Indo-German
Energy Forum

Market Study & Location Assessment for Green Ammonia Production in India

Study by:

Deloitte.

On behalf of:

GOVERNMENT OF INDIA
MINISTRY OF NEW
AND RENEWABLE ENERGY

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a descision the
German Bundestage

Imprint

Commissioned on behalf of
Ministry of New and Renewable Energy (MNRE), Govt. of India
Ministry for Economic Affairs and Climate Action (BMWK), Govt. of Germany

Commissioned by
Indo-German Energy Forum Support Office (IGEF-SO)
c/o Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
1st Floor, B-5/2 Safdarjung Enclave
110029 New Delhi, India
Email: info@energyforum.in
Website: www.energyforum.in
Tel.: +91 11 4949 5353

Study by
Deloitte Touché Tohmatsu India LLP
7th Floor, Building 10, Tower B
DLF Cyber City Complex
DLF City Phase-II
Gurgaon – 122002, Haryana, India
Website: www.deloitte.com
Tel.: +91 (124) 679 2000
Fax : +91 (124) 6792012

Advisors/Reviewers
Mr. DMR Panda, GM (Hydrogen), NTPC
Dr. Matthias Schlund, Principal Portfolio Manager, KfW
Mr. Rolf Behrndt, Senior Advisor-Hydrogen, GIZ
Mr. Tobias Winter, Director, IGEF-SO
Mr. Rahul Patballa, Sr. Manager (Hydrogen), NTPC
Mr. Vivek Jha, Expert Consultant
Mr. Gaurav Sharma, Advisor Green Hydrogen, IGEF-SO
Ms. Madhuri Negi, Communications Expert, IGEF-SO
Ms. Divya Joshi, Communications PtX, IGEF-SO
Ms. Pooja Bose, Communications H2UPPP, IGEF-SO

Version: May 2023
Design and Layout: Aspire Design

Table of Contents

List of Figures

List of Tables

Abbreviations

ADNOC	Abu Dhabi National Oil Company
AEA	Ammonia Energy Association
AGHA	Africa Green Hydrogen Alliance
AN	Ammonium Nitrate
ANFO	Ammonium Nitrate Fuel Oil
AREH	Asian Renewable Energy Hub
ARENA	Australia Renewable Energy Agency
AUD	Australian Dollars
CAGR	Compounded Annual Growth Rate
CBAM	Carbon Border Adjustment Mechanism
CCC	Consolidated Contractors
CCUS	Carbon Capture Utilisation Storage
CF	Central Farmers Fertiliser Company
CFCL	Chambal Fertilisers and Chemicals Ltd
CG	Coal Gasification
CIL	Coromandel International Limited
CMS	Carbon Management Service
CNG	Compressed Natural Gas
COD	Commercial Operation Date
COP27	Conference of the Parties
CUF	Capacity Utilisation Factor
DAP	Diammonium Phosphate
DFCL	Deepak Fertilisers and Petrochemicals Corporation Ltd
EBRD	European Bank for Reconstruction and Development
EPCC	Engineering, Procurement, Construction and Commissions
ETS	Emissions Trading System
EU	European Union
GH2	Green Hydrogen
GHG	Green House Gases
GHI	Global Horizontal Irradiation
GJ	Giga Joules
GNFC	Gujarat Narmada Valley Fertilisers & Chemicals
GNH_3	Green Ammonia
GSFC	Gujarat State Fertilisers and Chemicals
GW	Giga Watts
H_2	Hydrogen
HSN	Harmonized System of Nomenclature
HURL	Hindustan Urvarak and Rasayan Limited
IEA	International Energy Agency

IFA	International Fertilization Association
IFFCO	Indian Farmers Fertiliser Cooperative
IGFL	Indo Gulf Fertilisers Limited
IHI	Ishikawajima-Harima Heavy Industries
IMO	International Maritime Organization
INR	Indian National Rupee
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
ISTS	Inter-State Transmission system
KFCL	Kanpur Fertilisers and Cement Limited
KRIBHCO	Krishak Bharati Cooperative
KSFL/ KFL	Kribhco Shyam Fertilisers Limited
KTPA	Kilo tons per annum
LMT	Lakh Metric Tonnes
MAP	Monoammonium phosphate
MENA	Middle East & North Africa
MGO	Marine Gas Oil
MISC	Malaysia International Shipping Corporation
MMBtu	Million Metric British Thermal Units
MNRE	Ministry of New and Renewable Energy
MOP	Muriate of Potash
MRP	Maximum Retail Price
MSME	Micro, Small and Medium Enterprises
MMT	Million Metric tons
MMTPA	Million tons per annum
MW	Mega Watt
MWh	Mega Watt hour
NBS	Nutrient based Subsidy
NFCL	Nagarjuna Fertilisers and Chemicals Limited
NFL	National Fertilisers Limited
NG	Natural Gas
NH3	Ammonia
NHM	National Hydrogen Mission
NOx	Nitrogen Oxide
NPK	Nitrogen, Phosphorus, and Potassium
NPS	New Pricing Scheme
NUP	New Urea Policy
NYK Line	Nippon Yūsen Kabushiki Kaisha
OCI	Orascom Construction Industries
PEM	Proton Exchange Membrane
PLI	Production Linked Incentives
PNG	Piped Natural Gas
PV	Photo voltaic
RAC	Re-Assessed Capacity

RCF	Rashtriya Chemicals & Fertilisers
RE	Renewable Energy
RES	Renewable Energy Sources
RLNG	Regasified Liquefied Natural Gas
SCZone	Suez Canal Economic Zone
SEZ	Special Economic Zones
SFC	Salakta Fertiliser Company
SHI	Samsung Heavy Industries
SMR	Steam Methane Reformation
SSP	Single Super Phosphate
TEN	Target Energy Norms
TPA	Tons per annum
TPD	Tonnes per Day
TPD	Tons per day
TSP	Triple superphosphate
TUV	Technical Inspection Association
UP	Uttar Pradesh
USD	United States Dollar
USGS	United States Geological Survey

Executive summary

India is the third largest GHG emitter in the world, after China and USA, primarily driven by the coal-dominated energy mix. India contributes ~7% of global emission and 89% of total energy requirement is met through fossil fuel – Coal, Oil and Gas. India has recognized the need of emission reduction and has set a goal of achieving 50% installed renewable energy capacity (including hydro) by 2030, followed by achieving net-zero in 2070.

It's worthwhile to note that transition to a renewable energy portfolio is expected to address emissions mostly from the electricity and transport sector. The remaining 40 – 50% (mainly from industry sector) of emissions reduction would require other forms of deep decarbonization. Green hydrogen and its derivatives (mainly ammonia) will most likely play an important role in decarbonizing the sectors that cannot be realistically electrified; the so-called "hard-to-abate" sectors. While green hydrogen has several use cases, green ammonia production has been identified as one of the first applications of green hydrogen to become commercially viable.

Currently, NH3 production process is emission intensive, and it uses gas or coal as the feed. The need to decarbonize NH3 could hence act as a demand bridge or stimulator for the development of NH3 as low carbon fuel and/or H2 carrier. This study focuses on commercial feasibility of a 1000 TPD green ammonia production plant in India. The study has four (4) modules: a) Domestic market study, b) International market study, c) Price competitive analysis of green ammonia and d) Location assessment of a 1000 TPD green ammonia plant.

Module 1: Domestic Market Assessment for Green Ammonia

India currently consumes ~18.3 million tons of ammonia across industries, such as fertiliser, mining, pharmaceuticals, chemicals, refrigeration and textile. Fertiliser is the largest consumer with more than 90% share as it is the main input for providing nitrogen in all nitrogenous fertilisers. Urea is the main nitrogenous fertiliser with 80% contribution towards total ammonia consumption in the sector; others include Diammonium phosphate (DAP) and various grades of complex fertiliser having different nitrogen content.

Due to continuous nature of operation of fertiliser plants, fertiliser producers have developed in-house captive ammonia production units (grey ammonia) to meet the inhouse demand. Any excess ammonia production by the units is either sent to other consumer categories through direct short-term supply contracts or sold to the traders. Traders play an important role by aggregating the demand from consumers. Demand aggregation helps traders to negotiate on higher volumes and competitive prices for customers. Fragmented ammonia consumers prefer dealing through traders as they act as a central focal point for demand supply aggregation across the segments. Traders also provide logistics services to the customers.

Domestic merchant market contributes only 2 – 3% in the total ammonia demand while imports contribute up to ~15%. The imports of ammonia in India are mostly from countries with availability of cheap natural gas, such as Qatar, Saudi Arabia, Bahrain, Ukraine, and Egypt. India's ammonia imports typically satisfy partial demand located near ports. Inland transportation of ammonia is minimal (only the limited quantity aggregated by traders for small consumers).

The cost of grey ammonia production in India in 2022 ranges from USD 640 – 660 per ton at delivered natural gas price of USD 12/MMBTU; natural gas cost contributes 60 – 65% of total cost of grey ammonia production. The current pricing methodology of natural gas enables fertiliser companies to steer through volatility of international spot markets. Priority allotment of domestic natural gas to fertiliser producers ensures lower dependence of imported gas as well.

Currently, green ammonia is expensive. Current cost of production is USD 900 - 950 per ton at a landed cost of electricity of USD 60/MWh. It is important to note that for green ammonia production, round-the-clock RE is preferred as ammonia synthesis loop is a continuous process, which faces operational challenges in frequent ramp-up and ramp down. In India, without any carbon tax imposed, green ammonia is likely to be viable only at an elevated gas price (more than USD 10/MMBtu) and low renewable electricity cost for electrolysis (USD 30 – 40/MWh with CUF more than 75%).

India's fertiliser sector is highly subsidized. Urea is the most prevalent fertiliser, and any price rise in inputs is completely passed through and supported by increase in subsidy by Government of India. Existing urea plants could switch to 10 – 20% green ammonia, without minimum capex implication (retrofitting, layout changes etc.). However, this would escalate the subsidy requirement further due to higher operating expenditure of fertiliser units for using green ammonia. It has been estimated that 20% urea decarbonization would increase the annual subsidy requirement by INR 6000 – 7000 Cr (~$0.8 billion). The increase in subsidy is to compensate the incremental cost of green ammonia over grey ammonia.

In case of other prevalent fertilisers, such as DAP and complex fertilisers, 100% substitution of grey ammonia with green ammonia is more feasible. However, this will also have impact on subsidy disbursement from Government of India.

Recognizing the importance of green hydrogen and derivatives, in 2021, the Government of India launched the National Hydrogen Mission (NHM) to lay out its vision, intent, and direction for harnessing hydrogen energy. It was followed by the release of National Green Hydrogen Policy. The policy intends to facilitate green hydrogen adoption by bringing down the costs of green hydrogen and easing the setting up of green hydrogen projects. The government's hydrogen vision was further cemented as the Union Cabinet approved the provisions of NHM by sanctioning INR 19,744 crore outlay with an aim to make India a global hub for green hydrogen in January 2023. The mission aims to reach an annual green hydrogen (or derivatives) production to a minimum of 5 MMTPA by 2030 and sets an aspirational target to capture 10 percent of the global demand (expected to become 100 MMTPA by 2030). The announcement of incentives along with the aspirational production target, positions India as one of the attractive destinations globally for green hydrogen production.

The future demand of green ammonia in India is primarily expected to be from fertiliser production, with limited demand from marine fuel, power generation, and as a hydrogen carrier. The growth of fertiliser demand in the country is expected to be modest till 2040 at a CAGR of ~1% due to increasing efficiency and adoption of precision farming. The ammonia demand from fertiliser sector is expected to reach 18 million tons in 2025 and ~20 million tons in 2040. However, actual demand of green ammonia will depend on fertiliser production mix and actual substitution by the manufacturers – urea has a substitution potential up to 20% while DAP and complex fertilisers have 100% substitution potential. For example, with an overall substitution of 20% grey ammonia by 2040, green ammonia demand is expected to touch ~4 million tons.

Ammonia's usage as a marine fuel is a global phenomenon and is expected to pick up after 2030 only. The technology has not yet matured, and ships have to be re-engineered to run on ammonia. Ammonia can also be considered as a potential co-firing fuel in the coal fired power plants. However, the major challenge for ammonia as a substitute to coal is its unfavorable cost economics. In a country like India with availability of cheap renewables, power sector decarbonization will most likely to be led by deployment of grid scale renewable energy than by firing green ammonia in boilers.

The next relevant use case for ammonia is in its ability to be used as a hydrogen carrier. In reality, storing and transporting hydrogen is extremely difficult as the hydrogen molecules are small and light. Ammonia, as a hydrogen carrier, can be transported as a liquid at room temperature at the right pressure. In addition, ammonia is being transported in chemical manufacturing for decades which ensures availability of infrastructure, and that can be leveraged for further expansion. However, there are economic and technical challenges with this use case. The entire process (hydrogen – ammonia – hydrogen) involves energy losses through the chain and is expensive. H2 production from ammonia cracking may escalate the delivered cost of hydrogen by USD 1.5 – 2.0/kg. Hence, whilst ammonia offers a reasonable solution to transporting hydrogen in general, it is not expected to be adopted widely. Rather it is expected that the vast majority of hydrogen to be generated locally.

Recognizing the potential applications of green hydrogen and ammonia, several large scale projects have been announced. However, on-ground development is limited. Off-take assurance, bankability of projects and unfavorable cost structure are major deterrents. Developers are most likely to wait and watch the domestic and global demand supply scenario.

To develop the domestic ecosystem for green hydrogen and ammonia, there is an immediate need to establish a robust standard (globally harmonized) and certification mechanism to support the market development for green ammonia. The Certification Scheme will quantify the absolute GHG emissions associated with ammonia production and enable prospective producers and off-takers to trade ammonia based on certified, transparent, and verifiable emission reductions.

Module 2: International market study

Global ammonia demand was ~185 million tons in 2021. **The sector accounts for ~1.3% of the global emissions and 5% of the industrial emissions as well**. Emissions from current ammonia production is ~450 million tons of CO2, driven by use of natural gas and coal in the production process. Emissions per ton of ammonia production with SMR (Steam Methane Reformation) is 2.2 – 2.4 tons CO2 eq. and with the coal gasification route, it is 3.2 – 3.6 tons. Over 70% of global ammonia production is via natural gas-based steam reforming, while the remainder is via coal gasification. From a regional consumption perspective, China is the largest consumer as well as producer with ~25% share (~45 MMT), followed by North America (22 MMT), Europe (18 MMT), India (18 MMT) and Middle East (15.1 MMT).

Nearly 70% of the gross ammonia consumption is concentrated with fertilisers, with Urea having the largest share. The remaining is consumed in other industrial applications viz. chemicals, textiles, pharmaceuticals, mining, others. Fertiliser producers across the globe rely on captive setups. Contribution of international trade (~10%) and domestic merchant transaction (~15%) is limited. USA and China are the largest domestic merchant markets for ammonia. Deep sea trade and merchant volumes of ammonia largely includes the transactions between large players and imports done by traders.

The top importers of ammonia are USA, India, Morocco, South Korea, Belgium, Turkey, China, Mexico, Norway, and Taiwan and they represent ~70% of the traded volumes in 2021. The top exporters are Trinidad & Tobago, Russia, Indonesia, Algeria, Saudi Arabia, Canada, Qatar, Egypt, Iran, and Malaysia.

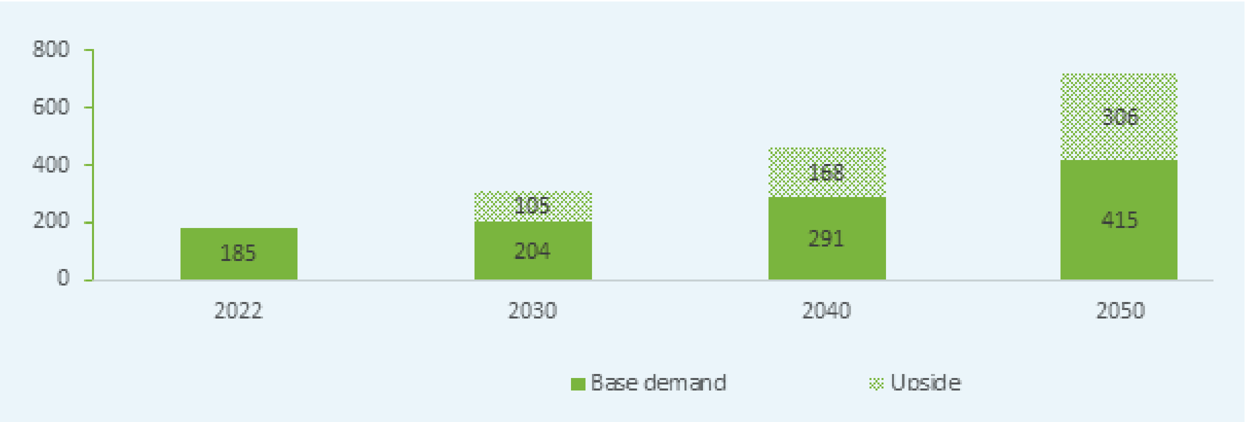
Globally, there is an increasing focus towards decarbonization of traditional ammonia applications (fertiliser and industrial) and use of green ammonia as a decarbonizing agent for several new applications (shipping, power generation and as hydrogen carrier). As a first step, several geographies, such as European Union, the USA, South Korea, and Japan have brought out policies and regulations to enable clean hydrogen/ammonia transitions in fertilisers, marine industry, and power sector. The increase in demand is expected to be driven by these conducive regulations, policies, and initiatives such as the EU ETS (Emission Trading Scheme), CBAM (Carbon Border Adjustment Mechanism), US IRA (inflation reduction act), marine decarbonization targets, and ammonia mandates in power generation.

- **EU ETS and CBAM:** The EU ETS assesses the carbon tax on emissions in the region, and CBAM penalizes high-carbon imports to prevent 'carbon leakage'. Implementation of CBAM is critical component of ETS to mitigate carbon leakage. With these schemes in place, demand for blue or green ammonia is likely to increase in the EU.
- **US IRA:** In August 2022, the US Congress passed the Inflation Reduction Act (IRA), introducing incentives to make green hydrogen cost competitive. The IRA will provide a "production tax credit" (PTC) between \$0.6/kg and \$3/kg for clean hydrogen development in the country if certain wage and labor requirements are met. This act is expected to be the game changer in global hydrogen ecosystem. Many developers are considering setting up projects in USA to cater demand from domestic as well as EU market – the current subsidy can compensate the transportation cost to Europe and ammonia cracking cost.
- **Ammonia mandates in power generation:** Globally, Japan and South Korea are two nations with focus on ammonia as a power generation fuel to achieve their decarbonization plans. However, going forward, some more countries may unveil similar plans.
- **Marine decarbonization target:** Ammonia has been identified as a future marine fuel along with methanol by the IMO (International Maritime Organization) in its 2030 and 2050 carbon intensity reduction roadmaps. Based on the physical and chemical properties, ammonia stands out as an alternative with low carbon footprint. The IMO has set targets for 50% reduction in GHG emissions by 2050 from 2008 levels and adopts a phase wise strategy. The EU Renewable Energy Directive II also targets renewable energy content in transport by 2030 and is a key driver for ammonia usage in maritime industry in the EU

Future demand of green ammonia is expected to be generated from both conventional and new application use; however, new applications are expected to contribute more than 50% by 2050.

- **Demand from shipping industry:** Ammonia is being considered as a future marine fuel. The demand of ammonia as forecasted by different agencies ranges between 2 – 37 MMT and 127 – 245 MMT in 2030 and 2050 respectively. As per recent developments, ammonia fueled engines are expected to be ready for commercialization by 2028–2030. With declining cost structure, ammonia is expected to gain more global acceptance as the alternative shipping fuel. However, additional focus would be required mitigate the NOx risk.
- **Demand from power generation:** Ammonia demand from power generation is expected to pick up in countries with high coal-based power generation and high cost of RE power production (or non-availability of RE potential). Japan, South Korea, and Taiwan are most likely countries to adopt NH_3 co-firing whereas India and China may initiate demonstration projects. Forecasted demand of green ammonia for power generation is expected to be in the range of 14 – 84 MMT by 2050; however, the generation assets would require significant modifications and de-NOx arrangements.
- **Demand from conventional applications (fertiliser and industrials):** Overall demand of ammonia from conventional applications (fertilisers and chemical industries) is expected to be in the range of 198 – 216 MMT in 2030 and 232 – 265 MMT in 2050. The demand for low carbon ammonia would be majorly driven by the emission reduction targets of fertiliser producers globally.
- **Demand as hydrogen carrier:** Ammonia demand as a hydrogen carrier is expected to be in the range of 21 – 127 MMT by 2050. While NH_3 is a mature technology to carry H_2 but may be uncompetitive due to uncertainty in cracking technology and associated energy losses through the value chain. Also, there is a risk of emergence of alternative H_2 carrier (e.g., LOHC) as more competitive

Figure: Overall demand of ammonia (MMT) in 2050



Significant quantity of future global ammonia demand is expected to be low carbon ammonia. While conventional applications (fertiliser and industries) will still have some use of grey ammonia, all new applications will demand only low carbon ammonia (green or blue depending on economics). The corresponding supply of green ammonia is envisaged to be from countries that enjoy low-cost renewable energy and availability of port infrastructure.

Regions with good RE potential (especially solar) and availability of government incentives are likely to emerged as global supply hubs for green ammonia. Major hubs include Oman and Saudi Arabia in the Middle East, Morocco and Egypt in the North Africa, Namibia in the Southern Africa, Australia, Chile in Latin America, USA and India. Europe is expected to be one of the major demand centers for green ammonia with nearly 50% dependence on import.

Importing ammonia from regions with low-cost renewables might be attractive for some countries (e.g., EU, Japan, Korea etc.). Government to Government collaboration and agreements are crucial to start piloting routes to ensure a global supply chain is established over time. As per analysis, Europe, Japan and Korea are likely to be major importers of hydrogen or ammonia, and MENA, Chile, India, Australia and USA are likely to be potential exporters. Many governments are forging bilateral deals for green ammonia/hydrogen in order to achieve energy security and meet the climate targets. These deals range from feasibility studies to signing memorandums of understanding, energy partnerships, and trial shipments. While India plans to emerge as an export hub, it is yet to forge any bilateral agreement or MoU with other governments, such as EU nations, Japan, Korea etc.

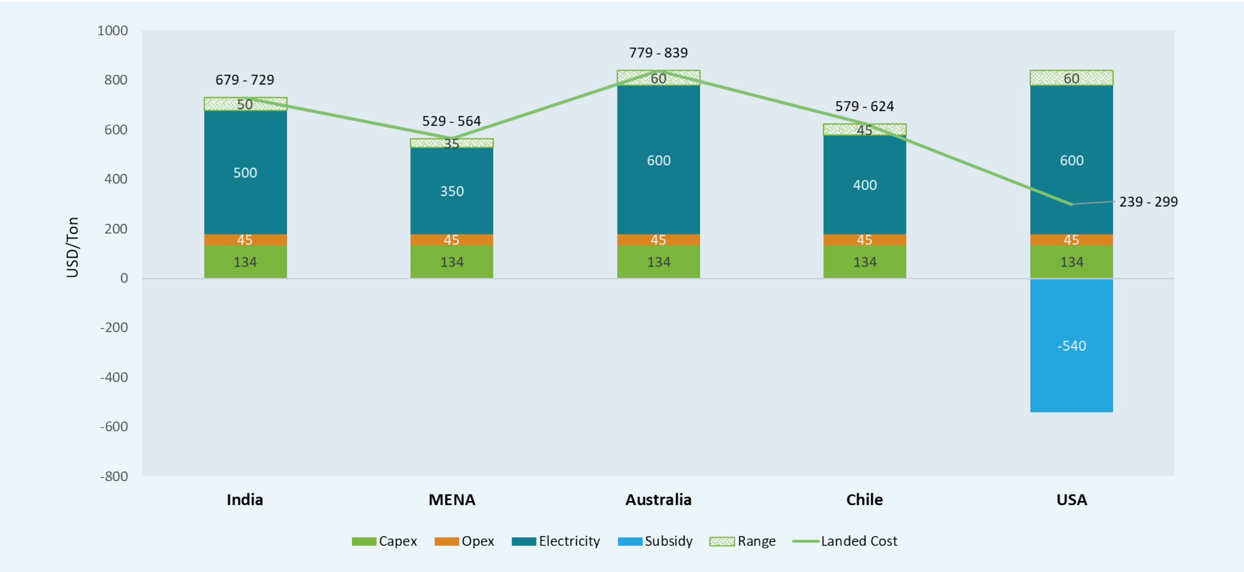
Module 3: Price competitiveness assessment

Natural gas is the primary feedstock for ammonia production globally. Global gas spot prices, especially European gas prices have hit exceptional highs in 2022 due to drop in Russian gas exports. The increase in natural gas prices was reflected through increase in grey ammonia price globally. During April 2022, ammonia spot price peaked at USD 1600/Ton; with some moderation of gas price, price touched ~USD 975/Ton in January 2023.

In the medium to long run, the gas price is likely to stabilize at around USD 9 – 10/MMBTU; but earlier price level of USD 3 – 6/MMBTU is unlikely. Without any carbon tax, the cost of production of grey ammonia in major demand centers is expected to be USD 600 – 650/ton.

Cost of production of green ammonia in major supply hubs primarily depends on levelized cost of renewable electricity and amount of subsidy offered towards hydrogen (or derivatives) production. Based on the prevailing RE tariff and considering 50% reduction in electrolyzer capex, the cost of green ammonia production by 2030 across geographies (USD/ton) is illustrated below:

Figure: Cost of green ammonia production in major supply hubs (2030)



Apart from USA, MENA region is expected to be the second-best destination for developers due to low cost of electricity, followed by Chile, India, and Australia. It is important to note that shipping cost is not significant with respect to the cost of production. Also, within shipping cost, 40 - 50% is fixed cost towards port charges and vessel capex. Therefore, producing cheap ammonia in locations with good RE potential and other support schemes is more critical to achieve price competitiveness.

At current market price of green ammonia and other alternative fuels, green ammonia is only feasible for fertiliser industry in certain geographies with high natural gas price. For other industries, such as power and shipping, economics are not still favorable. There is a need of imposition of carbon penalty to increase acceptance of green ammonia as an alternative fuel. "Willingness to Pay" for green ammonia in various industries differs region wise based on availability and cost of energy resources.

While there have been announcements of projects, on-ground progress on offtake contract finalization is limited. Most of the agreements are in the MoU stage and are non-binding in nature. As there is an anticipated price reduction of green ammonia, off takers prefer to "wait and watch".

In India, large scale deployment of green ammonia projects can be supported by demand aggregation, both from domestic and international consumers; the aggregation can be done by some identified organization/ institution (government entity or government appointed nodal body). Based on the aggregated demand through a combination of multiple contracts of different quantities and tenure, the aggregator can sign

"Ammonia (or Hydrogen) Purchase Agreement" with domestic producers and "Ammonia (or Hydrogen) Supply Agreement" with consumers. Domestic aggregation can be supported by taking a cluster specific approach. Setting up green hydrogen/ammonia projects at the vicinity of industrial clusters (demand centers) can help in scaling up of green ammonia use.

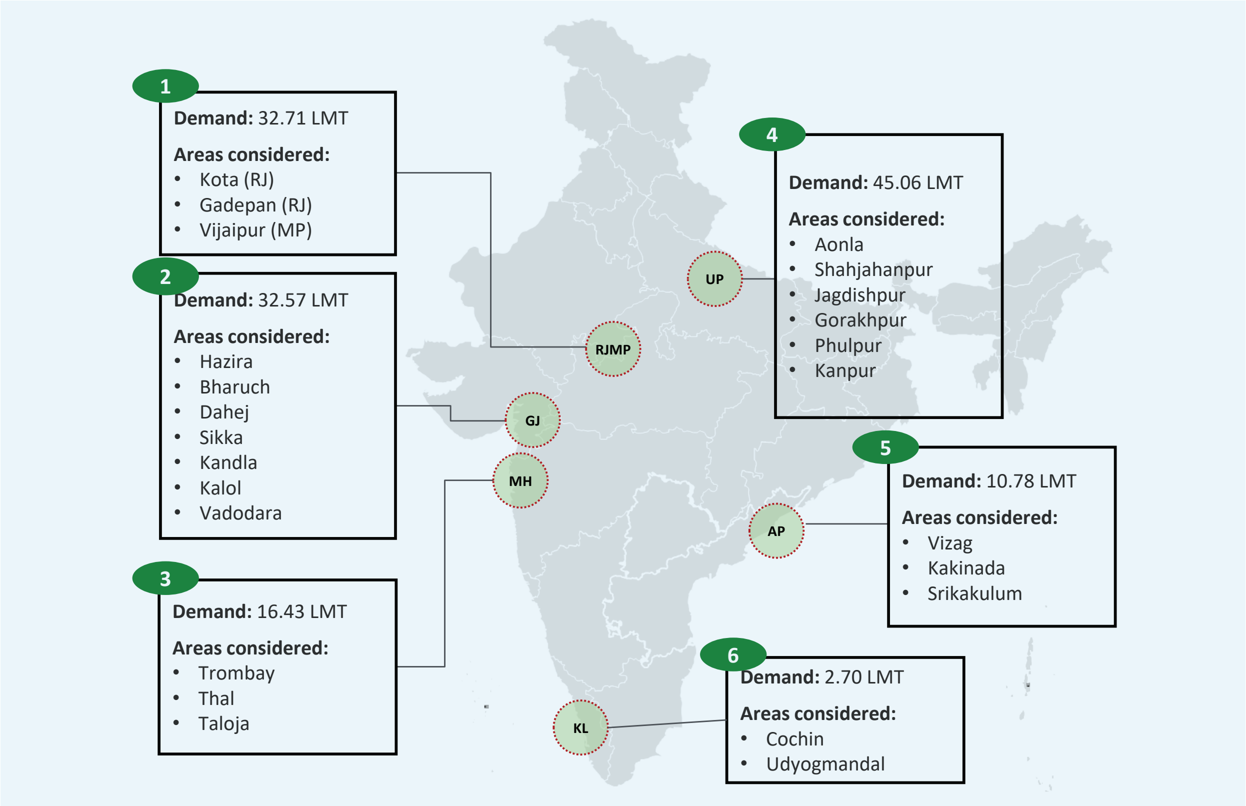
India's fertiliser sector is Urea heavy, where decarbonization potential is limited (maximum 20% in current scenario). While DAP and complex fertilisers (NPKs) have higher potential, overall consumption in current scenario is limited to ~2.5 million tons. It is expected that transition to green ammonia is likely to happen in phases (it may start with 10 – 15% obligation, and then gradually increases based on potential and economics). Overall demand is likely to be fragmented across pan-India in the initial years. Therefore, demand aggregation could emerge as a feasible option to meet the fragmented demand.

Module 4: Locational assessment

In India, demand of ammonia is concentrated in the states of Gujarat, Uttar Pradesh, Maharashtra, Rajasthan, Madhya Pradesh, and Andhra Pradesh due to presence of large fertiliser plants in these states. With anticipated demand mandates for green molecules (till cost parity between green and grey ammonia is achieved), some demand of green ammonia is expected to be generated from these fertiliser plants. In addition to the domestic demand, export opportunities are expected from major demand centers like EU, Japan and Korea. Therefore, a greenfield green ammonia plant should be located strategically to cater domestic demand as well as export demand. A cluster-based approach has been adopted to assess the domestic demand.

Based on the location of the fertiliser plants, six (6) clusters have been identified aggregating the ammonia demand from fertiliser production. These clusters were further examined and analyzed through a "prioritization framework".

***Figure:* Ammonia demand clusters in India**



Key attributes of the clusters are illustrated below:

- **Gujarat** – large demand, good solar and wind potential, good access to ports with ammonia terminal, better ease of doing rank
- **Andhra Pradesh** – moderate demand, moderate solar and wind potential, good access to ports with ammonia terminal, better ease of doing business rank; in addition, fertiliser producers have history of importing ammonia, making them easy target for green ammonia consumption
- **Maharashtra** – Low to moderate demand, moderate solar to wind potential, good access to ports with ammonia terminal, medium ease of doing business rank
- **Kerala** – Low demand, low solar but good wind potential, good access to ports with ammonia terminal, low ease of doing business rank. While domestic ammonia demand is low, state level RE policies are conducive and it is planning for a dedicated green hydrogen policy. In addition, Kerala ports can be considered as suitable location for setting up a bunkering arrangement.
- **Uttar Pradesh** - moderate demand, low solar and wind potential, no access to ports, medium ease of doing business rank; while the state is planning to come up with a dedicated hydrogen policy, inaccessibility of port makes it a less attractive cluster. UP has large number of fertiliser plants, but all produce only urea, therefore limiting the demand potential.
- **Rajasthan-MP** – low to moderate demand, moderate solar and wind potential, no access to ports, medium ease of doing business rank

A near-term market development would be possible by identifying attractive fertiliser clusters and aggregating demand from those. Those clusters can be served through localized ammonia production. While all of the above clusters provide opportunities for aggregating localized demand, most attractive locations for setting up a 1000 TPD green ammonia plant are the clusters located at Gujarat, Andhra Pradesh and Kerala (considering future bunkering opportunity).

Overall, the three clusters have sufficient domestic substitutable demand for ammonia and additional demand can be explored from export market and from supply of ammonia as bunkering fuel. The domestic demand is likely to be activated through anticipated demand mandates for fertiliser industries.

1. Introduction

1.1 Context

India is the third largest GHG emitter in the world, after China and USA, primarily driven by the coal-dominated energy mix. India contributes ~7% of global emission and 89% of total energy requirement is met through fossil fuel – Coal, Oil and Gas[1]. As of 2020, India's total emission was ~2500 million ton, and more than 40% of total emissions are attributed to the electricity sector[2]. Coal alone accounts for nearly 75% of India's energy related emissions. The second largest contributor to emissions is oil, primarily driven by the transport sector. However, India is amongst the few countries to have adopted emissions reduction targets. It has set a goal of achieving 50% installed renewable energy capacity (including hydro) by 2030, followed by achieving net-zero in 2070[3]. The task is daunting for the country considering significant economic growth and rise in population over the coming decades are expected to drive the country's energy needs and potential energy security risks arising out of meeting the energy need.

It's worthwhile to note that despite significant progress in adding RE in the last few years, India is still largely a fossil fuel-based energy economy. Transition to a renewable energy portfolio is expected to predominantly address emissions from the electricity and transport sector4. The remaining 40 – 50% (mainly from industry sector) of emissions reduction would require other forms of deep decarbonization. Green hydrogen and its derivatives (mainly ammonia) will most likely play an important role in decarbonizing the sectors that cannot be realistically electrified; the so-called "hard-to-abate" sectors. These are the sectors where hydrogen is used as a feedstock (fertiliser, refinery, methanol etc.) or high temperature heat is used as a source of energy (steel, process industry, conventional power generation etc.). Green hydrogen and its derivatives are expected to contribute in

- Substituting certain percentage of the existing usage of grey hydrogen (fossil fuel hydrogen), and
- Decarbonizing the economy's hard-to-abate sectors, where hydrogen can emerge as a commercially viable energy source

While green hydrogen has several use cases, green ammonia production has been identified as one of the first applications of green hydrogen to become commercially viable. Ammonia (NH3) is a colorless, non-flammable (at normal temperature and pressure) gas with a pungent odor, made up of three hydrogen atoms and one nitrogen atom. Ammonia is one of the most produced chemicals with ~183 MMT produced globally in 20215. It is used mainly in the production of urea & other nitrogenous fertilisers, nitric acid, ammonium nitrates and ammonium phosphate, and the rest is used for the manufacture of nitrogen-based explosives, refrigerants and other industrial applications. Looking forward, however, NH3 offers potential as use as a low-carbon fuel and as a hydrogen carrier. A detail assessment on domestic and global demand-supply is captured in the later part of this report.

Currently, NH3 is produced by combining atmospheric N2 with H2 typically derived from gas or coal and hence producing significant CO2 as a by-product. Existing NH3 production will hence need to be decarbonized and this will involve the substitution of Grey (from natural gas) NH3 routes with Green (H2 from renewables). The requirement to decarbonize existing NH3 production could hence act as a demand bridge or stimulator for the development of NH3 as low carbon fuel and/or H2 carrier. However, in India, the demand of green ammonia is likely to emerge mainly from the use of green feedstock, at least in the initial years.

1 IEA – India Energy Outlook 2021
2 IEA (access here)
3 PIB (access here)
4 Considering no constraint for electrification of transport
5 Ammonia Technology Roadmap, IEA, 2022

This study is focused on to analyze commercial feasibility of a 1000 TPD green ammonia production plant in India. The study has four (4) modules:

- Module 1: Domestic market study
- Module 2: International market study
- Module 3: Price competitive analysis of green ammonia
- Module 4: Location assessment of a 1000 TPD green ammonia plant

Each of the above modules are elaborated in the following chapters.

2. Domestic Market Study

Module 1 captures the essence of domestic ammonia market, with focus on demand-supply scenario, identification of key consumers, current pricing regime and feasibility of green ammonia substituting grey ammonia in various end-use sectors.

2.1 Introduction to Ammonia

2.1.1 What is ammonia

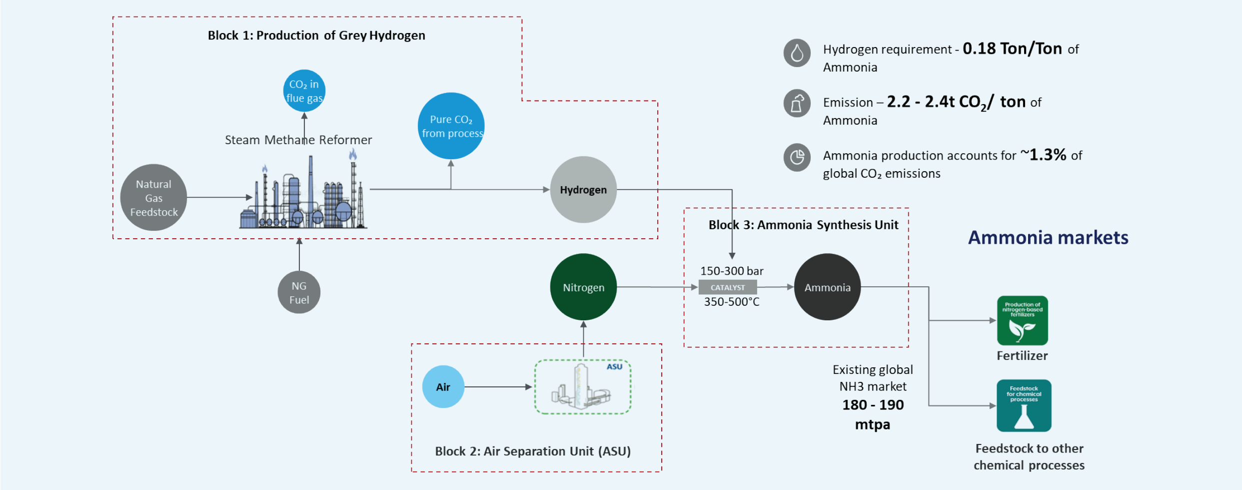
Ammonia (NH3) is one of the most widely produced chemicals in the world. It is a colorless gas which can be naturally occurring or produced synthetically. Current global capacity stands at ~183 MMT. Historically, the key source of demand for ammonia has been the nitrogen fertiliser industry. The remainder has a wide range of uses in chemicals and industry.

Table 1: Ammonia properties

Properties of Ammonia	
Formula	NH3
Molecular weight	17
Nitrogen content	0.82
Boiling point	-33.4 °C
Freezing point	-77.7 °C
Critical temperature	133 °C
Critical pressure	112.7 Atm
Density	0.73 kg/m3

Ammonia is commonly produced through the Haber-Bosch process, combining hydrogen (currently typically sourced from natural gas, but potentially from renewable green sources) with nitrogen from the air to form NH3. Ammonia contains ~18% of hydrogen content by mass, meaning 1 ton of ammonia contains ~180kg of hydrogen. Almost entire ammonia produced today is grey ammonia, with gas being the preferred option.

Figure 1: Schematic of Ammonia production process (Conventional)



Source: Industry input

India imports 45 – 50% of total natural gas requirement[6] (65 – 70 bcm), and significant portion is attributed to the fertiliser production. The fertiliser sector uses pooled gas, which comprises domestic gas and imported

6 Press Information Bureau (access here)

liquefied natural gas (LNG). In addition, India imports 2.3 – 2.5 MMTPA direct ammonia[7], mainly from the countries like Saudi Arabia, Qatar, Iran, Ukraine etc. due to availability of low-cost gas in these regions.

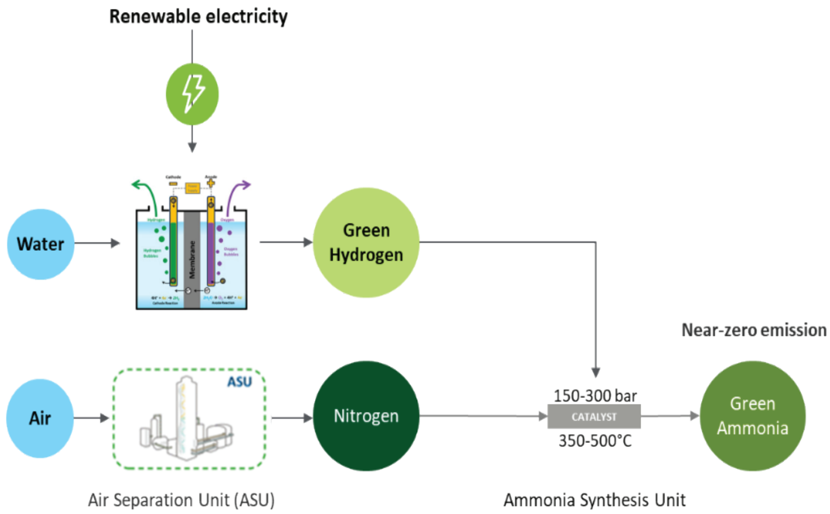
Depending on the efficiency of the ammonia production plant, anywhere between 32-36 MMBtu of gas may be required to produce 1 ton ammonia. It is also important to note that around 4GJ of excess steam (which is ~12.5% of total input energy) is produced which can be used for other applications, offsetting the overall energy requirement[8].

2.1.2 Emergence of green ammonia

The main issue with today's ammonia production is its carbon emissions. Theoretically, each ton of ammonia produced from gas should yield 2.2 – 2.4 ton of CO2 into the atmosphere (vis-à-vis 3.2 – 3.6 ton from coal). Globally ammonia production contributes to ~1.3% of the total CO2 emission[9].

Hence, existing ammonia production will need to be decarbonized if we are to meet net zero targets. This will likely be achieved by using a mixture of Blue (gas/naphtha/coal-based feedstock with CCUS) and Green (electrolysis of water using renewable electricity to generate H2 feedstock) routes to ammonia production. However, in India, focus is likely to be into green ammonia due to availability of cheaper renewable sources.

Figure 2: Schematic for green ammonia production



Captured below are few facts on green ammonia production[10]:

- 1 ton ammonia would require ~180 kg of hydrogen, and the hydrogen will be produced through electrolysis; 1 kg of green hydrogen would require 53 – 55 kwh of green electricity
- 1 ton of ammonia would require 0.3 MWh of electricity (apart from electrolysis process), and this will be met through renewable energy
- Approximately 4 GJ of steam credit would be available per ton of ammonia production.
- Green ammonia has also potential to substitute fossil fuels in hard-to-abate areas of the power and transport sectors. However, the use of ammonia as a fuel could increase NOX emissions, which must be avoided.

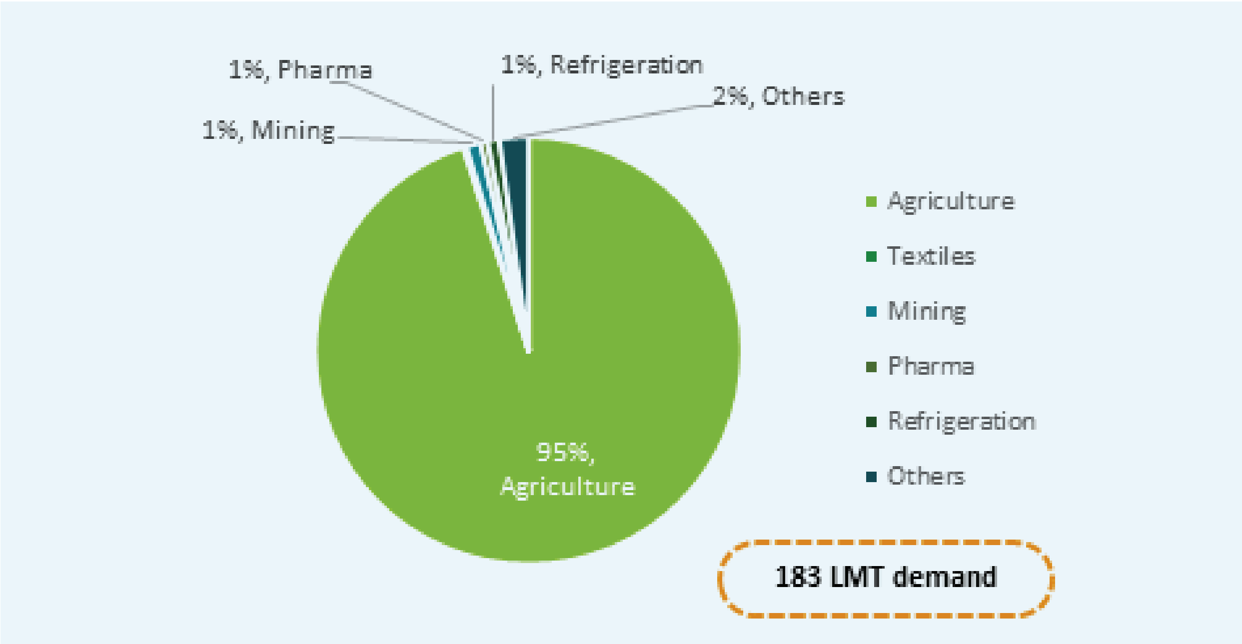
7 Industry research
8 Industry input
9 Ammonia Technology Roadmap, IEA, 2022
10 Based on inputs received from industry interaction

2.2 Current ammonia demand in India

2.2.1 Sectoral view of the demand of ammonia in India

Currently ammonia is well known for its use in fertiliser. It is estimated that, in India, ~95% of all ammonia consumed today is used for fertiliser while the remaining consumption is contributed by consumer and other industrial products as well as for explosives.

Figure 3: **Demand breakdown of Ammonia in India (FY21)**



Source: Deloitte analysis, Secondary research

Total consumption of ammonia was estimated at ~183 LMT[11] across the industries in FY21[12]. Ammonia is consumed through multiple derivatives like urea, complex fertilisers, nitric acid, ammonium nitrate, acrylonitrile, caprolactam, ammonium phosphate, ammonium sulphate, and others.

Each of the derivatives has varying ammonia consumption (specific ammonia consumption) with Urea having the highest value of 0.56[13]. In the agriculture sector, with the existing market structure around urea, the farmers prefer urea most followed by DAP and NPK fertilisers. A detail break-up of ammonia demand from various types of fertiliser is provided in the subsequent sections.

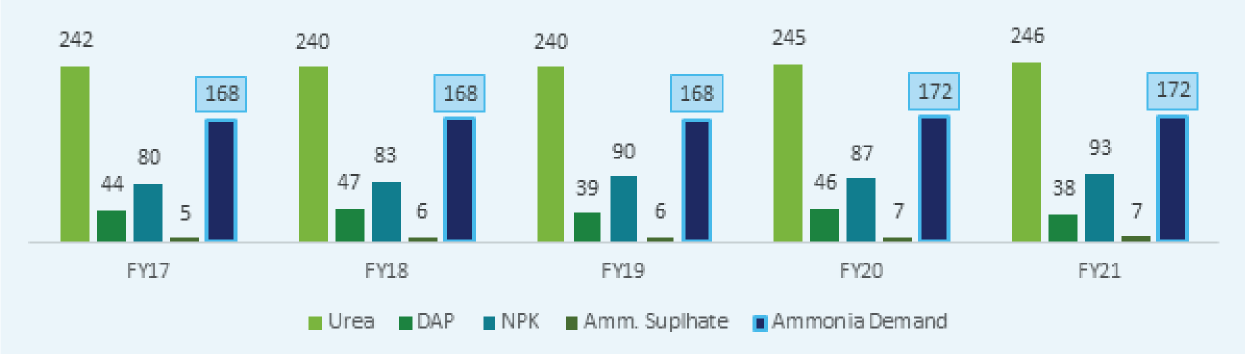
Other applications of ammonia derivatives include use of ammonium nitrate as an explosive in mining industry, ammonia as a refrigerant and as an input to synthetic drugs manufacturing in pharmaceutical sector. The demand of ammonia from these sectors are elaborated in the following sections. Total hydrogen demand from ammonia production in India is ~3.30 MMTPA. However, imports of fertiliser (14 – 15 MMTPA), mainly urea, lead to additional ammonia demand of 0.6 – 0.7 MMTPA[14].

2.2.1.1 Agriculture

Ammonia is the main input for providing nitrogen in all nitrogenous fertilisers. Urea is the main nitrogenous fertiliser; others include Diammonium phosphate (DAP) and various grades of complex fertiliser having different nitrogen content. Historical production of various types of fertilisers and associated ammonia demand are illustrated below:

11 LMT: Lakh Metric Tons
12 Deloitte analysis, Department of Fertiliser Annual reports, Mordor Intelligence
13 0.56 tons of Ammonia consumed for producing 1 ton of Urea
14 Department of Fertiliser, Deloitte analysis

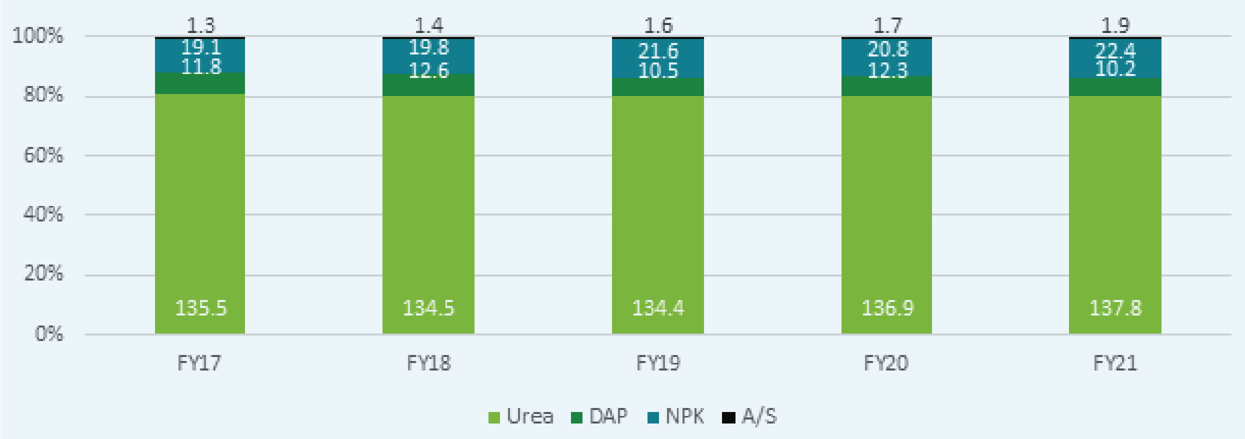
Figure 4: Fertiliser production and corresponding ammonia demand in LMT



Source: Deloitte analysis, Department of Fertiliser annual reports

The demand for fertilisers has remained stagnated over years due to increasing efficiency in agriculture processes. The distribution of ammonia demand from various categories of fertilisers is captured below:

Figure 5: Ammonia demand distribution among fertilisers in FY21 (LMT)



Source: Deloitte analysis, Department of fertilisers; Note: A/S: Ammonium Sulphate

Urea comprises 80% of the ammonia demand from fertilisers followed by NPK (complex fertilisers) and DAP. Favorable subsidy structure (government has set up MRP[15] for urea at INR 268 for a 50 kg bag) makes Urea as the go-to fertiliser for farmers. Urea has a specific ammonia consumption of 560kg/ton, while DAP and NPK have a specific ammonia consumption between 200kg/ton and 240kg/ton. They are used in specialized applications depending upon the farmer's requirement for nourishing their farmlands and for specific crops.

Ammonia derivative wise ammonia demand (in FY21) across public and private sectors is illustrated below:

Table 2: Sector wise ammonia demand from fertiliser industry

Ammonia derivative (production, LMT)	Ammonia demand (LMT)		Decarbonization potential
	Public & Cooper-ative	Private	
Urea	76.5	59.8	10 – 15%
DAP	5.2	5.0	100%
NPK (Complex Fertiliser)	9.1	13.2	100%
Ammonium Nitrate	0.55	1.3	100%
Ammonium sulphate	0.63	1.25	100%

Source: Department of Fertiliser, GOI

Currently, India has 15+ major fertiliser producers, as illustrated below:

15 Maximum Retail Price

Figure 6: Key fertiliser manufacturers in India (not exhaustive)

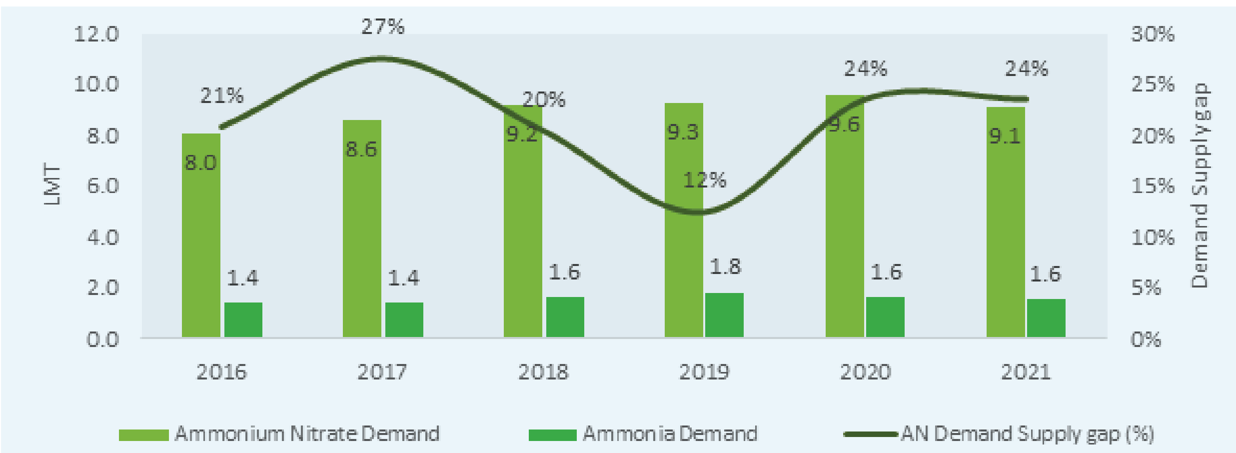
All the major fertiliser manufacturers have **captive ammonia production** capabilities and enjoy strategic location of facilities to consume imported ammonia (only for residual amount or procured through tactical buying when global price is on lower side) near ports. As per the above table, total substitutable ammonia demand (grey being substituted by green) is ~53 LMT. Therefore, a 1000 TPD ammonia production facility would have potential to cater to ~7% of domestic ammonia demand[16].

2.2.1.2 Mining

Ammonium nitrate (AN), a salt produced through reaction of ammonia and nitric acid, is used widely to develop explosives for the mining and construction sectors. Owing to its explosive nature, the government established Ammonium Nitrate Rules in 2012, which mandates licensing for any activity related to it. India is a net importer of ammonium nitrate with ~25% of the demand met through imports from Russia, Bulgaria, Georgia and Indonesia.

Ammonium nitrate is produced by reacting nitric acid with ammonia. Therefore, the entire ammonia, which is currently grey, can be replaced with green ammonia. The demand of ammonia and ammonium nitrate from mining industry is illustrated below:

Figure 7: Ammonium Nitrate consumption and ammonia demand (LMT)



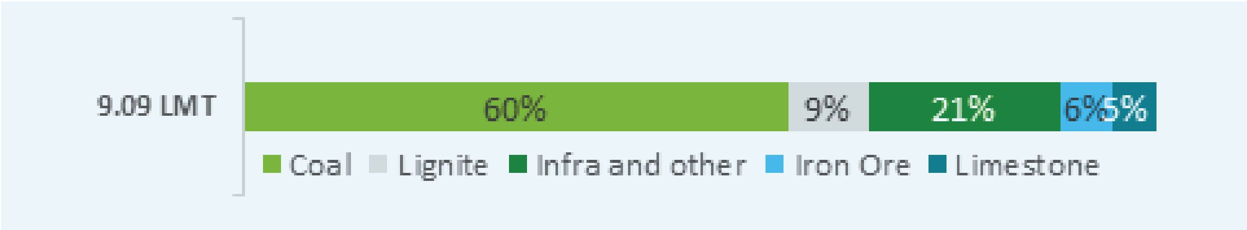
Source: Deloitte analysis, industry insights, Mordor Intelligence

Coal mining sector has the highest demand for ammonium nitrate, which is ~69% of the total demand, followed by infrastructure and other mining activities.

India is expected to increase coal production till 2035 and domestic production may reach 1300 – 1500 million ton by 2035[17]. With focus on self-reliance, other mining activities (e.g., iron ore) are also expected to increase, driving the overall demand for ammonium nitrate.

16 Estimated; a 1000 TPD plant would produce ~3 LMT ammonia annually
17 Industry inputs

Figure 8: Distribution of ammonium nitrate demand across different mining activities



Source: Deloitte analysis; Industry insights

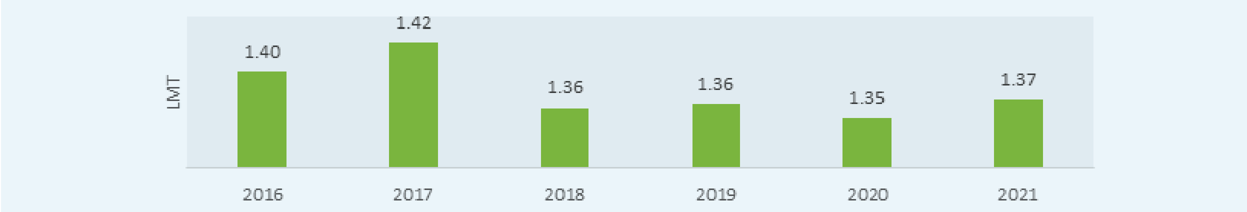
2.2.1.3 Refrigeration

Ammonia is a preferred refrigeration solution for large industrial installations and the only refrigerant outside the halocarbon group like CFCs and CFHCs. Ammonia is used a refrigerant (R717) in both compression and absorption refrigeration systems due to multiple advantages, such as:

- High latent heat
- Low vapor density
- Chemical stability
- Low corrosion of iron parts

Such properties allow for energy efficient, environment friendly systems requiring small piping with lower prices. The historical demand of ammonia as a refrigerant is captured below:

Figure 9: Ammonia demand from refrigeration (LMT)



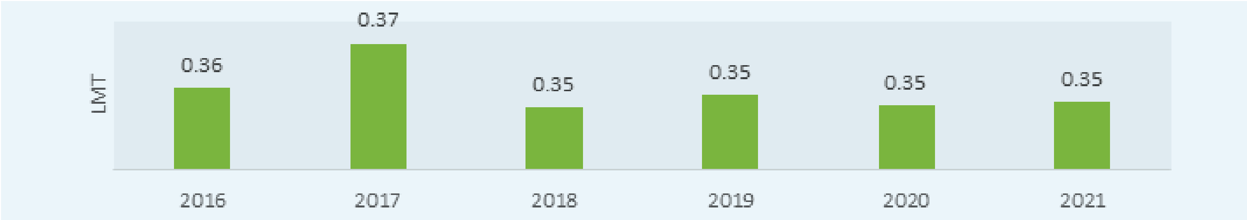
Source: Mordor Intelligence

In the last few years, the demand of refrigerants has been stagnant due to COVID-19, which resulted in limited expansion in industrial activity. The adoption of ammonia is expected to grow at a CAGR of 1.5 – 2% till 2030. Demand is primarily driven by the sectors like F&B, dairy etc. As ammonia is directly used as refrigerant, entire grey ammonia used currently can be replaced with green ammonia.

2.2.1.4 Textiles

Ammonia is used to improve the smoothness of fabrics and as an alternative to silket treatment for woven fabrics. It is used in a wet process to improve the quality of cotton/linen (warp/weft) fabrics. It is also used as an alternative to silket treatment for woven fabrics for improving dimensional stability, abrasion resistance, and appearance after washing.

Figure 10: Ammonia demand from textiles (LMT)



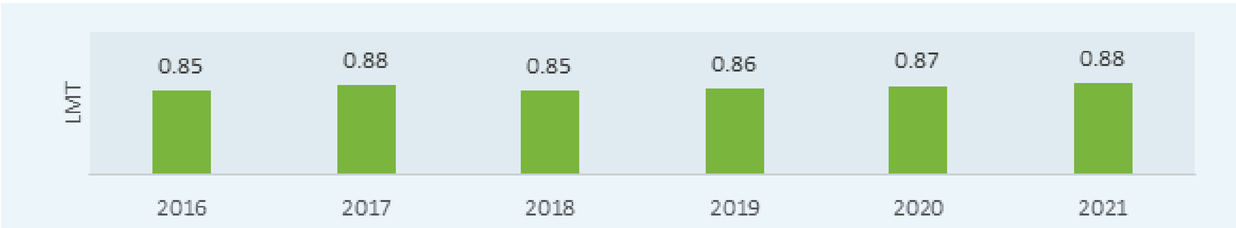
Source: Mordor Intelligence

The demand of ammonia has been stagnated in the last few years. With the growth in the sector, the demand is expected to rise at a CAGR of 0.5 - 1% till 2030.

2.2.1.5 Pharmaceuticals

Ammonia is used in the production of synthetic drugs such as sulphanilamide, sulphathiazole, sulphapyridine, and other sulphfadrugs, antibacterial agents, vitamins, antimalarial, methionine, amino acids, lotions and cosmetics. Despite the growth in Pharma sector, the demand of ammonia from the sector has been stagnated in the last few years.

Figure 11: Ammonia demand from pharmaceuticals (LMT)

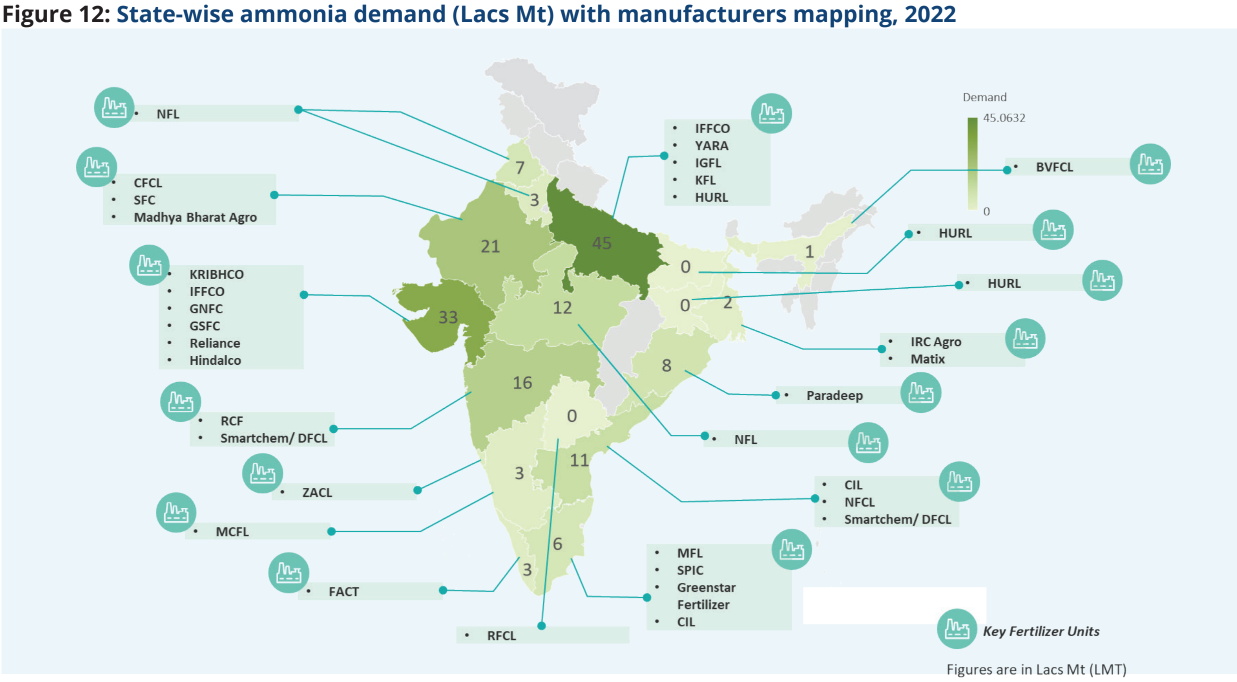


Source: Mordor Intelligence

2.2.2 State-wise ammonia demand in India

With ~95% of the demand for ammonia contributed by the fertiliser sector, demand for ammonia is highly concentrated in the clusters with fertiliser production facilities. An illustration of state-wise ammonia demand along with operating fertiliser companies is provided below:

Figure 12: State-wise ammonia demand (Lacs Mt) with manufacturers mapping, 2022



Source: Deloitte analysis, Department of Fertiliser annual reports

The states of Uttar Pradesh, Gujarat, and Rajasthan are the top states in terms of demand as they house multiple fertiliser manufacturers. Initial identification of potential clusters has been done based on actual demand of ammonia[18].

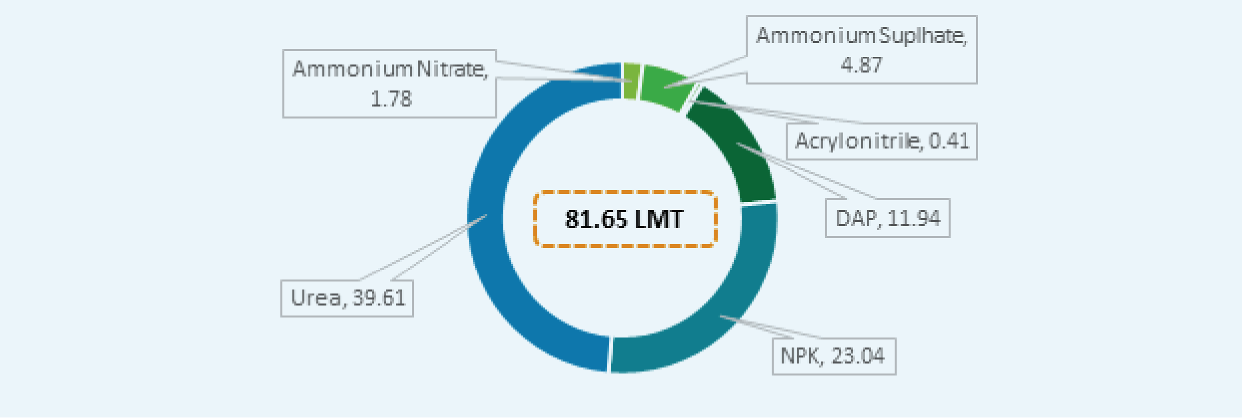
2.2.2.1 Gujarat

Large scale manufacturers viz. KRIBHCO, IFFCO, GNFC, GSFC, and Hindalco have fertiliser units located in Gujarat. In addition to the fertiliser units, Reliance operates the sole acrylonitrile facility in Vadodara. The state has a capacity to produce ~81 LMT of ammonia derivatives per annum (~90% is fertiliser)[19]. Approximately 50% of the state's capacity is dedicated towards urea production. The distribution of the manufacturing capacity is captured below:

18 This is total ammonia demand. Substitutable demand from the initially identified clusters is factored in to further prioritize the clusters; this assessment is provided the Chapter 4

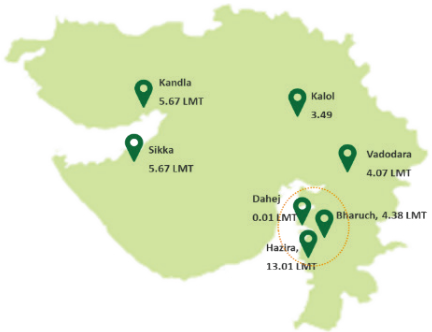
19 Department of Fertilisers Annual Report FY22

Figure 13: Demand of ammonia derivatives



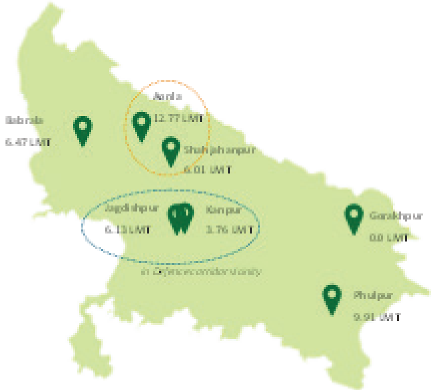
Source: Department of Fertilize

The ammonia demand for the above production capacity is ~33 LMT[20]. It has been observed that the cluster formed by Dahej, Hazira, and Bharuch is the largest one, and contributes to ~17.4 LMT ammonia demand. Cluster formed by Kandala and Sikka is the second largest and has an annual ammonia demand of ~11 LMT.



2.2.2.2 Uttar Pradesh

Uttar Pradesh has the highest demand for ammonia in the country, with a fertiliser production capacity of ~81 LMT per annum. The state has presence of major manufacturers, such as Grasim/ IGFL, HURL, IFFCO, KFCL, KFL, Yara etc.



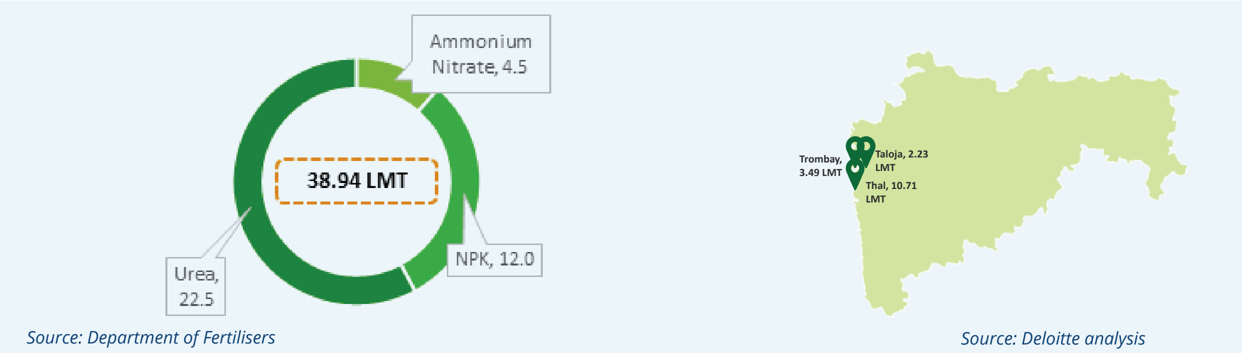
The entire fertiliser production in UP is urea based (~81 LMT). Urea has high specific ammonia consumption; therefore, the ammonia demand amounts to ~45 LMT (with decarbonization potential up to 8 - 9 LMT). The facilities are spread across the state; the most prominent clusters are Aonala-Shahjahanpur and Kanpur-Jagdishpur.

Aonla has production facility of IFFCO and Shahjahanpur has facility of KFL/ KSFL. The cluster has a demand of ~19 LMT for ammonia. The other cluster of Kanpur and Jagdishpur has an ammonia demand of ~10 LMT.

2.2.2.3 Maharashtra

Fertiliser manufacturers RCF and Smartchem/ DFCL have their units in Maharashtra. The distribution of the production capacity is illustrated below:

Figure 14: Fertiliser production capacity in Maharashtra (LMT)



Source: Department of Fertilisers

Source: Deloitte analysis

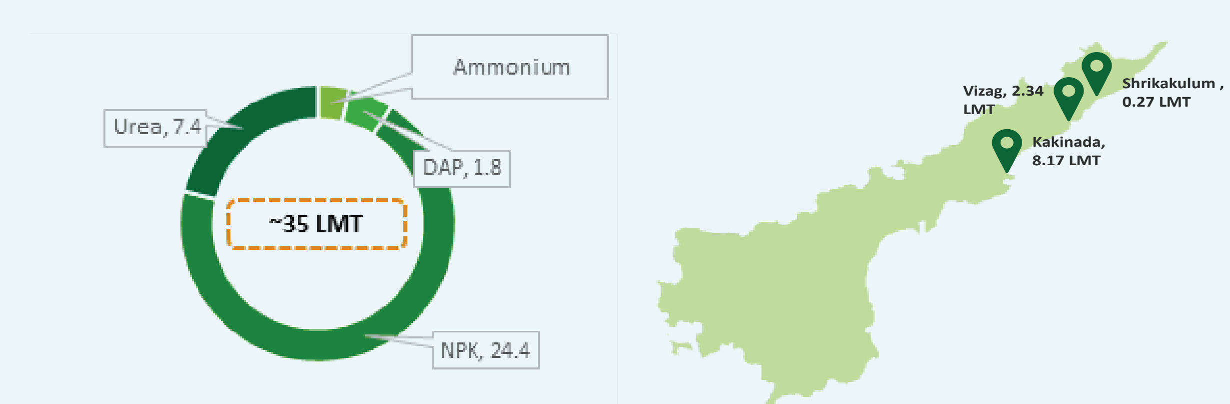
20 Deloitte analysis basis specific ammonia consumption of fertilisers and other chemicals

The aggregated ammonia demand is ~16.4 LMT; the cluster is located in the proximity of Trombay, Thal, and Taloja. The unit of Smartchem is located in Taloja produces ammonium nitrate and NPK fertilisers whereas RCF in Thal and Trombay produces Urea, NPK, ammonium nitrate, and NPK fertilisers.

2.2.2.4 Andhra Pradesh

Major units of CIL (Coromandel International Limited), NFCL, and Smartchem/ DFCL are located in Andhra Pradesh. Total fertiliser and ammonium nitrate production in Andhra Pradesh is ~35 LMT, which translates to ammonia demand of 11 LMT.

Figure 15: Fertiliser production capacity in Maharashtra (LMT)



Source: Department of Fertilisers

Source: Department of Fertilisers

All units of NFCL manufacture urea (~7.5 LMT) whereas Smartchem unit in Srikakulam produces only ammonium nitrate (~1.3 LMT). CIL units in Andhra Pradesh produce complex fertilisers (NPK) and DAP amounting ~26 LMT. The port in Vishakhapatnam falls midway between Kakinada and Shrikakulam and could be act as the focal point of imports for the facilities located in and around them.

2.2.2.5 Rajasthan

Rajasthan has presence of three fertiliser manufacturers i.e., CFCL, Madhya Bharat Agro, and SFC. The production capacity of the three companies amounts to ~38 LMT. Like Uttar Pradesh, all the units in the state produce Urea. The urea production capacity in the state amounts to ~21 LMT of ammonia demand.

The units are placed in Kota, Bhilwara, and Gadepan. They are also near Vijaipur in Madhya Pradesh which houses some fertiliser units, and a cluster can be formed with these units.

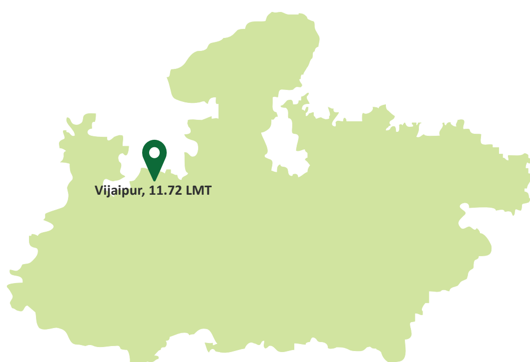
With the plants located inland, the units are unable to consume imports like the other units in the country.

Source: Department of Fertilisers

2.2.2.6 Madhya Pradesh

The units of NFL in Vijaipur with a capacity of ~17.3 LMT are dedicated for **urea production**. The production of urea requires ammonia equivalent to ~11.7 LMT on an annual basis.

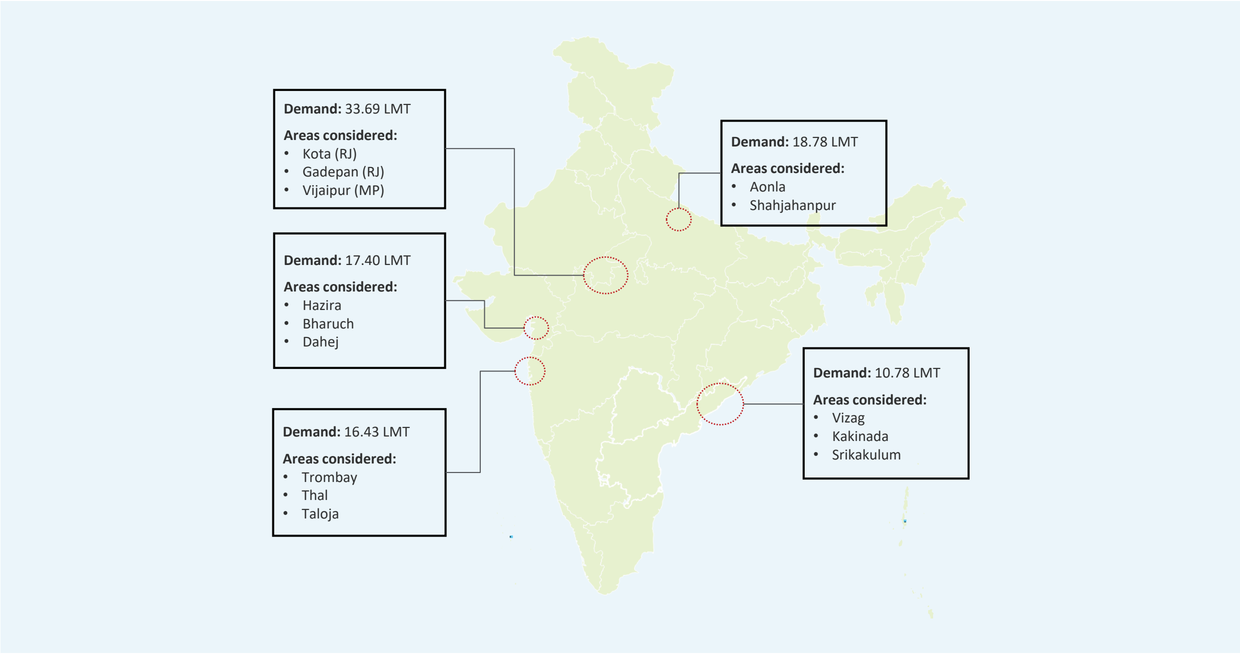
It is important to note that Vijaipur units of NFL are located at the proximity of fertiliser units in Kota and Gadepan. These three units can be considered under one cluster, with a total ammonia demand of ~33 LMT



Source: Department of Fertilisers

Based on the analysis of the key states, five (5) clusters have been identified as illustrated in Figure 16:

Figure 16: Ammonia demand across clusters in India



Source: Deloitte analysis

Green ammonia plant should ideally be located near the vicinity of the clusters to address the domestic demand at a lower cost. The above demand figures are total demand of ammonia; substitutable ammonia demand (grey being substituted by green) based on decarbonization potential for various derivatives has been estimated to further prioritize the clusters.

2.2.3 List of existing fertiliser consumers

Table 3: Major fertiliser producers and their ammonia consumption

	Fertiliser production (LMT)				NH3 demand (LMT)
	Urea	NPK	DAP	A/S	
BVFCL	1.32				0.74
CFCL	33.47				18.74
CIL		26.55	1.83		6.86
FACT		8.62		2.46	2.70
GNFC	6.43	1.67			4.37
Grasim/ IGFL	10.95				6.13
Greenstar Fert. Ltd.		2.41	1.19		0.90
GSFC	3.71	4.77	5.66	4.87	6.00
Hindalco			0.05		0.01
HURL	0				
IFFCO	46.75	23.48	19.24		37.01
IRC Agro/ TCL		4.47	2.23		1.67
KFCL	6.72				3.76
KFL/ KSFL	10.74				6.01
KRIBHCO	23.23				13.00
Matix Group	0				0.00
MCFL	3.54	1.42	1.16		2.60
MFL	4.81	0.54			2.80
NFCL	7.42				4.15

	Fertiliser production (LMT)				NH3 demand (LMT)
	Urea	NPK	DAP	A/S	
NFL	38				21.50
PPL (Paradeep)		3.84	6.39		2.64
RCF	22.51	5.39			14.19
RFCL	0				
SFC	4.01				2.24
Smartchem/DFCL		6.57			2.50
SPIC	3.54				1.98
YARA/ TCL	11.55				6.46
ZACL	4.66	3.53			3.45

Source: Department of fertiliser, Deloitte analysis

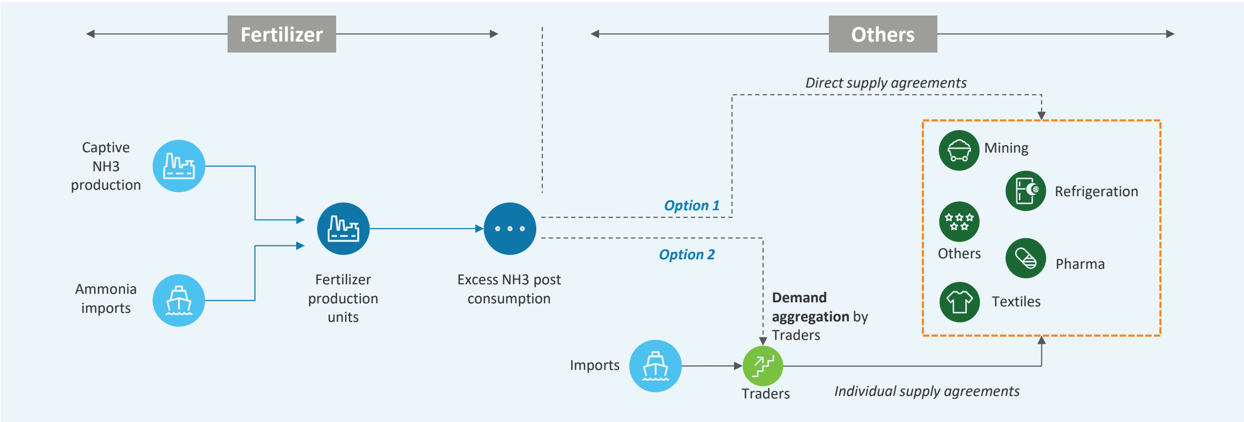
2.3 Supply of ammonia in India

2.3.1 Supply dynamics of ammonia

The ammonia market in India is heavily skewed towards fulfilling the demands of the fertiliser sector. Fertiliser producers have developed in-house captive ammonia production units (grey ammonia) to meet the inhouse demand. Any excess or residual capacity is supplied to other segments like mining, refrigeration, textiles, and pharmaceuticals etc.

Captured below is the current supply dynamics of ammonia in India.

Figure 17: Supply dynamics of ammonia in India



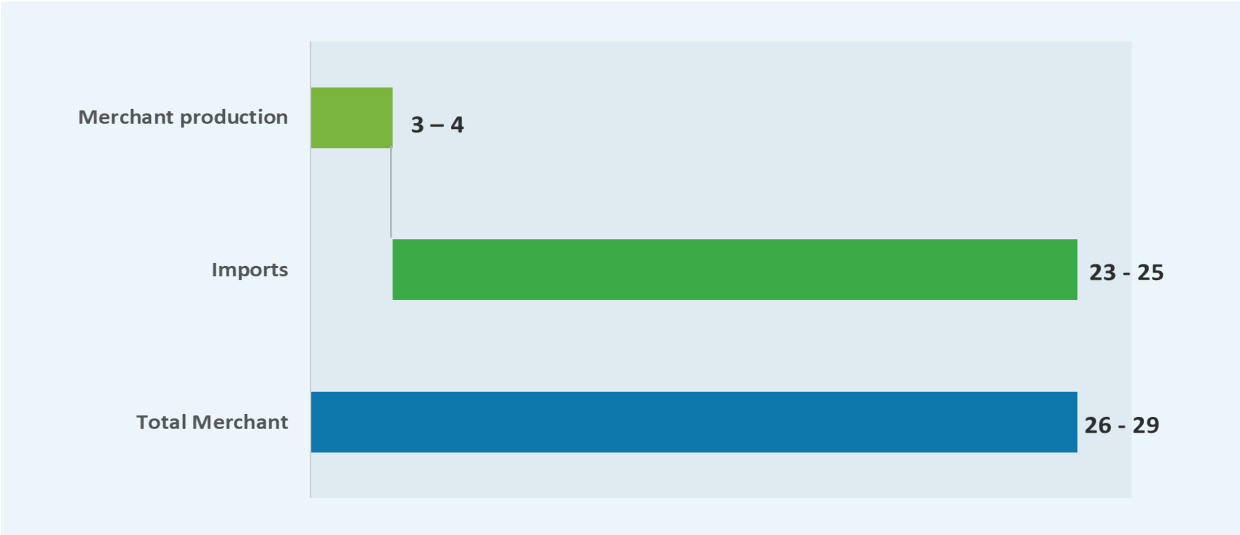
Source: Deloitte analysis, industry inputs

Due to continuous nature of operation of fertiliser plants, ammonia units are developed as captive units. The excess ammonia left after consumption by the fertiliser units is either sent to other segments through direct supply contracts or sold to the traders. Traders play an important role by aggregating the demand from all the sectors and map that with the supply of residual ammonia after fertiliser industry usage and imports. Demand aggregation helps traders to negotiate on higher volumes and competitive prices for customers. **Fertiliser producers and fragmented customers prefer dealing through traders as they act as a central focal point for demand supply aggregation across the segments. Traders also provide logistics services to the customers.**

2.3.2 Merchant market for ammonia

Indian domestic merchant market for ammonia is insignificant with contribution of 2 – 3% in the total ammonia demand. Imports have been a significant source of feed for the fertiliser manufacturers and contribute to ~15% of the ammonia demand in the country.

Figure 18: **Merchant market for ammonia in India (LMT)**

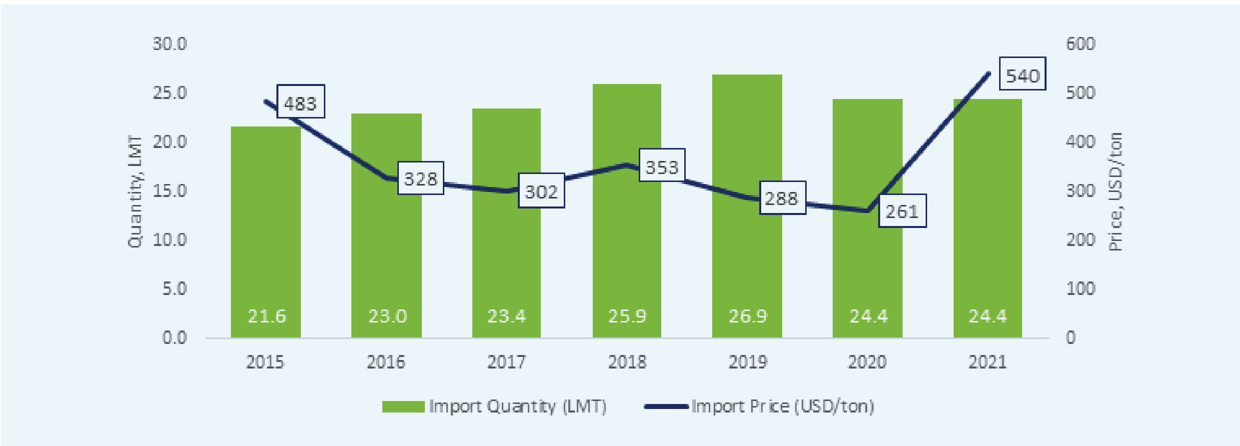


The merchant production (excess from fertiliser and chemical companies) is either supplied directly to smaller industries or through traders who aggregate their demand.

2.3.2.1 Ammonia imports in India

As stated above, imports contribute ~15% of the overall ammonia demand in the country. The quantum of ammonia imported in the last 5 years and the prices realized are captured below:

Figure 19: **Ammonia imports and prices of imports 2015 - 21**



Source: ITC Trade Map; (HSN 2814); Imports are considered for pure ammonia only not via the derivatives of ammonia

The imports of ammonia in India are mostly from Middle East (Qatar, Saudi Arabia, Bahrain), Ukraine, and Egypt. The prices of ammonia imports had witnessed a decline from 2015 to 2020 with favorable geopolitical scenarios and logistical ease. Import prices started increasing since 2020, and in 2022, prices have been around 1000 - 1200 USD/ton.

Some of the key drivers for imports in the country are stated below:

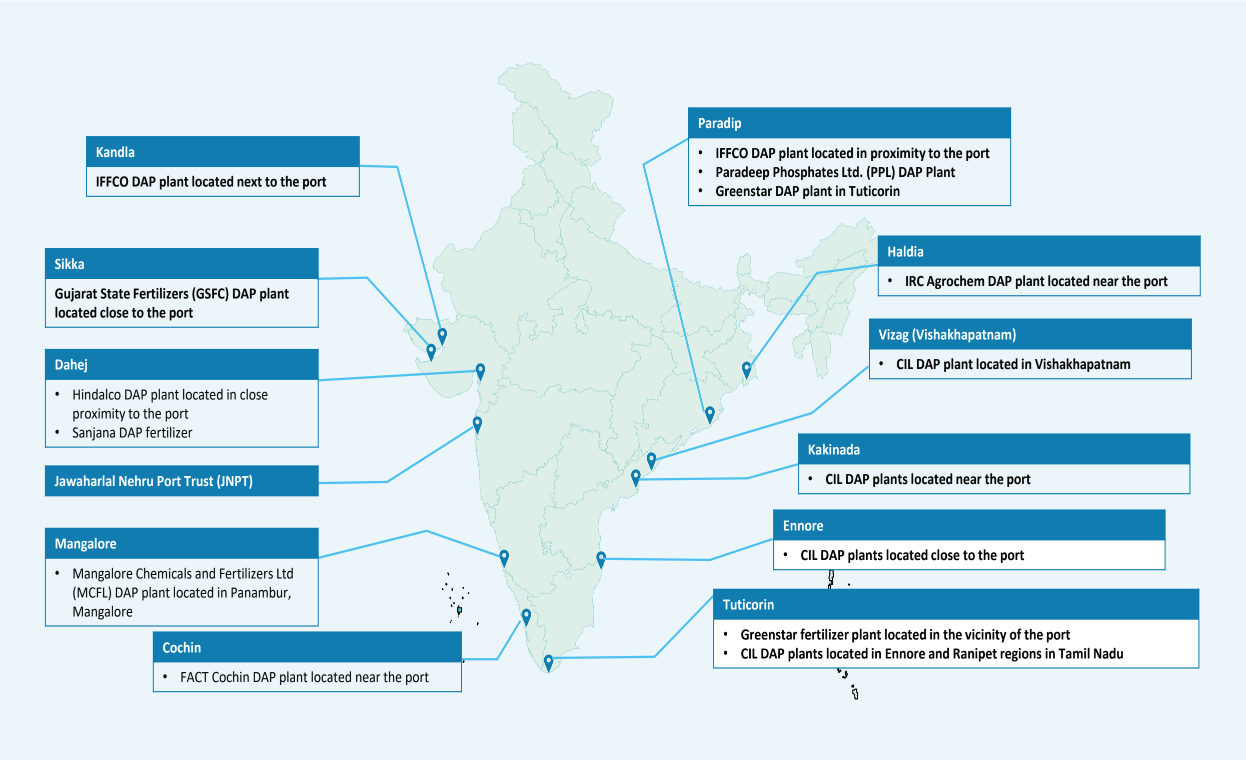
- High dependency on natural gas for ammonia production (through grey route) and limited natural gas resources in India
- Lower import duty on ammonia (5%) compared to urea and other fertilisers (10%). Such a structure is a proponent for some fertiliser manufacturers to import ammonia feedstock for production.
- Majority of the fertiliser units in India are operating at full capacity. Therefore, any incremental demand is met through import. It has been observed that 85 operational unit in country with aggregate installed capacity of 366 LMT produced fertilisers of 382 LMT in FY21[21].

21 Deloitte analysis; based on data from Department of Fertiliser Annual Report 2022

- The subsidy structure of urea is such that manufacturers are subsidized for the difference in their production cost (concessional rate) and the MRP of Urea[22] and the structure doesn't penalize higher input costs.

Ammonia imports are typically to satisfy the demand from facilities near the ports and the inland transportation of ammonia is minimal in India. Maximum imports of ammonia are done by DAP units. The figure shown below shows the rationale of having multiple units in the proximity of ports to ensure steady supply of ammonia feedstock to them.

Figure 20: Proximity of DAP units to ports



Source: Argus, Deloitte analysis

India's ammonia imports typically satisfy partial demand located near ports. Inland transportation of ammonia is minimal (only the limited quantity aggregated by traders for small consumers)

Contracting of Grey Ammonia in India

It is evident that ~85% of domestic demand of ammonia is met through captive production facilities. All the major fertiliser players have in-house ammonia production facilities. Rest 15% is met through import, supply from traders and supply of residual capacity by fertiliser companies. For, small scale consumers, traders act as aggregators. Generally, import and trading contracts are short-term, fragmented and on need basis. **Any long term grey ammonia contract between Indian consumers and major exporter/ trader is non-existent**. In India, there are 600+ active Ammonia importers in India Importing from 1,000 Suppliers[23]. Major importers include pharmaceutical and chemical companies.

22 Subsidy structure of fertilisers has been elaborated further in the subsequent sections of the report

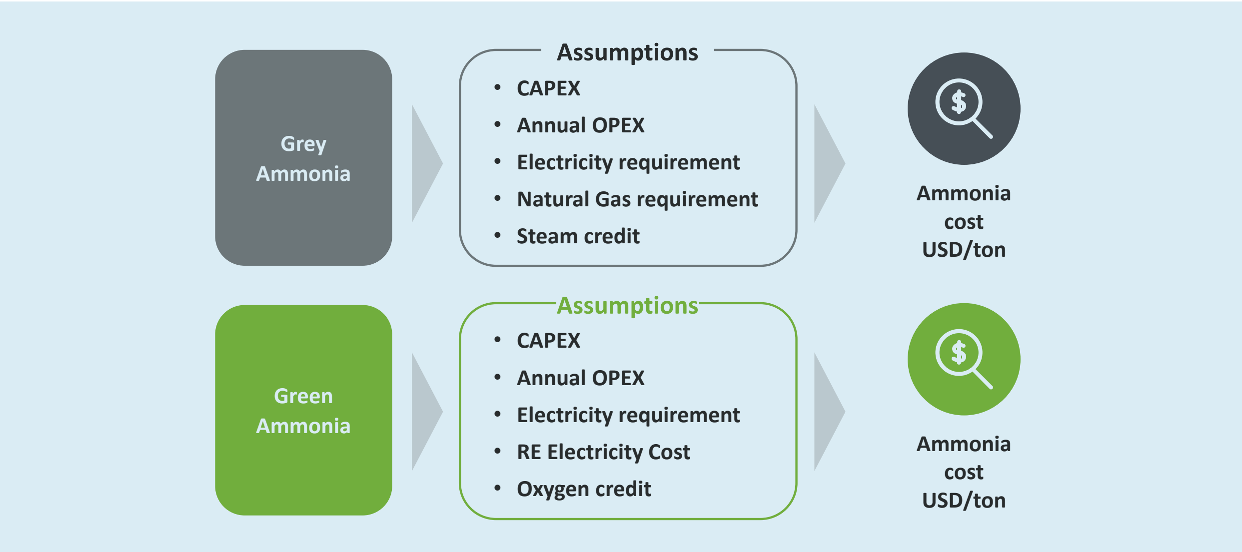
23 Industry input

2.4 Feasibility of green ammonia with present status quo

Ammonia production currently accounts for ~1.8% of the global CO2 emissions and conventional ammonia process is the largest carbon dioxide emitting chemical industry process[24]. Therefore, green ammonia will be instrumental in supporting the transition towards lower/ zero carbon fuels. However, the unfavorable cost structure of green ammonia is a major challenge in widespread adoption in end-use industries

In this chapter, the cost structures for green and grey ammonia and economic feasibility of green ammonia are analyzed in detail. The inputs considered and the methodology adopted to arrive at the cost structures for green and grey ammonia are illustrated below:

Figure 21: Methodology for cost estimation of ammonia production



Capex and opex assumptions for both grey and green ammonia have been estimated based on inputs received through industry interactions. The specific consumption of electricity is based on the electricity requirement in SMR, ASU and ammonia synthesis loop (grey ammonia) and electrolysis process (green ammonia). The cost of electricity would vary depending on source of power i.e., grid, captive generation unit and renewable source.

Key assumptions considered for estimating cost of grey and green ammonia production are captured below:

2.4.1 Cost of production of grey ammonia in India

The assumptions for grey ammonia production are tabulated below:

Table 4: Assumptions for grey ammonia production in India

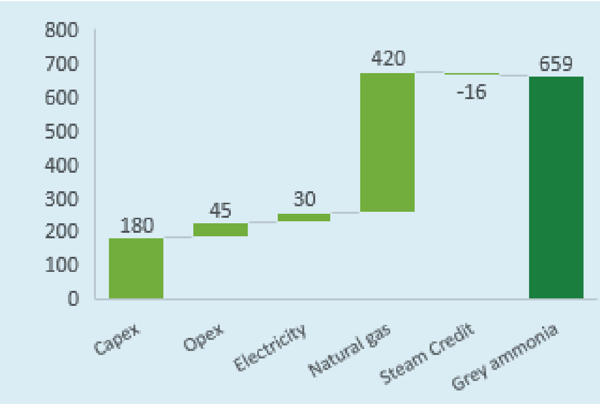
Particular	Unit	Value
Capex per ton of ammonia[25]	USD/ton per annum	1800
Cost of capital	%	10%
Annual operational expenditure	% of capital expenditure	2.5%
Electricity requirement	MWh/ ton of ammonia	0.3
Electricity cost from grid	USD/MWh	100
Electricity cost from captive generation	USD/MWh	55
Natural gas requirement	MMBtu/ton of ammonia	35
Natural gas price (delivered)[26]	USD/MMBtu	12
Steam credit	GJ/ton of ammonia	4
Source: Deloitte analysis, industry insights, Research reports		

Source: Deloitte analysis, industry insights, Research reports

24 Ammonia: zero-carbon fertiliser, fuel and energy store | The Royal Society (access here)
25 Industry input: capex includes SMR, ammonia synthesis loop
26 Landed natural gas cost is assumed as $12/MMBtu. In December 2022, it was ~$15/MMBtu (vis-à-vis $9/MMBtu in December 2021); average landed cost for 2023 is assumed as $12/MMBtu as the global gas price moderated in recent months

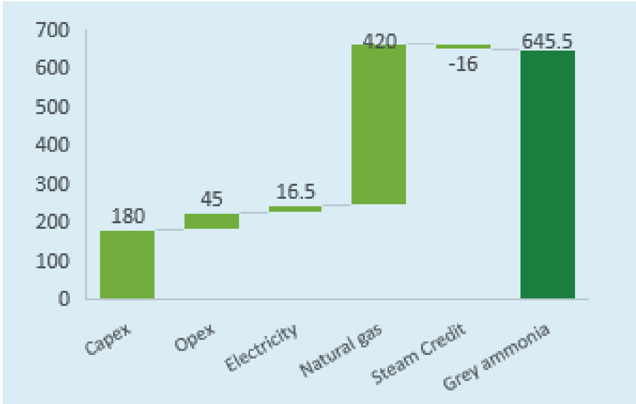
The cost of grey ammonia production based on the above assumptions is in the range of USD 640 – 660 per ton of ammonia, as illustrated below:

Figure 22: **Cost of grey ammonia production with electricity from grid (USD/ton)**



Source: Deloitte analysis

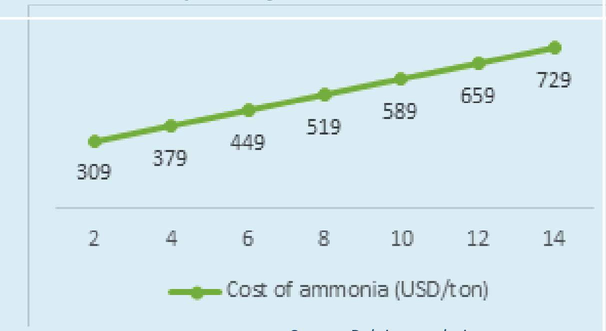
Figure 23: **Cost of grey ammonia production with electricity from captive generation (USD/ton)**



Source: Deloitte analysis

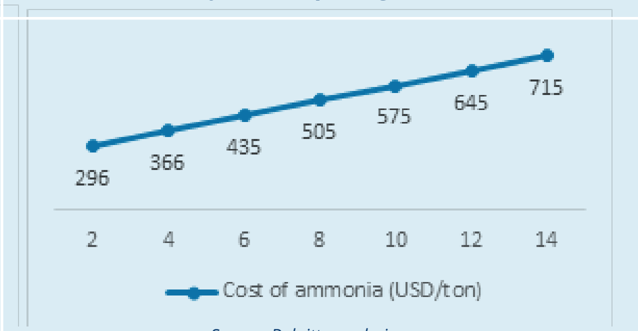
The steam credit realized is estimated as the savings in fossil based energy (coal) to generate the steam - for calculation, the calorific value of domestic coal is considered (4000 kcal/kg). However, it is evident from the cost buildup that cost of natural gas is the prime driver for grey ammonia cost of production (~65%). A sensitivity analysis basis the natural gas prices is illustrated below:

Figure 24: **Sensitivity of grey ammonia production with electricity from grid**



Source: Deloitte analysis

Figure 25: **Sensitivity of grey ammonia production w with electricity from captive generation**

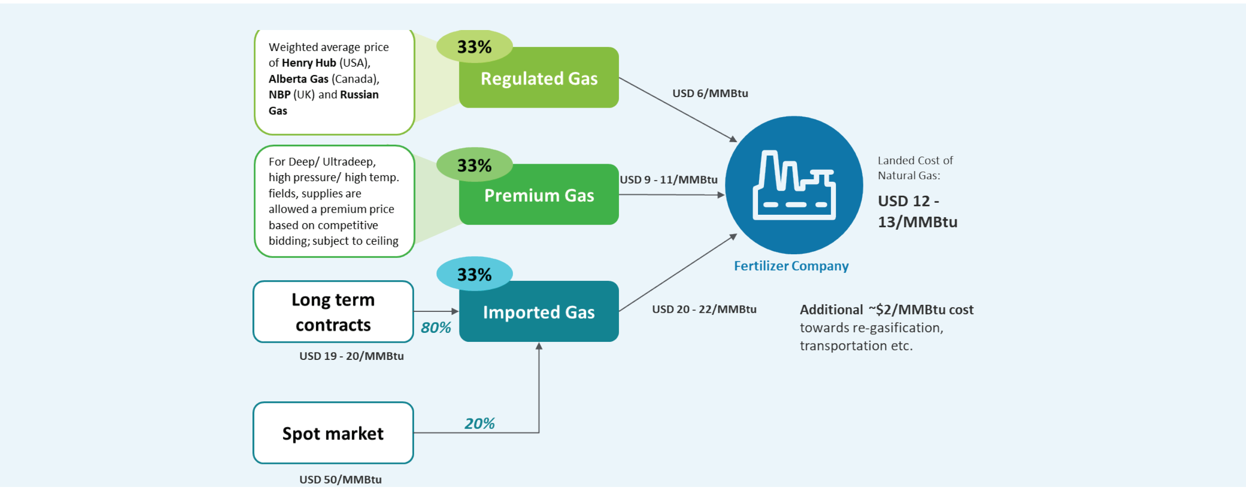


Source: Deloitte analysis

2.4.1.1 Natural gas pricing for fertiliser producers in India

The average landed price of natural gas to the fertiliser companies in 2022 has been in the range of 12 - 14 USD/MMBtu. The pricing of natural gas for the fertiliser sector is calculated based on price of regulated gas, premium gas, and imported gas, as illustrated below:

Figure 26: **Illustration for landed price of natural gas for fertiliser producers in India, 2022**



Source: Deloitte analysis validated by industry stakeholders

The regulated price of gas is guided by the New Exploration and Licensing Policy effective from November 2014. The premium pricing of natural gas is allowed under a special package which is decided based on competitive bidding. In India, 80% of the imported gas for fertiliser is through long term G2G contracts that Indian government has with gas exporting nations (e.g., Iran); 20% of the imported gas is procured from the spot market which is market driven (current price is ~50 USD/MMBtu).

The current pricing methodology of natural gas enables fertiliser companies to steer through volatility of international spot markets. Priority allotment of domestic natural gas to fertiliser producers ensures lower dependence of imported gas as well; hence, lower landed cost of natural gas is realized by the fertiliser producers.

2.4.2 Cost of production of green ammonia in India

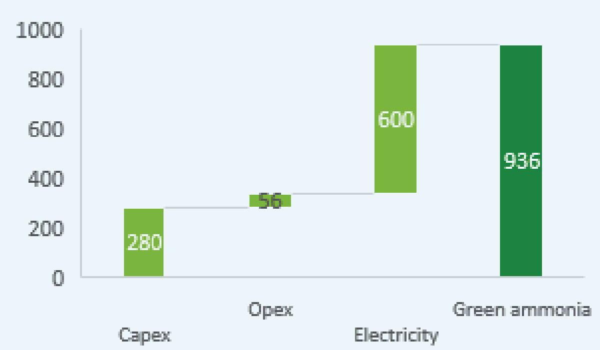
The assumptions for green ammonia production in India are captured below[27]:

Table 5: Assumptions for green ammonia production in India

Particular	Unit	Value
Capex per ton of ammonia	USD/ton	2800
Cost of capital	%	10%
Annual operational expenditure	% of capital expenditure	2%
Electricity requirement	MWh/ ton of ammonia	10
Renewable electricity cost[28]	USD/MWh	60
Oxygen credit	Kg/ton of ammonia	Not considered

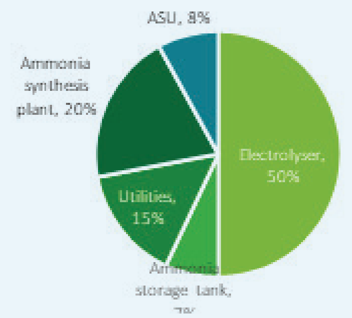
With the assumptions stated above, the cost of green ammonia stacks up as stated below:

Figure 27: Cost of green ammonia production (USD/ ton)



Source: Deloitte analysis

Figure 28: Capex breakdown for green ammonia plant using alkaline electrolysers



Source: Industry inputs

The capex for the green ammonia facility consists of the electrolyser cost, its building cost, ammonia storage tanks, utilities, ammonia synthesis plant, and the ASU. The cost contribution by various components is shown in the figure. The cost of electrolyser is the largest cost contributor followed by ammonia synthesis plant and utilities.

It is also important to note that for green ammonia production, round-the-clock RE is required as ammonia synthesis loop is a continuous process, which faces operational challenges in frequent ramp-up and ramp down. However, major technology providers are focusing on making ammonia loop flexible for using renewable energy based production.

27 Source: Deloitte analysis, industry interactions.

28 Renewable electricity cost – this is the RE cost at 70-75% CUF; with high CUF, cost of renewable increases due to oversizing and deployment of battery storage

Initiative by Topsoe - Renewable Dynamic Distributed Ammonia Plant

Global technology provider Topsoe is focusing on designing plant with dynamic ammonia technology to accommodate and adapt to the inherent fluctuations in power output from renewable sources. Renewable Dynamic Distributed Ammonia Plant (RDDAP) will be a so-called dynamic green ammonia plant at the commercial scale of 10 MW power. Here, renewables will drive the ammonia production process of producing hydrogen, which will subsequently be processed into ammonia.

The dynamic approach entails that the clean energy from wind turbines and solar panels will be connected directly to the electrolysis unit. The flexible ammonia plant will be able to operate from 5% to 100% load without hydrogen storage.

Source: https://energiforskning.dk/en/node/16250

A sensitivity analysis of RTC power vis-à-vis oversized electrolyzer and hydrogen storage is illustrated below:

Table 6: Impact of CUF and electricity cost on cost of green ammonia

CUF	Electricity cost (USD/MWh)	Electrolyser capacity (MW)	Electrolyser capex/ ton of ammonia (USD/TPA)	Capex – ASU and ammonia loop (USD/TPA)	Total capex (USD/TPA)	Cost of green ammonia (USD/T)
20 - 25%	30	4350	4133	1420	5553	966
40 - 50%	50	2175	2066	1420	3486	925
70 - 75%	60	1450	1380	1420	2800	936

Source: Deloitte analysis

Additional cost of hydrogen storage (steel tank) will be added to the cost of green ammonia; the cost of storage will depend on hours of storage and flexibility induced in the ammonia synthesis loop by the OEM. Cost of storage at lower CUF may add to USD 80 – 120 per ton of green ammonia.

The case of Oxygen credit

When hydrogen is produced through electrolysis, half the number of moles of oxygen is produced as a by-product of hydrogen. In a large-scale electrolysis facility, quantum of oxygen produced is also significant. Hence, the by-product oxygen should be fully utilized. Oxygen has different industrial uses, such as combustion, process industry, gasification industry, semi-conductor industry etc. In addition, it has use in medical applications also.

Therefore, there is potential of generating additional revenue from selling the by-product oxygen, directly to the industry or through off-take contracts with industrial gas companies. However, current demand-supply scenario and handling cost structure are not favorable for this mechanism. Key challenges include:

- **Lack of demand of O2 near the green hydrogen/ammonia production facilities**. Compressing, storing and transporting O2 to demand center is not commercially viable yet. Most of the industrial facilities have captive O2 plant.
- **Purity of oxygen produced through electrolysis is not at par with the requirement in medical application**. The oxygen must be completely separated from the hydrogen produced. Any kind of contamination is not allowed in medical grade oxygen. The hydrogen and oxygen separation is a major challenge in the electrolysis process. Suitable technology must be deployed at the downstream to separate the oxygen, which again require additional capex

Therefore, by-product oxygen can be monetized if the ammonia facility is located near demand cluster. For example, if the facility is located near a Steel plant, the by-product oxygen can be used in the blast furnace. In this analysis, no oxygen credit has been considered due to uncertainty of monetization; however, there is always a potential to generate additional revenue

2.4.3 Price sensitivity analysis of grey and green ammonia

The sensitivity analysis of the cost multiple of green ammonia vs grey ammonia has been conducted at different natural gas and electricity price. The analysis has been conducted for two type of electricity price for production of grey ammonia – grid electricity and electricity generated from coal based captive generation[29].

Scenario 1: Grey ammonia is produced using grid electricity (USD 100/MWh)

Table 7: Sensitivity analysis of green ammonia to grey ammonia cost multiple

	Cost of electricity (USD/MWh)							
Cost of NG (USD/ MMBtu)		30	40	50	60	70	80	90
	2	2.06	2.38	2.71	3.03	3.35	3.68	4.00
	4	1.68	1.94	2.21	2.47	2.73	3.00	3.26
	6	1.42	1.64	1.86	2.08	2.31	2.53	2.75
	8	1.23	1.42	1.61	1.80	2.00	2.19	2.38
	10	1.08	1.25	1.42	1.59	1.76	1.93	2.10
	12	0.97	1.12	1.27	1.42	1.57	1.72	1.88
	14	0.87	1.01	1.15	1.28	1.42	1.56	1.70
					LEGEND:	Commercially Viable Regime		

Source: Deloitte analysis

Note: Commercially viable regime is considered up to 15% green premium for green hydrogen

Scenario 2: Grey ammonia is produced using captive electricity (USD 55/MWh)

Table 8: Sensitivity analysis of green ammonia to grey ammonia cost multiple

	Cost of electricity (USD/MWh)							
Cost of NG (USD/ MMBtu)		30	40	50	60	70	80	90
	2	2.15	2.49	2.83	3.17	3.51	3.84	4.18
	4	1.74	2.01	2.29	2.56	2.83	3.11	3.38
	6	1.46	1.69	1.92	2.15	2.38	2.61	2.84
	8	1.26	1.46	1.65	1.85	2.05	2.25	2.45
	10	1.11	1.28	1.45	1.63	1.80	1.97	2.15
	12	0.99	1.14	1.30	1.45	1.60	1.76	1.91
	14	0.89	1.03	1.17	1.31	1.45	1.59	1.73
					LEGEND:	Commercially Viable Regime		

Source: Deloitte analysis

Note: Commercially viable regime is considered up to 15% green premium for green hydrogen

Without any carbon tax, green ammonia will be viable in India only at an elevated gas price (more than USD 10/MMBtu) and low renewable electricity cost for electrolysis (USD 30 – 40/MWh with CUF more than 75%)

2.4.4 Sensitivity analysis of green ammonia cost multiple with carbon pricing

To disincentivize grey ammonia production and obtain parity with green ammonia, carbon tax has been the go-to instrument. In addition to the assumptions mentioned in Table 4 and Table 5, a carbon penalty/ tax of USD 50 or 100 per ton of CO_2 is assumed. The production of a ton of ammonia produces 2 tons of carbon dioxide which is the basis of penalizing ammonia manufacturers.

2.4.4.1 With USD 50/ton carbon price

Interventions like imposition of carbon tax would accelerate the green ammonia transition by making it more viable commercially. Two more scenarios have been created considering a carbon tax of USD 50/Ton of CO_2, as illustrated below:

29 Some of the fertiliser units are equipped with captive generation unit; rest are dependent on grid electricity

Scenario 3: Grey ammonia is produced using grid electricity (USD 100/MWh) and carbon tax is imposed

Table 9: Sensitivity analysis of green ammonia to grey ammonia cost multiple with USD 50/ton carbon price

	Cost of electricity (USD/MWh)							
Cost of NG (USD/ MMBtu)		30	40	50	60	70	80	90
	2	1.50	1.73	1.97	2.20	2.44	2.67	2.91
	4	1.28	1.49	1.69	1.89	2.09	2.29	2.50
	6	1.13	1.30	1.48	1.66	1.83	2.01	2.19
	8	1.00	1.16	1.32	1.47	1.63	1.79	1.95
	10	0.90	1.04	1.19	1.33	1.47	1.61	1.75
	12	0.82	0.95	1.08	1.21	1.34	1.47	1.59
	14	0.75	0.87	0.99	1.11	1.23	1.34	1.46
					LEGEND:	Commercially Viable Regime		

Source: Deloitte analysis

Scenario 4: Grey ammonia is produced using captive electricity (USD 55/MWh) and carbon tax is imposed

Table 10: Sensitivity analysis of green ammonia to grey ammonia cost multiple with USD 50/ton carbon price

	Cost of electricity (USD/MWh)							
Cost of NG (USD/ MMBtu)		30	40	50	60	70	80	90
	2	1.55	1.79	2.03	2.27	2.52	2.76	3.00
	4	1.32	1.53	1.74	1.94	2.15	2.36	2.57
	6	1.15	1.33	1.52	1.70	1.88	2.06	2.24
	8	1.02	1.18	1.35	1.51	1.67	1.83	1.99
	10	0.92	1.06	1.21	1.35	1.50	1.64	1.79
	12	0.84	0.97	1.10	1.23	1.36	1.49	1.62
	14	0.76	0.89	1.01	1.13	1.25	1.37	1.49
					LEGEND:	Commercially Viable Regime		

Source: Deloitte analysis

The commercially feasible range widens with the introduction of carbon price of USD 50/ton; the cost of green ammonia becomes viable at gas prices greater than USD 8/MMBtu at an electricity cost ranging from USD 30 – 40 per MWh. Viability will increase further with the increase of carbon tax.

Table 11: Competitiveness of green ammonia by 2030

Parameter	2023	2030
Natural gas landed cost (USD/MMBtu)	12	10
Captive electricity cost (USD/MWh)	55	55
Renewable electricity cost (USD/MWh) @75% CUF	60	48
Carbon tax (USD/ton)	0	50
Grey Ammonia capex (USD/ton)	1800	1800
Electrolyser capex (USD/kW)	900	450
Green ammonia capex (USD/ton)	2800	2240
Cost of capital	10%	10%
Grey ammonia cost (USD/ton)	**645**	**690**
Green ammonia cost (USD/ton)	**936**	**750**

Source: Deloitte analysis

Assumptions:

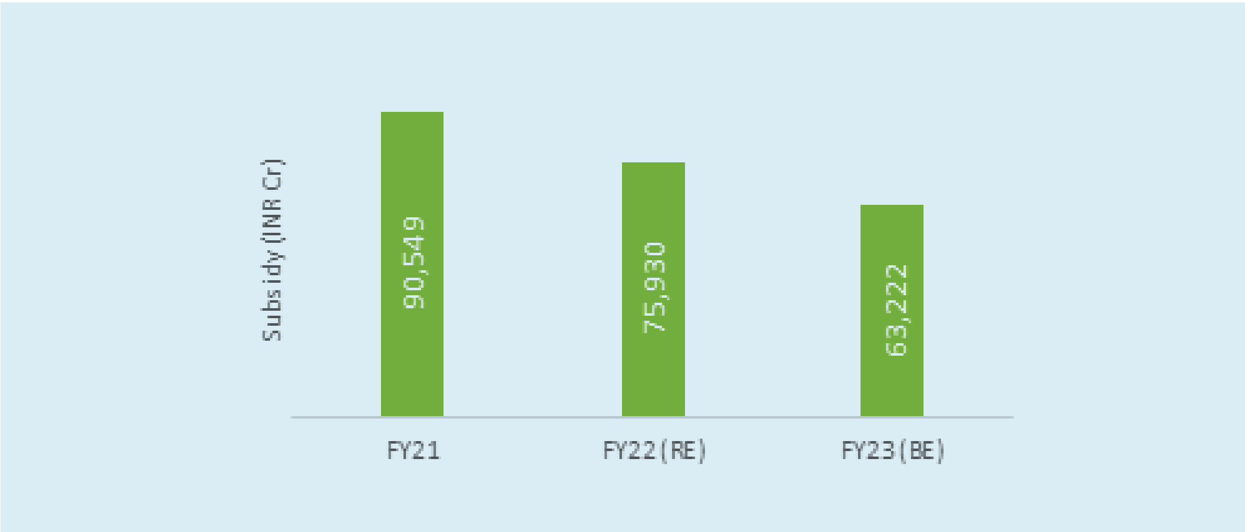
- Electrolyser capex will reduce by 40%, which is inline with various forecasts (IRENA, Research report etc.)
- Renewable electricity tariff will decline by 20%, driven by manufacturing scaling up in India, technology advancement (higher efficiency cell, such as HJT, Perovskite will become commercially viable)
- Landed natural gas cost will stabilize around USD 10/MMBtu
- Carbon tax by 2030 is assumed as USD 50/ton of CO2

2.4.5 Current subsidy structure for fertiliser production

Indian fertiliser sector is heavily subsidized. India provides subsidy to both urea and non-urea (nutrient based) fertilisers. The upstream subsidy for fertiliser units through preferential gas allocation is elaborated in Section 2.4.1.1.

2.4.5.1 Subsidy for Urea

Figure 29: Urea subsidy outlay (INR Cr)



Source: Union budget

The subsidy for urea is designed to socialize the cost of urea for farmers and at the same time ensure the cost recovery by fertiliser plants. Price of urea is statutorily fixed at Rs 268 per bag (50 kg) against the cost of production of Rs. 25000 – 28000 per ton. The balance is provided by the government as subsidy to the fertiliser units. On an average, subsidy provided to manufacturers is in the range of 20000 – 25000 per ton of Urea.

To decide on the subsidy, a concessional rate i.e., normative cost of production for each urea manufacturing unit is calculated. Concessional rate presumes the cost of energy (Natural gas, RLNG, Naphtha) which is a major component for captive grey ammonia production.

Some of the key announcements that drive urea subsidies are described below:

Announcement	Key features
New Pricing Scheme (NPS – III) and modified NPS, 2014	• This scheme lays the foundations for determination of fixed costs and variable cost.
New Urea Policy (NUP) 2015	• Determines fuel and feedstock cost of 25 gas-based urea stations • Determines concession rate for Urea production beyond Reassessed capacity • Provide guidance on Target Energy Norms (TEN) for the units for FY19
Revision of energy norms under NUP 2015	• TEN prescribed under NUP 2015 was enforced for 11 units from April 2018 • TEN for remaining 14 units were extended till September 2020 with certain penalties
Subsidy policy for Coal gasification-based urea production	• Allowed subsidy for Talcher Fertilisers plant to operate on coal gasification to produce urea

Source: Department of Fertilisers

The concessional rates are determined based on the variable cost components including energy costs (NG/ RLNG/ Naphtha), cost of non-plant use of power and water, and cost of bags. The fixed cost component of concessional rate includes salary and wages, contractual labour cost, consumables (catalyst, chemicals, etc.), administrative overheads, insurance, and factory overheads. To induce efficiency, target energy norms are set for the units.

In the case of Urea, any price rise in inputs is completely passed through and supported by increase in subsidy by GOI. Existing urea plants could switch to 10 – 20% green ammonia, without minimum capex implication (retrofitting, layout changes etc.). However, this would escalate the subsidy requirement further due to higher opex for using green ammonia. It has been estimated that 20% urea decarbonization would increase the annual subsidy requirement by INR 6000 – 7000 Cr (~$0.8 billion). The increase in subsidy is to compensate the incremental cost of green ammonia over grey ammonia.

An illustration of cost impact of urea decarbonization is provided below:

Table 12: **Cost and subsidy impact on Urea with decarbonization**

Sl. No.	Description	Unit	Value
A	Total Urea production	Lacs MT	242
B	Total ammonia requirement	Lacs MT	138
C	Decarbonization potential without any significant retrofit capex	%	20%
D	Price of grey ammonia @ USD 12/MMBtu NG price	USD/T	645
E	Price of green ammonia @75% CUF	USD/T	936
F	Production cost difference per ton of grey and green ammonia (E-D)	USD/T	291
G	Urea decarbonization potential (A*C)	Lacs MT	48.4
H	Ammonia requirement per ton of Urea	MT	0.57
I	**Additional cost/subsidy (G*H*F)**	**USD Billion**	**0.80**

Source: Deloitte analysis

Note:

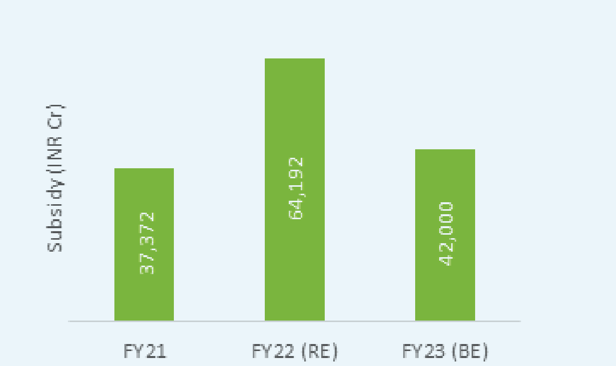
- *If natural gas (NG) price declines below USD 12/MMBtu, additional cost or subsidy requirement will increase further. For example, if landed NG price becomes USD 10/MMBtu, additional cost would be ~USD 1 billion.*
- *No additional cost towards capex retrofit has been considered (as confirmed by fertiliser players, cost implication would be limited for 10-20% decarbonization)*

2.4.5.2 Nutrient based subsidy for complex fertilisers

Nutrient based subsidy (NBS) is provided per kg for each nutrient (Nitrogen/ Phosphate/ Potash/ Sulphur) by accounting for international prices, exchange rate, inventory levels and prevailing reasonable MRPs (set by manufacturers). The MRP is monitored by the Department of Fertiliser on a regular basis to ensure consumer interests.

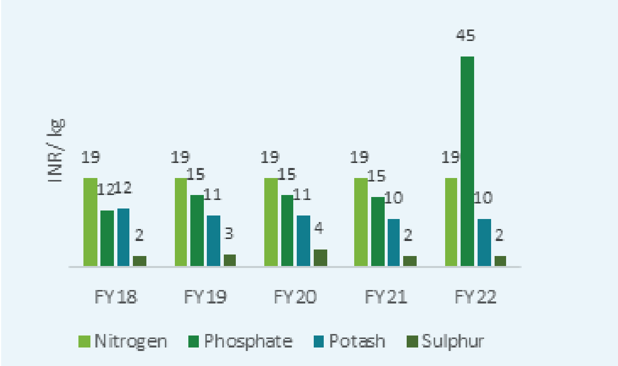
The annual subsidy outlay from NBS has been in the range of ~INR 40,000 – 65,000 Crores (USD 6 – 9 billion) in the last few years. The annual outlay and nutrient-based subsidy are captured below:

Figure 30: Nutrient based subsidy outlay (INR Cr)



Source: Union budget

Figure 31: Nutrient based subsidy (INR/kg)



NBS covers 18 grades of NPK, DAP, MAP, TSP, MOP, and Ammonium Sulphate and SSP. Phosphate and Potash subsidies are the largest component of NBS with ~INR 25.5 thousand crores outlay for them.

Entire production of NPK fertilisers can be decarbonized by substituting grey ammonia with green ammonia. However, this would cost additional INR 5,000 – 6,000 Cr (USD 0.6 – 0.7 billion) in terms of annual subsidy.

Table 13: Cost and subsidy impact on complex fertiliser from decarbonization

Sl No	Description	Unit	Value
A	Total complex fertiliser (CF) production	Lacs MT	90
B	Total ammonia requirement	Lacs MT	22
C	Decarbonization potential without any significant retrofit capex	%	100%
D	Price of grey ammonia @ USD 12/MMBtu	USD/T	645
E	Price of green ammonia @75% CUF	USD/T	936
F	Production cost difference per ton of grey and green ammonia (E-D)	USD/T	291
G	CF decarbonization potential (A*C)	Lacs MT	90
H	Ammonia requirement per ton of CF	MT	0.24
I	**Additional cost/subsidy (G*H*F)**	**USD Billion**	**0.63**

Source: Deloitte analysis

Note:

- *If natural gas (NG) price declines below USD 12/MMBtu, additional cost or subsidy requirement will increase further. For example, if landed NG price becomes USD 10/MMBtu, additional cost would be ~USD 0.8 billion.*
- *No capex implication has been considered*

2.5 Policy and regulatory environment for green hydrogen and ammonia in India

2.5.1 Current policy and regulations

In 2021, the Government of India launched the **National Hydrogen Mission (NHM)** to lay out its vision, intent and direction for harnessing hydrogen energy. The aim was to develop India as a global hub for manufacturing of hydrogen and fuel-cell technology across the value chain. Major activities envisaged under the NHM include increasing volumes and creating infrastructure, demonstrating niche applications (including transport and industry), and facilitating policy support. The NHM puts forward an ambitious target of reaching **5mmtpa** production of green hydrogen by 2030.

After the launch of NHM, in February 2022, India's government released its first **National Green Hydrogen Policy**. At its core, the policy seeks facilitate green hydrogen adoption by bringing down the costs of green hydrogen and improving ease of setting up green hydrogen projects. The hydrogen policy will be released in phases, with the second leg under review – which will focus on the industrial use of green hydrogen and ammonia in applications, such as refineries and fertilisers. **As of now, no mandates have been announced on hydrogen transition of hard to abate sectors**.

Key takeaways of the National Green Hydrogen Policy are captured below:

Figure 32: Key takeaways from Green Hydrogen Policy

Policy enabling low cost H2 production	Policy enabling "Ease of Doing Business"
• Green Hydrogen / Ammonia manufacturer may purchase RE power from exchange or set up RE capacity themselves or through any developer. • Manufacturer **can bank its unconsumed RE power**, up to 30 days with discom and take it back when required. • Distribution licensees can procure and supply RE to manufacturers **at concession** (procurement cost + wheeling charges + small margin as per State Commission). • Inter-state transmission charges are **waived for 25 years** for projects commissioned before 30th June 2025. • Manufacturers will be allowed to **set up bunkers near Ports** for storage of Green Ammonia for export /use by shipping. Storage land would be provided by Port Authorities • Renewable energy consumed shall count towards Renewable Purchase Obligation (RPO) compliance	• Open access for electricity will be granted within 15 days of receipt of application. • Manufacturer and RE plant will be given priority in grid connectivity. • Priority will be given for connectivity, at generation end and the Green Hydrogen / Ammonia manufacturing end, to the ISTS for RE capacity used to produce Green Hydrogen / Ammonia. • Ministry of New and Renewable Energy (MNRE) will set up a **single portal for granting statutory clearances** in a time-bound manner • MNRE may **aggregate demand** from different consumers and have consolidated bids for the procurement of GH/GA. This could help create competitive prices for GH. • **Land in RE parks** can be allocated towards green hydrogen/green ammonia plants

The next phase of the policy document is expected soon with specific mandates on industrial use of green hydrogen/ ammonia. The latest document has certain limitations with no comments on:

a. actual targets for green hydrogen production/consumption.

b. fiscal incentive for producers; or

c. targets for hard to abate sector (fertiliser, refineries, cement, steel) on their green hydrogen adoption.

Some of the key expectations from the next phase of the policy are listed below[30]:

- **Production linked incentives (PLI)** for electrolyser manufacturing; PLI has been announced already for solar cell and module manufacturers, battery manufacturers etc. Similar initiatives are expected for electrolyser manufacturing also
- **Direct export incentives** for green hydrogen/ammonia producers (likely to in special economic zones)
- **Demand creation** through **mandatory purchase obligation** – fertiliser/ammonia, refineries sectors are expected to witness 10% mandatory green hydrogen purchase obligation by 2025 -26
- **Blending mandate** with natural gas pipeline (up to 10%) for use in PNG and CNG
- **Waiver of certain Transmission & Distribution (T&D charges)** to lower the landed cost of electricity used for production of green hydrogen and green ammonia
- Announcement of pilot programmes on:
  - Deployment of Fuel Cell Vehicles
  - Decentralize production and use of green hydrogen in the remote part of India
  - Hydrogen blending in PNG lines

2.5.2 National Hydrogen Mission (NHM), India

The government's hydrogen vision was further cemented as the Union Cabinet approved the provisions of National Green Hydrogen Mission by sanctioning INR 19,744 crores outlay with an aim to make India a global hub for Green Hydrogen (GH2) in January 2023. The mission aims to reach an annual GH2 production to a minimum of 5 MMTPA by 2030 and sets an aspirational target to capture 10% of the global demand (~expected

30 Source: Industry interaction

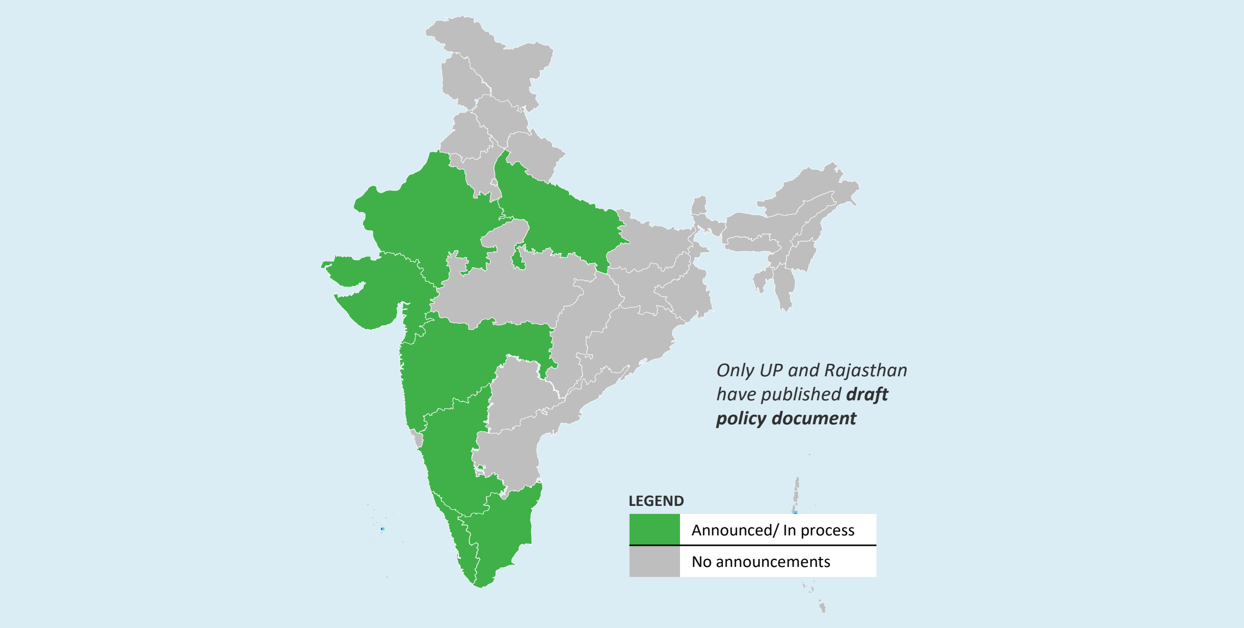
to become 100 MMTPA by 2030)[31]. The announcement of incentives, along with the aspirational production target, positions India as one of the attractive destinations globally for green hydrogen production.

Key highlights of the NHM:

- **Subsidy outlay breakup**: INR 17,490 Cr (USD 2.2 billion) towards hydrogen supply; 1,466 Cr for pilot projects; 400 Cr for R&D and 388 Cr was for other mission components
- Supply side incentives towards (1) production of green hydrogen, and the (2) manufacturing of electrolyzers
- Focus will be on substitution of grey hydrogen, GNH3 based bunkering, green steel and FCEV

The mission document has not commented on anything on the subsidy disbursal mechanism or any demand mandates. Clarity on these areas is expected by H1 2023 through new announcements.

2.5.3 State level policies on green hydrogen and ammonia



Source: Deloitte analysis

In addition to the central level policies, state specific green hydrogen policies are also expected to provide subsidy and incentives to the green hydrogen developers. The government has identified 10 states as preferred locations for green hydrogen production, as illustrated on the map.

These states are likely to produce state specific policies with customized subsidies and incentives for green hydrogen/ ammonia initiatives. Few states have started working on drafting the "Green Hydrogen Policy", such as Gujarat, Rajasthan, Tamil Nadu, Uttar Pradesh and Karnataka.

Examples of subsidies and incentives specific to green hydrogen/ ammonia projects being considered by these states are:

1. **Fiscal incentives:**
    - 100% exemption of land tax and land conversion charge
    - 50 – 100% exemption from industrial water consumption charge for GH2 project
    - Grant support for technology acquisition
    - Capex subsidy for electrolyser deployment
    - Subsidy on T&D charges for RE used for electrolysis
    - 100% exemption on cross-subsidy charges
    - Subsidy on green fertiliser production
    - Allowing banking of RE on monthly basis

31 Source: India National Hydrogen Mission document

2 **Ease of doing business:**

- Development of a portal with project specific databases; single window clearance platform for GH2/NH3 projects
- Reduced grievance redressal time
- Development of hydrogen based cluster and a vendor eco-system

2.6 Future demand of ammonia in India

Fertiliser sector will continue to drive the demand for ammonia in the short- to medium-term. However, future demand is expected from new applications, such as ammonia as a shipping fuel, ammonia as a fuel for power generation, and ammonia as a hydrogen carrier. Demand from these sectors is likely to be policy driven.

We see five (5) viable use cases for green ammonia, all of which provide decarbonization opportunities

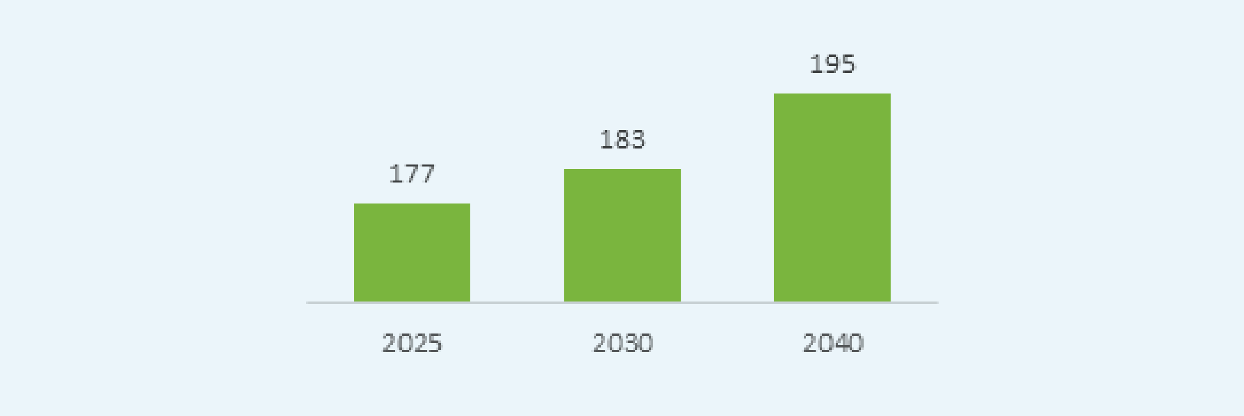
Table 14: Green ammonia use cases

Use Case	Current consumption (%)	Description	Decarbonization mechanism	Global examples
Fertiliser production	~95%	Ammonia is a feedstock for various nitrogenous fertilisers	Substitution of grey ammonia with green ammonia	YARA signed a green fertiliser offtake agreement with Lantmannen, an agricultural cooperative in Sweden
Chemical use	~5%	Ammonia as a feedstock in chemical manufacturing and use mining, pharmaceuticals, textiles etc.	Substitution of grey ammonia with green ammonia	Covestro signed an agreement to purchase green NH3 to decarbonize feedstock for polyurethane foam production
Marine Fuel	0%	Ammonia has potential to be used as marine fuel	Partial or complete substitution of fuel oil with ammonia in marine engines	Maersk announced to deploy ammonia ships by 2030
Power generation	0%	Ammonia can be co-fired with coal in power stations	Substitution of coal as a fuel, up to 20% without any major retrofit	Japan is doing pilot on ammonia co-firing
Ammonia as hydrogen carrier	0%	H2 can be converted to ammonia, shipped and converted back to H2 (through cracking) for use as a fuel	Enables import of H2 in locations with challenges of local production	NEOM and Air Product will ship green ammonia from KSA to Europe for cracking and use as a transportation fuel

Source: Deloitte analysis

2.6.1 Demand from fertiliser sector

Figure 33: Expected demand from fertiliser sector (in LMT)



Source: Deloitte analysis

The growth of fertiliser demand in the country is expected to be modest till 2040 at a CAGR of ~1% due to increasing efficiency and adoption of precision farming. The ammonia demand from fertiliser sector is expected to reach 177 LMT, 183 LMT, and 195 LMT in 2025, 2030, and 2040 respectively.

However, it is important to note that decarbonizing urea by substituting grey with green ammonia would be a challenge. **Only 10 – 15% substitution is practical unless CO2 is available from external sources at reasonable cost.**

Table 15: Future ammonia demand from Fertiliser sector

Ammonia derivative	Ammonia demand (LMT)			Decarbonization potential
	2025	2030	2040	
Urea	**139**	**144**	**153**	**10- 15%**
DAP	10.4	10.8	11.4	100%
NPK	23	24	26	100%
Ammonium Nitrate	1.8	1.9	2.2	100%
Ammonium Sulphate	1.9	2.0	2.3	100%
Total	177	183	195	100%

Source: Deloitte analysis

Fertiliser usage is expected to grow slowly due to efficiency measures. There is a possibility that, in the long run, India will focus more on NPK fertiliser to reduce overall market share of Urea to decarbonize the fertiliser sector. Industry will also look for commercial scale maturity of Carbon Capture & Storage (CCS), which will provide carbon requirement externally and help in urea decarbonization with green ammonia. However, initially cost of captured carbon may become prohibitive.

2.6.2 Ammonia as marine fuel

According to IRENA, 10% of the total transport energy consumption is attributable to freight transport and international shipping contributed to 2% of the global CO2 emissions. Keeping these in view, the International Shipping Maritime Organization targets 70% reduction in sector's carbon intensity (on a base of 2008) by 2050[32].

There are several solutions being proposed to reduce the carbon footprint of shipping, including low-carbon synthetic fuels and biofuels (e.g., Maersk's plan to use bio-methanol), nuclear, batteries and hydrogen. However, a significant amount of enthusiasm has coalesced around NH3 as a potential fuel given its advantages of energy density, existing volume production and infrastructure.

Table 16: Shipping fuel comparison

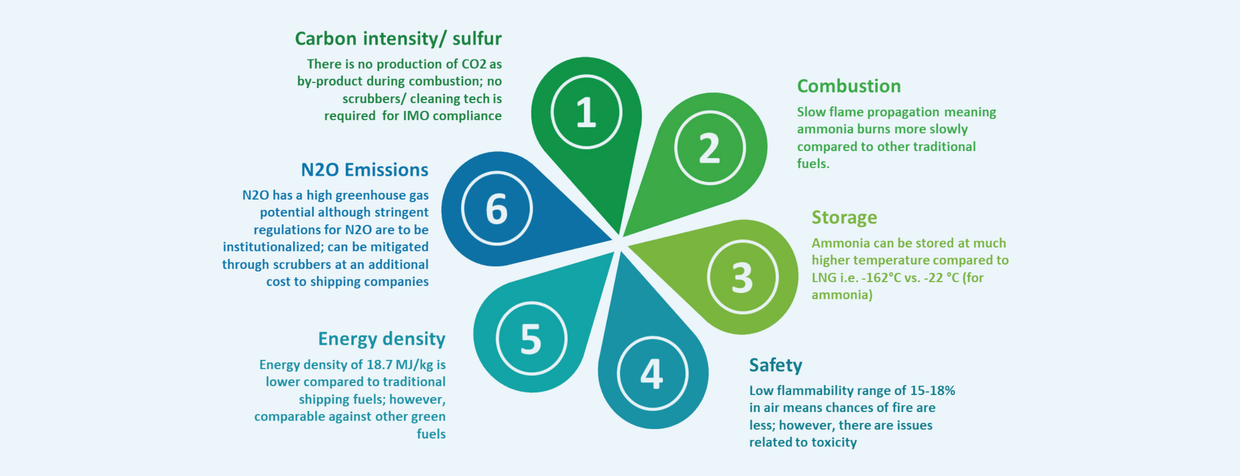
Fuel	Energy density (MJ/kg)	Relative tank volume	Supply pressure (bar)
Heavy Fuel Oil	40.5	1	7 – 8
LNG	50	1.6	300 – 380
Methanol	20	2.3	13
Ethanol	26	1.75	10
Ammonia	18.7	2.75	83

Source: Secondary research, Deloitte analysis

The key attributes of ammonia as a shipping fuel are illustrated below:

32 IMO; IMO's work to cut GHG emissions from ships

Figure 34: Key attributes of ammonia as a shipping fuel



However, ammonia comes with certain safety concerns. Ammonia is a toxic gas in ambient conditions and can be released rapidly into the air while kept in pressurized liquid form. Ammonia has a low flammability range (15 – 28%) which reduces the risks of fire, but it is highly corrosive, toxic, and potentially life threatening upon inhalation. In addition, during bunkering and transportation through pipelines, ammonia spillage in sea can be fatal for the marine ecosystem. Double walled pipelines for transportation[33], development of protocols for safe handling and product standards are critical for establishment of ammonia as a marine fuel[34].

The EU is examining inclusion of maritime shipping emissions into the ETS (Emission Trading Scheme). Negotiations for the proposal are still underway. In addition to the ETS, EU has also suggested to launch the 'Fuel EU Maritime initiative' which aims to increase the uptake of low carbon / renewable fuels in the maritime sector. In view of the regulatory environment, global majors such as Yara, OCI, CF and Nutrien have expressed confidence on ammonia as a shipping fuel in the coming decades. Shipping majors like NYK Line, Mærsk, etc. have initiated research into ammonia engines, bunkering, etc.

Some of the key developments in the area are showcased below:

Table 17: Key projects in the field of ammonia usage in maritime shipping

Company	Duration	Aim	Focus area
MAN Engines (Denmark)	2019 –24	USD 5 million project to develop the first ammonia-fueled two-stroke engine by 2022 and commercialize it by 2024.	Engine
Getting to Zero Coalition (Global)	2019 – On-going	Global coalition investigating pathways to decarbonize international shipping.	Ammonia fuel
Wartsila (Norway)	2020 - 23	To test an ammonia-fueled four-stroke engine; a USD 2 Mn grant from Norwegian Research Council	Engine
Viking Energy, consortium of 14 members (Europe)	2020 –24	The Viking Energy ship will be retrofitted with a 2 MW ammonia-fueled **solid oxide fuel cell**. The total project budget is around USD 28 million.	Solid oxide cell
NYK Line, Japan Marine United Corporation, IHI Power Systems, and Nippon Kaiji Kyokai (ClassNK) (Japan)	2020 – On-going	A joint R&D agreement for the commercialization of ammonia-fueled ships, including a gas carrier, a barge for offshore bunkering and a tugboat.	Engine, ammonia fuel

33 DNV, White Paper 2020 on Ammonia as a marine fuel
34 IRENA and AEA (2022), Innovation Outlook: Renewable Ammonia

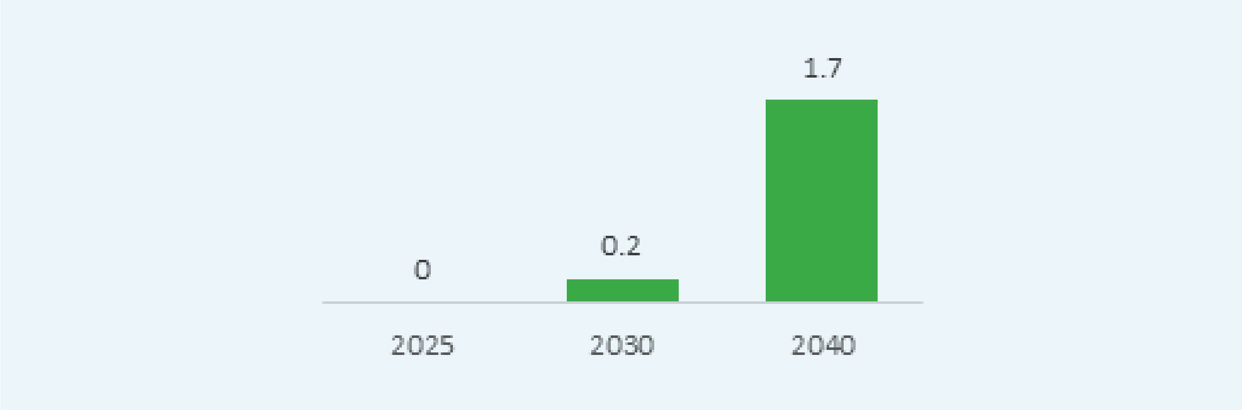
Company	Duration	Aim	Focus area
Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (Denmark)	2020 – On-going	Research institute intends to develop new fuel types and technologies to decarbonize the maritime sector. The institute launched with a start-up donation of around USD 60 million from the A.P. Møller Foundation.	Ammonia fuel
The Castor Initiative (Singapore)	2020 – On-going	A coalition of Lloyd's Register, MISC Berhad, MAN Energy Solutions, Samsung Heavy Industries (SHI), Yara, and the Maritime and Port Authority of Singapore aims to build an ammonia-fueled tanker by 2025	Vessel/ tanker
Potential for Ammonia as a Marine Fuel in Singapore (Singapore)	2021 – On-going	Coalition to study the potential of ammonia for Singapore, exploring supply, bunkering and safety challenges with ammonia as a maritime fuel; Consortium of American Bureau of Shipping, Nanyang Technological University, Singapore and the Ammonia Safety and Training Institute (ASTI)	Bunkering, safety, ammonia fuel

Source: IRENA and AEA (2022), Innovation Outlook: Renewable Ammonia, International Renewable Energy Agency, Abu Dhabi, Ammonia Energy Association, Brooklyn.

However, use of ammonia poses certain challenges for adoption in the maritime industry.

- High toxicity and corrosiveness present technical challenges for widespread adoption
- Bunkering solutions for ammonia shipping fuel is not yet matured and multiple companies in the industry are looking to come up with solutions in the field. Similarly, multiple companies are in process of development of ammonia-based engine.
- Ships will clearly have to be re-engineered to run on ammonia, which creates major complications, and to date there is little if no use of ammonia fuel in commercial shipping
- Market adoption is subject to technology development time and might be slowed down due to long life cycle of existing vessels

Figure 35: Expected demand from shipping fuel (in LMT)



The cost structure is not yet favorable, and at the same time, there are requirements of storage tanks along with bunkering solutions, which require additional capex. Apart from investment capex, shipowners also have to invest in scrubbing technology to mitigate the NOx emissions.

With this view of the challenges, it has been assumed that, in India, 1% of the energy requirement in 2030 and 8% of the energy requirement in 2040 will be met by ammonia[35]. Therefore, the overall demand for ammonia from shipping is expected to be ~0.2 LMT in 2030 and 1.7 LMT in 2040.

The demand estimation is based on a shipping fuel growth rate of 1% CAGR from 2020 to 2040 and ammonia specific energy density of 18.8 MJ/kg.

35 DNV Energy Transition Outlook 2022 for reference figures; aggressive adoption assumed in India

2.6.3 Ammonia as a fuel for power generation

To ensure decarbonization of electricity supply, the fuel mix for power generation has to change, and one of the options is to use ammonia which contains no carbon. There are challenges in ammonia combustion, though, such as ammonia has low flammability, high NOx emission and low radiation intensity which in addition to handling and transport issue have held back its use as a fuel. However, none of these are insurmountable issues (e.g., NOx can be reduced through selective catalytic reduction to negligible levels), and the energy transition puts the emphasis on CO2 emissions. Therefore, ammonia has potential to be used as a fuel for power generation like hydrocarbon fuels, such as coal, natural gas, etc. in both baseload and peaking plants to provide stability in the grid. **Up to 20% co-firing, no major retrofit in plant assets is required.**

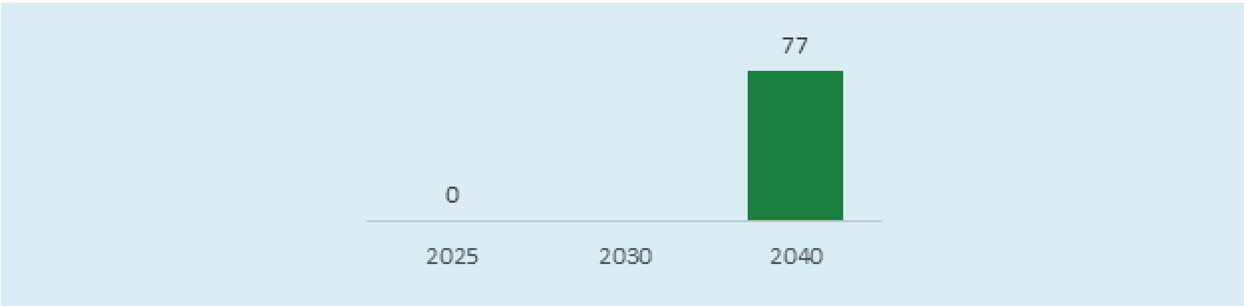
On the global stage, Japan is the front-runner in using low-carbon ammonia (green or blue) in coal fired power plants. The country has set an ambitious target to run all coal-based power plant on 100% ammonia by 2050.

However, the major challenge to ammonia as a substitute to coal is its unfavorable cost economics. An illustration is provided below:

Table 18: Commercial viability of 100% ammonia vis-à-vis coal-based generation in India

Particular	Unit	2022		2040	
		Green NH3	Coal	Green Ammonia	Coal
Heating value	MJ/kg	18.6	16.7	18.6	16.7
Thermal efficiency	%	40%	40%	40%	40%
MWh per ton of fuel	MWh/ton	2.08	1.87	2.08	1.87
Fuel price	USD/ton	900	70	400	142
Cost of 1 MWh	USD/MWh	432	37	192	76
Carbon tax	USD/tCO_2	0	0	0	90
Emission	tCO_2/ton of fuel	0	2.4	0	2.4
Carbon tax per MWh	USD/MWh	0	0	0	115
Cost of 1 MWh including carbon tax	**USD/MWh**	**432**	**37**	**192**	**191**

Figure 36: Ammonia demand from power sector (in LMT)



Source: Deloitte analysis

The economics of burning 100% ammonia at the current spot coal and ammonia price clearly doesn't stack up, but in a scenario where carbon emissions are priced at USD 90/ton, zero-carbon ammonia would be economic at ~USD 400/ton versus coal at ~USD 142/ton (long-term price with historical escalation rate of CIL[36] price).

In India, the uptake of ammonia co-firing plants is expected towards the late end of the 2030s. It is assumed that ~30% of the thermal power generators would adopt ammonia co-firing with 5% ammonia blending. This would translate to an ammonia demand of ~77 LMT in 2040.

Another option could be power generation through ammonia-fed combined cycle gas turbines, or hydrogen-fed gas turbines with ammonia cracking. Recently, Singapore Government has launched an Expression of Interest for similar arrangement[37].

36 Coal India Limited
37 https://www.ammoniaenergy.org/articles/singapore-launches-eoi-for-ammonia-bunkering-power-generation/

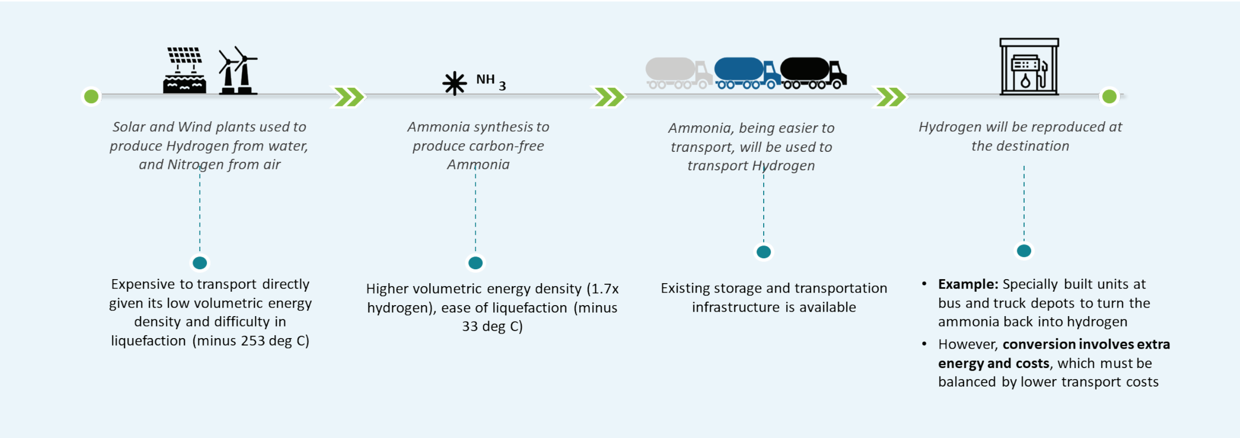
Ammonia co-firing in India has to be policy driven; economically green ammonia is not viable ($/MJ is ~10x higher than coal) with present cost and technology structures.

2.6.4 Ammonia as a Hydrogen carrier

The next relevant use case for ammonia is in its ability to be used as a hydrogen carrier. It is extremely challenging to store and transport hydrogen as the molecules are small and light which can result in leakage over time and transporting enough hydrogen for practical use adds to the challenge. Secondly, hydrogen requires extremely low temperatures (-253 degrees Celsius) for liquification and is extremely flammable thus the infrastructure required to transport hydrogen in a cost-effective manner to various locations around the world is almost non-existent to date and will be very expensive to implement.

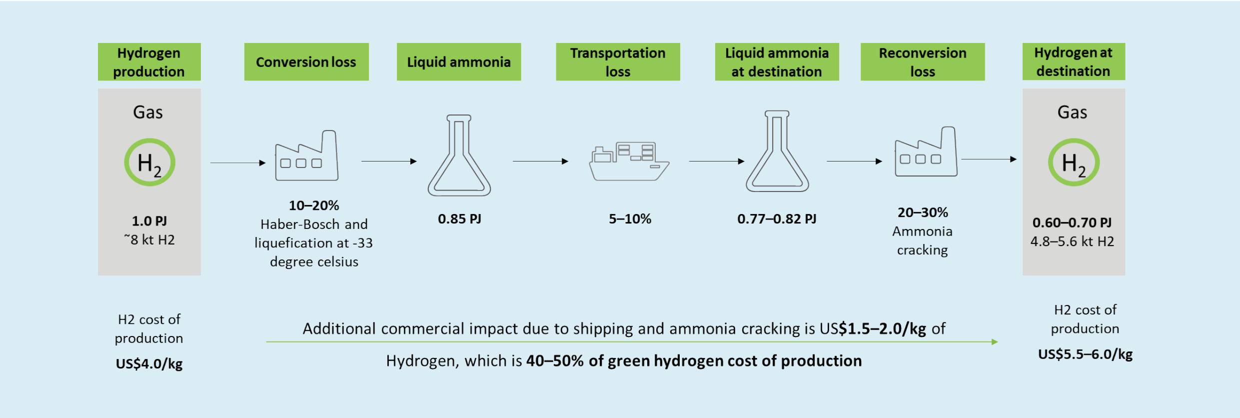
This is where ammonia may have a role to play: ammonia can be transported as a liquid at room temperature at the right pressure. In addition, ammonia is being transported in chemical manufacturing for decades which ensures availability of infrastructure, and that can be leveraged for further expansion. The value proposition here is that low-carbon hydrogen can be produced in cheap source locations and reacted with nitrogen to form green ammonia; the green ammonia can then be liquefied and transported or shipped to the desired location and converted back into hydrogen through cracking for use.

Figure 37: **Ammonia as hydrogen carrier**



However, there are economic and technical challenges with this use case. The entire process (hydrogen – ammonia – hydrogen) involves energy losses through the chain and is expensive. It has been estimated that ~20 - 40% of energy is lost in the re-conversion process during cracking only[38].

Figure 38: **Cost economics of ammonia as a hydrogen carrier**



Source: Deloitte analysis, Industry inputs, 'Limitations of Ammonia as a Hydrogen Energy Carrier for the Transportation Sector' (Chatterjee et,. al. ACS Energy Letters 2021)

Note: Shipping loss will not be applicable for domestic transport

38 Trevor Brown, "Round-trip Efficiency of Ammonia as a Renewable Energy Transportation Media" (access here)

H_2 production from ammonia cracking may escalate the delivered cost of hydrogen by USD 1.5 – 2.0/kg. Hence, whilst ammonia offers a reasonable solution to transporting hydrogen in general, it is not expected to be adopted widely. Rather we expect that the vast majority of hydrogen to be generated locally. Similarly, hydrogen - ammonia -hydrogen fuel cell configuration is not also expected to be commercially viable.

In the Indian context, amongst many sectors which are likely to switch to hydrogen fuel, only steel sector may see limited application of NH_3 as hydrogen carrier. A sector wise potential is illustrated below:

Figure 39: Potential of ammonia as hydrogen carrier

Sectors with hydrogen application	Potential of NH3 as hydrogen carrier	Remark
Refinery	Limited potential	Hydrogen is likely to be produced in-situ due to continuous nature of operation. However, considering large requirement, there may be demand for NH3 to meet the demand-supply
Steel	Limited potential	Hydrogen is likely to be produced in-situ due to continuous nature of operation. However, considering large requirement, there may be demand for NH3 to meet the demand-supply
Transport (Hydrogen Refueling Station)	No potential	Hydrogen is likely to be blended in the gas pipeline or dedicated hydrogen pipeline will be established
Building and domestic use	No potential	Hydrogen is likely to be blended in the gas pipeline
Electricity (Storage, H2 turbine)	No potential	Hydrogen is likely to be generated near consumption point

Source: Deloitte analysis

Limited demand of green ammonia may emerge in the long term from steel and refinery sectors once a market for PtX is established.

2.7 Announced projects on green hydrogen and ammonia in India[39]

More than 20 projects are either commissioned or under construction or have moved into tendering stage. However, all these projects are of pilot scale. Few large scale projects are also announced, mostly focused on ammonia production. A list of projects announced are illustrated below:

Figure 40: Green ammonia projects announced in India

Company	Investment (USD billion)	State	Ammonia capacity planned (Mt/year)
Acme Cleantech	6.2	Karnataka	1.2
Renew Power	6	Karnataka	1
ABC Cleantech	6	Karnataka	1
Avaada	5.5	Rajasthan	1
JSW Energy	5.2	Karnataka	Not announced
Petronas	3.7	Karnataka	0.5
O2 Power	2.1	Karnataka	Not announced
Jakson Group	2.8	Rajasthan	Combined H2 and NH3 to reach 3.6 MM/year by 2028

Acme Cleantech has unveiled several green ammonia projects in recent months. It has plan to set up a 1.2 MMT/year green ammonia plant in Karnataka (Mangalore) in between 2023 and 2027 with a capex of USD 6.2 billion (including RE assets)

- Malaysia based **Petronas** has expressed interest to build a 0.5 MM/year green ammonia plant in Karnataka with a capex of USD 3.7 billion
- **Avaada** plans to build an integrated RE and 1 MMT/year green ammonia project in Rajasthan with a capex of USD 5.5 billion

39 Source: Company announcements, Argus, Medial reports

- **Jakson Group** is planning a USD 2.8 billion integrated green ammonia project in Rajasthan's Kota region. Once completed, combined output of hydrogen and ammonia could reach 3.65 MMT/year
- **Oil and Natural Gas Corporation (ONGC)** and RE developer Greenko announced plans for 1.3 GW electrolyser project, which could produce 1 MMT/year ammonia
- **ABC Cleantech**, a subsidiary of Axis Energy, plans a facility that would produce 0.2 MMT/yr of hydrogen and 1 MMT/yr of ammonia, fed by 5GW of renewable energy
- **JSW Energy and O2 Power** have announced projects and investment in Karnataka; however, no production targets have been announced yet

While multiple announcements have been made, on-ground development is limited. Off-take assurance, bankability of projects and unfavorable cost structure are major deterrents. Developers prefer to wait and watch the domestic and global demand supply scenario.

2.8 Standards and certifications for clean ammonia

Certification and standard of hydrogen and ammonia is important to establish authenticity of low-carbon derivatives and boosting demand for those. While customers are willing to pay a premium for low-carbon products, there is an urgent need to develop certification standards and processes that infuse confidence among the stakeholders. Few important aspects pertaining to green ammonia certifications are:

- There is an immediate need of assessment of the green ammonia project for production methods, logistics methods and hydrogen applications before awarding the certificate, **which guarantees to customers that the hydrogen & ammonia produced at the green ammonia plant has zero emission or significantly lower emissions than fossil-based hydrogen or ammonia**.
- Certification schemes are required to distinguish between fossil-based ammonia, fossil-based ammonia with CCS and green ammonia produced with renewable energy. Certifications would enable the off takers to assess the carbon footprint and guarantees of origin. Basis the certified information, producers and off-takers would forge agreements on low-carbon ammonia. **Certification will be an important instrument to facilitate international trade of green ammonia**
- Certification mechanism would also **assess the purity grade of ammonia**. Specific applications, such as solid oxide fuel cells, require highly pure ammonia without any impurities.
- As a future step, Certification Scheme **may also include all type of emissions** (scope 1+ scope 2+ scope 3) as opposed to limiting the scope to emissions within the production facility (scope 1+2 but not scope 3)
- Certification Scheme may measure and track not only carbon emission intensity (CO_2e/tNH_3) but also **other sustainability metrics** (e.g., water intensity, energy intensity, environmental impact, etc.)

Globally the standards related to ammonia are widely adopted in chemical applications; however, standards and certifications related to green ammonia are yet to be released and harmonized across the globe. Recently, TÜV Rheinland has issued a world-first "Green Hydrogen and Green Ammonia Certificate" to Scatec & ACME's joint venture project in Duqm, Oman (1.2 MMT/year green ammonia capacity). The standard itself – H2.21 Carbon-Neutral Hydrogen – also allows for an optional color certification based on the assessment outcomes; in this case, "green" certification was also awarded[40].

There is an immediate need to establish a globally harmonized Certification Scheme for green/low-Carbon Ammonia to support the market development for green ammonia. The Certification Scheme will quantify the absolute GHG emissions associated with ammonia production and enable prospective producers and off-takers to trade ammonia based on certified, transparent, and verifiable emission reductions.

40 Ammonia Energy Association (access here)

2.8.1 Way forward for India

Currently, India does not have a robust framework for hydrogen and derivatives certification in place. India has announced “National Hydrogen Mission” with an ambitious target of 5 MMTPA domestic production and capturing up to 10% of global market. Clear standards and trusted certification schemes are expected to play a crucial role in meeting India’s ambitious targets for green hydrogen production, consumption, and export. There is an urgent need a robust and cost-effective approach to ensuring green hydrogen is ‘actually green’.

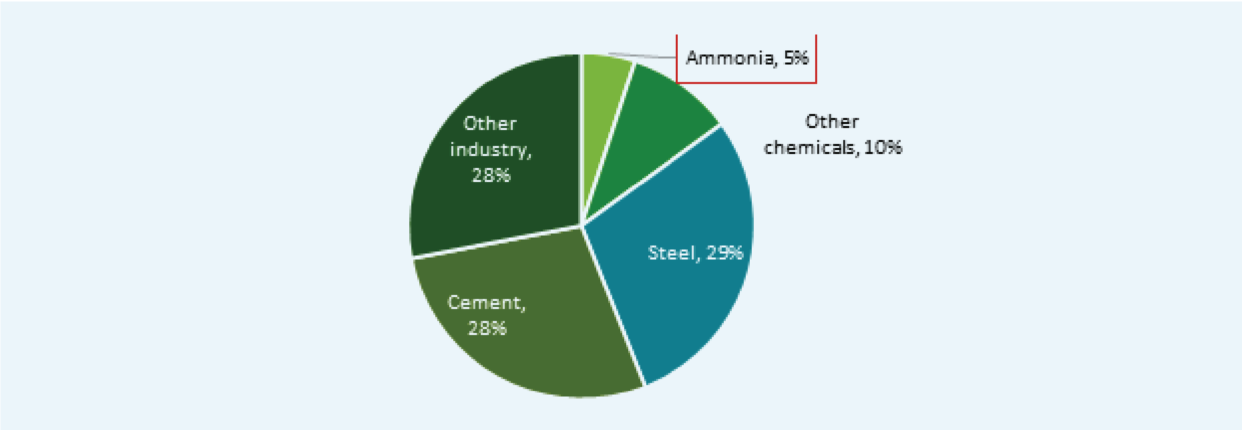
- Develop a national certification framework, which must be aligned with the international markets; create a database on globally adopted certification scheme and standards for green hydrogen and ammonia
- Define the system boundary and responsibility matrix of all stakeholders. System boundary may expand beyond the hydrogen and ammonia production stage to include storage, transportation, and distribution stages.
- Encourage and promote adoption of a Digital Monitoring, Reporting and Verification (MRV) system to capture data at all nodes of green hydrogen/ammonia value chain. Captured data would help in optimization of cost, process parameters and continuous improvement across the value chain
- Explore possibility to consume certain percentage of grid electricity until costs of Round-the-Clock supply of RE reaches grid parity
- Explore international collaboration to align with internationally acceptable certification scheme and standard.

3. International Market Study

3.1 Global production and demand of ammonia

3.1.1 Overview of global ammonia production

Figure 41: **Ammonia's contribution to world industrial emissions**



Source: Ammonia Technology Roadmap, IEA

Ammonia is a critical feedstock for fertilisers globally and ~183 million tons demand was realized in 2021[41]. The significant production volumes for ammonia account for ~1.3% of the global emissions and 5% of the industrial emissions as well. Emissions from current ammonia production is ~450 million tons of CO2 which is largely due to the fossil fuel-based production undertaken worldwide.

Emissions per ton of ammonia production with SMR (Steam Methane Reformation) is 2.2 – 2.4 tons CO2 eq. and with the coal gasification route, it is 3.2 – 3.6 tons[42]. Over 70% of global ammonia production is via natural gas-based steam reforming, while the remainder is via coal gasification.

From a regional consumption perspective, China is the largest consumer as well as producer with ~25% share (~45 MMT), followed by North America (22 MMT), Europe (18 MMT), India (18 MMT) and Middle East (15.1 MMT).

Figure 42: **Ammonia production, 2020 (in million ton per year)**

Source: IFA; Industrial Efficiency Technology Database, USGS;

41 Ammonia Technology Roadmap, IEA

42 Ammonia Technology Roadmap, IEA; actual emission varies with process and quality of fuels used.

Note- SMR: Steam Methane Reforming, CG: Coal Gasification

- **China:** China is the world's largest producer and consumer of ammonia. China hardly exports any ammonia and is almost self-sufficient. China only imports a small amount of ammonia each year; most of the imports come from Indonesia and the Middle East. China is the only country that has large amount of coal-based ammonia production (~20% of total production).
- **North America:** The USA and Canada accounts for ~12% of world ammonia production with the largest producers being CF Industries and Nutrient which account for more than 50% of total capacity in the region. Almost all the ammonia produced in the USA is for domestic use as exports are negligible; the USA is the second largest importer of ammonia. The imports come mainly from Trinidad & Tobago and other Latin American countries.
- **Middle East:** The Middle East accounts for ~8.5% of global ammonia capacity with QAFCO (Qatar), NPC (Iran), SABIC-Agri (Saudi) and Ma'aden (Saudi) having the lion's share of total capacity in the region. The region is the third largest exporter accounting for 15% of global exports, and much of its to Asia, including India.
- **Southeast Asia (mainly Indonesia):** Southeast Asia accounts for ~6% of global ammonia capacity with Indonesia being the largest producer in the region. The region is a large importer and exporter of ammonia but overall, a net exporter of ammonia, and exports most of its ammonia to China and other Asian countries
- **Southwest Asia (mainly India):** Southwest Asia accounts for ~9.5% of global ammonia capacity with India being the region's largest producer followed by Pakistan and Bangladesh. The region does not export any ammonia and is a net importer with most imports going to India. India is one of the largest ammonia importers and receives most of its imported ammonia from Saudi Arabia and Qatar.
- **Russia:** Russia accounts for 7% of global ammonia production. EuroChem, Acron and Phosagro are the largest producers in the region. Russia is the largest exporter of ammonia accounting for over 20% of world exports. Most of the exports go to Western Europe and other countries within the EU region.

The entire production fleet in the world is based on grey ammonia (gas and coal), contributing ~1.3% of global emission. China is the largest producer, followed by USA, India, and Middle East.

3.1.2 Market structure of ammonia

The ammonia market serves the captive production of fertiliser and other industrial products. Nearly 70% of the gross ammonia consumption is concentrated with fertilisers, with Urea having the largest share; the remaining is consumed in other industrial applications viz. chemicals, textiles, pharmaceuticals, mining, others.

Fertiliser producers across the globe rely on captive setups. Contribution of international trade (~10%) and domestic merchant transaction (~15%) is limited. USA and China are the largest domestic merchant markets for ammonia as the volumes of the chemical stays within country borders. Deep sea trade and merchant volumes of ammonia largely includes the transactions between large players and imports done by traders. The merchant volumes primarily cater to the industrial demand for ammonia concentrated in the chemical industries.

Figure 43: Ammonia consumption distribution in 2021 (MMT)

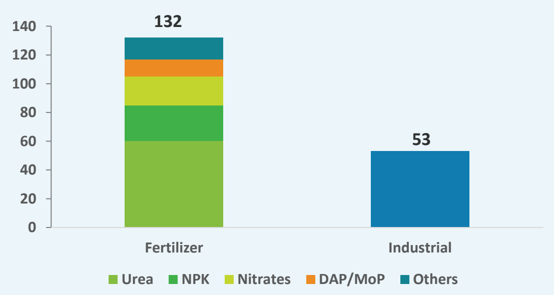


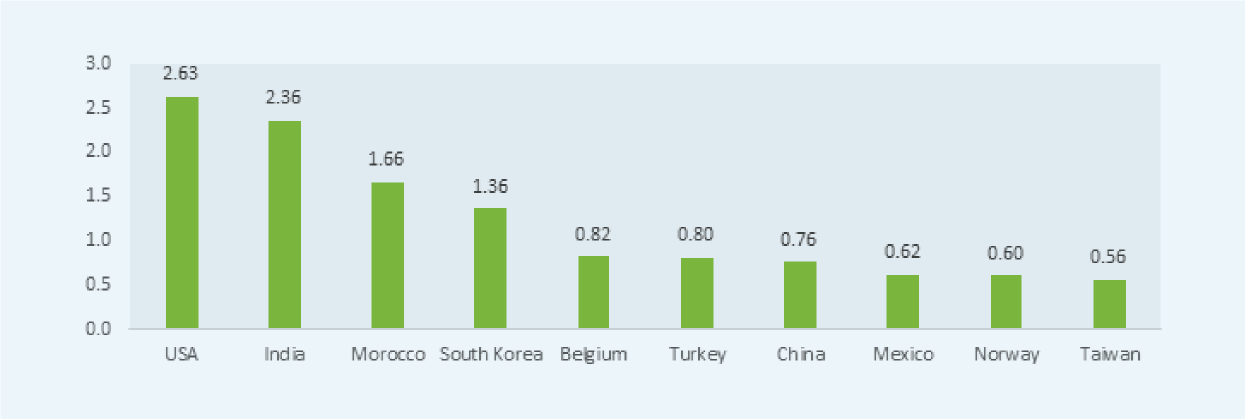
Figure 44: Market structure of ammonia in 2021 (MMT)

Source: Yara Clean Ammonia presentation on Capital Markets Day, June 2022 (access here

3.1.2.1 Major importers and exporters of ammonia

The top 10 importers of ammonia represent 70% of the traded volumes in 2021. USA, India, Morocco, South Korea and Belgium constitute 50% of the overall imports. The buyers of these countries are industrial consumers primarily in the chemical sector, production of phosphate fertilisers and direct application in the fields.

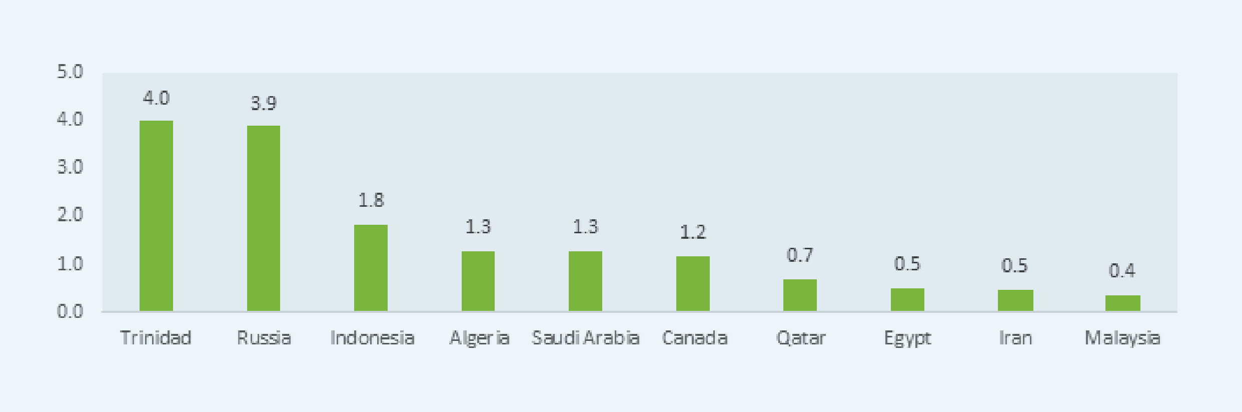
Figure 45: **Top 10 importers of ammonia in 2021 (MMT)**



Source: Yara Clean Ammonia, Secondary research

Ammonia exports are driven by exporters having access to competitive feedstock/ energy coupled with a deficit of domestic demand for ammonia and fertilisers. Ten (10) countries contribute to ~85% of the export volume as illustrated in Figure 46.

Figure 46: **Top 10 exporters of ammonia in 2021 (MMT)**

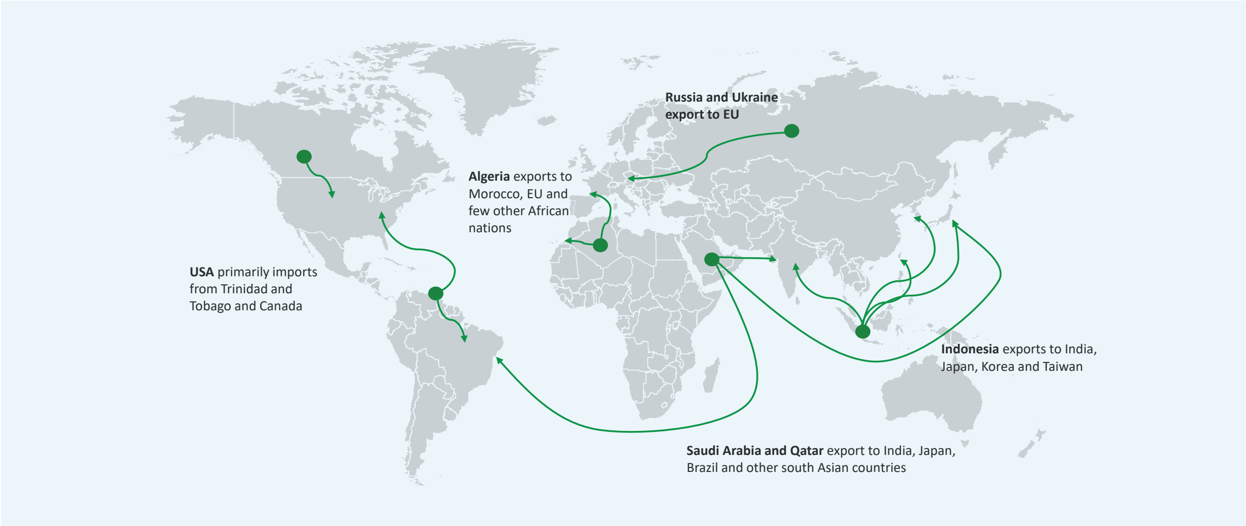


Source: Yara Clean Ammonia, Secondary research

Trinidad & Tobago is the largest exporter, with favorable natural gas reserves and low ammonia demand within the country. Other major exporters include Russia, Indonesia, Algeria, Saudi Arabia, Qatar, etc. All these countries have availability of low-cost natural gas, the major feedstock for ammonia production. Most of the export of ammonia is seaborn i.e., deep sea route with limited volumes via rail.

The prominent ammonia trade routes on a global stage are illustrated below:

Figure 47: Current trading partners and routes for ammonia



Source: Deloitte analysis

USA and India are the largest importers of ammonia while Trinidad & Tobago and Russia are the largest exporters. However, the ammonia trade market is small, with only around 10% (18-20 MMT) of the ammonia produced is being imported/exported.

3.1.2.2 Major demand centers of ammonia

Major demand centers across the globe are illustrated below:

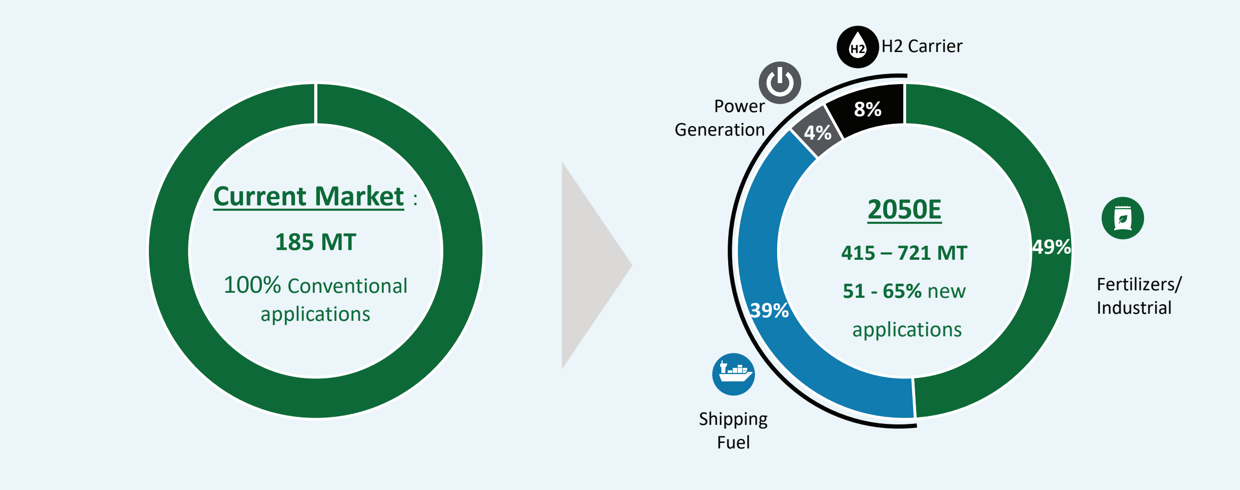
Figure 48: Ammonia demand in major demand centers (MMT)

Source: Deloitte analysis, multiple sources

Asia-pacific region holds the largest share of ammonia demand (120 – 130 MMT), led by China. Demand for both EU and North America is in the range of 18 – 19 MMT per year. Currently, the entire ammonia demand comes from fertiliser and industrial sectors. However, going forward, newer applications such as shipping fuel, power generation, and hydrogen carrier would contribute to increase in ammonia demand. It has been estimated that by 2050, existing applications would contribute only 49% of ammonia demand[43]. The details of future demand potential are elaborated in the later sections.

43 Yara Clean Ammonia

Figure 49: **Market expansion potential for ammonia via newer applications**



Source: Deloitte analysis, Yara Clean Ammonia, multiple sources

The demand from newer applications would be driven by enactment of conducive regulations and policies towards clean energy transition.

3.1.3 Regulations, policies and initiatives driving clean ammonia transition

Many nations in the European Union, the USA, South Korea, and Japan have brought out policies and regulations to enable clean hydrogen/ammonia transitions in fertilisers, marine industry, and power sector.

3.1.3.1 EU ETS scheme and Carbon Border Adjustment Mechanism (CBAM)

The European Union **Emissions Trading System (ETS)** was created in 2005 and has been fully implemented in 2008 with the objective of lowering overall CO2 emissions by 20% from 1990 levels by 2020 and 43% by 2030. It is a "cap and trade" scheme with overall emission ceiling (cap) is gradually reduced over time to ensure fall in total emissions. Beneath ceiling, companies receive or buy allowances, auctioned by member states. Companies are also allowed to trade and resell unused allowances on the secondary market. After each year, companies must surrender enough allowances to cover their emissions. EU ETS covers most of the emitting sectors and greenhouse gases.

The European Union also introduced CBAM (Carbon Border Adjustment Mechanism) as a proposal in July 2021. Subsequently, on 22 June 2022, the European Parliament adopted its own position on the CBAM. Captured below are the general principles of CBAM[44]:

- It aims to prevent 'carbon leakage' by subjecting the import of certain groups of products from other (non-EU and non-EFTA) countries to a carbon levy linked to the carbon price payable under the EU Emissions Trading System (ETS) when the same goods are produced within the EU.
- Current ambit of the CBAM include iron and steel, cement, fertilisers, aluminum, electricity, and hydrogen.
- Further scope extensions to include additional products (such as chemicals and polymers) are expected to be determined by 2026, and the full inclusion of all EU ETS products is planned by 2030.
- The transitional period for the CBAM is expected to start in January 2023, during which EU importers must submit quarterly CBAM-reports, stating their imports of the CBAM products, as well as the emissions 'embedded' in their imported products. Such emissions are proposed to include direct and indirect emissions occurring during the production process of the imported goods.
- The transitional period is proposed to end in January 2027, after which the carbon levy under the CBAM must be paid. To pay the carbon levy under the CBAM, EU importers must purchase CBAM certificates covering the emissions 'embedded' in the products they import and submit annual CBAM declarations.
- Importing CBAM products, purchasing CBAM certificates and submitting CBAM declarations will require a special authorization (the 'Authorized (CBAM) Declarant') issued to EU importers or representatives acting on behalf of one or more importers by the competent CBAM authority.

44 Deloitte, EU Carbon Border Adjustment Mechanism (CBAM) (access here)

The EU ETS assesses the carbon tax on emissions in the region, and CBAM penalizes high-carbon imports to prevent 'carbon leakage'. Implementation of CBAM is critical component of ETS to mitigate carbon leakage. With these schemes in place, demand for blue or green ammonia is likely to increase in the EU.

Additional to the EU ETS and CBAM, EU member states like Germany, France, Portugal, Netherlands, Spain, Norway, Denmark have developed state **hydrogen strategies** with targeted incentives and mechanisms to materialize clean hydrogen (and derivatives) supply and demand.

3.1.3.2 Inflation Reduction Act (IRA), USA

In August 2022, the US Congress passed the Inflation Reduction Act (IRA), introducing incentives to make green hydrogen cost competitive. The IRA will provide a "production tax credit" (PTC) between $0.6/kg and $3/kg for clean hydrogen development in the country if certain wage and labor requirements are met. Basically, the tax credit will bridge the cost gap between grey and green hydrogen. This applies to green H2 (with lifecycle emissions of <0.45kgCO2/KgH2) and a fraction for blue H2 (assuming lifecycle emissions stay below 4kgCO2/KgH2). The PTC is available for a 10-year period for any H2 production facility that starts construction before 2033. The IRA also incorporates an investment tax credit for new 'clean' facilities. As per industry experts, the PTC could bring the average US cost of green H2 production down to $2/kg in the short term (and to almost zero in the early 2030s).

Hence, all applications that use grey hydrogen today, such as ammonia, fertilisers, will now be able to buy green hydrogen at a competitive price with grey.

Figure 50: Key aspects of Inflation Reduction Act

Category	Provision summary	Credit Type
Hydrogen production Up to $3/kg hydrogen production credit on a sliding scale based on lifecycle greenhouse gas emissions of a project		Production Tax Credit (PTC)
Infrastructure	Up to 30% credit for fuel cells, hydrogen storage	Interest Tax Credit (ITC)
Refueling Infrastructure	Up to 30% for depreciable property, 30% for non-depreciable property	Interest Tax Credit (ITC)
Sustainable Aviation Fuel (SAF)	$0.50/gal credit on hydrogen used in aviation fuel	Credit on use
Grants for SAF	$300M to establish a competitive grant program to promote the development, use, production, and storage of SAF incl. Hydrogen	NA
CCS	Up to $85/t for projects capturing at least 12.5ktpa of CO2	45Q credit

Source: Deloitte analysis, US IRA

The scale of this incentive – which can compensate most or all the production cost – is causing market disruption, such as attracting investments into the US from other regions and creating the possibility for green hydrogen to be exported to demand centers (e.g., Europe) at a more competitive price (including transport and cracking) than local production. **As of now, there is no export restriction from IRA funded projects. Many developers are considering setting up projects in USA to cater demand from domestic as well as EU market – the current subsidy can compensate the transportation cost to Europe and ammonia cracking cost.**

In addition, with incentives in place for both upfront capex and future production, it is believed that the scale and speed of hydrogen and derivatives hub developments could surprise to the upside, enabling the US to leapfrog other nations in climate actions.

The IRA (Inflation Reduction Act) is expected to be the game changer in global hydrogen ecosystem. Recent interactions with green ammonia developers pointed towards high attractiveness of USA amongst developers

3.1.3.3 Marine decarbonization target

Ammonia has been identified as a future marine fuel along with methanol by the IMO (International Maritime Organization) in its 2030 and 2050 carbon intensity reduction roadmaps. Based on the physical and chemical properties, ammonia stands out as an alternative with low carbon footprint. The IMO has set targets for 50% reduction in GHG emissions by 2050 from 2008 levels and adopts a phase wise strategy. In the near term by 2030, reduction of 40% emissions from shipping vis-à-vis 2008 is targeted[45]. The initial strategy was launched in 2018 and likely to be further revised in 2023.

The EU Renewable Energy Directive II also targets 14% renewable energy content in transport by 2030[46] and is a key driver for ammonia usage in maritime industry in the EU.

3.1.3.4 Ammonia mandates in Power generation

Globally, Japan and South Korea are two nations to include ammonia as a power generation fuel in their ambitious 2050 net zero plans.

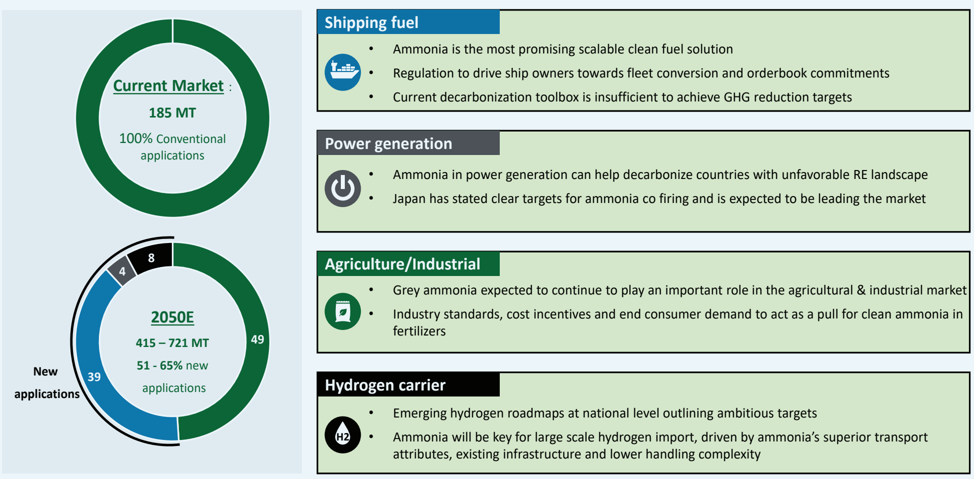
- Japan has plans to trial co-firing 20% ammonia in its coal fired power stations before ultimately moving to 100% and several MOU/ deals between Japanese power companies and ammonia producers have been announced[47].
- The Korean government has announced plans to fire hydrogen and ammonia for power generation from 2030. The Ministry of Trade, Industry and Energy intends to use a fuel mix of 30% hydrogen at all its gas-fired power plants by 2035, and 20% ammonia at half of its coal power stations from 2030, as part of its plan to reach net-zero emissions by 2050[48].

These initiatives are expected to boost ammonia demand globally from power generation. As of now, only Japan and Korea have announced plans to use ammonia in power generation; however, going forward, some more countries may unveil similar plans.

3.1.4 Demand assessment of green ammonia

Future demand of ammonia will be generated from both conventional and new application use; however, new applications are expected to contribute more than 50% by 2050[49], as illustrated below:

Figure 51: Existing and newer applications of ammonia

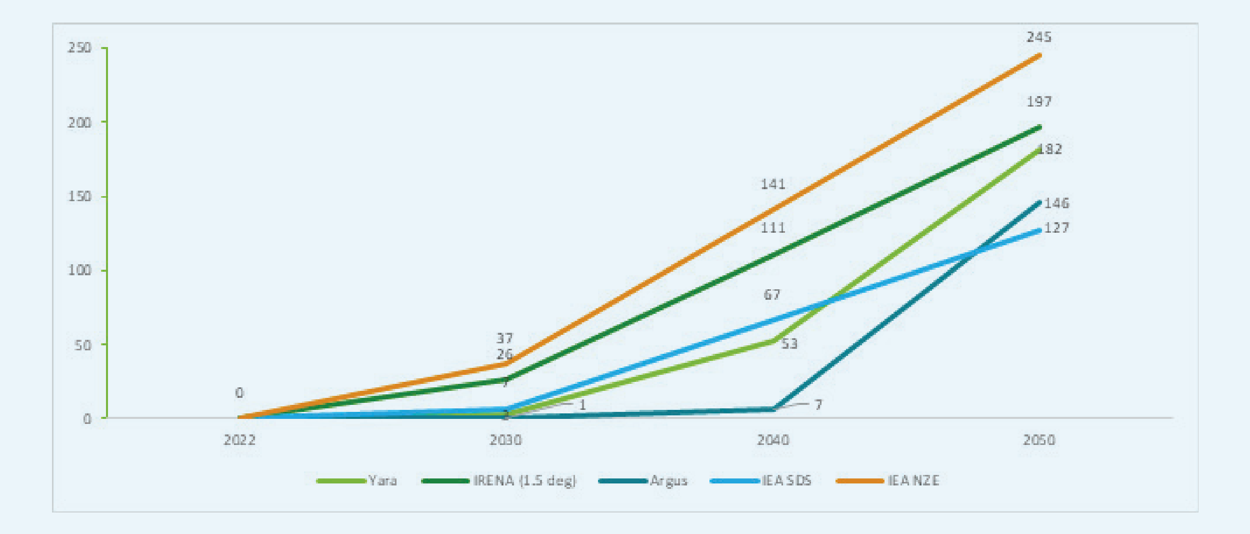


45 IMO: IMO's work to cut GHG emissions from ships (access here)
46 Renewable Energy Directive (access here)
47 Ministry of Economy, Trade and Industry of Japan
48 Recharge, South Korea aims to burn millions of tonnes of clean hydrogen and ammonia for giga-scale power production (access here)
49 Yara Clean Ammonia

3.1.4.1 Demand of green ammonia from shipping industry

Ammonia has been established as a future marine fuel by the IMO. The improvement of efficiency in the current fleets is expected to reduce emissions by the tune of 20 – 25% and ammonia usage as a fuel is eminent in the future. The demand of ammonia as forecasted by different agencies ranges between 127 – 245 MMT in 2050, as illustrated below:

Figure 52: Ammonia demand as a marine fuel (MMT)

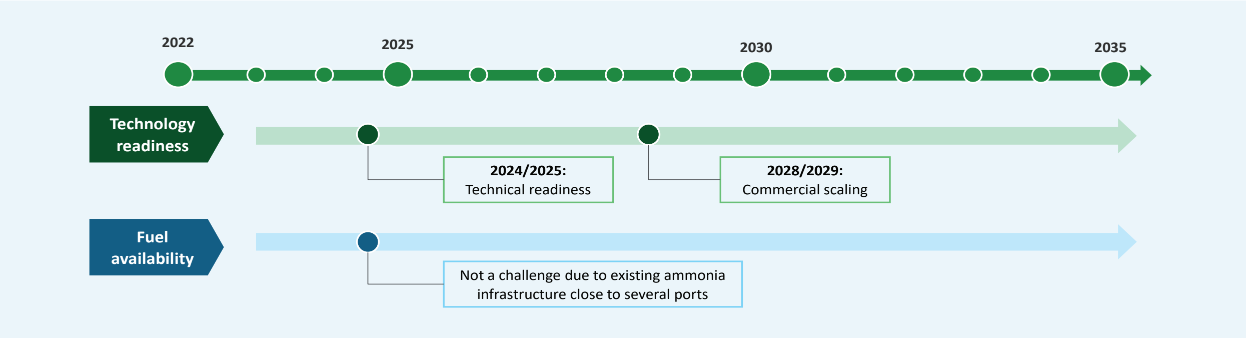


The expected inclusion of shipping in the EU ETS would lead to accelerated usage of ammonia in the marine ships as ammonia scores better than other green fuel. In a recent regulatory development, ship operators will be required to pay for the greenhouse gas emissions during their voyages to, from and between EU ports, with a phase-in period starting from 2024. Vessel operators will need to surrender EU Allowances in 2025 for 40% of their emissions in 2024, in 2026 for 70% of their emissions in 2025, and in 2027 for all their emissions in 2026, based on the preliminary agreement[50].

However, the emphasis on decarbonization of the shipping raises another key concern of "stranded assets" which are based on fossil fuel infrastructure. LNG assets have gained prominence in recent years as Sulphur emission limitations imposed by the IMO. Associated infrastructure such as LNG bunker facilities, LNG vessels have seen widespread adoption throughout Europe and Asia to accommodate the LNG shipping fleets. Shipowners looking to order LNG infrastructure and vessels could face the risk of the vessels becoming stranded assets if policymakers push shipping towards zero-emission fuels. As revealed by the study of University College London's UCL Energy Institute, the value at risk of being stranded could range from $129bn to $848bn in 2030 due shipping decarbonization[51].

As per recent developments, ammonia fueled engines are expected to be ready from 2024–2025, with commercialization in 2028–2029. Also, ship-owners across the globe are involved in "ammonia as a fuel" projects.

Figure 53: Anticipated progression of ammonia as a shipping fuel



50 S&P Global (access here)

51 University College London (access here)

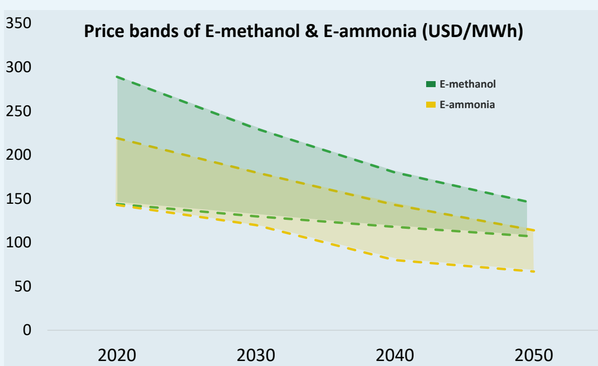
Figure 54: **Select ship-owners involved in ammonia-as-a-fuel projects**[52]

E-methanol is also viewed as an alternative fuel for marine shipping, like that of ammonia. The technology readiness of e-methanol, at present, is more mature compared to ammonia; however, in the long term ammonia is expected to score better due to declining cost structure and higher decarbonization potential. A comparative assessment of methanol and ammonia is illustrated below:

Figure 55: **Comparison of methanol and ammonia as shipping fuels**

	Technological readiness of fuel & engine	Scalability & Infrastructure	Fuel characteristics & other parameters	Costs associated
Methanol	✓ Minimal retrofitting required in existing engines ✓ Technology readiness is better than ammonia	✓ Well-established transportation and distribution infrastructure ✓ No special storage required for bunkering ✗ Major challenge is sourcing renewable and cheap carbon for production ✗ E-methanol production is very low currently	✓ Lowest carbon & highest hydrogen content among other fuels ✓ Liquid at ambient temperature making it cheaper to transport & store ✓ Low SOx & NOx emissions ✓ All types of tanks are suitable for storage ✗ Invisible flame, fire detection systems are required	✗ Future competitiveness of e-methanol depends on the costs of carbon capture and removal technologies
Ammonia	✗ Ammonia fuel applications, FCs and ICE, are still in development stage	✓ Existing logistical infrastructure with no need for cryogenic storage ✓ Established ammonia terminals across the world ✗ No existing commercial applications for ammonia as a fuel in the shipping sector ✓ Green ammonia production plants announced globally	✓ Transportation is simple & affordable ✓ Safety challenges – low flammability, high corrosion and toxicity but solid infrastructure is present ✗ NOx emissions require external system for treatment	✗ Capital costs are huge as installation of electrolyzers & bunkers required as ammonia is not compatible with existing infrastructure ✓ Production cost of e-ammonia does not depend on the costs associated with carbon capture and removal technology

Figure 56: **Expected progression of ammonia and methanol prices (2020-2050)**



Source: IRENA

52 Company announcements, Secondary research

Today the prices of ammonia & methanol are comparable, and methanol is the preferred option because of the technology readiness and minimum retrofit required in existing engines. However, in the long term, green methanol prices will likely to be higher than green ammonia due to higher costs associated with carbon capture & removal technologies. On the other hand, extensive investment, and economies of scale of electrolysers and hydrogen plants will bring down the ammonia production costs.

With declining cost structure, ammonia is expected to gain more global acceptance as the alternative shipping fuel. However, additional focus would be required mitigate the NOx risk.

Green ammonia bunkering opportunity for India

Bunker Fuels demand at Indian ports was about 1% of the global demand in the pre-covid time. Majority of the demand comes from defense ships, domestic vessels, coastal vessels and a small portion of international ships calling at Indian Ports[53].

India's export ambition (aspirational target of capturing 10% of global market, totaling to 10 MMTPA) may become fruitful by tapping the emerging demand of ammonia as the bunker fuel. India has a long coastline with presence of large number of major and minor ports. These ports can have dedicated bunker fuel stations to drive the demand of green ammonia by refueling the international shipping liners.

India's National Hydrogen Mission, published in January 2023, has indicated to develop one port with ammonia bunkering arrangement by 2025. Indian renewable developer Greenko has signed an MoU with Singapore based Keppel Infrastructure for supply of green ammonia that may be used to replace bunker fuels[54].

As a next step, following ports where bunkering arrangements are existing and are nearer to domestic demand clusters can be considered for setting up green ammonia based bunkering arrangement:

- Cochin
- Mumbai
- Kandla
- Vizag

Key factors that will drive the demand of bunker fuel in Indian ports are:

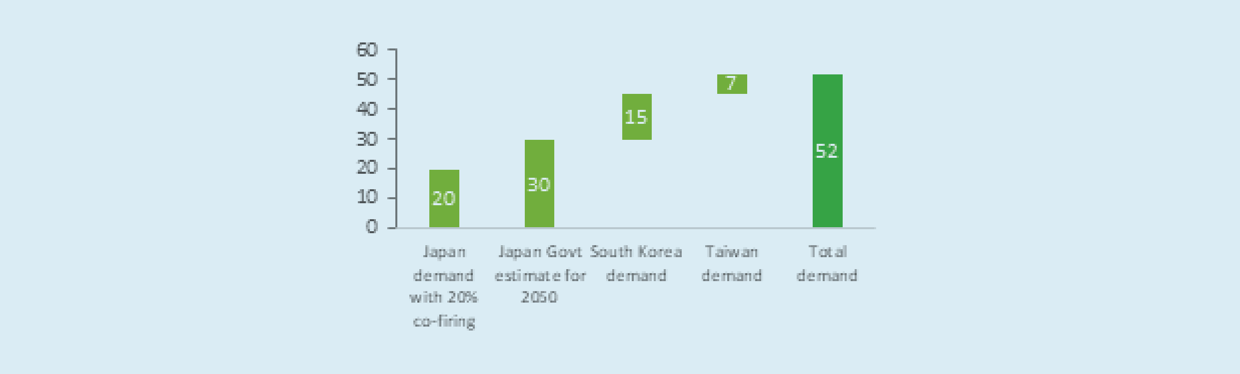
- Distance from international shipping routes
- Bunkering infrastructure
- Cost of fuel

Recently, the Maritime & Port Authority of Singapore and the country's Energy Market Authority (EMA) have jointly launched an EOI process to build, own and operate bunkering projects on Jurong Island55. India may take similar approach to develop bunkering projects in the identified ports through Public-Private Partnership mode (PPP).

53 Source: FICCI report on Maritime fueling, 2019 (access here)
54 Keppel, Greenko partners for renewable energy and green ammonia (access here)
55 https://www.ammoniaenergy.org/articles/singapore-launches-eoi-for-ammonia-bunkering-power-generation/

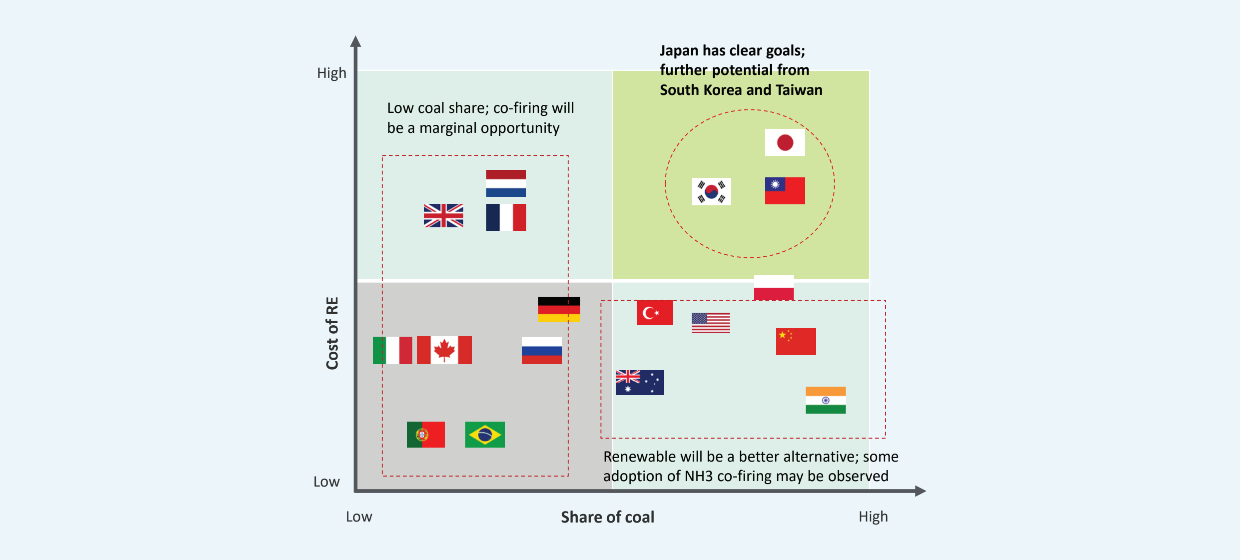
3.1.4.2 Demand of green ammonia from power generation

Figure 57: Ammonia demand estimation from co-firing in Japan, South Korea, and Taiwan in 2050 (MMT)



Source: Deloitte analysis, Yara Clean Ammonia

Figure 58: Comparative assessment of countries for ammonia co-fired power generation



Source: Deloitte analysis

Ammonia holds potential as a co-firing fuel in power generation and would be a vital tool for decarbonization. In general, ammonia emerges as a preferred decarbonization substitute in regions with poor renewable potential and heavy dependence on coal-based power fleets, such as Japan and South Korea. However, technological development is necessary for inclusion of high ammonia shares and to reduce NOx emissions. Asset modifications are required if the co-firing of ammonia exceeds 20%. As illustrated in the figure, ammonia co-firing is expected to be concentrated in few geographies across the globe with higher cost of renewable energy and significant share of coal-based generation in power mix.

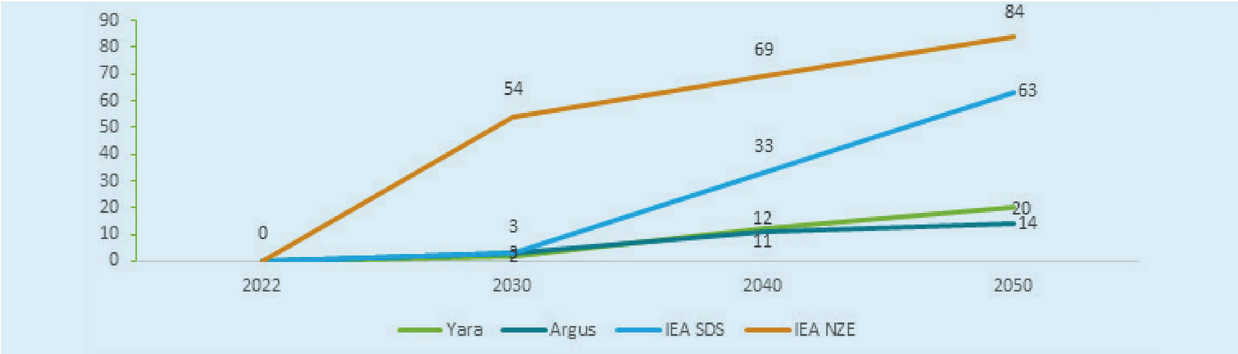
It is important to note that ammonia co-firing allows nations to operate young coal fleet throughout their remaining useful life and is a more practical option compared to CCUS. As per our assessment, Japan, South Korea, and Taiwan are most likely countries to adopt NH3 co-firing whereas India and China may initiate demonstration projects[56].

Among the three identified nations, Japan has set clear targets for ammonia co-firing and Korea has also announced plans to adopt ammonia co-firing by 2030. It is estimated that by co-firing with 20% ammonia in all coal fired power plants in Japan, the CO2 emissions from the electricity sector could be reduced by 10%.

As estimated, by 2050, these three countries may contribute up to 52 MMT of green ammonia demand from power generation only. However, several agencies have projected 14 – 84 MMT global ammonia demand from power generation, as illustrated below:

56 Large scale adoption may not be a reality due to ambitious renewable expansion plan

Figure 59: Ammonia demand from co-firing for power generation (MMT)



Ammonia demand from co-firing is likely to be restricted to Japan, South Korea and Taiwan to the tune of ~52 MMT in 2050. However, it would require adequate asset modification and de-NOx arrangement in place.

3.1.4.3 Demand of green ammonia from conventional applications (fertilisers and industries)

Figure 60: Ammonia demand from fertilisers and industries (MMT)

The merchant market and captive demand for ammonia is expected to be supported by fertilisers and industries. As per projection of several agencies, total ammonia demand will likely to be 232 – 265 MMT by 2050.

Grey ammonia production would experience a decreasing trend, but it would remain an important source of ammonia going forward. The cost parity between grey and green ammonia is expected to be achieved on the back of rising gas prices and commitment by multiple players to reduce Scope 1 and Scope 2 emissions.

An illustration of emission reduction target, which is likely to give an impetus to green ammonia use, by major fertiliser companies across the world is provided below. The trend is expected to continue with most of the global fertiliser and chemical companies.

Figure 61: Emission reduction targets by fertiliser producers across the globe

Source: Company annual/ sustainability reports; Deloitte analysis.

Demand from conventional applications is expected to support a traded and captive market. However, demand growth from fertiliser sector is likely to be subdued due to increasing efficiency in agriculture, adoption of precision farming etc.

3.1.4.4 Demand of green ammonia as a hydrogen carrier

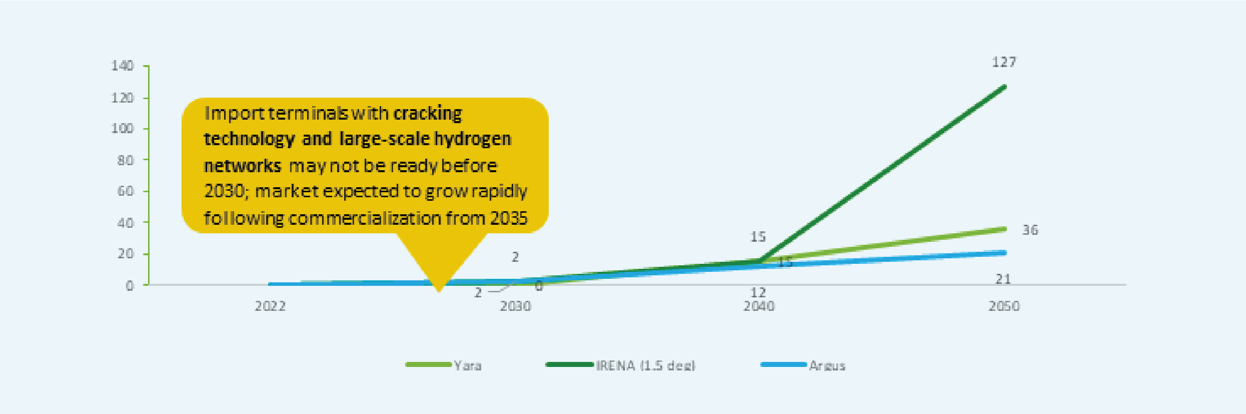
Another significant use case for ammonia is in its ability to be used as a hydrogen carrier. It is extremely challenging to store and transport hydrogen due to its very low volumetric density, which can result in leakage over time and transporting enough hydrogen for practical use adds to the challenge. Secondly, hydrogen requires extremely low temperatures (minus 253 degrees Celsius) for it to be liquefied thus the infrastructure required to transport hydrogen in a cost-effective manner to various locations around the world is almost non-existent to date and will be very expensive to implement.

This is where ammonia may have a role to play: ammonia can be transported as a liquid at room temperature at the right pressure. In addition, globally, the ammonia transportation infrastructure already exists at some level and can be leveraged or built on for further expansion. The value proposition here is that low-carbon hydrogen can be produced in countries with cheap renewable resource (Middle East, Chile, North Africa, India, etc.) and combined with nitrogen from the air to form green ammonia; the green ammonia can then be liquefied and shipped to the desired demand centers (e.g., Europe, Japan) and converted back into hydrogen for use.

However, there are economic and technical challenges with this thesis. Renewable energy has to be used to make the ammonia from the hydrogen in the first place, then to ship the ammonia and importantly to crack the ammonia and release the hydrogen at the end-use location – which has not yet been done at scale and involves energy losses through the chain and is expensive. Hence, whilst ammonia offers a reasonable solution hydrogen carrier in general, it is expected that most of the hydrogen to be generated locally (with exceptions of Japan, Korea and some part of EU).

Therefore, the forecast of global ammonia demand as hydrogen carrier till 2040, by several agencies, is limited to ~15 MMT only; however, this can be increased to 21 – 127 MMT by 2050 depending on the decarbonization aspiration of various countries. Captured below is the demand projection of ammonia as hydrogen carrier:

Figure 62: Ammonia demand as a hydrogen carrier (MMT)



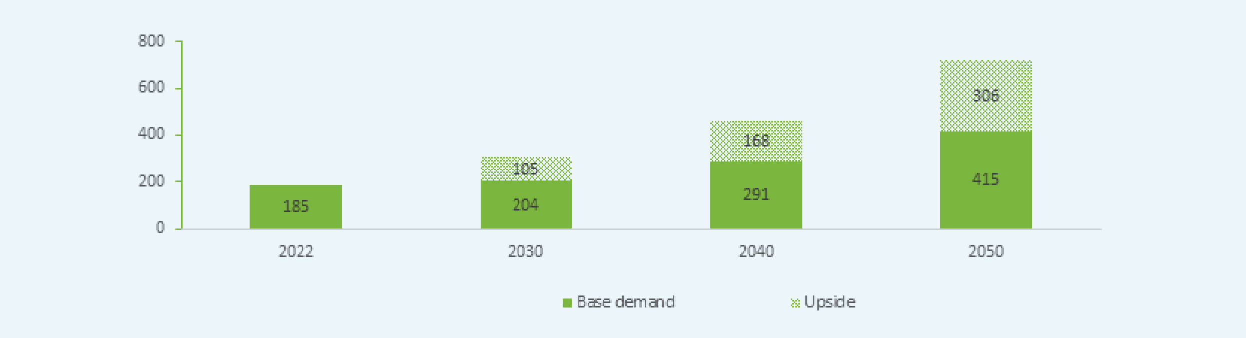
Demand centers for hydrogen carrier would emerge from Europe and some parts of Asia with significant need for imports.

NH3 is a mature technology to carry H2 but may be uncompetitive due to uncertainty in cracking technology and associated energy losses through the value chain. Also, there is a risk of emergence of alternative H2 carrier (e.g., LOHC) as more competitive.

3.1.4.5 Overall demand of ammonia

Aggregating the demand from various applications, as elaborated in the earlier sub-sections, overall global ammonia demand by 2050 is likely to be in the range of 415 – 721 MMT, as illustrated below.

Figure 63: Overall demand of ammonia (MMT) by 2050



Source: Deloitte analysis

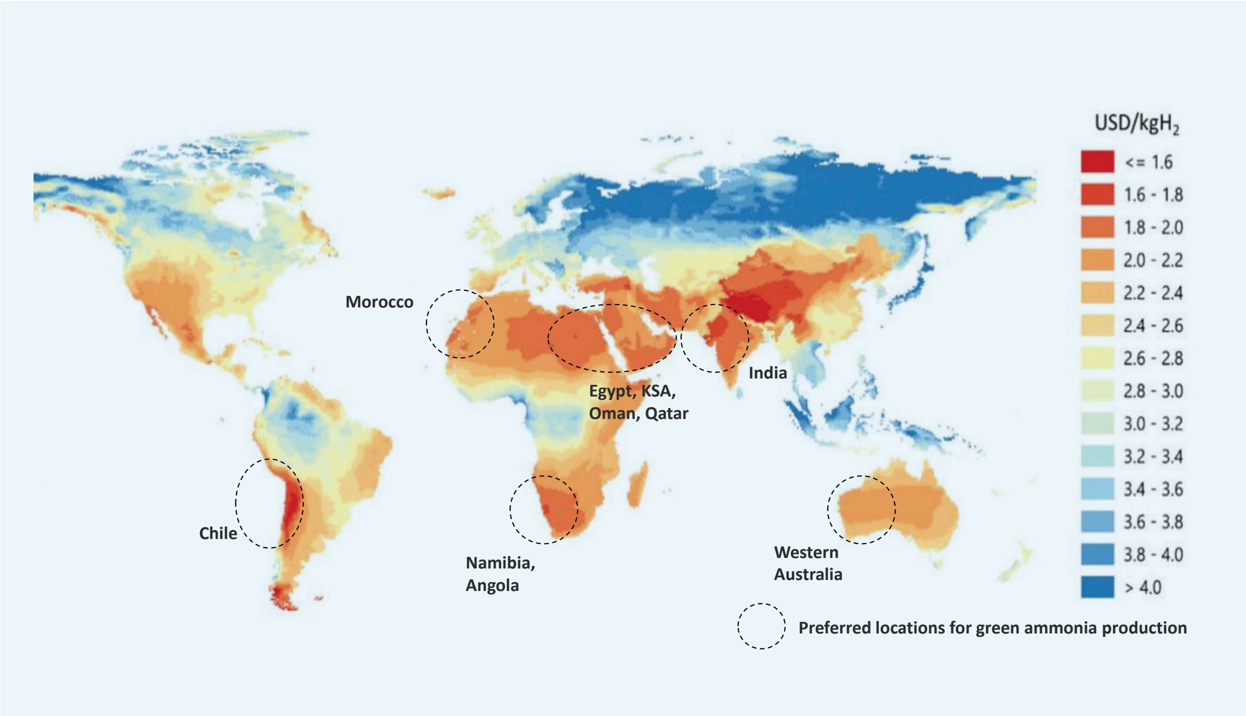
Significant quantity of future global ammonia demand is expected to be low carbon ammonia. While conventional applications (fertiliser and industries) will still have some use of grey ammonia, all new applications will demand only low carbon ammonia (green or blue depending on economics).

3.1.5 Supply assessment of green ammonia

The green ammonia supply hubs are likely to be concentrated in geographies with low-cost renewable energy and availability of port infrastructure. While low cost RE will help in achieving cost competitiveness, port infrastructure will help in capturing export opportunities.

As analyzed by IEA, geographies, such as Middle East, North Africa, India, Chile, Australia are likely to have low cost of production. It is important to note that these geographies have announced several initiatives and plans towards clean hydrogen/ammonia aspirations.

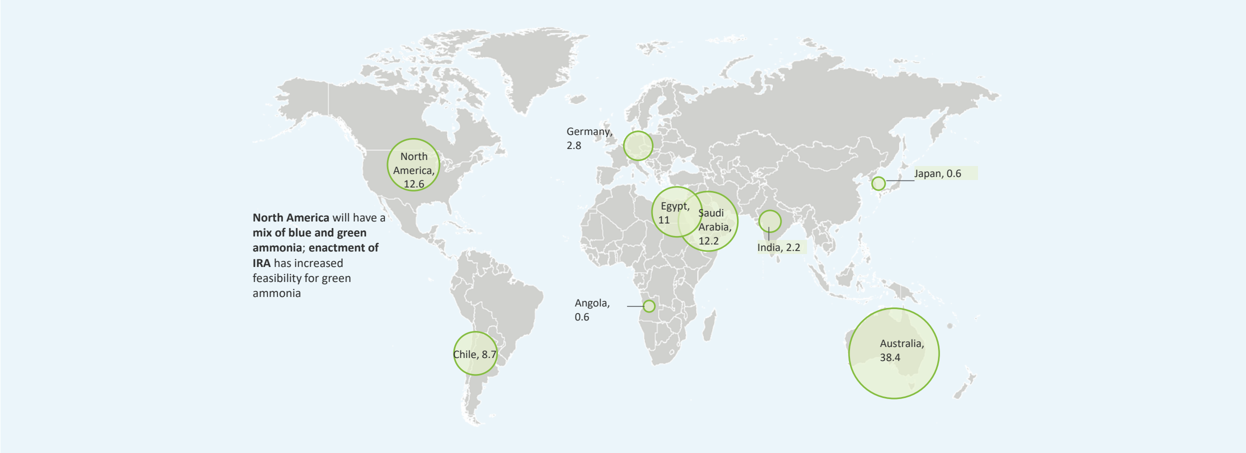
Figure 64: Cost of green hydrogen production in the long run (USD/kg H2)



Source: Reproduced from IEA report (Future of Hydrogen)

Traction is already visible in the market, with ~90 MMT of low carbon ammonia capacity has been announced globally as illustrated below:

Figure 65: Green/ blue ammonia capacity planned (MMTPA)



Source: Deloitte analysis

Australia has announced ~40% of the clean ammonia projects followed by the USA having ~12% of the announcements[57]. With the enactment of IRA, the attractiveness of the US has risen amongst developers due to the significant production incentives envisaged.

3.1.5.1 Middle East – Oman

Access to cheap renewable and end-user market makes Oman as a preferred green H2 and derivatives production center.

57 Deloitte analysis

Key advantages

Oman is well placed for production of green hydrogen, due to

- Access to competitive renewable resources, especially solar; Global Horizontal Irradiance (GHI) is ~2.1 MWh/Sq.-m
- Availability of industrial port infrastructure in Duqm and Salahla - Transportation cost (shipping) from Oman (Duqm, Salahla etc.) to Europe is likely to be $40 – 50 per ton of NH_3
- Availability of robust gas infrastructure – existing gas infrastructure can be leveraged for hydrogen and derivative projects

Major announcements – Policy, investment

- 50,000 sq.-km earmarked in Duqm, Dhofar and Al-Djazir in the southern and central parts of the country for green hydrogen production
- Oman has a target of producing 1-million-ton GH_2 By 2030 and 8 million ton by 2050, with an investment of USD 140 billion
- Oman has launched World's first auction for green hydrogen projects to achieve million-ton production target. The auction will happen in phases:
    - In the Phase I, Hydrom (Hydrogen Oman, the nodal agency) to award land blocks for green H_2 projects in 2023 to meet 2030 target of 1 MTPA production.
    - Developers are expected to bid as consortia and partner with a government-owned entity post-award.
    - Developers are expected to propose a wind/solar mix that ensures a competitive Levelized Cost of Hydrogen (LCOH). The technology mix can evolve over time
    - Developers are free to propose the electrolyzer technology of their choice (e.g., PEM vs. alkaline electrolyzers)
    - The choice of end-product (e.g., hydrogen, ammonia, methanol) is also left at the discretion of developers
    - Developers are expected to secure the offtake for their projects

Key projects announced

Following projects are announced in Oman:

Table 19: List of key green ammonia projects in Oman

Sl.	Project	Developer	Capacity	Details
1.	Air Products – ACWA consortium green ammonia project	ACWA Power, OQ Group, Air Products	1 million ton/year	• Joint Development Agreement and MoU signed with Oman Government in December 2021 • Project comprises use of wind and solar energy to power an electrolyser • The project is being developed in Oman's Salalah Free Zone
2.	ACME Group green ammonia plant in Oman	ACME Group, India	0.9 million ton/year	• Investment committed - $3.5 billion • Tied up with the Norway-based firm Scatec, which has 50% equity in the project • Integrated facility using 3 GWp of solar and 0.5 GWp of wind energy • Partial offtake agreement with Japan's NYL Lines & Yara • KBR has been selected as technology provider

3.1.5.2 Middle East – Saudi Arabia

Hydrogen is expected to be a key part of the future energy mix of Saudi Arabia, with ambitions to produce 4 million ton per year of "clean" hydrogen (or equivalent PtX products) by 2030[58].

58 S&P Global, COP27: Saudi Arabia targets Europe, Asia-Pacific in global hydrogen push (access here)

Key advantages

Saudi Arabia is well placed for production of green hydrogen, due to

- Access to competitive renewable resources, especially solar; Global Horizontal Irradiance (GHI) is ~2.13 MWh/Sq-m/year, with average 9 hours sunshine per day. In Saudi Arabia, discovered renewable tariff is in the range of USD 18 – 20/MWh, which is much lower than prevailing RE tariff in other countries.
- Availability of industrial port infrastructure with existing ammonia terminals in few; major ports include ports in Jeddah, Dammam, Yanbu, Jazan and Jubail.
- Availability of robust gas infrastructure – existing gas infrastructure can be leveraged for hydrogen and derivative projects

Major announcements – Policy, investment

- National Hydrogen Strategy is under finalization, with a target investment of $36 billion by 2030[59]; the strategy focuses on key elements of the value chain, including production, exports, and domestic use of clean hydrogen.
- The country's aspiration is in line with the launch of the Saudi Green Initiative in October 2021, in which the country pledged over $186 billion (SAR 700 billion) in investment towards green economy

Key projects announced

Following low carbon ammonia projects are announced in Saudi Arabia:

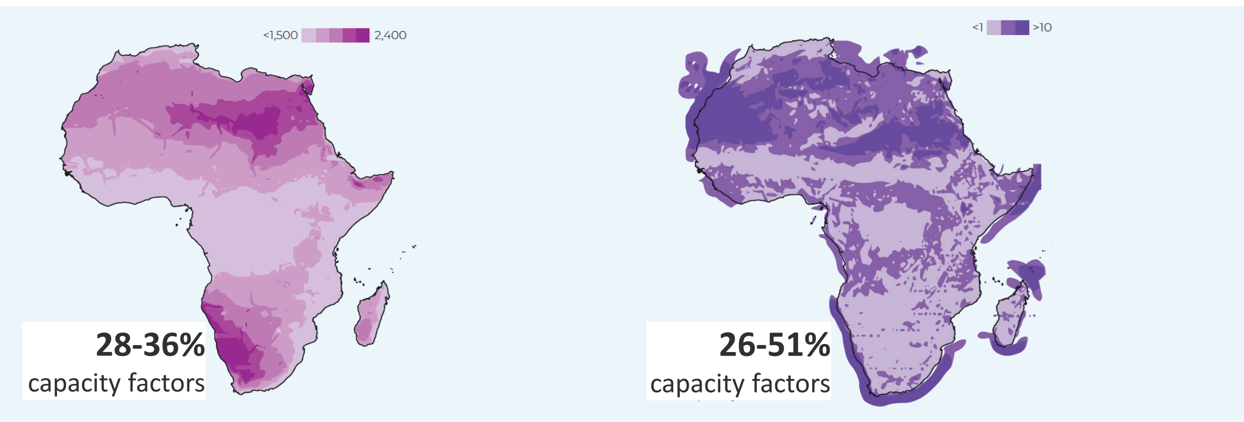
Figure 66: List of key clean ammonia projects in Saudi Arabia

Sl.	Project	Details
1	Aramco blue ammonia project	• 11 million metric tons of ammonia per year by 2030 • Aspiring 14 million metric tons of CO2e reduction annually • Partnered with Saudi Arabia Renewable Energy Hub
2	Neom's Saudi project	• An equal production joint venture of ACWA Power, Air Products and NEOM incorporated in August 2021 in Neom industrial cluster • Capex: USD 5bn for hydrogen production, USD2bn for distribution, 4GW of renewable energy • Air Products is the primary EPC contractor and will be the exclusive off-taker of the green ammonia and intends to export it around the world • Capacity – 1.2 MT, to be operational by 2025

3.1.5.3 Africa

African nations have unique renewable endowments and locational advantages to address the global demand supply mismatch for green ammonia and green hydrogen. The countries are gifted with dual potential of wind and solar resource, and the countries in the northern and southern are well suited for renewable hydrogen and ammonia production.

Figure 67: Solar (kWh/kW peak) and wind power (m/s) potential in Africa



Source: Africa's Green Hydrogen Potential by Africa Green Hydrogen Alliance

59 Zawya, Saudi Arabia's hydrogen strategy targets $36bln of investments by 2030 (access here)

Hybridization and optimal sizing can enable higher load factors for RE facilities and thus lower the levelized cost of green hydrogen and ammonia production.

Figure 68: Ports with ammonia terminals in Africa

African nations have formed AGHA (Africa Green Hydrogen Alliance), Hydrogen strategies and partnerships with European counterparts to develop green hydrogen and ammonia prospects. Potential locations in Africa for green hydrogen and ammonia production are Morocco, Egypt and Namibia.

3.1.5.3.1 Morocco

Morocco is aiming to replace costly ammonia imports with local green ammonia production and participate in the export market. In the future, Morocco plans to supply green hydrogen and derivatives to Europe. Morocco is also a preferred destination for developers:

Key advantages

- The country boasts extremely favourable climatic conditions required for solar generation. As reported by IRENA, Morocco is expected to have the third lowest green hydrogen production cost in 2050
- Availability of industrial port infrastructure with existing ammonia terminals; currently, Morocco has more than 10 major ports
- Strategic location near to demand centres (EU nations)

Major announcements – Policy, investment

- In December 2021, Morocco has launched "National Roadmap for Green Hydrogen". The strategy considers 3 phases of development:
  - Phase 1 (2020-30) considers local usage in the industries and exports to targeted countries in Europe. Project development will be based on government and international financial support.
  - Phase 2 (2030-40) considers increased export and local usage, including new applications. This phase will focus on cost reduction of green hydrogen.
  - Phase 3 (2040-50) will focus on improving the business case for a greater number of use cases
- As per the roadmap, by 2030, the country expects a local hydrogen market of 4 TWh and an export market of 10 TWh, which, taken together, would require 6 GW of new renewable capacity[60]
- Signed agreement with Germany (PAREMA) for setting up green hydrogen project and subsequent offtake; investment of ~Euro 300 million has already been pledged

60 Green Hydrogen Organization, Morocco (access here)

Key projects announced

Following low carbon ammonia projects are announced in Morocco:

Table 20: List of key projects for green ammonia/ hydrogen in Morocco

Sl.	Project	Capacity	Developer	Details
1	Hevo ammonia Maroc project[61]	0.18 million ton	Fusion Fuel, Ireland	• Agreement between Fusion Fuel Green and Consolidated Contractors (CCC) for $850 Mn investment • CCC to handle logistics, infra, transportation, Offtake with Vitol for the green ammonia product • Will be implemented in phases • Location is not yet finalized, but will be in the vicinity of port city Jorf Lasfar
2	AMUN Project[62]	2 – 2.5 million ton	CWP Global	• Projects announced in 2022; CWP Global has identified Bechtel as the implementing agency • Electrolyser would be powered through 15 GW hybrid RE • Deployment in three phases; the first two phases having both 3 GW of solar and 3 GW of wind and 2 to 2.5 Mn tonnes GNH3 • Third phase is in early development stage

3.1.5.3.2 Egypt

Key advantages:

- Egypt enjoys a strategic location which enables it to cater to both the European and Asia Pacific demand for green ammonia with the Suez Canal.
- Availability of cost competitive and abundant renewable energy; average daily sunshine totals about 9 to 11 hours per day, with solar direct radiation intensity of about 2 – 3 MWh/sq-m per year. In addition, Egypt is endowed with vast wind resources, with average annual speeds reaching 8–10 m/s by the coast of the Red Sea and 6–8 m/s along the south-west Nile banks and in the south of the Western Desert.[63]
- Egypt is already a top global fertiliser supplier, so, there exists a local demand; switching the existing customers onto green ammonia is likely to be easier

Major announcements – Policy, investment

- Egypt is yet to publish its hydrogen strategy, which is being finalized.
- EU-Egypt signed an MoU as part of the EU-Mediterranean renewable hydrogen partnership during COP27. The MoU will be key step in establishing long-term commitment for meeting the climate goals and ensuring energy security for the party nations.
- In June 2022, the Government of Egypt announced that the companies operating in the green hydrogen and ammonia project would benefit from the tax incentives stipulated under the 2017 Investment Law. In addition, the companies would pay a flat 2% customs rate on imported machinery, and benefit from a five-year exemption from stamp duty and notary fees on certain expenses[64]

Key projects announced

Egypt has announced multiple projects with Suez Canal Zone (SCZone) being central to the regional project development. Some of the key projects have participation from Statec, Toyota Tshusho, Egas, Egyptian Petrochemical Holding, OCI green hydrogen consortium, Masdar, Scozone and partners viz. EMEA Power, Total, ReNew (multiple projects). The country has seen interest from Saudi based Alfanar (0.5 MTPA), Globeleq (2 MTPA), Mediterranean Energy Partners (0.12 MTPA), Actis (0.2 MTPA) etc.

61 Argus Media, Morocco outlines plans for new green ammonia project (access here)
62 Ammonia Energy Association, CWP Global taps Bechtel to help develop African ammonia projects (access here)
63 IRENA, Outlook Egypt (access here)
64 Green Economy (access here)

Table 21: **List of key projects for green ammonia/ hydrogen in Egypt**

Sl.	Project	Capacity	Developer/Partner	Details
1	Green ammonia project in Ain Sokhna Industrial Zone	1 – 3 million ton/year	Statec, SCZONE, Egypt's Sovereign Fund, Ministry of Electricity and Renewable Energy	• Signed Memorandum of Understanding to develop project focused on exports to Europe and Asia • USD $5 billion deal to build green ammonia plant near the Suez Canal • Will start producing 1 million tonnes per year by 2025, increasing to 3 million tonnes
2	Blue ammonia project	Undisclosed	Japan's Toyota Tshusho, Egypt's state-owned Egas, Egyptian Petrochemical Holding	• Agreed to begin exploring opportunities • Focused on production of blue ammonia and exporting that to Japan • Feasibility study in progress
3	Green ammonia project in Ain Sokhna Industrial Zone	1 – 2.3 million ton/year	Masdar, Hassan Allam Utilities, SCZONE, New and Renewable Energy Authority, the Egyptian Electricity Transmission Company	• Part of two stage project with first stage dedicated to 100,000 TPA renewable bunker methanol production • Second stage is dedicated to electrolysis capacity of 4GW translating to 2.3 MMTPA green ammonia exports • Total investment pledged ~$5.5 billion
4	Green ammonia project in Ain Sokhna Industrial Zone	0.8 million ton/year	AMEA Power (UAE), SCZONE, New and Renewable Energy Authority, the Egyptian Electricity Transmission Company	• The Egyptian government has signed a Framework Agreement with UAE-based renewable energy firm AMEA Power to develop a 1,000 megawatt green hydrogen project and 800,000 ton per year green ammonia project
5	Green ammonia project in Ain Sokhna Industrial Zone	1 million ton/ year	SCZONE, ReNew Power (India), Egypt's Sovereign Fund, Egyptian Electricity Transmission Company	• Agreement for USD 8 billion investment to develop 1 MTPA green ammonia production plant. • First phase 2023-25 to produce 100,000 tons of GNH3 and second phase 2025-29 to develop 1 MTPA capacity
6	Other projects		Multiple	• Saudi based Alfanar (0.5 MTPA), Globeleq (2 MTPA), Mediterranean Energy Partners (0.12 MTPA) by 2025, Actis (0.2 MTPA) • Projects are announced; however, on-ground progress are limited

3.1.5.3.3 Namibia

The Government of Namibia is focusing towards developing a green fuel ecosystem, including green ammonia. Namibia's world-class solar and wind resources give it a long-term competitive advantage in producing green hydrogen and green ammonia.

Key advantages:

- The southern and western region of the country has world class solar and wind resources. GHI in certain areas could reach up to 2.5 MWh/Sq-m/year; Namibia's wind potentials, especially along the southern coast and at select inland locations, are good to excellent. In some of the southern region, wind potential identified as 900 – 1300 W/m2 at 100 m above the ground level[65].
- Namibian Port Authority (Namport) has well-established ports, suitable for ammonia export; recently, Namport signed a Memorandum of Understanding with the Port of Rotterdam (PoR), for exporting green hydrogen derivatives to Europe and the rest of the World. As part of readiness planning, Namport has allocated 350 hectares of land at the Port of Walvis Bay North Port for Green Hydrogen/Ammonia related industries. Additionally, the planned new deep-water port of Luderitz would complement the North Port in cementing the country's intention to become a hub for green fuel export.

65 Study by Konrad Adenauer Stiftung, November 2021

Major announcements – Policy, investment

- In May 2021, an inter-Ministerial Green Hydrogen Council was established by Government of Namibia to oversee the development of the Green Hydrogen and related opportunities; it was followed by inviting bids from green hydrogen project developers under its Southern Corridor Development initiative (SCDI).
- Namibia received 9 commercial proposals to develop large scale projects, and selected Hyphen as preferred bidder
- In November 2022, the country launched "Namibia Green Hydrogen and Derivatives Strategy", which sets out the Government›s action plan to establish Namibia as a major global hydrogen producer by 2025. The strategy document includes setting up a one-stop-shop implementation agency, providing support mechanisms to ensure low costs of production, suitable clauses for local content manufacturing, skill development and project finance. The strategy envisions that green hydrogen and derivatives could accelerate Namibia's economic development by contributing as much as USD 6 billion to Namibia's GDP by 2030 [66].
- The country is in process of finalizing a conducing tax structure for expanding green hydrogen/ammonia projects
- Namibia has taken a USD 400/ton of green ammonia production cost target

Key projects announced

Some of the key projects in the green ammonia domain in Namibia are tabulated below:

Table 22: List of key projects for green ammonia/ hydrogen in Namibia

Sl.	Project	Developer	Capacity	Details
	Hyphen Hydrogen Energy	RWE, Hyphen Hydrogen Energy	1.7 million ton/year	• Investment – USD 9.4 billion • The RWE-Hyphen consortium signed a MoU for offtake of 0.3 MT GH2 (~1.7 MT GNH3) from 5 – 7 GW RE and 3 GW electrolyser capacity • Target year of production start - 2027
	Cleanergy Namibia	CMB Tech, O&L Group (JV)	Undisclosed	• Country's first GH2 and GNH3 demonstration project for demonstration of H2 applications in Erongo region • USD 18 Mn pilot to be operational by 2024; EPC partner finalized
	HDF Energy Pilot project	HDF Energy	Undisclosed	• Located at Swakopmund coast, Erongo; USD 181.25 Mn investment comprising of 85 MWp solar PV and electrolyser unit • Expected commissioning in 2024

3.1.5.4 Oceania – Australia

The Australian government is focused on developing the country as a "hydrogen hub" provided the availability of solar and wind resources along with proximity to import hubs such as Japan and South Korea.

Key advantages:

- Second largest per capita renewable capacity with over 10,000 MWh per person per annum.
- Coastal Australia is well suited for green hydrogen and ammonia production because with GHI in certain regions reaching up to 1.97 MWh/sq-m/year and wind speeds exceeding 10 m/sec in multiple regions as well.
- Excellent infrastructure for ammonia trade through multiple ammonia terminal consisting ports in Dampier, Kwinana, Geelong, Newcastle and Gladstone.

66 Namibia Green Hydrogen and Derivatives Strategy

Major announcements-Policy, investment

- Australia has come up with its National Hydrogen Strategy focused towards building regional clusters of hydrogen development naming it "hydrogen hubs." The strategy identified 7 locations to develop as hydrogen hubs of future: Bell Bay (TAS), Darwin (NT), Eyre Peninsula (SA), Gladstone (QLD), Latrobe Valley (VIC), Hunter Valley (NSW), and Pilbara (WA) Western, and Northern Australia to export **25-30 MT** ammonia by 2035.
- The hydrogen strategy is phased out into two parts with Phase I (2020 – 25) and Phase II (2025 – 30). Phase I will focus on foundations and demonstrations for developing supply chains. 72 projects have been funded in this Phase of the strategy. The phase II of the strategy is focused on activation of large-scale markets. Technological advancements and exports to Asian markets would be the key targets in the later phase of the strategy.
- **ARENA** (Australian Renewable Energy Agency) has announced USD 100 million funding to develop three large scale green hydrogen projects. USD 150 million has been sidelines for "Hub Development and Design Grants" to support emerging hub concepts, and "Hub Implementation Grants" to help fund clean hydrogen industrial hub projects.
- With the conducive infrastructure and policy scenario, Australia is expected to have **~2 MT of green ammonia production by 2025, 12 MT by 2030, and 35 MT by 2050**.

Key projects announced

Some of the key projects for green ammonia/ hydrogen are listed below:

Table 23: List of key projects for green ammonia/ hydrogen in Australia

Sl.	Project	Developer	Capacity	Details
	Western Green Energy Hub	InterConti-nental Energy, CWP Global, and the Mirn-ing People	Undisclosed	• Investment – USD 70 billion • RE Capacity of 37 GW of wind and 15 GW solar power • Coastal project which allows export worldwide
	Fortescue Future Industries	Fortescue Future Indus-tries	15 MT Green Hydrogen	• Investment – USD 50 billion • Target production year – 2030
	Asian Re-newable Energy hub (AREH), Pilbara	InterConti-nental Energy, CWP Global, Vestas, BP and Macquarie	Undisclosed	• Investment – USD 36 billion • AREH is one of the largest green ammonia projects globally with 26 GW of solar & wind power

Details of all announced projects in the country has been provided in Annexure (7.2).

3.1.5.5 Latin America – Chile

A nation with enormous wind potential which has enabled the country to target exports of green ammonia to China, EU, US and South Korea.

Key advantages:

- Significant wind potential along the coastal lines with wind speeds reaching ~14 m/s in certain locations.

Major announcement-Policy, investments

- National Green Hydrogen Strategy which targets 5 GW of electrolyser capacity by 2025 and cheapest green hydrogen globally by 2030. The strategy also aims to bring Chile amongst the top 3 global exporters of green hydrogen by 2040 by infusing funding rounds of **USD 50 million**.
- The strategy has three phases from 2020-25, 2025-30, and post 2030. From 2020-25, accelerated deployments of green hydrogen capacities and local supply chains would be created. From 2025-30, local green hydrogen production would be leveraged to begin exports of green hydrogen. Post 2030, the nation

targets on becoming a global supplier of green hydrogen with special focus on the use of ammonia in shipping industry.

- Chile's Ministry of Energy and the Mærsk Mc-Kinney Moller Center for Zero Carbon Shipping are developing a network of transport corridors in the country.
- The country has an international agreement with Germany, Netherlands, Belgium and South Korea to promote green ammonia off-take. Chile is expected to have ~1 MT of green ammonia production by 2025, and ~9 MT by 2030[67].

Key projects:

Some of the key projects are listed below:

Table 24: List of key projects for green ammonia/ hydrogen in Chile

Sl.	Project	Developer	Capacity	Details
	HyEx project	JV between Engie and Enaex	7 MMT Green ammonia	• Green ammonia production in the North of Chile to meet domestic demand and carry out exports • 18,000 Tons production by 2025 and 7 MT production by 2030
	HNH project	JV between Austria Energy and Okowind	1 MT Green ammonia	• This project will be in the Magallanes region and aims at producing green ammonia for export • Expected COD by 2026 to be powered by 1.7 GW onshore wind farm with desalination to provide water for electrolysis
	H2 Magallanes project	JV between Total Eren, University of Magallanes & Wood	4.4 MT green ammonia	• 10 GW of wind capacity and 8 GW of electrolysers • Export oriented project in Magallanes consisting of a port facility. • Expected commissioning by 2027

3.2 Storage capacity and terminals across global ports

Hydrogen and its derivatives will play an important role in the energy transition. As predicted by IRENA and other think-tanks, 20 -30% of global hydrogen and ammonia demand are likely to be traded across borders by 2050. Therefore, an import terminal for green ammonia is an essential link in the hydrogen and ammonia chain, alongside storage and cracking facility. Although NH3 is traded globally, its handling volumes are much smaller than in the case of LNG, with accordingly sized infrastructure. With a spurt in demand of clean ammonia, new infrastructure must be built. Recognizing the need, most of the major ports across the globe have started exploring investment in setting up ammonia terminals.

Table 25: Mapping of ammonia terminals in major demand centers

Port	Country	Status of ammonia terminal	Throughput	Storage capacity	Remark
Wilhelmshaven	Germany	Upcoming	Uniper - 2.6 MMTPA	FEED in process	• Niedersachsen Ports, Uniper and Tree Energy Solutions (TES) will explore the feasibility of six-berth, "green gases" jetty infrastructure at Wilhelmshaven for future fuel imports. • Uniper will conduct a technical feasibility study that will eventually allow imports of around 2.6 MMTPA of ammonia at the German port • TES will take FID on the new infrastructure in 2023, with the first phase to be completed in 2026. • The terminal will also have an Ammonia cracking unit
Bransbuttel	Germany	Operating, to be augmented	Yara – 3 MMTPA RWE – 300 KTPA	NA	• Yara announced it will modify its existing ammonia terminals in Brunsbüttel to enable imports of up to 3 MMTPA • Brunsbüttel will also be home to RWE's planned ammonia import terminal, which will be ready to receive shipments from Namibia in 2026.

67 Basis announcements made for the geography

Port	Country	Status of ammonia terminal	Through-put	Storage capacity	Remark
Ros-tock	Germany	Operating	600 KTPA	NA	• Currently, Germany's largest ammonia import terminal • Yara currently imports 600,000 tonnes of ammonia per year • It has Germany's **largest refrigerated ammonia storage capacity** • Another terminal is planned by Total Eren and gas utility VNG
Ham-burg	Germany	Upcoming	Undis-closed	Undis-closed	• The ammonia terminal will be developed by Air Products and Mabanaft • To be equipped with storage tank and cracking facility
Rotter-dam – OCI termi-nal	Nether-land	Operating, to be aug-mented	Existing capacity – 400 KTPA, with a plan to increase it to 1.2 MMTPA	NA	• Currently, this is the only ammonia terminal in the Rotterdam port
Rotter-dam	Nether-lands	Upcoming	Up to 5 MMTPA	FEED in process	• Ammonia import terminal is planned by a consortium of Gasunie, bulk handling firm HES International and tank storage specialist Vopak; expected to be operational by 2026 • Will be equipped with storage and cracking facility • The terminal will be known as ACE terminal
Vliss-ingen, North Sea Port	Nether-land	Upcoming	1 MMTPA	60,000 Cubic Meters	• To be developed by Vesta Terminal BV
Im-ming-ham	UK	Upcoming	Not dis-closed	Not dis-closed	• This is a planned ammonia import facility by Air Products and Associated British Ports • The port will receive ammonia imports from Air Products ammonia projects around the world • This includes two-berth, deep water jetty for ammonia imports, with multiple cracking facility • Equipped with "refrigerated ammonia storage tank"
Liver-pool	UK	Upcoming	1 MMTPA	FEED in process	• The terminal will be developed by Stanlow Terminals as part of Essar' ambition to be a major hub of low carbon energy innovation and leader in production globally
Ant-werp	Belgium	Upcoming	Not dis-closed	Not dis-closed	• Will be developed jointly by Fluxys, Advario and Port of Antwerp • Expected to be operational by 2027 • To be equipped with storage tanks and cracking facilities

Source: Deloitte analysis, Secondary research

Maximum traction for setting up ammonia terminal is visible among major European ports. Most of the ports have started feasibility analysis, and some of them have reached to FEED stage. In addition, there has also been focus on repurposing and retrofitting of LNG terminals to ammonia terminals in Europe as well as in Japan.

Cost of ammonia storage

Liquid ammonia needs to be pressurized to around 8 bar at ambient temperature or be cooled down to −33°C at ambient pressure. Pressurized storage is usually preferred for low volumes while refrigerated storage is preferred as the scale increases.

	Capacity <10 KT	Capacity 10 – 30 KT	Capacity 30 – 60 KT
Cost of storage tank (USD/ ton of NH3)	**820 – 920**	**730 - 820**	**700 - 730**

Source: IRENA - Technology review of hydrogen carriers In addition, operational cost ranges between 1 – 1.5% of tank capex

4. Price Competitiveness Assessment

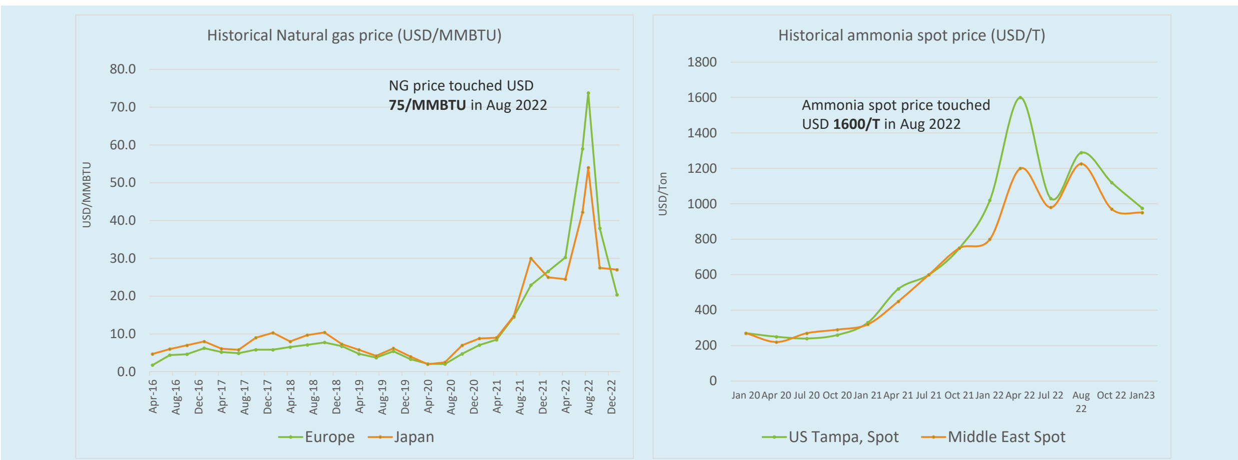
4.1 Grey ammonia and natural gas price – trends and outlook

Natural gas is the primary feedstock for ammonia production globally. In addition, natural gas is also used in the SMR process as a burning fuel to generate heat. Therefore, output price of grey ammonia is largely dependent on the regional natural gas prices.

Global gas spot prices, especially European gas prices have hit exceptional highs in 2022 due to drop in Russian gas exports. Spot prices on the Netherlands-based Title Transfer Facility (TTF) gas hub, the main reference for Western Europe, have risen from an average of €46 per megawatt-hour (MWh) in 2021 to €134 per MWh in November 2022. The price reached an historical peak of €330 per MWh in August[68]. While the price increases have impacted the entire world, maximum impact was visible in geographies like Europe and Japan, which are also major demand centers.

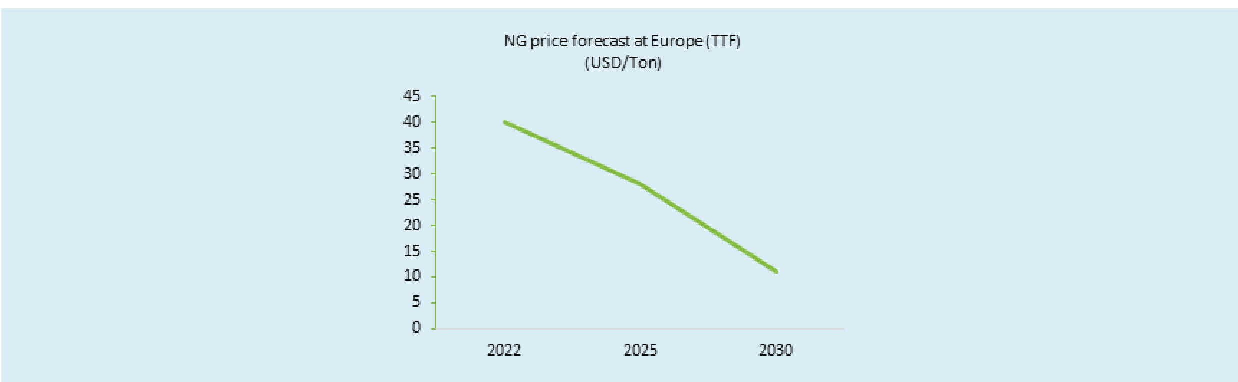
The increase in natural gas prices was reflected through increase in grey ammonia price globally. During April 2022, ammonia spot price peaked at USD 1600/Ton; with some moderation of NG price, price touched ~USD 975/Ton in January 2023. An illustration of change in natural gas price and ammonia spot price is provided below:

Figure 69: Historical price trends of natural gas (USD/MMBTU) and ammonia (USD/t)



Source: Platts

Figure 70: Forecast of natural gas prices



Source: Rystad Energy

68 Rystad Energy (access here)

4.1.1 Outlook of natural gas and grey ammonia price

- Based on projections by various agencies, in the short-term, price is likely to be elevated in the range of USD 25 – 30/MMBTU (TTF hub price). However, it's likely to stabilize at around USD 9 – 10/MMBTU by 2030; but earlier price level of USD 3 – 6/MMBTU is unlikely.
- It's important to note that there will be regional differences in price – for example, Middle east, USA are likely to enjoy a cheaper NG price in the future, but Europe, Japan and Korea are likely to have elevated price
- In addition to elevated natural gas price, imposition of carbon tax will increase the grey ammonia price (for example, EU has imposed carbon allowance of industrial emissions)

4.1.2 Grey ammonia price in Europe and Japan

With elevated natural gas price throughout 2022, grey ammonia price also skyrocketed. The assumptions and cost build-up for grey ammonia production in Europe and Japan are illustrated below.

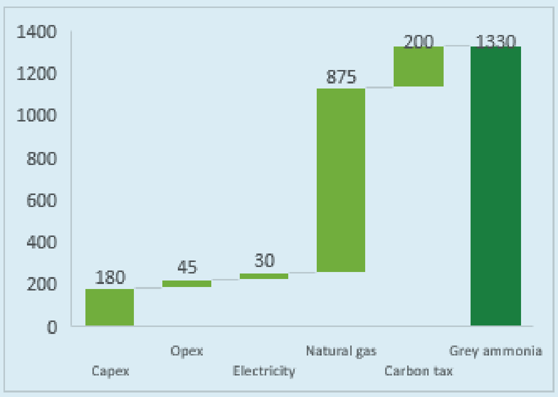
Table 26: Assumptions for grey ammonia production in Europe and Japan

Particular	Unit	Value- Europe	Value - Japan
Capex per ton of ammonia	USD/ton	1800	1800
Cost of capital	%	10%	10%
Annual operational expenditure	% of capital expenditure	2.5%	2.5%
Electricity requirement	MWh/ ton of ammonia	0.3	0.3
Electricity cost	USD/MWh	100	120
Natural gas requirement	MMBtu/ton of ammonia	35	35
Natural gas price	USD/MMBtu	25	25
Carbon tax	USD/ton of CO2 emission	100	0

Source: Deloitte analysis, industry insights

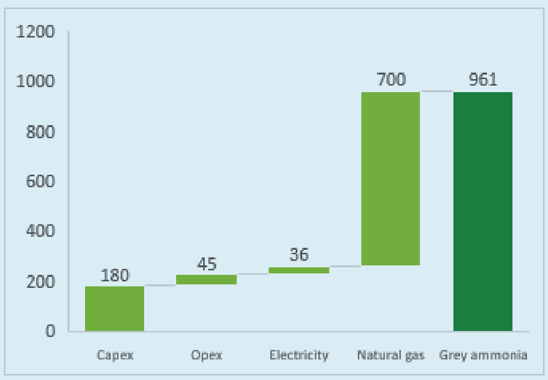
The cost of grey ammonia production basis the above assumptions is in the range of USD 950 – 1300 per ton of ammonia, as illustrated below:

Figure 71: Cost of grey ammonia production in Germany (USD/ton)



Source: Deloitte analysis

Figure 72: Cost of grey ammonia production in Japan (USD/ton)



Source: Deloitte analysis

Sensitivity analysis for Europe

A sensitivity analysis of grey ammonia price in Europe with natural gas landed cost and carbon tax is illustrated below:

Figure 73: **Sensitivity analysis of grey ammonia price with respect to natural gas landed cost and carbon tax**

Cost of grey ammonia (USD/Ton)		Landed natural gas cost (USD/MMBTU)					
		50	40	30	20	15	10
Carbon tax (USD/Ton)	20	2045	1695	1345	995	820	645
	40	2085	1735	1385	1035	860	685
	60	2125	1775	1425	1075	900	725
	80	2165	1815	1465	1115	940	765
	100	2205	1855	1505	1155	980	805
	120	2245	1895	1545	1195	1020	845
	140	2285	1935	1585	1235	1060	885

Current cost of grey ammonia production. Cash cost will be **USD 900 – 1300/Ton**

Likely cost of production by 2030 (the gas price is likely to be in the range of USD 10-15/MMBTU. Cash cost will be **USD 630 – 840/Ton**

Considering a carbon tax of USD 100/ton of CO2 by 2030, the grey ammonia price is likely to be in the range of USD 800 – 1000/ton.

Sensitivity analysis for Japan

As there is no carbon tax in Japan, sensitivity analysis is conducted with respect to the natural gas price:

Figure 74: **Sensitivity analysis of grey ammonia and ammonia cost with CCUS**

	Landed natural gas cost (USD/MMBTU)					
	50	40	30	20	15	10
Grey ammonia COP (USD/T)	2011	1661	1311	961	786	611
Ammonia cost with CCUS (USD/T)	2061	1711	1361	1011	841	661

Likely range of **grey/blue ammonia** cost in Japan/Korea by 2030

Source: Deloitte analysis

To estimate the cost of blue ammonia, cost of Carbon Capture, Utilisation and Storage (CCUS) is considered as USD 50/ton of CO2 as predicted by IEA[69]. This cost is derived based on project lifecycle assessment.

4.2 Cost of production in green ammonia in major supply hubs

Cost of production of green ammonia in major supply hubs primarily depends on levelized cost of renewable electricity and amount of subsidy offered towards hydrogen production. Key region-specific assumptions are captured below:

Table 27: **Region specific assumptions for Capex (USD/t), LCOE and subsidy support**

Region	Capex (USD/Ton)	LCOE (US cents/kWh) @75% Utilisation	Subsidy/Support offered (USD/T)
India	2240	5 – 5.5	Total $2.4 billion subsidy announced; mechanism to disburse the subsidy not yet disclosed
MENA	2240	3.5 – 4.0	NIL

69 IEA (access here)

Region	Capex (USD/Ton)	LCOE (US cents/kWh) @75% Utilisation	Subsidy/Support offered (USD/T)
Austra-lia	2240	6.0 – 6.5	NIL
Chile	2240	4.0 – 4.5	NIL
USA	2240	6.0 – 6.5	540 (production tax credit of $3/kg of green hydrogen)
Remark	Current capex is ~USD 2800/Ton. It is expected that cost of electrolyzer will decline by 40% by 2030. Cost of electrolyzer contributes up to 50% of green ammonia capex at higher Utilisation	Based on tariff discovered in various regions, normalized for 75% CUF in 2030	While India and few MENA countries have announced support scheme, exact disbursement is undisclosed. USA, through Inflation Reduction Act, will be offering production tax credit towards green hydrogen production

Source: Deloitte analysis

Based on the above assumptions, cost of production of green ammonia has been estimated for various regions, as illustrated below. It is important to note that USA has the lowest cost of production due to generous tax credit offered by the federal government.

Figure 75: Cost of green ammonia production across geographies (USD/t)

Source: Deloitte analysis Cost of capital for all geographies considered as 6%

Apart from USA, MENA region is expected to be the second-best destination for developers due to low cost of electricity, followed by Chile, India and Australia.

Table 28: Electricity tariff in different regions

Region	Discovered tariff (2022)	Tariff @75% CUF - considered
India	$40 - 70/MWh for RTC bids $30/MWh for plain vanilla solar	$50/MWh
Middle East[70]	$11 – 25/MWh for plain vanilla solar	$35/MWh
Chile[71]	$35 – 38/MWh for hybrid RE $13/MWh for plain vanilla solar	$40/MWh
Australia	No instances of auction	$60/MWh[72]

Source: Deloitte analysis

70 https://www.pv-magazine.com/2021/06/25/strong-growth-predicted-for-middle-eastern-solar-pv/
71 https://www.bnamericas.com/en/news/chile-awards-777gwhy-in-first-supply-auction-of-2022
72 Industry input

4.3 Landed cost matrix between destination ports and supply hubs

Landed costs have been estimated in two destination ports (Hamburg in Germany and Tokyo Bay in Japan) from selected ports from supply hubs. Detail break-up of landed costs are indicated below:

Destination port - Hamburg

Table 29: Key assumptions for the port of Hamburg (2021)

Supply port	Cost of production (USD/T)	Shipping Cost (USD/T)	Landed cost (US-D/T)	Shipping distance (km)
India - Mumbai	679	40	719	7451
India - Paradeep	679	43	722	8948
MENA - Duqm	529	38	567	6655
MENA - Morocco	529	29	558	1959
MENA - Egypt	529	34	563	4255
Chile	629	44	673	9398
USA - New York (with PTC)	240	33	273	4195
USA - Los Angeles (with PTC)	240	59	299	11024
USA - New York (w/o PTC)	780	33	813	4195
USA - Los angeles (w/o PTC)	780	59	839	11024
Australia - Victoria	779	47	826	11241

Destination port – Tokyo Bay

Table 30: Key assumptions for Tokyo Bay port (2021)

Supply Port	Cost of production (USD/T)	Shipping Cost (USD/T)	Landed cost (US-D/T)	Shipping distance (km)
India - Mumbai	679	38	717	6374
India - Paradeep	679	36	715	5671
MENA - Duqm	529	40	569	7287
MENA - Morocco	529	48	577	11648
MENA - Egypt	529	43	572	9101
Chile	629	60	689	17700
USA - New York (with PTC)	240	55	295	14984
USA - Los Angeles (with PTC)	240	79	319	20850
USA - New York (w/o PTC)	780	55	835	14984
USA - Los angeles (w/o PTC)	780	79	859	20850
Australia - Victoria	779	34	813	4306

References:

- Fuel ammonia supply cost analysis, Ministry of Economy, Trade and Industry, Japan (access here)
- Deloitte analysis of shipping distance and routes

Note:

- Shipping cost includes fixed cost and variable cost; fixed cost consists of port charge, vessel cost and tolling cost (e.g., Panama canal tolling is required for any port located on the west coast of USA). It varies from USD 25 – 35 per ton of NH_3
- Vessel size considered – VLGC, 55000 mt – NH_3
- Fuel cost considered as $2/ton, which may vary from USD 1.5 – 2.5/ton

It is important to note that shipping cost is not significant with respect to the cost of production. Also, within shipping cost, ~50% is fixed cost towards port charges and vessel capex. Therefore, producing cheap ammonia in locations with good RE potential and other support schemes is more critical to achieve price competitiveness.

4.4 On-ground progress of projects

While there have been announcements of projects, on-ground progress on offtake contract finalization is limited. Most of the agreements are in the MoU stage and are non-binding in nature.

Table 31: Example of global ammonia contract

Project	Off-taker	Contract details
Oman 1 MMTPA Green Ammonia project	Yara, Europe	• Offtake term sheet signed for 100,000 TPY (phase 1) • Contract price: Undisclosed • Duration: Undisclosed
Quebec, 2.5 MMTPA green ammonia project, TEAL Corp	Trammo, USA	• Offtake contract term sheet signed for 800,000 TPY • Contract period: 15 years • Contract price: Undisclosed
1.2 MMTPA green ammonia project at KSA	Air Product	• Offtake term sheet signed with Air Product • Contract price: Undisclosed • Duration: Medium term contract
1 MMTPA green ammonia project in India	Uniper	• Offtake term sheet signed for 250,000 TPY • Contract price: Undisclosed

Source: Industry inputs

As there is an anticipated price reduction, off takers prefer to "**wait and watch**". They are also preferring seasonal contract rather than long term contract[73]. Recently, **HINT.CO** in Germany has launched an auction for procuring green ammonia with a contract period of 10 years.

73 Till now, except Germany, no one has come up with any tender for offtake

Status of global contracts in the Green Ammonia space

- There have been very few (if any) industrial-scale green NH3 contracts signed to date globally. To date, the biggest green H2 project post final investment decision (FID) globally is 22ktpa (Shell's Holland Hydrogen 1) and it will only be operational by 2025[74].
- Most announcements made to date are Memorandum of Understanding (MoUs) / Letter of Intents (LoIs), or, in few cases, Head of Terms (HoTs). These agreements are at very early stage, at least 2-3 years away from any binding terms.
- **Pricing regime:** Most initial deals will likely by cost-plus with joint subsidy requests. This is required to close the value gap and coordinate investment gates. Some contracts are likely to be market-linked also (linked with natural gas or grey ammonia spot price) – there are scopes of innovation in determining the price of green ammonia.
- **Contract duration:** This is evolving, but most likely contract duration is expected to be longer term than LNG given market is illiquid.
- It is important that the suppliers and off takers need to work together long before the FIDs are taken to de-risk the business case. This has to be a structured joint process

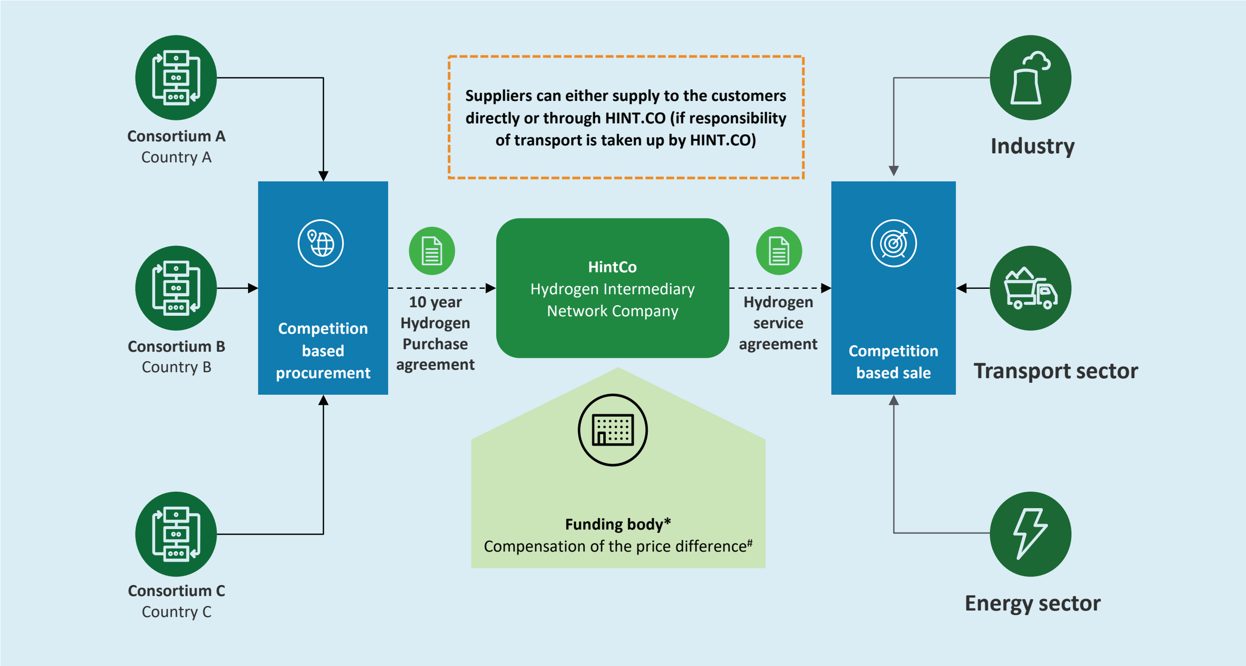
Source: Deloitte analysis, Consultation with international experts

As per BNEF and Deloitte analysis, only five international clean ammonia offtake contracts have been signed.

- The largest of these deals has been struck between NEOM and Air Products for 1.2 MMTPA of green ammonia produced in Saudi Arabia. It's a long-term binding contract.
- The second largest deal has been struck between US ammonia trader Trammo and Canadian developer Teal for 800,000 tonnes of green ammonia produced via hydropower in Quebec, Canada. It is a 15-year binding take or pay contract.
- The third large contract is 100,000 tonnes of green ammonia being shipped by India's Acme and Norway's Scatec from Oman to Norwegian-headquartered ammonia player Yara International (the exact import country has not been specified).
- Fourth offtake contract has been signed between Saudi Arabia's Ma'aden and Aramco and South Korea's Lotte Fine Chemical, which will ensure that at least 50,000 tonnes of blue ammonia — derived from natural gas with carbon capture and usage.
- Another supply contract has been signed for Japan's Cosmo Oil to import an undisclosed amount of blue ammonia from Adnoc and Fertiglobe in Abu Dhabi.
- In all of the above cases, the imported ammonia will be largely used for fertiliser production
- We may need to wait and watch the evolving contractual and pricing regime. Few large deals are under negotiation without any finalization of binding terms and conditions. It is important to note that ammonia trading companies are well-positioned to be the first clean ammonia offtakers because they have access to a large network of customers and own transportation and storage infrastructure. For example, Yara operates 11 ammonia carriers that can transport around 6MMT of ammonia per year. Trammo trades around 3MMT of ammonia annually through a fleet of refrigerated gas carriers. These companies also own a network of ammonia terminals and storage tanks.

74 Offshore Energy, Shell takes FID to build large renewable hydrogen facility in Rotterdam (access here)

Figure 76: Aggregation mechanism by HINT.CO



The key features of HINT.CO are as follows:

- The production of the products must take place outside the EU and EFTA countries.
- The products will be purchased for a total of EUR 300 million ± 20 percent per lot, but not more than EUR 900 million in total.
- The funds are provided by the Federal Ministry for Economics and Climate Action (BMWK) and spread over the period 2024 - 2033.
- The competitive bidding procedure is carried out in two stages: First stage will be a prequalification of candidates; selected candidates are then invited to submit their bids in the second stage.
- Delivery of product is allowed in destination country port or any other port in Germany/ Belgium/ Netherlands
- The contract price between Hintco and seller comprises of Product Price, Transport charge, Logistic & Dispatch charge, Export and Import duties.
- The transport charges include charter rate and bunker oil price and a fixed base price for transport

Recommendation for India

Large scale deployment of green ammonia projects can be supported by demand aggregation, both from domestic and international consumers; the aggregation can be done by some identified organization/ institution (government entity or government appointed nodal body). Based on the aggregated demand through a combination of multiple contracts of different quantities and tenure, the aggregator can sign "Ammonia (or Hydrogen) Purchase Agreement" with domestic producers and "Ammonia (or Hydrogen) Supply Agreement" with consumers. Domestic aggregation can be supported by taking a cluster specific approach. Setting up green hydrogen/ammonia projects at the vicinity of industrial clusters (demand centers) can help in scaling up of green ammonia use.

India's fertiliser sector is Urea heavy, where decarbonization potential is limited (maximum 20% in current scenario). While DAP and complex fertilisers (NPKs) have higher potential, overall consumption in current scenario is limited to ~2.5 million tons. It is expected that transition to green ammonia is likely to happen in phases (it may start with 10 – 15% obligation, and then gradually increases based on potential). Overall demand is likely to be fragmented across pan-India in the initial years. Therefore, demand aggregation could emerge as a feasible option to meet the fragmented demand.

4.5 Assessment of "Willingness to Pay" by various industries

The "willingness to pay" refers to maximum price or premium that end-consumers (industries) agree to pay for green ammonia at the current price landscape. As alternative, the industries would use grey ammonia or other cheaper fuel. Therefore, acceptance of green ammonia will be established on reaching a cost parity with other fuels.

4.5.1 Fertiliser industry

Fertiliser industry uses grey ammonia as the feedstock for producing nitrogenous fertilisers. Therefore, the industry is likely to switch to this green fuel when there would be a cost parity (after factoring in the additional carbon tax). Captured below is the "willingness to pay" by fertiliser industry in various geographies.

Table 32: Willingness to Pay in fertiliser industry

	EU		USA		Japan/Korea		India	
Parameters	**2023**	**2030**	**2023**	**2030**	**2023**	**2030**	**2023**	**2030**
Alternative fuel to GNH3	Grey Ammo-nia	Grey Ammo-nia	Grey Ammo-nia	Grey Ammo-nia	Grey Ammo-nia	Grey Ammo-nia	Grey Ammo-nia	Grey Ammo-nia
Landed Natural gas price (USD/MMBtu)	20	10	4	4	20	15	15	10
Grey ammonia cost of production (USD/ton)	925	575	370	370	925	750	750	575
CO2 emission (ton/ton of NH3)	2	2	2	2	2	2	2	2
Carbon tax (USD/ton CO2)	100	100	0	50	3	50	4	50
Premium for GNH3 (USD/ton)	20	20	20	20	20	20	20	20
Willingness to pay for GNH3 (USD/ton)	**1145**	**795**	**390**	**490**	**951**	**870**	**778**	**695**

Source: Deloitte analysis; Rystad energy (access here)

Note:

- Natural gas price is expected to be in the range of USD 10 – 12/MMBtu by 2030; Japan is likely to have a higher landed gas cost due to LNG import and associated regasification cost; USA is expected to have most competitive gas price – 2030 assumption is USD 4/MMBtu
- Minimum carbon price of USD 50/t CO2 is assumed in all geographies by 2030
- Green premium is assumed to be constant at USD 20/ton of ammonia

The above table considers three factors for determining "willingness to pay" – natural gas price, carbon tax and green premium accepted by industries. Europe is the only region with significant carbon tax; with carbon taxes imposed in other geographies, viability of green ammonia would improve.

4.5.2 Marine industry

Marine gas oil (MGO) is the most prevalent bunker oil in the maritime industry. The current cost of MGO is ~USD 700/Ton and its heating value is 42 MJ/kg.

Table 33: Willingness to Pay in marine industry

Parameters	2020	2030
Cost of Marine Gas Oil (USD/Ton)	700	805
Heating value of MGO (MJ/kg)	42	42
Ammonia's heating value (MJ/kg)	18.8	18.8
CO2 emission from MGO (ton/ton of MGO)	3.2	3.2
Carbon tax (USD/ton of CO2)	0	50
Green premium for GNH3	20	20
Willingness to pay for GNH3 (USD/ton)	**333**	**452**

Source: Deloitte analysis

Note:

- Cost of MGO is assumed to be in line with brent price forecast; brent is expected to increase by 15% by 2030 as per research reports.
- Green premium is assumed to be USD 20/Ton

It is evident that green ammonia is not cost competitive with marine gas oil. At current price, a cost parity can be achieved only at a carbon tax of USD 250 - 300/ton of CO_2.

4.5.3 Power generation

Ammonia can be blended with coal for co-firing for power generation. For assessing the willingness to pay, the landed imported cost of coal is assumed to be USD 240/ton with a heating value of 25 MJ/kg.

Table 34: Willingness to Pay in power generation industry

Parameter	2023	2030
Alternative fuel	Coal	Coal
Cost of alternative fuel (USD/ton)	240	90
Heating value of alternative fuel (MJ/kg)	25	25
Emission intensity (t CO_2/ton of fuel)	2.4	2.4
Carbon tax (USD/t)	0	50
Ammonia heating value (MJ/kg)	18.8	18.8
Green premium (USD/ton)	20	20
Willingness to pay for Green Ammonia (USD/Ton)	**200**	**208**

Source: Deloitte analysis

Note:

- Current Indonesian 6000 kCal/kg coal is priced at USD 240/ton; long term price target is USD 90/ton as per analyst report
- Carbon tax in 2030 is assumed as USD 50/ton of CO_2

Green ammonia is not cost competitive with coal. For acceptance of green ammonia (at USD 600/Ton) in power generation industry, emission must be taxed at ~USD 250/ton

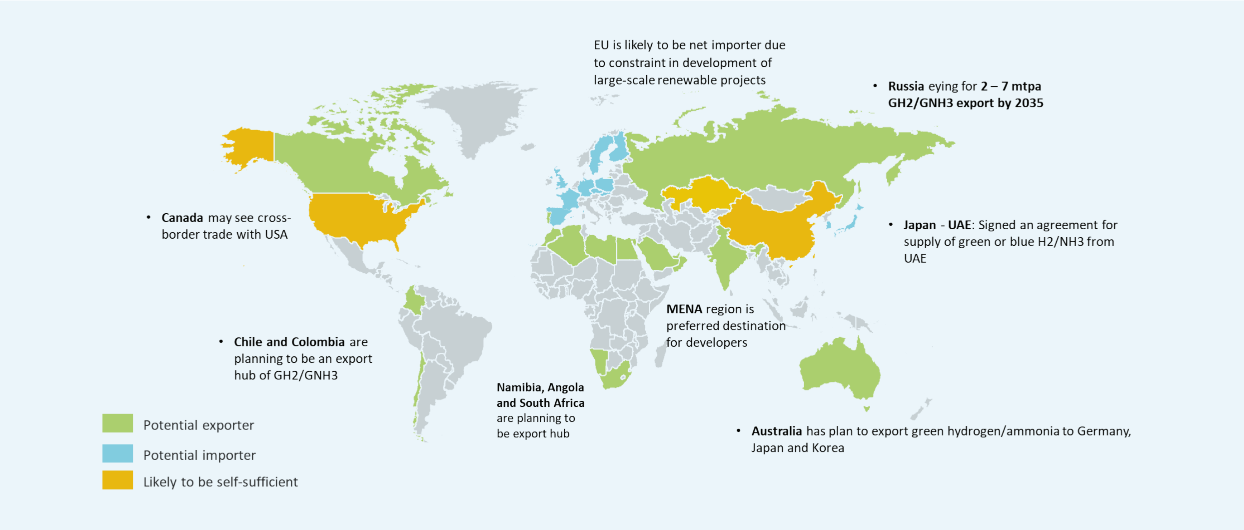
At current market price of green ammonia and other alternative fuels, green ammonia is only feasible for fertiliser industry in certain geographies with high natural gas price. For other industries, such as power and shipping, economics is not still favorable. There is a need of imposition of heavy carbon penalty to increase acceptance of green ammonia as an alternative fuel.

5. Global Trade Landscape for Green Hydrogen/ Ammonia

Importing ammonia from regions with low-cost renewables might be attractive for some countries. Government to Government collaboration and agreements are crucial to start piloting routes to ensure a global supply chain is established over time.

As reported by IRENA, more than 30 countries and regions have hydrogen strategies that include import or export plans, indicating that cross-border hydrogen trade is set to grow considerably. Countries that have not traditionally traded energy are establishing bilateral relations to trade on green molecules. As per analysis, Europe, Japan and Korea are likely to be major importers of hydrogen or ammonia, and MENA, Chile, India, Australia are likely to be potential exporters.

Figure 77: **Trade landscape of green hydrogen/ ammonia**



Source: Deloitte analysis

Many governments are forging bilateral deals for green ammonia/hydrogen in order to achieve energy security and meet the climate targets. These deals range from feasibility studies to signing memorandums of understanding, energy partnerships, and trial shipments. List of countries forging bilateral deals are listed below:

Table 35: **Example of bilateral deals**

Importing nations	Exporting nations
Germany	Namibia Chile Australia Tunisia
Japan	UAE Australia Saudi Arabia
Netherlands	Namibia Chile Canada Oman Morocco Australia

Importing nations	Exporting nations
Belgium	Chile Namibia
South Korea	Australia Saudi Arabia

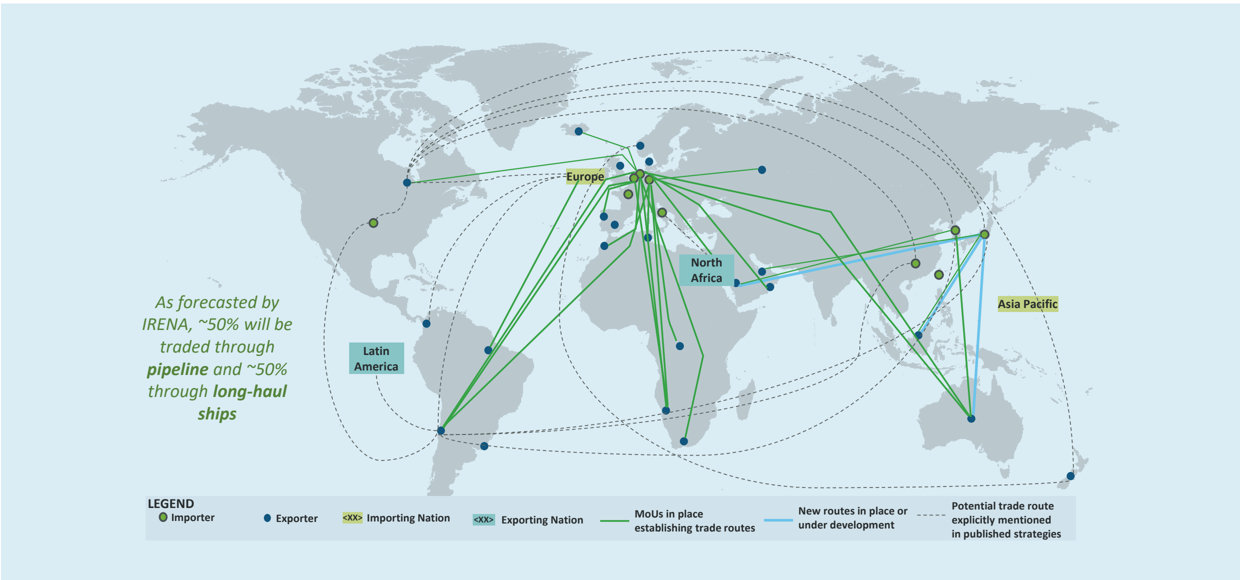
Source: Deloitte analysis

However, instances of firm offtake arrangement are yet to be seen. Most of the deals are currently in the MoU and discussion stages.

While India plans to emerge as an export hub, it is yet to forge any bilateral agreement or MoU with other governments, such as EU nations, Japan, Korea etc.

An illustration of potential trade routes is provided below.

Figure 78: Potential trade routes – key exporting and importing regions



Source: IRENA

As predicted by IRENA, ~30% of green Hydrogen/ ammonia would be traded across borders by 2050

5.1 Comparable green ammonia projects overview

Table 36: List of comparable green ammonia projects worldwide

Sl.	Project	General Specification	Port and Water availability	Agreement details	Status and Partners	Investment	Remarks
1.	**ACME group green ammonia plant, Oman**	**Location**: Oman **Capacity**: 1.2 MTPA (GNH3) **Electrolyser**: 3.5 GW (Alkaline) **Wind Power**: 0.5 GW **Solar**: 5.5 GW	**Nearest port**: Port of Duqm **Water**: Saline	**Project developer:** ACME Cleantech, India and Scatec, Norway **Off-taker(s):** Yara, NYK Lines **Status:** Agreement for offtake of 0.1 MT per year by Yara	• EPC contractor and technology providers are selected • **Ammonia technology**: KBR for ammonia synthesis equipment • Electrolyzer will be from Chinese OEM • **Partner**: SCATEC, Norway	USD 3.5 Bn	• Phase 1: Annual production of 0.1 MT of green ammonia using 300 MW of electrolysers and 500 MW of solar power. • **Capacity:** 1.2 MT. Operational by 2024
2.	**Neom Green Hydrogen, KSA**	**Location**: Kingdom of Saudi Arabia **Capacity**: 1.2 MMTPA (GNH3); 250 KTPA (GH2) **Electrolyser**: 2.65 GW **RE Power**: 4 GW	**Nearest port**: Al Jubail **Water**: Saline	**Project developer:** ACWA Power, Air Product **Off-taker(s):** Air Products **Status:** Binding agreements signed	• **Ammonia technology**: ThyssenKrupp (also Electrolyzer supplier). • **Other status:** Financing secured. Alfa Laval to deliver compact heat exchangers	USD 5 Bn	• **Capex:** USD 5 bn for hydrogen production, USD 2 bn for distribution (by Air Products), 4 GW of renewable energy & BESS • Air Products is the primary EPC contractor and will be the exclusive off-taker of the green ammonia and intends to export it around the world • **Capacity**: 1.2 MMT, to be operational by **2025-2026**.
3.	**Sept-Iles (Quebec) Green ammonia project, Canada**	**Location**: Quebec region, Canada **Capacity**: 2.5 MMTPA, Phase 1: 0.4 MMTPA **Electrolyser**: 3 GW **RE Power**: Hydro from Hydro Quebec	**Nearest port**: Port of Quebec **Water**: Saline	**Project developer:** TEAL Corp **Off-taker(s):** Trammo for 800,000 TPY capacity **Status:** Binding agreements signed	• **Not available**		• ~$1 billion investment approved for Phase 1 with 400,000 TPY capacity • Phase 1 is expected to be operational by 2026

Sl.	Project	General Specification	Port and Water availability	Agreement details	Status and Partners	Investment	Remarks
4.	**Point Tupper Green Ammonia Project, Canada**[75]	**Location**: Nova Scotia, Canada **Capacity**: 1 MMTPA (GNH3); 200 KTPA (GH2) **Electrolyser**: 1500 MW **RE Power**: Renewable power will be supplied by Nova Scotia Power Inc.	**Nearest port**: Port of Halifax **Water**: Saline	**Project developer:** Everwind Fuels **Off-taker(s):** E.on & Uniper Global **Status:** MoU signed	• **Ammonia technology**: KBR • **Electrolyzer**: NEL • **Engineering**: Hatch, FEED in process • Environmental approval received in Feb 2023	USD 1 Bn for phase 1 (200 KTPA)	• Phase 1: 200 KTPA ammonia by 2025. • Phase 2: 1 MTPA green ammonia production by 2026
5.	**HyEx project, Chile**[76]	**Location**: Tocopilla, Chile **Capacity**: 700 KTPA (GNH3) **Electrolyser**: 2 GW **RE Power**: 3 GW	**Nearest port**: Tocopilla Port **Water**: Saline	**Project developer:** ENGIE and Enaex **Off-taker(s):** Enaex (350 KT), Mining sector players, like BHP, Antofagasta, Codelco etc. **Status:** Strategic commercial partnership	• **Ammonia technology**: KBR • **Front End Engineering & Design (FEED)**: Toyo • **Electrolyzer:** Thyssenkrupp, Siemens • **Other status**: Feasibility study and environmental impact study is ongoing.	USD 2 Bn	• Phase 1 will be a Pilot project of 18 KT green ammonia per year by 2025; investment: USD 200 million; Electrolyser capacity: 26 MW • Phase 2 (700 KTPA) will be operational by **2030**. • Enaex is a major producer of ammonium nitrate; it will offtake 50% green ammonia from this project
6.	**AES ANDES**	**Location**: Tocopilla, Chile **Capacity**: 250 KTPA (GNH3), 50 KT (GH2) **Electrolyser**: 600 MW[77] **RE Power**: 800 MW	**Nearest port**: Tocopilla Port **Water**: Saline	**Project developer:** AES ANDES **Off-taker(s):** Undisclosed hydrogen producer and exporter **Status:** MoU signed. 100% offtake of green ammonia produced committed for maritime fuel and export for 30 years	• **Technology Provider**: AES ANDES • **Other status** Ongoing study for determining the correct setup of desalinization and production plant	USD 1 – 1.5 Bn	• Capacity to be operational by **2025**.

Source: Deloitte analysis

75 Source: https://everwindfuels.com/
76 Hy Ex (access here)
77 Electrolyser capacity has been calculated considering the following assumptions: electricity requirement 53 kWh/kg of H2; daily hours of operation: 12.

6. Locational assessment for green ammonia plant

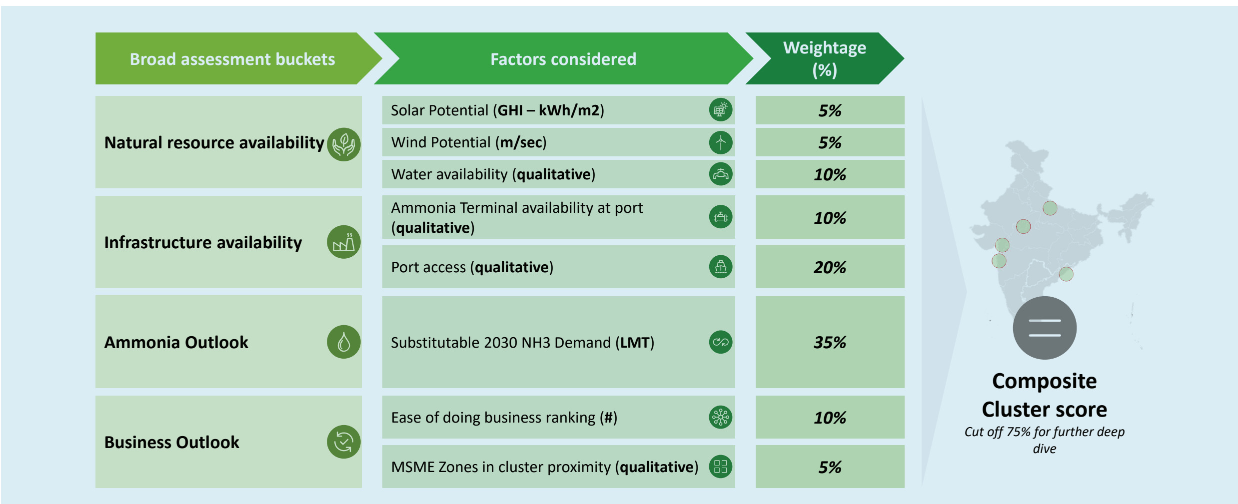
Ammonia demand is traditionally generated from the fertiliser sector (95% demand in India). In India, demand is concentrated in the states of Gujarat, Uttar Pradesh, Maharashtra, Rajasthan, Madhya Pradesh, and Andhra Pradesh due to presence of large fertiliser plants in these states. With anticipated demand mandates for green molecules (till cost parity between green and grey ammonia is achieved), some demand of green ammonia is expected to be generated from these fertiliser plants.

In addition to the domestic demand, export opportunities are expected from major demand centers like EU, Japan and Korea. Therefore, a greenfield green ammonia plant should be located strategically to cater domestic demand as well as export demand. A cluster-based approach has been adopted to assess the domestic demand.

6.1 Approach for comparative assessment and shortlisting of clusters

Based on the location of the fertiliser plants, six (6) clusters have been identified aggregating the ammonia demand from fertiliser production. These clusters were further examined and analyzed through a "prioritization framework" based on eight (8) factors, and a composite score was derived for each cluster by assigning specific weightage to each factor. An illustration of the prioritization framework is provided below:

Figure 79: Comparative assessment framework



Note: All attributes were brought to a 5 point scale with 5 being very favorable and 1 bring very unfavorable

Higher weightage was given to the substitutable demand in the cluster and access to ports and ammonia terminals to ensure adequate addressable domestic demand and ease of exporting to global demand centers.

Table 37: Factors for cluster scoring and rationale for their weightages

Factor	Weightage	Rationale
Solar Potential	5%	As it is easier to transmit the green electron and government policies favour RE generation, location of solar and wind plants can be anywhere in India irrespective of hydrogen plant location
Wind potential	5%	
Water availability	10%	Water availability is important, but if the plant is located near the coastline, desalinated water can be used for electrolysis
Ammonia terminal availability at port	10%	Ammonia terminal infrastructure at ports provides ease of exporting the chemical from potential producers
Port access	20%	Access to port will facilitate access to export market. Export demand can also be aggregated with domestic demand to ensure economies of scale
Substitutable ammonia demand in 2030	35%	Demand is the most important factor for setting up a green ammonia plant; the scoping of the plant, including electrolyzer sizing, will depend on demand in the cluster
Ease of doing business	10%	Better EODB will ensure ease of getting clearances, hassle free allocation etc.
MSME zones in cluster proximity	5%	Proximity to MSME zone will ensure a supportive ecosystem for the green ammonia plant

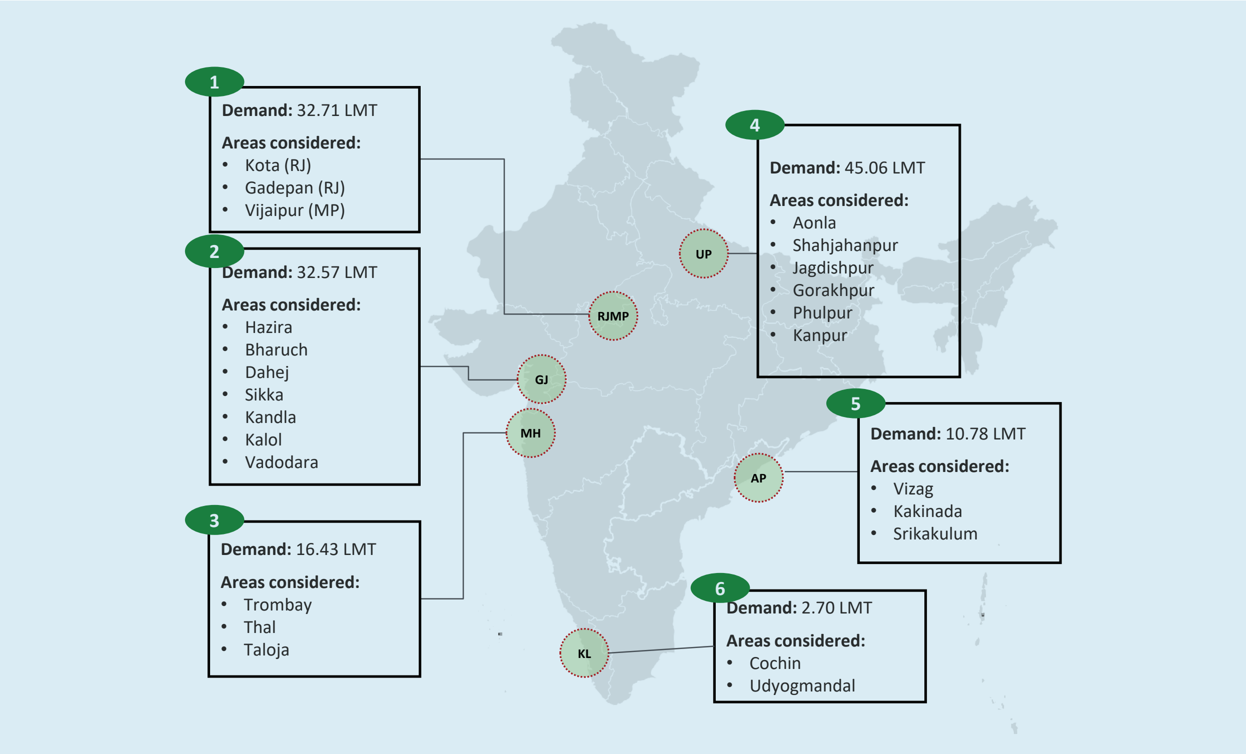
Considering India's intention to emerge as an export hub, significant weightage has been provided to port access and infrastructure. While water availability is a concern in some areas, plants located in coastal area are likely to use desalinated water.

A near-term market development would be possible by identifying attractive fertiliser clusters and aggregating demand from those. Those clusters can be served through localized ammonia production. Cluster identification should be guided primarily by concentration of existing or upcoming fertiliser capacities and access to port infrastructure to serve the export markets.

6.2 Cluster assessment

Six clusters have been identified through mapping of fertiliser plants. Clusters are located in Gujarat, Maharashtra, Andhra Pradesh, Uttar Pradesh, Kerala, and a combined cluster is located in Madhya Pradesh and Rajasthan. An illustration of clusters and their aggregate ammonia demand is shown below:

Figure 80: Ammonia demand clusters in India



Source: Deloitte analysis; Department of Fertiliser Annual Report (Details provided in Annexure (7.4)

6.2.1 View of ammonia demanding units in select cluster states

The state wise distribution of ammonia demand from these states are shown below:

State/ Plant Name	Sector	Ammonia Demand (LMT)
Andhra Pradesh		**10.79**
CIL: Kakinada	Private	4.02
CIL: Vizag	Private	2.34
NFCL: Kakinada	Private	2.95
NFCL: Kakinada Expn	Private	1.21
Smartchem/DFCL: Srikakulam	Private	0.27
Gujarat		**32.57**
IFFCO: Kalol	Co-operative	3.49
IFFCO: Kandla	Co-operative	5.67
KRIBHCO: Hazira	Co-operative	13.01
GNFC: Bharuch	Private	4.38
GSFC: Sikka	Private	2.07
GSFC: Vadodara	Private	3.93
Hindalco: Dahej	Private	0.01
Madhya Pradesh		**11.72**
NFL: Vijaipur	Public	5.41
NFL: Vijaipur Expn.	Public	6.31
Maharashtra		**16.43**
Smartchem/DFCL: Taloja	Private	2.23
RCF: Thal	Public	10.71
RCF: Trombay V	Public	3.49
Rajasthan		**20.99**
CFCL: Gadepan I	Private	6.24
CFCL: Gadepan II	Private	5.39
CFCL: Gadepan III	Private	7.11
Madhya Bharat Agro Ltd.	Private	0.00
SFC: Kota	Private	2.25
Uttar Pradesh		**45.06**
IFFCO: Aonla	Co-operative	6.18
IFFCO: Aonla II	Co-operative	6.59
IFFCO: Phulpur I	Co-operative	3.95
IFFCO: Phulpur II	Co-operative	5.96
Grasim/ IGFL: Jagdishpur	Private	6.13
HURL: Gorakhpur	Private	0.00
KFCL: Kanpur	Private	3.76
KFL/ KSFL: Shahjahanpur	Private	6.01

Source: Deloitte analysis; Preliminary data from Department of Fertilisers annual report 2021-22

6.2.2 Decision factor 1 - natural resource availability in clusters

The solar potential of the clusters is represented by GHI (Global Horizontal Irradiation in kWh/m^2))[78] and the wind potential for each cluster is represented by the wind speed (m/second)[79] in that region. To address the availability of water, availability, and access to sea water (if the demand is near the ports) or replenishable ground water (in billion cubic meters)[80] (if the clusters are inland) were assessed.

78 Global Solar Atlas (access here)
79 Global Wind Atlas (access here)
80 Wildlife Conservation (including species and habitats) using Geospatial Techniques, State wise Ground Water Resources Availability (access here)

Table 38: **Natural resource availability in clusters**

Sl.	Cluster	Solar Potential (kWh/ m2)	Wind Potential (m/sec)	Water Availability
	Gujarat	5.22 – 5.69	6.00 – 7.00	Sea water available
	Uttar Pradesh	4.63 – 5.23	4.96	77.19 bcm
	Maharashtra	4.99 – 5.43	6.3	Sea water available
	Rajasthan, Madhya Pradesh	4.91 – 5.65	5.73 – 5.8	11.94 bcm (Rajasthan), 35.04 bcm (Madhya Pradesh)
	Andhra Pradesh	4.89 – 5.53	6.45	Sea water available
	Kerala	4.36 – 5.45	7.56	Sea water available

The scoring for all three parameters was done on a scale of 5. Cluster locations with sea water availability were tagged with score of 5 (most favorable) and other states were tagged with a score between 1 to 3 based on their replenishable ground water resource availability.

6.2.3 Decision factor 2 - Infrastructure availability in clusters

All clusters were assessed based on availability of ports (Nos) and the ammonia terminals in them[81].

Table 39: **Infrastructure availability in clusters**

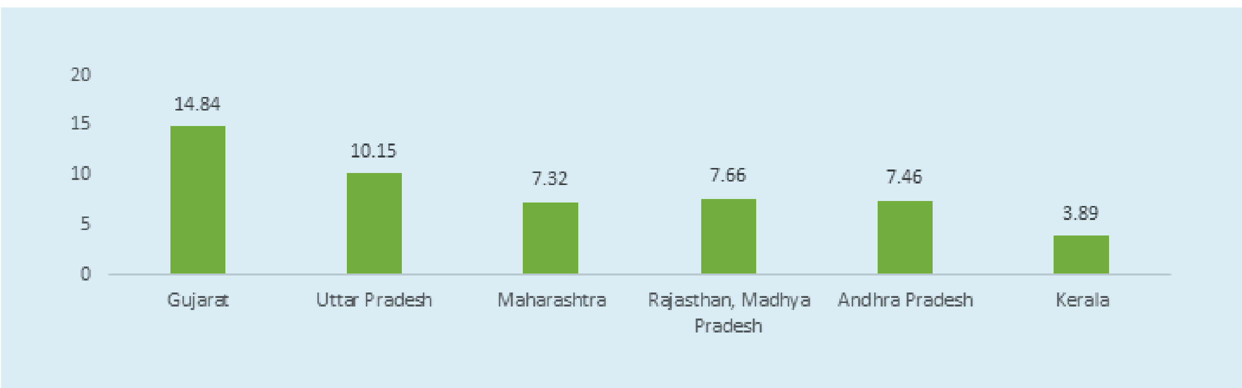
Sl.	Cluster	Port access/ nearby ports	Ammonia terminal installed ports
	Gujarat	Kandla, Sikka, Dahej	Kandla, Sikka, Dahej
	Uttar Pradesh	Not available	Not available
	Maharashtra	Mumbai, Trombay	Mumbai
	Rajasthan, Madhya Pradesh	Not available	Not available
	Andhra Pradesh	Kakinada, Vizag	Kakinada, Vizag
	Kerala	Cochin	Cochin

Nearly all the ports in Gujarat, Maharashtra, Kerala, and Andhra Pradesh house ammonia terminals for the DAP units operating in their vicinity.

6.2.4 Decision factor 3 – Substitutable grey ammonia demand

Substitutable grey ammonia demand in the clusters depend on the respective fertiliser production mix. For example, 100% grey ammonia used for producing DAP and NPK fertiliser can be substituted with green ammonia; but in case of urea, only 20% grey ammonia can be substituted due to process challenges. For estimation, fertiliser production mix has been considered for each cluster.

Figure 81: **Substitutable ammonia demand in 2030 (LMT)**



Source: Deloitte analysis

The future ammonia demand (2030) has been projected based on the capacity augmentation declarations by the fertiliser manufacturers. It is important to note that the Indian fertiliser industry is highly skewed towards urea production, which limits the decarbonization potential of the fertiliser sector – by 2030, total green ammonia demand in the identified clusters is limited to ~48 LMT.

81 Alfa Laval, Hafnia, Haldor, Topsoe, Vestas, Siemens Gamesa, Ammonfuel – an industrial view of ammonia as a marine fuel

6.2.5 Decision factor 4 - Business outlook in clusters.

All clusters have been rated on two factors – ease of doing business (ability to do hassle free business) and the presence of MSME base in the vicinity.

Table 40: Business outlook of clusters

Sl.	Cluster	Ease of doing business category	MSME Zones in Proximity
	Gujarat	Top Achievers	Yes
	Uttar Pradesh	Achievers	Yes
	Maharashtra	Achievers	Yes
	Rajasthan, Madhya Pradesh	Rajasthan (Aspires), Madhya Pradesh (Achievers)	Yes
	Andhra Pradesh	Top Achievers	Yes
	Kerala	Aspires	Yes

Top achievers were rated with a score of 5, achievers with 3 and aspires were rated a score of 1. All the clusters have MSME zones in their vicinity.

6.2.6 Cluster Attractiveness Score

All the clusters have been rated on the decision factors on a scale of 1 – 5 (1 being the least favorable and 5 being the most favorable), and a composite attractiveness score is derived for each cluster.

Table 41: Overall attractiveness score of clusters

Cluster	Solar Potential (kWh/m2)	Wind Potential (m/s)	Water availability	Port access	Ammonia terminal availability	Substitutable 2030 NH3 demand (LMT)	Ease of doing business rank	MSME proximity	Score (out of 5)
GJ	5	4	5	5	5	5	5	5	**4.95**
UP	1	1	3	1	1	3	3	5	**2.4**
MH	3	3	5	5	5	2	3	5	**3.7**
RJMP	3	2	1	1	1	2	1	5	**1.85**
AP	3	3	5	5	5	2	5	5	**3.9**
KL	1	5	5	5	5	1	1	5	**3.2**

Based on the assessment, Gujarat and AP clusters are emerging as most attractive clusters.

- **Gujarat** – large demand, good solar and wind potential, good access to ports with ammonia terminal, better ease of doing rank
- **Andhra Pradesh** – moderate demand, moderate solar and wind potential, good access to ports with ammonia terminal, better ease of doing business rank; in addition, fertiliser producers have history of importing ammonia, making them easy target for green ammonia consumption
- **Maharashtra** – Low to moderate demand, moderate solar to wind potential, good access to ports with ammonia terminal, medium ease of doing business rank
- **Kerala** – Low demand, low solar but good wind potential, good access to ports with ammonia terminal, low ease of doing business rank. While domestic ammonia demand is low, state level RE policies are conducive and it is planning for a dedicated green hydrogen policy
- **Uttar Pradesh** - moderate demand, low solar and wind potential, no access to ports, medium ease of doing business rank; while the state is planning to come up with a dedicated hydrogen policy, inaccessibility of port makes it a less attractive cluster. UP has large number of fertiliser plants, but all produce only urea, therefore limiting the demand potential.
- **Rajasthan-MP** – low to moderate demand, moderate solar and wind potential, no access to ports, medium ease of doing business rank

6.3 Deep dive on clusters

6.3.1Gujarat

The cluster in Gujarat has multiple fertiliser units producing Urea, NPK, DAP, ammonium sulphate, and ammonium nitrate. Due to favorable production mix, substitutable demand for ammonia is ~15 LMT, as indicated below:

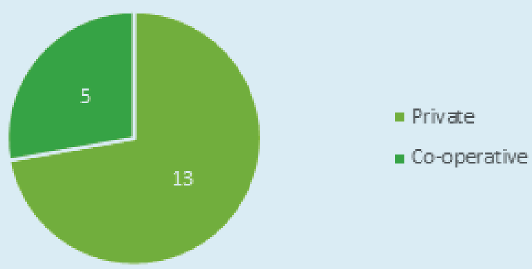
Table 42: **Fertiliser units in Gujarat**

Unit	Ownership structure	Product	Production FY21 (LMT)	NH3 Demand FY21 (LMT)	Substitutable NH3 demand FY30 (LMT)
GNFC Bharuch	Private	Amm. Nitrate	1.78	0.38	0.38
		NPK	1.67	0.40	0.40
		Urea	6.43	3.6	0.72
KRIBHCO Hazira	Co-operative	Urea	23.23	13.01	2.60
Hindalco Da-hej	Private	DAP	0.05	0.0135	0.0135
IFFCO Kandla	Co-operative	DAP	6.23	1.68	1.68
		NPK	16.6	3.98	3.98
IFFCO Kalol	Co-operative	Urea	6.24	3.49	0.72
GSFC Vadoda-ra	Private	Amm. Sulphate	4.87	1.25	1.25
		NPK	2.51	0.60	0.60
		Urea	3.71	2.08	0.42
GSFC Sikka	Private	DAP	5.66	1.53	1.53
		NPK	2.26	0.54	0.54

Source: Deloitte analysis; Department of Fertiliser Annual Report 2021-22

Figure 82: **Concentration of the fertiliser units in Gujarat**

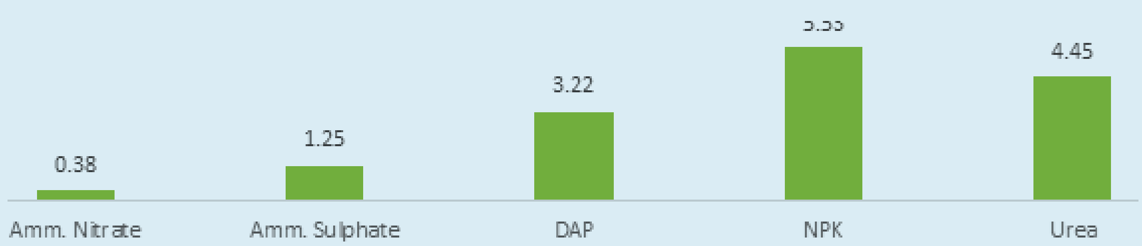
Figure 83: **Types of fertiliser firms in Gujarat**



Source: Deloitte analysis

Fertiliser units are spread out near the ports of Kandla, Sikka, Hazira, and Dahej with majority of the units having owned by private entities. Except Hazira, all other ports in the state have ammonia terminals[77]. The substitutable demand is ~15 LMT with majority demand expected from NPK fertilisers.

Figure 84: **Substitutable ammonia demand in Gujarat in 2030 (LMT)**



Source: Deloitte analysis

As ammonia transportation is easier to transport, entire state's demand is considered as part of location assessment. In Gujarat, two locations are preferable for setting up 1000 TPD ammonia plant i.e., Kandla SEZ and Dahej SEZ. As reported by the SEZs, ~292 acres land is available in Kandla SEZ[82] and ~978 acres are available in Dahej SEZ[83]. The distance of these ports from the international demand hubs are indicated below:

Table 43: Distance of import hubs from Gujarat (in nautical miles)

Import Hub	Nearest Distance (from Sikka) in Nautical Miles
Rotterdam	7146
Antwerp	7055
Hamburg	7425
Tokyo	6635

Source: Ports.com

With adequate demand aggregation, offtake of the entire capacity of the 1000 TPD plant is possible in the Gujarat cluster (total demand potential 4500 TPD). In addition, good RE potential and favorable government policies will help in competitive green ammonia production, further creating opportunities for export market.

6.3.2 Andhra Pradesh

Andhra Pradesh has 17 fertiliser units spread across Vishakhapatnam, Kakinada, and Srikakulam. The units produced DAP, NPK, Urea, and Ammonium Nitrate fertilisers totaling up to ~35 LMT in FY21[84]. Details of production are captured below:

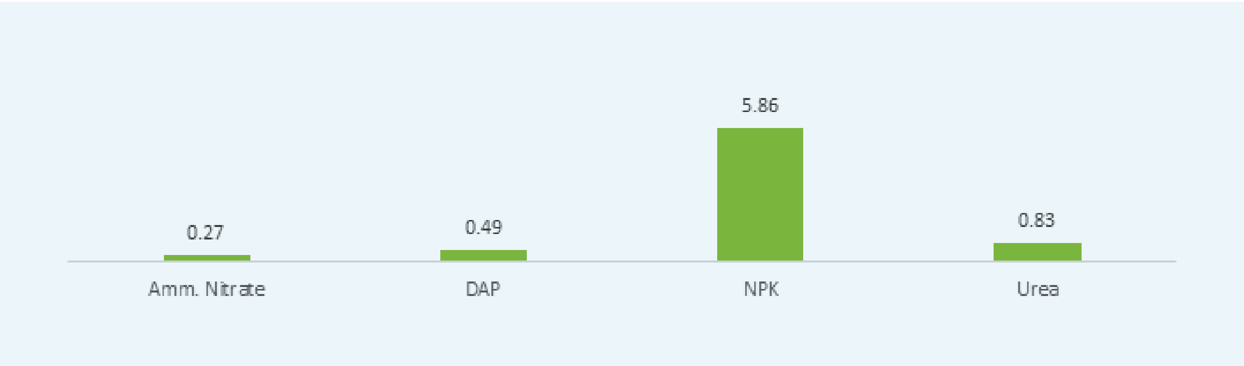
Table 44: Fertiliser production units in Andhra Pradesh

Unit	Ownership structure	Product	Production FY21 (LMT)	NH3 Demand FY21 (LMT)	Substitutable NH3 demand FY30 (LMT)
CIL Kakinada	Private	DAP	1.83	0.49	0.49
		NPK	14.68	3.52	3.52
CIL Vizag	Private	NPK	9.75	2.34	2.34
NFCL Kakinada	Private	Urea	7.42	4.15	0.59
Smartchem Srikakulam	Private	Ammonium Nitrate	1.29	0.27	0.27

Source: Deloitte analysis; Department of Fertiliser Annual Report 2021-22

Entire fertiliser capacity of AP is privately owned, with significant NPK and DAP capacity.

Figure 85: Substitutable ammonia demand in Andhra Pradesh in 2030 (LMT)



Source: Deloitte analysis

The ports of Kakinada, Bhavnapadu, and Vishakhapatnam are in the vicinity of the fertiliser units. Ammonia terminals are present in Kakinada and Vizag ports which are used for imports by the DAP units[77].

82 Kandla Special Economic Zone
83 Dahej Special Economic Zone Limited
84 Department of Fertiliser Annual Report

Land for the new 1000 TPD green ammonia facility can be targeted in the Kakinada and Vishakhapatnam SEZs. Kakinada SEZ is built over 10000 acres of land while Vishakapatnam SEZ has been built over an area of 360.5 acres[85]. More than 50% land is available in Kakinada SEZ.[86]

Table 45: Distance of import hubs from Andhra Pradesh (in nautical miles)

Import Hub	Nearest Distance (from Kakinada) in Nautical Miles
Rotterdam	8299
Antwerp	8209
Hamburg	8578
Tokyo	5755

Source: Ports.com

AP has ~7.5 LMT substitutable domestic demand (2200 TPD); favorable RE and government policies coupled with history of ammonia import by the fertiliser units offer good opportunities for green ammonia in this cluster.

6.3.3 Kerala

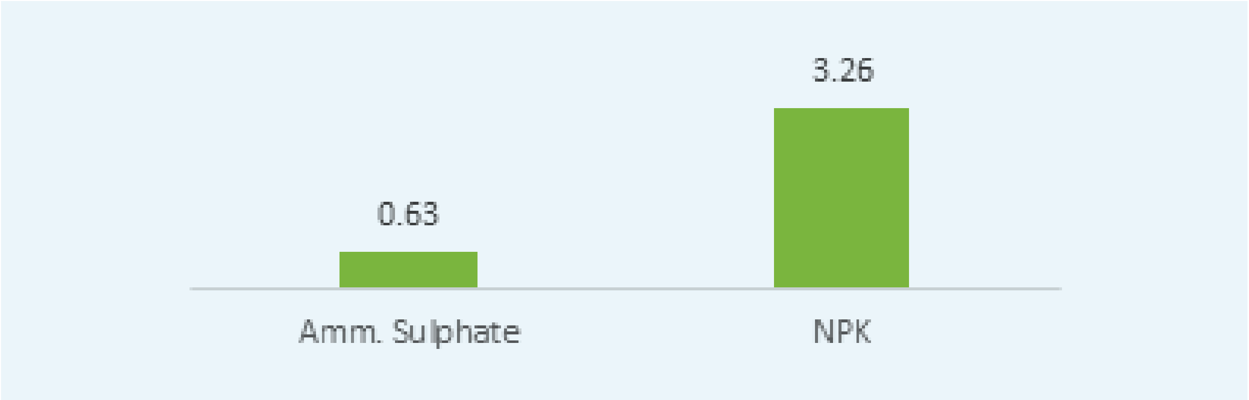
Kerala has 2 fertiliser units of FACT (Fertiliser and Chemicals Travancore) located at Cochin and Udyogmandal. The units produce NPK and ammonium sulphate fertilisers. Total production was ~11 LMT in FY21[87]. The entire capacity in the cluster is publicly owned.

Table 46: Fertiliser production units in Kerala

Unit	Ownership structure	Product	Production FY21 (LMT)	NH3 Demand FY21 (LMT)	Substitutable NH3 demand FY30 (LMT)
FACT Udyogmandal	Public	Amm. Sulphate	2.46	0.63	0.63
		NPK	2.16	0.52	0.52
FACT Cochin	Public	NPK	6.46	1.55	2.74[88]

Source: Deloitte analysis; Department of Fertiliser Annual Report 2021-22

Figure 86: Substitutable ammonia demand in Kerala in 2030 (LMT)



Source: Deloitte analysis

Total substitutable demand by 2030 would be ~3.90 LMT, and to substitute the entire capacity through green ammonia, a ~1200 TPD green ammonia is required.

Cochin port houses an ammonia terminal which is used for imports. **Bunkering** opportunities can be explored due to its proximity to the shipping routes connecting MENA region, Japan, South Korea.

85 Vishakhapatnam Special Economic Zone
86 Ministry of Environment, Forest, and Climate Change
87 Department of Fertilisers Annual Report
88 Capacity addition is planned

The distance of the major import hubs from the Cochin port is mentioned below:

Table 47: Distance of import hubs from Kerala (in nautical miles)

Import Hub	Nearest Distance (from Cochin) in Nautical Miles
Rotterdam	7359
Antwerp	7268
Hamburg	7637
Tokyo	5784

Source: Ports.com

If adequate demand aggregation is possible, Kerala would be an attractive location for setting up green ammonia plant.

Overall, above three clusters have sufficient domestic substitutable demand for ammonia; additional demand can be explored from export market and from supply of ammonia as bunkering fuel. The domestic demand is likely to be activated through anticipated demand mandates for fertiliser industries

7. Annexure

7.1 State level policies affecting green hydrogen/ ammonia

At present, Rajasthan is the only state with a hydrogen policy. Several other states such as Gujarat and Tamil Nadu are currently developing Hydrogen policies to drive the demand of green Ammonia/Hydrogen in the upcoming years. The table below captures the key state level policies.

State	Hydrogen Policy	RE policies	Other policies

Rajasthan	**Rajasthan Hydrogen Policy 2021**
	• Provision of adequate land near RE producing units at competitive rates
	• 100% Electricity duty payment exemption for 7 yrs.
	• 100% Land tax exemption for 7 yrs.
	• 100% exemption from payment of stamp duty and change of land use and conversion of land
	• Exemption from payment of open charges, wheeling charges, transfer charges, electricity duty and banking charges for use of RE for 14 years
	• One-time reimbursement of 50% of the cost of acquiring advanced technology from premiere national institutes capped at INR 2 crores.
	• First 5 manufacturing units investing more than 50 crores shall receive the following subsidies on plant and machinery:
	  ○ 5% interest subsidy on term loan for 5 yrs. up to 10 crores per year.
	  ○ 20% capital subsidy up to INR 50 crores.
		Rajasthan Solar Energy Policy 2019
		• Exemption from electricity duty consumed by the power producer for captive use for 7 years from commencement date.
		• Transmission and wheeling charges
		  ○ Solar plant w/o storage: 50% of normal transmission and wheeling charges from date of commissioning of the project
		  ○ Solar plant with storage: 25% of normal transmission and wheeling charges from date of commissioning of the project
		• Banking: Captive consumption and third-party sale within the state of the energy banked will be permitted. The banking charges will be @ 10% of the energy delivered at the point of drawl.	

Gujarat	The state government is yet to notify any Hydrogen Policy; however, the government is hopeful of coming out with the policy soon • Gujarat government has reserved 6000 sq km for Hydrogen fuel projects • Kutch and Banaskantha two district for majority of hydrogen fuel projects • Financial subsidy or viability gap funding to be provided for companies investing in Green Hydrogen • Make the state a Green Hydrogen/ Ammonia Manufacturing cluster	Gujarat Solar Power Project 2021: • Net metering is permitted for rooftop solar installations with a capacity between 1 kW and 1 MW • Wheeling and Transmission Charges are not applicable • Banking Charges are not applicable (except for demand based consumers and MSME units) • Cross Subsidy and Additional Charges are only applicable for third party sale • A subsidy of Rs. 10,000/KW in addition to increase our state's solar installation	• NTPC and Gujarat Gas Kawas started Green Hydrogen Blending with Natural Gas project in Gujarat • L&T to start a green hydrogen plant in Hazira with daily production of 45 kg • Gujarat refinery to produce finite purity hydrogen of 99.9999 per cent for hydrogen fuel cell buses

State	Hydrogen Policy	RE policies	Other policies
Uttar Pradesh	The government has notified the **Uttar Pradesh Draft Green Hydrogen Policy** in October 2022. The current hydrogen demand in the state stands at **around 0.9 million tonnes per annum (Mtpa)** • The government has set a target for having 20 percent green hydrogen blending in the state by 2028 and reaching 100 percent by 2035. • Promote production & consumption of 100 percent green hydrogen/ammonia in new units from 2025 onwards • Setting up of a Green Hydrogen Ecosystem Funds'	UP Solar Energy Project 2021: • Subsidy of Rs 15,000 per kW for the development of rooftop solar projects • Provision of Land on lease for development of Solar Park • Net-metering or gross-metering provision for solar PV systems. • Exemption on chargeable stamp duty, Electricity duty • Banking of energy is available • Single window clearance for solar power projects • cross subsidy surcharge, wheeling charges/Transmission charges are 100 % exempted for Intrastate Transmission system on Interstate sale of solar power • Exemption of 50 % on wheeling charges/transmission charges on Intrastate Sale of Power to third party or in case of Captive use	• The government has notified the Uttar Pradesh Draft Green Hydrogen Policy in October 2022. • The current hydrogen demand in the state stands at around 0.9 million tonnes per annum (Mtpa) • The government has set a target for having 20 percent green hydrogen blending in the state by 2028 and reaching 100 percent by 2035. • Promote production & consumption of 100 percent green hydrogen/ ammonia in new units from 2025 onwards • Setting up of a Green Hydrogen Ecosystem Funds'
Maha-rashtra	• The Maharashtra Government **proposes to release** a hydrogen policy for the automobile and energy sectors within a month. • Green Hydrogen/Ammonia Manufacturing Zone/cluster • State to give land to manufacture hydrogen-run vehicles • BEST (Brihanmumbai Electric Supply and Transport) has proposed to convert over 200 diesel-run buses into those running on green hydrogen • RE Policy may be Amended soon with Hydrogen context • Government in talks with Avaada Group for setting up a green hydrogen project worth Rs 45,000 crore in the state. • JSW and Maharashtra government to work for 960 MW Pumped Hydro Storage Project	**Policy for Projects Non-Conventional Transmission of Energy from Renewable (Non-Conventional) Energy Sources-2020** • Target of 500 GW is being set for the next 5 years • 30% of such leased property may be leased or charged	• Green Hydrogen and Alternate Fuel Technologies (GHAFT) to be one of the sub sections of ETAP(**Electrical Transient and Analysis Program**) cell. • German fundings for developing Green Hydrogen cluster • Study with CEA & BHEL nominees for a hydrogen project of approx. 200 MW power to Mumbai city , HFCEV charging infrastructure and Industrial hydrogen manufacturing and supply • Funding of approx. 12,000 Cr by green funding • Setup of 66,000 Kg Hydrogen production facility to commence soon. • Three pilot projects under OPEX with VGF model of 1 MW size

State	Hydrogen Policy	RE policies	Other policies
West Bengal	• No policies as of now	**Policy on co-generation and generation of electricity from Renewable Sources of Energy 2012** • Government land to be given for 30 years or the project life whichever is less for renewable projects • Exemption of demand cut to the extent of 50% of the installed capacity assigned for captive use purpose • No conversion of private/ agricultural land to non-agricultural land is required for renewable projects • WBGEDCL to act as a single window • Net Metering facilities are available to solar power system installed in rooftops and connected to grid • Open access is available for any RE developer	EV Policy 2021 • Asansol-Kolkata-Darjeeling-Howrah model cities for **hydrogen stations**-Specific goals in stipulated timelines • 100% net SGST for purchase of hydrogen generation • EV policy states that **first few Hydrogens stations shall be built by the government** • Smart City Proposals to include -Hydrogen Fueling stations • Durgapur Plant to set up green hydrogen plant in WB
Haryana	• No policies as of now	**Haryana Solar Power Policy, 2016** • Target of having 10% RE (total installed capacity) by 2022. • The rooftop solar system under net metering arrangement, to be exempted from banking and wheeling charges and losses, cross subsidy, and additional surcharge etc. • Single Window Mechanism	Government plans to run pilot cars, trucks that would run on green hydrogen produced from wastewater in an oil research institute in Faridabad
Punjab	• No policies as of now	**New and Renewable Sources of Energy (NRSE) Policy – 2012** • Lease of panchayat land at reasonable rates for solar projects for 30 years • Virtual and group net metering to be promoted in urban areas • Banking facilities to be allowed for grid connected solar rooftop for captive use • 10% exemption on total tax for manufacturing units of devices to solar power Industry and Commerce dept • Wheeling, Transmission charges , cross-subsidy charges and additional charges are exempted for solar projects • Exempted from electricity duty	Punjab EV Policy 2022 draft • Lease of panchayat land at reasonable rates for solar projects for 30 years • Virtual and group net metering to be promoted in urban areas

State	Hydrogen Policy	RE policies	Other policies
Karnataka	• No policies as of now	• RE project developers can sell energy to ESCOMS/Procurers, intermediaries, or consumers under open access • Banking is allowed for both captive and third- party sale. • KIADB will earmark 70% of allottable land in all Industrial areas for Large, Mega, Ultra & Super-Mega enterprises • Stamp duty exemption: 100% in Zone 1 and 75% in Zone 2* • Concessional registration charges in Zone 1 & 2: INR 1/- per INR 1000/- • 100% reimbursement of Land conversion fee in Zone 1 &2 • One-time capital subsidy up to 50% of the cost of ETP & CETP subject to a ceiling of INR 250 Lakhs and 500 Lakhs for all zones	Green Energy Open Access • Green Energy Open Access (GEOA) consumers shall have preference over normal Open Access consumers, excluding distribution licensees. • Consumers with captive power will have the right to open access. • Non-captive consumers with a sanctioned load of 100 kW or more will be eligible for open access
Tamil Nadu	• Hydrogen Energy Policy currently under development. • The Hydrogen Energy policy shall be released to drive investments in manufacturing green and blue hydrogen	**Tamil Nadu Solar Energy Policy (2019)** • Exemption from electricity tax for 2 years for consumer category solar energy • Government of Tamil Nadu will also promote manufacturing of solar cells, inverters, batteries, and mounting structures • Land will also be provided for solar system component manufacturing	**Tamil Nadu Industrial Policy 2021**: Incentives for RE component manufacturing and green fuel technology like Hydrogen fuel cell • Electricity tax exemption for 5 years on power purchased for TANGEDCO or generated or consumed from captive sources • 100% stamp duty exemption • 5% interest subvention for 6 years up to an annual ceiling 20-400 lakhs for large, mega, and ultra-mega industries
Kerala	**Kerala Green Hydrogen Mission** • Kerala is the first state to include hydrogen-powered mobility in its zero-emissions mobility policy • KSRTC has plans to buy 10 hydrogen buses • Hydrogen refilling infrastructure in nascent stage • 3-4 parallel processes for sorting hydrogen refilling under way • Production of green hydrogen from Kochi airport's solar power facility	-	-

State	Hydrogen Policy	RE policies	Other policies
Andhra Pradesh	-	• The government will encourage solar power producers to set up Solar and Wind Power Projects for captive use within the State or third-party sale within and outside the State of Andhra Pradesh. • Transmission and Distribution charges shall be exempted only for connectivity to the nearest Central Transmission Utility (CTU) via State Transmission Utility (STU) network for inter-state wheeling of power subject to the consent of APERC • Intra-state Open Access clearance for the whole tenure of the project or 25 years	
Madhya Pradesh		• Demonstration Projects/ Pilot project for green hydrogen are eligible to avail incentives under State RE Policy. • For electrolyser manufacturing units and green hydrogen production using RE power incentives will be provided as per the RE equipment manufacturing sector in the State's Amended Industrial Promotion Policy	**Industrial Promotion Policy** • The amended industrial promotion policy is yet to be released. • The amended policy will also include incentives for RE equipment manufacturing sector

7.2 List of green ammonia/ hydrogen projects announced in Australia

Project	Capacity	Focus area	Status	Investment details	Offtake Agreement
Yara's green ammonia project in Pilbara (Australia)	0.3 MTPA	Fertiliser industry	Construction to begin in 2022, to be completed by 2025-26	• The $87.1 million project is being developed in cooperation with Engie • The project is funded by the Australian Government with an AUD 47.5 million grant through ARENA's Renewable Hydrogen Deployment Funding Round • It includes a 10 MW electrolyzer, 18 MW of solar PV and battery storage • A consortium of Technip Energies and Monford Group has been awarded the Engineering, Procurement, Construction and Commissioning (EPCC) contract	Export ammonia to domestic and global markets from the nearby port of Dampier
Western Green Energy Hub	20 MTPA	Fertilisers and Industrial use	Construction will be in phases till 2028	• Capex: USD70bn • Capacity of 37 GW of wind and 15 GW solar power • Hub spread out in area approx. 15000 sq km • Coastal project which allows export worldwide • Project Consortium includes InterContinental Energy, CWP Global, and the Mirning People	Global exports

Project	Capacity	Focus area	Status	Investment details	Offtake Agreement
Fortescue Future Industries	5-7.5 MTPA	Industrial uses	First shipments to start in 2024, all phases by 2030	• The project would require $50 billion of capex • FFI targeting to produce 15 million tons of green hydrogen by 2030	Fortescue Future Industries secured a 5 million tonne per year hydrogen off-take deal with German energy giant E.ON.
Asian Renewable Energy hub, Pilbara	9 MTPA	Industrial & export	By 2028	• Capex: $36 billion • Asian Renewable Energy Hub (AREH) is one of the largest green ammonia projects globally with 26 GW of solar & wind power • The project is being developed by a consortium including InterContinental Energy, CWP Global, Vestas, BP and Macquarie	Global exports
Woodside petroleum – H2TAS blue ammonia project	2.6 MTPA	Industrial uses	Land secured, commissioning after 2030	• Capex: $745 million • Development in phases for 1.7 gigawatts (GW) of electrolysis for hydrogen and ammonia production • Initially 300 megawatts (MW) capacity, combination of hydro and wind energy	Global exports & domestic use
CIP, Hydrogen renewables Australia	2 MTPA	Industrial uses	commissioning after 2030	• Copenhagen Infrastructure Partners (CIP) announced a 2 MTPA ammonia plant near the port of Geraldton in Western Australia • 5,200MW of wind and solar energy and batteries will be used to fuel a 3,000MW electrolyser to produce the ammonia	Global exports
The Hydrogen Utility	1.8 MTPA	Industrial & export	Operations by 2025, exports by 2027	• Under-development H2-Hub in Gladstone, Queensland • International & domestic offtake agreements	Offtake agreement with Kepco, Korea & Orica
Mitsui blue ammonia project	1 MTPA	Industrial & export	commissioning after 2025	• Capex: $900 million • Mitsui E&P Australia (Mepau) in August signed an agreement with Australian conglomerate Wesfarmers to setup green ammonia	Export to Japan

7.3 List of green ammonia/ hydrogen projects announced in Chile

Project	Capacity	Focus area	Status	Investment details	Offtake Agreement
Gente Grande green ammonia project	1.3 MTPA	Industrial uses and export	Operational from 2026	• The $8 billion project is being developed by Petrofac and Transitional Energy Group (TEG) • This project will generate more than 3 GW of renewable power generation and 1.3 million tons of green ammonia production	NA
H2 Magallanes project	4.4 MTPA	Maritime fuel and export	Project to be launched by 2025. Hydrogen electrolysis will start by 2027	• Capex: USD 8 billion • 10 GW of onshore wind capacity to power 8GW of electrolysers, an ammonia production plant, a desalinization plant and port facilities for exporting green ammonia • Project Consortium includes Total Eren, University of Magallanes, and Wood	HIF Global, HIF Chile, and Uniper Global Commodities signed an LOI and will negotiate offtake agreements for selling and purchasing e-fuels from Megallenes
HyEx project	700 KTPA	Industrial uses, fertilisers, maritime fuel and export	Operation to start by 2030	• Capex: USD 2 billion • In the pilot, a green ammonia plant with 18KT capacity will be built by Enaex and 26 MW capacity of electrolyser shall be built by Engie with an initial investment of USD 200 million by 2025 • By 2030, the production capacity shall be 700 KT with 2 GW of electrolyser capacity	ENAEX will offtake 3,50,000 ton of ammonia annually for its ammonium nitrate Prillex plant. Remaining quantity to be commercialized for local market and international offtakers
HNH project	1 MTPA	Industrial uses, fertilisers, maritime fuel and export	Operations to start by 2026	• Capex: $ 3 billion • Off-grid project to be powered by 1.7 GW onshore wind farm for production of green hydrogen and green ammonia for express purpose of export • Project partners: Copenhagen Infrastructure Partners, Austria Energy and Okowind	Tammo will offtake the entire green ammonia production / output from this project.
ACH-MRP project	1 MTPA	Export and maritime fuel	Operations to begin by 2027	• Capex: $5 billion • Project partners: AKER clean hydrogen (ACH) and Mainstream Renewable Power (MRP) • 1 MTPA of green ammonia will be produced from 180 KT of green hydrogen	NA
AES ANDES	250 KT	Export and maritime fuel	Operations to begin by 2025	• Capex: $1.5 billion • Project partners: AES ANDES and AES Gener • 250 KT of green ammonia will be produced from 50 KT of green hydrogen	AES ANDES has committed 100% of the green ammonia output for maritime fuel and international for 30 years

6.4 List of Fertiliser Units in selected clusters

Table 48: Demand of ammonia and substitutable ammonia demand in clusters

State and Units	Ammonia Demand FY21 (LMT)	Substitutable Ammonia Demand in 2030 (LMT)
Andhra Pradesh	10.79	7.46
CIL: Kakinada	4.02	4.02
CIL: Vizag	2.34	2.34
NFCL: Kakinada	2.95	0.59
NFCL: Kakinada Expn	1.21	0.24
Smartchem/DFCL: Srikakulam	0.27	0.27
Gujarat	**32.57**	**14.84**
GNFC: Bharuch	4.38	1.50
GSFC: Sikka	2.07	2.07
GSFC: Vadodara	3.93	2.27
Hindalco: Dahej	0.01	0.01
IFFCO: Kalol	3.49	0.72
IFFCO: Kandla	5.67	5.67
KRIBHCO: Hazira	13.01	2.60
Madhya Pradesh	**11.72**	**2.34**
NFL: Vijaipur	5.41	1.08
NFL: Vijaipur Expn.	6.31	1.26
Maharashtra	**16.43**	**7.32**
RCF: Thal	10.71	3.09
RCF: Trombay V	3.49	2.01
Smartchem/DFCL: Taloja	2.23	2.23
Rajasthan	**20.99**	**5.32**
CFCL: Gadepan		0.42
CFCL: Gadepan I	6.24	1.62
CFCL: Gadepan II	5.39	1.40
CFCL: Gadepan III	7.11	1.42
Madhya Bharat Agro Ltd.	0.00	0.00
SFC: Kota	2.25	0.45
Uttar Pradesh	**45.06**	**10.15**
Grasim/ IGFL: Jagdishpur	6.13	1.23
HURL: Gorakhpur	0.00	1.14
IFFCO: Aonla	6.18	1.24
IFFCO: Aonla II	6.59	1.32
IFFCO: Phulpur I	3.95	0.79
IFFCO: Phulpur II	5.96	1.19
KFCL: Kanpur	3.76	0.75
KFL/ KSFL: Shahjahanpur	6.01	1.20
YARA/ TCL: Babrala	6.47	1.29
Kerala	**2.70**	**3.89**
FACT: Cochin	1.55	2.74
FACT: Udyogmandal	1.15	1.15

Source: Deloitte analysis; Department of Fertiliser Annual Report 2021-22

www.energyforum.in