# Prefeasibility Study for Decentralised Green Ammonia Production in India

## Market assessment, policies and pre-feasibility study for a 300TPD Green Ammonia plant

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The International Hydrogen Ramp-up Programme (H2Uppp) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) promotes projects and market development for green hydrogen in selected developing and emerging countries as part of the National Hydrogen Strategy.

New Delhi, August 2024

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# Abbreviations

APM. Administered Pricing Mechanism

BEV. Battery Electric Vehicle

BTS. Base Trans-receiver Stations

BVFCL. Brahmaputra Valley Fertilizer Corporation Ltd.

CAGR. Compound Annual Growth Rate

CAPEX. Capital Expenditure

CCPP. Combined Cycle Power Plants

CEEW. Council on Energy, Environment and Water

CF. Complex Fertilizers

CFCL. Chambal Fertilizers and Chemicals Ltd.

CFL. Coromandel Fertilizers Limited

CFR. Cost and Freight

CHP. Combined Heat and Power

CIF. Cost, Insurance and Freight

CIL. Coromandel International Ltd.

CoD. Commercial operation Date

DAP. Diammonium phosphate

DEG. Di Ethylene Glycol

DFCL. Deepak Fertilizers and Chemicals Ltd

DG. Diesel Generator

EBP. Ethanol Blended Petrol

ESG. Environment, Social, and Governance

FACT. Fertilizers and Chemicals Travancore Ltd.

FC. Fuel Cell

FMCG. Fast Moving Consumer Goods

FOB. Free on Board

GHG. Greenhouse Gas

GIZ. Deutsche Gesellschaft für internationale Zusammenarbeit GmbH

GNFC. Gujarat Narmada Valley Fertilizers & Chemicals Limited

GSFC. Gujarat State Fertilizers & Chemicals Ltd.

HDPE. High density polyethylene

HFO. Heavy Fuel Oil

HGU. Hydrogen Generation Unit

H-ICV. Hydrogen Internal Combustion Engine Vehicle

HURL. Hindustan Urvarak & Rasayan Ltd.

IFFCO. Indian Farmers Fertilizer Cooperative Ltd.

KFCL. Kanpur Fertilizer & Cements Ltd.

KLPD. Kilo liters per day

KRIBHCO. Krishak Bharati Cooperative Ltd.

KT. Kilo Tons

KTPA. Kilo Tons per Annum

kWh. Kilo Watt Hour

LCOA. Linear Alkyl Benzene

LCOH. Levelized Costs of Hydrogen

LLDPE. Linear low density polyethylene

LPG. Liquefied Petroleum Gas

MCFL. Mangalore Chemicals & Fertilizers Ltd.

MEG. Mono Ethylene Glycol

MFCL. Matix Fertilizers and Chemicals Ltd.

MFL. Madras Fertilizers Ltd.

MMT. Million Metric Ton

MMTPA. Million Metric Tonnes per Annum

MNRE. Ministry of New and Renewable Energy

MoCF. Ministry of Chemicals and Fertilizers

MoP. Ministry of Power

MoPNG. Ministry of Petroleum and Natural Gas

MoRTH. Ministry of Road and Transport and Highways

MoS. Ministry of Steel

MoU. Memorandum of Understanding

MSME. Micro Small and Medium Enterprises

MT. Metric Ton

MTBE. Methyl tert Butyl Ether

NABH. National Accreditation Board for Hospitals and Healthcare Providers

NDC. Nationally Determined Contribution

NFCL. Nagarjuna Fertilizers and Chemicals Ltd.

NFL. National Fertilizers Ltd.

NH. National Highway

NPK. Nitrogen Phosphorus Potassium

NPV. Not Present Value

NTPC. National Thermal Power Corporation

NUP. New Urea Policy

NW. National Waterway

OEM. Original Equipment Manufacturer

IMO. International Maritime Organization

Inland Water Transport. Inland Water Transport

INR. Indian Rupee

IRR. Internal Rate of Return

ISTS. Inter-State Transmission System

JV. Joint Venture

PV. Passenger Vehicles

PwC. PricewaterhouseCoopers

PX. Para-Xylene

RCF. Rashtriya Chemicals & Fertilizers Ltd.

RCFL. Ramagundam Fertilizers and Chemicals Ltd.

RLNG. Re-gasified Liquefied Natural Gas

RPO. Renewable Purchase Obligation

SBR. Styrene -butadiene rubbers

SBU. Strategic Business Unit

SEZ. Special Economic Zone

SFC. Shriram Fertilizers & Chemicals

SGST. State's Goods and Service Tax

SIGHT. Strategic Interventions for Green Hydrogen Transition

SIPCOT. State Industries Promotion Corporation of Tamil Nadu Limited

SMR. Steam Methane Reformation

SPIC. Southern Petrochemical Industries Corporation

SSBR. Solution Styrene Butadiene Rubber

OPEX. Operating Expenses

PBR. Phosphorus Tribromide

PEM. Proton Exchange Membrane

PET. Polyethylene terephthalate

PPAC. Petroleum Planning and Analysis Cell

PTA. Purified Terepthalic Acid

TAN. Technical Ammonium Nitrate

TCL. Tata Chemicals Ltd.

TCO. Total Cost of Ownership

TEDA. Tamil Nadu Energy Development Agency

TEG. Tri Ethylene Glycol

TEN. Target Energy Norm

TN. Tamil Nadu

TOE. Total Oil Equivalent

TPD. Tonnes per day

TPS. Thermal Power Station

TRAI. Telecom Regulatory Authority of India

TTZ. Taj Trapezium Zone

UPNEDA. Uttar Pradesh New & Renewable Energy Development Agency

UPPCL. Uttar Pradesh Power Corporation Limited

USD. United States Dollar

v/v. Volume/Volume

# Executive Summary

## The Underlying Context

India as a growing economy is expected to see a sharp growth in its energy demand, accounting for about 25% of global energy demand growth over the next two decades.[1] At the 26th session of the UNFCC (COP 26) in November 2021, India announced a target to achieve net zero by 2070.[1, 2] India also reiterated its commitment to reduce the emissions intensity of its GDP by 45% by 2030, from 2005 level. Therefore, such targets and ambitions can be well served by a strong green hydrogen economy. Currently, India's hydrogen consumption is nearly above 6 million tons, served almost entirely by grey hydrogen which is produced via Methane Reformation. Grey hydrogen, at present, finds its use mostly in refineries and fertilizer sectors. Likewise, being a versatile element, hydrogen possesses the potential to become an active ingredient in the value chains of many such industries/ sectors.

Pursuit of low carbon alternatives is leading various industries to explore the adoption of green hydrogen. Estimates suggest that at present, the costs of green hydrogen are high and range from USD 4 to USD 7 per kg. During the nascent stages of market development, costs are expected to be minimized through two approaches. The first approach entails creation of vertically integrated structures by integrating production steps at a single location. The second approach shall involve the establishment of regional hydrogen hubs/ clusters. The primary focus is expected to be on large industrial hubs, which serve as a nexus for ports, energy, and industry. In this regard, an emphasis is expected to be on refining and fertilizer production and/ or exporting. Nevertheless, given the high costs associated with transportation and the inherent risks of energy transmission over long distances, there may be viable prospects of producing distributed small-scale green hydrogen/ ammonia.

In this context, GIZ set out to test a hypothesis to assess if the lack of economies of scale can be mitigated via minimization of hydrogen transportation costs through Decentralised production. A feasibility assessment of small-scale green ammonia production has been undertaken to understand the techno-economics of a 50 TPD decentralised green ammonia plant. The study focuses on the states of Uttar Pradesh and Tamil Nadu due to their geography (with the former being land locked and the latter being coastal) and also the availability of distributed demands within these states.

With this in mind, the study has been divided into 5 chapters. The first chapter covers ammonia and hydrogen markets in India, along with an assessment of ammonia's commercial regime in India. This has been followed by an assessment of regulatory landscape, and risk assessment in the second chapter. The third chapter undertakes an assessment to understand willingness to pay for the consumer segments covered in chapter 1. The fourth chapter highlights the transport and storage modalities of ammonia

1 United Nations Framework Convention on Climate Change

2 MOEFCC

and hydrogen. The study concludes with a techno-commercial feasibility assessment of a decentralised green ammonia facility in the fifth chapter.

## Market Assessment of Ammonia

The chapter commences with a pan India assessment of ammonia consumption in India, covering multiple sectors like fertilizers, explosives, and nitric acid. This is followed by reviewing the consumption of hydrogen in refining sector. The chapter concludes with the state specific estimation of ammonia demand and potential for Uttar Pradesh and Tamil Nadu in sectors like power, mobility, maritime shipping, inland waterways, fertilizer, refineries, and glass.

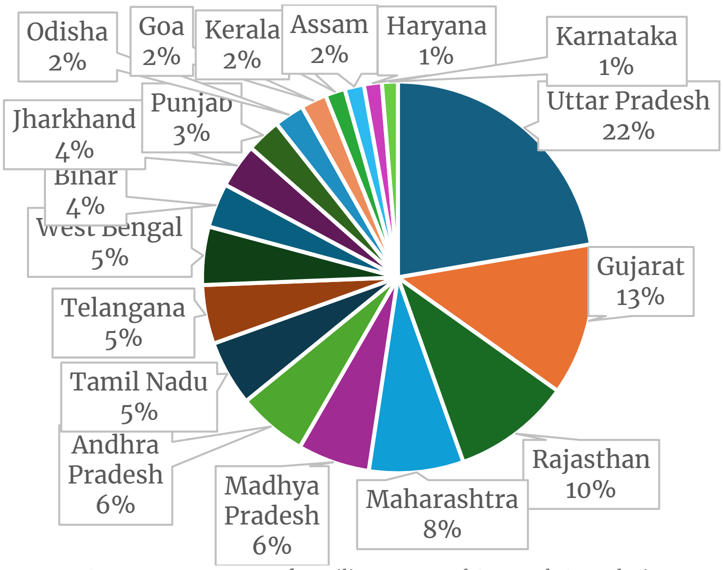
### Ammonia in Fertilizers

Fertilizer sector accounts for approximately 90% of ammonia consumption in India, wherein it is used to produce fertilizers like urea, DAP, and other Complex Fertilizers. Urea producers in India produce ammonia in-house, within the urea-ammonia complexes. On the other hand, DAP and other complex fertilizers (CF) meet the required ammonia demand mostly through import of ammonia. For fertilizer sector, the ammonia consumption is tabulated below:

Ammonia consumption in fertilizer industry by product (FY 2022-23)

| Sr. No. | Sector | Consumption of ammonia (KTPA) | Consumption of hydrogen (KTPA) |
|---|---|---|---|
| 1. | Urea | 14,024 | 2,522 |
| 2. | DAP | 868 | 156 |
| 3. | Other CF | 2,004 | 360 |
| | **Total** | **16,896** | **3,038** |

State wise distribution of ammonia demand in India's fertilizer sector




Source: Department of Fertilizer, Internal Research & Analysis

In addition to its use in fertilizer production, ammonia consumption has also been assessed in other sectors like technical ammonium nitrate and nitric acid.

## Ammonia in Technical Ammonium Nitrate (TAN)

In the explosive industry, ammonia is consumed via the production of Technical Ammonium Nitrate (TAN) which is an industry grade explosive. Consumption of TAN is highest in the coal mining industry, which accounts for about 67% of the domestic TAN demand.[3] Even though ammonium nitrate is a popular fertilizer globally, it is not used as a fertilizer in India due to regulations, safety concerns, and impacts on soil. Moreover, it has the potential to be misused for unregulated explosive production. Therefore, according to "The Ammonium Nitrate Rules, 2012" any mixture having more than 45% ammonium nitrate by weight, from which it can be extracted for unlicensed production of explosives, comes under the purview of Govt. regulations and is affected by supervision by the authorities. This measure limits the production of TAN in the absence of necessary licenses. Currently, the demand for TAN In India is higher than its domestic production, leading a demand-supply disparity. Industry sources suggest that during the year 2020-21, the domestic production stood approximately at 760 KT, whereas the demand was at approx. 993 KT. Come 2030, the demand is expected to increase at a CAGR of approx. 5% to 6%. The quantity of ammonia needed to cater to India's TAN requirements has been estimated to be about 546 KT.

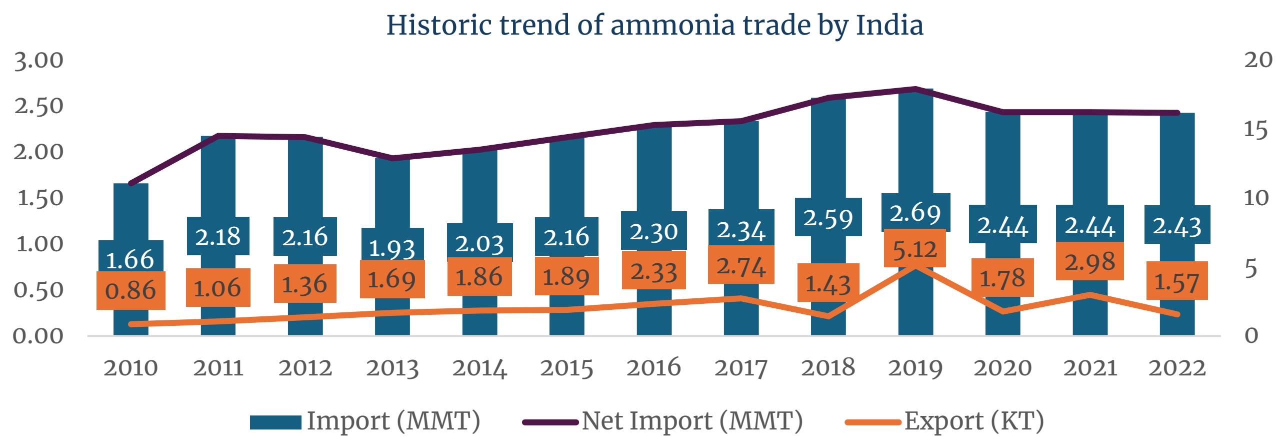
3 Ministry of Coal Report

## Ammonia in Nitric Acid

The major portion of the nitric acid produced goes into the manufacturing of ammonium nitrate, which is used in the explosive industry. Western states of Gujarat and Maharashtra are the major consumers, and majority of the chemical manufacturers are located in these states due to access to shipping ports. Additionally, as most of the nitric acid production capacity is held with fertilizer manufacturers, the producers are under the control and regulation of the Ministry of Chemicals and Fertilizers. The current demand for Nitric acid in the country is about 640 KT which is expected to grow at a CAGR of 5.5% to reach 1,284 KT by 2035. The country is almost self-sufficient in the availability of the chemical and only 2% of the total demand is being imported. For nitric acid produced in India, the corresponding ammonia demand is estimated to be close to 202 KT.

## Ammonia Trade and extant commercial regime

Next, the report delves into understanding India's trade of ammonia. Ammonia is a globally traded commodity with India being its third largest consumer in the world, behind China and USA. India also exports small volumes of ammonia as well. The graph showcases India's ammonia trade trend.

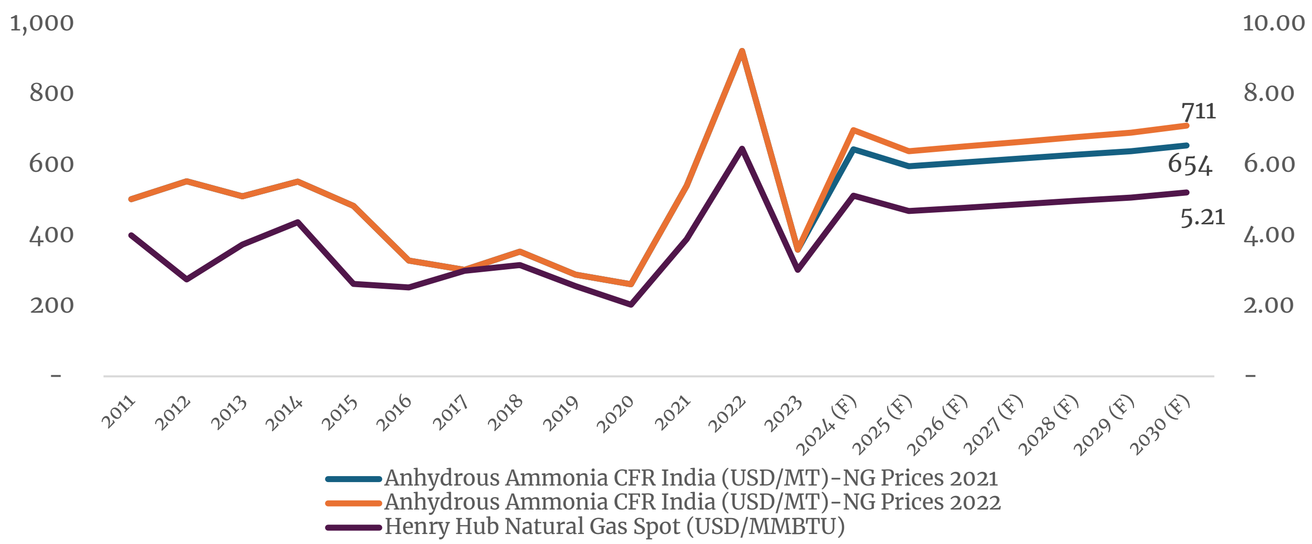



Source: Industry Sources

After studying the export and import of ammonia, an analysis of the prevalent ammonia commercial regime in India has been undertaken. The commercial landscape of ammonia in India is determined by import parity pricing (IPP). IPP is calculated by taking the international cost of ammonia and adding the expenses related to importing it, like freight, customs duties, taxes, etc. Till June FY24, the average landed price at the port had been assessed to vary between USD 390 per MT to USD 616 per MT.[4]

As natural gas is a key feedstock for ammonia production, the pricing of ammonia in India closely tracks natural gas prices. Consequently, a price forecast assessment to understand the future trends of grey ammonia prices has been undertaken w.r.t. (i) NG prices till 2021 and (ii) NG prices till 2022.

Forecasting of ammonia prices (USD per tonne)




Source: EIA, Industry Sources, Industry Natural Gas Forecasts

## Hydrogen consumption in refineries and petrochemicals

After assessing the ammonia market at the Indian level, we proceeded to understand the current consumption of grey hydrogen in India within the refining and petrochemical sectors in India. For these sectors, the existing HGU capacities were assessed, and the grey hydrogen demand was estimated to be 2,369 KTPA in 2022.

Post a pan-India assessment of ammonia and hydrogen consumption, a state level assessment for Uttar Pradesh and Tamil Nadu, which has been discussed next.

## State level assessment of ammonia and hydrogen demands

Ammonia and hydrogen demand potential have been estimated across sectors like power, mobility, fertilizer, refining, shipping, inland waterways, and glass.

4 It is to be noted that the average CIF (Cost, Insurance, and Freight) price of ammonia in India for FY 2022-23 was observed to increase to more than double due to the conflict between Russia and Ukraine.

## Hydrogen in the Power Sector

The use of hydrogen as a back-up fuel to replace diesel generators has been assessed for hospitals and telecom towers. Furthermore, the potential of hydrogen to provide decentralised power to remote villages has also been evaluated.

**Hospitals:** India's healthcare industry has been growing at a CAGR of around 22% since 2016.[5] Consequently, demand for emergency backup power and clean off-grid power generation systems has been on the rise. Therefore, for hospitals, the energy requirement per bed per year was reviewed in both Tamil Nadu and Uttar Pradesh. This was done considering two scenarios – realistic and conservative.[6] Likewise, the power outages in both the states was reviewed on hours per day basis. Subsequently, the potential of hydrogen fuel cells to replace the diesel generators as power back-up source was assessed. The hydrogen demand thus calculated was further demarcated within various districts of the two states. The hydrogen demand estimated has been tabulated below.

### Hydrogen demand potential from hospital Power Backup Systems for Uttar Pradesh (2023)

| Hydrogen Demand for 4 Hour Back-up Requirement with Conservative Scenario | Hydrogen Demand for 4 Hour Back-up Requirement with Realistic Scenario | Hydrogen Demand for 8 Hour Back-up Requirement with Conservative Scenario | Hydrogen Demand for 8 Hour Back-up Requirement with Realistic Scenario |
|---|---|---|---|
| 1.69 KT | 3.39 KT | 3.39 KT | 6.77 KT |

Source: Internal Analysis

### Hydrogen demand potential from hospital Power Backup Systems for Tamil Nadu (2023)

| Hydrogen Demand for 1 Hour Back-up Requirement with Conservative Scenario | Hydrogen Demand for 1 Hour Back-up Requirement with Realistic Scenario |
|---|---|
| 0.23 KT | 0.47 KT |

Source: Internal Analysis

**Telecom Towers:** Over the past decade, the telecommunication industry has experienced a growth of approx. 33%, leading to an ever-increasing reliance on reliable energy. Furthermore, industry sources suggest that India's telecom sector is expected to grow at a CAGR of 9.4% till 2028. The demand for continuous, reliable, and higher levels of communication services is leading towards applications that require excessive energy. This necessitates finding sustainable and eco-friendly backup energy solutions. In a manner similar to that of hospital sector, hydrogen demand in telecom sector has been assessed. The data pertaining to the number of telecom towers present in each state along

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5 NITI Aayog

6 Realistic and conservative scenarios correspond to the energy needed per bed per year

with the average power outage has been used to estimate hydrogen required to potentially replace the diesel consumption in the sector. This demand has further been demarcated district-wise.

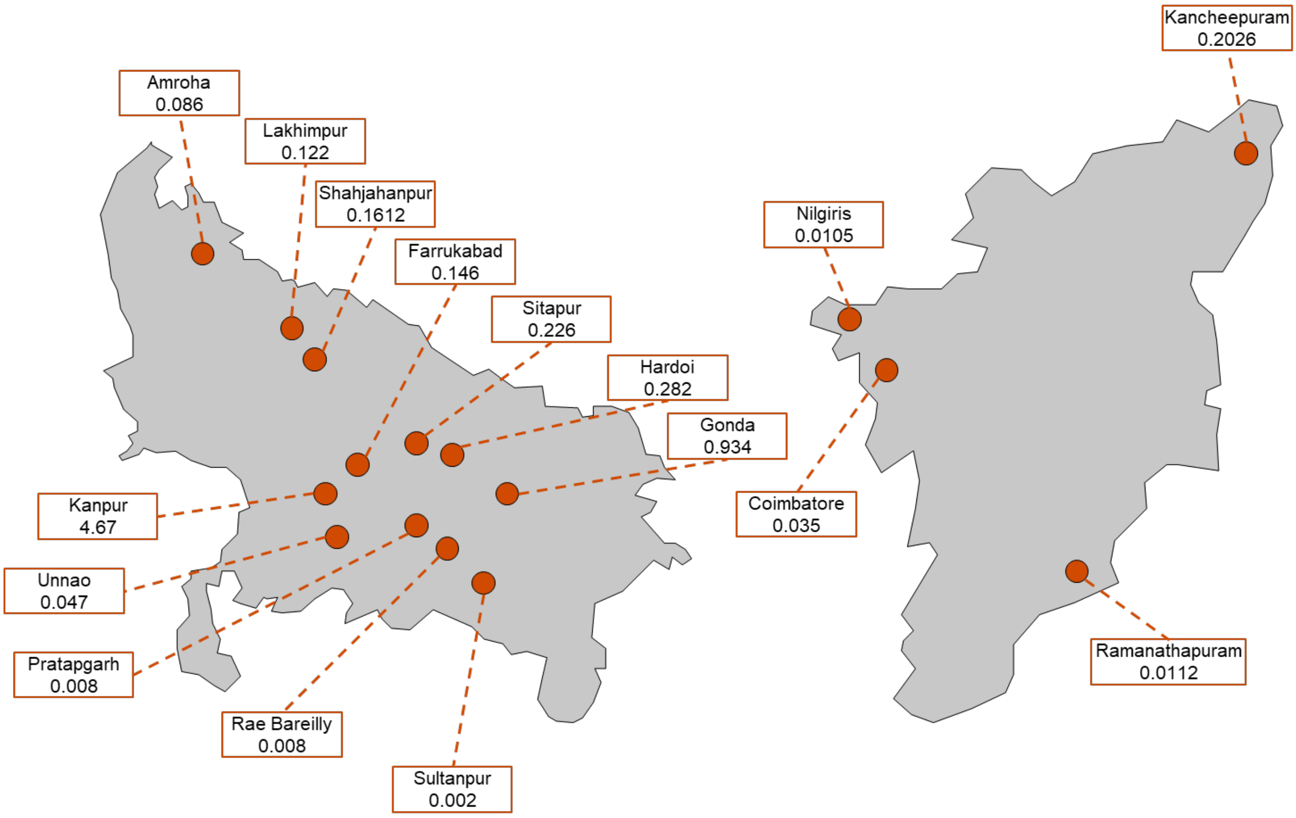
Hydrogen demand from Telecom Tower Backup Systems for Uttar Pradesh and Tamil Nadu (2023)

| State | Uttar Pradesh | | Tamil Nadu |
|---|---|---|---|
| Average power outage (in hours per day) | 8 | 4 | 1 |
| Hydrogen demand (in KT) | 82.74 | 41.37 | 7.19 |

Source: CEEW, Internal Analysis

**Remote Villages:** Government data suggests that every household in Uttar Pradesh and Tamil Nadu has been electrified via grid connectivity, or installation of diesel generators, or micro-grids. However, it has been observed through various industry sources that the consistent electricity supply is still limited in remote villages (at least in terms of duration of electricity supplied). We identified such remote villages that can be powered through a hybrid model of solar microgrid coupled with hydrogen backup system. After collating the data of remote villages, two scenarios of fuel cell-based power back-up have been considered – 8 hours backup and 16 hours backup. Solar micro grids have been assumed to simultaneously (a) supply energy to produce hydrogen and (b) electrify households during day times. The hourly household electricity requirement has been determined for each village to arrive at hydrogen needed. Based on the analysis for Uttar Pradesh, hydrogen demand has been estimated to be approx. 3.37 KTPA and 6.75 KTPA for 8-hour and 16-hour scenarios respectively. For Tamil Nadu, hydrogen demand has been estimated to be approx. 0.13 KTPA and 0.26 KTPA for 8-hour and 16-hour scenarios respectively.

Hydrogen demand for Uttar Pradesh and Tamil Nadu (16 hours of power backup) in KTPA (2023)



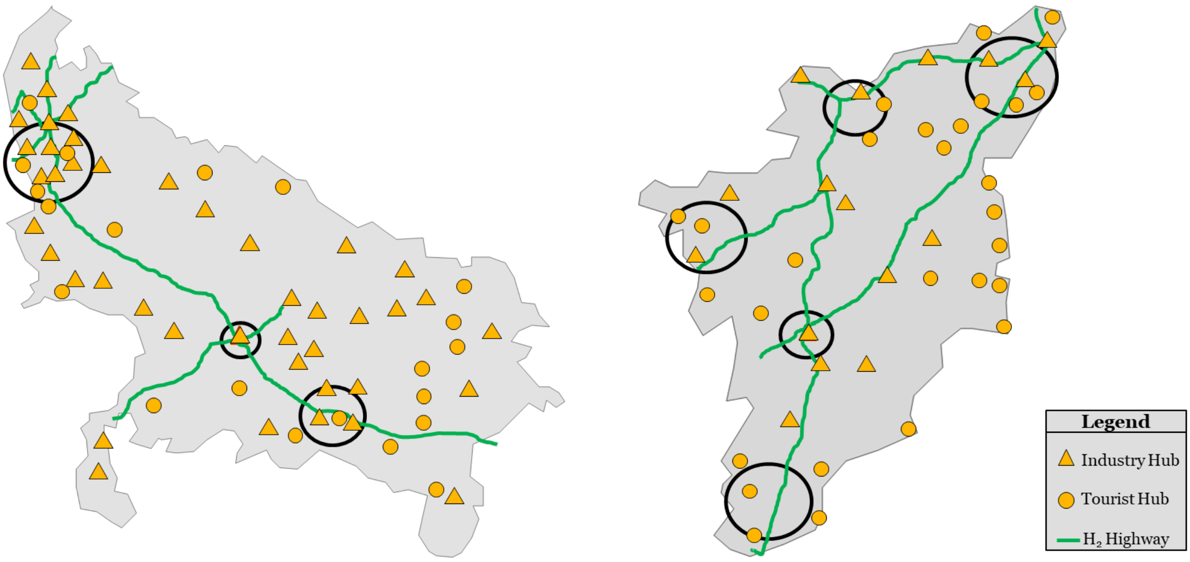

Source: Internal Research and Analysis

## Hydrogen in Mobility

Heavy-duty mobility industry is focusing on using hydrogen as a power source, either in the form of fuel cell-based vehicles or internal combustion-based engines.[7] Thus, in relation to the potential of hydrogen in mobility, we analyzed the offtake potential in heavy duty mobility. We assessed the diesel consumption patterns of the HDVs in Uttar Pradesh and Tamil Nadu. Mileages of trucks and buses (in terms of diesel and hydrogen) have been used as basis to obtain the corresponding hydrogen demand. The consequent hydrogen potential for Uttar Pradesh and Tamil Nadu has been estimated to stand at 2,901 KT and 1,479 KT, respectively. Furthermore, the demand split for individual districts of both states has also been highlighted along with the routes of high offtake volumes.

7 Light duty vehicle segment is expected to be dominated by electric mobility.

Probable locations for Hydrogen Refueling Stations along high hydrogen volume routes




Source: Internal Research and Analysis

## Ammonia in the Power Sector

In India, a major portion of energy needs is being fulfilled by thermal power plants that run on coal. Coal-based electricity accounts for 75% of the electricity produced in the country.[8] Carbon reduction from coal-based power plants is a key challenge and hence usage of ammonia in suitable proportions can support in greening the grid without the need to decommission these power plants.[9] We assessed the potential of ammonia in power sector, particularly its use as a fuel for cofiring in coal-based power plants.[10] To estimate the demand potential of ammonia in the states of Uttar Pradesh and Tamil Nadu, a 20% (by energy value) ammonia co-firing has been assumed across the thermal power plants in the two states.[11] Consequently, the total ammonia demand potential for power generation has been estimated to be 2,104 KT and 3,686 KT for Tamil Nadu and Uttar Pradesh, respectively.

### *Ammonia in Maritime Shipping and Inland Waterways*

Next, we assessed the potential role of ammonia in maritime shipping and inland waterways.

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8 Ministry of Coal

9 Ministry of Power

10 NTPC and GE Power India have signed an MOU to test ammonia cofiring in coal-based power plants. Adani Power has also signed an MOU as a part of the "Indo-Japan Clean Energy Partnership" to conduct 20% ammonia-coal co-firing in Gujarat's Mundra power plant.

11 Industry Sources

**Shipping:** The shipping sector plays a pivotal role in the global economy enabling the transportation of more than 80% of the world's cargo. Currently, Heavy Fuel Oil (HFO) is the prevalent fuel of choice for ships due to its large availability and low cost. The International Convention for the Prevention of Pollution from Ships (MARPOL) has set several regulations to control and reduce pollution from ships. However, the industry is facing backlash over sustainability concerns and usage of fossil fuel-based options.[12] In this context, green ammonia has been touted as one of the potential fuel candidates for the decarbonization of the shipping industry. We assessed the 3 major ports along Tamil Nadu coastline. It has been observed that major bunkering activity takes place at the Chennai port. Hence, bunker fuel sales volume at Chennai has been observed to be 47 KT.[13] This corresponds to a latent ammonia demand potential of 126 KT.

**Inland Waterways:** With an aim to promote Inland Water Transport (IWT) in India, 111 waterways (including 5 existing and 106 new) have been declared as National Waterways (NWs) through the National Waterways Act, 2016. Through techno-economic feasibility and detailed project reports of NWs, only 25 NWs have been found to be viable for cargo/passenger movement.[14] Furthermore, among the 21 NWs proposed by the government in the states of Tamil Nadu and Uttar Pradesh, infrastructure developments and operations have only started on NW 1 (Uttar Pradesh) and NW 4 (flows via Tamil Nadu). To assess the ammonia potential in these waterways, we assessed the cargo movement in ton-km for both the NWs along with the fuel requirement to carry per ton cargo. The consequent ammonia demand is summarized below.[15]

Summary of Results for Inland Water Ways in TN and UP

| National Waterway | State of Interest Traversed | Length after completion (in km) | Tonne kms 2021-22 (In Lakh) | Ammonia Requirement (in KT) |
|---|---|---|---|---|
| NW 1 | Uttar Pradesh | 1,620 | 20,082 | 21.05 |
| NW 2 | Tamil Nadu | 2,816 | 316 | 0.33 |

Source: Ministry of Ports, Shipping and Waterways

12 In June 2021, amendments to MARPOL Annex VI were adopted that require ships to reduce their greenhouse gas emissions. (Source: International Maritime Organization)

13 Internal Research

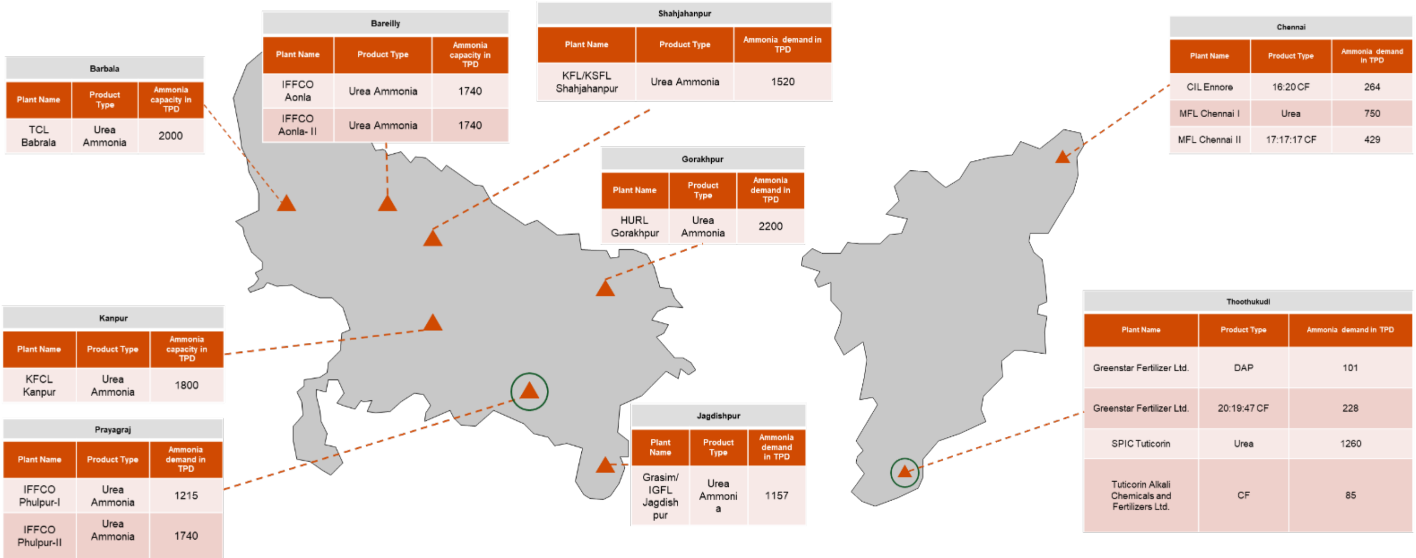
14 Ministry of Ports, Shipping and Waterways

15 The demand calculated above for maritime shipping and inland waterways indicates the potential that exists within the sector, and which is not necessarily expected to be realized till 2030 due to techno-commercial limitations.

### *Ammonia in Fertilizer plants of Uttar Pradesh and Tamil Nadu*

We also assessed the ammonia requirement within the fertilizer plants of Tamil Nadu and Uttar Pradesh. In the state of Uttar Pradesh, there are a total of 9 operational fertilizer plants, all being urea, with a combined ammonia capacity of 15,112 TPD.

Ammonia capacities and demands in fertilizer plants present in Uttar Pradesh and Tamil Nadu




Source: Industry Sources, Company Websites, Internal Analysis

Likewise, in the state of Tamil Nadu, there are a total of 7 fertilizer plants which are involved in the manufacture of Urea, DAP and other complex fertilizers, having a combined capacity of 3,117 TPD. The plants which manufacture DAP or other complex fertilizers meet their ammonia requirement mostly through imports.

Focusing specifically about the cluster in Thoothukudi in Tamil Nadu, all the fertilizer plants are located adjacent to each other within a radius of 2 km providing a potential case of green ammonia offtake for a decentralised setup. In this cluster, Tuticorin Alkali Chemicals and Fertilizer which also manufactures Soda ash, requires ammonia as a raw material.[16] Soda ash is later sold to the FMCG industry for the manufacturing of detergents and soaps.

Furthermore, we also highlighted the potential role of green ammonia in reducing the specific energy consumption for meeting Target Energy Norms (TEN) and reducing natural gas consumption in urea production. A set of policy measures was also highlighted that may drive up green ammonia offtake.

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16 Tuticorin Alkali Chemicals and Fertilizer

It is to be highlighted that the use of green ammonia in urea faces a challenge as urea requires CO2 as a feedstock for production. CO2 required is produced as a byproduct of the SMR process while the production of grey hydrogen. As during green urea production grey hydrogen is replaced by green hydrogen, a concomitant shortfall of this byproduct CO2 is expected. This can be mitigated by sourcing CO2 from nearby emitting industries.

### *Hydrogen in Refineries of Uttar Pradesh and Tamil Nadu*

Based on the Hydrogen Generation Unit capacities and utilization, the cumulative consumption of hydrogen in 3 refineries present in Uttar Pradesh and Tamil Nadu was estimated to be approx. 204 KT.

### *Hydrogen in the Glass Sector*

In India, almost 75% of the total glass industry is concentrated in Uttar Pradesh, Maharashtra, Gujarat, Karnataka and Andhra Pradesh with Uttar Pradesh having the highest share at 36.9% while Tamil Nadu has a share of 5.6%.[17] The majority of the energy consumption within the industry, i.e., about 99%, is thermal. Natural gas is the most commonly used fuel which is combusted to provide the required thermal power to heat and melt the glass.

Worldwide, glass manufacturing produces at least 86 million tonnes of carbon dioxide every year.[18] In glass production, the most energy intensive process step is the melting furnace section which runs continuously without pause, from its commissioning to final shut-down. The heat required for glass manufacturing, which comes from natural gas, accounts for between 75% and 85% of the carbon emissions from glass manufacturing.[19] Due to the rising sustainability concerns and increased focus to the usage of green fuels to curb carbon emissions, interest is being shown to employ hydrogen blending to supply the required thermal energy and reduce the GHG emissions from the energy intensive glass sector. [20]

To assess the hydrogen potential in the sector, a 20% v/v blending has been assumed and the subsequent energy requirement in kWh/year has been calculated. Consequently, the hydrogen demand which can potentially replace the existing fuel sources used to meet the thermal power requirement for glass melting operations and in-house electricity generation for major glass production centers in Uttar Pradesh and Tamil Nadu has been

17 Ministry of MSME

18 Nature

19 Nature

20 In addition to use in melting furnace, green hydrogen may also potentially find use in (a) batch pre-heating, (b) glass forming (to stop oxidation), and (c) annealing.

estimated. The corresponding hydrogen demand for 20% blending in furnaces for fuel applications has been calculated to be approx. 9.73 KTPA for the Firozabad glass cluster in Uttar Pradesh and 0.78 KTPA for Tamil Nadu.

### *Demand Consolidation for Tamil Nadu and Uttar Pradesh*

A consolidated summary of the demand potential in the states of Tamil Nadu and Uttar Pradesh has been presented below, showcasing the presence of various centralized and distributed industries across the two states.

Consolidated Consumption/ Demand Potential for Tamil Nadu and Uttar Pradesh (2023)

| Parameter | Tamil Nadu (in KT/ Year) | Uttar Pradesh (in KT/ Year) |
|---|---|---|
| Hydrogen in Power Sector: Backup for Hospitals | 0.47 | 6.77 |
| Hydrogen in Power Sector: Backup for Telecom Tower | 7.19 | 82.74 |
| Hydrogen in Power Sector: Decentralised Power in Villages | 0.26 | 6.75 |
| Hydrogen in Mobility | 1,479 | 2,901 |
| Ammonia in the Power Sector | 2,104 | 3,686 |
| Ammonia in Fertilizers | 551 | 949 |
| Ammonia for In-land Waterways | 0.33 | 21.5 |
| Hydrogen in Glass | 0.78 | 9.73 |

Source: Internal Research and Analysis

## Energy and Climate Related Supportive Policies

Post completion of the demand estimation, the policy landscape of India in relation to development of green hydrogen sector has been reviewed in Chapter 2. A discussion on the risks associated with the green hydrogen sector has also been undertaken in this chapter.

## Review of policies and incentives

We reviewed the National Green Hydrogen Mission and the associated subsidies and incentives in the form of the SIGHT programme. The Strategic Interventions for Green Hydrogen Transition (SIGHT) programme is a major financial part of the mission with an outlay of INR 17,490 Crores up to FY29-30. The programme proposes two distinct financial incentive mechanisms to support the domestic manufacturing of electrolysers and the production of green hydrogen. Specifically for green ammonia, direct incentives of INR 8.82/kg in the first year, INR 7.06/kg in the second year, and INR 5.30/kg in the third year are expected to be provided from the commencement of green ammonia production and supply. These incentives are aimed to enable rapid scale-up, technology development, and cost reduction of green hydrogen by 2030. Moreover, we assessed the state policies and studied the incentives and obligations therein for green hydrogen adoption. For the same purpose, a total of 10 states were studied. In addition to studying the soft infrastructure for with green hydrogen development, other decarbonization driving levers provided by Tamil Nadu and Uttar Pradesh have also been reviewed. This included studying the industrial, renewable, and bioenergy policies of these states.

Tamil Nadu has categorized hydrogen as a sunrise sector and is eligible for the associated sunrise sector incentives. Also, among other incentives, the sector is eligible for land subsidies and interest subvention of 5% (as a rebate in the rate of interest). In Uttar Pradesh currently 10% blending of Green Urea has been mandated in the state's Urea production. Also, the state intends to promote the blending of green hydrogen with grey hydrogen in existing N-fertilizers and refineries, achieving at least 20% of green hydrogen in the consumption mix by 2028 and 100% by 2035. Exemptions from wheeling charges, cross subsidy surcharges, and distribution charges have been announced, along with other incentives. Furthermore, an additional subsidy of INR 3,500 per tonne of urea has been announced for every extra tonne of green urea produced in the state beyond the announced 10% blending mandate.

## Risk assessment

Chapter 2 concluded with a qualitative discussion on risks associated with the green hydrogen sector. We undertook a high-level risk assessment and highlighted offtake risks, technology risks, safety risks, fiscal risks, and supply chain risks. Impact of renewables on power grid stability has also been briefly discussed.

The implementation of green hydrogen and green ammonia presents a series of risks that can impact their integration into the energy landscape. Key concerns revolve around the cost-intensive nature of production, limited incentivization mechanisms, and the intricate interplay with existing industries and governmental policies. A few of the key risks are highlighted below:

**Offtake Risks:** The high production costs of green hydrogen and green ammonia pose a challenge for widespread adoption, especially without substantial incentives to balance the additional expenses. Existing industries, particularly the heavily subsidized fertilizer sector in India, may resist the added financial burden without adequate governmental support. A lack of guaranteed offtake can further increase risks for developers.

**Technology Risks:** Current inefficiencies in energy conversion and storage limit the scalability of green hydrogen projects. The energy-intensive production process, coupled with efficiency losses, renders these solutions economically challenging in some sectors, especially where clean alternatives like battery technologies exist, for example in passenger mobility.

**Raw Material Availability:** Dependence on renewable energy and water for production poses risks, particularly in regions with water scarcity. Ensuring sustainable sourcing and usage practices for these raw materials becomes crucial for large-scale production.

**Safety Concerns:** Hydrogen's flammable nature demands stringent safety measures in handling, storage, and transportation. Also, there are challenges in infrastructure development and maintenance, for example in the natural gas grid where the use of hydrogen can cause metal embrittlement.

**Supply Chain Risks:** Reliance on imported electrolyser technology, fluctuations in critical metal prices, inadequate infrastructure, and scarcity of skilled manpower contribute to supply chain vulnerabilities, potentially causing delays and cost escalations in project development.

**Grid Stability:** The heavy reliance on intermittent renewable energy sources for production can impact grid stability, necessitating significant investments in energy storage and grid management techniques to balance supply and demand, adding to overall integration costs.

**Fiscal Risks:** Limited government support may create uncertainties, deterring potential investors and hindering sustained industry growth. Dependence on subsidies without a clear long-term vision risks destabilizing the sector. The allocation of subsidies to support the development of green hydrogen and green ammonia sectors can raise concerns about the opportunity cost of investing in emerging technologies over more immediate societal needs such as healthcare, education and poverty alleviation.

Navigating these multifaceted risks is expected to require a concerted effort from stakeholders to address technological limitations, establish supportive policies, enhance safety protocols, secure supply chains, and strategize for sustainable growth amidst evolving market dynamics.

## Willingness-to-Pay Analysis

Chapter 3 assessed the willingness of various sectors to incorporate green hydrogen and green ammonia in their operations. This included the willingness to pay analysis for green ammonia offtake in industry, green hydrogen offtake for power applications, and use of green hydrogen in mobility as discussed next.

### Fertilizer and downstream industry

Green ammonia can become a driver to reduce the dependence of India on ammonia imports, particularly for use in DAP and other complex fertilizer production. This, however, needs to become feasible from a pricing perspective. Currently, green ammonia production costs are higher (USD 900 per tonne to USD 1,250 per tonne), making it economically less viable without adequate reimbursement mechanisms. Furthermore, the absence of such a mechanism to compensate for the cost difference between green and grey ammonia is the major deterrent to the players that may intend on using green ammonia. This is particularly true if offtake is not mandated by the Government. Therefore, the willingness to pay for green ammonia in the Indian fertilizer industry hinges on the resolution of critical challenges, particularly the cost gap between green and grey ammonia.

In the context of the soda ash industry, replacing grey ammonia with green ammonia can help companies in this domain market their soda ash as "green" soda ash. This has the potential to enable these companies to fetch a premium in the market for sustainable sourcing. It is to be noted, however, that the usage of "green" chemicals in the FMCG industry is a relatively new but growing trend, with limited suppliers providing such products. In the long run, it is expected that a market pull is generated from various consuming industries (FMCG, chemicals, fertilizers, etc.) as they proceed to adopt sustainable sourcing practices to meet their sustainability targets. Also, to promote the widespread adoption of green ammonia, advancements in technology, policy revisions, development of reimbursement mechanisms, and government support are vital.

### Power

With regards to power in hospitals, the volatility in the costs of fossil fuels due to recent geopolitical developments has led to the skyrocketing of operational expenses, particularly that of backup power applications. In order to ensure that healthcare remains affordable and accessible to the general public and that rising costs do not trickle down to patients, several initiatives are being undertaken by the healthcare industry in India. The adoption of energy efficient processes is at the forefront of company and ministerial agendas, with energy audit studies conducted suggesting high energy saving potential.[21] Hospitals in particular are exploring innovative energy models which are reliable and cost-effective. Green hydrogen based CHP, in the long run, may help drive down costs of energy as it has advantages over pure RE sources, like that of low-intermittency. A key bottleneck here, however, is the lack of investors and developers, as most businesses go for options enabling higher and faster profitability. To understand this, an analysis has been undertaken to ascertain the unit cost to produce electricity through diesel gensets and hydrogen fuel cells for backup power applications for 2023 and 2030. Different scenarios of green hydrogen prices have been considered and the subsequent costs of electricity have been evaluated. Estimates show that the incorporation of green hydrogen-based fuel cells may lead to an additional cost burden in the range of approx. INR 7 – INR 25 per kWh in 2023. Furthermore, a role reversal favoring green hydrogen based CHP systems may happen in 2030, wherein the cost differential between green hydrogen and DG sets is expected to be around INR 5 – INR 24 per kWh. This is expected to be driven by the decrease in green hydrogen prices, improvement in fuel cell stack lifetimes and costs, and an increase in diesel costs. For telecom towers and remote villages, the incorporation of green hydrogen-based power indicated a similar propensity as that of hospitals at present and in 2030.

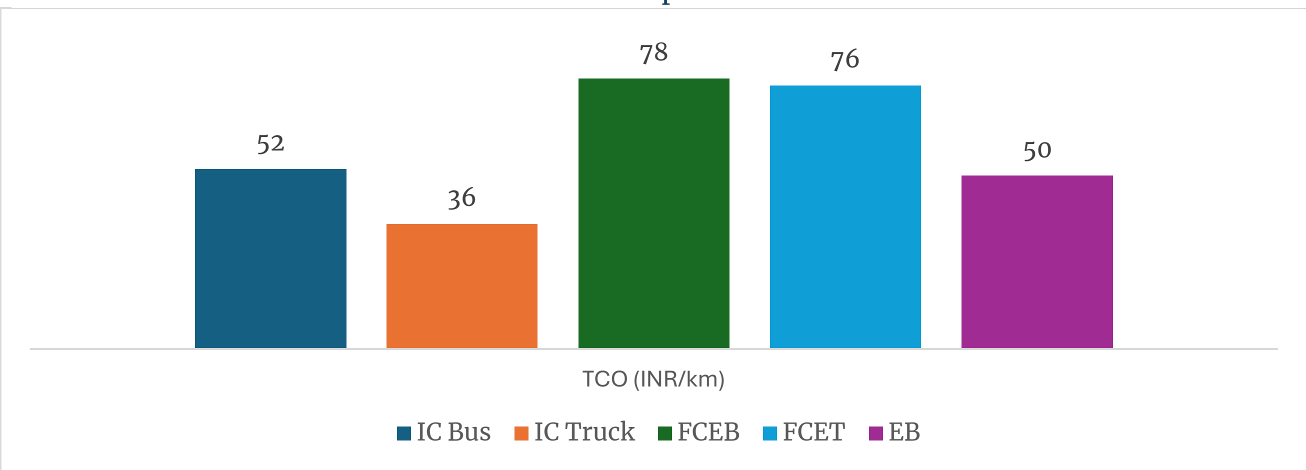
## Mobility

Chapter 2 concluded with an affordability analysis of the mobility sector. As highlighted earlier, the present study focuses specifically on the heavy-duty transport sector (trucks and buses). Hydrogen mobility is more suited for replacing heavy-duty internal combustion engine vehicles and is likely to take up the space once technology attains commercial maturity. Although BEVs have a higher adoption today, this adoption is limited to the Passenger Vehicles (PV) segment. For BEVs in in intensive and long-range travel segment, high energy requirement increases the battery mass, reduces the available space for cargo/ passenger volume in the vehicle, and increase the cost and energy consumption of the vehicle. Therefore, for heavy duty and long-haul mobility, hydrogen trucks and buses are expected to be a suitable alternative. This is due to the fact that, hydrogen tanks take up less space and are lighter than batteries, allowing more available volume for passenger or cargo transport and better potential cost economics in the long run.

21 CII Report on Energy Efficient Hospitals

However, due to the present high upfront costs of hydrogen vehicles and high green hydrogen costs, the sector faces limited adoption rates at present.[22] A Total Cost of Ownership (TCO) analysis for 2023 has been undertaken to compare different vehicles and understand the cost barrier associated with hydrogen-based mobility which showcases the the high costs associated with green hydrogen mobility. Therefore, large fleet owners in India are more likely to be early adopters to establish the financial and commercial viability of hydrogen powered mobility in heavy duty/ long haul mobility segment.[23] For buses, specifically, different state governments might plan or are already planning on introducing intra-city transport buses into their public transport fleet.[24] Hydrogen buses in intracity public transport are expected to be the likely initiator to establish the feasibility of the technology on Indian roads. These buses are not expected to face the challenge of the availability of hydrogen refuelling stations as ideally, all buses within a location would refuel at a single point.[25] It appears less likely that individual players would be the first adopters of fuel cell-based trucks and buses primarily due to exorbitant upfront costs.

Extant Total Cost of Ownership for different vehicle sections




Source: Internal Analysis

22 Cost of a fuel cell bus at present is more than INR 2.5 Crore.

23 Industry Sources

24 Kerala and Leh-Ladakh are two such regions.

25 Journal of Applied Sciences

## Transportation of Hydrogen and Ammonia

In this chapter, various pathways of transportation like pipelines, gaseous and liquid hydrogen trailers, and transportation as ammonia were elucidated. Furthermore, CAPEX associated with various modes of transportation, as estimated by IEA and other reputed agencies, was also highlighted.

Transportation of hydrogen via pipeline is expected to be viable for distances under 1,900 km. and for longer distances, pipeline transportation in the form of ammonia is expected to be cost effective.[26] Furthermore, transportation of gaseous hydrogen is cost economic if it is transported in quantities less than 50 tonnes per day (TPD) for a distance under 250 km. Quantities are as low as 5 TPD and distances under 500 km are cost effectively catered via gaseous hydrogen transportation route. Likewise, transportation of liquid hydrogen is cost economic if it is transported in quantities greater than 50 tonnes per day (TPD) for a distance above 250 km. For quantities within the range of 5 TPD, distances above 500 km are cost effective to be catered to by liquid hydrogen.[27] For larger quantities and distances in the range of 1000 km, transporting hydrogen as ammonia becomes economically feasible.[28] However, the benefit of ammonia as the carrier is highest when it is not to be reconverted to hydrogen at the eventual destination of consumption and is to be consumed directly as ammonia. Otherwise, the reconversion losses at the point of delivery pose a challenge to ammonia as a modality for hydrogen transport.

## Commercial Pre-feasibility of Decentralised Green Ammonia

Chapter 5 assesses the commercial pre-feasibility of a decentralised green ammonia plant.[29] The levelized costs of green hydrogen (LCOH) for a plant corresponding to a 300 TPD plant ammonia have been estimated for both alkaline and PEM electrolyser technologies and are tabulated below:

26 Ammonia: zero-carbon fertiliser, fuel and energy store - The Royal Society (2020)
27 Linde
28 Ammonia: zero-carbon fertiliser, fuel and energy store - The Royal Society (2020)
29 The viability of 50 TPD and 300 TPD plants has been assessed. Comparatively, the TIC of a 300 TPD plant has been discovered to be same as that of a 50 TPD plant. The reason being that the costs associated with critical components, while scaling down from 300 TPD to 50 TPD configuration, do not show significant reductions. Therefore, the TIC comes to be approximately same for both the configurations. Therefore, the overall commercial viability of 50 TPD plant has been estimated to be lower due to the high Total Installation Costs. Consequently, in this chapter, an analysis for 300 TPD configuration has been showcased and the analysis for the 50 TPD configuration has been annexed.

Levelized Cost of Hydrogen (LCOH) Estimates (for 2023)

| Electrolyser Technology | Cost USD per kg hydrogen |
|---|---|
| PEM | 4.90 |
| Alkaline | 4.81 |

Source: Internal Analysis

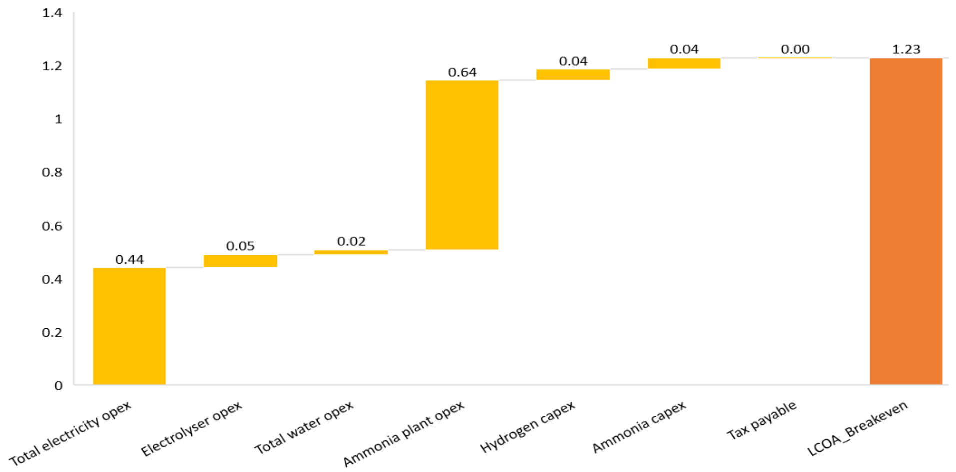
For the LCOHs specified above, the levelized cost of ammonia for a plant of capacity 300 TPD ammonia is:

Levelized Cost of Ammonia (LCOA) Estimates for a 300 TPD ammonia facility (for 2023)

| Electrolyser Technology | Cost USD per kg ammonia |
|---|---|
| PEM | 1.24 |
| Alkaline | 1.23 |

Source: Internal Analysis

LCOA in USD per kg of green ammonia using alkaline electrolyser technology for green hydrogen




Source: Internal Analysis

Furthermore, a sensitivity analysis has been undertaken to assess the dependence of LCOA on various parameters. The results for alkaline electrolyser case are tabulated below:

Impact of various parameters on LCOA

| Parameter | -20% | -10% | 0% | +10% | +20% |
|---|---|---|---|---|---|
| CAPEX sensitivity | 1.152 | 1.152 | 1.227 | 1.257 | 1.304 |
| OPEX sensitivity | 0.911 | 1.058 | 1.227 | 1.410 | 1.607 |

| | | | | | |
|---|---|---|---|---|---|
| Electrolyser efficiency | 1.444 | 1.325 | 1.227 | 1.153 | 1.152 |
| Electricity costs | 1.099 | 1.163 | 1.227 | 1.291 | 1.355 |

Source: Internal Analysis

Impact on LCOA by varying rate of interest

| Rate of Interest | 6% | 7% | 8% | 9% | 10% | 11% | 12% |
|---|---|---|---|---|---|---|---|
| **LCOA (USD/kg)** | 1.175 | 1.192 | 1.209 | 1.227 | 1.245 | 1.263 | 1.282 |

Source: Internal Analysis

As evident from the tables above, LCOA has been observed to be most sensitive to electricity costs which form a part of operational expenses in the case considered herein.

With time, it is expected that the fossil fuel costs would keep rising owing to an increased focus on taxing carbon. Likewise, the costs associated with producing green ammonia/ green hydrogen are expected to reduce as economies of scale are achieved, along with higher efficiencies, and domestic manufacturing of equipment. An additional thrust is expected to be provided by a widespread acceptance owing to green ammonia/ hydrogen's sustainable low-carbon nature. This acceptance is also likely to be complemented by a strong government support in the form of incentives and provisions which together can play a synergistic role in the growth of the sector in India.

# 1 Market Assessment of Ammonia

## Introduction

India, being one of the fastest growing economies, has emerged as a key player in the global energy sector. The continuous industrialization and urbanization have led to an increase in the country's energy demands. This has motivated India to increase its energy supplies through new energy policies and regulations. Presently, almost 80% of the country's energy demands are fulfilled by coal, oil, and solid biomass with renewable sources starting to gain momentum in the country's energy mix. In 2022, India took a proactive step in advancing its 2070 net zero objectives by updating its Nationally Determined Contribution (NDC) under the Paris Agreement where a key aspect of the updated NDCs is the target of meeting 50% of the cumulative installed capacity of electric power from non-fossil sources by 2030.[30]

Such an influx of clean energy can become an enabler of green hydrogen (and by extension green ammonia) introduction to various sectors in India. As the National Green Hydrogen Mission puts green hydrogen at par with renewable energy in terms of meeting Renewable Power Obligations, green hydrogen / green ammonia production is no more a second fiddle to RE. So, the lowering of green hydrogen and ammonia production costs can help their deployment in sectors where electricity can offer limited benefits due to storage or process limitations.

This market report aims to assess the demand of ammonia first at a pan India level followed by a deep dive into state specifics for Uttar Pradesh and Tamil Nadu. This demand assessment is further complimented by assessment of the commercial regime under which ammonia operates. Later, assessment of policies and incentives have been undertaken to gauge the support that the sector has at national and state levels. Furthermore, to have an understanding at how the industry views the sector, a willingness to pay analysis has been undertaken. The market study is concluded with a risk analysis (covering the risks that green hydrogen/ ammonia projects carry) and an assessment of the costs of molecule transportation.

30 PIB

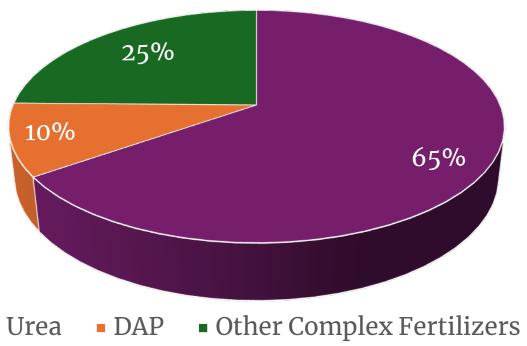
# 1.1 Ammonia demand and supply in India

## 1.1.1 Use of ammonia in fertilizer sector

India being an agricultural nation, depends vastly on fertilizer consumption to maintain the fertility of land. The country as of date has 29 major fertilizer companies that produce Urea, Di-ammonium phosphate (DAP), and other NPK complex fertilizers (Complex Fertilizers).

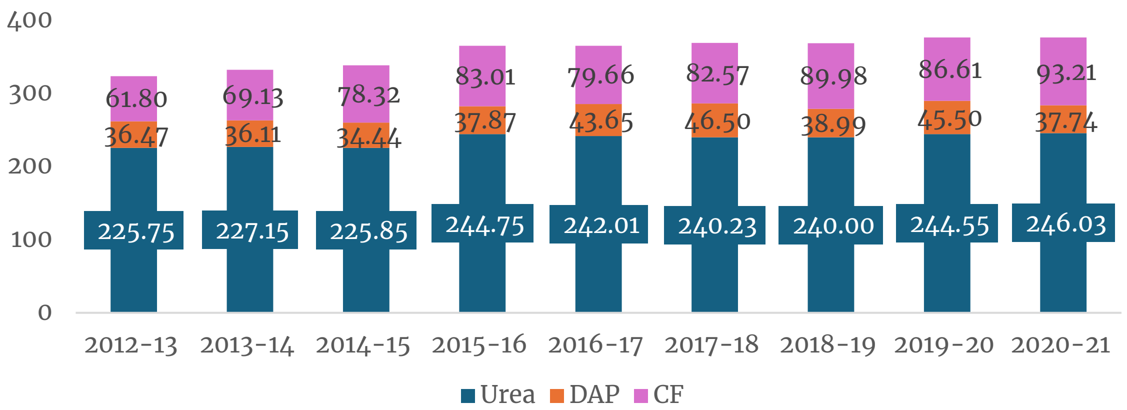
In FY21, India produced approx. 37.7 MMT of fertilizers – 24.6 MMT urea, 3.77 MMT DAP, and 9.32 MMT other complex fertilizers.[31] Given the expected growth of the population, the subsequent fertilizer demand is also expected to increase. Furthermore, Indian fertilizer market is dominated by the use of urea. Although all fertilizers are subsidized, the extent of subsidy from the government for urea production is much more.

Figure 1: Proportions of urea, DAP, and complex fertilizers




Source: Department of Fertilizers, Internal Analysis

Figure 2: India's Y-o-Y production of fertilizers (Urea, DAP, CF) – (in 10^5 Metric Tonnes)



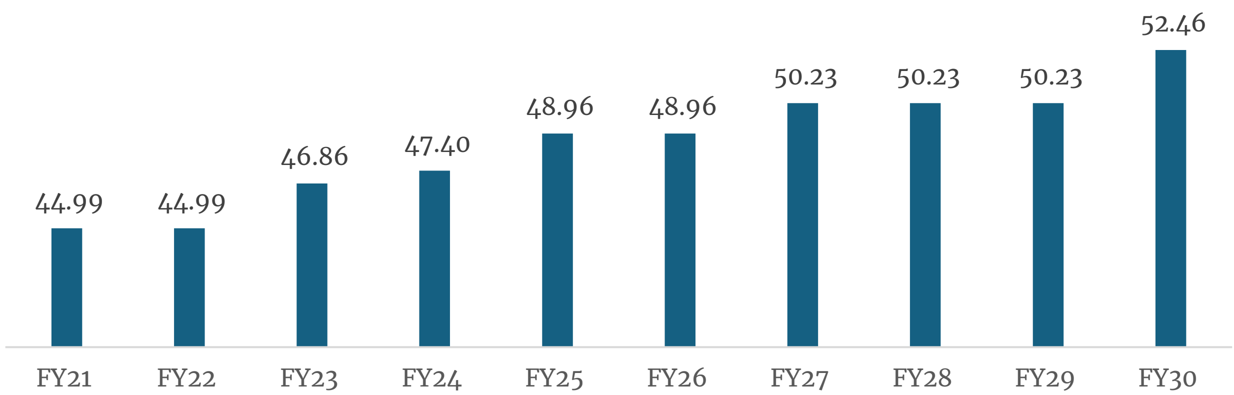

Source: Department of Fertilizers, Internal Analysis

31 NPK or complex fertilizers have varying Nitrogen, Phosphorous, and Potassium ratios. Note that DAP is also a complex fertilizer

# Fertilizer Players in India

The ownership of fertilizer plants can be grouped into 3 major categories – public (owned by Government), cooperative (owned by both public and private players), and private (owned in entirety by private players). To assess India's fertilizer sector, capacities of all the existing plants have been considered alongside their capacity expansion plans using publicly available data from Department of Fertilizers, annual reports, and investor presentations. We have also considered the greenfield expansions of existing players in the analysis. In case the year of commissioning of the brownfield or greenfield expansion is not known, know-how of the fertilizer sector has been used to assign the potential year of commissioning.

Figure 3: Expected growth of fertilizer capacities in India (MMT)




Source: Department of Fertilizers, Company Annual Reports, Company Investor Presentations

Table 1: Fertilizer players in India and associated installed capacities

| Sl. | Company | Type of fertilizer produced | Total Installed/ reassessed capacity (MMT) |
|---|---|---|---|
| 1. | Indian Farmers Fertilizer Cooperative Ltd. (IFFCO) | All | 8.0 |
| 2. | Hindustan Urvarak & Rasayan Ltd. (HURL) | Urea | 3.8 |
| 3. | National Fertilizers Ltd. (NFL) | Urea | 3.6 |
| 4. | Coromandel International Ltd. (CIL) | CF | 3.2 |
| 5. | Chambal Fertilizers and Chemicals Ltd. (CFCL) Gadepan | Urea | 3.0 |
| 6. | Rashtriya Chemicals & Fertilizers Ltd. (RCF) | All | 2.7 |
| 7. | Krishak Bharati Cooperative Ltd. (KRIBHCO); Hazira | Urea | 2.6 |

| | | | |
|---|---|---|---|
| 8. | Gujarat State Fertilizers & Chemicals Ltd. (GSFC) | All | 1.7 |
| 9. | Madras Fertilizers Ltd. (MFL) Chennai | All | 1.3 |
| 10. | Matix Fertilizers and Chemicals Ltd. (MFCL) | Urea | 1.3 |
| 11. | Ramagundam Fertilizers and Chemicals Ltd. (RCFL) | Urea | 1.3 |
| 12. | Paradeep Phosphates Ltd. Paradeep | DAP | 1.2 |
| 13. | Nagarjuna Fertilizers and Chemicals Ltd. (NFCL) Kakinada | Urea | 1.2 |
| 14. | Zuari Agro Chemicals Ltd. (ZACL) Goa | All | 1.2 |
| 15. | Grasim/Indo Gulf Fertilizer Ltd.; Jagdishpur | Urea | 0.9 |
| 16. | Tata Chemicals Ltd. /Yara (TCL/Yara): Barbala | Urea | 0.9 |
| 17. | Fertilizers and Chemicals Travancore Ltd. (FACT) | Other CF | 0.9 |
| 18. | Tata Chemicals Ltd. (TCL) Haldia | CF | 0.8 |
| 19. | Gujarat Narmada Valley Fertilizers & Chemicals Limited (GNFC); Bharuch | All | 0.8 |
| 20. | Kanpur Fertilizer & Cements Ltd. (KFCL); Kanpur | Urea | 0.7 |
| 21. | Mangalore Chemicals & Fertilizers Ltd. (MCFL) Mangalore | All | 0.6 |
| 22. | Southern Petrochemical Industries Corporation (SPIC); Tuticorin | Urea | 0.6 |
| 23. | Greenstar Fertilizer Ltd. | CF | 0.6 |
| 24. | Deepak Fertilizers and Chemicals Ltd. (DFCL) / Smartchem; Taloja | Other CF | 0.6 |
| 25. | Brahmaputra Valley Fertilizer Corporation Ltd. (BVFCL) | Urea | 0.6 |
| 26. | Hindalco Dahej | DAP | 0.4 |
| 27. | Shriram Fertilizers & Chemicals (SFC); Kota | Urea | 0.4 |

| | | | |
|---|---|---|---|
| 28. | Coromandel Fertilizers Limited (CFL) Ennore | Other CF | 0.3 |
| 29. | Madhya Bharat Agro | CF | 0.1 |
| | Total | All | 45.1 |

Source: Department of Fertilizers

Furthermore, the following observations have been made for various fertilizer companies in India.

| Sl. No. | Company | Observations |
|---|---|---|
| 1. | Indian Farmers Fertilizer Cooperative Ltd. (IFFCO) | IFFCO Paradeep (CF) is expected to be expanded to 3.0 MMT from existing 1.920 MMT by 2030 |
| 2. | Hindustan Urvarak & Rasayan Ltd. (HURL) | Revived under the revival process of closed fertilizer plants of FCIL and HFCL |
| 3. | National Fertilizers Ltd. (NFL) | All NFL plants run at high-capacity utilization (~110%). Nano Urea Plant addition is expected to be finished by FY25. NFL signed an MoU with NTPC-REL to collaborate in the field of renewable energy and Green Ammonia. According to MoU, NTPC will supply 90 MW RTC power to synthesize 50 TPD Green Ammonia for captive use and production of industrial products by NFL |
| 4. | Coromandel International Ltd. (CIL) | 400,000 TPA sulfuric plant exists in Coromandel Vizag to support a 1.23 MMT CF plant. An additional 500,000 TPA plant is to be installed to reduce import dependence of Sulphuric acid |
| 5. | Rashtriya Chemicals & Fertilizers Ltd. (RCF) | A JV company named Talcher Fert. Ltd. (TFL) (in Talcher Orissa) was incorporated with equity participation of 31.85% each by GAIL, RCF, CIL and 4.45 % by FCIL for setting up gas-based urea plant of 1.27 MMTPA urea capacity. It is expected to be commissioned by September 2023 |
| 6. | Madras Fertilizers Ltd. (MFL) Chennai | MFL has planned to construct a new greenfield plant with an ammonia plant of 2200 MTPD and urea plant of 3500 MTPD. |
| 7. | Matix Fertilizers and Chemicals Ltd. (MFCL) | The plant in Durgapur, West Bengal was commissioned in 2021 |
| 8. | Ramagundam Fertilizers and Chemicals Ltd. (RCFL) | The Ramagundam plant was commissioned in 2021 |
| 9. | Zuari Agro Chemicals Ltd. (ZACL) Goa | Acquired recently by Paradeep Phosphates |
| 10. | Fertilizers and Chemicals Travancore Ltd. (FACT) | Plans to add 1650 MTPD FACTAMOS (which is a type of CF) at Cochin plant |
| 11. | Paradeep Phosphates Ltd. (PPL) | PPL Paradeep has a production capacity of 1.2 MMT DAP. Capacity in this plant is expected to increase to 1.8 MMT by 2022 |
| 12. | Mangalore Chemicals & | Urea expansion to 0.57 MMT and DAP to 1.4 MMT per |

| | | |
|---|---|---|
| | Fertilizers Ltd. (MCFL) Mangalore | environment clearance reports and publicly available data |
| 13. | Deepak Fertilizers and Chemicals Ltd. (DFCL) / Smartchem; Taloja | Present $NH_3$ demand at Taloja is 1.6 KT which is expected to increase to 2.2 KT by 2025. Therefore, 0.52 MMT greenfield $NH_3$ plant under construction to reduce import dependency of $NH_3$. CAGR of this ammonia requirement has been mapped to urea growth till 2025 |
| 14. | Brahmaputra Valley Fertilizer Corporation Ltd. (BVFCL) | 1.27 MMT brownfield ammonia-urea unit within the premises of BVFCL expected to be developed. The tentative overall time schedule for mechanical completion and commissioning of Namrup – IV Project is 36 months from Zero Date. RCF and NFL are also involved in the project |

Source: Secondary Research

# Ammonia consumption in fertilizer sector

Fertilizer sector is one of the major sectors of ammonia consumption in India. Fertilizer plants consume ammonia produced through Grey Hydrogen via Haber-Bosch process. Ammonia is an important feedstock for fertilizers like urea, DAP, and other Complex Fertilizers. Furthermore, production of urea requires Ammonia and $CO_2$ as feedstock. To produce a certain quantity of urea, the demand of $CO_2$ is met through $CO_2$ produced as a by-product in ammonia plant, in-situ within a fertilizer complex, by the Methane Reformation process. It has been observed that the natural gas being supplied to fertilizer plants has become lean in carbon content, now predominantly containing methane. This is because the gas being imported from the spot market first undergoes an extraction process to remove $C_2$ / $C_3$ / $C_4$ fractions before it is supplied to fertilizer plants. Hence, urea producers are required to operate ammonia plants at higher capacities than required to ensure availability of $CO_2$ for urea production. This has resulted in generation of surplus ammonia by Urea producers which gets sold in the market.

The complex fertilizer production facilities can adjust the proportion of Nitrogen, Phosphorous, and Potassium to produce CFs of various compositions as shown in the preceding table. For DAP and other complex fertilizers (CF), many of the Indian manufacturers meet the required ammonia demand through import of ammonia (e.g., Paradeep Phosphates, GSFC Sikka, among others). The import of ammonia for DAP and other CF makes commercial sense.[32]

Estimates of ammonia consumption per unit fertilizer production is given below:

32 Industry sources

Table 2: Ratios to convert a certain quantity of ammonia to fertilizer

| Entity | Ratio |
|---|---|
| Ammonia : Urea | **0.57** |
| Ammonia : DAP | **0.23** |
| Ammonia: Other CF [33] | **0.22** |
| Hydrogen: Ammonia | **0.1798** |

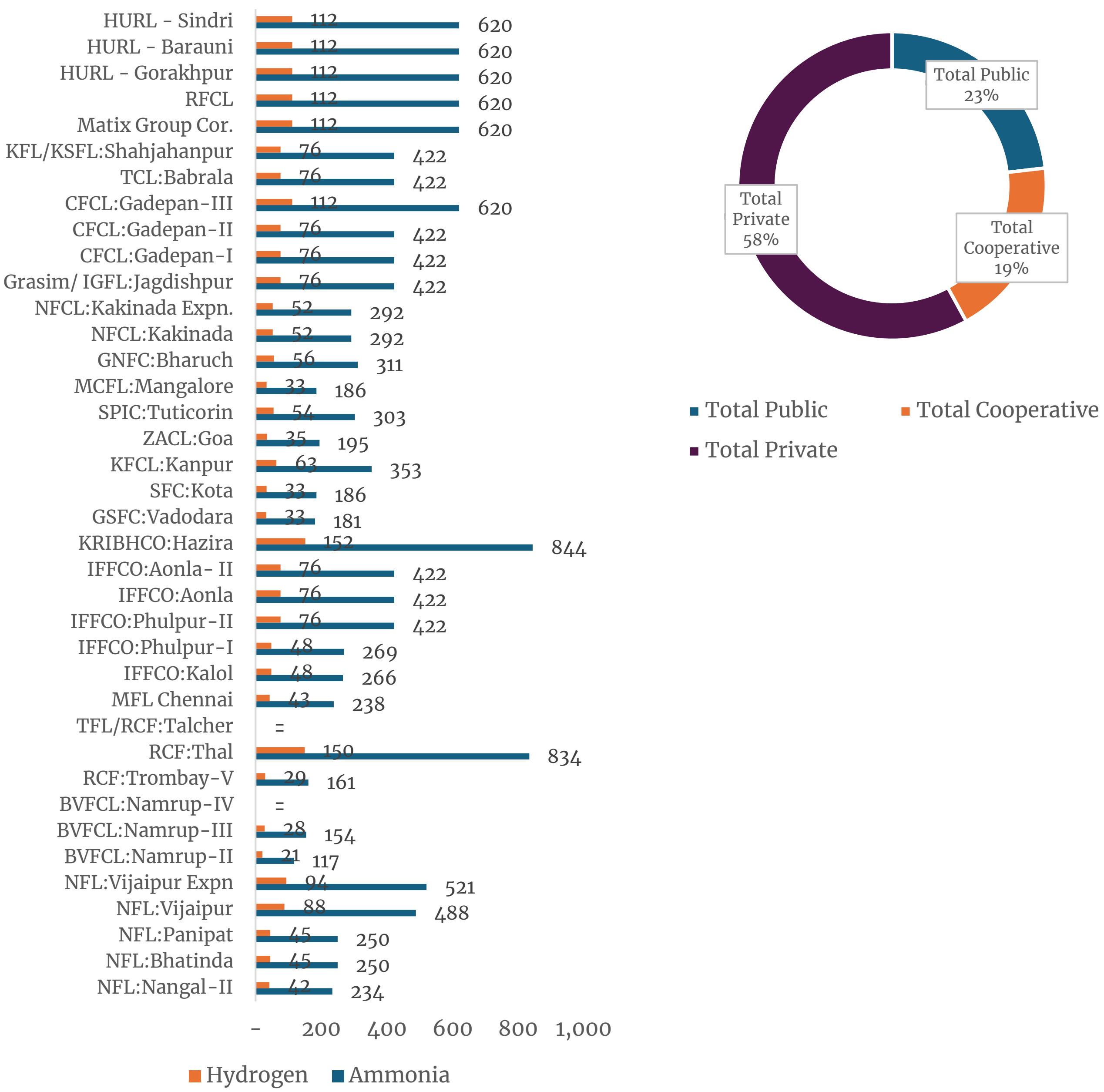
Source: Internal Research

33 Weighted average of capacities and NPK proportions has been considered

# Ammonia consumption in Urea

Figure below indicates the ammonia consumption in Urea production in India.

Figure 4: Ammonia and hydrogen consumption (KT) in urea production in India - FY22



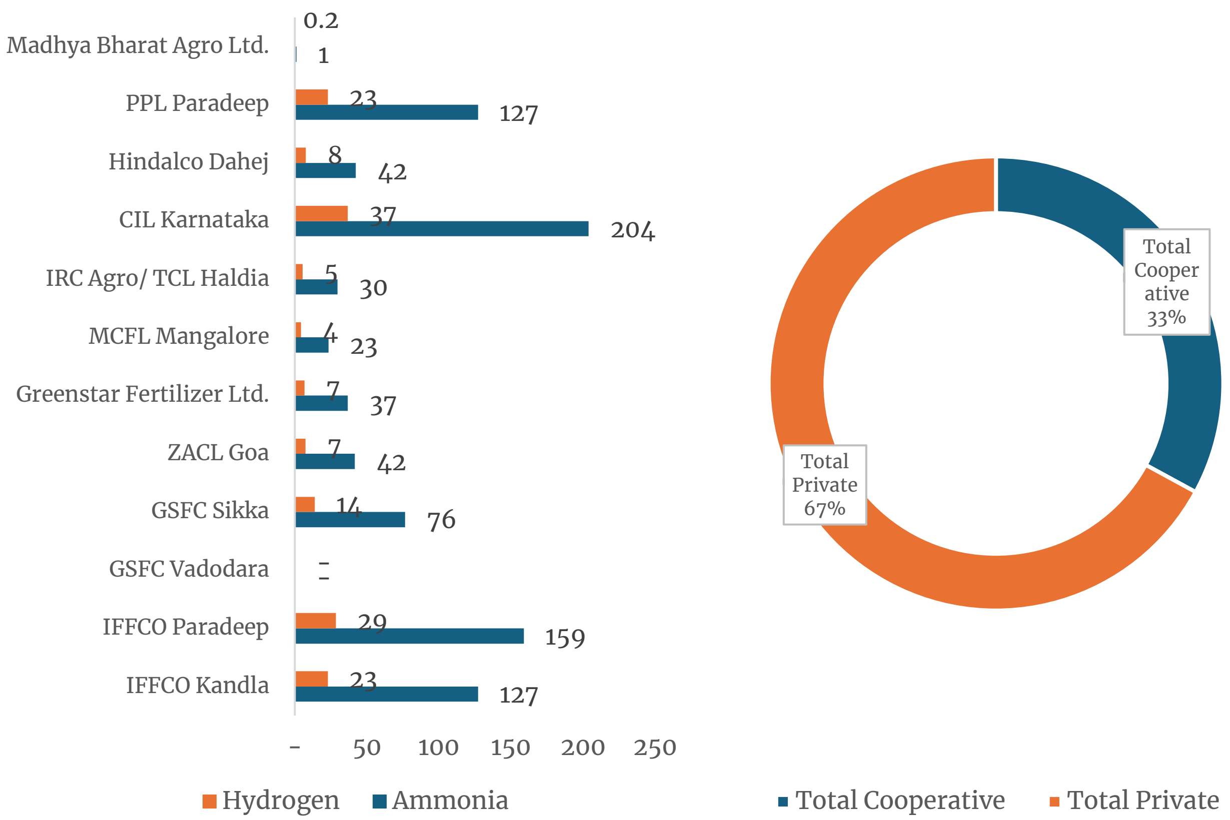

Source: Internal Research & Analysis

At the end of FY22, the consumption of ammonia in urea was approx. 14 million tonnes per annum (MMTPA) corresponding to 24.6 MMTPA urea production and 28.7 MMT of installed/reassessed capacities. This ammonia consumption corresponds to a hydrogen (grey) consumption of approx. 2.52 MMTPA.

# Ammonia consumption in Di-Ammonium Phosphate

Figure below indicates the ammonia consumption in DAP production in India.

Figure 5: Ammonia and hydrogen consumption (KT) in DAP production in India - FY22




Source: Internal Research & Analysis

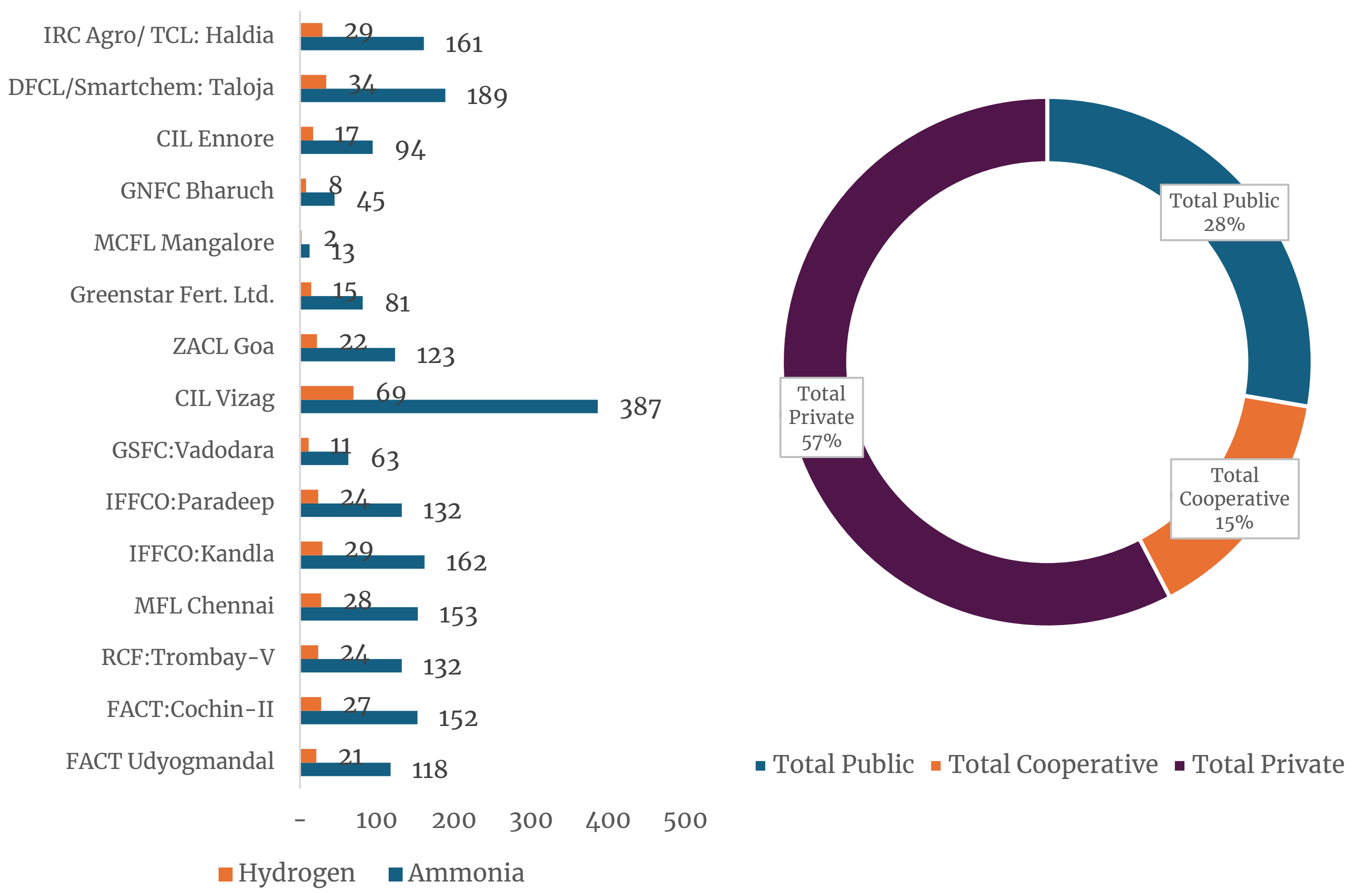
At the end of FY22, the consumption of ammonia in DAP was approx. 0.86 MMTPA corresponding to approx. 3.78 MMTPA DAP production and approx. 8.2 MMT of installed / reassessed capacities. The associated grey hydrogen consumption in the DAP sector is therefore estimated to be 156 KTPA.

# Ammonia consumption in other Complex Fertilizers

Figure below indicates the ammonia consumption in other Complex Fertilizer production in India.

At the end of FY22, the consumption of ammonia in other CF was approx. 2 MMTPA corresponding to approx. 9.32 MMTPA complex fertilizer production and approx. 6.38 MMT of installed/reassessed capacities. This corresponds to a hydrogen consumption of 360 KTPA.

Figure 6: Ammonia demand (KT) in other complex fertilizer production in India - FY22

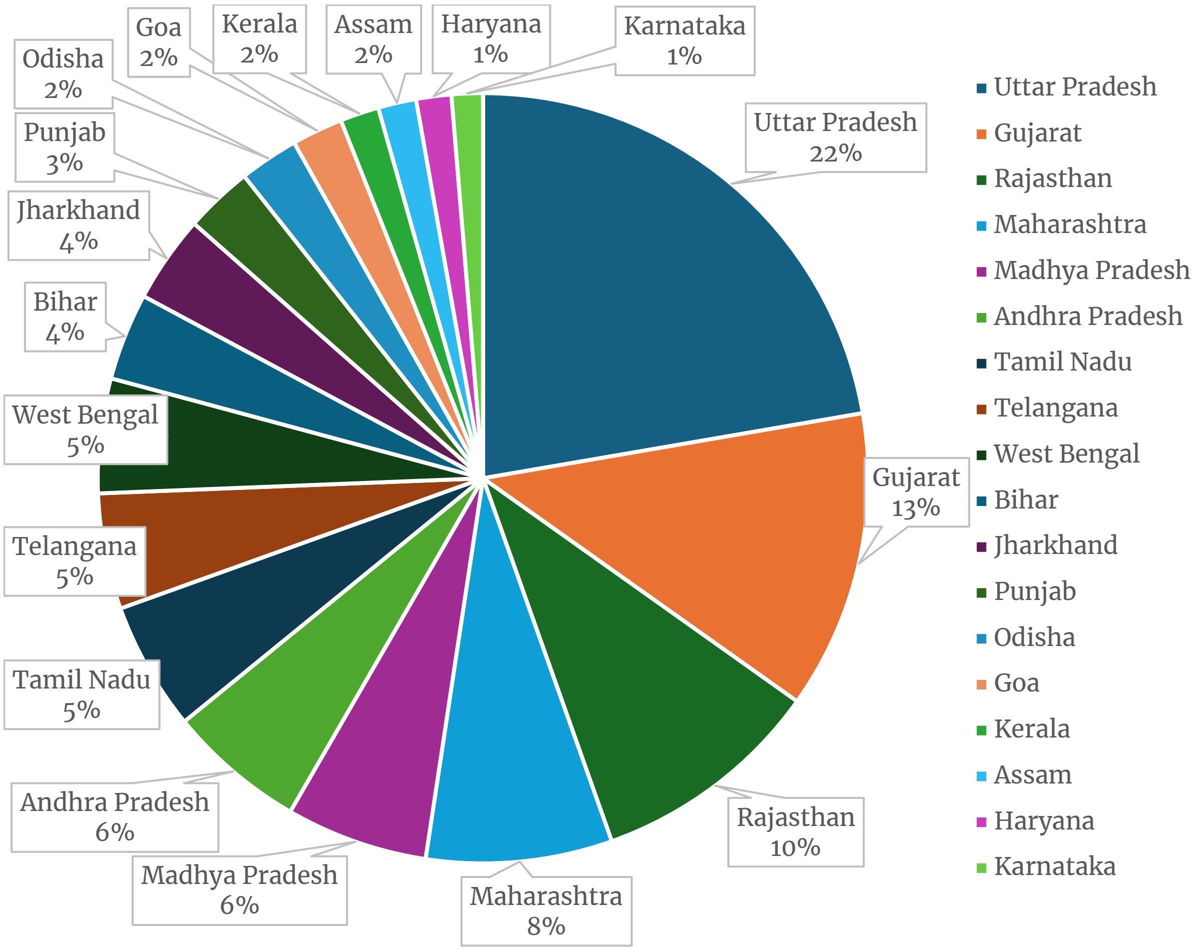



Source: Internal Research & Analysis

# State-wise ammonia consumption distribution in fertilizer industry

Below we indicate how the distribution of ammonia consumption in urea, DAP, and other Complex Fertilizers varies across states.

Figure 7: State wise distribution of ammonia demand in India's fertilizer sector




Source: Internal Research & Analysis

Table 3: Ammonia consumption in fertilizer industry by product

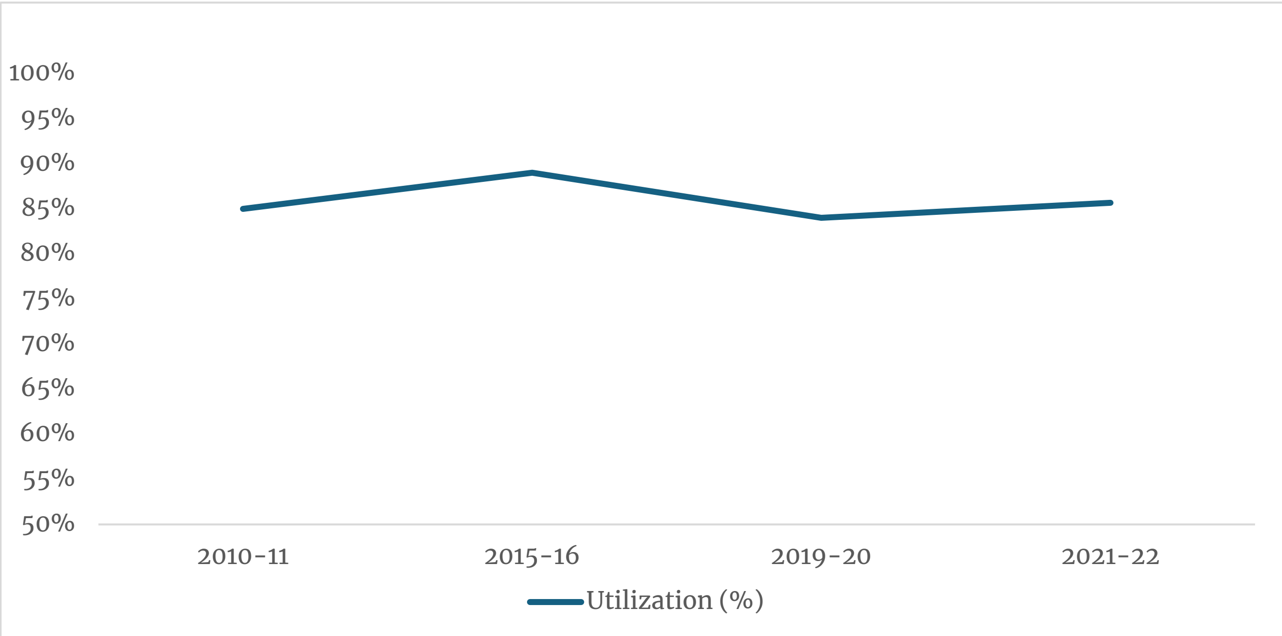
| Sr. No. | Sector | Consumption of ammonia (KTPA) – FY22 | Consumption of hydrogen (KTPA) – FY22 | % of total ammonia/ H2 consumption |
|---|---|---|---|---|
| 1. | Urea | 14,024 | 2,522 | 83% |
| 2. | DAP | 868 | 156 | 5% |

| | | | | |
|---|---|---|---|---|
| **3.** | **Other CF** | **2,004** | **360** | **12%** |
| | **Total** | **16,896** | **3,038** | |

Source: Internal Analysis

Furthermore, it is to be noted that a DAP facility can also be used to produce other Complex Fertilizers by modifying the production process and adjusting the input materials. For example, MAP (monoammonium phosphate) can be produced by using only one molecule of ammonia instead of two in the DAP production process. By adding Potash, N:P:K (complex) fertilizers can be manufactured. Different micronutrients such as zinc or boron may also be added during the production process, to manufacture micronutrient enriched fertilizers. However, the specific modifications required to produce different fertilizer grades depend on the particular DAP facility and its capabilities. Also, it is noteworthy that India's fertilizer industry operates at a high utilization factor (>80%).

Figure 8: Capacity utilization of India's fertilizer industry




Source: Secondary Research

## 1.1.2 Use of ammonia in other sectors

### Explosives

In India, the highly regulated explosive industry is the second largest demand driver for ammonia after the fertilizer sector. The sector is estimated to account for approx. 6% of the total ammonia demand.[34] The ammonia which goes into the explosive industry as a raw material is majorly used for the production of Technical Ammonium Nitrate (TAN), an industrial grade explosive. Consequently, it is used as a raw material for the production of industrial explosives which are majorly used in the mining, power, construction and steel sectors. Consumption of TAN is highest in the coal mining industry, accounting for ~67% of the domestic TAN demand.[35]

Even though ammonium nitrate is a popular fertilizer globally, it is not used as a fertilizer in India, as it is not subsidized by the government. Moreover, it has potential of being misused for unregulated explosive production. According to "The Ammonium Nitrate Rules, 2012" any mixture having more than 45% of Ammonium Nitrate by weight from which it can be extracted for unlicensed production of explosives comes under the purview of the said regulations and is affected by supervision by the authorities. Thus, it cannot be manufactured without obtaining necessary licenses. In India the supply of TAN in India is controlled by 4 major players, namely SmartChem Technologies (wholly owned by DFPCL[36]), RCF, GNFC, and NFL.

Industrial production of Ammonium Nitrate is done by neutralizing nitric acid (HNO3) with ammonia (NH3). Ammonia in the form of a liquid is used as a reactant, which is later evaporated/superheated and fed to the reactor where it reacts with the nitric acid, to form ammonium nitrate liquor. This is later purified to obtain the TAN in the required form.

## Demand of ammonia for TAN production

Currently, the demand for TAN is higher than its domestic production. During the year 2020-21, the domestic production stood at approx. 760 KT, whereas the demand was at approx. 993 KT. The demand is expected to increase at a CAGR of approx. 5% to 6% by 2030. The consolidated installed TAN capacity in India stands at 940 KT, distributed among Smartchem Technologies, RCF, GNFC, and NFL. A distribution of the production

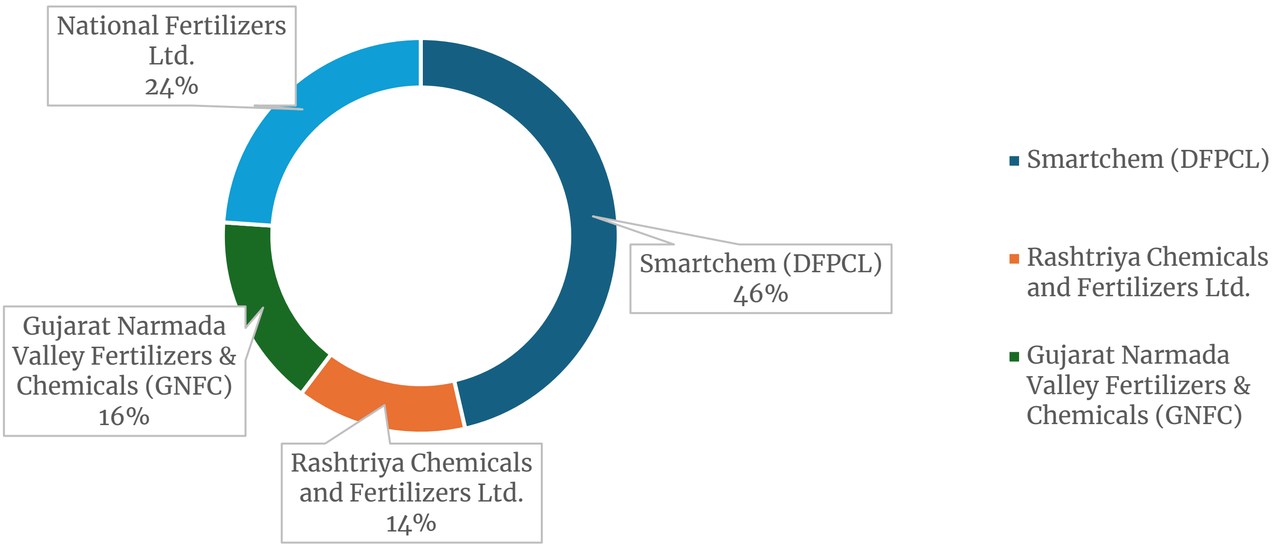
34 Internal Research

35 Ministry of Coal Report

36 Deepak Fertilizers & Petrochemicals Corporation Ltd.

capacities of the 4 players is shown below.

Figure 9: Distribution of TAN Production Capacities in India




Source: Company Reports, Internal Analysis, Industrial Sources

The supply-demand gap of approx. 20% is met through imports. The imports of TAN have grown at a CAGR of ~5% over the last 5 years. Turkey, Russia and Bulgaria being the major sources for import. Recent geopolitical events have initiated discussions in India for a need to increase production capacities. This supply-demand gap and the growth of the sector is expected to lead to an enhancement in domestic production. Several major players have initiated pre-feasibility studies to evaluate the in-house production of TAN in-order to cater to the increasing domestic demand and, to protect profit margins by integrating the supply chain.

Catering a total of 993 KT TAN demand, the ammonia required is expected to be approx. 546 KT. Consequently, the corresponding hydrogen consumption would be 109 KT.

## Capacity Expansion Plans for TAN Production

The market for industrial explosives is witnessing tremendous growth supported by an increase in mining and construction as a result of India's increased capital expenditure to build public infrastructure. Additionally, increasing population and rapid urbanization is ensuring significant opportunities for ongoing and upcoming industrial and commercial projects, that need explosives for various uses.

The supply demand gap for Ammonium Nitrate is another attractive factor which has evoked interest from major players in the industry to enhance in-house capabilities. Some of the major investments made in the recent years have been listed below:

- Chambal Fertilizers have announced capacity addition of 220 KTPA Technical Ammonium Nitrate in Kota, Rajasthan
- Deepak Fertilizer is setting up a 377 KTPA Technical Ammonium Nitrate (TAN) plant at Gopalpur in Odisha to tap both the growing demand in the domestic and overseas market.
- Coal India Limited plans to produce around 700 KTPA a year of ammonium nitrate, about half the amount it consumes, amid efforts to protect profit margins.

The biggest challenge for the Technical Ammonium Nitrate (TAN) industry is the constrained availability and increasing prices of ammonia and increase in domestic ammonia production can further aid in reducing India's reliance on imports.

# Nitric Acid

Nitric acid is one of the widely used commodity chemicals used in India and is available in different grades such as Dilute Nitric acid (60%), Concentrated Nitric Acid (98%) and Strong Nitric Acid (available in 64%,68%, and 72%)[37]. Nitric acid production in India is an organized business with production capabilities held majorly by fertilizer producing units. Nearly 83% of the nitric acid is consumed by the fertilizer producers within their own production plants and the rest 17% is sold to third parties as a raw material. The chemical is used in a variety of industries including pharmaceuticals, defense, explosives, dyes, rubber, steel rolling and pesticides.

The major share of the Nitric Acid produced goes into the manufacturing Ammonium Nitrate, which is used in the explosive industries. It alone was responsible for 98% of Nitric Acid demand.

## Nitric Acid Market

Western states of Gujarat and Maharashtra are the major consumers, and majority of the chemical manufacturers are located in these states along with the feasibility of shipping ports. Ministry of Commerce and Industry is the prime regulatory body for setting up of Nitric Acid plants in India. Additionally, as most of the nitric acid production capacity is held with fertilizer producing companies, the producers are under the control and regulation of Ministry of Chemicals and Fertilizers. The important players involved in Nitric Acid sector are listed below:

37 Industry Sources

- Deepak Fertilizers & Petrochemicals Corporation Ltd.
- Rashtriya Chemicals and Fertilizers Ltd.
- Gujarat Narmada Valley Fertilizers Company Ltd.
- National Fertilizers Ltd.
- Smartchem Technologies Ltd. (wholly owned by DFPCL)

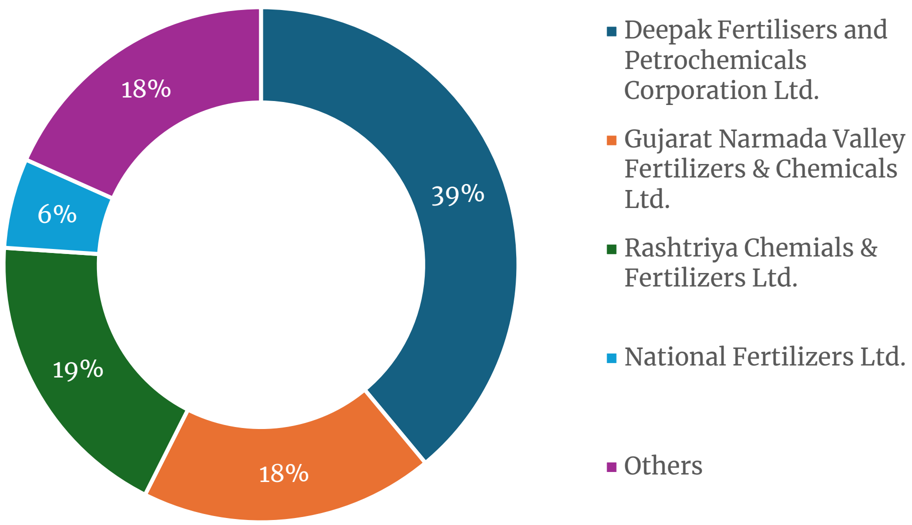
The current demand for Nitric acid in the country is about 640 KT which is expected to grow at a CAGR of 5.5% to reach 1,284 KT by 2035. The country is almost self-sufficient in the availability of the chemical and only 2% of the total demand is being imported from South Korea, Belgium, Germany and Taiwan. The production capacity far exceeds the demand, and hence the industry suffers from a low-capacity utilization rate.

Currently, DFPCL, along with its subsidiaries is the market leader with a combined production capacity of 5,24,700 MT and is the largest producer of Nitric acid in Southeast Asia, while Aarti Industries is the largest consumer of Nitric acid in India. Almost 90% of the concentrated Nitric Acid produced by Deepak fertilizers is used for captive consumption and the company holds a 45-50% market share[38].

While the chemical is produced by several factories, NFL Nangal, RCF Trombay, GNFC Bharuch, and DFPCL Taloja produce the nitric acid for Ammonium Nitrate production and the rest produce it for various other applications. The major sites of Nitric Acid production along with a distribution of nitric acid production capacities of the major players is given below.

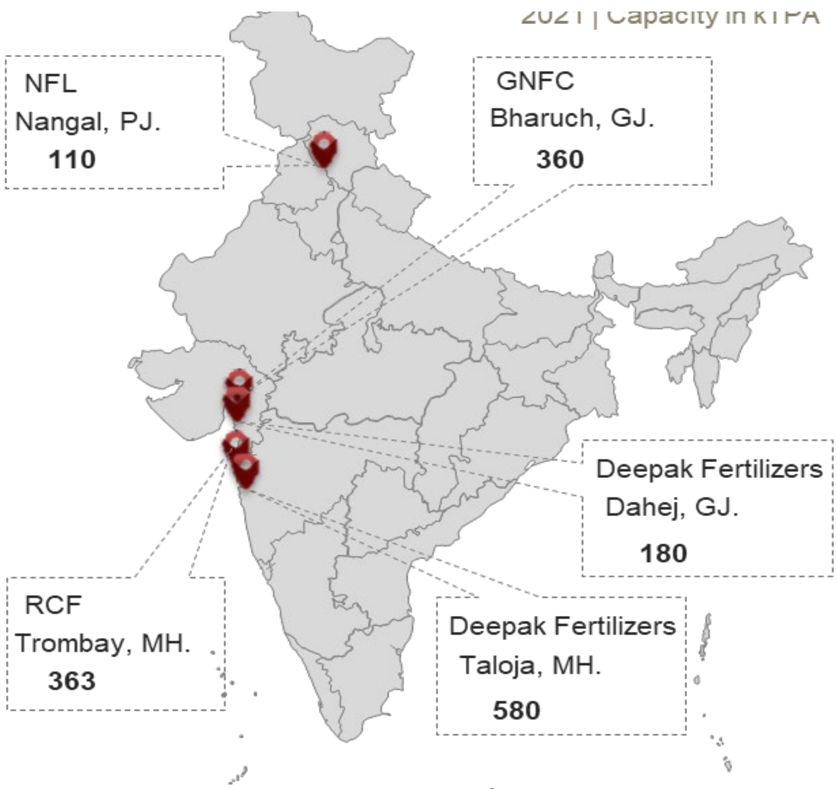
38 Company Annual Report

Figure 10: Nitric Acid Capacity by Player, 2021 (in KT)




Source: Company Reports, Internal Analysis, Industry Sources

Figure 11:Key Nitric Acid Producers in India



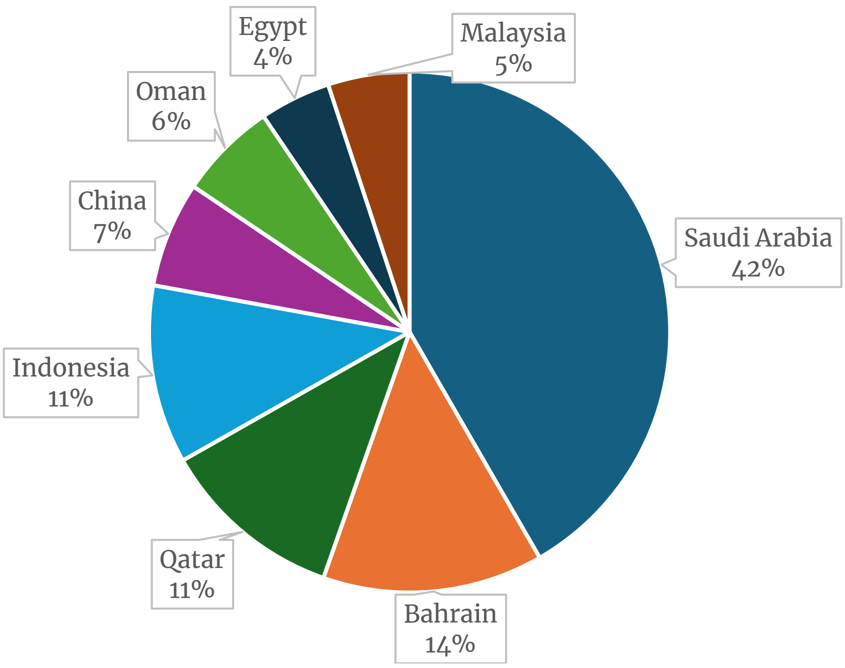

Source: Company Reports, Industry Sources

For the 640 KT Nitric acid produced in India, the corresponding ammonia demand would be approx. 202 KT.[39] This is bound to grow, majorly supported by growth in construction and fertilizers industries. Additionally, the production of Ammonia requires Hydrogen as a raw material. For 202 KT of Ammonia, the corresponding Hydrogen demand would be approx. 36.33 KT.

# 1.2Trade of ammonia

Ammonia is a globally traded commodity with India being the third largest consumer of ammonia in the world, behind China and USA. To cater to its demand, particularly for the segments other than urea, India imported approx. 2.43 MMT ammonia worth USD 2.25 Bn in FY23, mainly from Saudi Arabia (1.0 MMT), Bahrain (0.33 MMT), Qatar (0.28 MMT), Indonesia (0.27 MMT), and China (0.16 MMT).

Figure 12: Origins of ammonia imported to India in FY23



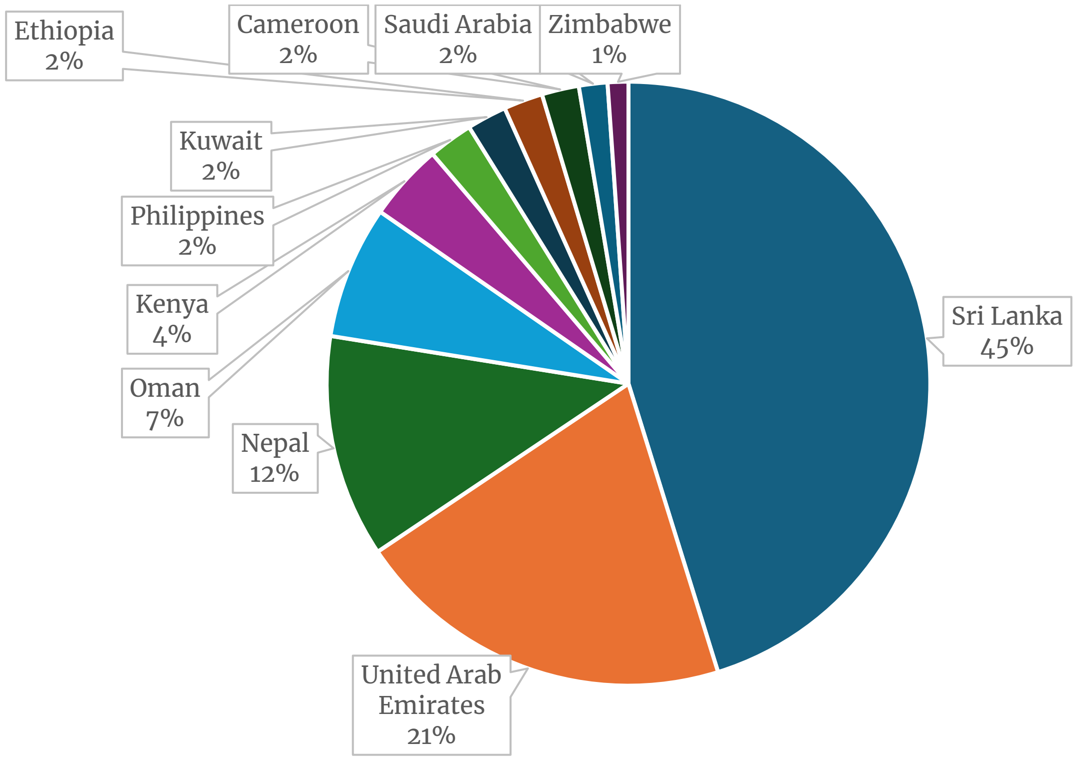

Source: Industry Sources

Due to the high demand, India has been a net importer of ammonia and imports have steadily increased throughout the years from countries such as Saudi Arabia and Qatar in the Middle East. Furthermore, since 2010, India has also increased its export volumes to

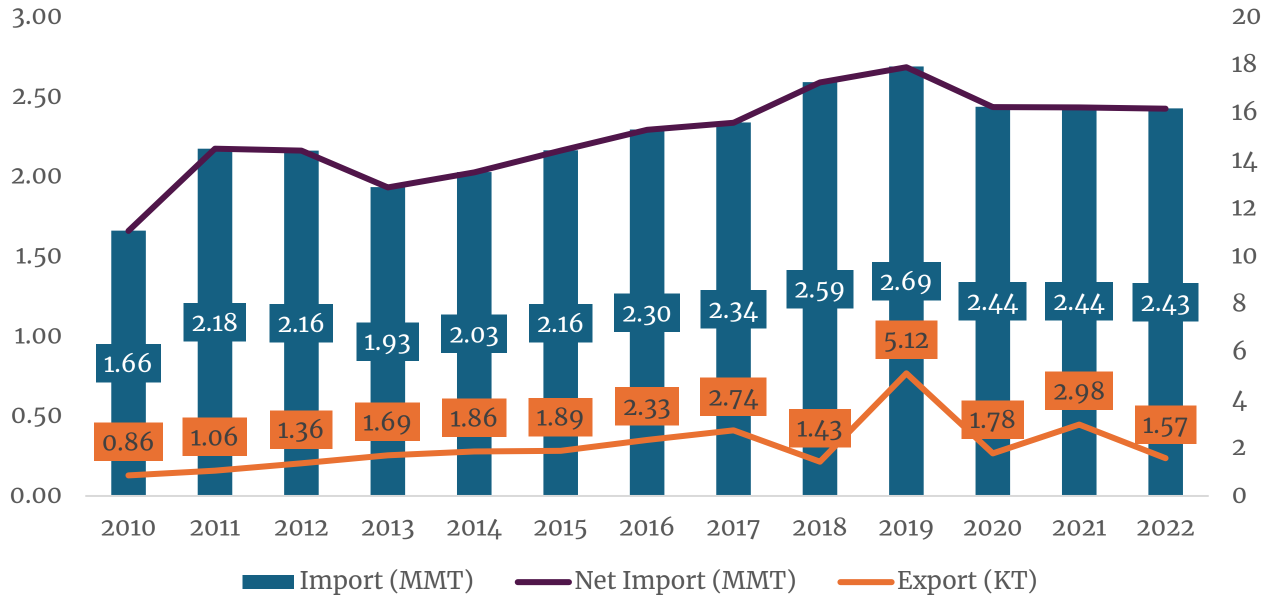
39 Stoichiometry indicates 126 kg of HNO3 requires approx. 34 kg of NH3

countries in South-East Asia and Middle East. India exported 1.57 KT ammonia, worth USD 2.1 Mn in in FY23. The main destinations of India's exports of ammonia were Sri Lanka (0.7 KT), UAE (0.3 KT), Nepal (0.2 KT), and Oman (0.1 KT).

Figure 13: Major destinations of ammonia exported from India in FY23




Source: Industry Sources

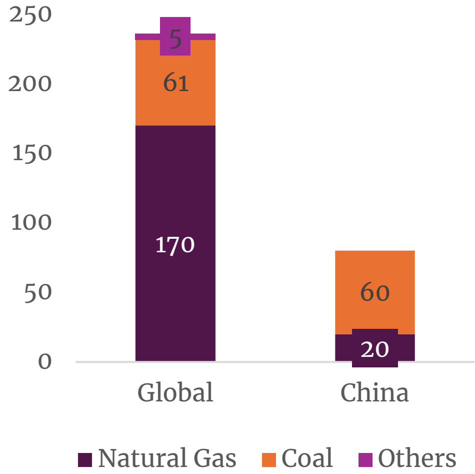



Source: Industry Sources

# 1.3 Prevailing Commercial Regime in India

Asian countries contribute to around two third of total consumption of ammonia in the world with Korea, China, Chinese Taipei, Bangladesh and Thailand being among the top Asian countries in terms of import volumes. Majority of global ammonia requirement is produced from natural gas with the exception of China, which in addition to natural gas utilizes coal gasification techniques for ammonia production.

Figure 15: Ammonia Production Capacity by Feedstock, FY22 (MMT)

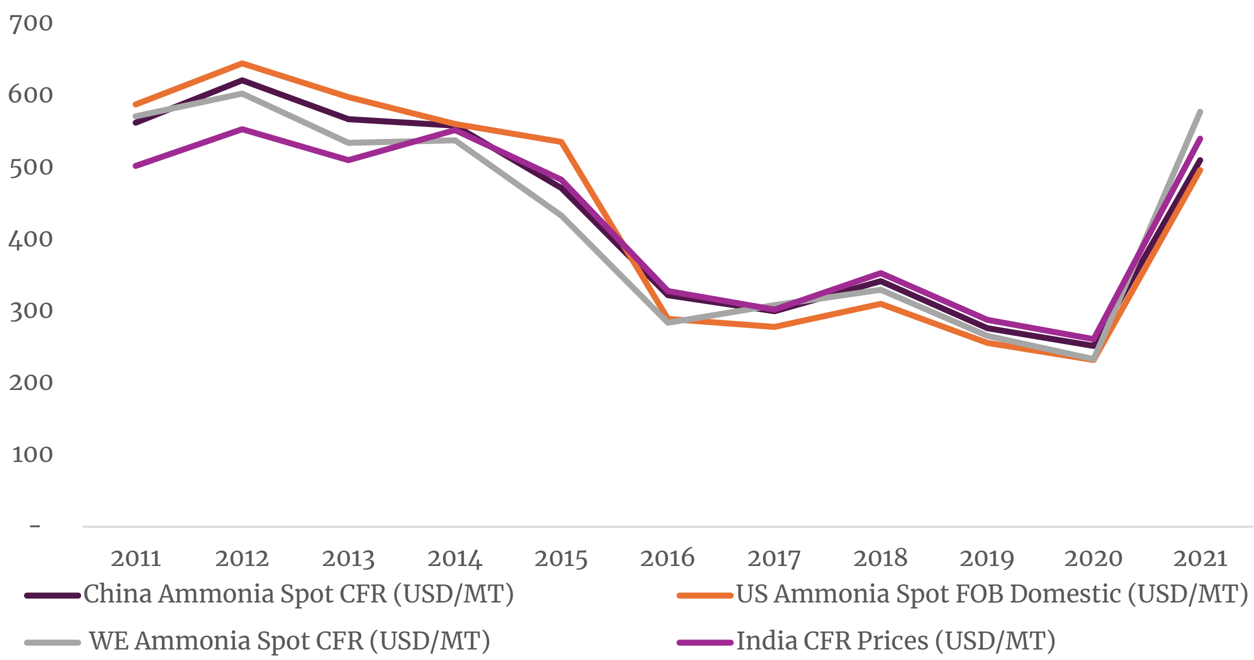



Source: Industry Sources

Global ammonia prices mimic the volatility of China's prices which are considered the benchmark rates in spot trade. China is one of the largest producers of ammonia worldwide, which means fluctuations in its production or demand can impact global prices. In 2020, China was the largest producer of ammonia, accounting for nearly 31.6% of global production.[40] Furthermore, China's demand for ammonia, both for domestic use and for the production of downstream products like urea and ammonium nitrate, is substantial.

Therefore, the pricing of ammonia in China influences global ammonia prices, especially

Figure 16: Ammonia Global Price Trends, 2011-2021 (USD/MT)




40 International Fertilizer Association

in the spot market where commodities are bought and sold for immediate delivery. When there are fluctuations in China's domestic ammonia prices due to factors such as changes in demand, supply disruptions, production costs, government policy changes, or other market conditions, these fluctuations propagate to global markets, causing volatility in the global price of ammonia. For example, if demand for ammonia in China increases significantly, and China starts importing more ammonia to meet this demand, this drives up global spot prices for ammonia. On the other hand, if China's ammonia production increases and it reduces its imports or increases exports, this puts downward pressure on global ammonia prices.

### 1.3.1. Ammonia import parity pricing

India ammonia price is based on CFR (Cost and Freight) price in the country. The import parity price (IPP) acts as a 'price floor' for the imported ammonias. The IPP is calculated by taking the international cost of the product and adding the expenses related to importing it, like freight, customs duties, taxes, etc. Because of these added costs, the IPP is usually higher than the international price of the product. For domestic producers, this IPP acts as a 'price ceiling'. If the domestic producers price their goods higher than the IPP, then buyers may prefer to import the product. So, from the perspective of domestic producers, the IPP forms a 'price ceiling' - a limit that they typically can't price their product above without losing competitiveness.

Table 4: Import Parity Prices of Anhydrous Ammonia (Till June 2023 of FY24)

| Attributes | Exporting Country | Saudi Arabia | Qatar | Oman |
|---|---|---|---|---|
| 1 | CFR India (USD/MT) | **345** | **298** | **472** |
| 2 | Insurance (USD) | 0.14 | 0.12 | 0.19 |
| 3 | Average CIF Price (USD/MT) | 359 | 310 | 492 |
| 4 | Landing Charges (USD/MT) | 3 | 3 | 5 |
| 5 | Accessible Value (USD/MT) | 363 | 313 | 496 |
| 6 | Basic Custom Duty (USD) | 18 | 16 | 25 |
| 7 | Assessable Value + BCD (USD/MT) | 381 | 329 | 521 |
| 8 | Social Welfare Sur Charge (USD) | 1.81 | 1.57 | 2.48 |
| 9 | Anti-Dumping Duty (USD) | - | - | - |
| 10 | Total Duty (USD) | 20 | 17 | 27 |

| | | | | |
|---|---|---|---|---|
| 11 | Duty Paid Value (USD/MT) | 383 | 330 | 524 |
| 12 | Price After GST (USD/MT) | 451 | 390 | 618 |
| 13 | Less Landing Charges (USD/MT) | 448 | 387 | 613 |
| 14 | Port Handling Charges (USD/MT) | 3.09 | 3 | 3 |
| | ***Landed Price at Port (USD/MT)*** | ***451*** | ***390*** | ***616*** |

Source: Trade Data, Internal Research and Analysis

The average CIF (Cost, Insurance, and Freight) price of ammonia in India for FY23 was observed to increase to more than double due to the conflict between Russia and Ukraine. However, the prices since have returned back to normal ranges.

Table 5: Import Parity Prices of Anhydrous Ammonia (FY 2023)

| zzz | Saudi Arabia | Qatar | Oman |
|---|---|---|---|
| Average CIF Price (USD/MT) | 904 | 1,001 | 911 |
| ***Landed Price at Port (USD/MT)*** | **1,131** | **1,252** | **1,139** |

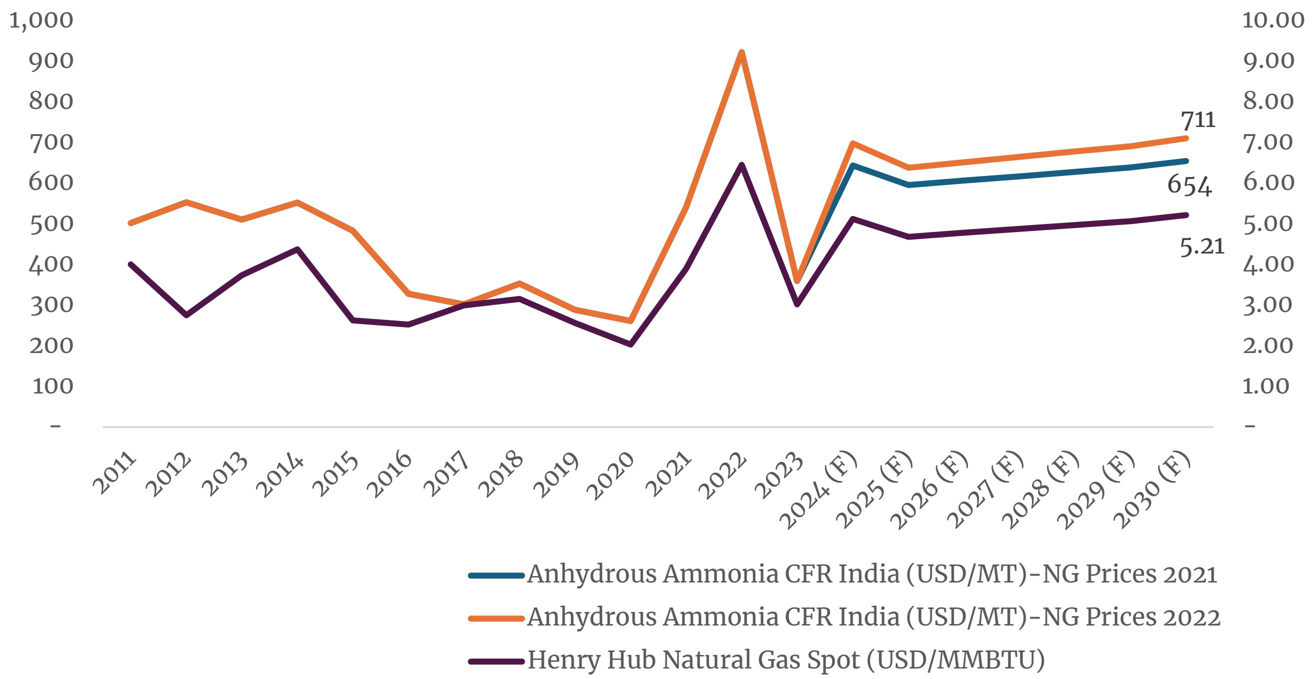
Source: Trade Data, Internal Research and Analysis

## 1.3.2. Forecasting of Ammonia Prices and Price Competitiveness Analysis

Due to the fact that ammonia is predominantly manufactured from natural gas, ammonia prices typically follow natural gas prices and generally have a strong positive correlation. Also, as previously stated, ammonia being a commodity and given how intertwined the world's ammonia markets are, its price in India closely tracks the international ammonia pricing in addition to the natural gas prices.

Two scenarios have been considered – (a) natural gas prices of 2021 and (b) natural gas prices of 2022. Subsequently two trendlines have been plotted using which two forecasted prices have been arrived at. Ammonia prices were observed to correlate with natural gas prices.

Figure 17: Forecasting of ammonia prices (USD per tonne)




Source: EIA, Industry Sources, Industry Natural Gas Forecasts

A similar analysis was performed using Europe Brent FOB as the independent variable. A weak correlation of ammonia prices was observed with brent prices.

Regression statistics for the scenarios are indicated in the table below:

Table 6: Statistics for regression analysis performed with natural gas prices till 2021

| Anhydrous Ammonia | Henry Hub NG | Europe Brent FOB |
|---|---|---|
| Multiple R | 89% | 76% |
| R Square | 79% | 57% |
| Adjusted R Square | 78% | 52% |

Source: Internal Analysis

Table 7: Statistics for regression analysis performed with natural gas prices till 2022

| Anhydrous Ammonia | Henry Hub NG | Europe Brent FOB |
|---|---|---|
| Multiple R | 89% | 66% |
| R Square | 80% | 44% |
| Adjusted R Square | 78% | 38% |

Source: Internal Analysis

The output of the analysis is presented below:

Table 8: Ammonia Price Forecasts

| Year | Anhydrous Ammonia CFR India (USD/MT)-NG Prices 2021 | Anhydrous Ammonia CFR India (USD/MT)-NG Prices 2022 | Henry Hub Natural Gas Spot (USD/MMBTU) |
|---|---|---|---|
| 2011 | 502 | 502 | 4.00 |
| 2012 | 553 | 553 | 2.75 |
| 2013 | 510 | 510 | 3.73 |
| 2014 | 552 | 552 | 4.37 |
| 2015 | 483 | 483 | 2.62 |
| 2016 | 328 | 328 | 2.52 |
| 2017 | 302 | 302 | 2.99 |
| 2018 | 353 | 353 | 3.15 |
| 2019 | 288 | 288 | 2.56 |
| 2020 | 261 | 261 | 2.03 |
| 2021 | 540 | 540 | 3.89 |
| 2022 | 922 | 922 | 6.45 |
| 2023 | 359 | 359 | 3.02 |
| 2024 (F) | 644 | 697 | 5.12 |
| 2025 (F) | 595 | 638 | 4.68 |
| 2026 (F) | 606 | 651 | 4.78 |
| 2027 (F) | 617 | 664 | 4.87 |
| 2028 (F) | 628 | 678 | 4.97 |
| 2029 (F) | 638 | 691 | 5.07 |
| 2030 (F) | 654 | 711 | 5.21 |

Source: Internal Analysis, Industry Sources, Industry Natural Gas Forecasts

# 1.4. Refineries

India has witnessed a spectacular growth in the refining sector over the years. Currently, India is the global refining hub with a refining capacity of 248.9 MMTPA and is the fourth largest in the world after the United States, China and Russia. The country's refining network capacity has more than tripled over the past two decades. There are total 23 refineries in the country, 18 in the Public Sector, 2 in the Joint Venture and 3 in the Private Sector well spread geographically and connected by cross country pipelines. The list of refineries is mentioned in the table below.

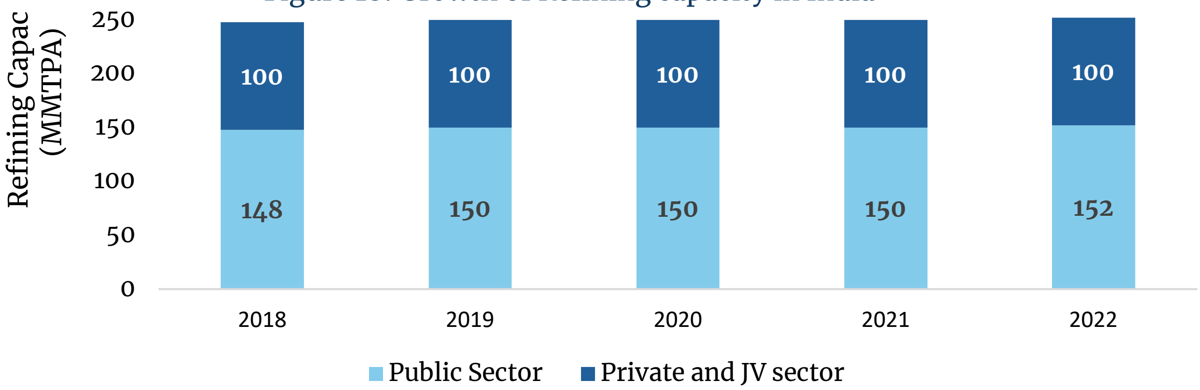
Table 9: List of Refineries of India with current capacities

| Site | State | Owner | Current Capacity (in MMTPA) |
|---|---|---|---|
| **Public sector refineries** | | | |
| Digboi | Assam | IOCL | 0.65 |
| Guwahati | Assam | IOCL | 1.00 |
| Barauni | Bihar | IOCL | 6.00 |
| Koyali | Gujarat | IOCL | 13.70 |
| Haldia | West Bengal | IOCL | 8.00 |
| Mathura | Uttar Pradesh | IOCL | 8.00 |
| Panipat | Haryana | IOCL | 15.00 |
| Bongaigaon | Assam | IOCL | 2.70 |
| Paradip | Odisha | IOCL | 15.00 |
| Mumbai | Maharashtra | BPCL | 12.00 |
| Kochi | Kerala | BPCL | 15.50 |
| Mumbai | Maharashtra | HPCL | 9.50 |
| Visakh | Andhra Pradesh | HPCL | 8.30 |
| Manali | Tamil Nadu | CPCL | 10.50 |
| Nagapattinum | Tamil Nadu | CPCL | 0.00 |
| Numaligarh | Assam | NRL | 3.00 |
| Mangalore | Karnataka | MRPL | 15.00 |
| **Private sector refineries** | | | |
| Jamnagar | Gujarat | RIL | 33.00 |
| Jamnagar (SEZ) | Gujarat | RIL | 37.00 |
| Vadinar | Gujarat | NEL | 20.00 |
| **Joint Venture** | | | |
| Bina | Madhya Pradesh | BORL | 7.80 |
| Bathinda | Punjab | HMEL | 11.25 |

Source: Ministry of Petroleum and Natural Gas, Government of India

As per International Energy Agency's forecast, India's oil demand is expected to rise by 50% by 2030 as against the global expansion of 7%. India's oil consumption is forecasted to rise from 4.8 million barrels per day (mbd) in 2019 to 7.2 mbd in 2030 and 9.2 mbd in 2050, as per the IEA's key scenario based on stated policies.

Figure 18: Growth of Refining capacity in India




Source: Indian Petroleum and Natural gas statistics 2021-22

Globally, Refineries are one of the major emitters of greenhouse gases which account for 9% of total manmade emissions.[41] Hydrogen is an important part of refining operations since it is required in several units for the desulphurization and upgrading of various oil fractions. At present, most of the refineries meet their hydrogen demand through methane steam reformation, which is highly carbon intensive process. The Hydrogen produced from Steam methane process is known as Grey Hydrogen. Hydrogen is currently used in two critical processes as described below:

1) Hydro Desulphurization Process

2) Hydro Cracking Process

Hydro desulphurization process, where hydrogen is introduced to remove sulfur (a downstream pollutant) and other undesirable compounds, such as unsaturated hydrocarbons and nitrogen from the process stream. Hydrogen is added to the hydrocarbon stream over a bed of catalyst that contains molybdenum with nickel or cobalt at intermediate temperature and pressure (other operating conditions also matter). This process causes sulfur compounds to react with hydrogen to form hydrogen sulfide, while nitrogen compounds form ammonia. Aromatics and olefins are saturated by the hydrogen and lighter products are created. The final product of the hydrotreating process is typically the original feedstock, but free of sulfur and other contaminants. Single or multiple product streams (fractionated) are possible, depending on the process configuration.

The second critical process where hydrogen is utilized is the hydrocracking process. It is a much more severe operation to produce lighter molecules with higher value for diesel, aviation fuel, and petrol. Heavy gas oils, heavy residues or similar boiling range heavy distillates react with hydrogen in the presence of a catalyst at high temperature and pressure. The heavy feedstocks are converted (cracked) into light distillates (for example, naphtha, kerosene, and diesel) or base stocks for lubricants. The hydrocracker unit is the top hydrogen consumer in the refinery. Hydrogen is the key enabler of the hydrocracking to reduce the product boiling range appreciably by converting the majority of the feed into lower boiling products. Hydrogen also enables hydrotreating reactions in the hydrocracking process; the final fractionated products are free of sulfur and other contaminants. Other refinery processes including isomerization, alkylation and tail gas treatment also consume small amounts of hydrogen.

Currently Hydrogen demand in refineries is met through Hydrogen generation units (HGU) set up within the refineries. HGUs employ steam methane reforming process to generate hydrogen. Steam-methane reforming is a mature production process in which high-temperature steam (700°C–1,000°C) is used to produce hydrogen from natural gas. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure in the

41 Intenral Research

presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic in nature—that is, heat must be supplied to the process for the reaction to proceed.

Once the syngas is produced, "water-gas shift reaction," process in which syngas and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. The final process of separating carbon dioxide and hydrogen is "pressure-swing adsorption," where carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen.

Assuming an 85% average HGU utilization, we indicate the grey hydrogen consumption below in the table.

Table 10: Grey hydrogen consumption in refining sector in India

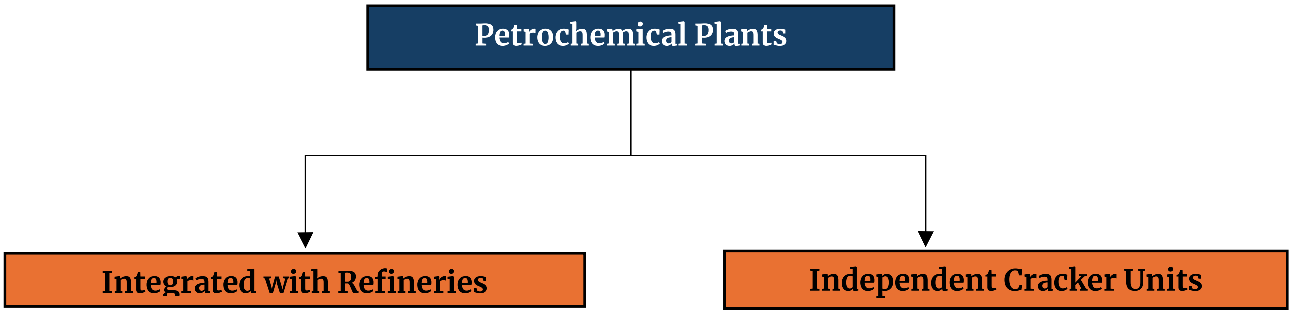
| Site | Owner | Current HGU Capacity (KTPA) | Grey Hydrogen Consumption (KTPA) (KTPA) |
|---|---|---|---|
| **Public sector refineries** | | | |
| Digboi, Assam | IOCL | 15 | 12.75 |
| Guwahati, Assam | IOCL | 20 | 17 |
| Barauni, Bihar | IOCL | 58 | 49.3 |
| Koyali, Gujarat | IOCL | 198 | 168.3 |
| Haldia, West Bengal | IOCL | 105 | 89.25 |
| Mathura, Uttar Pradesh | IOCL | 94 | 79.9 |
| Panipat, Haryana | IOCL | 178 | 151.3 |
| Bongaigaon, Assam | IOCL | 94 | 79.9 |
| Paradip, Odisha | IOCL | 193 | 164.05 |
| Mumbai, Maharashtra | BPCL | 128 | 108.8 |
| Kochi, Kerala | BPCL | 148 | 125.8 |
| Mumbai, Maharashtra | HPCL | 51 | 43.35 |
| Visakh, Andra Pradesh | HPCL | 54 | 45.9 |
| Manali, Tamil Nadu | CPCL | 110 | 93.5 |
| Nagapattinum, Tamil Nadu | CPCL | 0 | 0 |
| Numaligarh, Assam | NRL | 49 | 41.65 |
| Mangalore, Karnataka | MRPL | 127 | 107.95 |
| Barmer, Rajasthan | HRRL | 0 | 0 |
| **Private sector refineries** | | | |
| Jamnagar, Gujarat | RIL | 406 | 345.1 |
| Jamnagar (SEZ), Gujarat | RIL | 434 | 368.9 |
| Vadinar, Gujarat | NEL | 97 | 82.45 |
| **Joint Venture** | | | |
| Bina, Madhya Pradesh | BORL | 98 | 83.3 |
| Bathinda, Punjab | HMEL | 110 | 93.5 |
| | | | |
| **Total Hydrogen demand** | | **2787** | **2368.95** |

Source: Internal Analysis

# 1.5. Petrochemicals

The Indian petrochemical industry has outperformed in the past and holds tremendous potential to continue this performance in the coming decade. The per capita consumption of various chemical products and segments is significantly lower compared to developed economies and this gap offers substantial space for demand growth and investment opportunities. Demographic dividends, low per capita consumption, increasing export demand and enabling Government initiatives are the key growth drivers for the industry. Indian petrochemical companies are also adopting the evolving trends in decarbonization, sustainability, and digitalization, and these are expected to bring further investment opportunities and create value. Petrochemical projects worth approximately USD 16 billion are under implementation and projects worth around USD 100 billion have been announced so far.[42]

The assessment herein involves identifying major petrochemical assets by each player and explore the hydrogen consumption in the process units. The petrochemical units in India exist in two forms as described in the below mentioned diagram.




The feedstock to petrochemical process plants is Naphtha/Natural gas or both based on design. Four crucial factors govern the choice of feedstock in petrochemical plants: availability, cost, power consumption and the product portfolio to be produced. In India there are 13 petrochemical facilities integrated with refineries of PSUs, Private players as well as JVs. Apart from thirteen integrated facilities, India currently has 10 independent crackers, in operation with combined ethylene capacity of about 7.05 MMTPA.[43] In petrochemicals plants, Hydrogen is mainly used for hydrotreating operations and as a

42 Evolving horizons: The Indian chemical and petrochemical industry, Internal Knowledge paper on the Indian chemical and petrochemical industry

43 Ministry of Chemicals and Fertilizers, Government of India

reactant or stabilizer in polymerization reactions. The volumes of hydrogen consumed in petrochemical plants is quite low as compared to refinery operations.

Petrochemical complexes which are integrated with refineries, the Hydrogen is directly sourced from HGU units of refineries via pipelines to be used in further downstream processing. The following section encompasses the list of all integrated petrochemical complexes and product portfolio along with their capacities.[44] Further it elaborates on the independent standalone crackers in India.

In the below petrochemical complexes, the demand of hydrogen is not envisaged independently, but merged with demand estimation of refineries, as refinery HGUs are the sole source of hydrogen for these units.

Table 11 : Integrated Petrochemical Complex with Product portfolios and Expansion

| Site | Owner | Existing Products/ Units | Expansion plans /Remarks |
|---|---|---|---|
| Petrochemical Complexes Integrated with Refineries | | | |
| **PSU Refineries** | | | |
| Barauni, Bihar | IOCL | **Polypropylene** (200 KTPA) | Greenfield 200 KTPA PP unit is to be established in the recent expansion plan, to be commissioned in 2023. The Hydrogen requirement for new unit is already considered in refining section. |
| Koyali, Gujarat | IOCL | **MTBE** (210 KTPA), **LAB** (162 KTPA), **Butene-1** (60KTPA) | Greenfield 400 KTPA PP unit is to be added in recent refinery expansion to 18 MMTPA. N butanol plant of 90 KTPA is also planned and to be commissioned in future. As part of expansion plans of Gujarat refinery, 90, KTPA acrylic acid unit and a 150 KTPA butyl acrylate unit will also be installed at Dumad near the Gujarat refinery complex. |
| Panipat, Haryana | IOCL | **PX** (360KTPA), **PTA** (550KTPA), **Polypropylene unit** (600 KTPA), **LLDPE and HDPE Swing unit** (350KTPA), **HDPE** (300 KTPA), **MEG**(300 KTPA) | The capacity of PX and PTA plants post expansion will be 460KTPA and 700 KTPA respectively. Additional 450 KTPA PP will be part of complex post refinery expansion to 25 MMTPA |
| Paradip, Odisha | IOCL | **PP** (700 KTPA), **MEG** (332 KTPA) **Toluene** (50 KTPA), **Di ethylene Glycol** (24 KTPA), | A greenfield PX and PTA units of capacity 800 KTPA and 1200 KTPA respectively are expected to be commissioned in 2024 |
| Mumbai, Maharashtra | BPCL | Presently, the integrated petrochemical complex does not exist | As a part of crude to chemical integration, BPCL is installing a greenfield PP (450 KTPA) at Rasayni to increase the profitability of bottom residues. For this particular project it is proposed to utilize green hydrogen (70 TPA). The plant is |

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| | | | |
|---|---|---|---|
| | | | expected to be commissioned in next 5 years. |
| Kochi, Kerala | BPCL | **Acrylic Acid** (47 KTPA), **Butyl Acrylate** (180 KTPA), **N butanol** (38 KTPA), **2 Ethyl-Hexanol** (47 KTPA), **Iso Butanol** (7 KTPA) | Hydrogen for production is sourced from dedicated BOO Plant set up close to the refinery |
| Nagapattinum, Tamil Nadu | CPCL | Presently, the Engineering and construction of New greenfield refinery and petrochemical complex is underway. | As a part of Expansion plan for setting up greenfield 9 MMTPA refinery, it is envisaged to install Polypropylene unit of 475 KTPA capacity. The expansion project is expected to be completed by 2025. |
| **Petrochemical Complexes Integrated with Refineries** | | | |
| Mangalore, Karnataka | MRPL | **PP** (380 KTPA), **Paraxylene** (900KTPA), **Pet coke** (374 KTPA), **Benzene** (300 KTPA) | - |
| Barmer, Rajasthan | HRRL | **PP** (1200KTPA), **Butadiene** (202 KTPA). **LLDPE/HDPE** (756 KTPA), **Benzene** (80 KTPA), **Toluene** (106 KTPA), **Mixed Xylene** (40 KTPA) | - |
| **Private sector** | | | |
| Jamnagar (SEZ), Gujarat | RIL | **Polyvinyl Acetate** (350KTPA); **Polyvinyl Alcohol** (125KTPA); **Ethylene oxide for derivatives production (including MEG, DEG, TEG)** (1250KTPA). **LDPE/LLDPE/HDPE** (750KTPA). **Acrylic Acid and derivates** (450KTPA); **(n-Butyl Acrylate, n-butyraldehyde, n-Butanol,2-EthylHexanol)** (500 KTPA); **Propylene Derivatives like Propylene Oxides, Cumene, Phenol** (400 KTPA); **Propylene Glycols** (200 KTPA). **POLYOLS** (200KTPA); **Polypropylene** (250KTPA); **Butyl/Halo Butyl Rubber, ESBR, SBR, PBR, SSBR** (470 KTPA); **Paraxylene** (2500 KTPA); **styrene** (100 KTPA), **PTA** (1875 KTPA). **PET** (1500KTPA) | |
| Vadinar, Gujarat | NEL | Presently Construction of New Polypropylene unit is underway | As a part of expansion and diversification into petrochemicals, a greenfield |

| | | | |
|---|---|---|---|
| | | | Polypropylene unit of 450 KTPA would be set up by 2023 |
| **Joint Venture** | | | |
| Bina, Madhya Pradesh | BORL | **Ethylene Cracker unit** (1200 KTPA), **LLDPE/HDPE** (650KTPA), **HDPE** (500 KTPA), **PP** (650KTPA), **Butene-1** (50KTPA) | - |
| Bathinda, Punjab | HMEL | **Ethylene Cracker unit** (1200 KTPA), **LLDPE/HDPE** (800KTPA), **HDPE** (450 KTPA), **PP** (400 KTPA), **Butene-1** (55KTPA) | Additional Polypropylene facility of 500 KTPA would be commissioned by 2023. |

Source: Environment clearance reports, Prefeasibility studies, Company Annual reports, Industry Sources

In the second category of petrochemical complexes with independent Naphtha/Natural gas or dual feed cracker, the hydrogen is produced as a byproduct in cracking process which is later consumed in downstream processing. The below table encompasses player wise 10 independent crackers with their capacity currently operational in the country.[45]

Table 12: Independent Crackers in India

| Naphtha Crackers | Ethylene Capacity (KTPA) |
|---|---|
| Reliance Industries Ltd., Vadodara, Gujarat | 175 |
| Reliance Industries Ltd, Hazira, Gujarat | 887 |
| Haldia Petrochemicals Ltd, Haldia, West Bengal | 700 |
| Indian Oil Corporation Ltd., Panipat, Haryana | 800 |
| **Sub- Total** | **2,562** |
| **Natural Gas Crackers** | **Ethylene Capacity (KTPA)** |
| Reliance Industries Ltd., Nagothane, Maharashtra | 421 |
| Gas Authority of India Limited, Pata, UP | 850 |
| Reliance Industries Ltd, Dahej, Gujarat | 400 |
| **Sub- Total** | **1,671** |
| **Dual Feed Crackers** | **Ethylene Capacity (KTPA)** |
| Brahmaputra Cracker and Polymer Limited (BCPL), | 213 |
| ONGC Petro additions Ltd. (OpaL) | 1,100 |
| **Sub- Total** | **1,313** |
| **Off Gas Cracker** | **Ethylene Capacity (KTPA)** |

*45 Ministry of Chemicals and Fertilizers, Government of India*

| | |
|---|---|
| Reliance Gas industry, Jamnagar | 1,500 |
| **Sub- Total** | **1,500** |
| **Independent Crackers-Total Installed Capacity** | **7,046** |

Source: Ministry of Petroleum and Natural gas

Hydrogen requirement in the independent cracker installation in downstream processing is met by hydrogen produced as a byproduct of Naphtha/Natural gas cracking process.

# 1.6. Assessment of Hydrogen and Ammonia demand in Uttar Pradesh and Tamil Nadu

## 1.6.1. Hydrogen and Ammonia in Power Sector

### Power Back-up to replace diesel generators in Hospitals

In the power sector, diesel generators are used for providing the necessary power back up required during power cuts and blackouts. This power back-up becomes a critical requirement for hospitals during exigencies in order to prevent life threatening scenarios and loss of life.

As energy costs keep rising due to the highly volatile oil market and sustainability becoming an important strategic goal with the net zero targets inching closer there is an ever growing need to replace old technology with greener and more energy efficient systems. Demand for emergency backup power and off-grid power generation systems is on the rise as India builds its health infrastructure by addition of new hospitals both in public and private sectors. It has been observed that the newly constructed state-of-the-art hospitals have higher energy requirements and hence, the demand for energy is only envisioned to increase further.

Currently used diesel generators can potentially be replaced by fuel cells which use hydrogen as a power source to produce electricity. Several technologies are in development and hydrogen fuel cell-based electricity generators are already available in the market. Having a varied portfolio with respect to sizes and power capacities will provide the hospitals a choice to select from based on their unique requirements going forward.

In Israel, ABB in partnership with GenCell have successfully installed and demonstrated the use of Hydrogen fuel cells as a power backup solution at the Hillel Yaffe Medical Center in Israel. The hospital has been able to reduce the hospital's environmental impact by replacing the diesel-based generators and cut operation costs via safeguarding the expensive medical equipment. The hospital is already respected globally for its progressive measures to implement sustainability without compromising on patient care. With this move, it became the first hospital in Israel to be granted the "Green Label" certificate from the Standards Institution of Israel and the Environment Ministry.[46]

**Demand Estimation**

Information from secondary sources suggested that Uttar Pradesh faces daily power outages to the tune of 4 hours in urban regions and 8 hours in rural regions. Similarly, Tamil Nadu was found to face an average daily power outage of 1 hour in both urban and rural regions. 47 DG sets are expected to cater to the energy shortfall observed during these hours. The hydrogen demand thus enumerated has been tabulated below.

Table 13: Hydrogen Demand from Hospital Power Backup Systems for Uttar Pradesh

| H2 Demand for 4 Hour Requirement with Conservative Energy Use | H2 Demand for 4 Hour Requirement with Realistic Energy Use | H2 Demand for 8 Hour Requirement with Conservative Energy Use | H2 Demand for 8 Hour Requirement with Realistic Energy Use |
|---|---|---|---|
| 1.69 KT | 3.39 KT | 3.39 KT | 6.77 KT |

Source: Internal Analysis

Table 14: Hydrogen Demand from Hospital Power Backup Systems for Tamil Nadu

| H2 Demand for 1 Hour Requirement with Conservative Energy Use | H2 Demand for 1 Hour Requirement with Realistic Energy Use |
|---|---|
| 0.23 KT | 0.47 KT |

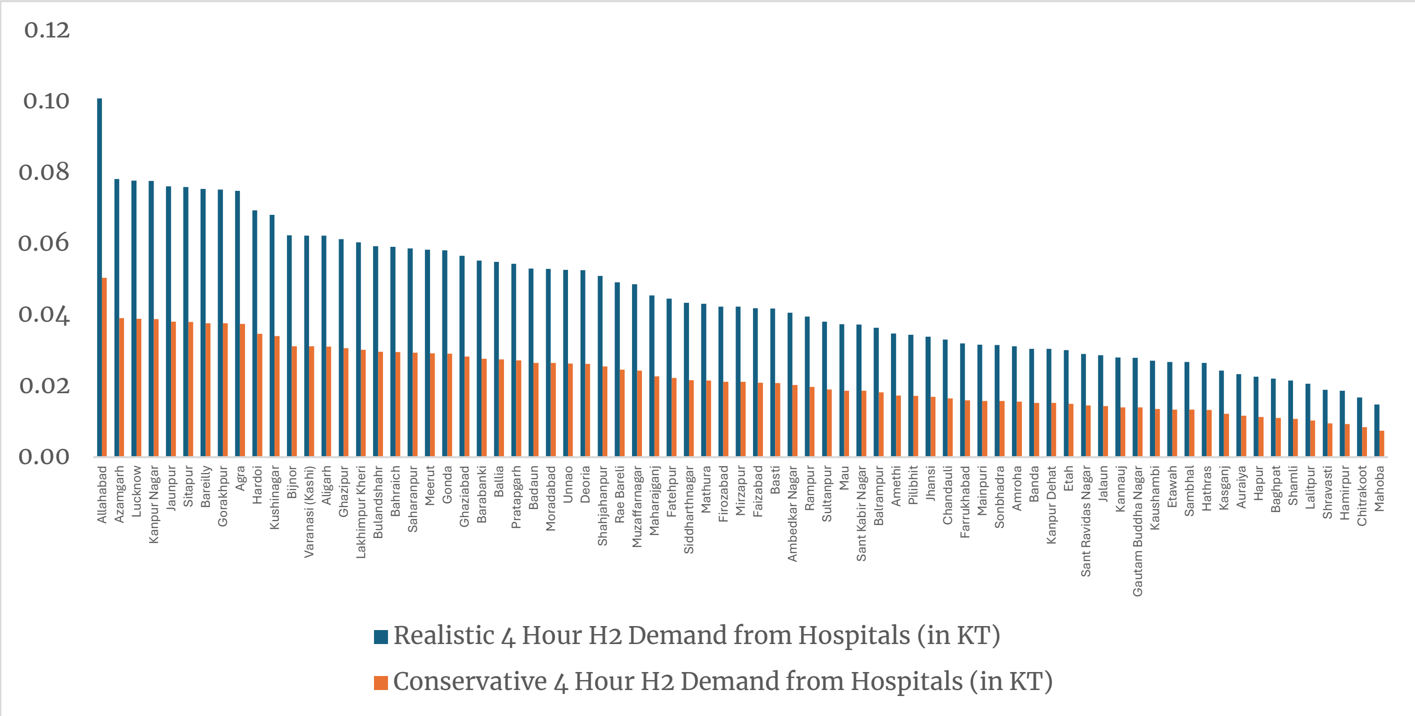
Source: Internal Analysis

46 Press Release

47 CEEW

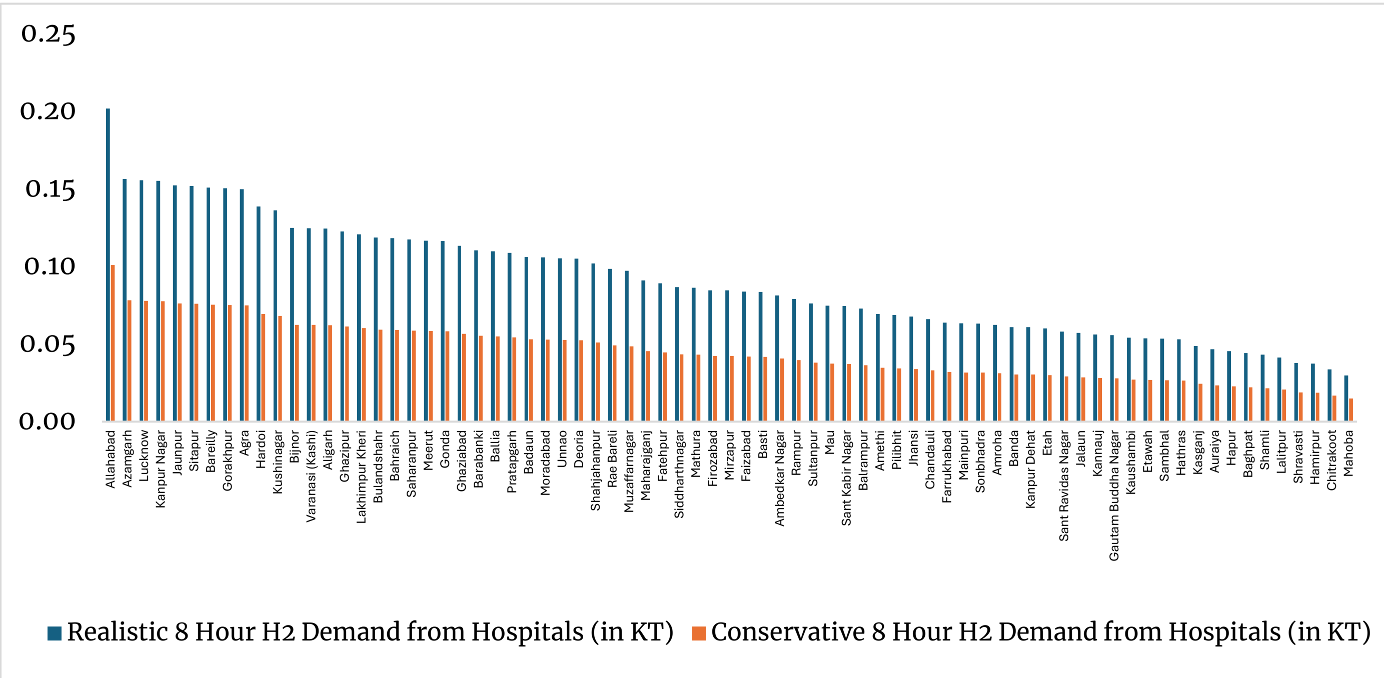
The district-wise hydrogen demand for Tamil Nadu and Uttar Pradesh has therefore been highlighted below:

Figure 19: Hydrogen demand (KT) in power backup for hospitals in Uttar Pradesh for 4-hour requirement




Source: Internal Analysis

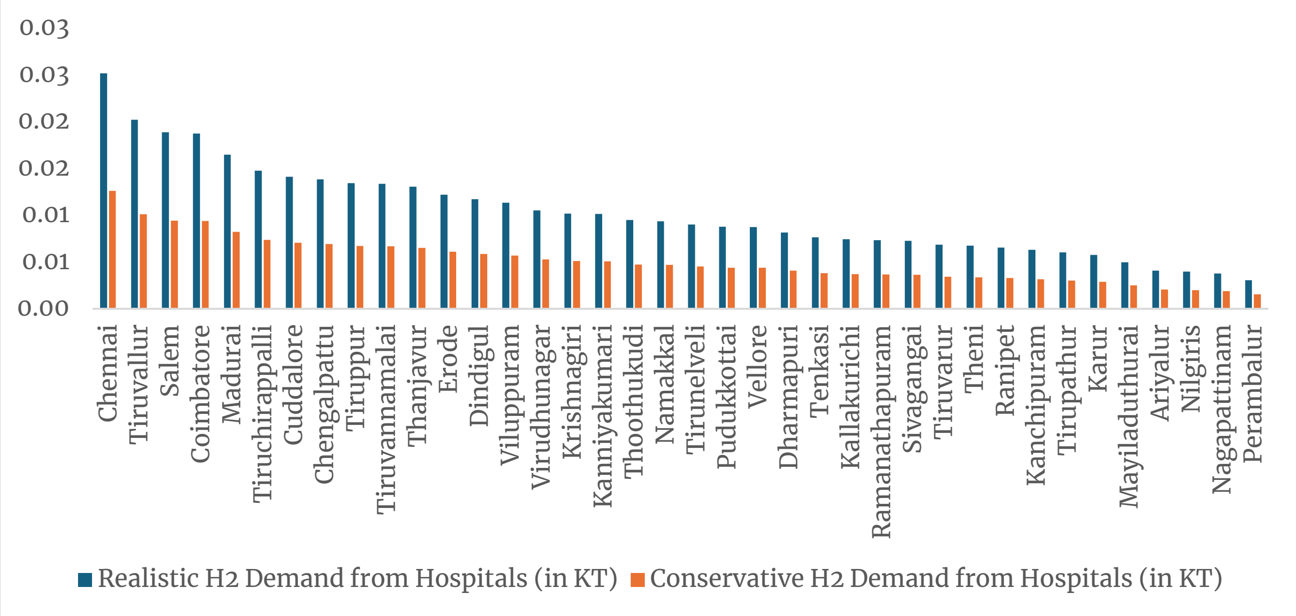
Figure 20: Hydrogen demand (KT) in power backup for hospitals in Uttar Pradesh for 8-hour requirement




Source: Internal Analysis

The top 10 demand centers for Tamil Nadu and Uttar Pradesh and their corresponding hydrogen demand for power backup for hospitals have been shown in the table below

Figure 21: Hydrogen demand (KT) in power backup for hospitals in Tamil Nadu for 1-hour requirement




Source : Internal analysis

Table 15: Top 10 Hydrogen demand centers for Hospital Power Backup systems in Tamil Nadu

| Rank | District | H2 Demand for 1 Hour Requirement with Conservative Energy Use (in KT) | H2 Demand for 1 Hour Requirement with Realistic Energy Use (in KT) |
|---|---|---|---|
| 1 | Chennai | 0.03 | 0.01 |
| 2 | Tiruvallur | 0.02 | 0.01 |
| 3 | Salem | 0.02 | 0.01 |
| 4 | Coimbatore | 0.02 | 0.01 |
| 5 | Madurai | 0.02 | 0.01 |
| 6 | Tiruchirappalli | 0.01 | 0.01 |
| 7 | Cuddalore | 0.01 | 0.01 |
| 8 | Chengalpattu | 0.01 | 0.01 |
| 9 | Tiruppur | 0.01 | 0.01 |
| 10 | Tiruvannamalai | 0.01 | 0.01 |

Source: Internal Analysis

Table 16: Top 10 Hydrogen demand centers for Hospital Power Backup systems in Uttar Pradesh

| Rank | District | $H_2$ Demand for 4 Hour Requirement with Realistic Energy Use (in KT) | $H_2$ Demand for 4 Hour Requirement with Conservative Energy Use (in KT) | $H_2$ Demand for 8 Hour Requirement with Realistic Energy Use (in KT) | $H_2$ Demand for 8 Hour Requirement with Conservative Energy Use (in KT) |
|---|---|---|---|---|---|
| 1 | Allahabad | 0.10 | 0.05 | 0.20 | 0.10 |
| 2 | Azamgarh | 0.08 | 0.04 | 0.16 | 0.08 |
| 3 | Lucknow | 0.08 | 0.04 | 0.16 | 0.08 |
| 4 | Kanpur Nagar | 0.08 | 0.04 | 0.16 | 0.08 |
| 5 | Jaunpur | 0.08 | 0.04 | 0.15 | 0.08 |
| 6 | Sitapur | 0.08 | 0.04 | 0.15 | 0.08 |
| 7 | Bareilly | 0.08 | 0.04 | 0.15 | 0.08 |
| 8 | Gorakhpur | 0.08 | 0.04 | 0.15 | 0.08 |
| 9 | Agra | 0.07 | 0.04 | 0.15 | 0.07 |
| 10 | Hardoi | 0.07 | 0.03 | 0.14 | 0.07 |

Source: Internal Analysis

# Power Back-up to replace diesel generators in Telecom Towers

In the past decade, the telecommunication industry has experienced unprecedented growth of approx. 33%, leading to an ever-increasing reliance on reliable energy. Industry sources suggest that India's telecom industry is expected to grow at a CAGR of 9.4% till 2028. As the demand for continuous and reliable communication services increases and as the globe moves towards higher levels of communications requiring excessive energy, finding sustainable and eco-friendly backup energy solutions has become imperative. Green hydrogen emerges as a promising candidate in this endeavor, offering a clean and efficient alternative for powering telecom towers, particularly during power outages and in remote areas.

Green hydrogen's eco-credentials are a standout feature in the drive for sustainability. When utilized in fuel cells, hydrogen reacts with oxygen to produce electricity, leaving behind only water and heat as byproducts. This environmentally friendly process stands in stark contrast to traditional backup power options, like diesel generators, which often release harmful emissions and contribute to climate change. By incorporating hydrogen as a backup energy source, telecommunication companies can significantly reduce their carbon footprint and align their operations with global efforts to combat environmental challenges.

A notable advantage of hydrogen-based systems lies in their energy storage capabilities. In remote or off-grid areas where grid power is unavailable or unreliable, hydrogen offers a reliable means of storing energy for future use.

The longevity of hydrogen-based backup systems is another aspect that makes them appealing to the telecommunication industry. Unlike conventional battery solutions, which may have limited duration backup, hydrogen fuel cells can provide power for extended periods. This characteristic is particularly advantageous in remote or disaster-prone regions where maintaining continuous communication is critical for emergency response and disaster management.

However, the integration of hydrogen as a backup energy source does present some challenges. The initial investment and ongoing maintenance costs associated with hydrogen production, fuel cells, and the required infrastructure may be significant considerations for telecom companies.[48]

**Demand Estimation**

**Uttar Pradesh**

For telecom sector, the state boasts the highest share of diesel consumption which stands at 32% because of high number of mobile Base Trans-receiver Stations (BTS).[49] All these towers are potential sites to be powered by renewable sources of energy and reduce the reliance on diesel. Total unconstrained hydrogen demand for telecom towers was estimated to be 82.74 KT for 8-hours power outage scenario and 41.37 KT for 4-hours power outage.

Table 17: Green Hydrogen Requirement in Telecom Towers (KT) for Uttar Pradesh

| S. No | District | Hydrogen Demand in KT (8 hours power outage) | Hydrogen Demand in KT (4 hours power outage) | S. No | District | Hydrogen Demand in KT (8 hours power outage) | Hydrogen Demand in KT (4 hours power outage) |
|---|---|---|---|---|---|---|---|
| 1 | Agra | 1.8 | 0.9 | **19** | Jalaun | 0.7 | 0.3 |
| 2 | Aligarh | 1.5 | 0.8 | **20** | Jaunpur | 1.9 | 0.9 |
| 3 | Allahabad | 2.5 | 1.2 | **21** | Jhansi | 0.8 | 0.4 |

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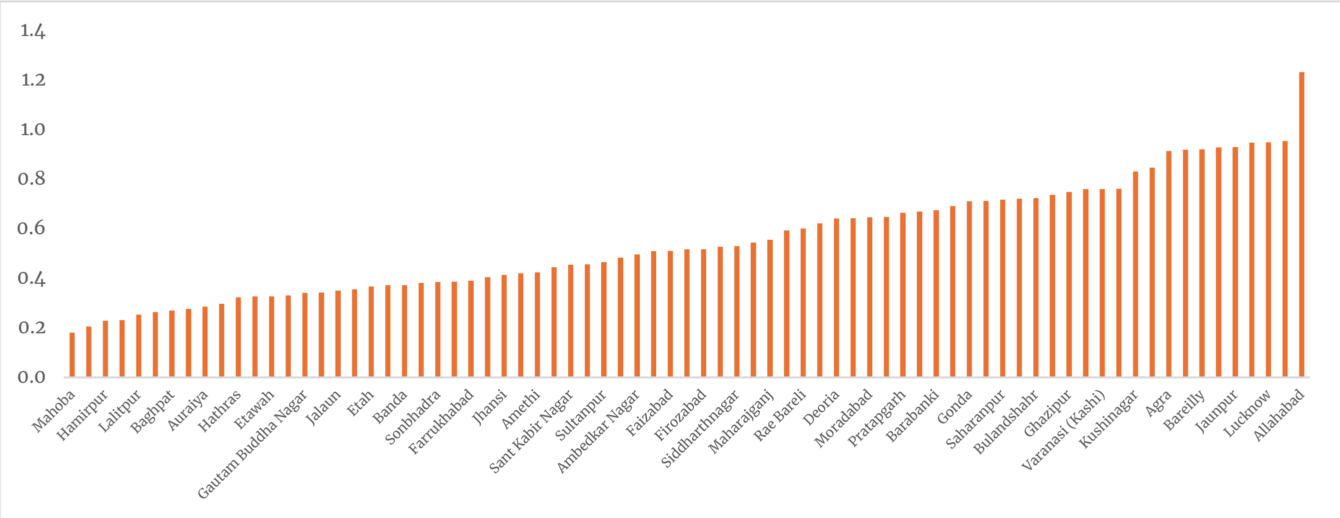
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | Ambedkar Nagar | 1.0 | 0.5 | 22 | Kannauj | 0.7 | 0.3 |
| 9 | Amethi | 0.9 | 0.4 | 23 | Kanpur Dehat | 0.8 | 0.4 |
| | Amroha | 0.8 | 0.4 | 24 | Kanpur Nagar | 1.9 | 0.9 |
| 7 | Auraiya | 0.6 | 0.3 | 25 | Kasganj | 0.6 | 0.3 |
| 8 | Azamgarh | 1.9 | 1.0 | 26 | Kaushambi | 0.7 | 0.3 |
| 9 | Badaun | 1.3 | 0.6 | 27 | Kushinagar | 1.7 | 0.8 |
| 10 | Baghpat | 0.5 | 0.3 | 28 | Lakhimpur Kheri | 1.5 | 0.7 |
| 11 | Bahraich | 1.5 | 0.7 | 29 | Lalitpur | 0.5 | 0.3 |
| 12 | Ballia | 1.4 | 0.7 | 30 | Lucknow | 1.9 | 1.0 |
| 13 | Balrampur | 0.9 | 0.4 | 31 | Maharajganj | 1.1 | 0.6 |
| 14 | Banda | 0.8 | 0.4 | 32 | Mahoba | 0.4 | 0.2 |
| 15 | Barabanki | 1.4 | 0.7 | 33 | Mainpuri | 0.8 | 0.4 |
| 16 | Bareilly | 1.9 | 0.9 | 34 | Mathura | 1.1 | 0.5 |
| 17 | Basti | 1.0 | 0.5 | 35 | Mau | 0.9 | 0.5 |
| 18 | Bijnor | 1.5 | 0.8 | 36 | Meerut | 1.4 | 0.7 |
| 37 | Bulandshahr | 1.5 | 0.7 | 56 | Mirzapur | 1.0 | 0.5 |
| 38 | Chandauli | 0.8 | 0.4 | 57 | Moradabad | 1.3 | 0.6 |
| 39 | Chitrakoot | 0.4 | 0.2 | 58 | Muzaffarnagar | 1.2 | 0.6 |
| 40 | Deoria | 1.3 | 0.6 | 59 | Pilibhit | 0.8 | 0.4 |
| 41 | Etah | 0.7 | 0.4 | 60 | Pratapgarh | 1.3 | 0.7 |
| 42 | Etawah | 0.7 | 0.3 | 61 | Rae Bareli | 1.2 | 0.6 |
| 43 | Faizabad | 1.0 | 0.5 | 62 | Rampur | 1.0 | 0.5 |
| 44 | Farrukhabad | 0.8 | 0.4 | 63 | Saharanpur | 1.4 | 0.7 |
| 45 | Fatehpur | 1.1 | 0.5 | 64 | Sant Kabir Nagar | 0.9 | 0.5 |
| 46 | Firozabad | 1.0 | 0.5 | 65 | Sant Ravidas Nagar | 0.7 | 0.4 |
| 47 | Gautam Buddha Nagar | 0.7 | 0.3 | 66 | Sambhal | 0.7 | 0.3 |
| 48 | Ghaziabad | 1.4 | 0.7 | 67 | Shahjahanpur | 1.3 | 0.6 |
| 49 | Ghazipur | 1.5 | 0.7 | 68 | Shamli | 0.5 | 0.3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 50 | Gonda | 1.4 | 0.7 | **69** | Shravasti | 0.5 | 0.2 |
| 51 | Gorakhpur | 1.9 | 0.9 | **70** | Siddharthnagar | 1.1 | 0.5 |
| 52 | Hamirpur | 0.5 | 0.2 | **71** | Sitapur | 1.9 | 0.9 |
| 53 | Hapur | 0.6 | 0.3 | **72** | Sonbhadra | 0.8 | 0.4 |
| 54 | Hardoi | 1.7 | 0.8 | **73** | Sultanpur | 0.9 | 0.5 |
| 55 | Hathras | 0.7 | 0.3 | **74** | Unnao | 1.3 | 0.6 |
| | | | | **75** | Varanasi (Kashi) | 1.5 | 0.8 |

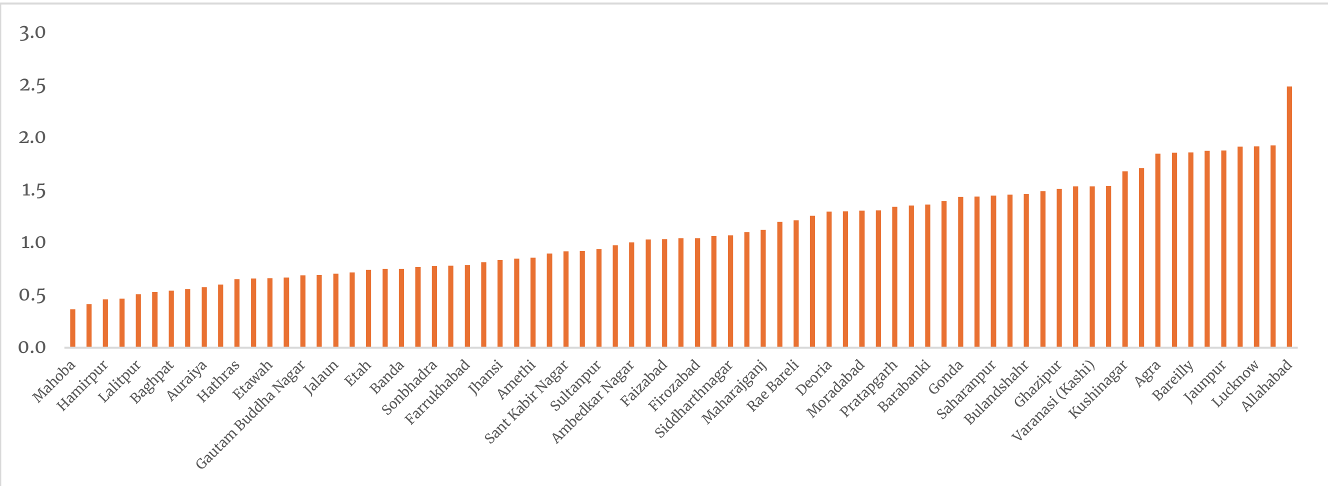
Source: Internal Analysis

Figure 22: Hydrogen demand (KT) for 4 hours of power outage (Uttar Pradesh)




Source: Internal Analysis

Figure 23: Hydrogen Demand (KT) for 8 hours of power outage (Uttar Pradesh)




Source: Internal Analysis

**Tamil Nadu**

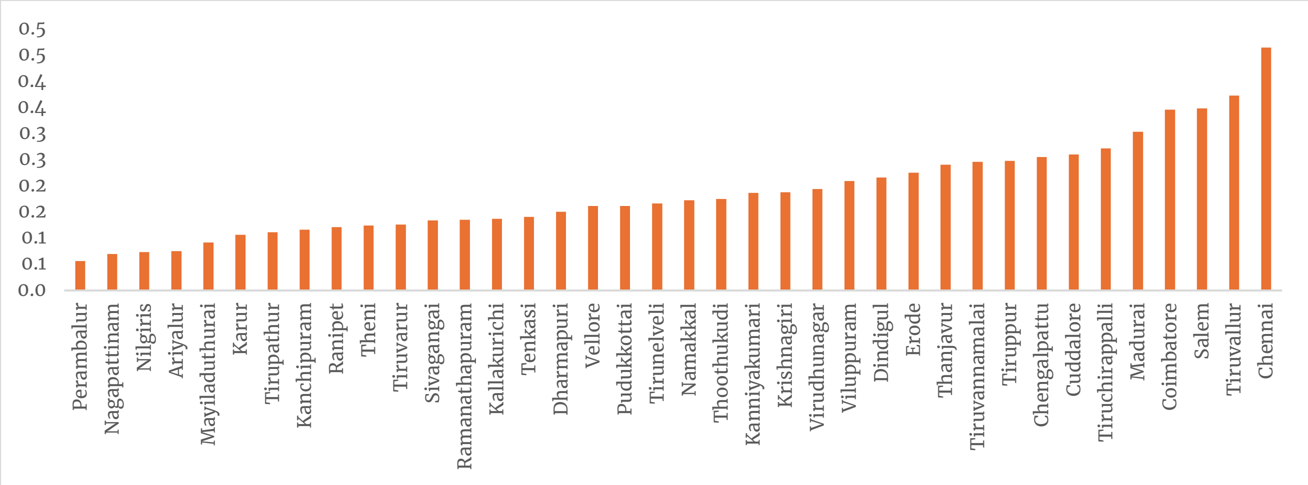
Total hydrogen demand is estimated to be 7.19 KT in the state.

Table 18: Green Hydrogen Requirement in Telecom Towers (KT) for Tamil Nadu

| S. No. | District | Hydrogen Demand in KT | S. No. | District | Hydrogen Demand in KT |
|---|---|---|---|---|---|
| 1 | Ariyalur | 0.1 | 20 | Pudukkottai | 0.2 |
| 2 | Chengalpattu | 0.3 | 21 | Ramanathapuram | 0.1 |
| 3 | Chennai | 0.5 | 22 | Ranipet | 0.1 |
| 4 | Coimbatore | 0.3 | 23 | Salem | 0.3 |
| 5 | Cuddalore | 0.3 | 24 | Sivagangai | 0.1 |
| 6 | Dharmapuri | 0.2 | 25 | Tenkasi | 0.1 |
| 7 | Dindigul | 0.2 | 26 | Thanjavur | 0.2 |
| 8 | Erode | 0.2 | 27 | Theni | 0.1 |
| 9 | Kallakurichi | 0.1 | 28 | Thoothukudi | 0.2 |
| 10 | Kanchipuram | 0.1 | 29 | Tiruchirappalli | 0.3 |
| 11 | Kanniyakumari | 0.2 | 30 | Tirunelveli | 0.2 |
| 12 | Karur | 0.1 | 31 | Tirupathur | 0.1 |
| 13 | Krishnagiri | 0.2 | 32 | Tiruppur | 0.2 |
| 14 | Madurai | 0.3 | 33 | Tiruvallur | 0.4 |
| 15 | Mayiladuthurai | 0.1 | 34 | Tiruvannamalai | 0.2 |
| 16 | Nagapattinam | 0.1 | 35 | Tiruvarur | 0.1 |
| 17 | Namakkal | 0.2 | 36 | Vellore | 0.2 |
| 18 | Nilgiris | 0.1 | 37 | Viluppuram | 0.2 |
| 19 | Perambalur | 0.1 | 38 | Virudhunagar | 0.2 |

Source: Internal Analysis

Figure 24: Hydrogen demand (KT) for 1 hour of power outage (Tamil Nadu)

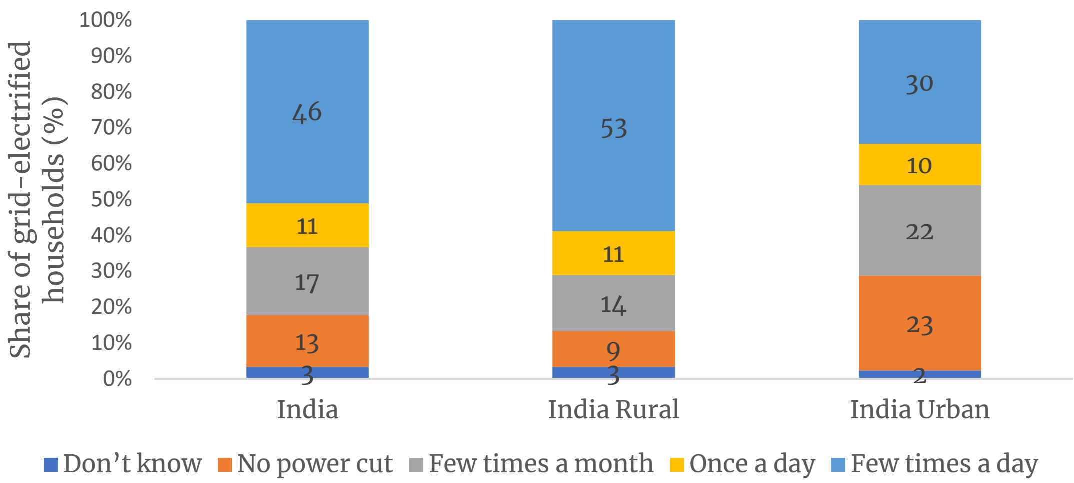



Source: Internal Analysis

# Decentralised Power Supply or for Remote Villages

In the pursuit of ensuring equitable growth opportunities to the entire population of the country, providing access to reliable electricity is a critical requirement. While India has made strides in providing electricity access in the past decade, there are still many remote villages which do not enjoy uninterrupted access to power.[50] In most remote villages and towns, power blackouts are largely unpredictable, and people have to tolerate multiple interruptions daily.

Figure 25: Power Outage Statistics of India




Source: CEEW [50]

50 Council On Energy, Environment and Water

A survey conducted by the CEEW highlighted that nearly two-thirds of rural households in India face power failure at least once a day. Only 9% of rural and 23% of urban grid users reportedly receive almost an uninterrupted supply.[50]

In order to ensure access by overcoming geographical barriers and the high costs associated with extending grid connectivity, alternative options such as decentralised power supply solutions are being explored.[51] These alternatives include solar micro-grids, hybrid micro-grids, among others. Hydrogen emerges as an avenue with promise, offering a clean and efficient energy source to empower these remote communities. Hydrogen-based hybrid energy systems have the potential to revolutionize energy access in remote villages. These systems harness renewable energy sources, such as solar, wind, or hydropower, to power electrolysis, which converts surplus energy into hydrogen.

The stored hydrogen can then be utilized efficiently for later use (during RE downtime), providing a dependable and constant power source independent of centralized grids. This versatility and scalability can allow these power systems to be adapted to meet the specific energy demands of diverse remote villages, from single households to microgrids serving entire communities, ensuring maximum efficiency and resource optimization. One of the significant challenges faced by remote villages with intermittent energy sources, such as solar or wind, is energy storage. Hydrogen proves to be a reliable storage medium, allowing excess energy generated during peak periods to be stored for use during low production periods. This energy balancing feature ensures a stable and consistent power supply, promoting resilience and adaptability to varying environmental conditions.

While hydrogen technology shows immense promise, its successful implementation in remote villages requires addressing certain challenges. The initial investments for setting up hydrogen production, storage, and fuel cell technologies can be substantial.[52] Ensuring adequate funding and support from governments and organizations is essential to overcome financial barriers. Furthermore, providing technical expertise and training to local communities is vital for the effective operation and maintenance of these systems. Empowering residents with the knowledge and skills to manage hydrogen-based power solutions will foster self-sufficiency and sustainability in the long run.

**Demand Estimation**

Government data suggests that every household in Uttar Pradesh and Tamil Nadu has been electrified through grid connectivity, or the installation of diesel-based generator, or micro-grids. However, it has been observed through various secondary sources that the

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consistent electricity supply is still limited in remote villages (at least in terms of duration of electricity supplied).

In the present analysis, the objective is to identify such remote villages that can be powered through a hybrid model of solar microgrid coupled with hydrogen backup system. Government has identified various villages to be electrified through mini/micro grids. Based on the government initiatives, these villages may be considered to have limited availability of electricity and can be considered for hydrogen based mini grids. Similarly, there are villages which have been reported to have limited electricity availability in different surveys and studies. Leveraging such data points, on best effort basis, several villages were identified.

Based on the analysis for Uttar Pradesh, the hydrogen demand was estimated to be approx. 3.37 KTPA and 6.75 KTPA for 8-hour and 16-hour scenarios respectively. For Tamil Nadu, the hydrogen demand is estimated to be approx. 0.13 KTPA and 0.26 KTPA for 8-hour and 16-hour scenarios respectively. A summary of the above results disaggregated by village and district name has been tabulated below.

Table 19. Hydrogen demand analysis for Uttar Pradesh

| District | Village name[53] | Annual H2 Demand considering 8-hour power back up (in KTPA) | Annual H2 Demand considering 16-hour power back up (in KTPA) |
|---|---|---|---|
| Hardoi | Jharuiya | 0.024 | 0.048 |
| | Nevada vijay | 0.012 | 0.023 |
| | Beruwa | 0.016 | 0.031 |
| | Gaaju | 0.014 | 0.029 |
| | Badagaon | 0.009 | 0.018 |
| | Kamalpur | 0.012 | 0.023 |
| | Som | 0.003 | 0.006 |
| | Janigaon | 0.034 | 0.069 |
| | Kothawan | 0.015 | 0.030 |
| | Kursath | 0.003 | 0.006 |
| | Sinduriabagh | 0.000 | 0.006 |
| Sultanpur | Jagdishpur | 0.001 | 0.002 |
| Gonda | Mathia | 0.467 | 0.934 |

53 UPNEDA - Status-MiniGrid CSE India – Mini grid in UP report Statistics at glance 2021-2022, Uttar Pradesh Power Limted

| | | | |
|---|---|---|---|
| Kanpur | Swuansi Khera (comprises 900)[54] | 2.336 | 4.672 |
| Amroha | Daranagar | 0.043 | 0.086 |
| Sitapur | Basura | 0.011 | 0.021 |
| | Tikdha | 0.014 | 0.029 |
| | Garhi | 0.007 | 0.014 |
| | Kaima | 0.007 | 0.014 |
| | Bihatgaur | 0.005 | 0.010 |
| | Aurangabad | 0.011 | 0.021 |
| | Sanda | 0.009 | 0.019 |
| | Gonda deoria | 0.004 | 0.008 |
| | Sambaripurwa | 0.004 | 0.008 |
| | Maholi | 0.012 | 0.024 |
| | Biswa | 0.005 | 0.011 |
| | Saray pitthu | 0.020 | 0.041 |
| | Mehmudabad | 0.004 | 0.007 |
| Unnao | Barithana | 0.014 | 0.028 |
| | Devrakala | 0.005 | 0.010 |
| | Bangarmau | 0.004 | 0.009 |
| Lakhimpur | Behjum | 0.014 | 0.029 |
| | Bhurwara | 0.005 | 0.009 |
| | Sansarpur | 0.017 | 0.034 |
| | Adhachat | 0.012 | 0.023 |
| | Mailani | 0.009 | 0.019 |
| | Kotra | 0.004 | 0.009 |
| Farrukabad | Kampilkhas | 0.014 | 0.028 |
| | Khudaganj | 0.025 | 0.049 |
| | Pipargaon | 0.014 | 0.029 |
| | Ataipur jadid | 0.017 | 0.035 |
| Shahjanpur | Hamjapur | 0.017 | 0.035 |
| | Sehwaj nagar bangar | 0.017 | 0.034 |

54 Energypedia- Energizing Rural India Using Micro-Grids-The case of Solar DC Micro Grids in Uttar Pradesh State India

| | | | |
|---|---|---|---|
| | Kanth | 0.010 | 0.020 |
| | Chakkanhu | 0.010 | 0.020 |
| | Banda | 0.013 | 0.026 |
| | Gangsara | 0.009 | 0.019 |
| | Chaudhera | 0.004 | 0.008 |
| Raibareilly | Maneharoo | 0.004 | 0.007 |
| | Jagatpur | 0.007 | 0.013 |
| | Belaguasisi | 0.004 | 0.009 |
| | Govindpur bhera | 0.005 | 0.010 |
| | Aihar | 0.005 | 0.009 |
| | Bahai | 0.004 | 0.008 |
| Pratapgarh | Dhingwas | 0.004 | 0.008 |
| **Total** | | **3.37 KTPA** | **6.747 KTPA** |

Source: Internal Analysis

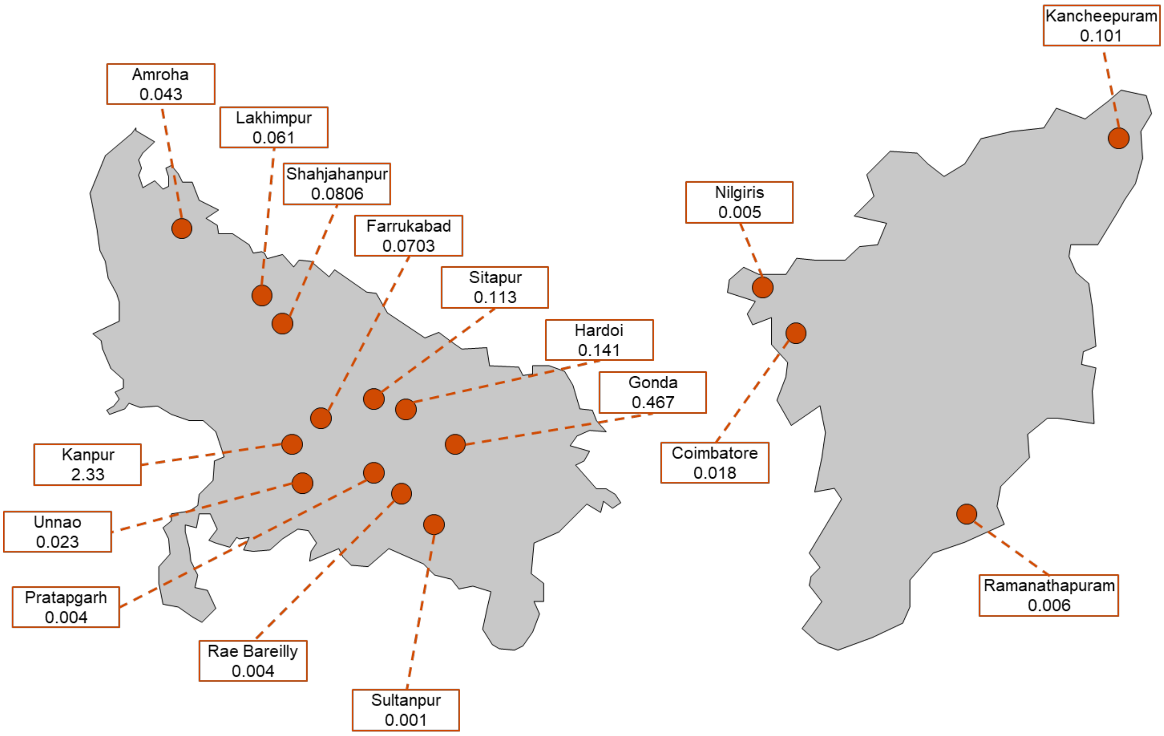
Table 20. Hydrogen demand analysis for Tamil Nadu

| District | Villages[55] | Annual Hydrogen Demand considering 8-hour power back up (in KTPA) | Annual Hydrogen Demand considering 16-hour power back up (in KTPA) |
|---|---|---|---|
| Nilgris | Sembukkarai | 0.005 | 0.0105 |
| Coimbatore | Thoomanur | 0.018 | 0.0350 |
| Kanchipuram | Echur | 0.101 | 0.2026 |
| Ramanathapuram | Chinna Mayilar | 0.006 | 0.0112 |
| **Total** | | **0.13 KTPA** | **0.26 KTPA** |

Source: Internal Analysis

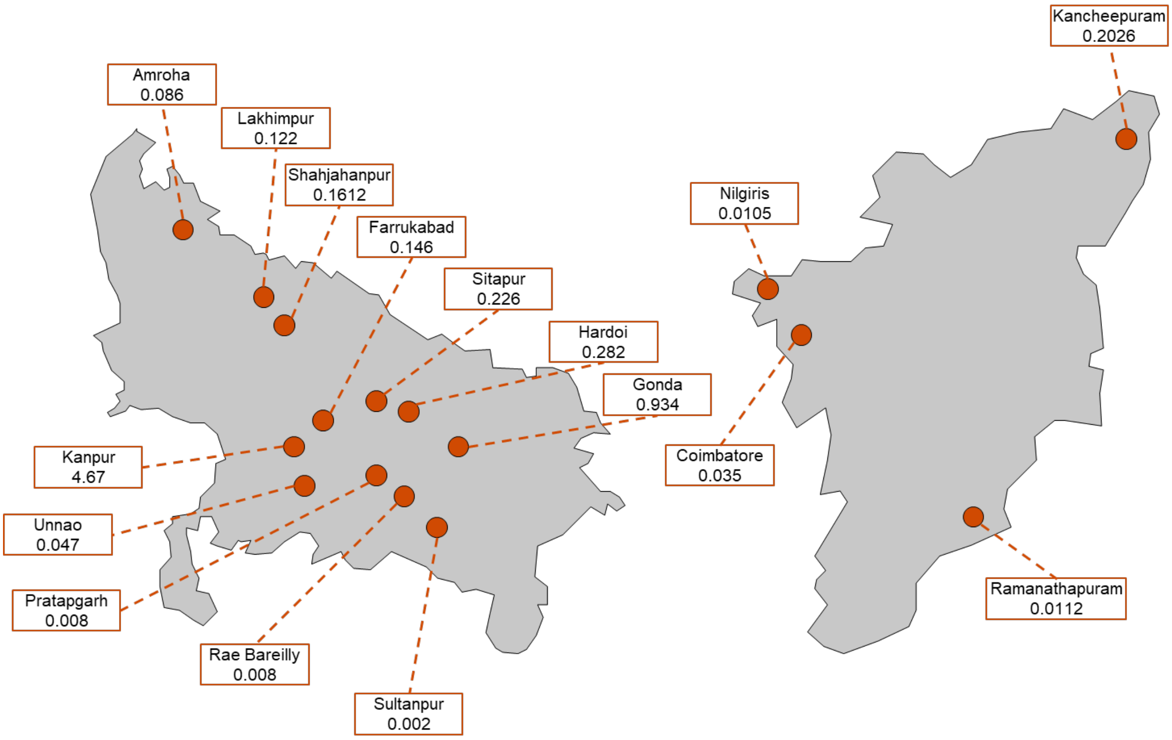
55 Tamil Nadu Energy development Agency Oxford University Press - microgrid for the secluded Paana Theertham Kani settlement

Figure 26: Hydrogen demand for Uttar Pradesh and Tamil Nadu (8 hours of power backup) in KTPA




Source: Internal Research

Figure 27: Hydrogen demand for Uttar Pradesh and Tamil Nadu (16 hours of power backup) in KTPA




Source: Internal Research

## 1.6.2. Hydrogen in mobility

India is the third largest emitter of CO2 globally. In order to lower its carbon footprint and achieving the aim of being carbon neutral by 2070, the government is prioritizing the adoption of green hydrogen. In its attempt to go green, heavy-duty mobility has been identified as one of the major sectors which is earmarked for the uptake of green hydrogen. The transportation industry is undergoing a transition to decarbonize, as the regulatory changes and changing consumer preferences are causing the entire value chain to rethink its position and operations to adopt the greener alternatives. While the momentum for electric vehicles is picking up in the passenger vehicle category, the possibility that a similar trend shall be witnessed in long-haul trucking seems low.[56] This is due to the inherent nature of the industry which regularly witnesses long distances, unpredictable routes, inconsistent road infrastructure, high uptime needs and heavy payloads. These all factors have made it hard for the sector to decarbonize and meet the pace at which the rest of the automotive industry is progressing. Hence, based on this scenario, electrification of heavy-duty mobility is particularly challenging.

In order to overcome such challenges, heavy-duty mobility industry is focusing on using Hydrogen as a power source, either in the form of fuel cell-based vehicles or internal combustion-based engines. The assessments regarding the same reveal that Hydrogen FCEVs become cost competitive for long range heavy trucks (>800 km) by 2035.[57] Since economics are the most likely factor to drive adoption of Hydrogen based trucking, demand is expected to rise once cost parity is reached.

The current study focusses specifically on the heavy-duty transport sectors (trucks and buses) as hydrogen-based solutions are better equipped for replacing heavy-duty internal combustion-based engines. Due to the nature of their operations which involve intense and long-range travel $H_2$ based fuel cells might be a better alternative than the battery electric vehicles which are witnessing a high adoption rate in the passenger vehicle segment. Due to the high energy requirements, the mass of the battery is expected to increase and reduce the volume available for cargo. Thus, the cost and energy consumption of the vehicle would increase if a battery electric vehicle option is selected.[58] Alternatively, hydrogen tanks take up less space and are lighter than batteries allowing more cargo to be shipped.

**Demand Estimation**

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56 Industry Sources

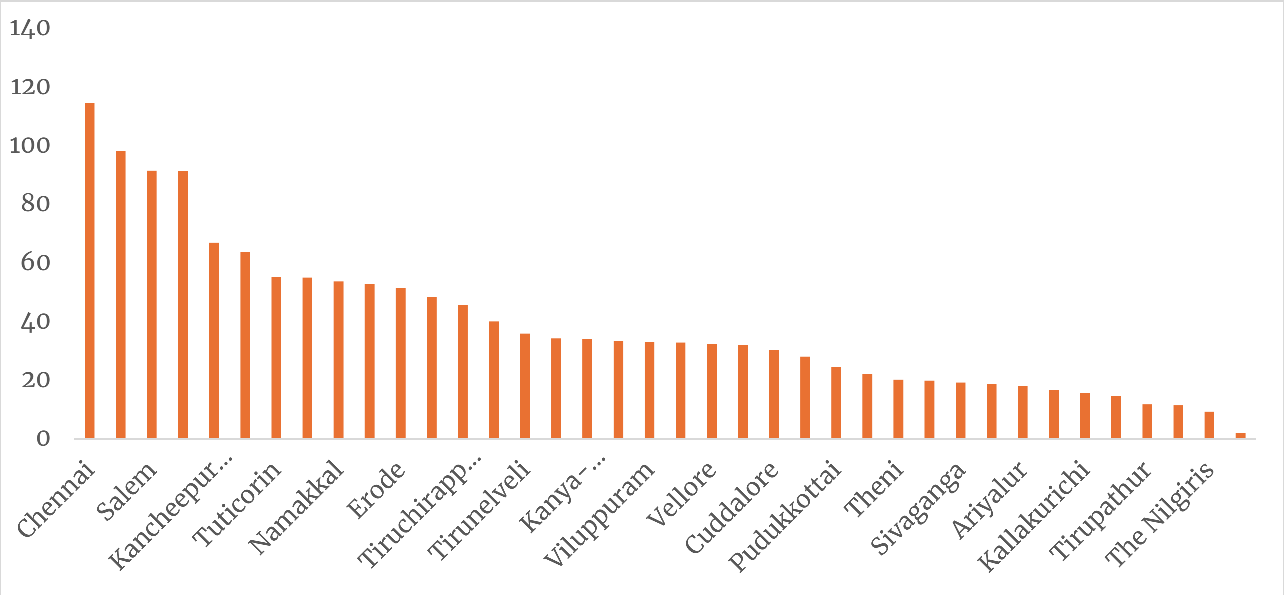
57 National Renewable Energy Laboratory (U.S Department of Energy)

58 Hydrogen fuel cell heavy-duty trucks: Review of main research topics (Elsevier)

Research on the consumption patterns of diesel in India revealed that the transport segment accounted for 87% share of the diesel sold through retail channels. The diesel uptake by trucking (Light Commercial Vehicle/Heavy Commercial Vehicles) and buses stood at 64.2% and 4.1% respectively.[59]

For the demand assessment arising from the heavy-duty mobility sector, which comprises of trucks and passenger buses, the unconstrained Hydrogen demand was calculated assuming the transition potential of the entire fleet to using green hydrogen as a fuel. The actual diesel demand through retail channels was assessed and demarcated at the district-level to understand demand density. Consequently, the total hydrogen demand for both the states was found out to be 4,380 KT. Uttar Pradesh stood at 2,901 KT while Tamil Nadu stood at 1,479 KT. The district-wise breakdown of demand for the 2 states has been given below.

Figure 28: Mobility - District-wise hydrogen demand in Tamil Nadu (in KT)



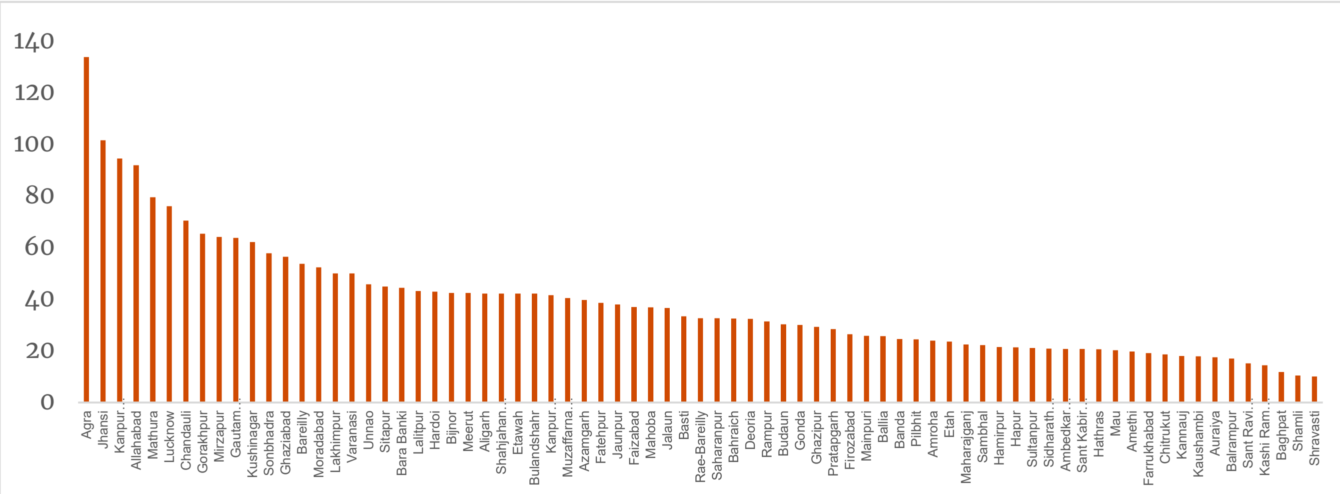

Source: Internal Analysis

59 Petroleum Planning & Analysis Cell

# Identification of Potential Hydrogen Highways in the two states

The heavy mobility segment is expected to be the early adopters who might transition into using hydrogen as a fuel. Hence, to supplement the above analysis, identification of possible highways routes where hydrogen refueling stations could be installed was conducted. The top 5 high volume traffic highways were shortlisted for both Tamil Nadu and Uttar Pradesh each. The summary of these findings has been given below.

Figure 29: Mobility - District-wise hydrogen Demand in Uttar Pradesh (in KT)




Source: Internal Analysis

Table 21: Highways in Tamil Nadu with high traffic volumes

| Rank | National Highway Number |
|---|---|
| **1** | **NH 48** |
| High Traffic Volume Section | Krishnagiri – Walajahpet |
| | Walajapet – Poomalle |
| **2** | **NH 5** |
| High Traffic Volume Section | Chennai – Tada |
| **3** | **NH 45** |
| High Traffic Volume Section | Chennai Bypass |
| | Madurai Toturian |
| | Madurai Tuticorin |

| | |
|---|---|
| | Padalur – Trichy |
| | Tambaram - Tindivanam (Km 28.000 - Km 74.500) |
| | Tambaram - Tindivanam (Km 74.500 - Km 121.000) |
| | Tindivanam – Ulundurpet |
| | Trichi Bypass - Tovarankurichi – Madurai |
| | Trichy – Dindigul |
| | Ulundurpet – Padalur |
| **4** | **NH 44** |
| High Traffic Volume Section | Hosur – Krishnagiri |
| | Karur Bypass - Dindigul bypass |
| | Krishnagiri – Thumbipadi |
| | Omallur – Namakkal |
| **5** | **NH 544** |
| High Traffic Volume Section | Chengapalli - Coimbatore Byepass(Km 102.035 to 144.680) |
| | Kumarapalayam - Chengalpalli |
| | Salem Kumarapalayam |

Source: Internal Analysis, National Highway Authority of India

Table 22: Highways in Uttar Pradesh with high traffic volumes

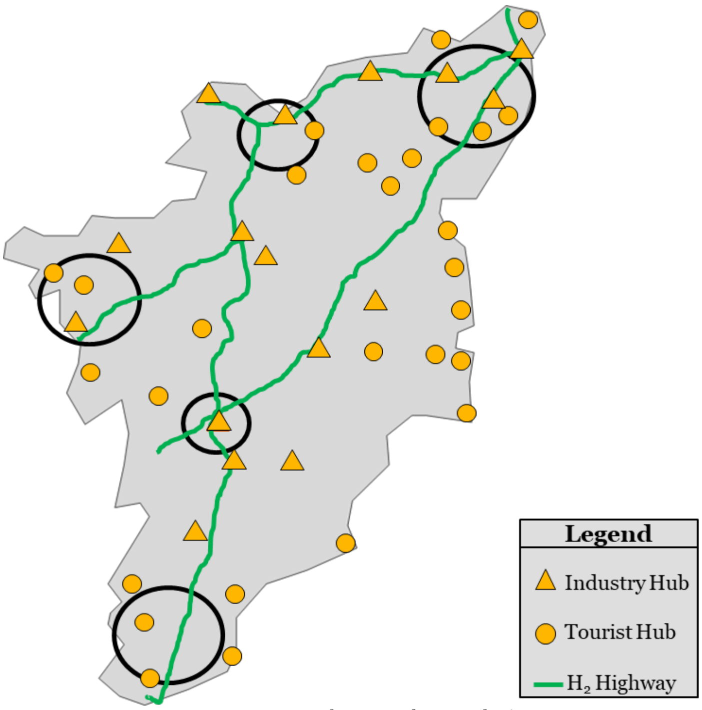
| Rank | National Highway Number |
|---|---|
| **1** | **NH 58** |
| High Traffic Volume Section | Meerut – Muzaffarnagar |
| **2** | **NH 334** |
| High Traffic Volume Section | Meerut Bulandsahar |
| **3** | **NE II** |
| High Traffic Volume Section | From Km 1.000 to 22.000 |

| | |
|---|---|
| | From Km 22.000 to 46.500 |
| | From Km 46.500 to 71.000 |
| | From Km 71.000 to 93.000 |
| | From Km 93.000 to 114.00 |
| **4** | **NH27** |
| High Traffic Volume Section | Jhansi Orai section of NH25 (New NH27) from Km. 90.300 to Km. 225.713 (length 135.413 km) |
| **5** | **NH 709AD** |
| High Traffic Volume Section | Panipat to Shamli |

Source: Internal Analysis, National Highway Authority of India

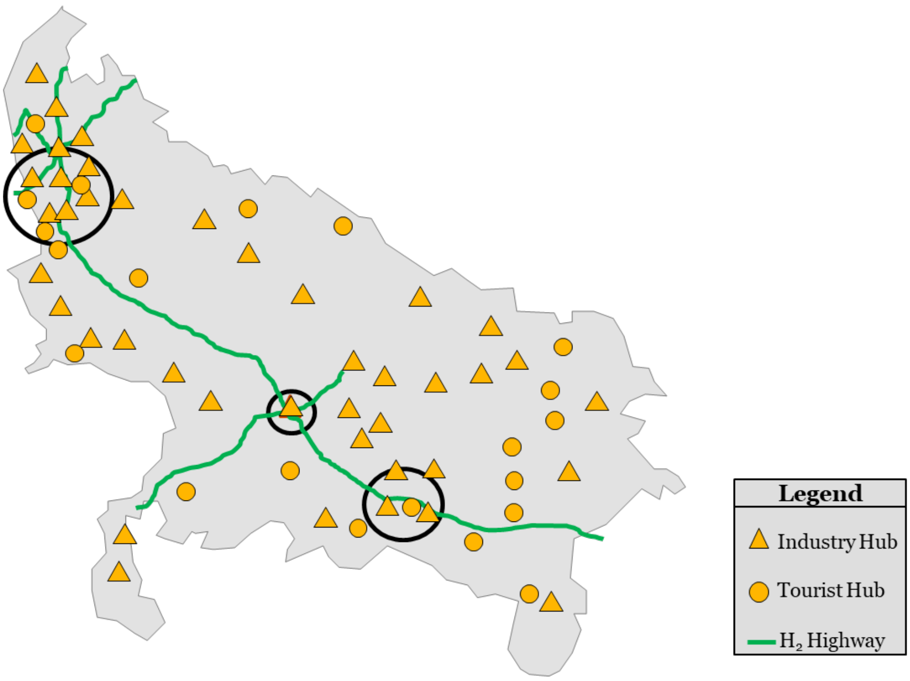
Heavy duty mobility segment is likely to transition into using Green Hydrogen as a fuel, which majorly comprises of trucks and buses. Hence, the tourist hotspots and industrial hubs were also highlighted on a map. The rationale being that these 2 vehicle segments would possibly move to-and-fro between industrial clusters and tourist hotspots/major cities, respectively. All three of these parameters were super imposed on a map to identify possible high volume heavy mobility routes. Similarly, common junctions of these high-volume routes were also selected. The highways which have been listed above superimposed on a map with the respective state's industrial and tourist hubs is given below.

Figure 31: Probable locations for Hydrogen Refueling Stations in Tamil Nadu




Source: Internal Research & Analysis

Figure 30: Probable locations for Hydrogen Refueling Stations in Uttar Pradesh




Source: Internal Research & Analysis

## 1.6.3. Ammonia in Power Sector

In India, major portion its energy needs are being fulfilled by thermal power plants run on coal, which accounts for 75% of the electricity produced in the country.[60] Carbon reduction from coal-based power stations is a key challenge. It is less likely that all the coal-based power plants will be decommissioned in order to meet the country's ambitious net zero goals, as such a step may not be taken at the expense of not fulfilling the current energy needs of the country and the energy that is needed for economic growth. However, gradual retiring of such power plants may happen and in addition potential retrofits may be undertaken by the plants to use an increased amount of alternative low carbon fuels like biomass. Likewise, co-firing of ammonia in thermal power plants is being considered as a solution to a two-pronged problem i.e., decarbonizing the power sector and utilizing the thermal power plants that the country heavily relies on, in a greener and sustainable way. Co-firing involves replacing a portion of the coal used for combustion be replaced by ammonia.

A first of its kind MOU has been signed by NTPC, the country's leading power generating utility, and GE Power India. This MOU is expected to help the parties to demonstrate the feasibility of $NH_3$ co-firing in coal-based power plants with the aim to reduce carbon footprint of existing coal fired power plants. The parties might also explore the possibility of ammonia total co-firing with lower carbon fuels in coal based thermal power plants.[61] In the private sector, Adani Power has signed an MOU as a part of the "Indo-Japan Clean Energy Partnership" to conduct 20% ammonia-coal co-firing in Gujarat's Mundra power plant. They are also expected to investigate the results of increasing the co-firing percentage all the way up to 100% ammonia (mono-firing) in coal-based plants and their possibility to become carbon neutral.[62] Semantically, a 20% co-firing ratio entails ammonia would replace 20% of the coal by energy content.[63]

**Demand Estimation**

To understand what the possible demand of ammonia might be in the states of Uttar Pradesh and Tamil Nadu if 20% ammonia is co-fired, the capacities of all the available thermal power plants in the 2 states were assessed. Assuming that 20% of the energy requirements are met by ammonia, the energy requirement was estimated. The total

60 Ministry of Coal

61 Press Information Bureau

62 Adani Power

63 Industry Sources

ammonia demand for power generation was found to be 2,104 KT and 3,686 KT for Tamil Nadu and Uttar Pradesh, respectively. A summary of the findings is given below.[64]

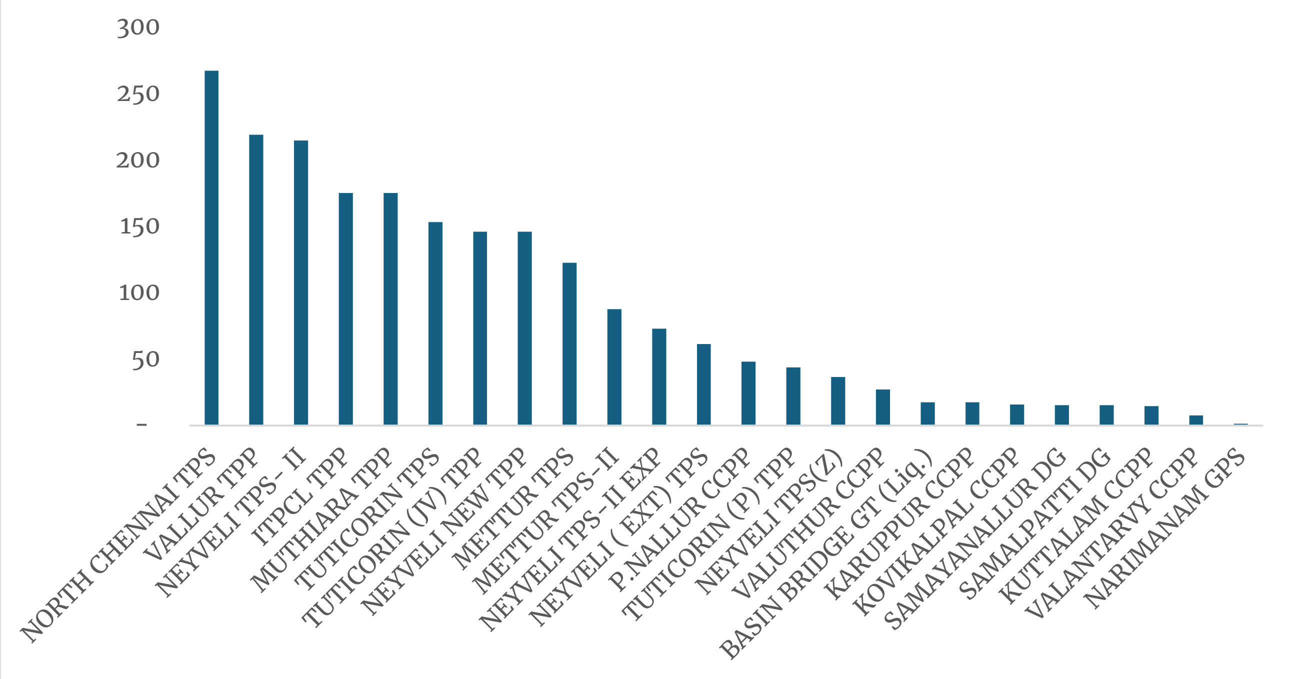
Table 23: Project wise Ammonia Demand in Thermal Power Plants of Tamil Nadu

| Project Name | Ammonia Demand (in KT/year) |
|---|---|
| North Chennai TPS | 268 |
| Vallur TPP | 219 |
| Neyveli TPS- II | 215 |
| ITPCL TPP | 175 |
| Muthiara TPP | 175 |
| Tuticorin TPS | 153 |
| Tuticorin (JV) TPP | 146 |
| Neyveli New TPP | 146 |
| Mettur TPS | 123 |
| Mettur TPS-II | 88 |
| Neyveli TPS-II EXP | 73 |
| Neyveli ( Ext) TPS | 61 |
| P.NALLUR CCPP | 48 |
| Tuticorin (P) TPP | 44 |
| Neyveli TPS(Z) | 37 |
| Valuthur CCPP | 27 |
| Basin Bridge GT (Liq.) | 18 |
| Karuppur CCPP | 18 |
| Kovikalpal CCPP | 16 |
| Samayanallur DG | 15 |
| Samalpatti DG | 15 |
| Kuttalam CCPP | 15 |
| Valantarvy CCPP | 8 |
| Narimanam GPS | 1 |

Source: CEA

64 Consequently, the corresponding hydrogen demand for ammonia in co-firing applications was calculated to be ~378 KT and 663 KT for Tamil Nadu and Uttar Pradesh, respectively.

Figure 32: Project wise Ammonia Demand for for 20% Co-firing in Thermal Power Plants of Tamil Nadu (in KT)




Source: Internal Analysis

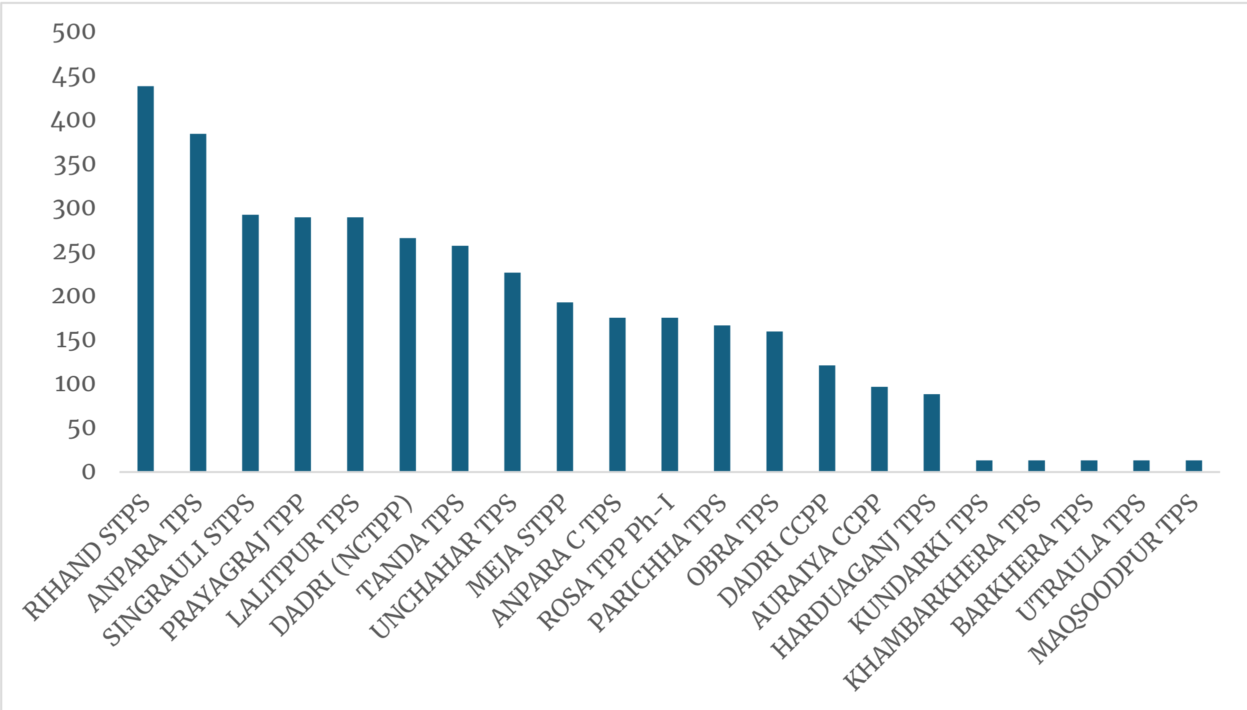
Table 24: Project wise Ammonia Demand in Thermal Power Plants of Uttar Pradesh

| Project Name | Ammonia Demand (in KT/year) |
|---|---|
| Rihand STPS | 439 |
| Anpara TPS | 384 |
| Singrauli STPS | 292 |
| Prayagraj TPP | 289 |
| Lalitpur TPS | 289 |
| Dadri (NCTPP) | 266 |
| Tanda TPS | 257 |
| Unchahar TPS | 227 |
| Meja STPP | 193 |
| Anpara C TPS | 175 |
| Rosa TPP Ph-I | 175 |
| Parichha TPS | 167 |

| | |
|---|---|
| Obra TPS | 160 |
| Dadri CCPP | 121 |
| Auraiya CCPP | 97 |
| Harduaganj TPS | 88 |
| Kundarki TPS | 13 |
| Khambarkhera TPS | 13 |
| Barkhera TPS | 13 |
| Utraula TPS | 13 |
| Maqsoodpur TPS | 13 |

Source: Internal Analysis

Figure 33: Project wise Ammonia Demand for for 20% Co-firing in Thermal Power Plants in Uttar Pradesh (in KT)




Source: Internal Analysis

Although Ammonia co-firing is expected as an alternative to transition currently operational thermal power plants to low emitters, the use of ammonia in the power sector has range of challenges it needs to overcome in order to become a feasible option. At this stage, the co-firing alternative to decarbonization can be considered at the nascent stage, unproved at the commercial scale. Additionally, severe energy losses due to conversion from hydrogen (which is produced from electricity and therefore has losses associated with it) make ammonia a less efficient fuel alternative for power generation. A recent analysis found that co-firing with high ratios on green or blue ammonia is expected to be more expensive than renewables. In order for 20% co-firing to become economically viable, a carbon price of at least USD 400/tCO2 in 2030 may be required.[65] Furthermore, shifting from conventional coal power to 20% ammonia co-firing is expected to double fuel costs, even while using grey ammonia, which is the cheapest form of ammonia available in the market.[66] Due to these reasons, ammonia may not be extensively used in the power sector, via co-firing at the commercial scale unless heavy subsidies and incentives are provided or ammonia is available in surplus supply to bring down its costs.

## 1.6.4. Ammonia for inland waterway transport and maritime shipping

### Maritime Shipping

The shipping sector plays a pivotal role in the global economy enabling the transportation of more than 80% of the world's cargo. Compared to other modes of transporting cargo, shipping allows regional and intercontinental movement of large quantities of cargo in the most fuel and cost-efficient manner. Currently, Heavy Fuel Oil (HFO) is the prevalent fuel of choice for ships due to its large availability and low cost. However, the industry is facing severe backlash over sustainability concerns and usage of fossil fuel-based options. The maritime shipping industry faces serious challenges in adopting new technologies and operational practices to comply with increasingly stricter norms imposed by international, national and local bodies. In line with the Paris agreement, the International Maritime Organization (IMO) has adopted a strategy for a progressive reduction in greenhouse gas (GHG) emissions of the shipping sector, aiming to half it by 2050 compared to 2008 figures. Additionally, strategy includes initial targets to reduce the average carbon dioxide (CO2) emissions per transport work from 2008 levels by at least 40 percent by 2030, and 70 percent by 2050.[67] The strategy proposed by IMO provides different paths for a progressive reduction of GHG emissions, including short-, mid- and long-term measures. But the target set by IMO for 2050 cannot be achieved without the adoption of alternative carbon fuels. In this context, Green Ammonia has developed a growing interest as of the potential fuel candidates for the decarbonization of the shipping industry. [68]

65 BloombergNEF

66 Transition Zero

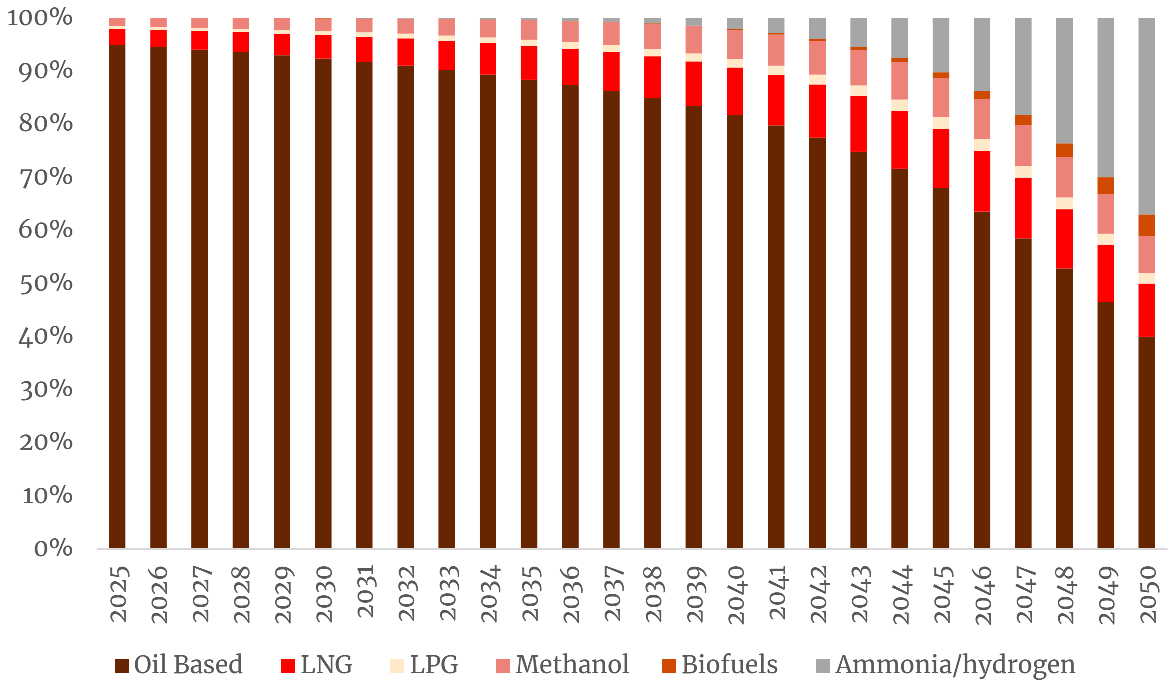
67 International Maritime Organization

68 DNV-GL Maritime forecast to 2050 – Energy Transition Outlook 2019

The potential of ammonia as a fuel for marine engine propulsion is related to the expected fulfillment of emission regulations. In 2012 the International Maritime Organization (IMO) estimated that international shipping accounted for about 2.2% of the total global anthropogenic CO2 emissions, and that emissions from international shipping could further increase due to the growth of the world maritime trade.[69]

In this regard, green ammonia being carbon neutral fuel seems to be one of the strategic fuels for the future. However, adoption of green ammonia as a fuel possesses certain challenges. Currently, there are very limited experiences about combustion of ammonia in a reciprocating engine. Literature reviews suggest that ammonia has high auto ignition temperature, low flame speed and limited flammability limits. To be self-ignited, it will require very high compression rate and temperature, also leading to high production of NOx. Using Ammonia as a fuel would lead to significant changes in the engine room.[70] These modifications would lead to increase in cost of ownership of vessel by 30%-65% by 2030, compared to vessel that runs on Heavy Fuel Oil.[71]

Figure 34: Projected Marine fuel use till 2050




Source: American Bureau of Shipping

Several manufacturers such as DNV and MAN Energy solutions are working on developing of an ammonia fueled engine. As per the latest update, the MAN Energy Solutions is

69 Initial IMO Strategy On Reduction of GHG Emissions

70 Ammonfuel – an industrial view of ammonia as a marine fuel

71 Green corridors: A lane for zero-carbon shipping

planning to have an engine ready for commercial use in 2024.[72] American Bureau of Shipping projected marine fuel use until 2050 as the industry strives to meet the GHG emissions-reduction targets mandated by the IMO as described in below graph.

Based on above discussion, adoption of green ammonia as a marine fuel for bunkering is not expected till 2030. As the technology evolves and experience is garnered for using ammonia in marine propulsion engines along with reduction in cost of green ammonia, the adoption may then increase substantially.

For the Chennai port the fuel bunkering sales volume was estimated to be approx. 47 KT. The associated ammonia demand for this quantity would be 126 KT.

# Inland Waterway Transport

With an aim to promote Inland Water Transport (IWT) in the country, 111 waterways (including 5 existing and 106 new) have been declared as National Waterways (NWs) through the National Waterways act, 2016. Through techno-economic feasibility and detailed project reports of NWs, only 25 NWs have been found to be viable for cargo/passenger movement. Of the 25 NWs, development work for 13 of the NWs has been initiated. Focusing on Tamil Nadu and Uttar Pradesh, the details of the proposed NWs have been listed below.

| Sr. No. | National Waterway No. | Length (km) | Details of Waterways | States Traversed |
|---|---|---|---|---|
| 1 | 1 | 1,620 | Ganga-Bhagirathi-Hooghly River System (Haldia - Allahabad) | Uttar Pradesh, Bihar, Jharkhand & West Bengal |
| 2 | 4 | 2,816 | Multiple | Andhra Pradesh, Telangana, Chhattisgarh, Karnataka, Tamil Nadu, Pondicherry and Maharashtra |
| 3 | 12 | 5.5 | Asi River | Uttar Pradesh |
| 4 | 13 | 11 | Avm Canal | Kerala & Tamil Nadu |
| 5 | 19 | 67 | Betwa River | Uttar Pradesh |
| 6 | 20 | 95 | Bhavani River | Tamil Nadu |
| 7 | 24 | 61 | Chambal River | Uttar Pradesh |

72 Engineering the future two-stroke green-ammonia engine", MAN Energy Solutions, November 2019

| | | | | |
|---|---|---|---|---|
| 8 | 37 | 296 | Gandak River | Bihar & Uttar Pradesh |
| 9 | 40 | 354 | Ghaghra River | Bihar & Uttar Pradesh |
| 10 | 42 | 514 | Gomti River | Uttar Pradesh |
| 11 | 54 | 86 | Karamnasa River | Bihar & Uttar Pradesh |
| 12 | 55 | 311 | Kaveri - Kollidam River System | Tamil Nadu |
| 13 | 69 | 5 | Manimutharu River | Tamil Nadu |
| 14 | 75 | 142 | Palar River | Tamil Nadu |
| 15 | 77 | 20 | Pazhyar River | Tamil Nadu |
| 16 | 80 | 126 | Ponniyar River | Tamil Nadu |
| 17 | 99 | 62 | Tamaraparani River | Tamil Nadu |
| 18 | 103 | 73 | Tons River | Uttar Pradesh |
| 19 | 107 | 46 | Vaigai River | Tamil Nadu |
| 20 | 108 | 53 | Varuna River | Uttar Pradesh |
| 21 | 110 | 1,080 | Yamuna River | Delhi, Haryana & Uttar Pradesh |

Source: Ministry of Ports, Shipping and Waterways 73

Among the 21 NWs proposed by the government in the states of Tamil Nadu and Uttar Pradesh, infrastructure developments and operations have begun on NW 1 and NW 4.[74]

Inland Water Transport (IWT) is regarded as an environmentally friendly cost-effective mode of transport. The comparative cost for movement of freight has been described below which indicates IWT might be an attractive way for shipping in the future, depending on the level of infrastructure development the government undertakes.

Table 25: Comparative Cost of Movement of Freight

| Mode | Railways | Highways | IWT |
|---|---|---|---|
| Freight (Rs./T.km) | 1.36 | 2.50 | 1.06 |

Source: Ministry of Ports, Shipping and Waterways

**Demand Estimation**

73 Ministry of Ports, Shipping and Waterways

74 Ministry of Ports, Shipping and Waterways

To assess the potential ammonia demand, Internal focused only on the operationalized NW1 and NW4. The cargo movement in ton-kms was assessed along both the NWs.[75] The subsequent ammonia demand was analyzed and results have been summarized below.

Table 26: Summary of Results for Inland Water Ways in TN and UP

| National Waterway No. | State of Interest Traversed | Length after completion (in km) | Tonne km 2021-22 (In Lakh) | Ammonia Requirement (in KT) |
|---|---|---|---|---|
| NW 1 | Uttar Pradesh | 1620 | 20082.07 | 21.05 |
| NW 4 | Tamil Nadu | 2816 | 316.47 | 0.33 |

Source: Ministry of Ports, Shipping and Waterways

Even though ammonia demand has been estimated, it is important to highlight that there are currently no in-service ships which can use ammonia as a fuel. Ammonia-fueled engines are not yet commercially available, and no existing vessel models are equipped for ammonia propulsion. Research on the same is underway and 2 stroke and 4 stroke ammonia fueled engines are under development, along with regulations for handling ammonia as a fuel.[76] According to a recent survey of shipping industry leaders representing 20% of the world's current fleet capacity conducted by the global maritime Forum, the Global Centre for Maritime Decarbonisation, and the Mærsk Mc Kinney Møller Center for Zero Carbon Shipping, the sentiment of the industry insiders of the global shipping industry has been captured through the survey. The survey reveals that conventional ship engines are set to remain the preferred technology until at least 2050.[77,78] The survey results also highlighted almost all respondents saw their fleets running on a mix of fuels. 45% of the respondents believe their fleets might be running on one particular mix of fuels such as fuel oil/biodiesel, methane, methanol, and Ammonia, with no fuel dominating. The viability of ammonia as a fuel in shipping is expected to be tested in due time as developments continue in this space, after which the ammonia demand will be realized.

## 1.6.5. Ammonia in Fertilizer sector

### Uttar Pradesh

In the state of Uttar Pradesh there are a total of 9 operational fertilizer plants. All these

75 Ministry of Ports, Shipping and Waterways Transport Research Wing

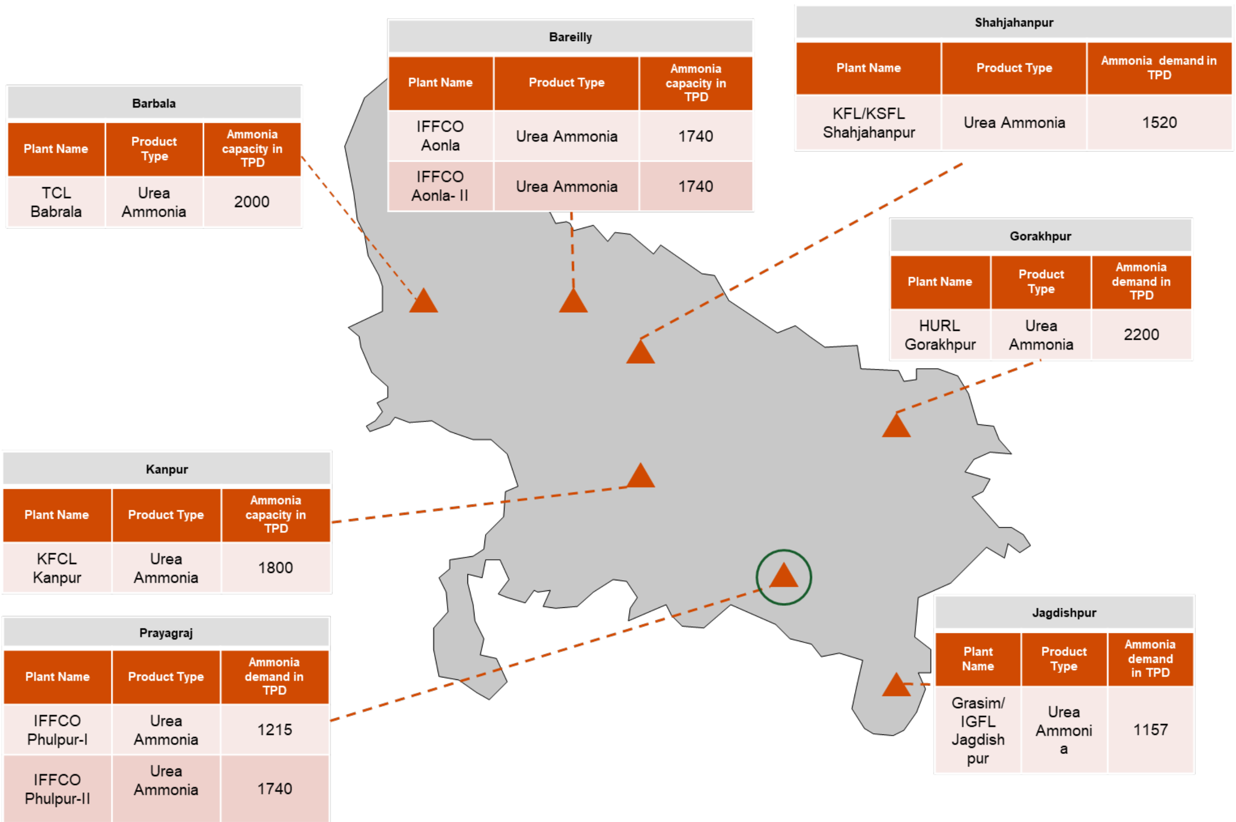
76 Industry Sources

77 Ammonia Energy Association

78 Global Maritime Forum

plants are involved in the manufacture of Urea and have a combined ammonia capacity of 15,112 TPD. The ammonia requirement for the manufacture of Urea is met through in-house production of ammonia through the process of Methane reformation. Due to the presence of lean natural gas in the overall natural gas pool, these plants end up producing excess ammonia which is sold in the open market.[79] Due to this reason, it is expected that the demand for green ammonia in these plants would be dictated by blending mandates that the government may impose and therefore are otherwise expected to have limited green ammonia offtake potential. However, assuming a 20% blending mandate is implemented in the state, the total green ammonia demand is expected to be approx. 2,600 tonnes per day.[80]

Figure 35: Fertilizer Plants in Uttar Pradesh

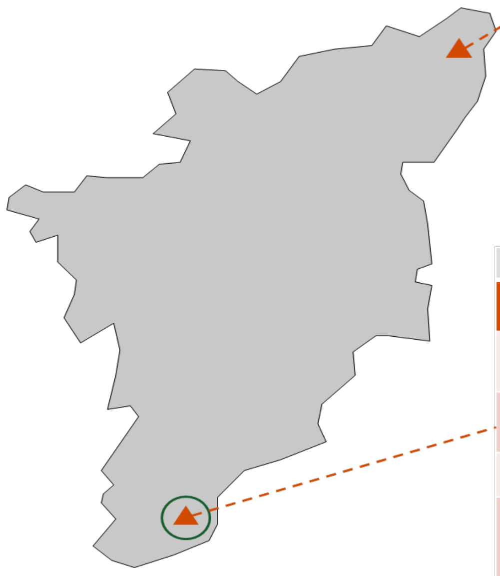



Source: Internal Research

79 Reason for this has been discussed in detail in the section "Ammonia consumption in fertilizer sector".

80 A capacity utilization rate of 86% for Urea plants has been assumed for calculating the Ammonia demand in TPD

Figure 36: Fertilizer Plants in Tamil Nadu



| Chennai | | |
|---|---|---|
| Plant Name | Product Type | Ammonia demand in TPD |
| CIL Ennore | 16:20 CF | 264 |
| MFL Chennai I | Urea | 750 |
| MFL Chennai II | 17:17:17 CF | 429 |

| Thoothukudi | | |
|---|---|---|
| Plant Name | Product Type | Ammonia demand in TPD |
| Greenstar Fertilizer Ltd. | DAP | 101 |
| Greenstar Fertilizer Ltd. | 20:19:47 CF | 228 |
| SPIC Tuticorin | Urea | 1260 |
| Tuticorin Alkali Chemicals and Fertilizers Ltd. | CF | 85 |

Source : Internal Research

# Tamil Nadu

In the state of Tamil Nadu, there are a total of 7 fertilizer plants which are involved in the manufacture of Urea, DAP and other complex fertilizers, having a combined capacity of 3,117 TPD. The plants which manufacture DAP or other complex fertilizers meet their ammonia requirement through imports. The urea plants in Tamil Nadu are expected to face similar challenges as faced by those in Uttar Pradesh in relation to offtake of green ammonia. Assuming a similar blending target of 20% as set by Uttar Pradesh for urea plants in Tamil Nadu, the total green ammonia demand from fertilizer plants is expected to be approx. 1,509 tonnes per day for the state of Tamil Nadu.[81]

Focusing specifically about the cluster in Thoothukudi, all the fertilizer plants are located adjacent to each other within a radius of 2 km providing ease of offtake if such a decentralised plant is to be setup. As 3 of these facilities are complex fertilizer producing plants, which currently import ammonia, setting up a 300 TPD plant in the vicinity can

81 A capacity utilization rate of 86% and 90% for Urea plants and CF plants respectively has been assumed for calculating the Ammonia demand in TPD.

eliminate the potential supply reliability issues they might face and render them impervious to the volatility and changes in the international market.

In the Thoothukudi cluster, Tuticorin Alkali Chemicals and Fertilizers Ltd. which also manufactures Soda ash, requires ammonia as a raw material. This chemical is later sold to the FMCG industry for the manufacturing of detergents and soaps.[82] Swapping the grey ammonia with green ammonia as a raw material can help similar companies market their soda ash as “green” soda ash enabling them to fetch a premium in the market as sustainable sourcing and usage of “green” chemicals in the FMCG industry is a relatively new but growing market trend with limited suppliers providing such products. In the long run, it is imperative that a market pull is generated from various consuming industries (FMCG, Chemicals, Fertilizers, etc.) as they proceed to adopt sustainable sourcing practices to meet their own sustainability agendas.

## Potential Factors Supporting Green Ammonia Adoption

Indian fertilizer industry is reliant on government incentives to sustain its operations. These incentives are subject to the fulfilment of Target Energy Norms (TEN) which have been imposed by the government to promote energy efficiency in Urea producing plants. The Urea plants in the state of Tamil Nadu, namely MFL and SPIC have a TEN of 6.5 GCal/MT against the actual energy consumption, non-compliance of which can invite a heavy penalty, as high as 10% of energy difference between New Urea Policy (NUP) norms and TEN, and reduction in the availed subsidy. [83]

At present, as explained in the earlier sections, ammonia required for urea manufacturing is produced using the method of Steam Methane Reformation (SMR). By SMR of Natural Gas, Hydrogen and Carbon Dioxide are extracted. This hydrogen is then combined with the nitrogen obtained from air to produce ammonia by the Haber-Bosch process which is later used for Urea production. It is to be noted that the process step of ammonia production alone accounts for 80% of the specific energy consumed in the urea production process. Additionally, the SMR route is highly carbon intensive, where for producing every ton of ammonia there is a release of about 1.6 tons of $CO_2$.

Hence, there is an opportunity to reduce the energy and fossil fuel consumption of Ammonia-Urea complexes by reducing the reliance on the SMR production route. Hence these probable cost savings act as a supporting factor for adoption of Green Ammonia as

82 Tuticorin Alkali Chemical and Fertilizers Ltd.

83 Ministry of Chemicals and Fertilizers

a raw material in Urea-Ammonia complexes.

The use of green ammonia offers the following benefits for Urea producing plants:

- It can enable reduction in specific energy consumption by procuring the green ammonia externally and reducing internal energy consumption.
- Reduction in energy consumption would ensure TEN are met in order to avoid a penalty payment. Additionally, by meeting TEN the company shall be able to avail additional subsidies from the government.
- Urea producers can use green ammonia as a substitute to grey ammonia, leading to reduction in requirement of natural gas whose prices are expected to rise with time. The shortage of carbon dioxide resulting from reduction in load of ammonia plant can be potentially made up by sourcing liquefied carbon dioxide (at −35°C) from nearby $CO_2$ emitters.

Certain measures from the government, if implemented, are envisaged to increase the pace of adoption of green ammonia in the fertilizer industry. The possible measures have been listed below:

- Government may recognize green ammonia and carbon dioxide as feedstock for the production of urea and include their cost in its pricing mechanism.
- The loss of energy resulting from inefficient (lower level) operation of ammonia plant can be compensated by providing concession in the energy norm.
- Concession rate may be kept at the same rate in spite of reduction in energy consumption due to use of green ammonia.

### 1.6.6. Hydrogen in Refining sectors of Uttar Pradesh and Tamil Nadu

#### Uttar Pradesh

The state possesses an IOCL refinery in Mathura.

Table 27: Annual hydrogen consumption in IOCL Mathura in KT

| Plant | Plant Capacity (MMT) | City | Annual H2 Demand (KT) |
|---|---|---|---|
| IOCL Mathura | 8 | Mathura | 94 |

Source: Internal Research and Analysis

Figure 37: Hydrogen demand in Uttar Pradesh (KT)


Source: Internal Research and Analysis

# Tamil Nadu

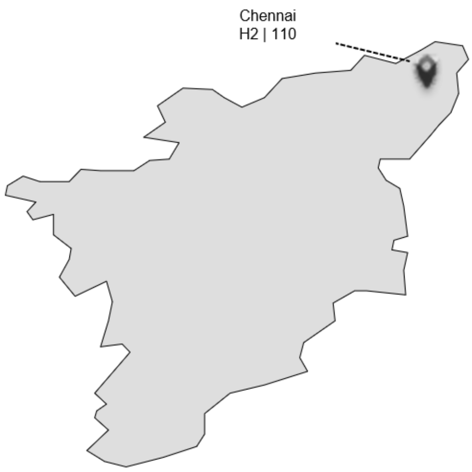
The state possesses 2 refineries as indicated in the table below.

Table 28: Annual ammonia and hydrogen consumption in refineries of Tamil Nadu in KT

| Plant | Plant Capacity (MMT) | City | Annual H2 Demand (KT) |
|---|---|---|---|
| CPCL Manali | 10.5 | Manali | 110 |
| CPCL Nagapattinum | 1 | Nagapattinum | 0 |

Source: Internal Research and Analysis

Figure 38: Hydrogen demand in refineries in Tamil Nadu (KT)




Source: Internal Research and Analysis

## 1.6.7. Hydrogen in Glass

India is among the top 15 glass markets in the world and is the 3rd fastest growing market after Turkey and Brazil.[84] Production of glass in India predominantly takes place in the states of Uttar Pradesh, Tamil Nadu, Maharashtra, Gujarat, Andhra Pradesh, and Karnataka. Almost 75% of the total glass industry is concentrated in Uttar Pradesh, Maharashtra, Gujarat, Karnataka and Andhra Pradesh with Uttar Pradesh having the highest share at 36.9% while Tamil Nadu has a share of 5.6%.[84] The share of organized sector in the glass industry is higher at about 55% whereas the unorganized sector accounts for about 45%.[85]

The Indian glass industry consists of seven segments namely, sheet and flat glass, glass fiber and glass wool, hollow glassware, laboratory glassware, table and kitchen glassware, glass bangles, and other glassware. The industry has been showing a positive growth trend across all segments, mainly driven by the growth in the automotive and construction sectors. It is reported that the glass industry might witness a CAGR of around 12% during the years 2019-2027.[86] The key players involved in glass production in India are Saint-Gobain India, Asahi India glass (AIS), Gujarat Guardian, Hindustan National

84 Ministry of MSME

85 The Associated Chambers of Commerce and Industry of India (ASSOCHAM)

86 Bureau of Energy Efficiency

Glass & Industries, La Opala RG, Borosil Glass Works, and Piramal Glass. In 2018, these players accounted for up to 55% of the total organized market share in terms of revenue.[87]

The glass industry is an energy intensive industry where the energy costs account for approx. 41% of the total production cost. The majority of the energy consumption (about 99%) is thermal.[88] A mix of fuels is used for thermal power generation including Natural Gas, Coal, Pet Coke, LPG, Kerosene, and diesel. Natural Gas is the most commonly used fuel which is combusted to provide the required thermal power to heat and melt the glass. In the glass production value chain, the process step which consumes the most energy involves the melting furnace section which runs continuously, from its commissioning to final shut-down activities, without pause. It is important that the melting furnace is powered all the time and does not stop during the operation as charged material can be irretrievably lost causing huge losses.

Due to the rising sustainability concerns and increased focus to the usage of green fuels to curb carbon emissions, considerable interest is being shown to employ hydrogen blending for supplying the required thermal energy and reduce the GHG emissions from the energy intensive glass sector.

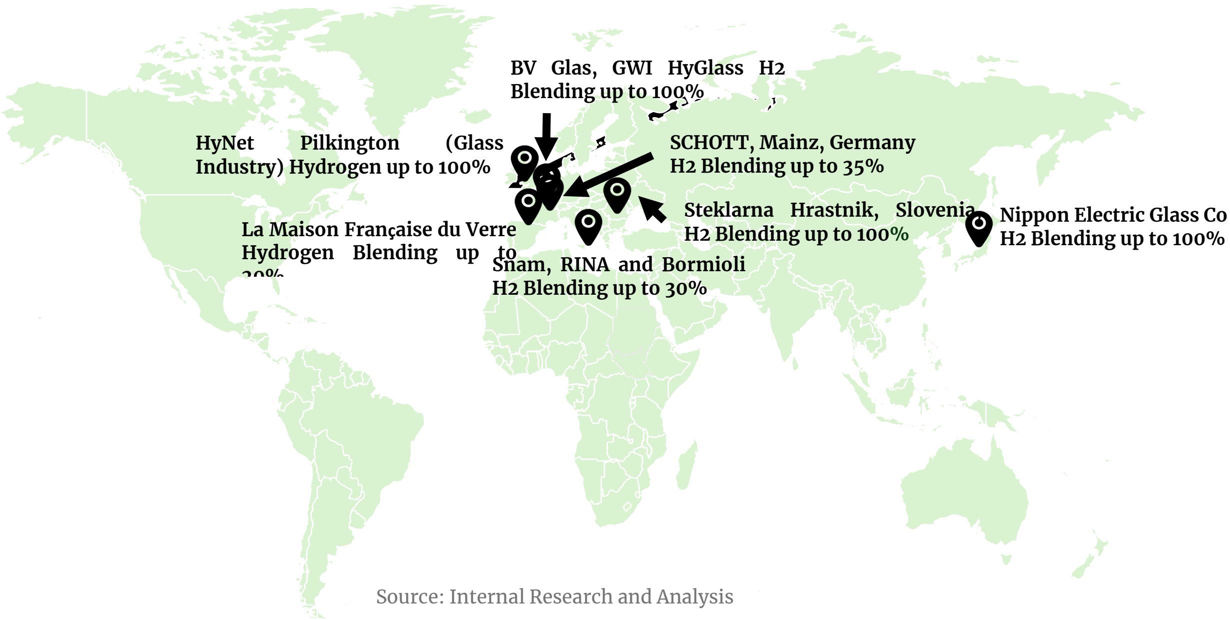
Following this increased interest, several glass players globally have run pilot studies to assess the feasibility of Hydrogen firing in furnaces to generate the required thermal power for glass melting applications. The below figure provides a summary of recent developments taking place globally to produce glass using hydrogen as a fuel. It is noteworthy that some players have even demonstrated the technical feasibility to fire 100% hydrogen in furnaces for the production of glass.[89]

87 Care Ratings

88 Bureau of Energy Efficiency

89 Company Press Release

Figure 39: Global Developments of hydrogen use in glass production




Source: Internal Research and Analysis

Table 29: International pilots for H2 firing in the glass industry

| Company Name | Hydrogen % | Outcomes |
|---|---|---|
| Saint Gobain, Germany[90] | More than 30% $H_2$ blending | • The company has emerged as the first manufacturer in the world to carry out production of flat glass using more than 30% Hydrogen during R&D trials.<br>• This change is believed to reduce scope 1 $CO_2$ emissions by ~70%.<br>• The research is being conducted in partnership with German laboratory Gas and Heat Institute Essen e.V. (GWI), supported by Land of North Rhine-Westphalia to the amount of €3.64 million. |
| HyNet, Pilkington[91] | Up to 100% $H_2$ Firing | • This is believed to be the first large-scale demonstration of 100% firing of $H_2$ in a live float sheet glass production environment in the world. |

90 Saint Gobain Press Release

91 HyNet Press Release

| | | |
|---|---|---|
| | | • In February 2020, BEIS' Energy Innovation Program awarded funds to the HyNet Industrial Fuel Switching program in the amount of £5.3 million. |
| La Maison Française du Verre[92] | Up to 20% $H_2$ mix (by Power Requirement) | • The company were able to validate this approach to decarbonization at a true glass melting scale with a full load.<br>• The viability of using hydrogen instead of some of the natural gas used in the melting furnace were being investigated by a team from Saint-Gobain Research Provence, who was also present at the pilot.<br>• The French environmental organization Ademe provided €1.8 million to La Maison Française du Verre as part of its energy transition program. |
| BV Glas, GWI HyGlass[93] | Up to 100% $H_2$ firing | • The study found that the use of hydrogen in the molten glass can indirectly cause changes in glass quality such as discoloration.[94] |
| SCHOTT, Germany[95] | • Up to 100% $H_2$ firing in lab<br>• Up to 35% in large-scale setups | • The successful results showed that a change in melting technology away from using fossil fuels is indeed possible.<br>• Against the backdrop of technology improvement, the company is testing 2 alternatives: electrification of melting tanks with green electricity and use of green hydrogen in furnaces.<br>• €714,000 R&D project sanctioned to develop low carbon glass production. |
| Steklarna Hrastnik, Slovenia[96] | Up to 100% $H_2$ blending | • The company was first to install a working industrial pilot for using hydrogen as a fuel for melting.<br>• The company developed an in-house system to produce RE (Solar) and $GH_2$ using electrolysers.<br>• The company was able to cut down GGE by ~65%. |
| Snam, RINA and Bormioli[97] | Up to 30% $H_2$ blending | • With the goal to decarbonize the Italian Glass Industry, a working group headed by Snam, RINA and Bormioli will test the use of hydrogen to power melting furnaces in glassworks. |

92 Industry Sources

93 BV Glas

94 Industry Sources

95 Schott Press Release

96 Hrastnik

97 Company Website

| | | |
|---|---|---|
| | | • With the undertaken project the companies aim to design and optimize future furnace designs to support up to 100% firing of Hydrogen.<br>• The workgroup represents the entire value-chain involving specialists in the energy sector, top-level glass groups, fuel production and transport operators, leading companies in certification and integration of complex systems, companies that design glass melting furnaces as well as university and research centres. |
| Nippon Electric Glass Co. [98] | Up to 100% $H_2$ firing | • The company has successfully demonstrated melting of glass using only $H_2$ from a hydrogen-oxygen combustion burner jointly developed with Taiyo Nippon Sanso Corp.<br>• As a part of its medium-term business strategy the company has set "promotion of carbon neutrality" as a priority measure and is working on development of $CO_2$ free fuels to attain net zero by 2050. |

Source: Internal Research

The sections next will concentrate on the glass industry specifically located in the states of Tamil Nadu and Uttar Pradesh, to estimate hydrogen demand which can potentially replace the existing fuel sources used to meet the thermal power requirement for glass melting operations and in-house electricity generation.

### Uttar Pradesh

Firozabad in Uttar Pradesh is an important glass manufacturing hub in India. The industrial cluster is home to a large aggregation of MSMEs (Micro Small and Medium Enterprises). The Firozabad cluster accounts for ~70% of the total unorganized glass production industry across India.[86] The industrial cluster on an average produces 1,500 tons/day glass.[99] Major players of the glass Industry located in Uttar Pradesh have been listed below.[100]

Table 30: List of Major Glass Manufacturers in Uttar Pradesh

| Sr. No | Name | City | State |
|---|---|---|---|
| 1 | Adarsh Kanch Udyog Pvt. Ltd. | Firozabad | Uttar Pradesh |
| 2 | Advance Glass Works | Firozabad | Uttar Pradesh |
| 3 | Designco | Moradabad | Uttar Pradesh |

98 Nippon Electric Glass Press Release

99 NTPC

100 All India Glass Manufacturers' Federation

| | | | |
|---|---|---|---|
| 4 | Durgesh Block & China Glass Works Ltd. | Firozabad | Uttar Pradesh |
| 5 | Farukhi Glass Industries | Firozabad | Uttar Pradesh |
| 6 | Firozabad Ceramics P. Ltd. | Firozabad | Uttar Pradesh |
| 7 | Firozabad Glass Shell Industries | Firozabad | Uttar Pradesh |
| 8 | Geeta Glass Works | Firozabad | Uttar Pradesh |
| 9 | General Traders | Firozabad | Uttar Pradesh |
| 10 | Gm Glass Works No.2 | Firozabad | Uttar Pradesh |
| 11 | Goyal Glassware Private Limited | Firozabad | Uttar Pradesh |
| 12 | Kwality Glass Works | Firozabad | Uttar Pradesh |
| 13 | Meera Glass Industries | Firozabad | Uttar Pradesh |
| 14 | Mittal Ceramics | Firozabad | Uttar Pradesh |
| 15 | Nipro Pharmapackaging India Pvt. Ltd | Meerut | Uttar Pradesh |
| 16 | Om Glass Works Pvt. Ltd. Unit of Advance Group Of Glass Industries | Firozabad | Uttar Pradesh |
| 17 | Paras Glassware (P) Ltd. | Firozabad | Uttar Pradesh |
| 18 | Pooja Glass Works P. Ltd. | Firozabad | Uttar Pradesh |
| 19 | Shri Sitaram Glass Works | Firozabad | Uttar Pradesh |
| 20 | Tiger Son's Glass Industries Pvt.Ltd | Firozabad | Uttar Pradesh |
| 21 | Triveni Pattern Glass Private Limited | Allahabad | Uttar Pradesh |

Source: All India Glass Manufacturers' Federation

As the cluster falls within the Taj Trapezium Zone (TTZ), this zone is mandated to use only clean fuels. The cluster is supplied with Natural Gas through pipelines by GAIL to meet the cluster's energy requirements, priced as per the "Administered Pricing Mechanism" (APM), which is declared by the Petroleum Planning and Analysis Cell (PPAC). APM ensures i) ensure stability in selling price; ii) insulate consumers against international price fluctuations; and iii) subsidization of consumer prices. Once the prescribed quota is finished, any extra usage is priced based on the price of Re-gasified Liquefied Natural Gas (RLNG) which is higher than APM pricing, which increases the cost of production for glass manufacturing companies.

**Demand Estimation**

To arrive at the possible hydrogen demand which can be generated by the glass MSME cluster in Firozabad, the fuel consumption statistics were used, as highlighted in the table below.

Table 31: Fuel Consumption Statistics of the Firozabad Glass Cluster

| Fuel | Total Energy Consumption (in toe/year) |
|---|---|
| NG | 264,663 |
| Coal | 16,940 |
| Pet Coke | 11,340 |
| LPG | 3,332 |
| Kerosene | 6,290 |
| Diesel | 7,434 |
| Total fuel consumption (in toe/year) | 309,999 |
| Total Energy Requirement (in kWh/year) | 3,605,288,370 |

Source: Bureau of Energy Efficiency, Industry Sources

In the Indian context, it is envisaged that at the initial stages a 20% v/v H2 blending is assumed to take place in the Indian Glass industry.[99] The corresponding hydrogen demand for 20% blending in furnaces for fuel applications was found to be approx. 9.73 KT/Year for the Firozabad glass cluster in Uttar Pradesh.

**Tamil Nadu**

Unlike Firozabad in Uttar Pradesh, there are no established MSME clusters in the state of Tamil Nadu which engage in glass manufacturing. In the state of Tamil Nadu, the glass market is largely captured by 2 organized players who are also the market leaders in various end-use segments, namely Saint Gobain India Pvt. Ltd and Asahi India Glass Ltd. which have plants in Sriperumbudur and Kancheepuram, respectively. Other glass producing capacities in the state are largely disaggregated and distributed amongst small players.

Market insights suggest that Asahi India Glass's plant in Kancheepuram manufactures automotive glass. The key raw materials required for manufacturing automotive glass are auto-quality float glass and Poly Vinyl Butyral. Being an integrated company, it procures raw glass from its Architectural Glass SBU, that manufactures the glass outside Tamil Nadu.[101] Furthermore, the company also procures additional raw glass from external

101 All India Glass Manufacturer's Federation

domestic and global sources.[102] Therefore, the hydrogen consumption for energy requirements in glass making for Asahi in Tamil Nadu is negligible.

To arrive at the possible Hydrogen demand which can be generated in the state, the glass production capacity of Saint-Gobain was assessed. Secondary research suggested that the power requirement per ton of glass produced is around 793 kWh/ton.[103] For the state of Tamil Nadu, the approximate Hydrogen demand from the glass industry is therefore estimated to be approx. 0.78 KT, as per the approach described earlier.

Table 32: Hydrogen Demand in Tamil Nadu from Glass Sector

| Company Name | Location | Capacity (in Ton/day) | H2 Requirement (in KT/Year) |
|---|---|---|---|
| Saint Gobain | Sriperumbudur | 1000 | 0.78 |

Source: Internal Research and Analysis

# 1.7. Demand Consolidation

A consolidated summary of the demand potential in the states of Tamil Nadu and Uttar Pradesh has been presented below.

Table 33: Demand Consolidation for Tamil Nadu and Uttar Pradesh

| Parameter | Tamil Nadu (in KT/ Year) | Uttar Pradesh (in KT/ Year) |
|---|---|---|
| Hydrogen in Power Sector: Backup for Hospitals | 0.47 | 6.77 |
| Hydrogen in Power Sector: Backup for Telecom Tower | 7.19 | 82.74 |
| Hydrogen in Power Sector: Decentralised Power in Villages | 0.26 | 6.75 |
| Hydrogen in Mobility | 1,479 | 2,901 |
| Ammonia in Power Sector | 2,104 | 3,686 |
| Ammonia in Fertilizers | 551 | 949 |
| Ammonia for In-land Waterways | 0.33 | 21.5 |

102 SEBI and Asahi India Glass

103 Glass Technology Services

| | | |
|---|---|---|
| Hydrogen in Glass | 0.78 | 9.73 |

Source: Internal Research and Analysis

# 2. Energy and climate related supportive policies

After the Prime Minister's address to the nation in his Independence Day speech of August 2021, India conveyed its plan on the global stage of their intention to become a global leader by unveiling the National Green Hydrogen Mission in January 2023. The mission aims to achieve the following objectives.[104]

- Developing green hydrogen production capacity of at least 5 MMT (Million Metric Tons) per annum, alongside adding renewable energy capacity of about 125 GW (gigawatt) in India by 2030.
- It aims to entail over INR 8 lakh crore of total investments and is expected to generate six lakh jobs.
- It is expected to lead to a cumulative reduction in fossil fuel imports by over Rs 1 lakh crore and an abatement of nearly 50 MT of annual greenhouse gas emissions.

Upon approval of the National Green Hydrogen Mission by the Union Cabinet, with a sanctioned outlay of INR 19,744 crores up to FY 2029-30, the development of the green hydrogen capacities in the country by all stakeholders have entered the mission mode in order to accelerate the goal of establishing India as a global leader in the green hydrogen space. The policy document published by the Ministry of New and Renewable Energy (MNRE) has broadly outlined the objectives of the mission along with a proposed framework for demand creation, a basket of measures to support domestic production and consumption of green hydrogen with the final aim of substituting India's import dependance of fossil fuels by becoming energy independent and a net exporter of Green Hydrogen. The mission is expected to be implemented in a stagewise manner with a series of measures to introduce hydrogen into the energy mix of the country. However, these incentives are said to be offered for a limited time only, whose beneficiaries are to be selected on a competitive selection criterion. Provisions notified by the Ministry of Power under the Green Hydrogen / Green Ammonia Policy have been quoted below.[105]

104 Press Information Bureau

105 Ministry of Power (2022)

1. Green Hydrogen / Ammonia producers may purchase renewable power from the power exchange or set up RE capacities themselves or through any other, developer, anywhere.
2. Open access will be granted within 15 days of receipt of application.
3. The Green Hydrogen / Ammonia manufacturer can bank their unconsumed renewable power, up to 30 days, with distribution company and take it back when required within this period.
4. Distribution licensees can also procure and supply renewable energy to the manufacturers of Green Hydrogen / Green Ammonia in their States at concessional prices which will only include the cost of procurement, wheeling charges, and a small margin as determined by the State Commission.
5. Waiver of inter-state transmission charges for a period of 25 years will be allowed to the manufacturers of Green Hydrogen and Green Ammonia for the projects commissioned before 31st December 2030.
6. The manufacturers of Green Hydrogen / Ammonia and the renewable energy plant shall be given connectivity to the grid on priority basis to avoid any procedural delays.
7. Renewable Purchase Obligation (RPO) mandates that all electricity distribution licenses should produce or purchase a minimum specified quantity of their needs from RE sources. The benefit of RPO will be granted incentive to the hydrogen/Ammonia manufacturer and the Distribution licensee for consumption of renewable power.
8. To ensure ease of doing business a single portal for carrying out all the activities including statutory clearances in a time bound manner shall be set up by MNRE.
9. Connectivity, at the generation end and the Green Hydrogen / Green Ammonia manufacturing end, to the ISTS for Renewable Energy capacity set up for the purpose of manufacturing Green Hydrogen / Green Ammonia shall be granted on priority.
10. Manufacturers of Green Hydrogen / Green Ammonia shall be allowed to set up bunkers near Ports for storage of Green Ammonia for export / use by shipping. The land for the storage for this purpose shall be provided by the respective Port Authorities at applicable charges.

## 2.1. Consumption Centers and Demand Generation

India has set its target to become energy independent by 2047 and achieving Net Zero by 2070. To achieve this target, increasing renewable energy use across all economic spheres is crucial for India's energy transition. Ten potential states that are expected to be the key enablers for manufacturing green hydrogen in India to kickstart its national green hydrogen mission, due to them being first movers have been identified. These states include Karnataka, Odisha, Gujarat, Rajasthan, Maharashtra, Tamil Nadu, Andhra Pradesh, Kerala, Madhya Pradesh, and Uttar Pradesh. This identification is based on the already existing refineries, fertilizer plants, steel industries, and ports located in the states. Operational and potential renewable energy resources which are expected to be used to produce the green hydrogen has also been considered. Several MOUs and project announcements have already been published in the public domain with many more projects already in the pipeline.

In the Phase 1 of the mission, which aims to generate demand, utilization of the produced Green Hydrogen will be taken up by refineries, fertilizers, and city gas sectors. Additionally, the policy is expected to also lay the foundation for future energy transition projects in hard-to-abate sectors by creating the required R&D impetus. Several pilot projects are to be supported for initiating the green transition in steel production, long-haul heavy-duty mobility, and shipping. The proposed measures in the Phase 1 of the mission are expected to help drive down costs and facilitate greater and wider deployment of green hydrogen in the next phases.

To facilitate efficient implementation of the mission on a national scale MNRE shall be responsible for the overall coordination and implementation of the mission. As part of the integrated mission strategy for successful implementation, other ministries, and departments of the Govt. of India are to work in unison and undertake focused steps to ensure successful achievement of target objectives. Ministry-wise objectives to generate demand as part of the Phase 1 of the mission implementation plan have been summarized below.[106]

1. Ministry of Power: MoP is to engage with state governments, distribution companies, regulators, and technical institutions to align the electricity ecosystem for large scale green hydrogen adoption.
2. Ministry of Petroleum and Natural Gas: MoPNG is to facilitate uptake of Green Hydrogen in refineries and city gas distribution grids through both Public and Private entities. In order to replace imported fossil fuels, new refineries and city gas projects are also to be planned and designed for maximum uptake of the Green Hydrogen produced.
3. Ministry of Chemicals and Fertilizers: MoCF is to encourage adoption of domestic green ammonia uptake by fertilizer producing companies in order to reduce imports of fossil fuel-based feedstocks and fertilizers. More importantly, the

106 National Green Hydrogen Mission, MNRE

Ministry will enable procurement of green ammonia for its designated entities to create large-scale demand.

4. Ministry of Road and Transport and Highways: MoRTH is to enable uptake of green hydrogen in mobility by defining standards, regulations, and codes, primarily for heavy commercial vehicles and long-haul operations.
5. Ministry of Steel: MoS is to drive adopting of green hydrogen by identifying and facilitating pilot projects for accelerating production of green steel.
6. Ministry of Ports, Shipping and Waterways: The Ministry is to develop the export capabilities of the country by developing infrastructure including storage bunkers, port operations equipment, and refueling facilities. It shall also drive uptake of hydrogen and derivatives (ammonia/methanol) as engine fuel for ships, and hence establish India as hydrogen/derivative refueling hub for the global shipping industry.
7. Ministry of Finance: The Ministry is to make available suitable financing options by exploring fiscal and financial frameworks to promote production, utilization and export of hydrogen and derivatives.
8. Ministry of Commerce and industry: The Ministry shall serve as a support pillar for encouraging investments, facilitate east of doing business and implement industrial and trade policies for trade and production to flourish.
9. Ministry of Railways: The Ministry shall work on transitioning to operate trains on Green Hydrogen. It shall also transport Green Hydrogen across geographies and is to do so by setting up standards and regulations.
10. State Governments: Each state shall have the opportunity to create hydrogen ecosystems within its territories. They will do so by creating incentives and policies for provisioning land, water, tax and duty structures to facilitate Green Hydrogen projects.

## 2.2. Subsidies and incentives

### National Green Hydrogen Mission

A total sanctioned outlay of INR 19,744 crores up to FY 2029-30 has been announced under the NGHM. The Strategic Interventions for Green Hydrogen Transition (SIGHT) Programme is a major financial part of the mission with an outlay of INR 17,490 Crores up to FY 29-30. In addition, INR 1,466 Cr. And INR 400 Cr. have been earmarked for Pilots and R&D, respectively.

The SIGHT Programme proposes two distisnct financial incentive mechanisms to support domestic manufacturing of electrolysers and production of green hydrogen. These incentives are aimed to enable rapid scale-up, technology development and most importantly cost reduction to meet the target of USD per kg hydrogen production by 2030. In the recently published guidelines for the SIGHT program dated June 2023, a total outlay of INR 13,050 crores have been sanctioned from FY 2025-26 to FY 2029-30 as an incentive scheme for Green Hydrogen Production. The Mission is expected to also support pilot projects in emerging end-use sectors and production pathways. Regions capable of supporting large scale production and/or utilization of Hydrogen are to be identified and developed as Green Hydrogen Hubs.

Two of the currently identified modes are.[107]

- **Mode 1:** Bidding based on least incentive demanded over the three-year period, through a competitive selection process.
- **Mode 2:** Demand aggregation to be done by implementing agency by calling bids for procurement Green Hydrogen and its derivatives at the lowest cost through competitive selection process.

Various schemes launched under the NGHM have been explained next:

**SIGHT Programme Component I: Incentive Scheme for Electrolyser Manufacturing**

In the specified timeline from FY25-26 to FY 29-30, a substantial financial outlay of INR 4,440 Cr has been earmarked for the implementation of a significant scheme. The scheme is set to be executed through the Solar Energy Corporation of India (SECI), with the Ministry of New and Renewable Energy (MNRE) having the authority to designate National Accreditation Board for Testing and Calibration Laboratories (NABL) accredited labs or other third-party certification agencies for the crucial task of technical parameter verification.

The overarching objectives of this initiative are multifaceted, aiming to: (A) maximize indigenous electrolyser manufacturing capacity, (B) achieve a lower levelized cost of hydrogen production, (C) ensure globally competitive performance and quality of products, (D) progressively enhance domestic value addition, and (E) support established and promising technologies in the sector.

A key element of the scheme is the implementation of a base incentive, commencing at INR 4,440/kW in the first year, with a gradual tapering down on an annual basis. The distribution of incentives will be contingent upon specific energy consumption and Local Value Addition. Bidders will be ranked in decreasing order of the Selection Parameter for the allocation of the admissible bid capacity.

To qualify as a beneficiary, entities must demonstrate a commitment to the cause by showcasing a minimum of 50% of annual sales of electrolysers for installation in projects within India. Furthering the initiative to promote indigenously developed electrolyser

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technologies, the scheme encourages bids in the first tranche for 1500 MW, comprising 1200 MW from any stack and an additional 300 MW specifically from indigenous stacks. Bidders are constrained by a maximum capacity of 300 MW and a minimum capacity of 100 MW.

**SIGHT Programme Component II: Incentive Scheme for Green Hydrogen Production (under Mode 1)**

In the timeline spanning FY25-26 to FY 29-30, a substantial financial outlay of INR 13,050 Cr has been allocated for a strategic scheme aimed at maximizing the production of Green Hydrogen and its derivatives in India. The implementation of this scheme will be overseen by SECI. MNRE holds the authority to designate NABL accredited labs or other third-party certification agencies for the verification of technical parameters.

The primary objectives of this initiative are threefold: (A) to maximize the production of Green Hydrogen and its derivatives within the country, (B) to enhance the cost-competitiveness of Green Hydrogen and its derivatives compared to fossil-based alternatives, and (C) to encourage the large-scale utilization of Green Hydrogen and its derivatives.

To incentivize production, a structured incentive plan has been devised. In the first three years, incentives will be provided and capped at INR 50/kg, INR 40/kg, and INR 30/kg for the 1st, 2nd, and 3rd years of production, respectively. The target production to be achieved within this timeframe is set at 4,50,000 MT, with 4,10,000 MT to be attained via a technology-agnostic pathway and an additional 40,000 MT through the biomass route. This strategy aims not only to bolster the production of Green Hydrogen but also to make it cost-competitive and promote its widespread utilization, aligning with broader renewable energy and sustainability goals.

**SIGHT Programme Component-II Incentive Scheme for Green Ammonia Production and Supply (under Mode-2A)**

The overarching objectives of this Mode are threefold: (A) to maximize the production of Green Ammonia in India, (B) to enhance the cost-competitiveness of Green Ammonia in comparison to fossil-based alternatives, and (C) to encourage large-scale utilization of Green Ammonia.

Mode 2A involves the aggregation of demand by the implementation agency/agencies and the issuance of bids for the production and supply of Green Ammonia. The selection process for Mode 2A includes a fixed incentive structure.

Under the scheme, direct incentives will be provided for a period of three years from the commencement of Green Ammonia production and supply. The incentive will be Rs. 8.82/kg in the first year, Rs. 7.06/kg in the second year, and Rs. 5.30/kg in the third year.

The allocation of capacities to qualified bidders will be based on the Quoted Price of Supply (in Rs. /kg), with the bidder quoting the least price being allocated its admissible capacity first. SECI may also engage bidders with prices within a specified range to match their prices with the lowest (L1) price in sequential order.

For Tranche I of Mode 2A, the available capacity for bidding is set at 5,50,000 MT per annum of Green Ammonia, with a maximum capacity of 200,000 MT per annum and no specified minimum capacity. This approach aims to not only incentivize Green Ammonia production but also to ensure competitive pricing and efficient allocation of production capacities.

**SIGHT Programme Component-II; Incentive Scheme for Green Hydrogen Production and Supply (under Mode-2B)**

Oil & Gas companies and the Centre for High Technology (CHT) have been designated as the Implementing Agencies to execute the Mode 2B initiative, as nominated by the Ministry of Petroleum and Natural Gas (MoPNG). The primary objectives of this scheme are threefold: (A) to maximize the production of Green Hydrogen in India, (B) to enhance the cost-competitiveness of Green Hydrogen compared to fossil-based alternatives, and (C) to encourage large-scale utilization of Green Hydrogen.

Mode 2B involves the aggregation of demand by the implementation agency/agencies, calling for bids for the production and supply of Green Hydrogen at the lowest cost for a single refinery or multiple refineries, as decided by the Implementing Agency. The selection process for Mode 2B also includes a fixed incentive structure.

Under this scheme, a direct incentive in terms of Rs/kg of Green Hydrogen produced and supplied will be provided for a duration of three years from the commencement of Green Hydrogen production and supply. The incentive will be Rs. 50/kg in the first year, Rs. 40/kg in the second year, and Rs. 30/kg in the third year.

The point of delivery for the Green Hydrogen is specified to be at the respective refinery battery limit, with the supplier being responsible for the delivery of the product to the Point of Delivery, including storage and transportation.

The allocation of capacities to qualified bidders will be based on the Quoted Price of Supply (in Rs. /kg), with the bidder quoting the least price being allocated its admissible capacity first. The capacity available for bidding under Tranche I of Mode 2B is set at 2,00,000 MT per annum of Green Hydrogen, with a maximum capacity of 50,000 MT per annum, and no specified minimum capacity. This approach aims to incentivize Green Hydrogen production, ensure cost-competitive pricing, and facilitate efficient allocation of production capacities.

**Scheme Guidelines for implementation of Pilot projects for use of Green Hydrogen in the Steel Sector under the National Green Hydrogen Mission**

The Mission views steel production as a crucial sector where Green Hydrogen can potentially replace fossil fuels. As the costs of renewable energy and electrolysers decrease, Green Hydrogen-based steel is expected to become cost-competitive in the coming years. The provision of carbon credits and the imposition of market barriers on carbon-intensive steel in some countries are likely to further enhance the viability of Green Hydrogen-based steel.

Given the current higher costs of Green Hydrogen, the Mission proposes steel plants to begin by blending a small percentage of Green Hydrogen into their processes, with the proportion gradually increasing as cost-economics improve and technology advances. Additionally, new steel plants are to be designed to operate with Green Hydrogen, ensuring their participation in future global low-carbon steel markets. Greenfield projects targeting 100% green steel production are also to be considered.

To evaluate the potential for using Green Hydrogen in the steel industry, the Mission supports the establishment of pilot projects in this sector, which will be implemented by the Ministry of Steel (MoS) and the Scheme Implementing Agencies as identified by MoS. The expenditure on this scheme is to be met from the budget provisions made under the National Green Hydrogen Mission Head. The key focus areas of this Scheme for supporting the development, selection, and validation of commercially viable technologies for utilizing hydrogen in the steel sector include:

1. Using 100% Hydrogen in the Direct Reduced Iron (DRI) process with a vertical shaft or kiln.
2. Utilizing Hydrogen in the Blast Furnace within prescribed limits.
3. Gradually substituting fossil fuels with Hydrogen in the DRI process.
4. Exploring other innovative uses of Hydrogen to reduce carbon emissions in iron and steel production.

**Guidelines released for implementation of Pilot projects for use of Green Hydrogen in the Transport Sector**

Transportation represents a promising arena where Green Hydrogen stands poised to replace conventional fossil fuels. With the decreasing costs associated with renewable energy sources and electrolysers, it is anticipated that vehicles powered by Green Hydrogen could achieve cost parity in the coming years. Furthermore, projected economies of scale and rapid advancements in hydrogen-based vehicle technology are expected to bolster the feasibility of Green Hydrogen as a viable mobility solution. In order to evaluate the potential application of Green Hydrogen within the transportation sector, the Mission advocates for the establishment of pilot initiatives. These pilot projects will be executed in collaboration with the Ministry of Road Transport and Highways (MoRTH) and the designated Scheme Implementing Agencies (SIAs), as outlined within this initiative. The budgetary outlay for this scheme is INR 496 Cr till FY 2025-2026.

Highways are to be earmarked for movement of Hydrogen fueled inter-state buses and commercial vehicles. The necessary Green Hydrogen production projects, distribution infrastructure and refueling stations are to be built along such highways.

The scheme aims to offer financial support to bridge the viability gap resulting from the initially higher capital expenses associated with hydrogen-powered vehicles (such as Fuel Cell Electric Vehicles and Hydrogen Internal Combustion Engine vehicles) and the establishment of hydrogen refueling infrastructure. Insights gained from the pilot initiatives will assist inter-city bus and truck operators, including State Transport Undertakings, in acquiring practical experience with the adoption and utilization of hydrogen fuel vehicles and refueling technologies. It's important to note that expenses related to hydrogen production, land acquisition, etc., will not be covered under this scheme.

The thrust areas for providing support under the scheme are as follows:

i. Development of commercially viable technologies for the utilization of hydrogen in transport sector through:
   a. Use of Green Hydrogen as fuel in buses and trucks. (Component A)
   b. Supporting infrastructure like Hydrogen refueling stations. (Component B)

ii. Any other innovative use of Hydrogen for reducing Carbon emissions in transport sector like blending Green Hydrogen based Methanol/ Ethanol and other synthetic fuels derived from Green Hydrogen in automobile fuels.

Objectives of the scheme are to:

i. support the deployment of Green Hydrogen as fuel in buses and trucks, in a phased manner on a pilot basis.
ii. validate the technical feasibility and performance of Green Hydrogen operated vehicles under real-world operational conditions.
iii. evaluate the economic viability of hydrogen-based vehicles.
iv. assess the effectiveness of hydrogen refueling station.
v. evaluate the performance of hydrogen-based vehicles and identify the areas for improvement.
vi. demonstrate safe and secure operations of hydrogen-based vehicles and hydrogen refueling stations.

Scope of the scheme is as follows:

Component A: Development/selection/validation of technologies for use of Green Hydrogen as fuel in the following categories of vehicles: -

i. Bus with Fuel Cell based propulsion technology
ii. Bus with Internal Combustion Engine based propulsion technology
iii. Truck with Fuel Cell based propulsion technology
iv. Truck with Internal Combustion Engine based propulsion technology
v. Four-wheeler vehicles with Fuel Cell/Internal Combustion engine based propulsion technology

Component B: Development/selection/validation of technologies for supporting infrastructure like Hydrogen refueling stations will be carried out.

**Scheme Guidelines for setting up Hydrogen Hubs in India under the National Green Hydrogen Mission**

National Green Hydrogen Mission envisages large-scale Hydrogen Hubs, which are expected to act as a foundation for the development of the Hydrogen ecosystem and act as the backbone of the decarbonisation efforts in India. Given the technical and logistical challenges inherent in transporting hydrogen over long distances, a cluster-based production and utilization model would enhance the viability of Green Hydrogen projects in the initial years. This would, in turn, enable economies of scale and convergence of key infrastructure requirements in geographically proximate areas.

The scheme is set to be executed by Ministry of New and Renewable Energy (MNRE) who will nominate a Scheme Implementing Agency (SIA) having the authority to issue call for Proposals for projects. The eligible agencies for sending project proposals include CPSUs, State-PSUs, Private sector, State Corporations, Autonomous Bodies, JV s/ Partnerships/ Consortia of such entities to become Executing Agencies (EA) for such hub projects. Once the project is awarded to an EA, work shall be executed as per the approved scope of work. The SIA shall make all necessary efforts to complete the project, in all aspects, before 31.03.2026. The budgetary outlay for the scheme has been earmarked to be INR 200 Crore till FY 2025-26. The financial support development of at-least two Green Hydrogen hubs with CFA of up to INR 100 Crore each will only be for supporting core infrastructure.

The objectives of this scheme are (A) to identify and develop regions capable of supporting large-scale production and/or utilization of Hydrogen as Green Hydrogen Hubs, (B) development of Green Hydrogen Projects inside the Hubs in an integrated manner to allow pooling of resources and achievement of scale, (C) enhance the cost-competitiveness of Green Hydrogen and its derivatives vis-à-vis fossil-based alternatives, (D) maximize production of Green Hydrogen and its derivatives in India within the stated financial support, (E) encourage large-scale utilization and exports of Green Hydrogen and its derivatives, and (F) enhance viability of Green Hydrogen assets across the value chain.

The Scheme will provide support for development of the following core infrastructure at Hydrogen hubs for common services/facilities such as (A) Storage and transportation facilities for Green Hydrogen/its derivatives, (B) Development or upgradation of pipeline infrastructure, (C) Green Hydrogen powered vehicle re-fuelling facility, (D) Hydrogen compression and/or liquefaction technologies, (E) Hydrogen storage systems, including bulk liquid, gaseous, materials-based technologies, or subsurface options (e.g., salt caverns, depleted oil and gas fields, unused coal mines etc.), (F) Water treatment facility and associated storage facility, (G) Development of bunkering facilities in case of ports including provision of bunker barges for handling large vessels such as Very Large Crude Carriers (VLCC), (H) Infrastructure upgradation for shipping, including expansion of port/jetty infrastructure for exports, (I) Power transmission infrastructure to nearest existing grid substation and establishment of new dedicated substations, (J) Land re-development, (K) Energy Storage to manage RE intermittency, (L) Effluent Treatment Plants, and (M) Any other infrastructure required.

**SIGHT Programme Component I: Incentive Scheme for Electrolyser Manufacturing Tranche – II**

For the timeline of FY25-26 to FY 29-30, a financial outlay of INR 4,440 Cr has been earmarked for the implementation of the scheme (across all tranches). The scheme is set to be executed through the Solar Energy Corporation of India (SECI), with the Ministry of New and Renewable Energy (MNRE) having the authority to designate National Accreditation Board for Testing and Calibration Laboratories (NABL) accredited labs or other third-party certification agencies for the crucial task of technical parameter verification.

The overarching objectives of this initiative aim to: (A) maximize indigenous electrolyser manufacturing capacity, (B) achieve a lower levelized cost of hydrogen production, (C) ensure globally competitive performance and quality of products, (D) progressively enhance domestic value addition, and (E) support established and promising technologies in the sector.

A key element of the scheme is the implementation of a base incentive, commencing at INR 4,440/kW in the first year, with a gradual tapering down on an annual basis. The distribution of incentives will be contingent upon specific energy consumption and Local Value Addition. Bidders will be ranked in decreasing order of the Selection Parameter for the allocation of the admissible bid capacity.

Furthering the initiative to promote indigenously developed electrolyser technologies, the scheme encourages bids in the first tranche for 1500 MW, comprising 1100 MW from any stack (Bucket 1), an additional 300 MW specifically from indigenous stacks (Bucket 2A), and 100 MW from smaller units of indigenously developed stack technologies (Bucket 2B). Bidders are constrained by a minimum capacity of 100 MW in Bucket 1 and Bucket 2A. The maximum and minimum capacity that can be bid under Bucket 2B would be 30 MW and 10 MW. The maximum capacity allocated to any single bidder across multiple tranches sand buckets the programme for Electrolyser Manufacturing is not to exceed 300 MW.

# State-wise incentives and obligations

The state governments and state agencies are expected to play an instrumental role in development of the green hydrogen ecosystem. The states are to have an opportunity to establish themselves as top investment destinations in the sunrise sector through various initiatives. A state-wise overview of the incentives and policies in place for promoting Green Hydrogen production has been summarized in the table below.

Table 34: State-wise incentives that support adoption of Green Hydrogen

| Sr No | State | Policies Supporting Green Hydrogen Production | Incentives |
|---|---|---|---|
| 1 | Karnataka | • Karnataka Renewable Energy Policy 2022-2027[108]<br>• New Industrial Policy 2020-25.[109] | • The Govt. of Karnataka has included hydrogen production under the manufacturing industry and shall provide incentives to companies till a separate state hydrogen policy is released.<br>• As a part of the new Karnataka RE policy, the state shall be supporting new initiatives, Pilot Projects and R&D for creating new RE markets within the state, which includes Hydrogen and fuel cell technology.<br>• RE Project developers can sell the energy to consumers under open access both within and/or outside Karnataka to promote Intra and Interstate transmission system.<br>• All RE projects are proposed to be treated as manufacturing industry and they are eligible for incentives and concessions, as applicable to manufacturing industry mentioned in the State Industrial Policy and its amendments from time to time, except the investment promotion subsidies.<br>• The policy also aims to promote creation of hydrogen hubs within the state along with the development of RE parks. |
| 2 | Odisha | • Odisha Renewable Energy Policy 2022[110]<br>• Odisha Industrial Policy 2022[111] | • The government shall come up with a separate policy for development of an ecosystem for green hydrogen / green ammonia in the state. Additional incentives may be provided for production of green hydrogen / green ammonia under the Industrial policy resolution until the state comes up with a separate policy. |

108 Govt. of Karnataka, Karnataka Renewable Energy Policy, 2022-2027

109 Govt. of Karnataka, New Industrial Policy 2020-25

110 Govt. of Odisha, Odisha Renewable Energy Policy 2022

111 Govt. of Odisha, Odisha Industrial Policy 2022

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| | | | • Exemption of 50 paisa per unit of electricity duty shall be provided to captive / open access consumers on consumption of energy from RE projects set up inside the state during the policy period. Such electricity duty exemption shall be available for consumption of energy from the project for a period of 15 years from date of commission of the project. In case a project is commissioned before 31/03/2026 the exemption shall be for a total of 20 years.<br>• 50 % exemption of cross-subsidy surcharge shall be provided to open access consumers on consumption of energy from RE projects commissioned in the state during the policy period of 15 years.<br>• 25% exemption of wheeling charges shall be provided to captive/open access consumers on consumption of energy from RE projects<br>• Stamp duty on purchase/lease of land, land conversion charges and registration charges shall not be applicable for RE projects. Under the Industrial policy of Odisha (2022) the industries undertaking manufacture of green hydrogen and green ammonia come under the thrust sectors and will be receiving additional support from the state government in the form of incentives. The state will help players to set up factories by availing concessional land rates and will help with investment facilitation. Depending upon the classification of the regions as per the policy, industrial units will allow to set up at a concessional industrial rate along with no payment of stamp duty.<br>• New industrial units in the thrust sectors shall be provided with 100% exemption from payment of electricity duty for a period of 10 years from the date of commencement of commercial production.<br>• New industrial units in the thrust sector shall be provided reimbursement of Power Tariff of Rs. 2 per unit consumed and purchased from local DISCOMs for a period of 10 years from the date of commencement of commercial production. |
| 3 | Gujarat | Policy on leasing of government waste land for green hydrogen production (using non-conventional energy sources)[112] | • The government shall come up with a separate policy for development of an ecosystem for green hydrogen / green ammonia in the state. Additional incentives may be provided for production of green hydrogen / green ammonia under the Industrial policy resolution until the state comes up with a separate policy. |

112 Govt. of Gujarat Policy-2023 for leasing the government fallow land for green hydrogen production

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| | | | • The Gujarat govt. has assigned a land bank of 6000 sq. km for green hydrogen fuels projects. |
| 4 | Rajasthan | Rajasthan Investment Promotion Scheme[113] | • 100% electricity duty exemption for 7 years under captive RE generation.<br>• One-time capital subsidy up to 50% of the cost of projects subject to a ceiling of Rs. 10 Cr. per project under the green incentive themes.<br>• First 3 units belonging to the sunrise category and falling under Mega and Ultra Mega project category slabs (per Manufacturing project category slabs) to get a sunrise booster of 20% on the Asset Creation Incentives chosen (Capital Subsidy, Turnover Linked Incentive or SGST Reimbursement).<br>• 100% banking, wheeling and transmission charges waived off/ reimbursed for Captive Power Plants set up by the first 3 units belonging to each sunrise category and falling under Mega and Ultra Mega project category slabs (per Manufacturing project category slabs).<br>• 5% interest subsidy for term loans for investing in machinery and plant (for 5 years up to INR 10 Cr./year) or capital subsidy equal to 20% of the investments made up to INR 50 Cr.<br>• One-time 50% reimbursement of the cost incurred for acquiring technology from premier national institutes in India (up to INR 2 Cr.) |
| 5 | Maharashtra | Maharashtra Green Hydrogen Policy[114] | • The State cabinet has approved INR 8,562 crore for the implementation.<br>• All green hydrogen projects need to be registered with the energy office. The policy will provide incentives to projects who procure RE through open access channels from in or out of state DISCOMs.<br>• As per the policy, 50% and 60% concessions will be given for transmission charges and wheeling charges respectively for a period of 10 years from the time of project implementation.<br>• Standalone and hybrid power plants will be given 100 per cent concession in power tariff for the next 10 years and 15 years respectively and will also be exempted from cross subsidy and surcharge.<br>• A subsidy of INR 50 per kg will be provided for blending green hydrogen into gas for 5 years. |

113 Govt. of Rajasthan, Rajasthan Investment Promotion Scheme

114 Industry Sources

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| | | | • First 20 green hydrogen re-fuelling stations can avail 30% capital cost subsidy up to a maximum of INR 4.5 Cr.<br>• Land allotted for green hydrogen projects will be fully exempted from paying any local body tax, non-agriculture tax, and stamp duty.<br>• INR 4 Cr per annum for 10 years has been approved for recruitment of skilled manpower, their training, and skill development. |
| 6 | Tamil Nadu | Tamil Nadu Industrial Policy 2021[115] | • The Tamil Nadu state government is yet to release the policy draft for incentivizing green and blue hydrogen.<br>• Hydrogen production in the state has been categorized as a sunrise sector in the state's Industrial Policy. This enables green hydrogen projects in the state to avail a bouquet of incentives.<br>• Land cost subsidy to avail land at concessional rate and 100% stamp duty exemption in SIPCOT land banks. In case of private land, a 100% stamp duty concession can be availed for up to 50 acres of land.<br>• Interest Subvention of 5% as a rebate in the rate of interest shall be provided be on actual term loans taken for the purpose of the financing the project, for a period of 6 years depending on the size of the investment.<br>• The project shall also be eligible for standard incentives, namely, electricity tax exemption for 5 years and green industry incentives of up to Rs. 1 Cr. |
| 7 | Andhra Pradesh | Andhra Pradesh Green Hydrogen & Green Ammonia Policy – 2023[116] | • To target Green Hydrogen production up to the capacity of 0.5 MMTPA or Green Ammonia production up to the capacity of 2.0 MMTPA in the next five years by harnessing the RE potential in the state<br>• 100% reimbursement of net SGST revenue to the developer from sale of Green Hydrogen/ Green Ammonia within the State for a period of five years from commercial operation date (CoD).<br>• Exemption from Electricity Duty: 100% exemption of Electricity Duty for the power consumed for production of Green Hydrogen/Green Ammonia from RE plants (with or without storage) for a period of five years from commercial operation date.<br>• 25% of Intra-state transmission charges shall be reimbursed to the developer for a period of five years from CoD for the power procured from RE (with or without |

115 Govt. of Tamil Nadu, Tamil Nadu Industrial Policy 2021

116 Govt. of Andhra Pradesh, Andhra Pradesh Green Hydrogen & Green Ammonia Policy – 2023

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| | | | storage) plants located within the State subject to maximum of INR 10 Lakhs/MW/year of installed electrolyser capacity.<br>• For land allotment a nodal agency shall allocate the Government land for development of both RE plants and Green Hydrogen/Green Ammonia Plants on priority basis at lease rate of INR 31,000 per acre per year with an escalation of 5% every two years during the project period. Alternatively, Green Hydrogen/Green Ammonia plants can also be developed in any of the proposed industrial zones/parks as per prevailing policies.<br>• 100% exemption from payment of land use conversion charges and 100% exemption from payment of stamp duty as part of land usage incentives Green Hydrogen/Green Ammonia production, consumption or elements like storage and transportation. |
| 8 | Kerela | Draft yet to be released[117] | • The state government has issued an Expression of Interest to explore and set up hydrogen hubs within the state.<br>• Large-scale Green Hydrogen hubs to be evaluated by government, industry and financial institutions with a focus to boost domestic consumption and export under India Hydrogen Alliance (IH2A).<br>• Development of hydrogen hubs expected to happen in Kochi and Thiruvananthapuram.<br>• The state is aiming to achieve a 30% green hydrogen blending by 2027.<br>• The state is actively exploring partners to form a consortium to build its hydrogen valleys. A proposal for this is expected to be submitted to the Department of Science and Technology. |
| 9 | Madhya Pradesh | Madhya Pradesh Renewable Energy Policy - 2022[118] | • Projects shall be entitled to receive 100% percent exemption from payment of Electricity Duty on generation of electrical energy for period of ten years from the date of COD<br>• No energy development cess shall be payable on the power supplied by Renewable Energy projects for a period of ten years from the COD<br>• 50% reimbursement on stamp duty on purchase of private land for the project shall be available for developers. |

117 Industry Sources

118 Govt. of Madhya Pradesh, Madhya Pradesh Renewable Energy Policy - 2022

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| | | | • Government land, if available, shall be provided on concessional rate (rebate of 50% on circle rate) to the developers.<br>• 50% waiver on wheeling charge shall be applicable or as may be approved by Madhya Pradesh Electricity regulatory Commission from time to time. This waiver shall be applicable for 5 years from COD.<br>• If investment amount is less than 50 Cr. incentives may be availed as per the general incentives available as per respective policy of Industry/MSME Department.<br>• If investment size if greater than 50 Cr. then Special incentives for RE Equipment Manufacturing Sector under Industrial Promotion Policy can be availed. |
| 10 | Uttar Pradesh | Uttar Pradesh Green Hydrogen Policy[119] | • The state intends to promote blending of green hydrogen with grey hydrogen in existing N-fertilizers and refineries, achieving at least 20% percent of green hydrogen in the consumption mix by 2028 and 100% by 2035.<br>• 100% exemption from payment of land tax, if any.<br>• 100% exemption from payment of land use conversion charges.<br>• 100% exemption from payment of stamp duty.<br>• 50% exemption from industrial water consumption charges if the water consumption is to produce green hydrogen.<br>• 30% one-time grant support for technology acquisition subject to a maximum of 5 crores for R&D centers and industries.<br>• 100% reimbursement of State's Goods and Services Tax (SGST) for green hydrogen/ammonia production<br>• 50% exemption from wheeling charges<br>• 50% exemption from intra-state transmission charges<br>• 100% exemption from cross-subsidy surcharge.<br>• 100% exemption from distribution charges.<br>• Currently, 10% blending of Green Urea needs to be achieved in the state's Urea production. An additional subsidy of INR 3,500 per tonne of urea will be applicable for every extra tonne of green urea produced in the state beyond this blending mandate.<br>• The policy is to provide 50% reimbursement of employer's contribution to Employees' Provident Fund and Employees' State Insurance in the form of employment generation subsidy |

Source: Internal Research

119 Govt. of Uttar Pradesh, Uttar Pradesh Green Hydrogen Policy

# Policies and incentives in other decarbonization alternatives

Apart from the policies implemented by the central government, there are several state level policies that have come up to attract investment in their respective states to combat climate change. An assessment of energy and climate related policies being enacted in Tamil Nadu and Uttar Pradesh for other decarbonization alternatives has been provided below. The policies that indirectly support the green hydrogen economy though already covered earlier, have been highlighted in the tables below, wherever needed, for the sake of completeness of the sections in and of themselves.

# Tamil Nadu

Table 35: Additional policies that support low carbon transition in Tamil Nadu

| Policy | Provisions |
|---|---|
| Tamil Nadu Industrial Policy 2021[120] | • One of the provisions under the Policy is to provide thrust to sunrise sectors by making available additional incentives as a part of sunrise sector incentives, which includes Renewable energy components manufacturing and green fuel technology such as hydrogen.<br>• For projects having an investment size >300 Crore can avail Investment Promotion Subsidy through any 1 of the 4 available mutually exclusive routes. They are:<br>1. SGST Reimbursements for Final products<br>2. Flexible Capital Subsidy<br>3. Fixed Capital Subsidy<br>4. Turn-over based Subsidy.<br>• For eligible projects in SIPCOT, land allotment will be done at 10% concessional rate depending on the class of the district.<br>• 100% stamp duty exemption will be given for lease or purchase of land/shed/building meant for industrial use in land obtained from SIPCOT land bank. |
| Tamil Nadu Solar Energy Policy[121] | • The policy aims to obtain 900 MW solar generation of which 40% is earmarked for consumer category solar systems.<br>• As a part of the policy all public buildings will be encouraged to install solar systems for energy production, both photovoltaic and thermal.<br>• The govt. of Tamil Nadu will promote the in-house manufacture of solar energy components including solar cells, inverters, mounting structures and batteries, etc.<br>• The state will aid in procurement of land to manufacture solar system component manufacturing.<br>• TEDA has been given the responsibility to expedite and facilitate access to various concessions and incentives provided by the MNRE, including capital cost subsidies wherever possible.<br>• A suitable scheme will be drafted later to promote co-utilization of land for solar energy projects, crop cultivation and water conservation. |

120 Tamil Nadu Industrial Policy 2021

121 Tamil Nadu Solar Energy Policy 2019

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| Tamil Nadu Ethanol Blending Policy [122] | • The Tamil Nadu Ethanol Blending Policy seeks to support indigenous production of fuel grade ethanol under the EBP Program.<br>• The goal of the policy to make the state self-sufficient and meet the estimated ethanol blending requirement of 130 Crore liters and attract and investments worth INR 5000 Crore in molasses /grain-based ethanol production in the state.<br>• Tamil Nadu has proposed policies, environment clearance procedures relaxed for distillery and sugar mills going in for expansion under the ethanol blended petrol program, waiver of EC for incidental increase in ethanol production, special provision in EIA for grain-based ethanol.<br>• Tamil Nadu currently has installed plant capacity of 664 KLPD specifically to produce fuel grade ethanol under the EBP, with a further 160 KLPD capacity to be developed, in pipeline. The existing plants and immediate pipeline of projects are molasses based, and several investors have expressed interest to invest and establish standalone grain-based ethanol plants. |

Source: Internal Research

# Uttar Pradesh

Table 36: Additional policies that support low carbon transition in Uttar Pradesh

| Policy | Provisions |
|---|---|

122 Tamil Nadu Ethanol Blending Policy 2023

| | |
|---|---|
| Uttar Pradesh New Industrial policy 2022[123] | • Under the new UP's new industrial policy, Renewable energy production has been included under the focus sectors while the green hydrogen production has been included under the Sunrise sector.<br>• Due to this inclusion both these sectors will be able to benefit from additional financial incentives apart from the incentives available through their own respective policies enforced by the state.<br>• A stamp duty exemption of 100% in Bundelkhand & Poorvanchal, 75% in Madhyanchal & Paschimanchal (except Gautam Buddh Nagar & Ghaziabad districts) region of the state and 50% in Gautam Buddh Nagar & Ghaziabad districts has been sanctioned.<br>• A one-time choice of choosing only 1 among the mutually exclusive 3 options has been made available for availing the Investment Promotion subsidy. The modes are:<br>• Capital Subsidy<br>• Net SGST reimbursement<br>• Top-up incentive received under Production Lined Incentives (PLI) scheme of Govt. of India. |
| Uttar Pradesh Solar Energy Policy -2022 | • The policy aims to achieve a target of establishing 22,000 MW solar power projects up to 2026-27 in the state.<br>• The policy will promote setting up of Solar Power Projects to sell power to third parties or for captive use.<br>• Land will be provided to the state govt / central govt PSUs or JVs on lease for 30 years.<br>• Land bank of land unsuitable for agriculture will be created by UPNEDA for solar projects.<br>• Land will be provided on lease to govt players at a rate of INR 1 per acre per year for a period of 30 years.<br>• Land will be provided on lease to private sector at a rate of 15,000 per acre per year for a period of 30 years.<br>• "Saurya Uttar Pradesh Yojna" is proposed to be implemented during the policy period. Under this Yojna State Government will provide subsidy of Rs 15,000/kW to a maximum limit of subsidy Rs 30,000/- per consumer.<br>• The policy will provide an exemption of 50% on wheeling charges/transmission charges on intrastate sale of power to 3rd party or in case of captive use.<br>• Cross subsidy surcharge and wheeling charges/Transmission charges will be exempted 100 % for Intrastate Transmission system on purchase of solar power.<br>• 100 % exemption from Stamp duty on the Land used for setting up Solar Power Projects/Solar Park in entire State of Uttar Pradesh. Capital State Subsidy of Rs 2.50 Crore per megawatt will be provided to Utility scale |

123 Uttar Pradesh Industrial Investment and Employment Promotion Policy 2022

| | |
|---|---|
| | solar power projects set up with 4 hours battery storage system of 05-megawatt capacity or above and standalone battery storage system (energized by solar energy only) for sale of power to Distribution licensee/ UPPCL.<br>• In respect to all solar projects set up within the State, electricity duty shall be exempted for ten years on sale of power to Distribution licensee, third party, and for captive consumption. |
| Uttar Pradesh State Bio-Energy Policy-2022[124] | • Under this policy, 100% exemption in electricity duty will be provided to the bio-energy enterprises stablished for 10 years from the date of commencement of commercial production.<br>• In case of acquisition of land through lease or purchase from private tenants for setting up of bio-energy enterprises/plants or feedstock collection and storage, 100% exemption of stamp duty payable on rent deed/lease/sale deed/registration will be provided.<br>• Bio-energy enterprises will be given 100% exemption from the development charges charged by the development authorities of the state.<br>• In addition to the maximum 50% subsidy given on the plants under the Central Government's Submission on Agricultural Mechanization scheme to the aggregators defined devices like belar, raker and troller will be provided by the state government through UPNEDA under this policy, [30 percent subsidy (up to a maximum limit of Rs. 20 Lakh)].<br>• For establishment and operation of bio-energy enterprises in Uttar Pradesh, 10 acres of land is required for 10-ton capacity CBG plant and 25 acres of land for storage at various places.02 acres of land is required for 100 ton per day bio-coal plant and 1.5 acres of land is required for 100 kiloliter biodiesel /bio-ethanol plant. Accordingly, applications of developers for grant of land related permissions such as exemption from land ceiling etc. will be processed.<br>• Land will be made available by the Revenue Department on token lease rent of Re 1 per acre annually for a maximum lease period of 30 years for setting up of bio-energy enterprises/plants and for collection and storage of feed stock.<br>• In every district of the state, a budgetary arrangement will be made at the rate of Rs.1 lakh per district with the aim of motivating the entrepreneurs by giving wide publicity to the bio-energy policy. |

Source: Internal Research

## 2.3. Risk Analysis

With increasing focus on greening the energy space, prominence of green hydrogen and green ammonia has increased multifold over the years. Green hydrogen and green

124 Uttar Pradesh State Bio-Energy Policy 2022

ammonia, both perceived as fuel for future having almost minimal carbon footprint. Therefore, countries, industries and many other relevant stakeholders are evaluating the opportunity and feasibility to introduce green ammonia and green hydrogen in the existing energy landscape.

By definition, green hydrogen is the specific type of hydrogen produced through electrolysis of water using renewable power sources. Therefore, primarily, green hydrogen value chain requires a sustainable source of renewable energy (solar, wind, etc.) and infrastructure for electrolysis. Furthermore, to use green hydrogen as energy storage systems, suitable storage system needs to be developed. However, due to inherent nature of hydrogen molecules, transportation and storage of hydrogen is expensive and limited by technical challenges.

Green hydrogen can further be reacted with nitrogen to produce green ammonia. Green ammonia with further downstream processing can be used as a fertilizer, energy carrier or for various industrial applications contributing to sustainable development, as discussed in earlier sections.

The cost of producing green hydrogen depends on the price of renewable energy used in electrolysis, the scale and efficiency of electrolyser technology. The green ammonia production costs are influenced by the cost of green hydrogen, the chosen ammonia synthesis method, and the expenses associated with nitrogen sourcing and ammonia processing. Given India's commitment to renewable energy and its efforts to reduce carbon emissions, it is likely that green hydrogen value chain may gain more traction and further developments in the coming years indicating a more cost competitive environment for these two molecules.

However, the implementation of green hydrogen and introduction of green ammonia is associated with multiple practical challenges and risks. Therefore, a careful understanding of such risks and challenges needs to be taken under consideration. In the following section, number of such risks and associated challenges have been discussed.

**<u>Risk associated with Green Hydrogen and Green Ammonia Implementation</u>**

1. **<u>Offtake Risks:</u>** Consultations with stakeholders from industry have highlighted that at present green hydrogen costs around USD 5-6 / kg and green ammonia costs around USD 9-12 / kg. As highlighted above, the high cost is primarily driven by the available renewable power cost and high cost of electrolyser units. The primary usage of green hydrogen and green ammonia as a fuel and feedstock shall impact the project cost of the interventions discussed earlier in the report resulting in deteriorating project economics for the developers. Therefore, without any substantial mechanism of incentives to pass the additional cost to the consumer/customer, the usage of green hydrogen in the energy economy is expected to stay limited.
   Furthermore, in India, fertilizer industry, particularly urea, is heavily subsidized by government to ensure that the farmers buy the fertilizers at affordable rates. An added burden of greening ammonia may lead to the worsening of project economics even more. In this scenario increase in raw material costs in the form of green ammonia may not be welcomed by the industry players without any aid from the government in form of subsidies to directly bridge the gap. As of now, no such commitment by the government has been made to the existing players.
   In some cases, Government may mandate the usage of green hydrogen to certain percentage such as in refinery and fertilizer sectors. However, under a lack of clarity on such mandates green hydrogen projects suffer from the risk of not having sufficiently guaranteed offtake to hedge the risks of the developers.
2. **<u>Technology Risks:</u>** With the existing technology, approx. 55 kWh of renewable energy is needed to produce 1 kg of hydrogen which contains approx. 33.33 kWh of energy. Furthermore, on conversion through fuel cell, the available energy further reduced to approx. 60% to 70% of the overall energy. Therefore, electrification of regions which can directly be powered through renewable energy via hydrogen fuel cells is an expensive affair due to efficiency loss. The same can be said for green ammonia which is converted from hydrogen and then either directly use via ammonia fuel cells or as hydrogen after ammonia cracking (to release the stored hydrogen). This limits the application of green hydrogen / ammonia as energy storage solutions. Though this may not be a risk directly impacting its implementation, however, and in view of the potential improving battery costs and technology in longer term, scaling of green hydrogen projects may be limited.
3. **<u>Limited availability of raw materials:</u>** Primarily, green hydrogen production needs water and RE power as its raw material. Availability of RE power and sufficient supply of water can be another challenge especially for large-scale production,

particularly in water stressed areas. Ensuring the sustainable water sourcing and usage practices is critical in water-scarce regions.

4. **Safety:** Hydrogen is a highly flammable gas, and the storage of hydrogen needs extreme pressure and temperature consideration.
   Hydrogen has different storage and safety requirements compared to traditional fuels, and ensuring safe handling, storage, and transportation of green hydrogen is a challenge that needs to be addressed. Due to the nature of hydrogen, additional considerations are needed to mitigate the issue of embrittlement of metals like steel, that form the spine of India's gas grid.

Along with such sectoral challenges, green hydrogen and green ammonia space is susceptible to certain supply chain risks in India. Some of them are discussed below:

1. **Dependence on Electrolyser manufacturer from outside India:** Considering the present-day landscape, local availability of scalable electrolyser manufacturers for green hydrogen production is very limited. Constant dependence on imports of electrolysers and import dependence on technical expertise can lead to supply chain constraints and potential delays in developing green hydrogen/ green ammonia projects. Furthermore, the import of critical components for electrolysers can be expensive, impacting the overall production cost of green hydrogen.
2. **Risk of material price fluctuation:** Each electrolyser technology is based on different mix of metals minerals, particularly for electrolyser stacks. Therefore, international cost fluctuation of such critical metals is expected to have material impact on electrolyser cost impact green hydrogen projects negatively.
3. **Lack of supply infrastructure:** The lack of dedicated hydrogen pipelines or a comprehensive transportation network for hydrogen may hinder its cost-effective distribution. Adequate infrastructure for storing and handling green hydrogen at different scales and location might be lacking.
4. **Lack of skilled human resources:** Green hydrogen space is relatively new and the technology is yet to commercially established at scale. Due to its limited application at present, availability of ready skilled manpower for operating such projects is scarce. Due to this, manpower costs for green hydrogen projects can be relatively high or in some instances, manpower availability can altogether be an issue, even in the presence of sufficiently allocated funds. This may create the risk in project execution.

Apart from the above-mentioned risks, the sector is exposed to certain technical challenges. Green hydrogen and green ammonia space is yet to achieve its full potential in terms of technological readiness level, rendering the sector commercially unviable at present. Furthermore, technological disruptions in battery storage space and electric vehicles have potential to delay the emergence of green hydrogen/ ammonia as the preferred storage route. However, such challenges are part and parcel of competing technologies.

**Implication of overly Renewable Energy dependent Grid**

A reliance on renewable energy sources for production of green hydrogen and green ammonia can pose challenges to grid stability and reliability due to their intermittent nature, introduction of green hydrogen at scale is only going to exacerbate this challenge. Solar power generation is subject to weather conditions, and sudden changes in power output can strain the grid, leading to voltage fluctuations or even blackouts. To mitigate the variability of renewable energy, significant investments in energy storage technologies (such as large-scale batteries or pumped hydro storage) is expected to be necessary. This adds to the overall cost of the renewable energy integration. Integrating a high share of renewable energy into the grid requires enhanced grid management techniques to balance supply and demand in real-time. This may involve demand response measures, smart grid technologies and flexible power generation options. The main grid might require substantial upgrades and expansions in transmission infrastructure which can be costly and time-consuming. The overall cost of integrating large amounts of renewable energy into the grid, along with necessary storage and grid upgrades should be carefully evaluated to ensure economic viability.

**Fiscal Risks and Challenges for Green Hydrogen and Green Ammonia Projects considering Government Support**

The government subsidies and incentives for green hydrogen and green ammonia production are not sufficient to bridge the expected viability gap. This is expected to deter potential investors and hinder the industry's growth. Unclear or changing policies and regulations can create uncertainty for investors and slow down the adoption of green hydrogen and green ammonia. A short-term focus on subsidies and policies without a clear long-term vision for the sector can lead to a lack of sustained growth. Misalignment between different government departments and policies related to renewable energy, hydrogen, and ammonia may impede the development of an integrated and efficient supply chain. Depending on the scale and pace of development, these subsidies can require significant financial resources, potentially impacting other sectors that rely on government funding. The allocation of substantial subsidies to support the development of green hydrogen and green ammonia industries can raise concerns about the opportunity cost of investing in emerging technologies over more immediate societal needs such as healthcare, education and poverty alleviation.

If the fiscal burden of providing subsidies becomes too high, the government might be compelled to reduce or withdraw the support in the future, affecting the stability and predictability of the sector. Over-reliance on subsidies to sustain the green hydrogen and green ammonia industries may create a situation where the sectors struggle to become economically viable without continued government support. The subsidy policies may not be consistent or might change over time due to shifting political priorities, leading to uncertainty for investors and industry players. If the subsidies are not well targeted or efficiently utilized, the sectors may face challenges in competing with traditional, carbon-intensive alternatives, hindering their growth and market penetration.

# 3. Willingness To Pay Analysis

As the population steadily grows and rapid industrialization and urbanization drive the steady growth in developing countries like India, the demand for resources are believed to increase substantially. This is happening with a backdrop of the international community that is putting in significant efforts to transition into a world which runs on environment friendly alternatives. As the world rushes to curb its carbon emissions with the goal to achieve aspirational net-zero targets, it is imperative that there is sufficient demand pull from the market in order to support the transition to a sustainable world and reach the targets of the Paris Agreement to limit the increase of temperatures to less than 2°C.

In the willingness to pay analysis the sentiment of the industry associated with the demand centers which are likely to uptake the ammonia and hydrogen have been assessed. The analysis is based on the likelihood of consumers to shift and use green ammonia and green hydrogen as a fuel for power applications and, as a raw material in key industries like fertilizers. The analysis has been performed as per the demand segments to provide a comprehensive picture of the developments happening in the respective sectors.

## 3.1. Green Ammonia

The global fertilizer industry heavily relies on ammonia as a key component in both urea and complex fertilizer production. In India, the demand for ammonia in complex fertilizer manufacturing is primarily met through imports, whose costs are determined by CIF or FOB rates and drive the prices for domestically produced ammonia via Import Parity Pricing. Likewise, the industrial ammonia consumption (in nitric acid, TAN, etc.) is also catered to by the local fertilizer players, at present via the technical surplus ammonia. However, the emergence of green ammonia as an environmentally sustainable alternative has sparked an interest in its potential adoption in the Indian fertilizer market. To explore the willingness to pay for green ammonia by the ammonia producers in India (i.e., the fertilizer players), focus has been put on its competitiveness with the domestic and international market prices and the challenges associated with its adoption.

The Indian government plays a pivotal role in supporting the farmers through the subsidy on fertilizers. The subsidy is targeted for the farmers and routed through the producers/importers, in view of difficulties in direct transfer of these subsidies to the farmers. As the subsidy is fixed from time to time based on certain norms, the industry is looking for low price feedstocks. In other words, enhanced price of input such as green ammonia does not support the industry to claim higher subsidy.

Urea production, which relies on natural gas as a raw material, benefits from a pool of available domestic and imported natural gas, with prices determined accordingly. On the other hand, complex fertilizer production depends on directly imported ammonia. The government additionally provides subsidies on the final product. As a result, many fertilizer producers are hesitant to adopt green ammonia due to its higher production costs, which would translate to either increased fertilizer prices for consumers or higher levels of subsidies. Likewise for ammonia consumption in other industries, as there are no direct or indirect subsidies, the costs of consuming green ammonia can trickle down to the consumers.

One of the primary challenges hindering the widespread adoption of green ammonia in India is the substantial cost difference between green and conventional (grey) ammonia. The price of imported ammonia (say from Qatar) at present is close to USD 310 per tonne. Consultations highlighted that domestic ammonia is mostly linked with urea and the subsidy mechanism for urea takes care of price of natural gas and hence the price of ammonia, based on energy norms. Furthermore, the cost of production of green ammonia in India at present is estimated to lie approx. between USD 900 per tonne to USD 1,200 per tonne. For green ammonia to become viable in the market, the price differential between green and grey ammonia should be reduced to less than $100/ton.

Consultations also highlighted, that the absence of a mechanism to compensate for the cost difference between green and grey ammonia is a significant deterrent to the players that may intend on using green ammonia, particularly if it is not mandated by the government. Currently, green ammonia production costs are considerably higher, making it economically unfeasible without adequate reimbursement mechanisms. The existing government provisions do not sufficiently address the cost gap, further discouraging the consumers from incorporating green ammonia into their operations.

Likewise, technical constraints and policy barriers further impede the feasibility of green ammonia production at a competitive cost. Need for policy support regarding power usage, custom duties, and open access for power distribution (in terms of allowing RE adjustments against the banked power during the times of low RE availability). Consultations with industry players highlighted that, for example in Tamil Nadu, adjustments for the banked RE power are not allowed between 6 p.m. to 10 p.m., which is expected to lead to a decrease in utilization of the green hydrogen/ ammonia plant. Furthermore, the government had imposed the 40% solar panel import duty in April 2022 and a 25% tax on solar cells to discourage Chinese imports. This has also led to an increase in costs to set up solar plants. A revision of such barriers may make the green ammonia space viable. In addition to above, the utilization of carbon credits presents a potential solution to mitigate the financial limitations of green ammonia production.

The willingness to pay for green ammonia in the Indian fertilizer industry hinges on the resolution of critical challenges, particularly the cost gap between green and grey ammonia. To promote the widespread adoption of green ammonia, advancements in technology, policy revisions, and government support are vital. Furthermore, Government reimbursement mechanisms are expected to play a crucial role in fostering market uptake and encouraging the fertilizer industry to transition to greener practices. Additionally, with the anticipated rise in fossil fuel costs in the coming years, the production of green hydrogen, and subsequently green ammonia, could become economically more viable. As the fertilizer industry moves towards a more sustainable future, the potential for green ammonia uptake becomes substantial, supporting the goal of decarbonizing the sector while ensuring environmental sustainability.

## 3.2. Hydrogen in Power Sector

### Power Backup for Hospitals

Hospitals and healthcare facilities are one of the most energy intensive consumers in the commercial sector.[125] For effective functionality and non-stop operations, it is a necessity for hospitals to ensure continuous power backup facilities in case of any emergencies. With the rising costs of fossil fuels due to recent geopolitical developments, the OPEX costs for hospitals have skyrocketed as they rely on the use of diesel for their energy backup needs that are currently being fulfilled by DG sets. It is important that hospitals start taking proactive measures in a timely manner for averting the risks which might arise during the upgradation of the infrastructure.

In the private sector, healthcare executives today are facing a rising challenge in managing the facility operating budget. This is a driving factor that has made the industry reevaluate its current energy practices. In order to ensure that healthcare remains affordable and accessible to the general public and that the rising costs do not trickle down to the patients, several initiatives are being undertaken by the healthcare industry in India. The adoption of energy efficient processes is at the forefront of company and ministerial agendas, with energy audit studies conducted suggesting huge energy saving potential.[126] Hospitals in particular are exploring innovative energy models which are reliable, and cost-effective technologies are needed to address energy concerns.

A major chain of multispecialty hospitals, primary care facilities and heart centers having presence across 18 cities in India, Narayana Health has saved approx. INR 4 Cr. by adopting renewable energy to power most of its operations in India.[127] Currently, 32% of Narayana Health's energy needs are met by renewable sources majority coming from solar

125 Journal of Clean Energy

126 CII Report on Energy Efficient Hospitals

127 Narayana Health Company Reports

(12%), wind (8%) and hydropower (2%). The company is trying to decarbonize its operations in order to fulfill its ESG plans set for the group. Although solar remains the top choice for RE procurement, the healthcare facilities lack the required rooftop space and hence need to rely on procuring renewable energy from solar and wind parks.[128] This provides an indication of the willingness of the industry players to pay a premium for greener sources.

The lack of availability of rooftop space can be seen as an enabler for hospitals to consider other alternatives which consume less floor space. Hydrogen fuel cells in the near future may be able to provide a solution to this challenge as they can be used for primary power, backup power, or combined heat and power (CHP) applications. The case of CHP is a peculiarly interesting one, as it might further help drive down utility costs of steam and other equipment, which cannot be provided by other RE sources as they can only be used for electricity generation. A key bottleneck here is the lack of investors and developers as most businesses go for options enabling higher and faster profitability. The changing environment and an increased focus on ESG as a part of sustainable finance and investment considerations can change this scenario going forward. The attractiveness of the soon to be introduced carbon credit market in India can further help secure the investment required to overcome financial constraints.

The government is also envisaging to undertake initiatives to turn all AIIMS facilities across India into "green hospitals" by adopting environmentally friendly methods.[129] Likewise, in semi-urban and rural regions of India, decentralised RE, particularly solar power, has emerged as a key driver to provide modern healthcare. The government has implemented several schemes to promote the adoption of solar energy across the country, which can be adopted by hospitals. The solar rooftop photovoltaic subsidy scheme, which offers up to 40% subsidy for installing solar panels on their rooftops can help hospitals overcome the financial barriers.

Major accreditation bodies in the healthcare industry, such as JCI (Joint Commission International), NABH (National Accreditation Board for Hospitals and Healthcare Providers), and ISO (International Organization for Standardization) have strict mandates for hospitals to ensure power availability. Providing round-the-clock power is therefore one of the core scoring metrics used to assess hospitals.[130] The standards also give the top "excellence" rating to hospitals that takes initiatives towards increasing energy-efficiency and developing environmentally friendly hospitals. Accreditations are seen as certificates of superior service and standards. Hospitals aiming to secure such

128 Industry Sources

129 Industry Sources

130 NABH Accreditation Standards for Hospitals

reputed accreditations might have a non-financial incentive to adopt emerging technologies such a hydrogen to improve their brand image in the eyes of the general public and differentiate themselves from the local competition.

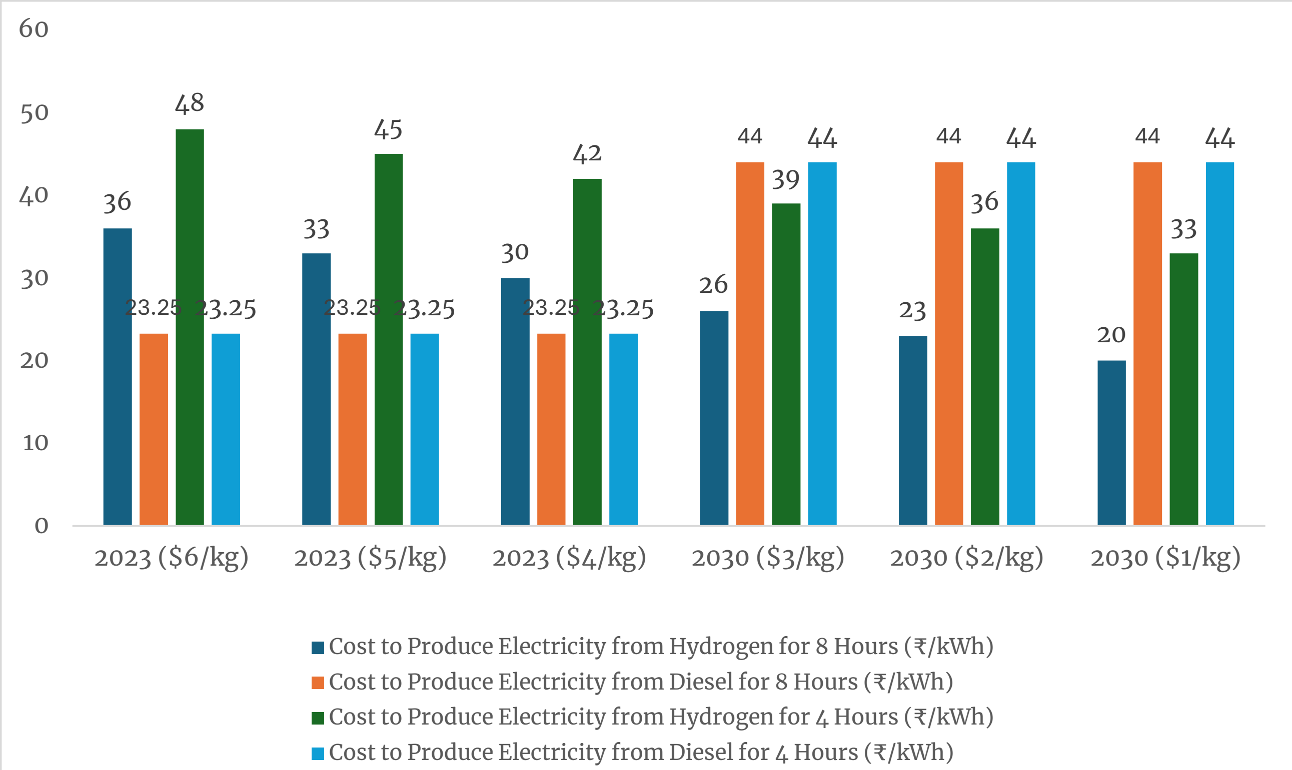
Based on analysis the unit cost to produce electricity through diesel gensets and hydrogen fuel cells for backup power applications were calculated for 2023 and 2030. Different scenarios of Hydrogen prices were considered. Currently, if a hospital wishes to integrate Hydrogen based fuel cells into their operations, they are expected to be needed to pay an extra premium over the current method of using diesel gensets. This premium can be in the range of approx. INR 7 – INR 25 per kWh in 2023. Furthermore, a role reversal can possibly happen in 2030, where due to decrease in green hydrogen prices, improvement in fuel cell stack lifetimes and prices, and an increase in diesel costs, the cost differential per unit of energy can be around INR 5 – INR 24 per kWh. In future as developments are made to make India a hydrogen-based economy, using hydrogen fuel cells for power backup in hospitals can become an attractive option. A comparative cost summary of the cost per unit to produce electricity using Hydrogen FCs and diesel gensets is given below.

Table 37: Comparison of Cost to Produce Electricity for Different Hydrogen Price Scenarios 2023 v/s 2030 (Hospitals)

| Year | Hydrogen Price Scenario ($/kg) | Cost to Produce Electricity from Hydrogen for 8 Hours (₹/kWh) | Cost to Produce Electricity from Diesel for 8 Hours (₹/kWh) | Cost to Produce Electricity from Hydrogen for 4 Hours (₹/kWh) | Cost to Produce Electricity from Diesel for 4 Hours (₹/kWh) |
|---|---|---|---|---|---|
| 2023 ($6/kg) | 6 | 36 | 23.25 | 48 | 23.25 |
| 2023 ($5/kg) | 5 | 33 | 23.25 | 45 | 23.25 |
| 2023 ($4/kg) | 4 | 30 | 23.25 | 42 | 23.25 |
| 2030 ($3/kg) | 3 | 26 | 44 | 39 | 44 |
| 2030 ($2/kg) | 2 | 23 | 44 | 36 | 44 |
| 2030 ($1/kg) | 1 | 20 | 44 | 33 | 44 |

Source: Internal Analysis

Figure 40: Hospitals- Comparison of Cost to Produce Electricity for Different Hydrogen Price Scenarios 2023 v/s 2030 (Hospitals)




Source: Internal Analysis

Even though there is a propensity to pay for cleaner alternatives, but the prices of green hydrogen-based power at present makes it an unlikely route of decarbonization.

# Power Backup for Telecom Towers

The telecom sector is one of the largest consumers of diesel in India. The diesel is used to power the DG sets that provide the required power to telecom towers in case of power cuts to ensure no disruption in services. Due to the continuous increase in fossil fuel costs, energy costs of telecom companies have become as large as 25% of total network operation costs. A typical telecom company spends nearly 1% of its revenues on its energy needs, which for large operators may amount to hundreds of crores in energy costs.[131]

Indus Towers, a subsidiary of the Bharati Airtel, is India's largest user of diesel generators which are utilized to supply backup power to the telecom towers. It is also the market

131 Telecom Regulatory Authority of India (TRAI)

leader in terms of number of operating telecom towers in India.[132] The company has completed trials for methanol-based fuel cells which work on hydrogen as a fuel to provide clean energy to the telecom towers in an attempt to combat rising fuel costs and achieving its sustainability targets. The company has revealed that that pilot had positive results when tested in its northeast telecom circles and the solution is ready to be deployed in its operations.[133] This is a direct indication that the current market leader might be ready to uptake the green hydrogen and their willingness to pay a "green" premium despite cheaper alternatives being available. It is a trend that other major players in the telecom tower market may potentially follow, once the economic feasibility is proven on-ground.

Additionally, Bharti Airtel subsidiary "Nxtra Data Ltd." has become the first data center company in India to install Hydrogen Fuel Cell Technology to provide clean energy. This has been done in partnership with Bloom Energy. Nxtra has further elaborated on the company's ambition to be net zero by 2031 and assured that the company is taking all possible initiatives to adopt innovative energy solutions.[134]

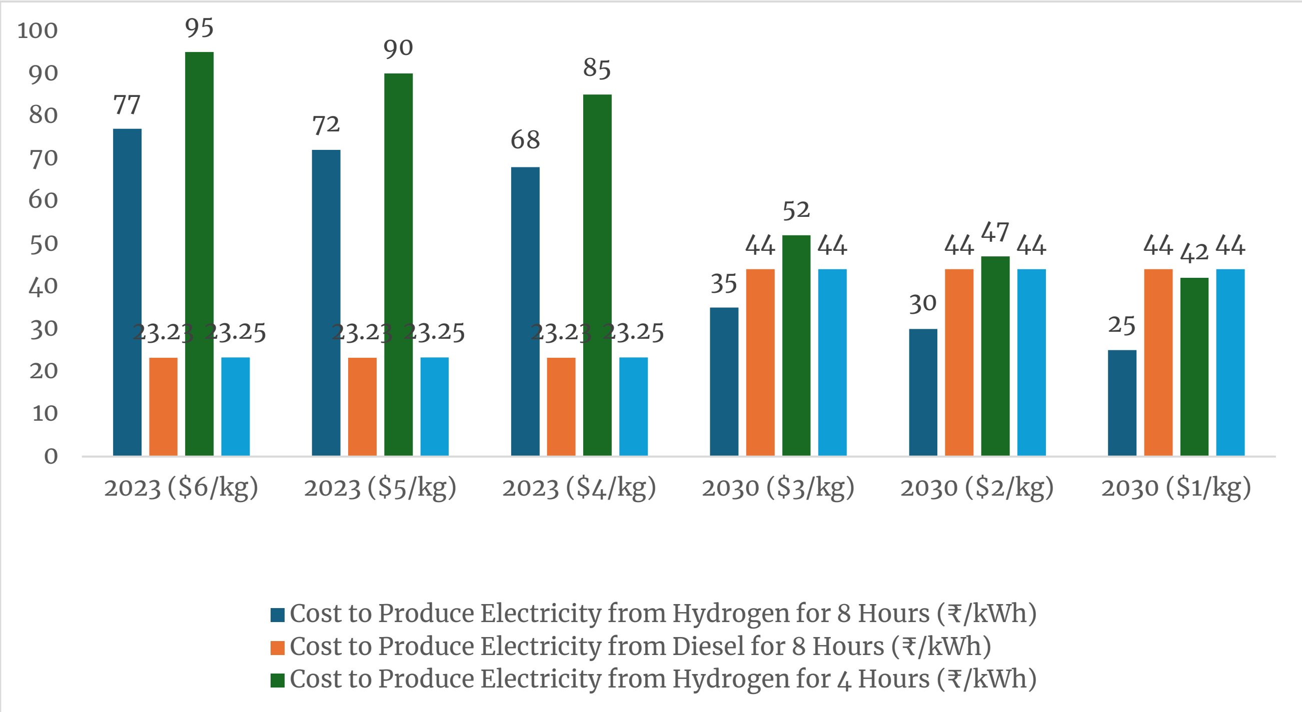
Based on analysis the unit cost to produce electricity required by the telecom towers through diesel gensets and through hydrogen fuel cells for backup power were calculated for the years 2023 and 2030. Different scenarios of hydrogen prices were considered to estimate potential cost savings. At this stage if a telecom tower operator were to implement a green hydrogen based fuel cell technology for power backup, the operators might need to pay extra as diesel remains a cheaper alternative in 2023. This premium might be in the range of INR 45 - INR 72 per kWh in 2023. Conversely, in 2030 as diesel costs are expected to rise and with decreasing costs of hydrogen and fuel cells, the latter may become a cost saving option. The cost savings in 2030 are expected to be around INR 9 – INR 19 per kWh for higher utilization scenario. A comparative cost summary of the cost per unit to produce electricity using Hydrogen FCs and diesel gensets is given below.

132 Industry Sources

133 Business Responsibility and Sustainability Report – Indus Towers

134 Airtel Press Release

Figure 41: Comparison of Cost to Produce Electricity for Different Hydrogen Price Scenarios (2023 v/s 2030)




Source: Internal Analysis

# Decentralised Power Supply in Villages

For the villages that face blackouts or are not electrified, exploring the technical and economic feasibility of installation of fuel cells to provide the basic and most essential commodity such as electricity is important. Taking a look at the current scenario, it was observed that majority of the electrification happening in such remote villages employed renewable energy such as solar, wind, hydropower and/or a mixture of all of them together with provisions for battery storage.[135] The possibility of transporting hydrogen produced at a decentralised hydrogen plant to highly remote locations, which may have inadequate road connectivity, for power generation seems limited. Apart from the high transportation costs and other risk factors involved in the transportation of hydrogen to remote villages, there is also the challenge of availability of technically sound maintenance and repair personnel to be deployed to such locations. Looking at the several developments that have been made in the recent past to bring down the cost of producing electricity from sources such as wind and solar and given the already established success of solar and wind with many such projects

135 MNRE Report

already operational, the likelihood that hydrogen may immediately be used as a fuel for decentralised power supply to villages seems limited.

The supply for electricity is a basic need and the sentiment around having this basic necessity by the villages may be strong. Unlike other cases such as hospitals and telecom towers, which had a sustainability angle and the goal of reducing their operational costs, in villages obtaining electricity is viewed as a fundamental necessity, irrespective of the source of the electricity. Therefore, villagers may want to go for a solution which is well-established in multiple cases on-ground.

Even in the case, where the villages may use fuel cells for meeting their energy requirements, it is less likely that they would procure the required hydrogen from ad external source such as a plant that is away from the village due to transport constraints. Rather, a captive solution where they produce their own hydrogen using electrolysis, powered by solar and wind sources installed on-ground seems more likely.

In a case study, regarding the economic feasibility of a renewable integrated hybrid power generation system for a rural village of Ladakh, which assessed the associated cost of electrifying Turtuk, a remote village in Ladakh, a hybrid system of PV (115 kW) / Wind (1 kW) / Battery (164 strings of 6-V each) / DG (50 kW) would result in a net present cost and energy cost of USD 2,78,176 and USD 0.29 / kWh (approx. INR 24 / kWh), respectively, which is significantly lower than what would be required for a standalone hydrogen fuel cell system (as seen corroboratively from earlier sections).[136] Due to these reasons, the potential of hydrogen based fuel cells for remote villages seems low at the current stage, unless the Govt. provides substantial subsidies to make it compete with the alternatives.

# 3.3. Hydrogen in Mobility

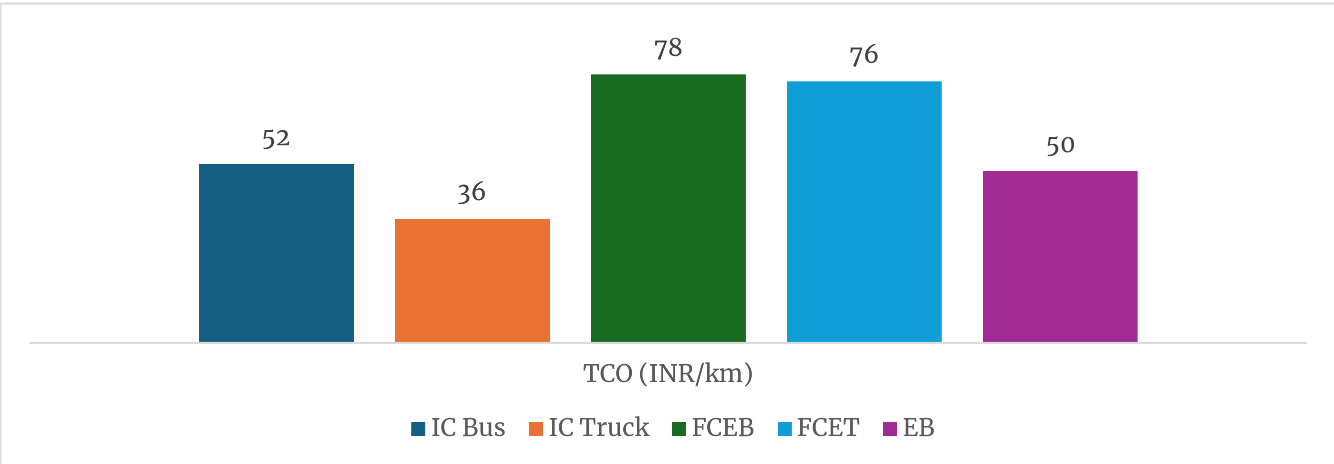
Road transportation is a significant emitter of CO2 and boasts a very high energy demand. This sector is hard-to-abate with a high degree of difficulty in terms of decarbonization. This difficulty emanates from high vehicle dependency, low-cost and mature technology of internal combustion engine, low fuel costs and limited alternatives to fossil fuels available in the market. Several technologies are under development all having their own merits and demerits. In case of mobility, Hydrogen Fuel Cell Electric Vehicles (FCEV), Battery Electric Vehicles (BEV), Hydrogen Internal Combustion Engine Vehicle (H-ICV) and hybrid alternatives are the most likely alternatives under development and with some already available in the market for the consumers to buy.

136 Economic Feasibility of a Renewable Integrated Hybrid Power Generation System for a Rural Village of Ladakh (MDPI, 2022)

The present study focusses specifically on the heavy-duty transport sector (trucks and buses) as hydrogen mobility is more suited for replacing heavy-duty internal combustion engine vehicles and is likely to take up the space once technology attains commercial maturity. Although, BEVs have a higher adoption today, this adoption is limited to Passenger Vehicles (PV) segment. For intensive and long-range travel, which trucks and buses need due to the nature of their commute requirements, hydrogen mobility might turn out to be a better alternative, as for battery vehicles in this segment high energy requirement increases the battery mass, reduces the available space for cargo/passenger volume in the vehicle, and increases the cost and energy consumption of the vehicle.[137] Furthermore, hydrogen tanks take up less space and are lighter than batteries, allowing more cargo to be transported.

Although there are several challenges that need to be addressed before widescale adoption of hydrogen mobility can happen, if the technology receives the right policy support to overcome the main barriers related to purchase price and fuel availability, adoption rates are likely to soar. Hydrogen cost over this decade is expected to decrease with economies of scale and improved technology, which may in-turn reduce the overall cost of ownership of such vehicles.

Figure 42: Mobility Total Cost of Ownership




Source: Internal Analysis

Note: It has been assumed that each vehicle travels 70,000 km each year

Private fleet owners need to be presented a strong business case in-order for them to consider the switch. This needs to be supported by making hydrogen refueling stations widely available, to curb the anxiety related to operations and wait times at refueling stations. It is expected that if Green Hydrogen is used a fuel for FCEVs, it might enable the

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reduction in GHG emissions by 50% compared to gasoline-based ICE Engines.[138] Hence, with the implementation of the highly anticipated carbon markets legislation in India, fleet owners may start showing interest in opting for hydrogen fleets in order to claim carbon credits that provide financial incentives to transition to alternatives. It is less likely that individual players would be the first adopters of fuel cell-based trucks and buses primarily due to exorbitant upfront costs of Fuel Cell Electric Bus. Large fleet owners in the country are more likely to be early adopters to establish the financial and commercial viability of hydrogen powered trucking on road.[139] For buses, specifically, different state governments might plan or are already planning on introducing intracity transport busses into their public transport fleet in order to support the national green hydrogen mission.[140] Hydrogen buses in intracity public transport are expected to be the likely initiator to establish the feasibility of the technology on Indian roads as it won't face the challenge of availability of hydrogen refueling stations as essentially all busses would refuel at a single specific location.[141]

Developments have already taken place in the heavy-duty mobility sector. Olectra in partnership with Reliance is planning on commercially launching their hydrogen buses on the Indian road with a range of 400 km in a single hydrogen fill and offer next generation transport system to the Indian market.[142] It is also expected that Hydrogen Fuel-cell buses may soon be tested in Delhi this year. The buses have been jointly developed through a JV between IOCL and Tata Motors. The JV plans on experimenting the same buses to be operational for inter-city transport on routes such as Delhi-Faridabad, Delhi-Agra, Vadodara to Kevadia, Thiruvananthapuram Airport to Thiruvananthapuram City Centre in the near future.[143] Pune city recently unveiled India's first truly indigenously developed Hydrogen Fuel Cell Bus.[144] The success of such pilots is expected to be important for the industry as it may create a positive ripple effect and motivate other players to opt for hydrogen based heavy duty mobility. Furthermore, developing indigenous technology infrastructure is expected to help bring down the costs without having to rely on international technology providers. This shall also further help increase the adoption rates and create a substantial demand of hydrogen.

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139 Adani Enterprises

140 Kerala and Ladakh are two such regions

141 Journal of Applied Sciences

142 Industry Sources

143 Industry Sources

144 Press Information Bureau

# 4. Transportation of Hydrogen and Ammonia

The infrastructure for hydrogen and ammonia transportation holds paramount importance in facilitating the widespread adoption and utilization of these clean energy carriers. As the world seeks to transition from fossil fuels to renewable energy sources, hydrogen and ammonia play pivotal roles in achieving a carbon-neutral future. To become viable alternatives, a robust transportation infrastructure is necessary to connect production sites to end-users, such as industrial facilities, power plants, and transport applications. By diversifying energy sources and providing multiple supply routes, a well-designed transportation infrastructure enhances energy security and reliability, reducing dependency on a single source or region and minimizing the risk of supply disruptions. Additionally, it opens up opportunities for international trade and cooperation in clean energy, allowing countries with abundant resources to export hydrogen and ammonia to regions with limited local production capabilities. However, transporting hydrogen and ammonia requires adherence to stringent safety standards and regulations due to their flammable and reactive nature. A well-planned infrastructure takes these safety considerations into account, ensuring safe transportation for both the environment and the communities along the transportation routes. Moreover, the infrastructure must accommodate various transport modes, such as pipelines, ships, trucks, and rail networks, to ensure flexibility and cost-effectiveness in meeting diverse transportation needs. As demand for clean energy carriers increases, the infrastructure must be scalable to accommodate higher volumes of hydrogen and ammonia transportation, planning for future growth to ensure resilience and sustainability over the long term.

As elucidated in the preceding sections, green hydrogen possesses significant potential for facilitating partial or complete decarbonization across various sectors in India, including refining, chemical production (such as fertilizers), power generation, and transportation, among others. While India is still in the early stages of developing its green hydrogen sector, it is crucial to evaluate the availability and suitability of existing infrastructure and formulate plans for enhancing and repurposing current infrastructure or establishing new assets as necessary. The establishment of a robust supporting infrastructure is paramount for the realization of a Green Hydrogen economy within the country. In the subsequent discussion, we will explore different modes of hydrogen and ammonia transportation, along with their associated cost economics.

## 4.1. Pipelines

Pipelines are expected to constitute a critical component of Hydrogen infrastructure in future. Furthermore, pipeline Hydrogen transport avoids electricity grid capacity constraints caused by integration of increasing renewable electricity production. So, instead of transporting bulk electricity, it may also be more cost efficient to transport Hydrogen via a pipeline infrastructure. In addition, Hydrogen, like natural gas, can be stored[145] over seasons and can hence serve as a dispatchable source of bulk energy, a distinctive advantage over electricity. Blending of H2 into cross country transmission pipelines as a transportation modality has not been yet tested in India. The potential for this method of distribution is still being studied for feasibility in India. Recently, Avantika Gas successfully conducted a pilot study to test the feasibility of carrying 18% Hydrogen in a part of their gas network in Indore. Transporting volumes larger than this is expected to require repurposing of pipelines given the fact that Hydrogen causes embrittlement of carbon steel. City gas and regional distribution grids can be the cheapest means for transporting hydrogen if the network has a high utilization.[146]

Figure 43: Hydrogen and Ammonia Pipeline Costs

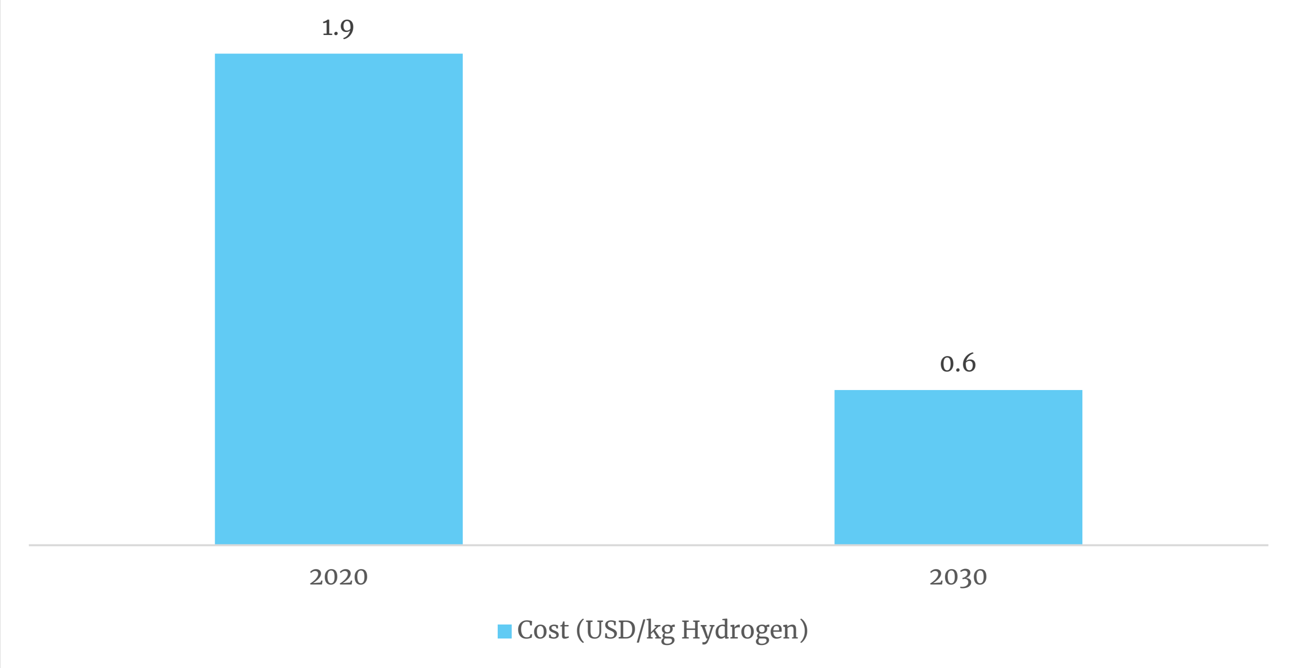
| Type | Parameter | Hydrogen | Ammonia |
|---|---|---|---|
| Transmission Pipeline | CAPEX USD Mn./km | 1.21 | 0.55 |
| Distribution Pipeline (High-Pressure) | CAPEX USD Mn./km | 0.5 | 0.25 |
| Distribution Pipeline (Low-Pressure) | CAPEX USD Mn./km | 0.3 | - |

Source: IEA

145 Although technically possible, the storage of H2 is expensive from a CAPEX and technological perspective

146 Hydrogen Council (2021)

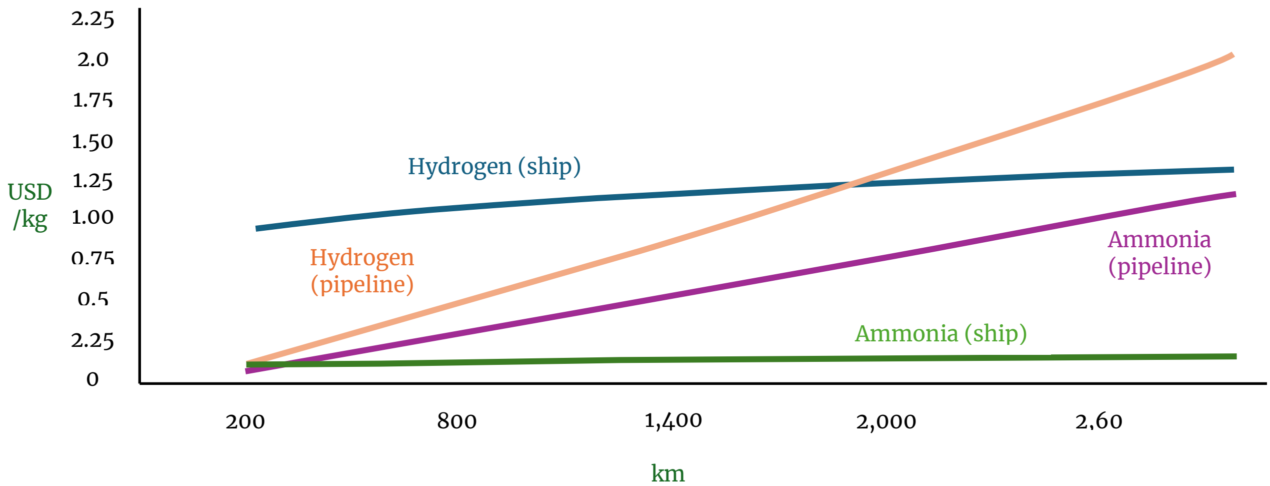
Figure 43: Cost of hydrogen transportation via pipeline (USD/kg)




Source: Hydrogen Council

Transportation of hydrogen via pipeline is expected to be viable for distances under 1,900 km and for longer distances, pipeline transportation in the form of ammonia is expected to be cost effective.[147]

Figure 44: Costs of transportation of hydrogen and ammonia over different distances (USD/kg H2)




Source: Ammonia: zero-carbon fertiliser, fuel and energy store (The Royal Society – 2020)

147 Ammonia: zero-carbon fertiliser, fuel and energy store - The Royal Society (2020)

# 4.2. Gaseous and Liquid Hydrogen Trailers

Tube trailers are the trucks that haul gaseous hydrogen, which is compressed to pressures of 180 bar or higher into long cylinders that are stacked on a trailer that the truck hauls.[148] This gives the appearance of a long tube and hence named tube trailer. For limited quantities and short distances, gaseous route remains most feasible.[149] Transportation of hydrogen as gas is cost economic if it's transported in quantities less than 50 tonnes per day (TPD) for a distance under 250 km. For quantities as low as 5 TPD, distances under 500 km are cost effective for gaseous hydrogen transportation route.[150]

Transportation of hydrogen as liquid is cost economic if it's transported in quantities greater than 50 tonnes per day (TPD) for a distance above 250 km. For quantities in range of 5 TPD, distances above 500 km are cost effective to be transported by liquid hydrogen.[151]

Table 38: Capital and operational expenditure for hydrogen transportation via road

| Type | Parameter | Gaseous Hydrogen | Liquid Hydrogen |
|---|---|---|---|
| Trailers | CAPEX USD Thousand | 650 | 1,000 |
| | Annual OPEX (% of CAPEX) | 2% | 2% |
| | Net Capacity (kg) | 670 | 4300 |

Source: IEA

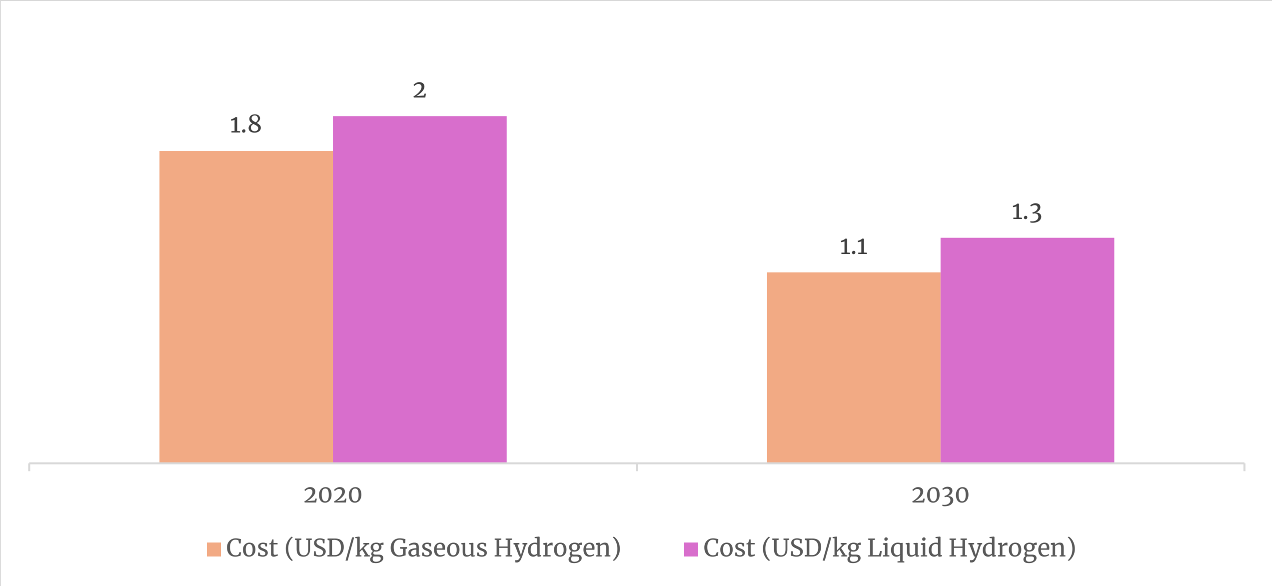
148 US-DOE

149 Linde

150 Linde

151 Linde

Figure 45: Cost of gaseous and liquid hydrogen transportation via tube trailers(USD/kg)




Source: Hydrogen Council

# 4.3. Hydrogen as Ammonia

Ammonia is cheaper to transport via road and rail as compared to hydrogen, but the conversion and reconversion costs make the transportation process expensive. In terms of safety, ammonia faces a few challenges as it is acutely toxic if inhaled. In addition, it is a flammable substance, a precursor to air pollution (if leaked). For larger quantities and distances in range of 1000s of km, transporting hydrogen as ammonia becomes economically feasible. At present the cost of ammonia via road is approx. USD 0.23 per tonne per km. [152]

Table 39: Capital and operational expenditure for ammonia transportation via road

| Type | Parameter | Ammonia |
|---|---|---|
| Trailers | CAPEX USD Thousand | 220 |
| | Annual OPEX (% of CAPEX) | 2% |
| | Net Capacity (kg) | 2,600 |

Source: IEA

152 Ammonia: zero-carbon fertiliser, fuel and energy store - The Royal Society (2020)

# 5. Commercial Pre-feasibility

Assessments until now have highlighted the discrete ammonia and hydrogen demands that exists across various sectors in Uttar Pradesh and Tamil Nadu. In this chapter, an analysis of the techno-commercials for setting up a decentralised green ammonia facility has been undertaken.

## 5.1. Assessment for 300 TPD Plant

### 5.1.1. Plant Specifications

For a 300 TPD green ammonia plant, Haber-Bosch production process has been assumed. Furthermore, assumptions for both PEM and Alkaline electrolysers have been built in, with the expected electrolyser sizes expected to be dependent on efficiencies. Industry insights suggest that the efficiency of a PEM electrolysis system is marginally better than an Alkaline electrolysis system. Therefore, for the present context, the efficiency of the PEM electrolyser has been assumed to be 67% while as the efficiency of the alkaline electrolyser has been assumed to be 63%. Therefore, the subsequent electrolyser sizes are approx. 110.6 MW and 117.62 MW, respectively.

#### Assessment of energy requirements

Energy requirements per unit of ammonia and hydrogen have been assessed. Bosch-Haber process has been assumed for green ammonia production.

For a 300 TPD rated ammonia plant (or equivalently 109.5 KTPA), the daily hydrogen requirement is 53.15 TPD (equivalent annual hydrogen demand of 19.48 KTPA). The associated energy requirements are tabulated below:

Table 40: Energy requirements for an integrated hydrogen-ammonia facility

| Sl. No. | Process | Energy Requirement in kWh per unit output | Per day energy requirement |
|---|---|---|---|
| 1 | Electrolysis (electrolyser + BOP) | • ALK – 52.91 kWh per kg H2<br>• PEM – 49.75 kWh per kg H2 | • ALK – 2.81 MUs per day<br>• PEM – 2.64 MUs per day |
| 2 | Ammonia Plant (Haber Bosch + Air Separation Unit) | 0.456 kWh per kg ammonia | 0.137 MUs per day |

Source: Elsevier

Therefore, the net daily energy consumption to produce 300 TPD ammonia lies between 2.78 Mn. units to 2.95 Mn. units.

## 5.1.2. Results

## Levelized costs of Green Hydrogen and Ammonia

The levelized cost of hydrogen (LCOH) for a plant capacity of approx. 19.48 KTPA is:

Table 41: Levelized Cost of Hydrogen (LCOH) Estimates

| Electrolyser Technology | Cost USD per kg hydrogen |
|---|---|
| **PEM** | **4.90** |
| **Alkaline** | **4.81** |

Source: Internal Analysis

For the LCOHs specified above, the levelized cost of ammonia for the associated ammonia plant of capacity 300 TPD is:

Table 42: Levelized Cost of Ammonia (LCOA) Estimates

| Electrolyser Technology | Cost USD per kg ammonia |
|---|---|
| **PEM** | **1.24** |
| **Alkaline** | **1.23** |

Source: Internal Analysis

## Project NPV and IRR

Against an assumed selling price of USD 566 per MT of ammonia, NPV and IRR are tabulated below:

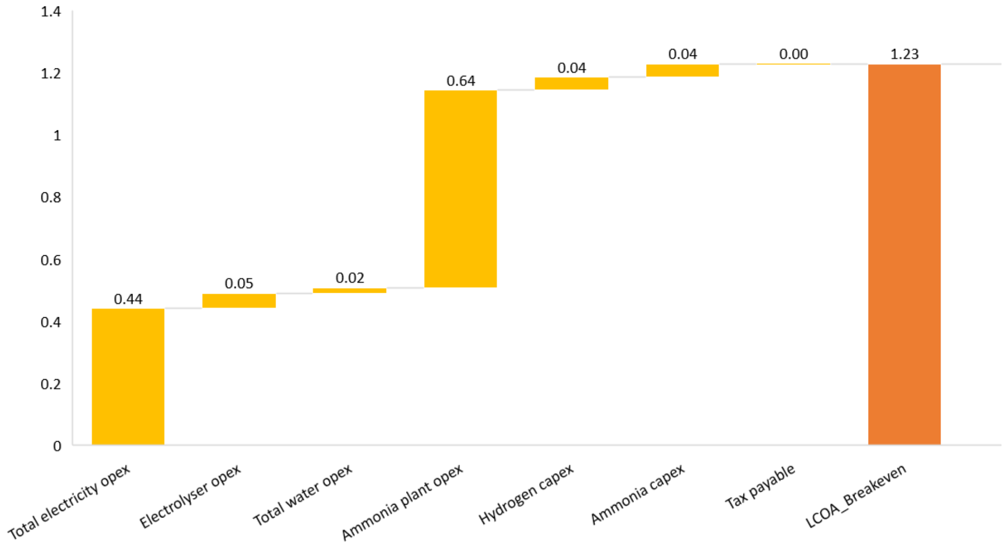
Table 43: Levelized Cost of Ammonia (LCOA) Estimates

| Electrolyser Technology | Project NPV (USD Mn.) | Project IRR (%) |
|---|---|---|
| **PEM** | **-296.55** | **Value goes beyond -100%** |
| **Alkaline** | **-289.49** | **-88.35%** |

Source: Internal Analysis

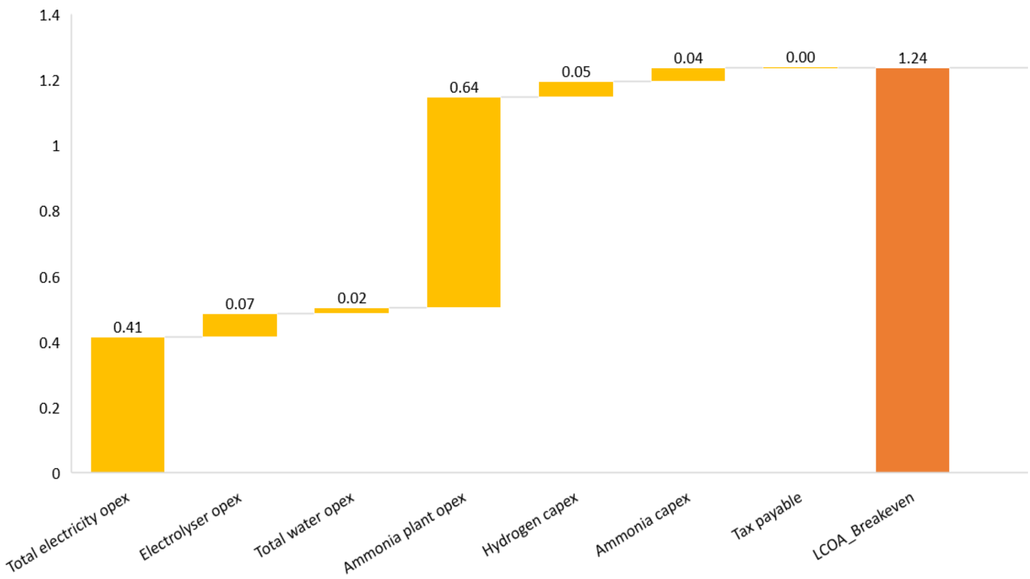
—

Figure 46: LCOA (using alkaline electrolyser)




Source: Internal Analysis

Figure 47: LCOA (PEM electrolyser)




Source: Internal Analysis

# Sensitivity Analysis

Dependence of LCOA on various parameters is discussed below, for the alkaline electrolyser:

Table 44: Impact of various parameters on LCOA

| Parameter | -20% | -10% | 0% | +10% | +20% |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| CAPEX sensitivity | 1.152 | 1.152 | 1.227 | 1.257 | 1.304 |
| OPEX sensitivity | 0.911 | 1.058 | 1.227 | 1.410 | 1.607 |
| Electrolyser efficiency | 1.444 | 1.325 | 1.227 | 1.153 | 1.152 |
| Electricity costs | 1.099 | 1.163 | 1.227 | 1.291 | 1.355 |

Source: Internal Analysis

Table 45: Impact on LCOA by varying rate of interest on debt

| Rate of Interest on Debt | 6% | 7% | 8% | 9% | 10% | 11% | 12% |
|---|---|---|---|---|---|---|---|
| LCOA (USD/kg) | 1.175 | 1.192 | 1.209 | 1.227 | 1.245 | 1.263 | 1.282 |

Source: Internal Analysis

## 5.2. Discussion on results and commercial viability

The distributed demands established in earlier chapters helped in understanding who the off takers of the product might be, in a decentralised setup, and subsequently test the hypothesis if minimal transportation costs can offset disadvantages of lack of economies of scale. Though the market assessments have established the demand potential of green ammonia and green hydrogen within the states of Tamil Nadu and Uttar Pradesh for different end use sectors, it is important to note that the ability to consume ammonia for many of these sectors is still at a very nascent state and not yet ready to uptake green ammonia/ green hydrogen on "as-of-now" basis. Although, sectors such as mobility and ammonia in power exhibit a high potential demand, they cannot readily offtake green ammonia/ green hydrogen as they lack the technology and infrastructure required. Considerable efforts in terms of technology and infrastructure development are required for the goal of a hydrogen-based economy to be realized.

In this regard the willingness to pay section of this study was able to capture the sentiment of the players in the various demand sectors that, although there might be clear inclination to shift to sustainable alternatives like green ammonia/ green hydrogen, the capacity to pay and the ability to employ them in operational activities might be a challenge, keeping in mind the costs associated with using fossil fuel based feedstocks are still low with the price differential being much higher than what would be ideal.

At present the LCOA turns out to be USD 1.227 per kg of ammonia. This value is considerably higher than the price of grey and green ammonia available in the international market.[153] Hence, to make the production of green ammonia viable, this cost would be required to come down considerably in order to become competitive.

153 S&P Global Platts Ammonia Price Chart

# 6. Annexure 1

## 6.1. Assessment for 50 TPD Plant

### 6.1.1. Plant Specifications

For a 50 TPD green ammonia plant, Haber-Bosch production process has been assumed. Furthermore, assumptions for both PEM and Alkaline electrolysers have been built in, with the expected electrolyser sizes expected to be dependent on efficiencies. The electrolyser efficiencies for both PEM and Alkaline have been assumed as per the 300 TPD model. Therefore, the subsequent electrolyser sizes are approx. 18.43 MW and 19.60 MW, respectively.

#### Assessment of energy requirements

The net daily energy consumption to produce 50 TPD ammonia lies between 4,64,800 units to 4,93,800 units.

### 6.1.2. Results

Under the above-mentioned CAPEX and OPEX assumptions, an RE cost of INR 4.7 per kWh has been assumed. We shall discuss the levelized costs in the following sections.

#### Levelized Costs of green hydrogen and ammonia

The levelized cost of hydrogen (LCOH) for a plant capacity of approx. 3.25 KTPA is:

Table 46: Levelized Cost of Hydrogen (LCOH) Estimates

| Electrolyser Technology | Cost USD per kg hydrogen |
|---|---|
| **PEM** | 5.55 |
| **Alkaline** | 5.29 |

Source: Internal Analysis

For the LCOHs specified above, the levelized cost of ammonia for the associated ammonia plant of capacity 50 TPD is:

Table 47: Levelized Cost of Ammonia (LCOA) Estimates

| Electrolyser Technology | Cost USD per kg ammonia |
|---|---|
| **PEM** | 2.09 |
| **Alkaline** | 2.05 |

Source: Internal Analysis

# Sensitivity Analysis

Dependence of LCOA on various parameters is discussed below, for the alkaline electrolyser case:

Table 48: Impact of various parameters on LCOA

| Parameter | -20% | -10% | 0% | +10% | +20% |
|---|---|---|---|---|---|
| **CAPEX sensitivity** | 1.85 | 1.93 | 2.05 | 2.14 | 2.26 |
| **OPEX sensitivity** | 1.72 | 1.87 | 2.05 | 2.24 | 2.45 |
| **Electrolyser efficiency** | 2.27 | 2.15 | 2.05 | 1.97 | 1.90 |
| **Finance costs** | 2.04 | 2.05 | 2.05 | 2.05 | 2.05 |
| **Electricity costs** | 1.93 | 1.99 | 2.05 | 2.11 | 2.17 |

Source: Internal Analysis

# Impact of Electrolyser Oversizing

Below the impact of electrolyser oversizing is highlighted on the LCOH and LCOA.

Table 49: Variation of LCOH and LCOA based on electrolyser oversizing

| Parameter | Baseline ALK (19.60 MW) | ALK (39.21 MW) | ALK (58.81 MW) | ALK (78.41 MW) | ALK (98.02 MW) | ALK (117.62 MW) | ALK (137.22 MW) |
|---|---|---|---|---|---|---|---|
| | 3.25 KTPA | 6.49 KTPA | 9.74 KTPA | 12.98 KTPA | 16.23 KTPA | 19.48 KTPA | 22.72 KTPA |
| **LCOH (USD/kg)** | 5.29 | 4.84 | 4.71 | 4.65 | 4.61 | 4.18 | 4.16 |
| **LCOA (USD/kg)** | 2.05 | 1.96 | 1.94 | 1.93 | 1.92 | 1.85 | 1.85 |

Source: Internal Analysis

The variation of LCOH and LCOA highlights that by oversizing the electrolyser even though the LCOH shows an improvement, due to the inherent high costs of the ammonia plant the drop in the LCOA is not significant. Furthermore, even if the electrolyser is scaled within 100-MW scale, the LCOH improvements do not significantly translate to LCOA improvements, again due to the previous reason.

Furthermore, the cost savings that are attained while scaling up the electrolyser (to cater to the external hydrogen market) are not significant to a level that can offset the transportation costs incurred to carry the same hydrogen to end-use. Hence, results in a higher delivered cost than the case if the hydrogen were to be produced and consumed onsite, at the hydrogen consumption site.

Table 50: Cost comparison between green and grey alternatives

| Sector | Cost of Grey Alternative | Cost using Green Hydrogen / Ammonia of the 50 TPD plant |
|---|---|---|
| Hydrogen in the Power Sector | INR 23 / kWh | INR 45 / kWh |
| Hydrogen in Mobility | • Buses – INR 50 / km<br>• Trucks – INR 33 / km<br>• Electric Bus – INR 52 / km | Buses – INR 70 to 73 / km<br><br>Trucks – INR 49 to 70 / km |
| Ammonia in Fertilizers | • USD 310 / ton (via ammonia imports at import parity price)<br>• USD 655 to USD 767 / ton (via pool of domestic subsidized NG and imported NG) | USD 2,048 / ton |

Source: Internal Analysis

With time, it is expected that the fossil fuel costs will keep rising and the costs associated with producing green ammonia/ green hydrogen might reduce as economies of scale are achieved supported by widespread acceptance and strong government support in the form of incentives and provisions.

The analysis undertaken highlights that a small scale 50 TPD plant in itself may not be a viable route to produce ammonia owing to the high levelized costs of production. Particularly ammonia, as in the 50 TPD case the disadvantages from a cost perspective are significant. So much so that the Total Installed Cost of a 50 TPD plant is expected to be in the close proximity of a 300 TPD plant, which has the LCOA close to USD 1,227 per tonne of ammonia.[154] The potential mitigation of this is expected to be the production of hydrogen and/or ammonia at large-scales.

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The International Hydrogen Ramp-up Programme (H2Uppp) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) promotes projects and market development for green hydrogen in selected developing and emerging countries as part of the National Hydrogen Strategy.