change, that usually represent a gradual change, generally long-term, in the factors that will define the future of an organization, business sector or country.

Wildcards
Discontinuities on the usual course of things. They are sudden events with low probability to happen, and high impact on the Focal issue.

Mega-trends
Long-term processes of transformation with a broad scope and dramatic impact. They are powerful factors which shape future markets.

Uncertainties
Factors, events, or trends that are critical drivers for understanding the future dynamics of the focus. These Uncertainties can signficantly impact the future landscape; they define the dynamics that must be monitored and towards which it is crucial to find answers.

Weak Signals
Internal or external warnings that are too incomplete to permit an accurate estimation of their impact, and/or to determine a complete response.

In the short term, the evolution of the ammonia industry will witness a transition from carbon-intensive ammonia production to blue ammonia production. The development of technologies aimed at reducing the carbon footprint of existing carbon-intensive ammonia production facilities signifies a commitment to making the industry more environmentally sustainable. Additionally, the adoption of ammonia as a marine transport fuel, particularly in countries with a proactive hydrogen economy agenda, suggests a growing interest in leveraging ammonia's potential as a cleaner fuel for various applications. The initiation of large pilot projects for using ammonia as a fuel in heat-intensive industries further emphasizes the industry's exploration of diverse applications beyond its traditional uses.

In the medium term, an increase in the production capacity of ammonia industry plants is anticipated. This growth brings forth challenges related to the scaling of electrolyzer production volumes and the exploration of alternative, more efficient methods for hydrogen energy storage and transportation. Should ammonia maintain its status as a main source for hydrogen energy storage and transport, it is foreseeable that global relations in hydrogen fuel trade will develop within the 5–10 year horizon. The active shaping of the global market and the establishment of new supply chains for trade in renewable ammonia suggest a pivotal period between 2030 and 2035. During this timeframe, stakeholders in the ammonia industry will play a crucial role in defining the industry's ecosystem, including traditional ammonia-using industries and emerging applications.

In the long term, the anticipation is for the development of green ammonia production, relying on renewable energy sources. This trajectory will necessitate significant advancements in green ammonia production technologies. A noteworthy application of ammonia in this phase will be its use as a source of hydrogen energy.

Table 4: Future Radar Signals Description

Trends	
Electrified Methane Reforming (eSMR)	This emerging technology suggests partial replacement of the natural gas used in conventional Steam Methane Reforming (SMR) with electricity. This technology is proven and cost-effective. According to current benchmarks, it reduces the CO2 footprint from carbon-intensive ammonia production by about 30%[14]
Carbon capture and storage (CCS)	CCS can be used instead of carbon capture and utilization (CCU) and its adoption will be connected with the process of blue ammonia technologies development with >90% of Carbon capture.[15]
ATR instead of SMR	While Steam Methane Reforming (SMR) is cost-effective and relatively simple to capture, accounting for approximately 50-70% of CO2, the Auto Thermal Reforming (ATR) method enables over 90% capture of carbon. The difference between the two primarily lies in the way heat is provided to activate the endothermic steam reforming reaction; thus, ATR is expected to replace SMR during the transition to blue ammonia.
Technologies of cost-effective renewable ammonia production	The elevated price of renewable ammonia currently constrains its market potential, particularly in traditional applications such as the agriculture industry and chemistry. Nevertheless, the long-term outlook is optimistic, with an anticipated reduction in ammonia prices by 2-3 times by the year 2050.[16]

Source: Sia Partners Analysis

Table 4: Future Radar Signals Description	
Trends	
Ammonia powered container ships	Approximately 90% of global trade is conducted through maritime transportation, with the shipping sector contributing approximately 3% to global CO2 emissions. Presently, this is the most mature and viable scenario for the utilization of ammonia-based fuel.
Ammonia as a fuel for heat-intensive industries	The generation of heat for industrial processes currently contributes to approximately 10% of the global carbon footprint[17]. The retrofitting of gas turbines, furnaces, and internal combustion engines is essential to accommodate the use of renewable ammonia as a fuel in these industrial settings.
Ammonia for hydrogen trade	Ammonia boasts a higher volumetric energy density than liquid hydrogen, enabling the transportation of more energy using less volume. This characteristic renders the transportation of ammonia more cost-effective and logistically feasible, particularly for large- scale export operations.
Mega-trends	
Blue ammonia	Ammonia, produced with technologies (especially- CCS), allows the reduction of over 90% in carbon emissions. The mega-trend serves as a pivotal factor in propelling the development of the ammonia industry. It signifies the transformation of a substantial portion of the existing carbon-intensive ammonia production capacity towards more sustainable processes, predominantly reliant on non-renewable energy sources.
Green ammonia	Ammonia produced using green hydrogen obtained through water electrolysis. The mega-trend represents a long-term developmental trajectory for the ammonia industry, necessitating a fundamental shift in ammonia production technology. This transformation entails substantial capital investment and a significant focus on R&D initiatives.
Weak signals	
Carbon intensive ammonia	Ammonia produced from fossil fuels and dominated among the existing capacities. Over the long term, the market competitiveness of carbon-intensive ammonia is expected to diminish, leading to the necessity for the modernization or phasing-out of existing carbon- intensive ammonia plants.
Uncertainties	
Capacity of electrolysers	Producing renewable ammonia at a commercial scale requires more than 1,000 gigawatts of global electrolyzer capacity: 2,000 times the current availability.[18] The dynamic of the growth of electrolyzer capacities will have an effect on the possible amount of production for ammonia.
Pink ammonia	Pink hydrogen is produced with nuclear energy. Currently technology readiness level for large-scale production is low and this method might become an important one in the long term after R&D and the increase of nuclear energy capacities.
Wildcards	
New alternative H2 carriers	The development of alternative hydrogen carriers, such as Liquid Organic Hydrogen Carriers (LOHC), and the establishment of sustainable and cost-effective manufacturing technologies for these alternatives may pose a potential challenge to the long-term demand for ammonia.

Source: Sia Partners Analysis

Drivers of Change Analysis

The analysis of Drivers of Developmental Change serves as a valuable tool to enhance the comprehensive understanding of the Ammonia Economy and its evolving trends. These key drivers will influence the technology development and implementation and they are strongly interlinked with creating an environment for hydrogen energy and Ammonia Economy sector development.

Table 5: Drivers of Change Analysis

Name	Description	Implications	Options	Impact
Regulatory framework	• Complex regulations for ammonia manufacturers and consumers	• Common carbon footprint accounting rules • Standards for ammonia manufacturers • Rules for licensing ammonia manufacturers • Requirements for information disclosure for ammonia manufacturers • Third-side experts, agencies, and organizations in the area of sustainable development of the ammonia production industry	• The regulatory environment for ammonia manufacturers is transparent and promotes their development	↗ 2023 → 2027 ↘ 2030
Renewable energy sources demand stimulation	• Financial support for blue and green ammonia manufacturers and consumers	• Carbon pricing mechanisms support the industry transition to renewable ammonia in conventional applications • Availability of information about different renewable ammonia manufacturers sustainability levels and CO2 footprint • Special taxes and payments for companies using carbon-intensive ammonia • Support measures for manufacturers and transport companies, using renewable ammonia as a fuel	• Demand for renewable ammonia growth both from traditional applications and companies using ammonia as a fuel	↗ 2027 → 2030 ↘ 2035

Source: Sia Partners Analysis

Table 5: Drivers of Change Analysis

Name	Description	Implications	Options	Impact
Development of hydrogen as one of the main renewable energy sources	• Growing importance of the global green agenda and the role of hydrogen fuels in the energy transition	• International cooperation for the hydrogen economy development • Defined application and widespread practice of hydrogen fuels usage instead of fossil fuel usage	• Stable growing demand for hydrogen fuels from different industries	↗ 2030 → 2035 ↘ 2040

Source: Sia Partners Analysis

Key Uncertainties Analysis

The process of development of the ammonia economy faces several uncertainties, which will affect the ammonia industry developments.

Table 6: Key uncertainties analysis for long-term horizon

Uncertainties	Description	Degree of Potential Impact (L, M, H)	Degree of Uncertainty Impact (L, M, H)
Price of renewable ammonia	• The market competitiveness of renewable ammonia depends on its price compared to carbon-intensive ammonia and other alternative energy sources.	High	Medium
CO2 footprint control level of ammonia customers	• Manufacturers' investments in sustainable development are defined by the importance of achieving a sustainability level, announced in the regulatory framework, global and national rules, and standards.	Low	Low
The amount of new ammonia capacities & their location	• Currently, several countries have started to broaden their ammonia capacities, but to meet the long-term demand a lot of new capacities need to be launched.	High	Medium
Requirements for traditional industries to switch to renewable ammonia	• Shift to the renewables for traditional ammonia customers will reduce their manufacturing margin. Transition to it is possible only if the costs of carbon-intensive ammonia usage are higher.	High	Low
Availability of commodity materials for large-scale renewable ammonia production	• Green ammonia production relies on electrolyzers and to meet the ammonia industry demand for electrolyzers by 2050, the industry will face the challenge to increase capacities two thousand times.[19]	High	Medium
Access to sustainable technologies & processes for large-scale ammonia production	• Most near-zero-emission technologies are not yet available on a commercial scale because of high implementation costs and deficits of industrial plants and raw materials for their realization.	Medium	Low

Source: Sia Partners Analysis

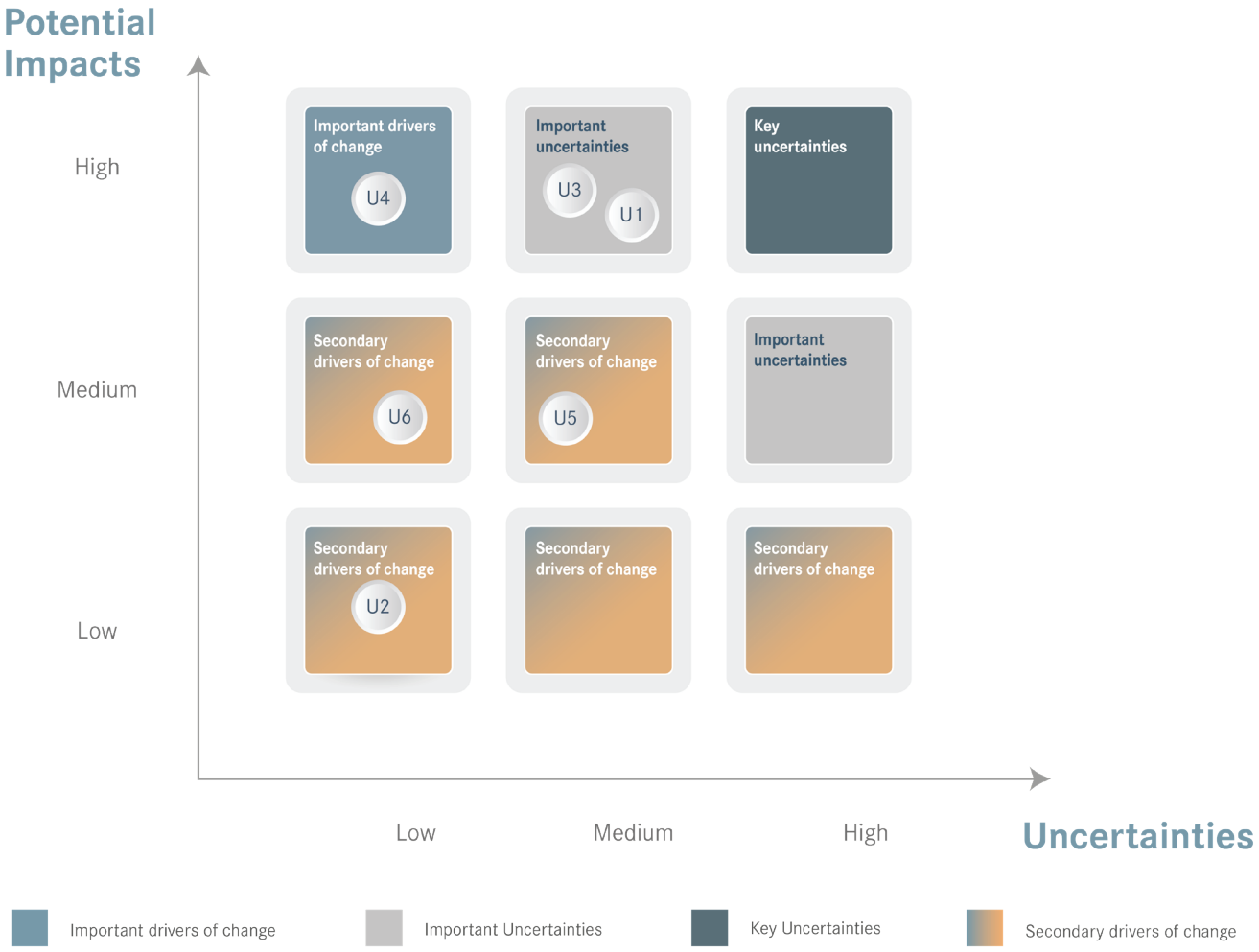


Figure 4: Key Uncertainties Matrix

Source: Sia Partners Analysis

The scenario matrix highlights two pivotal long-term uncertainties.

U1 – Price of renewable ammonia

While there are current estimates for the target competitive price of renewable ammonia in 2030 and 2050, the technologies capable of delivering these price levels are not yet available. This discrepancy highlights a challenge within the industry, indicating a gap between the desired cost goals and the current state of technological readiness.

U3 – The amount of new ammonia capacities and their location

Presently, as outlined in The National Hydrogen Leadership Roadmap, three major projects are expected to increase the production capacity of blue ammonia in the medium term and currently there are no plans for long-term green ammonia scaling up. This uncertainty is further compounded by global market dynamics, where short-term plans for ammonia production capacity are known, but estimates for potential demand, particularly for green ammonia in 2030 and beyond, are speculative.

Build Future Worlds

Scenarios for the Ammonia Economy development can be defined based on 2 parameters affecting the market competitiveness of renewable ammonia in comparison with carbon-intensive ammonia and other renewable energy sources:

- Price of renewable ammonia:

Renewable ammonia is several times more expensive than alternatives (-)

Competitive price of renewable ammonia (+)

- The amount of new ammonia capacities and their location:

Refusal to scale ammonia capacities in Abu-Dhabi (-)

Abu-Dhabi is a global center of renewable ammonia production (+)

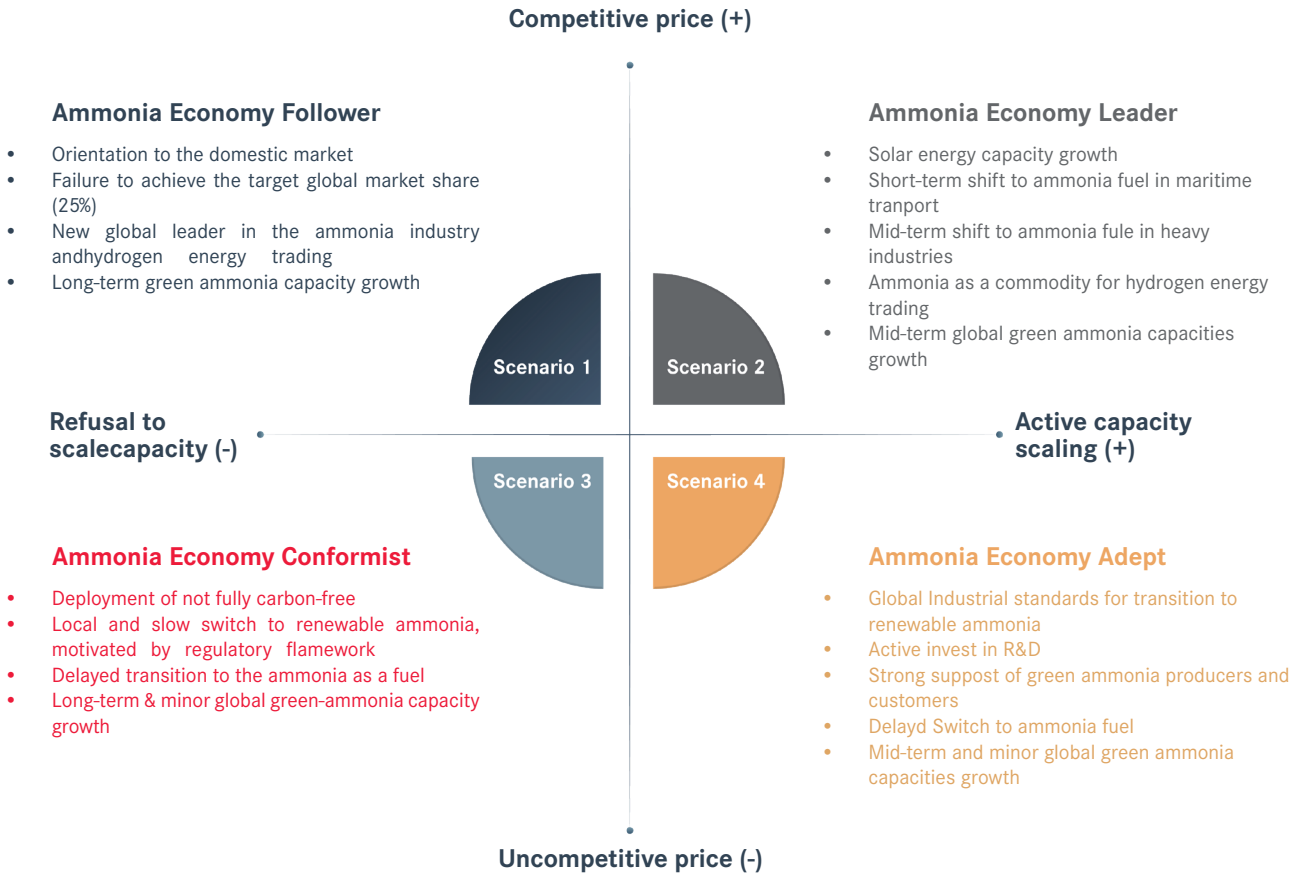


Figure 5 – Future scenario matrix

Source: Sia Partners Analysis

Forecasting potential developments of the Ammonia Economy in the UAE, it is possible to see direct and indirect effects and consequences for the government and society, resulting from the transition to renewable ammonia as a fuel and energy carrier.

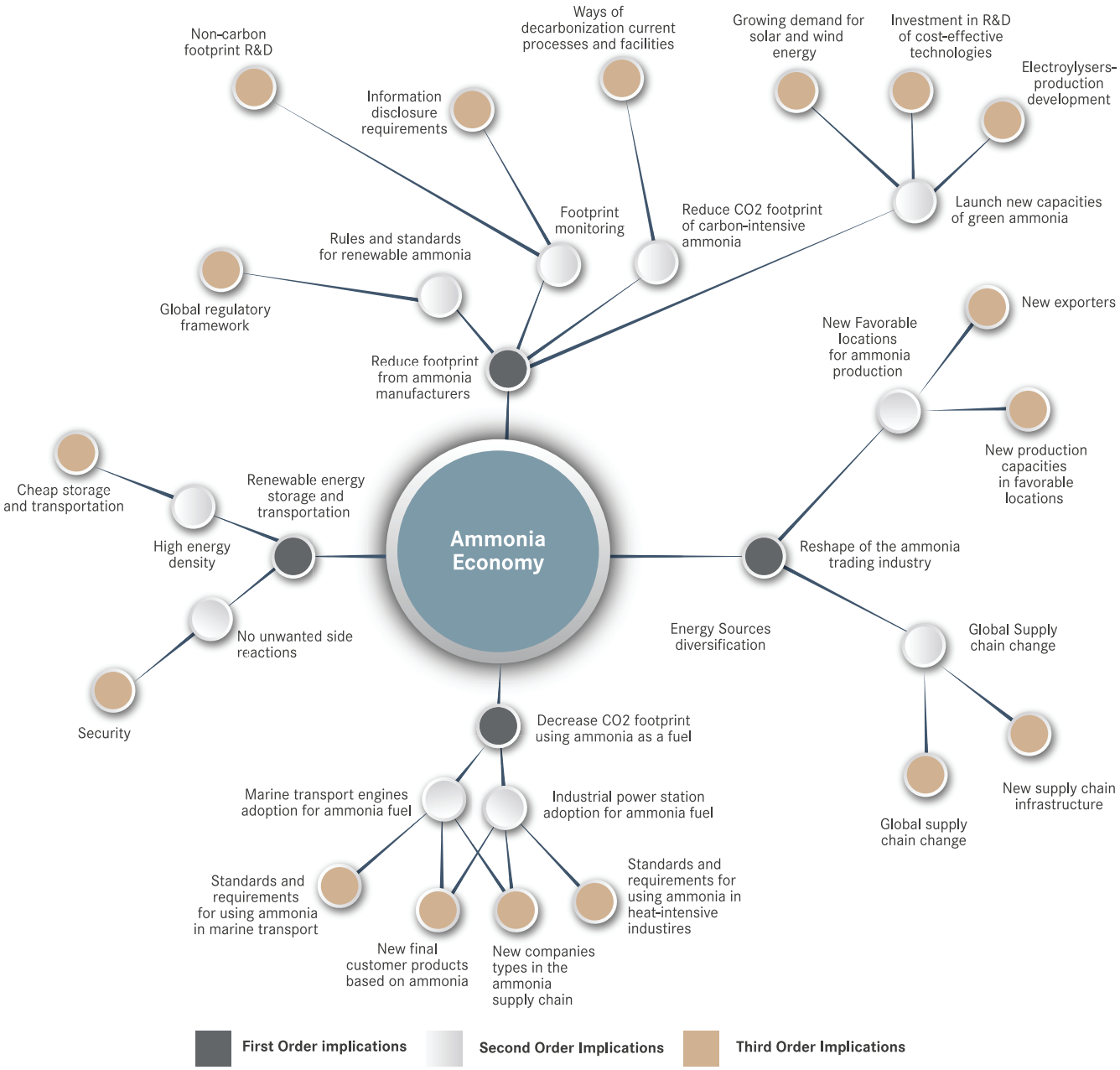


Figure 6: Future Wheels Tool

Source: Sia Partners Analysis

The development of an Ammonia Economy can yield significant implications for the ammonia industry and associated sectors. The high-level outcomes of this development include:

- Availability of cheap, easy, and safe method for storage and transportation of hydrogen renewable energy;
- Production footprint reduction from existing and future ammonia plants;
- Reshaping the ammonia trading industry;
- CO2 footprint reduction using ammonia as fuel.

The most advantageous scenario for Abu Dhabi aligns with the second scenario, characterized by a substantial domestic and global demand for Ammonia. In this scenario, Abu Dhabi will benefit from the rising trend in renewable energy resources. The region's planned capacities for renewable ammonia, coupled with its favorable climate, geographic location, and well-established global supply chain infrastructure for the energy sector, position Abu Dhabi to capitalize on the increasing demand for ammonia as a key energy carrier.

Identify Implications

Based on the results of the previous analysis there were determined 4 possible scenarios for the development of the Ammonia Economy:

Scenario 1 – Ammonia Economy Follower

Competitive price of renewable ammonia

Refusal to scale capacity

The Follower scenario

Envisions a comparable price for renewable ammonia to carbon-intensive ammonia, without significant scaling up of green ammonia production capacity in the UAE. The focus on the domestic UAE market is justified, while the external market development potential remains high.

Market development and product accessibility:

Under this scenario, ammonia consumers will actively and quickly transition first to blue ammonia and then to green ammonia. The introduction of ammonia as a fuel in the water transport sector and stationary power plants is expected to occur on a large scale within the 5–10 year horizon.

Planned projects to expand ammonia production capacity may continue, but their scale will be small and not significantly contribute to the emerging global market for renewable ammonia. There will be localized trade in renewable ammonia and hydrogen with selected countries based on existing supply chains of the ammonia industry.

Necessary steps:

In this scenario, the AD DOE role will primarily involve stimulating the transition of water transport and heavy industries to the use of renewable ammonia as a fuel. AD DOE will need to play a key role in facilitating the development of standards and guidelines for the transition to ammonia as a fuel in these sectors. Prioritizing and supporting projects aimed at adapting engines and plants to use ammonia instead of fossil fuels, along with the development and research in cost-effective renewable ammonia production technologies, will be crucial vectors for the UAE.

Opportunities for further development:

The scenario assumes the development of low-cost green ammonia production technologies and the generation of large amounts of renewable (primarily solar) energy and focuses on creating a supply chain for the domestic market. Low carbon hydrogen export demand scenario of The National Hydrogen Strategy can be realized.

Additionally, the UAE has the potential to effectively integrate into the production chains of products and components that support the ammonia industry, such as establishing active production of electrolyzers for export.

Scenario 2 – Ammonia Economy Leader

Competitive price of renewable ammonia

Active capacity scaling

The Leader scenario

Is highly favorable for the Abu Dhabi ammonia industry as it envisions the attainment of a competitive price for renewable ammonia and a substantial expansion of green ammonia production capacity in the UAE. The plausibility of this scenario hinges on the policies and the level of investment dedicated to the development of the ammonia industry in the Gulf Cooperation Council (GCC) region throughout the 2040-2050 horizon.

Market development and product accessibility:

The scenario envisions a swift reconfiguration of ammonia production, initially increasing the proportion of blue ammonia and subsequently expanding green ammonia capacity. Following the achievement of the 1.4 mtpa renewable hydrogen production target outlined in The National Hydrogen Roadmap by 2031, further scaling of capacity is anticipated.

The scenario envisions widespread adoption of renewable ammonia as the primary source of hydrogen energy. The transition to renewable ammonia consumption is expected to be rapid, potentially occurring within a decade, driven by its competitive cost.

Necessary steps:

A key challenge in this scenario is ensuring an adequate supply of electrolyzers, requiring the establishment of electrolyzer production facilities or competitive imports. The AD DOE's role involves assessing feedstock production capacity to meet the future demands of an expanded ammonia industry.

Moreover, it is crucial to create favorable conditions for active ammonia exports, positioning Abu Dhabi as the central hub of the ammonia industry. Given the extensive development plans of other countries in the GCC region, including Saudi Arabia and Qatar, forging strategic partnerships with them becomes imperative.

Opportunities for further development:

The UAE is expected to actively engage in international cooperation, collaborating with other leading renewable energy countries to address the development of a global regulatory framework for the industry.

The challenge lies in effectively competing with MENA countries to sell renewable ammonia to global markets. To address this challenge, substantial investments in R&D and cost optimization for renewable ammonia production will be essential.

Scenario 3 – Ammonia Economy Adept

Uncompetitive price of renewable ammonia

Active capacity scaling

The Adept scenario

Assumes long-term capacity expansion in Abu Dhabi at uncompetitive renewable ammonia costs. Domestic and external demand for ammonia from the transport and heavy industries may be high and can be successfully met by UAE production capacity. The realization of this scenario is accompanied by complexities and challenges in the marketing of green ammonia.

Market development and product accessibility:

The volume and dynamics of demand for renewable ammonia in the domestic and foreign markets will be largely determined by government and international standards and support measures. Switching to renewable ammonia in this scenario implies a significant increase in costs for ammonia-consuming organizations - primarily the chemical industry and agriculture, so companies will only be incentivized to switch to renewable ammonia if there are no alternatives.

The UAE's potential in the external market is contingent on the development of production technologies and the cost of renewable ammonia in other countries. If the issue of non-competitive costs is addressed globally, the UAE has the potential to become a key player in the global hydrogen energy trading market. Ammonia could be actively utilized as a means of transporting energy to Asian and European countries.

Necessary steps:

The realization of this scenario requires DOE to participate in global cooperation and develop sufficiently stringent measures to regulate the ability to use carbon-intensive ammonia. Restrictions should be expressed in regulatory standards and penalties for their violation, as well as in measures to support demand.

Due to the high level of ammonia consumption by traditional and price-sensitive industries, demand support should be provided through effective pricing methods, financial instruments, and rebates that minimize the high cost of switching to renewable ammonia.

Opportunities for further development:

The development of the UAE ammonia industry will remain localized in Abu Dhabi, and new projects will be developed and implemented in addition to the production capacity expansion projects already launched. This includes incentives and institutional support for ammonia research, necessitating DOE to develop long-term plans for R&D and capacity expansion.

Scenario 4 – Ammonia Economy Conformist

Uncompetitive price of renewable ammonia

Refusal to scale capacity

The Conformist scenario

There is no long-term scaling up of renewable ammonia production capacity in Abu Dhabi, and it is characterized by unattractive prices for renewable ammonia. This scenario is considered the most negative one.

Market development and product accessibility:

While domestic demand for renewable ammonia could be met by production in the UAE, there are risks of not reaching the expected domestic market capacity in the long term, as projected under The National Hydrogen Strategy for 2050. Planned projects to expand ammonia production capacity will continue, but the launch of new projects may be constrained. Even under this projection scenario, starting a new capacity in 2030-2050 will be necessary to fulfill the demand for ammonia from traditional consumer industries.

The market will remain concentrated around key ammonia producers and their existing supply chains. The stakeholder ecosystem of the ammonia market development will form in an inactive manner, focusing on servicing the production and distribution chain of renewable ammonia in the domestic market.

Necessary steps:

It is crucial to develop a plan for scaling up production capacity and R&D in the ammonia industry in the long term and compare it with the plans of other MENA countries that are contenders for leadership in the ammonia industry. Under this scenario, leaders in renewable ammonia production could be other regional players that implement an active ammonia-centric agenda and share favorable climatic and geographical conditions, potentially becoming world leaders in this field. The transition to renewable ammonia will require substantial demand support and the development of a system of requirements and standards for renewable ammonia consumption.

Opportunities for further development:

While effective international cooperation on ammonia industry regulatory issues and participation in global R&D projects is possible, the markets for ammonia produced in the UAE will be individual countries with which there is already active energy trade.

Future Vision

The trend for the formation of the Ammonia Economy is a long-term one, and it will start to develop actively in the horizon of 5 years or more. Therefore, the activities and projects implemented by DOE in this area will be decisive in the short term, when the first signals of the trend emerge, and during the most active growth of the Ammonia Economy and its transition to the commodity stage in 2035-2050.

Based on the analysis of the 4 scenarios, the following recommendations for AD DOE to develop the Ammonia Economy in the country were identified. These recommendations are basic for all 4 scenarios:

Strategic Initiatives:

- Regularly interact on ammonia industry development and capacity scaling with MENA mills, which, in the long term, are also focused on becoming key players in the global renewable ammonia market.
- Develop a plan to construct a supply chain for renewable ammonia in both domestic and export markets and identify new participants in the supply chain, involving Small and Medium-sized Businesses.
- Pinpoint priority foreign markets for the short and medium-term supply of renewable ammonia, evaluate the potential demand from these markets, and assess the readiness of the ammonia supply chain for exports to these countries.
- Create a long-term plan for the supply of plant components and reagents, including electrolyzers, needed to increase ammonia production.

Policies & regulations:

- Develop a transition plan and a system of accompanying renewable ammonia standards for various industries that consume ammonia, as well as industries that can use ammonia as a fuel (water transport, power plant generation).
- Develop a system of support measures for organizations in traditional ammonia-using industries when they switch to renewable ammonia.
- Enforce stricter policies for carbon-intensive ammonia usage.
- Creation mechanisms for environmental impact accounting, to adapt and make more informed carbon-intensive ammonia regulations.

Projects:

- In the short term, prioritize R&D activities in the areas of ammonia production technologies, making them less costly, and adaptation of engines to be fueled by ammonia.
- Determine the essential areas of development in human resources and competencies for the Ammonia Economy. Develop a comprehensive plan for implementing measures in these areas, with a focus on establishing a center for the training and development of specialists in the field of hydrogen economy in the United Arab Emirates.
- Identify long-term plans for scaling up the capacity of the ammonia industry in the state to ensure production volumes are sufficient to meet the 2040-2050 demand for the product.

Appendix

Three Focal Issues of an Ammonia Economy were identified based on the analysis of global trends in the ammonia and related industries, current and planned initiatives of the UAE government, and key ammonia applications.

01. Ammonia-based fuel for transport industry and manufacturing

Ammonia is an alternative zero-carbon liquid fuel and in perspective, its use as fuel might surpass its current primary application as a fertilizer. According to the International Energy Agency[20], to achieve zero emissions by 2050, hydrogen-based fuels like ammonia will account for nearly 30% of transport fuels by 2050. While cars will run on electricity and planes on biofuels, the unique properties of ammonia, such as its high energy density and ease of storage and transport, make it a viable option for the shipping industry and marine transport, however, there is also potential in using ammonia fuel for vehicle engines and power generators.

02. Ammonia for energy storage and delivery

Ammonia is viewed as one of the leading options for storing and transporting energy from renewable power sources to ensure electricity is available when needed. Liquid ammonia is one of the best ways for large-scale, long-term energy storage. Several countries have established national strategies to use green ammonia to store, import, and export renewable energy. Ammonia can act as a profitable hydrogen carrier and enable additional options for international trade in renewable energy.

03. New generation of the ammonia production processes and technologies.

The ammonia production process currently relies on antiquated, energy-intensive industrial methodologies, resulting in substantial greenhouse gas emissions. The ammonia industry, responsible for 1-2% of global carbon emissions, thus stands as a noteworthy contributor to the overall environmental pollution landscape.

Moving forward, the key focus is to shift ammonia production toward environmentally sustainable practices, avoiding pollutive methods. Achieving this requires adopting more sustainable, efficient, and digitally advanced technologies in the manufacturing process.

References

1. INNOVATION OUTLOOK RENEWABLE AMMONIA. IRENA, URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf. Accessed 14 January 2024

2. National Climate Change Plan of the UAE 2017–2050. The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/national-climate-change-plan-of-the-uae. Accessed 20 January 2024

3. UAE Energy Strategy 2050. The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/uae-energy-strategy-2050. Accessed 20 January 2024

4. UAE Environment Policy. The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/policies/environment-and-energy/uae-environment-policy. Accessed 20 January 2024

5. UAE National Hydrogen Strategy. The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/national-hydrogen-strategy. Accessed 22 January 2024

6. Abu Dhabi Climate Change Strategy. The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/abu-dhabi-climate-change-strategy. Accessed 22 January 2024

7. Environment Vision 2030 (Abu Dhabi). The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/environment-vision-2030-abu-dhabi. Accessed 22 January 2024

8. UAE Net Zero 2050. The United Arab Emirates' Government portal, URL: https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange/uae-net-zero-2050. Accessed 22 January 2024

9. National Water and Energy Demand Management Programme. The United Arab Emirates' Government portal, URL: https https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/national-water-and-energy-demand-management-programme. Accessed 22 January 2024

10. UAE Hydrogen Leadership Roadmap. The United Arab Emirates' Government portal, URL: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/-/media/Documents-2023/UAE-Hydrogen-Roadmap--Eng.ashx Accessed 22 January 2024

11. Net Zero by 2050. A Roadmap for the Global Energy Sector. IEA, May 2021, URL: https://www.iea.org/reports/net-zero-by-2050. Accessed 12 January 2024

12. Thyssenkrupp to provide technology for UAE's first green ammonia plant. Ammonia Energy Association, URL: https://www.ammoniaenergy.org/articles/thyssenkrupp-to-provide-technology-for-uaes-first-green-ammonia-plant/ Accessed 14 January 2024

13. Building an ammonia supply chain in the UAE: bunkering, blue, and 2 GW of green ammonia. Ammonia Energy Association, URL https://www.ammoniaenergy.org/articles/building-an-ammonia-supply-chain-in-the-uae/ Accessed 15 January 2024

14. Brooge Renewable Energy Limited Successfully Concludes Feasibility Study for Green Ammonia Project, Ushering in a Bright and Sustainable Energy Future in UAE. Brooge Energy Limited, URL https://broogeenergy.com/press-releases/brooge-renewable-energy-limited-successfully-concludes-feasibility-study-for-green-ammonia-project-ushering-in-a-bright-and-sustainable-energy-future-in-uae/ Accessed 15 January 2024

15. National Hydrogen Strategy. The United Arab Emirates' Government portal, URL https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/national-hydrogen-strategy/ Accessed 16 January 2024

16. Having Achieved 2.3 GW Cumulative Installed Renewable Energy Capacity By 2020, Rystad Energy Expects UAE To Achieve 9 GW By 2025, Dominated By Solar PV With 8.5 GW Share. Taiyangnews, URL https://taiyangnews.info/uae-to-sport-8-5-gw-installed-solar-pv-capacity-by-2025/ Accessed 18 January 2024

17. Accelerating Action Towards a Green, Inclusive and Resilient Economy. United Nations Climate Change, COP28, URL https://unfccc.int/sites/default/files/NDC/2023-07/Third%20Update%20of%20Second%20NDC%20for%20the%20UAE_v15.pdf Accessed 18 January 2024

18. ADNOC to Build World-Scale Blue Ammonia Project. ADNOC, URL https://www.adnoc.ae/news-and-media/press-releases/2021/adnoc-to-build-world-scale-blue-ammonia-project Accessed 18 January 2024

19. Nine key takeaways from the UAE's new Hydrogen Strategy. Allen & Overy, URL https://www.allenovery.com/en-gb/global/news-and-insights/publications/nine-key-takeaways-from-the-uaes-new-hydrogen-strategy Accessed 18 January 2024

20. TAQA Group and Abu Dhabi Ports developing 2GW green hydrogen-to-ammonia project. H2 Energy News, URL https://energynews.biz/taqa-group-and-abu-dhabi-ports-developing-2gw-green-hydrogen-to-ammonia-project/ Accessed 18 January 2024

21. Siemens Energy to drive the development of green hydrogen economy in the Middle East. Siemens-energy, URL https://www.siemens-energy.com/global/en/home/press-releases/siemens-energy-drive-development-green-hydrogen-economy-middle-east.html Accessed 18 January 2024

22. Emissions-free sailing is full steam ahead for ocean-going shipping. European Commission, URL https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going-shipping Accessed 18 January 2024

23. Electrified Methane Reforming Could Reduce Ammonia's CO2 Footprint. Ammonia Energy Association, URL https://www.ammoniaenergy.org/articles/electrified-methane-reforming-could-reduce-ammonias-co2-footprint/ Accessed 19 January 2024

24. Taking climate credit for carbon capture and utilization. LinkedIn, URL: https://www.linkedin.com/pulse/taking-climate-credit-carbon-capture-utilisation-james-tilbury Accessed 19 January 2024

25. Green Ammonia – An Alternative Fuel. Future Bridge, URL https://www.futurebridge.com/industry/perspectives-energy/green-ammonia-an-alternative-fuel/ Accessed 19 January 2024

26. Ammonia in the Mix as an Industrial Energy Source. Ammonia Energy Association, URL https://www.ammoniaenergy.org/articles/ammonia-in-the-mix-as-an-industrial-energy-source/ Accessed 19 January 2024

27. Short-Term Solutions for Bending the Ammonia Emissions Curve. BCG, URL https://www.bcg.com/publications/2023/harnessing-the-potential-of-renewable-ammonia Accessed 19 January 2024

28. Solar energy. The United Arab Emirates' Government portal, URL https://u.ae/en/information-and-services/environment-and-energy/water-and-energy/types-of-energy-sources/solar-energy Accessed 19 January 2024

29. PROGRESS TOWARDS NET ZERO INDUSTRY. Net zero climate, URL https://netzeroclimate.org/sectors/heavy_industry/ Accessed 18 January 2024

30. Accelerating Action Towards a Green, Inclusive and Resilient Economy. United Nations Climate Change, COP28, URL https://unfccc.int/sites/default/files/NDC/2023-07/Third%20Update%20of%20Second%20NDC%20for%20the%20UAE_v15.pdf Accessed 18 January 2024

Glossary

Future Foresight	Is a structured, analytical, interactive, and systematic future-oriented process that aims to better prepare and motivate for change and enhance decision-making, both medium and long-term.
Triggers	Events, signals, or actions that indicate a change or a condition that instigates the need to activate the Future Foresight model.
Environment Scanning	A continuous process of monitoring signals, collecting ideas and insights, organizing information, collecting data on past and current trends, and researching sources of change to relate information about triggers and their relationships internally and in the external environments helps to determine the drivers of change.
Focal Issue	The focal issue is the topic or question that will guide the Future Foresight exercise. The focal issue should be defined as precisely as possible. During the entire foresight project, it will act as an anchor for regaining focus and re-centering discussions.
Time Horizon	The time horizon is the period, usually defined in years, considered in the Future Foresight project. This period is always long-term, although the year defining the long-term may change. Close time horizons are more detailed and rigorous compared with distant time horizons which are more diffuse and general. The ideal Time Horizon for a foresight study is the horizon of ruptures.
Future Worlds	The process of imagining and building alternative futures, including scenarios, future narratives, and generated images and representations of the future.
Scenarios	Scenarios are narratives of alternative environments in which today's decisions may be played out. Scenarios are very powerful communication tools. They knit together multiple facets of the foresight analysis and illustrate the whole through a narrative that can be very effectively recounted, visualized, and discussed.
Models	Models are qualitative or quantitative descriptions of key components of a system and relationships between those components, used to forecast or simulate scenarios and options with the support of historical data. (Part: https://www.ipbes.net/scenarios-models/what)
Trends	A trend is a manifestation of the direction of change. It is usually a gradual and long-term change in the drivers that shape the future of an organization, business sector, or country.
Megatrends	Megatrends are long-term processes of transformation with a broad scope and a dramatic impact. Based on the available evidence, they can be considered powerful factors that will shape the future.
Weak Signals	Weak signals are external or internal warnings that are too incomplete to allow an accurate estimation of their impact and/or to determine what a suitable response should be.

Wild Cards	Wild card is an event with a relatively low probability of occurrence, but an inordinately high impact in the conduct of businesses, catching most people by surprise.
Pre- Determined Elements	Predetermined elements are events where change is largely predictable (or has already occurred), but whose consequences have not yet unfolded. In other words, it is what we know that we know, such as demographic changes, accelerating technology, and increasing health concerns.
Key Uncertainties	Key uncertainties are variables that are essential for understanding the future dynamics of the change. They must have a strong potential impact on the focal issue, a high level of uncertainty, and a high degree of independence. This concept stems from the concept of structural uncertainty; an event that is unique enough not to provide us with an indication of its likelihood, such as the COVID confinement period, prices of a commodity, and international competition.
Net Zero Emissions	The point at which a country, industry, company, etc. removes as many emissions as it produces.
Electrolyser	A key factor for green ammonia production, it uses electricity to split water into hydrogen and oxygen
Ammonia Economy	Use of renewable (blue, green, pink) ammonia as a replacement for fossil fuels, hydrogen energy carrier, and switch of the ammonia industry from black and grey to renewable manufacturing technologies.
Carbon- intensive ammonia	Ammonia produced using traditional carbon-intensive technologies via coal or fossil fuels (usually methane).
Blue ammonia	Ammonia produced via fossil fuels with subsequent carbon capture and storage.
Green ammonia	Ammonia produced via renewable energy sources using water electrolysis and nitrogen from air separation.
Pink ammonia	Ammonia, produced via nuclear energy.
mtpa	Metric tonnes per annum
CCU	The process of capturing CO2 from energy-related sources, transporting it via pipelines, and using it in industrial processes
CCS	A process consisting of the separation of CO2 from energy-related sources, transport to a storage location, and long-term isolation from the atmosphere
Autothermal reforming (ATR)	A process of creating a thermally neutral process by utilizing steam reforming to boost hydrogen production while using partial oxidation to generate heat.
Steam methane reforming (SMR)	A process of extracting dihydrogen from methane using steam at high temperatures at moderate pressures.

دائـــــرة الـــطـــاقـــة
DEPARTMENT OF ENERGY