International Hydrogen Ramp-up Programme – H2Uppp

Feasibility Study for 1000 tons per day Green Ammonia Production Plant in India

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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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, September 2024

Foreword

It is my privilege to introduce the feasibility study on the 1000 TPD (tonnes per day) Green ammonia production facility at Khavda, Gujarat. This study provides a comprehensive technical roadmap for developing a Green ammonia plant in India, supporting the country's Green Hydrogen goals. This study is the result of a collaboration between NTPC and the Indo-German Energy Forum (IGEF) Support Office, with execution by Fichtner Consulting Engineers. As India's demand for Green Hydrogen and ammonia grows, having access to detailed feasibility studies for large-scale production plants becomes increasingly important.

The study begins by outlining the requirements and challenges of the proposed site, including corrosive soil, seismic activity, and cyclonic risks. It addresses water needs through desalination and borewell water treatment, focusing on minimising consumption and waste. The approach to ammonia synthesis highlights the potential for scalability, and the use of computer simulations and optimisation ensures that the plant can adapt to the variable renewable energy supply. The proposed layout, plant arrangement, and logistics plan present a well-rounded view of how the project will integrate into the existing ecosystem. By prioritising risk mitigation for ammonia production and transport, the project advances technological capabilities while ensuring the safety of the community and the environment.

The financial modelling in the study offers a clear and practical assessment of the project's economic viability. The analysis of capital and operating expenses provides key insights into the factors that will affect the levelised cost of ammonia production. Making this financial scrutiny publicly available is essential for attracting investment and ensuring the project's long-term success.

This feasibility study is more than just a blueprint for a state-of-the-art green ammonia plant in India; it serves as a guiding light for future green ammonia developers in the country. The potential impact of this project on India's energy landscape and export capabilities is significant, aligning perfectly with the National Green Hydrogen Mission (NGHM) and Atmanirbhar Bharat.

I commend the authors, reviewers, partners, and the Indo-German Green Hydrogen Task Force for their hard work on this study, and I encourage stakeholders to use its findings as a guide for sustainable growth in the Green Hydrogen sector.

Shri Sujit Pillai
Scientist -F
Ministry of New & Renewable Energy

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Glossary

ACC	Air Cooled Condenser
ACF	Activated Carbon Filter
AEA	Ammonia Energy Association
ALE	Alkaline Electrolyser
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTI	Ammonia Safety Training Institute
ASU	Air Separation Unit
AVB	General Terms and Conditions of Contract (AVB) for supplying services and work 2022
AWWA	American Water Works Association
BBS	Bar Bending Schedule
BMWK	German Federal Ministry for Economic Affairs and Climate Action
BMU	Federal Ministry of the Environment, Nature Conservation and Nuclear Safety
BMZ	Federal Ministry for Economic Cooperation and Development
BOG	Boil Off Gas
BoL	Beginning of Life
BoP	Balance of Plant
BOOT	Build-Own-Operate-Transfer
CapEx	Capital Expenses
CO2	Carbon di-oxide
CPU	Condensate Polishing Unit
CRS	Corrosion Resistant Steel
DAS	Distributed Acoustic System
DCS	Distributed Control System
DRE	Decentralised Renewable Energy
DSO	Dynamic Simulation & Optimisation
DWT	Dead Weight Tonnage
EIA	Environmental Impact Assessment
EoL	End of Life
EOT	Electric Overhead Travelling
ESIA	Environmental and Social Impact Assessment
ETP	Effluent Treatment Plant
FEED	Front End Engineering Design
FEI	Fire and Explosion Index
FI	Fichtner India
FID	Final Investment Date
FRLS	Flame Retardant Low Smoke
FS	Fichtner Stuttgart
GIS	Gas Insulated Switchgear
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GNFC	Gujarat Narmada valley Fertilisers and Chemicals
GSFC	Gujarat State Fertilisers and Chemicals
GSM	Global System for Mobile Communications
GST	Goods and Service Tax
HART	Highway Addressable Remote Transducer
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HFL	High Flood Level

HMI	Human Machine Interface
HP	High Pressure
HV	High Voltage
HVAC	Heating, ventilation, and air conditioning
IEC	International Electrotechnical Commission
IFFCO	Indian Farmers Fertilizer Cooperative Limited
IGEF	Indo-German Energy Forum (IGEF).
IGEF-SO	Indo-German Energy Forum Support Office (IGEF-SO)
IGST	Integrated Goods and Service Tax
IP	Ingress Protection
IRC	Indian Roads Congress
IS	Indian Standards
KRIBHCO	Krishak Bharti Cooperative Limited
LCOA	Levelised Cost of Ammonia
LCOH	Levelised Cost of Hydrogen
LNTP	Limited Notice to Proceed
LP	Low Pressure
LPL	Lightning Protection Level
LV	Low Voltage
MB	Mixed Bed
MCC	Motor Control Centre
MGF	Multi grade filter
MLDB	Main Lighting Distribution Board
MNRE	Ministry of New and Renewable Energy
MOEF&CC	Ministry of Environment, Forests & Climate Change
MP	Medium Pressure
MT	Metric Ton
MV	Medium Voltage
NFPA	National Fire Protection Association
NH_3	Ammonia
NM	Nautical Miles
NPTI	National Power Training Institute
NSTI	National Skills Training Institute
NTPC	National Thermal Power Corporation
NTPCREL	NTPC Renewable Energy Ltd.
NTU	Nephelometric Turbidity Unit
O&M	Operations and Maintenance
OFC	Optical Fibre Cable
OISD	Oil Industry Safety Directorate
OPC	OLE for Process Control
OpEx	Operating Expenses
PEM	Polymer Electrolyte Membrane (or Proton Exchange Membrane)
PESO	Petroleum and Explosives Safety Organisation
PGM	Platinum Group of Materials
PGHRU	Purge Gas Hydrogen Recovery Unit
PLC	Programmable Logic Controller
PPA	Power Purchase Agreement
PtX	Power to X (derivates of hydrogen)
QRA	Quantitative Risk Assessment
RCC	Reinforced Cement Concrete

RO	Reverse Osmosis
SAREP	South Asia Regional Energy Partnership
SCADA	Supervisory Control and Data Acquisition
SDI	Salt Density Index
SMPV	Static and Mobile Pressure Vessels
STG	Steam Turbine Generator
TDS	Total Dissolved Solids
TI	Toxicity Index
ToR	Terms of Reference
TPD	Tons Per Day
TRL	Technological Readiness Level
TSS	Total Suspended Solids
UF	Ultra Filtration
UMREPP	Ultra Mega Renewable Energy Power Park
VDU	Video Display Unit
VLGC	Very Large Gas Carriers
XLPE	Cross Linked Polyethylene

Introduction

About Indo-German Energy Forum (IGEF)

The Indo-German Energy Forum (IGEF) was established by the Indian Prime Minister and the German Chancellor to enhance and deepen the strategic dialogue about the ongoing energy transition between India and Germany. The forum aims at initiating strategic cooperation projects between German and Indian governments, institutions, and the private sector. It aims at promoting cooperation in energy security, energy efficiency including energy conservation, renewable energy, investment in energy projects, and collaborative research and development in identified areas, considering the environmental challenges of sustainable development. The Support Office to the Indo-German Energy Forum (IGEF-SO) is implemented by GIZ and has been tasked provide liaison services for all stakeholders, identifies possible topics for dialogue and supports private sector projects.

About Indo-German Green Hydrogen Task Force

On 2 May 2022, the Governments of the Federal Republic of Germany and of the Republic of India, under the co-chairmanship of the Federal Chancellor Olaf Scholz and Prime Minister Shri Narendra Modi, respectively, held the 6th India-Germany Inter-Governmental Consultations. As per the final Joint Statement "both sides agreed to develop an Indo-German Green Hydrogen Roadmap based on the inputs by the Indo-German Green Hydrogen Task Force supported by the Indo-German Energy Forum (IGEF)."

The Task Force comprises of four Subworking Groups along the green hydrogen value chain:

- Plant Engineering and Production
- Transport, Storage and Consumption
- Finance, Insurance Industry and Trading
- Quality Infrastructure, Safety and Legal Framework

About H2Uppp

The International Hydrogen Ramp-up Programme (H2Uppp) accompanies and supports efforts to ramp up the market for green hydrogen (H2) and Power to X (PtX) applications in India. The programme has been commissioned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). Unlike other hydrogen support initiatives, H2Uppp focuses on the early stages of green hydrogen project development. Green ammonia production has been identified as one of the first applications of green hydrogen to become commercially viable. The Public Private Cooperation projects (PPPs) address specific questions along the GH_2 value chain to analyse bottlenecks in project and business model development of replicable project concepts. In the PPPs, private and public partners contribute their strengths in a formalised partnership to develop the market for GH_2/PtX technologies and applications along the value chain. GIZ is the public partner and contributes technical expertise, its structures and networking on the ground to the projects. This feasibility study and location assessment for green ammonia production in India shall enable the development of this promising market segment in India.

About NTPCREL

NTPC is India's largest power utility established way back in 1975 to accelerate power development in India. Since then, it has established itself as a dominant power major with presence in the entire value chain of the power generation business. From fossil fuels, it has forayed into generating electricity via hydro, nuclear and renewable energy sources. This foray will play a major role in lowering its carbon footprint by reducing greenhouse gas emissions.

Formed on 7th October 2020 NTPC Renewable Energy Ltd. (NTPCREL) is a wholly owned subsidiary of the NTPC Limited. NTPCREL has been formed with an objective to accelerate the Renewable Energy growth of the Company and increase the green footprint across country and overseas.

NTPCREL is taking up large Solar, Wind and Hybrid Projects all over the country and developing Gigawatt scale Renewable Energy Parks and Projects in different states under UMREPP (Ultra Mega Renewable Energy Power Park) scheme of Government of India. In addition to this Green Hydrogen based Mobility and ESG projects are also being pursued.

About Fichtner Consulting Engineers

Fichtner Consulting Engineers (India) Pvt. Ltd. (Fichtner India), established in 1987, is a leading Consulting Engineering Company and is part of Fichtner Group, with headquarter located in Stuttgart, Germany and having presence in more than 60 countries worldwide, providing services in the fields of Energy, Environment, infrastructure, and IT.

Fichtner India handles challenging projects in India and abroad providing a complete solution.
Fichtner India offers consultancy services in the following sectors:

- Power Generation and Transmission
- Oil & Gas
- Chemical & Petrochemical
- Water & Infrastructure
- Environment
- Renewable

For the energy sector, Fichtner India offers wide-ranging technical, commercial, and economic solutions ranging from energy generation to its efficient utilisation. Its experience in power generation spans from conventional power generation technologies to emerging technologies including renewable energy.

Fichtner India (along with their parent company Fichtner Stuttgart) have been given the task to prepare the Feasibility Study for the 1000 TPD capacity green ammonia plant.

Summary of Feasibility Study

The present work is a feasibility study for a green ammonia plant with a production capacity of up to 1,000 TPD (tons per day) at Khavda, Gujarat, India. The study involves a comprehensive analysis of site requirements and available resources, system designing and simulations of the hydrogen and ammonia synthesis plants and secondary equipment, layout and plant arrangement, transport infrastructure and logistics, safety and risk mitigation, personnel and manpower, project implementation, and financial modelling. The study is executed by Fichtner, supported by NTPC and commissioned by GIZ on behalf of the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

The proposed site presents many challenges such as corrosive soil and seismic and cyclonic risks. The water requirements are addressed through desalination and treatment of borewell water, with a focus on minimizing consumption and waste generation. Electrolyser capacity requirements as well as CAPEX and OPEX were also evaluated in this study. The study also explores transport options including various safety measures, fire protection, and pre-requirements and introductions to HAZOP, HAZID, and QRA studies.

This feasibility study provides a detailed technical roadmap for the development of a green ammonia plant in India, aligning with the country's green hydrogen ambitions and contributing to sustainable energy and economic growth.

Site requirements

The proposed site at Khavda is about 125 km the nearest airport and railway station at Bhuj, Gujarat. Based on the site visit and sample geotechnical investigation reports from an adjacent site, it is observed that the site poses certain challenges due to the expansive nature and the corrosive characteristics of the soil. This will necessitate use of corrosion resistant steel. The foundations will require the use of corrosion resistant steel piling thereby increasing the construction schedule and costs.

The site falls in a location classified as Zone 5 which is seismically the most active region (very severe intensity zone). The basic wind speed at the site is 50 m/s requiring the design for this zone as per Indian Standard. The site is vulnerable to cyclones originating from the Arabian sea.

Overall, the site is vulnerable to both risks, viz., earthquake and cyclone.

Water requirements

From the interactions during the site visit, it is understood that the only source of water available near the site is from borewells containing brackish water containing high levels of TDS viz., 50,000 - 60,000 mg/l. The borewell water will be desalinated in a RO plant and subsequently treated in a Mixed Bed unit to produce the required quality of water. For the feasibility study, it is assumed that water from borewell will be available in sufficient quantities to operate the Ammonia plant for 25 years. It is recommended to carry out a hydrogeological test to determine the number of borewells, location, hours of pumping of each borewell and safe pumping capacity to confirm suitability of this option. With a view to limit the overall consumption of water in the plant and to minimize the overall quantity of liquid waste generation, only closed loop cooling water systems using air cooled radiators are considered for the plant including major equipment like electrolyser coolers, steam turbine auxiliaries, and coolers in ASU, Ammonia plant and BoP equipment. Air cooled condenser is considered for condensing the exhaust steam from the steam turbine. Therefore, continuous consumption of water is limited to meeting the requirements of the electrolysis process and the steam-water cycle make-up only. Accordingly, the water treatment plant will be sized for producing 130 m^3/hr of demineralised water.

It is proposed to discharge the non-chemical effluents from the RO plant to the adjacent salt pans. The other liquid effluents, both continuous and intermittent, generated in the Ammonia plant, RO plant, steam water cycle, etc. will be treated to an acceptable quality as required by the Gujarat state pollution control board prior to discharge from site.

Ammonia synthesis

Medium pressure Haber-Bosch process (pressure range of 100-200 bar g) and temperature of 350-525^{o}C having a TRL of 9 has been considered for Ammonia production. The licensors can offer Ammonia plants that are capable of flexible operation over a wide operating range, at higher ramp rates to minimise or avoid storage of Hydrogen and Nitrogen while operating in a Variable RE environment. However, Hydrogen storage of 5 tons (net) is considered for the study to handle transient conditions. Similarly, a storage of 20m^3 of liquid Nitrogen is considered for the feasibility study.

The study has determined that the waste heat produced in the Ammonia synthesis loop can be used to produce high pressure & high temperature steam that is suitable for expanding in a steam turbine to produce ~15 MW of power. It is possible that the Licensor may design the system for production of medium pressure steam resulting in a slightly reduced power generation. This generation will meet the power requirements of the plant BoP systems partially. The Ammonia plant will be provided with electrical drives for Syngas compressor, recycle compressor, refrigerating units, etc. to facilitate quick response in a variable RE environment. Therefore, the use of turbo-compressors within the Ammonia plant is not envisaged.

Dynamic Simulation and Optimisation (DSO)

The Variable RE profile provided for the study is equivalent to 6735 hours/annum full load hours, with minimum load of 25%. Using this profile, the Dynamic System Optimisation study concluded that the capacity of the installed Ammonia plant must be 1300 TPD to produce 1000 TPD of Ammonia, equivalent to an annual production of 332,150 Tons assuming a plant availability of 91%. The required production of green Hydrogen to be produced by the electrolysers would be 60,451 Tons/annum. For this, the simulation study identified the required electrolyser capacity as 623.8 MW (only PEM type), 606.6 MW (only Alkaline type) or a combination of (200.7 MW PEM + 414.6 MW Alkaline type). The study also determined that the difference in specific cost of electrolysis between the two types is marginal when the Opex for both Alkaline type and PEM type is assumed to be the same at 2% of capex per annum. For the base case however, the Opex for Alkaline is assumed to be at 4% of capex per annum. The annual quantity of Nitrogen required for the plant has been estimated to be 281,995 Tons which would be produced in the Air Separation Unit. Bulk of the power required in the plant would be consumed by the Electrolysers whose specific power consumption has been assumed to be the average specific power between the Beginning of Life and End of Life. Therefore, the effect of degradation is not considered separately, and a constant value (equal to the average specific power consumption) is considered for the lifetime of the project assuming that the stack is replaced at End of Life.

The DSO has estimated a LCOA to be INR 90.27/kg NH_3 for the base case where the cost of the Ammonia plant was assumed to be USD 650/t. NH_3 (INR 53,755 / t. NH_3) per annum. However, the LCOA has been recomputed separately based on additional inputs such as provision of steam turbine for power generation using the steam generated from the Ammonia synthesis process and better granularity in the power consumption and costs of the plant and BoP systems.

Layout & plant arrangement

The estimated plot size required is about 50 hectares. The electrolyser area occupies a large footprint and is based on a typical 5MW unit capacity electrolyser of containerized construction. The arrangement of the sub-systems is based on the consideration of safety distances and the economic flow of materials. The safety distances for flare stack, storage of gaseous Hydrogen storage (1.7 Tons(net/useable) at 40 bar g), storage of liquid Ammonia (2x5000 Tons) is governed by guidelines specified in national and international standards.

Transport infrastructure and logistics

The feasibility of various modes of transport required for supplying Ammonia to domestic consumers has been examined. Due to the presence of large fertilizer production units in the state of Gujarat, it is assumed that the domestic consumers will be within the state. Road transport will be a better option if Ammonia must be supplied to multiple consumers who are geographically distributed. However, if a single off-taker is identified withing the state, transport by pipeline is recommended. Among all options, transport by pipeline is considered carbon neutral since RE power will be used by the transfer pumps.

The study has assumed that ammonia must be transported to an Offsite storage/transport terminal located near the port for exporting to international consumers. The distance between the plant and the Offsite storage/transport terminal is assumed to be nearly 180 km. The cross-country pipeline will be buried to enhance safety and will be continuously monitored for leakages. Ammonia will be stored in two tanks of 10,000 Tons capacity each, at atmospheric pressure and cryogenic conditions in the transport terminal, from where it will be loaded into the vessels/ships using loading pumps of either canned type or submersible type construction. The transport terminal will be provided with suitable safety measures including a flare stack to prevent discharge of toxic Ammonia vapours into the atmosphere.

Safety and risk mitigation

The risk mitigation measures are identified based on the understanding of the risks and consequences associated with the two major hazards viz., gaseous Hydrogen (highly Flammable) and Ammonia (highly Toxic). The mitigation measures must include provision to detect Hydrogen leakages and fire at an early stage because of its unique properties viz., colourless, odourless, tasteless, and non-toxic. A combination of flame detectors and gas detection equipment will mitigate the risks arising from large scale generation, storage, and use of Hydrogen at the site.

Ammonia leak detection from the cross-country pipeline will be detected using a Distributed Acoustic system (DAS) which is also based on the principle of detecting ultrasonic sound generated by a leak. This will be complemented by other systems that work on the internal leak detection system. A combination of DAS and the internal leak detection system will ensure that the pipeline is monitored round the clock and any leak is detected without any delay.
The risk of fire and explosion risk from Ammonia is generally quite low. Ammonia can however form flammable mixtures in air within certain limits (16 to 25 percent by volume).

Outside storage tanks will be located at least 15 m away from buildings or adjacent to blank masonry building walls. The location should be away from any flammable liquid storage. Dyke of adequate size will be constructed around the storage tank to contain large scale spillage along with the water used to dilute the spill.

Fire protection system will be designed in accordance with local/international standards. It will consist of a network of hydrants to ensure coverage of all the assets. A high velocity spray system will be provided for the transformers in the substation. Sprinkler system will be provided for the warehouse /stores. The manned areas will be provided with smoke detectors and alarm system. Portable fire extinguishers will be provided in the manned areas.

HAZOP, HAZID and QRA studies will be conducted during the project implementation phase to identify and quantify the risks associated with the operation of an engineering process and to identify the mitigation measures also. The techniques used to conduct such studies are proven and well established in the process industry. Such studies will support in the understanding of exposure of risk to the employees, the environment, and the company assets.

Personnel and manpower

The indicative staffing i.e., full time employees, comprising of operators, maintenance technicians, supervisors, engineers and support function staff like administration, procurement, accounts, etc. is estimated to be nearly 250. This is inclusive of staff at the offsite storage (Transport terminal). However, it does not include contract staff employed for the purposes of plant security, for running the canteen, for janitorial services, etc. The staffing numbers could change depending on the maintenance philosophy / nature of the service agreement to be adopted for the electrolysers and AHU.

Project implementation

The producer will typically require (i) Environmental and Regulatory clearances (pollution NOC, and other certificates/permits from MOEF&CC), (ii) Land use permits, building permits, Electricity (connectivity) permits, Gujarat state pollution control board permits, and Tax registrations for developing the project.

The total project schedule is assumed to be 26 months, which broadly consists of two major activities viz., FEED phase for 8 months followed by the Implementation phase of 18 months. The schedule will however depend on the electrolyser vendors shop loading at the time of award. The loading of the Ammonia plant EPC contractor is also critical as this could potentially extend the project schedule of 26 months, to nearly 34 months. The completion of FEED phase coincides with the FID (Final Investment Date). The six (6) months preceding the commencement of FEED is proposed to be utilised for activities related to soil investigation at proposed site, borewell capacity assessment, preliminary discussions to identify Technology Licensors, finalise draft PPA, identify land near port, identify piping corridor for cross country pipeline, etc. Such activities will reduce the project contingencies and the schedule uncertainties for the implementation phase.

Financial modelling

The total CAPEX for the project is summarised below –

Total CAPEX (including Contingency, GST & Land Development, and freight rate), million INR	**99985.17**
Interest during construction (IDC), million INR	**12598.13**
Total Capital cost for 1000 TPD Ammonia plant, million INR	**112583.30**

The financial parameters assumed for the modelling are shown below –

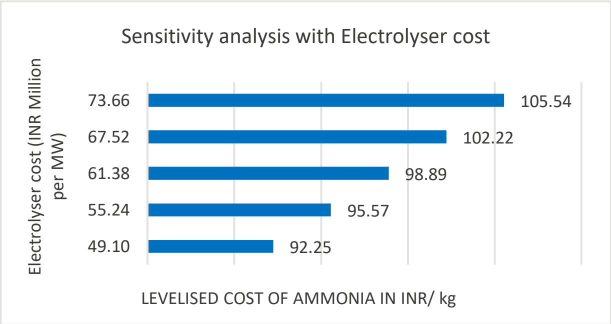
Parameters	**Units**	**Values**
Debt: Equity Ratio		70:30
Interest on Loan	%	9
Repayment period (including Moratorium)	Years	17
Moratorium Period	Years	3
Design useful life of the plant	Years	25
Useful life of Stack	Years	10
Annual availability of overall system	%	91
Electricity Cost	INR/kWh	4
Maintenance cost (Electrolyser)	%	2% of Capex
Maintenance cost (Balance of System)	%	3% of Capex
Escalation on O&M (y-o-y)	%	3
Escalation on Manpower Cost (y-o-y)	%	5
Depreciation for Stack	%	10
Depreciation for Balance of System for first 15 years	%	5
Depreciation for Balance of System from 16th year	%	2.5

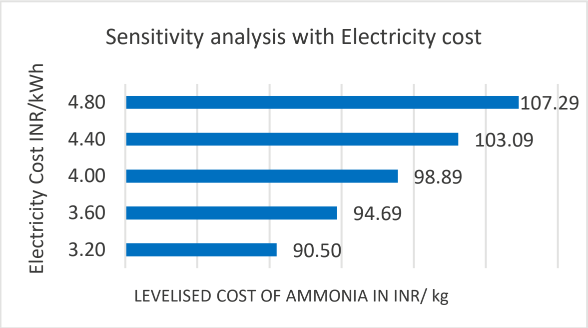
The summary of the operating expenses and the Levelised cost of Ammonia is as follows -

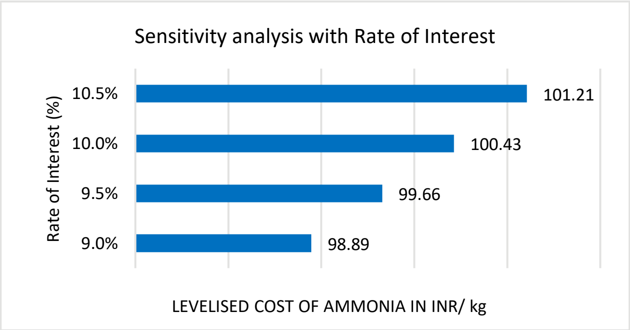
Fixed Cost (for the Project lifetime)	Million INR
Interest on loan	52030.28
Return on Equity	170453.67
Depreciation	119710.15

Interest on working capital	4824.94
O&M expenses	99447.11
Total Fixed Cost	**446466.15**
Variable Cost (for the Project lifetime)	
Cost of electricity	348592.40
Chemical/Solid Waste Cost	2138.18
Total variable cost	**350730.58**
Total cost of production	**797196.72**
Levelised Cost of Ammonia, INR/kg	**98.89**

Sensitivity analysis for levelised cost of generation for Ammonia with variation in Electrolyser cost, electricity cost, rate of interest is presented below. It is observed that the variation in electricity cost has a significant impact on the LCoA. With a 10% increase in the electricity cost, the LCoA varies from INR 98.89/kg to INR 103.09/kg. Similarly, with 10% increase in the Electrolyser cost the LCoA varies from INR 98.89/kg to INR 102.22/kg. With increase in the rate of interest from 9% to 10% LCoA increase from INR 98.89/kg to INR 100.43/kg. The results are summarized in the graph below.







1 Site requirements

1.1 Location

The proposed plant site is at Khavda, Bhuj district in the state of Gujarat. Based on a site visit conducted by the Fichtner team, it is observed that the nearest highway connecting the site is State Highway 45. The site is located about 500 m from the existing 60 ft main road. It is observed that there is no road access presently available to the site from the nearest main road. Access to the site is possible only on foot by traversing through a muddy pathway for nearly 500m. The nearest airport and railway station are at Bhuj located about 125 km from the site.

1.1.1 Climatic Data

Ambient temperature Min, Max	5°C, 45 °C
Relative Humidity	52 %
Wind Speed (as per IS 875-Part 3)	50 m/s
Rainfall (Avg)	411 mm/annum

1.1.2 Environmental data with special precautions regarding natural disasters

1.1.2.1 Flooding risk

The proposed site is plain and with gentle gradients. Such a site is prone to flooding with the water remaining stagnant at certain portions over substantial periods of time. As per information collected during the site visit, flooding occurred about 0.5m to 0.75m above the existing ground level. The risk of flooding can be mitigated by conducting detailed hydrology study to identify the High Flood Level (HFL) and suitably sizing the storm water drainage system.

1.1.2.2 Soil risk

It is observed that Geotechnical investigation is not carried out for the proposed area. However, extracts from the geotechnical investigation carried out at the adjacent area was provided for review. As the proposed site is very close to the investigated area, property of the adjacent area has been considered.

During the site visit, it was observed that the soil over the entire area is not uniform and appears to vary over the proposed area. The top layer of soil comprises of very soft saturated clayey silts and silty clay followed by soil of same characteristics but with soft and very stiff clay layer at depths.

The top two-meter layer of site is soft clay. As this layer is of expansive type, it will swell on contact with water and shrink when the soil is dry. When it swells, it exerts pressure on the supported structure. Alternate swelling and shrinking will result in differential settlement.

Also, the top 2-meter soil is of corrosive nature. Such soil type will adversely impact buried metallic pipes, concrete and other underground structures. Uncoated steel and steel in concrete erected in this soil will require corrosion protection.

As per soil report, soil in 25% of the bore hole exhibits liquefiable soil characteristics due to horizontal force application resulting in liquefaction during an earthquake. Based on the soil report, it can be concluded that the soil in this zone has poor characteristics.

Further, the site is located within a seismically active region (Zone 5 as per Indian standard) implying that the foundations of the structures/buildings will be subjected to strong ground motion resulting from seismic activity along local and distant active faults.
The geotechnical report does not recommend open foundations. The structure built in this area will require to be supported on short piles for light structures and piles of 25m to 30m length of suitable diameter for heavily loaded structures.

Ground water is found at 2.5m to 3.0m below the existing ground level.

1.1.2.3 Corrosion risk

The top 2m soil layer is highly corrosive in nature and the foundation provided in this layer requires corrosion protection for both concrete as well as for reinforcement and structural steel.

The chloride content and the sulphate content in the soil and water are high as reported in the soil analysis report. When both chloride and sulphate content are high, sulphate resistant cement also cannot be used to reduce the effect of sulphate attack on concrete. Ordinary Portland cement with C3A content between 5 and 8 % or Portland slag cement may be used.

In such cases, protection such as tanking is required for concrete foundations. This will however increase the cost of foundations substantially.

The reinforcement bars need corrosion protection also. Either fusion bonded epoxy coated bars or corrosion resistant steel (CRS) bars must be adopted. The reinforcement bars are epoxy coated after the bars are fabricated as per BBS, at factory. The epoxy coating is vulnerable to damage either during transportation or site handling (loading/unloading) increasing the risk of corrosion. Also, the cost of fusion bonded bars is higher (additional INR 10,000 per ton) compared to CRS bars. Due to the limited number of fusion bonding units, it could become a long lead item and impact the construction schedule. Hence, corrosion resistant bars appear to be a better option as compared to fusion bonded epoxy bars.

Due to the corrosive nature of the soil, any deficiency during the concreting of the piling will result in failure due to corrosion. The risks can be mitigated using methods such as –

1) Non-metallic polymer solution
2) Jacketing the pile
3) Providing galvanic anodes.

1.2 Process, cooling and wastewater

Water is required for hydrogen production, cooling water system (for Hydrogen plant/ Ammonia plant & BoP), service water, firefighting system, drinking water, etc. Refer the flow diagram titled Saline water treatment system FCE-20522173-ME-DWG-PFD-3591-004.

Based on the site visit report, it is understood that the only source of water is from borewells. For the feasibility study, it is assumed that water from borewell will be available in sufficient quantities to operate the Ammonia plant for 25 years.

The other option is to convey sea water from roughly 125 km distance. This option is however not considered in the Feasibility Report due to the technical challenges and expected high costs of O&M over the plant lifetime.

Assuming that borewell is the only source of water, it is necessary to carry out a hydrogeological test to decide the number of borewells, location, hours of pumping of each borewell and safe pumping capacity to confirm suitability of this option. The plant water system will be designed to minimize the overall water consumption. The system design will avoid the use wet cooling system that require continuous make-up water supply to compensate for evaporation and blowdown losses.

Low water consuming cooling system options such as air-cooled condensers (ACC) for condensing steam from the steam turbine exhaust, and closed loop radiator coolers for Electrolysers, and STG auxiliaries, Ammonia plant coolers, BoP equipment coolers, is considered for the system design.

Demineralised water must be supplied to the electrolysers continuously for producing Hydrogen. A limited amount of demineralised water will be required for make-up to the steam cycle to compensate for blowdown. All other users of demineralised water require only intermittent supply to compensate for leakages and for loop filling during plant start-up and maintenance. Such consumers are radiator coolers of the electrolysers, syngas compressors, Ammonia plant, ASU, H2 booster compressors, and the BoP system (air compressors and other coolers).

Process water is required for other applications such as Firefighting system (filling and make-up), Service water system, and HVAC system. This will be tapped off from the outlet of the RO system first pass and stored in the Raw water/Firewater storage tanks.

Drinking water requires a minimum level of TDS and therefore cannot be obtained from the Desalination plant. Drinking water of 2000 litres/day capacity) is required for the plant. A portion of Product water from First Pass RO system will be utilised to produce drinking water.

Effluents produced in the water treatment plant are collected and treated in an Effluent Treatment Plant before discharge. Biological waste will be treated separately in skid mounted sewage treatment plant, and the discharged water will be used for landscaping purposes. Continuous effluents generated in the Desalination plant are from the Multigrade filter, Activated Carbon filter, Ultra Filtration system, and RO system. These effluents are proposed to be disposed to nearby salt pans. However, disposal into the nearby salt pans will require approval from the State Pollution Control Board.

The other liquid wastes generated are–

1) Ammonia plant - Continuous
2) Blowdown from the Steam water cycle- continuous
3) Mixed Bed Ion Exchanger in the Demineralizer plant – intermittent (during weekly regeneration)
4) RO System cleaning – Intermittent (once in 4-5 months)
5) UF system cleaning – Intermittent (once in 4-5 months)
6) Condensate polishing unit (CPU) – intermittent (weekly or monthly depending on impurities coming from the process heat exchangers of the Ammonia plant)
7) Electrolysers - intermittent (only during maintenance)
8) Miscellaneous sources like floor washes and radiator coolers – intermittent.

The above liquid effluents will be collected and treated in a neutralization pit before discharge from plant.

The demineralised water from the water treatment plant will be stored in two storage tanks that will have a combined total capacity equivalent to 24 hours of consumption. The tanks will be constructed of carbon steel material and the internal surfaces will be lined with Epoxy (or PU liner or rubber liner or PU coating) to prevent corrosion.

Considering the remoteness of the plant, the quantity of chemicals required for operating the water treatment plant such as Sodium Hydroxide, Hydrochloric Acid, Sodium Hypochlorite and Ferric Chloride will be stored onsite to meet the operational requirement of about 30 days.

1.2.1 Water balance diagram

Refer attached diagram - FCE-20522173-ME-DWG-PFD-3591-005

1.3 Power

1.3.1 Summary of energy storage options

The Variable RE (VRE) profile viz., 70%, 80%, 90%, Solar only, provided for analysis has been used in the simulation. The VRE profile and tariff provided for the analysis has been derived from a combination of solar, wind and Battery storage. The RE profile was derived with an intent to minimize the variability. The simulation results did not recommend onsite any form of energy storage (such as battery or pumped storage) to maintain process stability.

Banking has not been considered since it will involve additional costs (to be paid to the state Discoms for the banking facility) and will limit the opportunities of exporting Ammonia to certain countries where banking (either monthly or quarterly) is not approved due to concerns of increased emissions.

1.3.2 Electricity demand

From the simulation results, the sizing of Ammonia synthesis loop, ASU, and Electrolysers are derived to produce 1000 TPD of green Ammonia. The BoP systems have been sized to support the electrolysers, Ammonia loop and ASU. Accordingly, the maximum electricity demand at full load is estimated to be ~658MW (refer Annexure 7 for details). The electricity demand at part load will not be proportional to the load due to the non-linear relationship between load and efficiency for mainly in the Ammonia synthesis loop and Electrolysers. At part loads, the Electrolyser efficiency is assumed to be higher than at rated capacity, whereas the Ammonia plant efficiency drops sharply at part load. The combined impact is considered in the simulation.

1.3.3 Power tariff

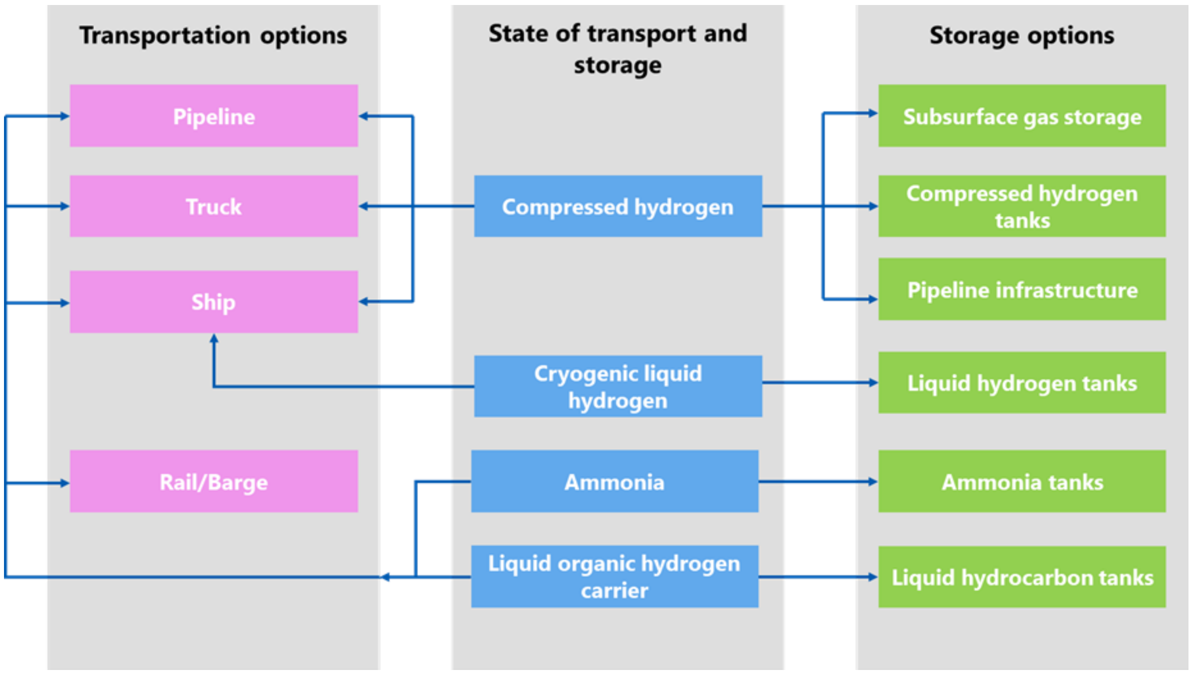
Constant/uniform tariff of INR 4.0/kWh has been assumed for the study.

1.4 Transport infrastructure and logistics

1.4.1 Infrastructure required for supplying to domestic consumers

The typical options for transportation and storage of Hydrogen derivative (Ammonia) shown in the figure below. It must be noted that transportation of Hydrogen and LOHC (referred in the figure below) to an offsite location for storage is not envisaged in the Feasibility study.

Figure 1: Typical transportation and storage options for Hydrogen (Source: IRENA – Hydrogen Forecast to 2050)



For transporting Ammonia from the plant to the domestic consumer(s), all the available options identified above can be utilised depending on the location of the consumer with the final selection of the transportation option being determined by the least cost of transportation.

1.4.1.1 Transportation by road

As the green Ammonia plant is in Gujarat, major consumers could likely be within the state itself because large scale manufacturers such as KRIBHCO, IFFCO, GNFC, GSFC, and Hindalco have operational fertiliser units located in Gujarat. It is understood that a significant quantity of Ammonia is presently imported through Kandla port for use by the fertiliser plants. The recent government policies are aimed at curbing such imports and replacing them with indigenous production through the green Ammonia route.

Assuming that Ammonia must be transported to these fertiliser plants within Gujarat, the distance between the plant and the fertilizer units will range between 150 km to 600 km. Road transportation is considered most suitable for this distance. The transportation cost for this option is likely to be approx. INR 3.0 to 3.50 per ton per km.

Typical capacities of the mobile tankers range from 7MT to 25 MT, with a Bulker of 35MT capacity also available. Assuming 15MT as the average capacity of the tankers, the total number of tankers required will be approx. 67 per day. 4-5 loading bays, located adjacent to the storage tanks, will be constructed to load the trucks simultaneously. If Bulkers were employed the number of tankers to be employed would reduce to 30 per day, with a requirement of 4 loading bays.

Contingency plans must be prepared to deal with potential road accident involving Ammonia tankers. The plan will typically provide information on the safety measures to be observed, sources of help available, and the personnel responsible for the control actions. It will also contain information on the travel route along with a comprehensive response plan to react to foreseeable emergencies anticipated during the transportation of ammonia by road to prevent loss of lives and damage to property, to help return to near normal conditions.

1.4.1.2 Transportation by rail

Ammonia transportation by rail will be preferred for longer distances such as fertilizer units located in other states such as Uttar Pradesh, Rajasthan, and Madhya Pradesh. Indian railways, which operates a large network (~125,000 km) could offer a feasible solution. The advantages of this mode of transportation vis-a-vis road transportation are –

- the ability to transport large quantities resulting in lower transportation cost,
- greater certainty on the transportation times,
- Lower carbon footprint, and
- higher level of reliability and safety

For the project site, it will require additional infrastructure to transport by rail including the new link from site to the next city. This will require a detailed study with inputs from the railways department to estimate the cost of transportation. However, there could be additional constraints in the availability of sufficient number of cars for the required route as several green Ammonia plants in future are built at locations away from the consumers.

1.4.1.3 Transportation by pipeline

For the project site, it will require additional infrastructure to transport by rail including the new link from site to the next city. This will require a detailed study with inputs from the railways department to estimate the cost of transportation. However, there could be additional constraints in the availability of sufficient number of cars for the required route as several green Ammonia plants in future are built at locations away from the consumers.

When a single large domestic consumer willing to sign a long-term offtake agreement is identified and is located within the state, transportation by pipeline can be considered. Transportation by pipeline is economical when compared to both road and rail transport. A suitable corridor must be identified following a survey to avoid densely populated areas. Pipeline is also envisaged for transporting Ammonia from the plant to the offsite storage facility from where it will be eventually loaded into ships/vessels for ocean transport to international customers.

A single cross-country pipeline is envisaged for transporting Ammonia from the plant to the inland bulk customer (located within the state) or to the offsite bulk storage facility located near the port. The distance to the port (either Kandla or Mundra) is likely to be ~180 km. However, the exact length will be determined during the project implementation phase after carrying out detailed routing surveys. The pipeline will be installed below ground for most part of the route except at certain crossings where belowground routing is not possible.

The following parameters are considered for design of the pipeline-

- Material of construction : SA 106 Gr. B (seamless)
- Design pressure : 20 bar (g)

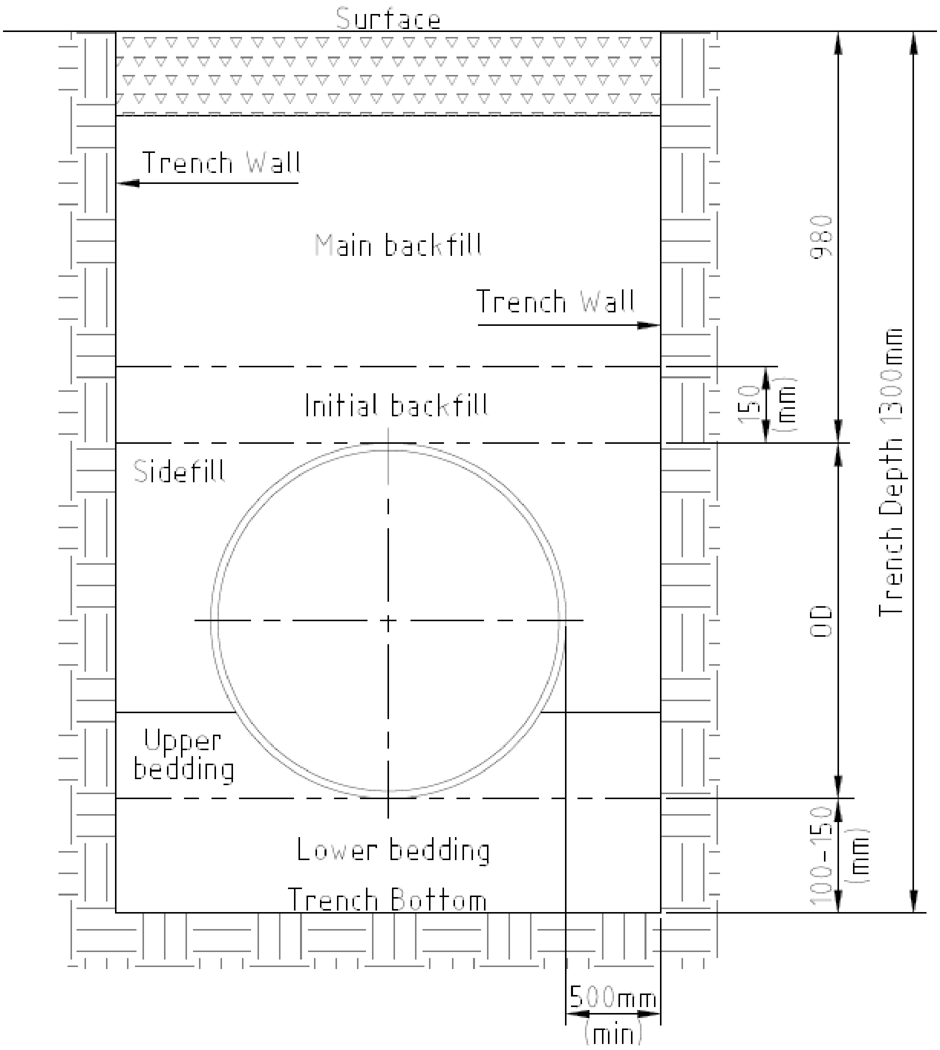
- Design Code : ASME B31.3
- Corrosion allowance : 1.6 mm
- Pipe size : 219.1 mm (OD) x 8.18 mm (wall thickness) - 8" schedule 40

As the product temperature will be in the range of 0 to 5°C, cold Insulation will be provided to avoid heat gain from outside and to avoid condensation. Cold insulation is envisaged for the above ground section of the pipe only. The commonly used material for cold insulation is Polyurethane Foam which is considered suitable for handling low thermal conductivity and products with below freezing temperatures. Polyurethane foam also allows for low smoke emission and low water vapor permeability.

The pipeline will be installed below ground (in a trench) for most sections along the route therefore exposing the buried pipeline to the risk of corrosion. Mitigation in the form of cathodic protection (by either impressed current method or sacrificial anode method) is envisaged. Additional protection will be provided by coating and wrapping using corrosion resistant tapes applied on the external surface of the pipe.

Based on the selected pipe diameter, the trench dimensions will be 1.3 m (depth) and 0.9 m (width) in conformance to standard AWWA M11-Steel pipe-A guide for design and installation. See figure below for the trench cross section.

Figure 2: Trench cross section of transportation pipeline



To ensure a firm support for the pipe, proper bedding will be provided under the pipe. During trench excavation, a pipe bedding thickness of at least 150 mm envisaged. In case of very poor native soils such as silt, clay or mud an additional foundation layer will be provided below the bedding.

Selected backfill material will be placed at the foundation and bedding levels and thoroughly compacted by plate vibrators or by hand tamping.

Leak detection in cross country pipelines is crucially important for safe operation given the toxic properties of Ammonia. Delay in detecting leaks could leads to loss of valuable product and endanger human life depending on the location and extent of leakage. Pipeline leak detection systems play a key role in minimization of the probability of occurrence of leaks and the consequential impacts. Details of the proposed leak detection system are provided in Chapter 3 – Safety and Risk Mitigation.

1.4.2 Required facilities for exporting to international consumers

For transporting Ammonia from the plant to the international consumer(s), shipping from the nearest port (either Kandla or Mundra) up to the port of the international consumer is the only option. Considering the distance between the port and plant, a storage bunker is envisaged in the port. Since the vessel capacity and frequency is not known presently, it is envisaged to size the bunker for 20,000 Tons storage capacity at atmospheric pressure and temperature of (-)33°C. The storage tanks will have provision to recover the Boil off Gas (BOG) thereby avoiding the risk of toxic Ammonia vapour emissions.

It is understood that LPG shipping vessels are presently used for shipping liquid/cryogenic Ammonia. The typical vessel capacity ranges are –

- Small vessels: 10,000 m^3
- Mid-size vessels: 10,000 m^3 – 20,000 m^3
- Large vessel: 40,000 m^3 – 60,000 m^3
- Very Large Carrier: 60,000 m^3 – 100,000 m^3

Assuming large vessels will be used, the average capacity of Ammonia that can be loaded is approx. 50,000 m^3 or 34,000 MT. Therefore, the planned capacity of 20,000 Tons storage (bunker) is not adequate to load a large vessel but is adequate to load a mid-sized vessel fully. The offsite storage facility however has layout provision to add another tank of 10,000 Tons capacity in future, if required. This will help in fully loading at Large Vessel.

Kandla port that is the nearest to the proposed storage site, is used for import Ammonia and therefore familiar with Ammonia handling. It has been identified as one of the green Ammonia refuelling hubs along with Tuticorin port. The draft available for berthing of ships at Kandla port is about 10.70m (oil Jetty terminal) which will allow berthing of ships with capacity of 56,000 DWT (Dead Weight Tonnage). This could also be utilised for loading of Very large Ammonia carriers. Logistics costs vary depending on the point of origin, the size of the ship, and the number of times the product is loaded and unloaded. Based on article titled "The Cost of CO2-free Ammonia" published by Ammonia Energy Association in Nov 2020, the logistics costs are estimated as follows –

- Middle East to Japan, logistics costs are INR 3300 per ton-NH_3.
- North America to Japan, INR 6600 per ton- NH_3.

In both cases above, very large gas carrier (VLGC) vessels are used with approximate capacity of 80,000 m^3. The average shipping distance of 7000 NM (Nautical Miles) or ~13,000 km between ports in Gujarat and Ammonia import hubs in Europe, would be slightly greater than the distance between Middle East to Japan (6500 NM). Therefore, ballpark cost of shipping from Kandla to the importing hubs can be assumed to be INR 3300 per ton- NH_3.

1.5 Area

1.5.1 Infrastructure required for supplying to domestic consumers

1.5.1.1 Building and plant areas:

The overall plant is comprised of main plant areas such as –

a. Electrolyser area (Hydrogen production)
b. Desalination & Water Treatment Plant area
c. Steam Turbine Generator (STG) & Air-Cooled Condenser (ACC)
d. Air Separation Unit (Nitrogen production)
e. Ammonia Synthesis area
f. Ammonia buffer storage area
g. Gaseous H2 storage area
h. Balance of Plant area
i. Electrical Substation

The following buildings are envisaged in the plant–

a. STG building
b. Desalination & Water Treatment Plant
c. Control building – This may be integrated with the STG building also.
d. Electrical Substation
e. Switchgear building
f. Fire water pump house
g. Plant building – for O&M office, conference/meeting rooms, training centre, technical documentation, Safety/PPE room, and Laboratory
h. Stores & Workshop
i. Non-plant building (for Admin, procurement, Finance dept staff, Canteen)
j. Fire station / First Aid room

<u>Design criteria</u>:

Dead loads	: As per IS 875 part 1.
Live load	: Minimum as per IS 875 – 2, or higher loads as per standard power plant design.
Wind load	: Basic wind speed 50m/s. Design shall be as IS 875 part -3.
Seismic	: Zone 5, seismic design shall be as per IS 1893.

<u>Structures / building in Green Ammonia plant area</u>

Power block area – This block area will comprise of the Main powerhouse building constructed as steel-framed structures with infilled brick masonry wall up to operating floor level. EOT crane will be provided in the STG Bay. These structures will rest on isolated/combined foundation. Roof of STG bay will be provided with colour coated sandwiched insulated metal cladding over steel purlin and trusses. In all other areas, roof and floor will be provided with normal cast-in-situ RCC slab. Radiator cooler structures are open structures supported on structural steel members. All the electrolysers of skidded construction will be housed under a canopy. In the Ammonia plant, the reactor columns, separators, condensers, coolers, etc. are all installed outdoors, except for the syngas compressors that will be provided with a shed.

<u>Air Cooled Condenser</u>

Cooling fans are supported on the RCC columns and beams with necessary RCC floor at fan deck level. The condensate pumps and other equipment are installed on ground or intermediate floor as necessary.

<u>Green Hydrogen Plant</u>

It is proposed to house the electrolysers on skids inside a shed (canopy) or building as per recommendations of the vendor. However, electrolysers of fully containerised construction can be installed outdoors. Containerised construction is available up to a unit capacity of 5MW. The green H2 plant will be constructed using the modular features of the electrolysers whether of skidded or containerized construction.

A cable trench (or cable gallery) adjacent to the electrolysers building is proposed to route the power supply cabling. Hydrogen produced in the individual electrolysers is connected to a sub-header running adjacent to the electrolyser sheds. The different sub-headers will be connected to a common header that runs up to the Ammonia plant. Hydrogen and utility pipes will be routed on pipe rack / sleepers.

Besides the electrolyser sheds, new buildings (or shelters) will be required for installing the additional instrument air compressors, air separation plant. The dimensions of the sheds/buildings will be reconfirmed during the project implementation phase after obtaining actual equipment dimensions from the Vendors.

Desalination/ Water treatment plant.
Desalination plant building will be a framed RCC structure with infilled brick work. The equipment foundation and underground RCC neutralization pit shall be constructed. Degasser and acid storage tanks being outdoor type installations, RCC foundation along with dyke wall will be constructed. The foundation for DM tanks will be of RCC ring walls. Underground RCC chamber will be constructed with concrete of suitable grade. The inside surfaces of the neutralization pit will be provided with acid/ alkali resistant lining.

Raw water and fire water Storage tank and pump house
A raw water and fire water storage tank (either above ground or below ground) will be provided for storing raw water and fire water. The raw water and fire water pumps will be housed in a RCC building.

Flare stack
One number flare stack (in steel construction) of approx. height 70m is envisaged, along with a safety clearance of 60m radius.

Transformer Areas
RCC foundation will be provided for the power transformers together with fire wall, drainage, and arrangements for containing oil spillage. Transformer foundations will be provided with necessary rail tracks for handling and removal from their foundation without disturbing the other transformers. Gravel filling will be provided in the transformer area for proper drainage. Fencing and fire protection will be provided around transformer area as per Electricity Rules.

Gas Insulated Switchgear (GIS)
The GIS will be indoor type. The building and equipment foundations will be constructed in accordance with the Vendor recommendations. The foundations for gantries / towers foundations of the bay and the gantry structures for take-off of outgoing lines to be constructed.

Auxiliary buildings
Auxiliary buildings include compressor house, effluent treatment plant (ETP), control building, electrical substation building, etc. Generally, all these buildings are of RCC framed construction with infilled brickwork.

Non-Plant Buildings
Administration building, canteen building, laboratory, health care centre, central store, gate house complex etc. are generally RCC framework with infilled brick wall.

Ammonia Storage
The ammonia produced will be stored in buffer tanks of 2 x 5000 Tons capacity, (double wall double integrity type) located inside the plant. It will be subsequently transported via pipeline to the offsite storage area planned near the port. The ammonia will be stored in two tanks of 10,000 tones capacity each, with layout provision for a third tank. The tanks will be erected on an elevated piled concrete slab foundation to prevent the ground from freezing below the tank. This design will negate the potential damage of the foundations, or the tank itself, due to frost heave. The top of the concrete slab will be at an elevation of about 2.0 m above the surrounding area. All the three tanks (two present and one future) in the storage terminal will be provided with dyke area of suitable size. The storage tanks are supported on suitable RCC foundation.

1.5.2 Site area

The site area comprises of plant areas, buildings, Pipe corridors, storage areas, access roads and drains, assembly areas, etc.

Preliminary site activities

Topographical survey must be conducted for the proposed site area. The site however appears level and without undulations. The Reduced Level of the existing ground is RL 225.000. From information collected during the site visit, the site is flooded to about 0.5 to 0.75m above the existing level. Hence, it is recommended to grade the site at 1.0m above the existing ground level. The finished floor level for the proposed structures will be 1.5m above the existing ground level. Single grade level is recommended as the existing ground is fairly level. The extent of grading required is for about 50 hectares.

Approach Road

The site is located about 0.5 km away from the state Highway (SH - 45) requiring the construction of an approach road of ~ 0.5 km length.

Plant roads

Double Lane roads will be 9.0 m wide with 1.5 m wide shoulder on both sides of the road. Single lane roads will be of 4.0 m wide with 1.0 m wide shoulder on both sides of the road. Access roads to building/facilities will generally be single lane roads with or without shoulders. All culverts will be designed for the Class – AA of IRC loading conditions.

Drains

Rainwater from the plant area will be collected through a network of drains and discharged to rainwater collection pits. All drains in the plant area and around buildings will be covered drains. Storm water drain will be directly connected to rainwater collection ponds or rainwater harvesting system planned at different places.

Paving/Plinth Protection

Plinth protection around building and paving in the areas will be provided. Paving/hard surface will be provided for vehicle parking near service and administrative buildings.

Sewage treatment & disposal

Sewage from the plant will be treated in skid mounted sewage treatment plant proposed at a few locations like the Plant building, Control building, and non-plant buildings. The treated effluent will be utilised for the irrigation of landscaped areas.

Plant Security

To prevent unauthorised access into the plant, the perimeter will comprise of boundary wall with concertina fencing. Closed circuit TV cameras will be installed for surveillance of the perimeter. Additional access controls will be provided for entry into the control building. Watch towers are also envisaged at locations to enable physical monitoring of potential vulnerable areas.

Staff quarters/Township

It is proposed to construct staff quarters for housing approx. 200 staff and their families. The township will consist of family units such as 3-bedroom, 2-bedroom quarters for senior executives and hostel type single room arrangement for bachelors and short-term visiting staff. The township will have basic amenities such as treated water, sewage plant, roads, drainages etc. Depending on the selected location of the town ship, other amenities such as primary school, medical centre, shopping centre can also be considered. The cost of Staff quarters is however not included in the Capex of the plant.

1.6 Profiling of manpower

1.6.1 Construction phase

The overall construction phase of the project is assumed to be fourteen (14) months, of which the first six (6) months will be spent in carrying out piling and up to completion of pile cap. The remaining duration of the construction phase will be utilised for the civil works related to super structure and the finishing works.

The profiling of manpower for the civil works is shown below –

Table 1: Profiling of manpower for civil works

Sl No.	Activity / months	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1	Pile and pile cap												
2	Super structure civil works												
3	Finishing works												
	Manpower												
1	Skilled	80	80	80	80	120	120	200	200	200	200	200	200
2	Semi-skilled	160	160	160	160	220	220	400	400	400	400	400	400
3	Unskilled	160	160	160	160	220	220	400	400	400	400	400	400
	Total	**400**	**400**	**400**	**400**	**560**	**560**	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**

The super structure civil works and finishing works phase will see an overlap between the civil works and the mechanical erection along with electrical & instrumentation installation works also.

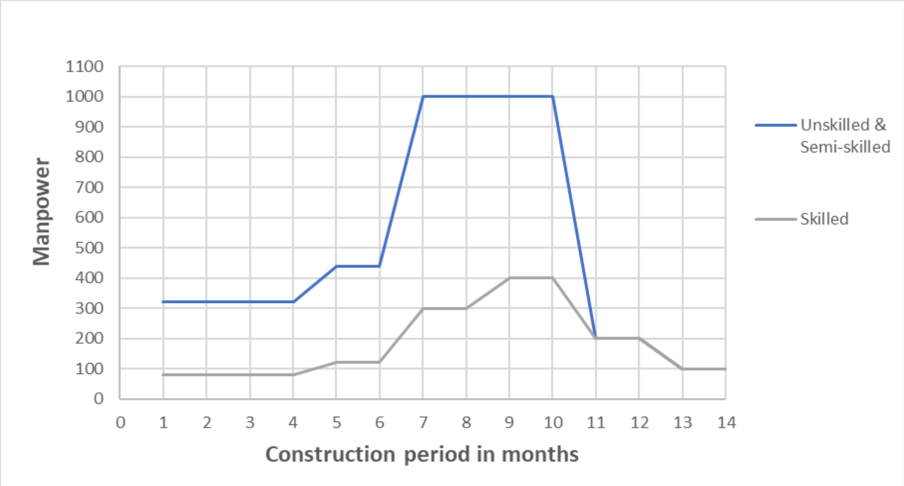
Mechanical works will be manpower intensive during the equipment and Piping installation works. The electrical works will be manpower intensive during substation installation and the cabling works. The requirement of unskilled labour will be lower for electrical and mechanical works when compared to the civil works. The table below indicates the manpower requirement during the mechanical, electrical, and instrumentation phase of the works.

Table 2: Manpower requirement during mechanical, electrical and instrumentation phase

Sl No.	Activity / months	M7	M8	M9	M10	M11	M12	M13	M14
1	Mechanical Equipment erection								
2	Piping & electrical cabling works								
3	Instrumentation works								
4	Pre-commissioning and Commissioning works								
	Manpower								
1	Skilled	100	100	200	200	200	200	100	100
2	Semi-skilled	100	100	100	100	100	100	50	50
3	Unskilled	100	100	100	100	100	100	50	50
	Total	**300**	**300**	**400**	**400**	**400**	**300**	**200**	**200**

The phasing of the total construction manpower deployment is shown in the figure below.

Figure 3: Total construction manpower deployment



The temporary households will be required mainly for the unskilled/semi-skilled category of workers as most workers will be from other states. From the above discussion, it is observed that the maximum requirement of such manpower is nearly 1000 from M7 to M12. Therefore, temporary accommodation with adequate power supply/lighting, water supply (including drinking water), and sanitary provisions must be provided by the respective contractors who employ such labour.

It is estimated that the area required for creating such temporary facilities will be 1.0 hectare.

It must be noted that the construction manpower required for the cross-country pipeline and the offshore storage facility will be significantly lower than the above and therefore temporary households for such labour is not envisaged.

1.6.2 Profiling for the O&M of plant

Please refer to the Chapter 5 - Personnel and Manpower

2 System design

2.1 Electrical Scheme (LV/MV/HV)

The design concept of the electrical system is based on the requirements for the safe and reliable electrical system with provision for easy maintenance and overhauling. The design principles and standards delineated herein are generally in compliance with the latest IEC/IS Standards, and Code of Practice and Electricity Rules already established in the state.

Design ambient temperature for the electrical equipment is considered as 50°C.

2.1.1 Electrical System Description

Power Supply for the proposed Green Ammonia production project will be from Khavda Pooling substation KPSS-04, of 900MW capacity at 400kV from the substation to the plant. Refer Key Single Line Diagram FCE-20522173-EL-DWG-SLD-2050-001-Rev-1.

A 400kV switchyard/substation will be constructed to receive the power. Based on the assumption of power requirement of 5MW for each electrolyser, ten numbers of 400/33kV180MVA transformers are envisaged to supply power to approx. 124 nos. of electrolysers and their auxiliaries. The transformers step down the voltage from 400kV to 33kV and feed five numbers of 33kV GIS (Gas Insulated Switchgear).

Three numbers of 180MVAr Static Compensators are considered based on the estimated reactive power consumption data of electrolysers. This will be validated during detailed engineering with data from the vendor. The compensators are connected to the 400kV switchyard bus through 400/33kV transformers to regulate the voltage at the point of connection to a power grid. Static Compensators provide or absorb reactive current and thereby regulate the voltage.

Four numbers of 33kV switchgears will have a double incomer with a bus-coupler arrangement and receive power from 2X100% rated 400/33kV 180MVA transformers. Each of these 33kV switchgear will supply power to 25 numbers of the rectifier transformers.

The fifth 33kV switchgear will have three incomers and two bus couplers supplied by 2 numbers 400/33kV 180MVA transformers and one no. source from STG source. This switchgear supplies power to the remaining electrolyser rectifier transformers as well as 2X100% 33/6.6kV auxiliary transformers. The auxiliary transformers will feed the balance of plant loads. The two incomer one bus coupler arrangement provides 100% redundancy and ensures power supply to the BoP auxiliaries even when one of the power transformers fails.

Each 33kV switchgear will be provided with a harmonic filter to mitigate the harmonic distortions caused by the rectifier circuits. One 6.6kV switchgear is envisaged for the plant Medium Voltage (MV) auxiliaries i.e., motors/loads rated 160kW and above. This includes MV drives of air separation unit, hydrogen compressor station, ammonia synthesis plant, ammonia storage plant and all other balance of plant facilities.

The heat from the exothermic reaction in the ammonia synthesis will be used to produce steam that runs a steam turbine generator (STG) of 15MW rating at 6.6kV, 50Hz and 0.8pf lag. Considering the variation in ammonia production and the resulting heat generation, the STG will be designed to operate in a range of 25% to 100%.

The generator will be connected to the Grid through 6.6/400kV transformer for import/export of power and 6.6kV auxiliary switchgear. The MV auxiliaries of the STG system will also be connected to the 6.6kV switchgear.

The 6.6 kV voltage level is further stepped down to 415 V level through 2x100% rated 6.6/0.415kV transformer. Low Voltage drives (motors/loads rated less than 160 kW) and all lighting loads shall be connected to 415 V switchgear panel. The number of switchgears at each level shall be decided during the execution stage.

LV transformers shall be rated to a maximum of 2.5 MVA and the LV system shall be designed for a fault level of 65kA for 1sec.

Two numbers of lighting transformers will be provided to feed lighting loads. The 220 V DC system will supply all control circuits of all the electrical equipment. 110 V AC UPS units shall be required for back up of normal supply.

Continuous duty 415 V motors rated 110 KW and up to 160 kW will be controlled by ACBs. 415 V Motors rated less than 110 KW will be controlled by MCCB and contactors. MV Motors will be controlled by Vacuum Contactors.

The rating of these transformers will be selected based on the various connected loads to be finalized during detailed engineering.

2.1.2 Equipment for Hazardous Areas

Cables will be segregated to reduce fire risk, damage, and shutdown. Electrical equipment located in hazardous areas such as hydrogen compressor/storage, synthesis gas compression, and Ammonia synthesis areas shall be explosion proof, flame proof, intrinsically safe or otherwise designed to be suitable for the location zone. Electrical equipment required for safety critical operation and continued operation upon gas detection shall be rated for Zone 1.

The fire protection / detection system shall be in accordance with NFPA requirements. Automatic water spray deluge protection for all oil filled transformers and cable floors. Gas extinguishing fire protection system shall be provided for Electrical rooms, MCC rooms, switchgear rooms, panels rooms, instrument rooms, control rooms, raised flooring cellars (NFPA 2001 Clean Agent System).

2.1.3 Uninterruptible Power Supply

The uninterruptible power supply (UPS) furnishes a reliable and interruption free source of required voltage, three/single phase power to equipment/instrument vital for plant control and emergency operation.

Two (2) UPS units (2x100%) shall be furnished for the Power Plant sized to feed essential AC loads like DCS and other C&I equipment. The DC supply for the UPS system shall be sourced from an independent DC system. The UPS system shall be provided with two (2) Nos. 100% capacity inverters.

2.1.4 Control of Electrical System

Control of 400kV Switchyard

400 kV switchyard will be controlled from the SCADA through a dedicated Video Display Unit (VDU) or HMI in the switchyard control room that provides an interface to control the system through mimic screens. An additional VDU will be provided in the main plant control room also.

All the I/Os will be terminated in a marshalling panel / remote I/O panel located in the switchyard control room. Sequence event recording / status of breakers & fault reporting shall be indicated in the SCADA system.

The complete MV and LV electrical system of the power plant shall be controlled and monitored from the plant DCS system. The controls for the following shall be through mimic screens in the VDU. A backup control panel is also envisaged.

Critical signals, Analog signals, Status alarms and controls of all switchgears shall be extended to DCS. All the I/Os of plant auxiliary systems shall be terminated in a marshalling / remote I/O panel. Sequence event recording / status of breakers & fault reporting of 33 kV, 6.6 KV, 415 V distribution system, 220 V D.C system, 230 V UPS etc. shall be indicated in the Plant DCS. Separate mimic screens shall be provided for 33 KV, 6.6 KV and 415 V system. Control of all motors shall be from DCS only.

2.1.5 Protection Philosophy

The protection scheme for the electrical system will ensure reliable and speedy isolation of the faulty equipment from the system as well as protect the system from external faults to prevent damage to the plant.

For protection of equipment against abnormal system conditions, adequate protective devices will be installed in the respective switchgear and/or control and relay panels. Proper discrimination and selectivity shall be provided to isolate only the faulty elements, keeping the healthy part of the system in service.

All protection relays will be numerical microprocessor based with IEC 61850 Communication Protocol with Ethernet port except Anti pumping, Trip circuit supervision, Master trip Lock out, Fuse failure and synchronous check relays.

The total protection system can be classified broadly as-

- Protection for 400 kV switchyard with 400 KV grid transformers.
- Protection of Auxiliary Transformers and MV switchgear.
- Protection of power plant auxiliary equipment circuits.

The major electrical equipment will be provided with the following critical protections -

Generator Protection

- Differential protection - generator winding
- Over voltage protection
- 100% stator earth fault protection
- Reverse power protection
- Negative phase sequence current protection
- Field failure protection
- Rotor earth fault protection
- Generator overload protection
- Overall differential protection for generator
- Generator under frequency/ over frequency protection
- Local breaker back-up protection
- Backup impedance protection
- Low forward power protection
- Pole slipping protection.
- Winding temperature protection
- Standby stator earth fault protection
- VT fuse failure protection
- Interturn fault protection
- Dead machine protection
- Loss of field protection

Power Transformer

- Differential protection
- Restricted Earth Fault protection for LV winding
- Over current protection on HV side & LV side
- Backup Earth fault protection
- Buchholz protection
- Oil/winding temperature protection
- Pressure Relief valve
- OLTC surge relay protection.

LV transformers

- Over current protection (IDMTL & instantaneous)
- Earth fault Protection
- LV side Backup Earth fault protection
- Buchholz protection
- Oil/winding temperature protection

6.6kV Motors

Multifunction motor protection relay having flexibility to accommodate following protections:

- Differential protection (for motors rated 1000 kW and above)
- Thermal overload protection
- Instantaneous over current and definite time - over current protection
- Earth fault protection
- Single phase and phase unbalance protection
- R.T.Ds. for winding/bearing temperature protection (for motors rated 1000 kW and above)
- Locked rotor Protection

2.1.6 Power and Control Cables

33/6.6kV cables will be of stranded aluminium/copper conductor with heavy duty XLPE insulated, each core screened on conductor as well as on insulation, colour coded, extruded bedding, extruded PVC inner sheathed, armoured, and overall FRLS PVC sheathed. The cables will be suitable for unearthed systems.

LV power cables will be 1100 V grade with stranded aluminium/copper conductor, XLPE/PVC insulated, extruded PVC inner sheathed, armoured, and overall FRLS PVC sheathed. Control cables will be multicore 1100 V grade, PVC insulated, PVC inner sheathed armoured and overall FRLS PVC sheathed with 2.5 mm stranded copper conductors. The cables will conform to the relevant Indian/IEC standards in general with the following special, FRLS properties for the outer sheath. Cables used in hazardous locations will comply with IEC 60332.

2.1.7 Illumination System

The plant lighting system includes the –

- normal AC lighting (70% of total lighting)
- emergency AC lighting (30% of the total AC lighting fed from emergency UPS).
- Escape system (lighting fittings with integral batteries or DC/UPS supply)

Lighting feeders shall be provided with lighting transformers of voltage ratio 1:1 to reduce the fault level. For general illumination, LED fixtures are taken into consideration. This lighting shall be energised from 3-phase, 4-wire, 415 V main lighting distribution boards fed from suitably rated lighting transformers.

These MLDBs shall feed lighting panels for each individual area/room. The average illumination levels for the lighting system design shall follow OISD guidelines.

2.1.8 Grounding and Lightning Protection

The plant grounding system will be designed as per the requirements of IEEE-80/IEEE 142/IS-3043/IEC:62305. The earth mat of the station shall be designed such that the total ground impedance does not exceed 1.0 ohm.

The plant and switchyard shall be equipped with lightning protection. Lightning Protection Level LPL 1 of IEC62305 will be provided. Lightning protection conductors located on the top of the structures shall be connected to the ground loop surrounding the structures with down conductors as per the provisions contained in the latest issues of Indian Electricity Rules and IS 2309.

Electrical insulating mats / flooring will be provided for all electrical switchgear to protect operators from electric shock.

2.2 Electrolytic Hydrogen Production

Refer to section 2.1 on Broad Design Concept

2.3 Process and cooling water provision & storage

Refer to section 2.1 on Broad Design Concept

2.3.1 General system description

Bore well water from underground Aquifers is the source of water for Saline Water Treatment plant. Saline water will be treated through a series of processes like Chlorination, Coagulation, Flocculation, Clarification, Multigrade Filtration, Activated Carbon Filtration (ACF), Ultrafiltration (UF) and Two Pass Reverse Osmosis (RO) system, Mixed Bed Ion Exchange system (MB) to produce Demineralised water required for production of green Hydrogen and as make-up in the steam cycle system.

2.3.2 Proposed technology for demineralised water production

Reverse Osmosis (RO) technology followed by Mixed Bed Ion Exchange is proposed for Demineralised water production due to the following reasons-

1) No need for Thermal Energy Source (such as low-pressure steam)
2) Low capital cost
3) Requires only Electrical energy.

2.3.3 Battery limits

Bore well Water Supply to Saline water treatment Plant	From new Bore well water Intake pumping station to Stilling chamber which is located inside the Desalination plant
Desalinated water	New Brackish RO Product Water storage tank
Demineralised water	New DM water Storage tank
Dirty Backwash water from UF and Activated carbon filter	Disposed along with RO Reject water into the salt pans which is located 5 km from the proposed site
Neutralized Chemical waste from RO System	Into the new neutralization pit and from where it will be pumped into salt pans which are ~5 km from the proposed site
Brine (RO Reject) discharge	Into the salt pans which are ~5 km from the proposed site
All chemicals	Chemical storage house or yard inside the boundary of Saline Water Treatment Plant

2.3.4 Saline water treatment plant design basis

Flow Data:

Demineralised water production rate: 130 m^3/hr

Bore well Water Quality:

Sl. No	*Units of Measurement*	*Parameters*	*Value*
1	Degree Centigrade	Temp	24-35
2	mg/l	TDS	50000-60000

Desalinated Water Quality Requirement - DM Feed Water Production:

Parameter	*Unit of measurement*	*Value*
TDS	mg / l	< 10

Demineralised Water Quality Requirement - Green Hydrogen Production:

Parameter	*Unit of measurement*	*Value*
pH		5.5-8
Chlorides	mg/l	< 2
Turbidity	NTU	< 1

2.3.5 Basic description & design basis - pretreatment system

Pre-chlorinated bore well water will be pumped from the Intake pumping station to pretreatment system through bore well water intake pumps.

Pre-treatment system comprises of Lamella Clarifiers, Multi grade Filters, Activated Carbon filters and Ultra-filtration system. Saline water will pass through lamella clarifiers for the removal of suspended solids and turbidity present.

The clarified water will pass through Multigrade Filters and Activated carbon filters for the removal of Turbidity, Colour, and dissolved organics and then through Ultrafiltration system for the removal of residual colloidal solids and silt particles present in it. The filtered water from Ultrafiltration system will be stored in a filtered water storage tank. Backwash waste generated from Ultra filtration system will be sent to salt pans along with RO reject which is located 5 km from the proposed site.

2.3.6 Flow data

- Feed flow to Pre-Treatment System: 482 m3/hr
- Clarified water from Lamella clarifier: 468 m3 /hr
- Filtered water flow from ACF Filter: 459 m3/hr
- Filtered water flow from Ultrafiltration system: 422 m3/hr

Feed water Quality to Pre-treatment System:

Parameter	*Unit of measurement*	*Value*
TSS	mg/lit	150
Silt Density Index	>5	
Appearance	Turbid	
Turbidity	NTU	100
Dissolved Organics	Present	

Clarified water Quality from Lamella Clarifier:

Parameter	*Unit of measurement*	*Value*
TSS	mg/lit	< 15
Turbidity	NTU	20-30

Filtered water Quality from Activated Carbon Filter:

Parameter	*Unit of measurement*	*Value*
TSS	mg/lit	5
Turbidity	NTU	2
Dissolved Organics	Traces	

Filtered water quality at the outlet Ultrafiltration system:

Parameter	Unit of measurement	Value
TSS	mg/lit	< 1
Turbidity	NTU	0.1-0.2
SDI	< 3	

2.3.7 Basic description & design basis - Reverse Osmosis System and Mixed Bed Ion Exchange system

Filtered water from the Ultrafiltration system stored in UF water tanks will be pumped to Reverse Osmosis System (RO) membranes to remove the dissolved solids.

RO system is a Two Pass System in which RO product water from First Pass RO will be fed into the Second Pass RO

First Pass RO system will have the Recovery of 35%-40% and the TDS of First Pass RO will be in the range of 350-600 mg/lit. This product water will be supplied as feed for the Second Pass RO.

Second Pass RO system will have the Recovery of 85-90% and the TDS of Second Pass RO will be less than 10 mg/ lit. This product water will be pumped into the Mixed Bed Ion Exchange unit Demineralized water where all the cations and anions present in the water will be removed by adsorption process. Demineralized water from Mixed Bed Ion Exchange column will be stored in Demineralized water storage tanks from where it will be distributed to the various users.

Refer flow diagram - FCE-20522173-ME-DWG-PFD-3591-005 for details.

2.3.8 Description basis for Reverse Osmosis System and Mixed Bed Ion Exchange system

Flow data:

- Feed flow to RO system First Pass: 422 m3/hr
- Product water flow from RO System First Pass: 148 m3/hr
- Reject water flow from RO System First Pass: 274 m3/hr
- Feed flow to RO system Second Pass: 148 m3/hr
- Product water flow from RO System Second Pass: 133 m3/hr
- Reject flow from RO system Second pass: 15 m3/hr
- Demineralised water from Mixed Bed Exchanger: 130 m3/hr

Feed water quality to Reverse Osmosis System-First Pass:

Parameter	*Unit of measurement*	*Value*
TDS	mg/l	50000-60000

Reverse Osmosis System (RO Product water Quality)-First Pass:

Parameter	*Unit of measurement*	*Value*
TDS	mg/l	350-600

Feed water quality to Reverse Osmosis System-Second Pass:

Parameter	*Unit of measurement*	*Value*
TDS	mg/l	350-600

Reverse Osmosis System (RO Product water Quality)-Second Pass:

Parameter	*Unit of measurement*	*Value*
TDS	mg/l	< 10

Demineralised water quality from Mixed bed Ion Exchange column:

Parameter	*Unit of measurement*	*Value*
PH		5.5-8
Chlorides	mg/l	< 2
Turbidity	NTU	< 1

The water from the Mixed Bed units will be stored in two storage tanks that will have a total storage capacity adequate to meet the demineralized water requirements of 24 hours. The tanks will be constructed in carbon steel material and the internal surfaces will be lined with Epoxy to prevent corrosion. Considering the overall operating range of the Ammonia plant (100% to 25%), transfer pumps (3W+1S) will be provided to supply Demineralized water to the electrolysers and the steam water cycle.

2.3.9 Liquid & solid wastes generated in the plant

The overall liquid waste generated by the Desalination & Demineralised plant is ~8120 m3/day with the break-up as shown in the table below.

Table 3: Liquid waste generated in Saline water Treatment Plant

Liquid waste generated in Saline water Treatment Plant				
Parameters	*Reject flow from RO*	*Dirty backwash from MGF filters*	*Dirty Backwash from ACF Filters*	*Dirty Backwash from UF system*
Flow- m^3/hr	274	-	-	37
Flow- m^3/day	6576	444	216	880
TDS-mg/lit	95454	60000	60000	60000
TDS - kg/day	627699	26661	12932	52783
TSS -mg/lit	0.5	185	155	54
TSS-Kg/day	3	82	33	48

The overall solid wastes generated in the plant is about 740 m^3/day as shown in the table below.

Table 4: Sludge Generation from saline water Treatment plant

Sludge Generation from saline water Treatment plant					
Parameters	*Sludge flow from Lamella clarifier*	*Thickened sludge from Gravity thickener*	*Supernatant from Gravity Thickener*	*Dewatered sludge from Centrifuge*	*Supernatant from Centrifuge*
Flow- m^3/hr	14	2	13	1	4
Flow- m^3/day	347	46	301	6	39
TSS -mg/lit	4515	30900	520	214000	1791
TSS- Kgs/day	1567	1410	157	1340	71

2.4 Emergency backup battery storage system

The emergency Power requirement of the plant is estimated as shown in table below –

Table 5: Emergency power requirement (at Ammonia plant)

Emergency power requirements			
Sr.no.	*Section*	*Power (kW)*	*Remarks*
	Ammonia & ASU plant		
1	Syngas compressor barring gear	15	
2	ASU plant air compressor barring gear	15	
3	Ammonia transfer pump	17	1 transfer pump in operation
4	Ammonia Storage Boil off Gas refrigeration system	100	
	Power plant		
1	STG turning gear	25	
2	STG radiator coolers	30	During an emergency, about 20% of normal power will be required
	Balance of Plant		
1	Instrument Air Compressor	100	One (1) no. 750 Nm3/h capacity air compressor
2	Closed loop cooling water pump	250	Unit pump of 2000 m3/h capacity
3	Radiator cooler fans	450	Two (2) fans in operation
4	Liquid Nitrogen storage –Gasification for Utility Nitrogen	2	
5	Flare system	5	
6	UPS (AC/DC) Power supply	213	
7	Local Control panel power supply	50	
8	Motor operated valves in the plant	10	
9	Fire and Gas leakage monitor system	22	
10	Emergency area and control room lighting	50	
	Total power required, kW	*1354*	

Power requirement of approx. 1500KW will be considered for sizing of the emergency backup system.
Among the battery storage options, Lithium-ion battery technology can be considered due to fast response and high specific power. However, such a system is advantageous when the duration of disruption is limited to a few hours.

In the event of a longer outage (say greater than 2 hours) in the transmission system, DG sets using environmentally friendly fuels such as biodiesel can be considered.

Table 6:Emergency power requirement (at Ammonia storage terminal)

Emergency power requirements			
Sr.no.	*Section*	*Power (kW)*	*Remarks*
	Storage Terminal		
1	Refrigeration Compressor	450	
2	BOG compressor	150	
3	Ship loading pump	30	1 loading pump in operation
4	Miscellaneous	70	Emergency lighting, HVAC, etc.
	Total power required, kW	*700*	

2.5 Air Separation Unit (ASU)

2.5.1.1 Cryogenic Air Separation Process

A 48 TPH capacity cryogenic air separation unit (single train) is envisaged for the plant. There are several steps in the cryogenic process of air separation.
The first step is filtering, compressing, and cooling. The incoming air will be compressed to 12 bar and the compressed air cooled resulting in condensation of most of the water vapour from the incoming air. The condensed water vapour is removed as the air passes through a series of inter stage coolers plus an after cooler following the final stage of compression.

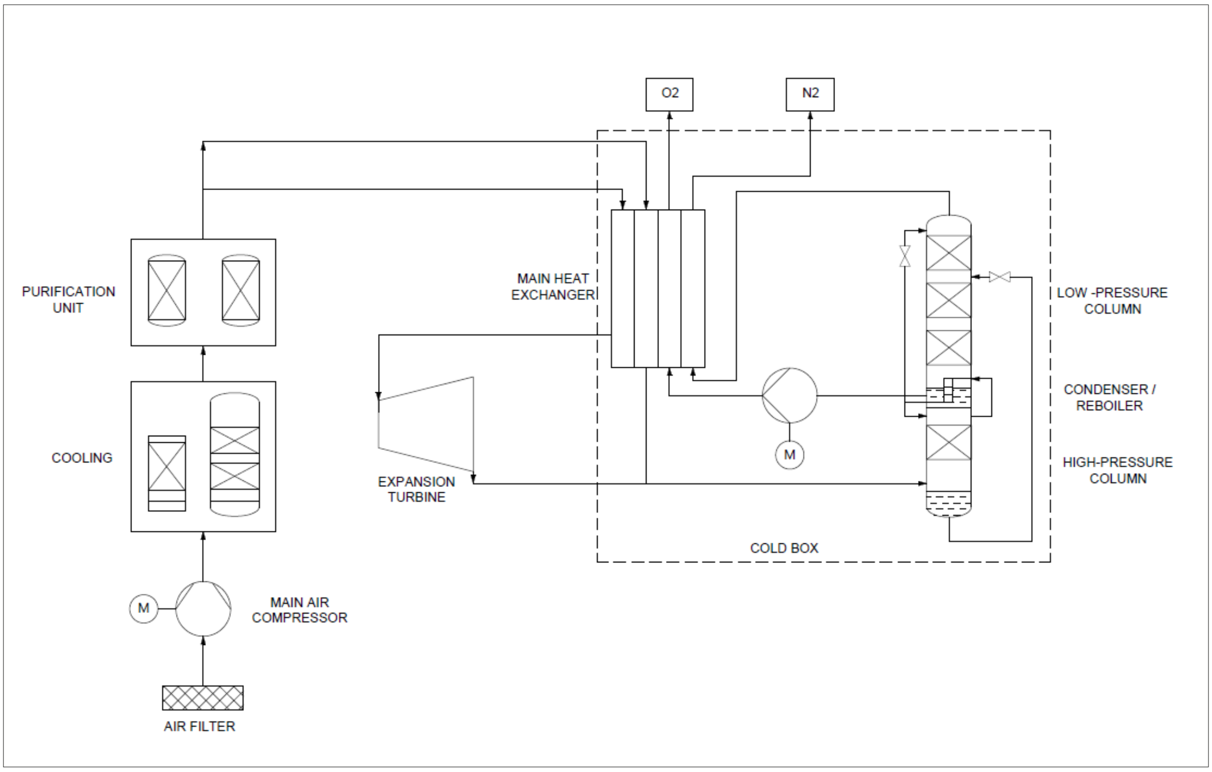
The second step involves the removal of impurities but not limited to, residual water vapour, and carbon dioxide (CO_2). These components will be removed in molecular sieve units to meet the product quality specifications, and prior to air entering the distillation portion of the plant.

The third step is additional heat transfer against product and waste gas streams to bring the air stream to the cryogenic temperature of (-) 185°C. This cooling will take place in brazed aluminium heat exchangers which allow the exchange of heat between the incoming air feed and cold product and waste gas streams leaving the separation process. During the heat exchange, the leaving gas streams are warmed to close to the ambient air temperature. Recovering refrigeration from the gaseous product streams and waste stream will minimize the amount of refrigeration to be produced by the plant. Cold temperatures needed for cryogenic distillation are created by a refrigeration process which includes expansion of one or more elevated pressure process streams.

The fourth step is the process of distillation which separates the air into the desired products. To make oxygen, the distillation system will use two distillation columns in series, called the high- and low-pressure columns. Nitrogen will leave the top of each distillation column while oxygen will leave from the bottom. Impure oxygen produced in the initial (higher pressure) column will be further purified in the second, lower pressure column. Argon has a boiling point close to that of oxygen and preferentially stays with the oxygen. If high pure oxygen is needed, then argon must be removed. Since Oxygen will not be recovered, Argon removal is not required in the process. Waste streams which emerge from the air separation columns are routed back through the front-end heat exchangers. As they are warmed to near-ambient temperature, they chill the incoming air. The heat exchange between feed and product streams minimizes the net refrigeration load on the plant and hence the energy consumption.

Refrigeration is produced at cryogenic temperature levels to compensate for heat leak into the cold equipment and for imperfect heat exchange between incoming and outgoing gaseous streams. In the refrigeration cycle of air separation plants, one or more elevated pressure streams (which can be intake air, nitrogen, waste gas, feed gas, or product gas, depending upon the type of plant) will be reduced in pressure to chill the stream. To maximise chilling and plant energy efficiency, the pressure reduction (or expansion) takes place inside an expander (a form of turbine). Removing energy from the gas stream will reduce its temperature more than in the case with simple expansion across a valve. The energy produced by the expander will be recovered by operating a compressor.

Figure 4: Schematic Diagram of Cryogenic Air Separation Unit



2.6 Intermediate hydrogen, nitrogen, and water storage

Intermediate storage of Hydrogen of about 1.7 Tons (net/usable) capacity is envisaged. This will be stored at 40 bar g pressure supply in pressure vessels of 200 m^3 capacity each. Hydrogen from storage will be drawn during transient conditions. To optimise the storage footprint and power consumption, 11 numbers of vertically installed pressure vessels (each vessel of 3.5 m dia. x 22.3 m height) is envisaged.

The spacing between the vessels and the adjacent equipment will be governed by the requirements of NFPA-2. The approval of PESO will be required for storage of Hydrogen including the layout and the design of pressure vessel. It must be further noted that periodic pressure testing requirements (once in 5 years) will be necessary to comply with the requirements of SMPV.

Nitrogen produced in the ASU will be stored as liquefied Nitrogen in vessel of 20 m^3 volume, equivalent to 140,000 Nm^3 of effective gas volume. The storage pressure of Nitrogen in the vessel is about 7 bar g. Utility Nitrogen will be drawn from the storage vessel as required.

3120 m^3 of demineralised water will be stored in 2 x50% capacity tanks. This will be adequate to meet the fluctuating demand of the electrolysers.

2.7 Compression system for hydrogen, nitrogen

Compression of Hydrogen produced in the Electrolysers will be necessary if the discharge pressure from the purification system (at outlet of electrolyser) is lower than the pressure required at suction flange of the Syngas compressor. PEM electrolysers can deliver hydrogen at high pressure (>30 bar g) therefore avoiding the use of booster compressors. However, booster compressors will be required if atmospheric pressure Alkaline electrolysers are employed. The PEM type electrolyser supplied by Siemens also produces atmospheric pressure Hydrogen necessitating use of booster compressor. Pressurized Alkaline type electrolysers can produce Hydrogen at pressures up to 30 bar g. This will avoid the use of booster compressor. If the generated hydrogen gas pressure is <30 bar g, the suction pressure of the syngas compressor can be reduced to < 25 bar g to avoid the use of booster compressors.

For storage of Hydrogen, an optimised pressure of 40 bar g has been selected. Low-capacity storage compressors will be employed to step-up the pressure from either 25 bar or 30 bar g depending on the type of electrolyser, to the storage pressure of 40 bar g.

Reciprocating type of compressors (in compliance to API 618) will be used for both booster and storage applications. Non-lubricated (dry) type compressors are available for the low pressures envisaged above. However, oil lubricated type of compressors with oil filters in series, can be considered subject to approval of the Ammonia technology licenser. To optimise the number of booster compressors (if required) large unit capacity compressors, say ~1500 kg/hr will be used. At rated Ammonia plant capacity of 1300 TPD, about 10.1 TPH of Hydrogen must be supplied to the loop necessitating use of seven (7) numbers of Hydrogen compressors of 1500 kg/h capacity. Since Hydrogen storage is planned only for emergency conditions, low-capacity storage compressors (2 x 108 kg/hr capacity) are envisaged. These compressors will step up the pressure from approximately 25-30 bar g to 40 bar g and operate intermittently. The pipeline (including the pressure reduction station) from storage to the Ammonia synthesis loop will be sized for a flow rate as required by the Licensor to meet the transient requirements.

The syngas compressors used in the Ammonia plant will be of centrifugal type and will boost the pressure from about 25/30 bar g (at suction) to a discharge pressure of ~150 bar g. The unit capacity of compressor will be determined by the Ammonia technology licensor.

Nitrogen compressor is required to boost the pressure of Nitrogen from the discharge pressure of the ASU, which is likely to be about 5-6 bar g up to the Syngas compressor suction pressure (25 or 30 bar g).

Centrifugal compressors will be used for this application. At rated Ammonia plant capacity of 1300 TPD, the amount of Nitrogen required is 48 TPH, which will be supplied using 2 x100% centrifugal compressors.

2.8 Ammonia synthesis via Haber-Bosch process

Ammonia synthesis will be done in a medium pressure Haber-Bosch process using nitrogen and hydrogen as feed gas. Hydrogen from the electrolyser is mixed with Nitrogen from the Air separation unit with a ratio of 3:1 and fed to the synthesis gas compressor suction. The syngas is compressed at 150 bar g pressure from 30 bar g.

The ammonia synthesis takes place in the ammonia synthesis converter according to the following reaction scheme:

$$3H_2 + N_2 \longleftrightarrow 2NH_3 + \text{Heat}$$

The reaction is reversible and only a part of the hydrogen and nitrogen will be converted into ammonia say 20% (by volume) by passing through the 'Fe'-catalyst bed. The reaction will be carried out in three stages/beds. The temperature of the feed gas will be controlled by sending part of the gas through a by-pass line. The unconverted synthesis gas will be sent back to the reactor after the separation of the liquid ammonia.

The make-up gas coming from the Synthesis gas Compressor is mixed with the reacted gas coming from Ammonia reactor and then mixed with circulating gas coming from Recycle compressor.

The reaction will take place at 150 bar g pressure and 390-480°C temperature and is highly exothermic. The converted gas is cooled stepwise, in the loop waste heat boiler, in the BFW preheater, in the feed/effluent heat exchanger and then in the syngas cooler The final cooling of the gas will be done in the ammonia chillers. The liquid ammonia after condensation is separated as product.

The liberated heat will be utilised by the waste heat boiler to produce high pressure steam that will be subsequently superheated to 450°C in the steam superheater. The superheated steam an 'extraction-condensing' type steam turbine. The extractions in the steam will be controlled for maintaining the steam parameters required for the process heat exchangers in the Ammonia plant at part loads also. The remaining steam will be expanded fully in the steam turbine and condensed in an Air-cooled condenser.

Separation of product liquid ammonia will be done in the HP separator, MP separator and LP separator. Recycle gas from HP separator is sent to the suction of the recycle gas compressor. Liquid ammonia from HP separator is let down to MP separator and the gas from the MP separator is sent for purging followed by ammonia recovery. Liquid ammonia from MP separator is let down to LP separator and the product liquid ammonia is sent to ammonia storage tank.

After the separation of liquid ammonia in the MP separator, the gas from the top of the separator is sent for purging to remove the small amount of dissolved inert gas and to recover any carried-out ammonia in the purge gas, the purge gas is sent to ammonia recovery section. In the ammonia recovery section, the separation of ammonia from the purge gas is done by absorption process. The separated ammonia will be sent to storage tank.

2.9 Ammonia storage and bulk transportation facilities

Refer to section 1.4 on Transport Infrastructure and Logistics.

2.10 Utilities and Effluent Treatment Plant

Refer to section 2.3 f) Utilities and h) Effluent List and Effluent Treatment Plant

2.11 Broad Design Concept

2.11.1 Selection and assessment of suitable technology options

2.11.1.1 Electrolysers

Electrolyser is the heart of the green hydrogen plant and influences the overall CapEx & OpEx, plant performance and defines the requirements of the BoP. The electrolyser must operate in a VRE environment with the given generation profile. This will require the electrolyser to have characteristics such as a wide operating range, quick start up, ability to ramp up and down rapidly, low degradation, etc.

Given the current state of development of technology, the most suitable type of electrolysers would be either PEM type or the Pressurized Alkaline type. Atmospheric type Alkaline electrolysers is not considered for the feasibility study due to the requirement of hydrogen booster compressor to raise the pressure from atmospheric pressure up to 30 bar g (the required pressure at the syngas compressor suction). Booster compressors will have a significant impact on both the CapEx and OpEx of the green Hydrogen plant.

In terms of maturity of the technology, it must be noted that Alkaline technology has been around for almost 90 years and possesses extensive operational experience. It can be considered to have a Technological Readiness Level (TRL) of 9. The pressurized Alkaline type is a variant of the atmospheric type of Alkaline electrolyser and possesses advantages such as the ability to respond to load fluctuations and produce hydrogen at a high pressure thereby avoiding subsequent downstream compression equipment.

Unlike the Alkaline type of Electrolyser, PEM cell has a solid electrolyte, which eliminates the need for a lye management system and therefore makes the electrolyser cell more compact. It can be considered to have a TRL of 8.

For the feasibility study, the Hydrogen pressure required at the syngas compressor suction is assumed to be 30 bar g which can be easily provided by PEM. Discussions will be required with pressurized Alkaline type vendors to confirm supply of gas at 30 bar g. Otherwise, the selected syngas suction pressure must be lowered to say 20 bar g after discussions & agreement with the Ammonia technology licensor. This will avoid the use of Hydrogen booster compressors for the pressurized Alkaline type of electrolyser.

The marginally higher upfront cost of PEM electrolyser is due to the use of precious Platinum Group of Materials (PGM) that are emissions intensive during mining and manufacturing. The cathode and anode layers of a PEM stack are created by depositing metals like iridium or platinum on either side of the membrane. The bipolar plates of the PEM stack are constructed from gold or platinum-coated titanium while the Porous Transport Layer (PTL) is of titanium construction. The general shortage/scarcity of such precious metals worldwide and more so in India will impede the large-scale deployment of PEM domestically. If the precious materials can be efficiently recycled and/or alternative materials (non-PGM materials for the stack components) can be successfully developed, the prospects of large-scale deployment are likely to improve.

Alkaline electrolysers rely mostly on Nickel whose supply is diversified and therefore inexpensive compared to PEM electrolysers. The relatively easy availability of nickel coupled with a simpler design could make alkaline electrolysers less expensive as compared to PEM electrolysers.

In terms of operational flexibility, PEM has a faster response to the variability of the RE source when compared to Alkaline type (higher ramp-up rate of 20% per second versus 4% per second) and is therefore able to closely follow the generation profile.

PEM also has a wider operational range i.e., 10%-100% when compared to Alkaline type which typically has an operating range of 30% - 100% only.

PEM also has shorter start-up times (5-10 minutes for cold, and <5 secs and hot start-up) when compared to the alkaline type (30-80 minutes for cold, and 10-15 minutes for hot start-up). Clearly PEM has better characteristics for a VRE environment. When the RE profile drops to the expected minimum level 25%, the PEM electrolysers will easily follow the profile. In the case of Alkaline type, some electrolysers must be stopped to follow the RE profile. Stopping and subsequent re-starting of the Alkaline electrolysers involves delays and loss of Hydrogen production due to the longer starting times.

In terms of the power consumption, Alkaline type has a slight advantage over the PEM type due to its higher efficiency, however PEM vendors are quickly narrowing the gap. Similar efficiencies are likely with both types.

The stack life is nearly the same for both electrolyser types. However, the stack life of PEM type indicated by the OEMs remains to be validated as they are yet to complete the operating cycle of 8-10 years.

In terms of the footprint, the overall difference is marginal when considering the stack, separators, recirculating pumps, radiators for cooling, and purification unit.

To minimise the overall water consumption in the plant, radiator closed loop cooling (with demineralized water) is considered for all electrolysers. This will minimize the corrosion related to the water chemistry of open recirculating cooling water system.

2.11.1.2 Electrolyser suppliers

The following are the leading electrolyser vendors –

1. PEM type
    - i. Plug Power
    - ii. GreenH Electrolysis (H2B2)

iii. Ohmium
iv. Siemens**
v. Cummins

2. Alkaline type
   i. Eastern Electrolyser
   ii. Homi Hydrogen
   iii. John Cockerill
   iv. Thyssenkrupp
   v. Cummins
   vi. L&T

** It must be noted that Siemens supplies PEM type electrolysers that produce Hydrogen at atmospheric pressure only. Therefore, booster compressors will be required.

All OEMs have marketing offices in India. The extent of domestic manufacturing and supply chain inputs won't be provided at this stage. For e.g., Siemens will presently supply electrolysers entirely manufactured in Germany. OEMs such as Ohmium have already set-up facility in India for up to 500MW per annum capacity. Other vendors are in the process of establishing a manufacturing facility in India. Such details will be provided only during project implementation phase.

2.11.1.3 Ammonia

The technology options for the Ammonia synthesis are summarized in the table below.

Table 7: Ammonia synthesis technology options

Technology Options	*Ideal Operating Conditions*	*TRL (Scale 1 to 9)*	*Advantages*	*Disadvantages*
High-pressure Haber-Bosch process	Temperature: 400-550°C Pressure: 300-460 bar	TRL 9	• Well-known technology • No sharp separation required. • No refrigeration	• Very high pressure and temperature • Operating safety • High capital investment
Medium-pressure Haber Bosch process	Temperature: 350-525°C Pressure: 100-200 bar	TRL 9	• Well-known technology • No sharp separation required	• Requires large scale • High pressure and high temperature • Refrigeration required (high OpEx) • Operating safety
Absorbent-enhanced Haber Bosch process	Temperature: 370-400°C Pressure: 10-30 bar	TRL 4-5	• Relatively low pressure • Lower CapEx and OpEx • Safer operation • No refrigeration Kinetics no longer rate limiting, recycle is rate limiting	•Efficient separation required (low ammonia partial pressure)

For the feasibility study, Medium Pressure Haber Bosch process is considered.

Please refer to Chapter 8 for potential FEED Contractors, technology providers, EPC players for the Ammonia plant.

2.11.2 Operation management and storage concept

The dynamic simulation report (described in Section 3.2) has concluded that Hydrogen storage requirement is governed by the CapEx of the Ammonia plant. Further, due to the ability of the Ammonia synthesis loop to follow the RE generation profile, storage in the form of Ammonia is preferred, instead of gaseous H2. However, the dynamic response parameters and the operational range will be reconfirmed with the technology licensors during the project implementation phase.

However, Hydrogen storage is required for operational safety reasons also. For this, a minimum storage equivalent to 30 minutes requirement duration is envisaged. The pressure let-down station will be sized during the detailed engineering phase once the transient requirements are identified.

From the above criterion, storage of about 1.7 tons (net/usable) of gaseous Hydrogen at 40 bar pressure is envisaged.

The spacing between the vessels and the adjacent equipment will be governed by the requirements of NFPA-2. The approval of PESO will be required for storage of Hydrogen including the layout and the design of pressure vessel. It must be further noted that periodic pressure testing requirements (once in 5 years) will be necessary to comply with the requirements of SMPV.

See chapter 5 for further details on operation management.

2.11.3 Arrangement of sub-systems

The attached plot plan (DWG. No. FCE-20522173-EL-DWG- LAY-3000-002) shows the arrangement of the various sections of the plant covering an area of ~50 hectares. The criteria considered are safety, economic flow of materials and possible future expansions.

The following considerations are considered while arranging the systems –

1. Safety Distances – The predominant direction of the wind (from South-West direction) will govern the location of the main sections of the plant because hydrogen is a light gas and rapidly disperses into the atmosphere in the event of a leak. However, it forms an explosive mixture over a wide range (4% to 75%) in air. Therefore, the layout must ensure that any hydrogen leakage in the plant will not be carried over to manned areas or critical plant areas where ignition can occur. The location of the electrolysers will ensure that any leakage will not result in Hydrogen being carried into critical areas such as sub-station, electrical build the Ammonia plant or the manned areas of the plant such as control room and non-plant building. The Hydrogen storage area is provided near the eastern periphery of the plant (with the minimum required safety clearances in conformance to NFPA-2 code) to safely carry any leak away from plant area. Similarly, the flare is located at the North-East corner of the plant area with the required safety distance of 90m radius from boundary and other equipment within the plant. Storage of Ammonia in cryogenic condition at (-) 33°C and atmospheric pressure will ensure that any leakage from the tanks (2 x 5000 Tons) is minimal. The Boil off Gas recovery systems will ensure that there is no release of toxic Ammonia vapours from the storage. The Ammonia storage tanks will be located at the Eastern periphery for additional safety to avoid toxic vapours from being carried over to the plant area.

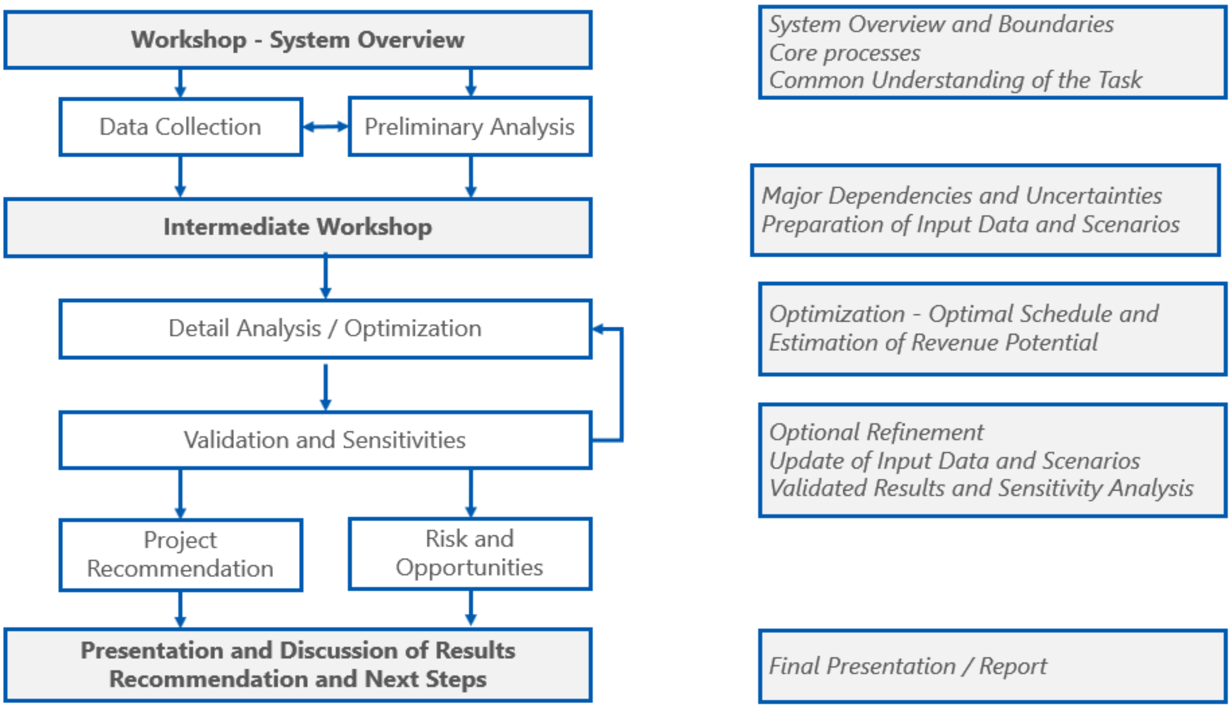
2. Economic flow of materials – This will be achieved by minimising the length of interconnecting pipework between the Electrolysers /ASU plant and the Ammonia plant. This will minimize the pressure drop and reduce the auxiliary power consumption.

3. Future expansions – A compact layout is envisaged and therefore any future expansion must be implemented in an adjacent land only. It must be noted that out of the total available land of ~210 hectare, the proposed plant will require only ~50 hectares. Sufficient land is therefore available for future expansion. The proposed plant layout will optimise the costs of the future plant by locating the flare, storage tank and gaseous Hydrogen storage close to the periphery. These facilities can be utilised by the future plant to reduce costs.

2.12 Dynamic Simulation and Optimisation

2.12.1 General Approach

Figure 5: General Approach



In a first step, the main characteristics of the system components of the ammonia plant and the main intercorrelations between major system were identified with the purpose of their proper representation into the "Fichtner H2 optimiser" optimisation model. For that purpose, within a **System Overview Workshop** a general design concept was established in close cooperation with project experts and stakeholders. The System Overview Workshop was executed in two parts on 20 and 22 February 2023. Contents and output of the System Overview Workshop are further described in section 2.2.2. A block diagram of the system and system components served as major tool for defining system boundaries and core processes to be represented with the H2 optimiser. This block diagram was permanently further adjusted within this and further workshops for defining the final system representation in the model.

Already at the System Overview Workshop and based on specification of the system design concept identified together in that workshop, data collection was started. For that purpose, FS prepared a data collection sheet, with which the complete parametrization of all system components and model assumptions was collected. In parallel to this data collection process, FS undertook preliminary analysis and plausibility checks for a coherent system composition and representation, that were reflected with all workshop participants in the further workshops.

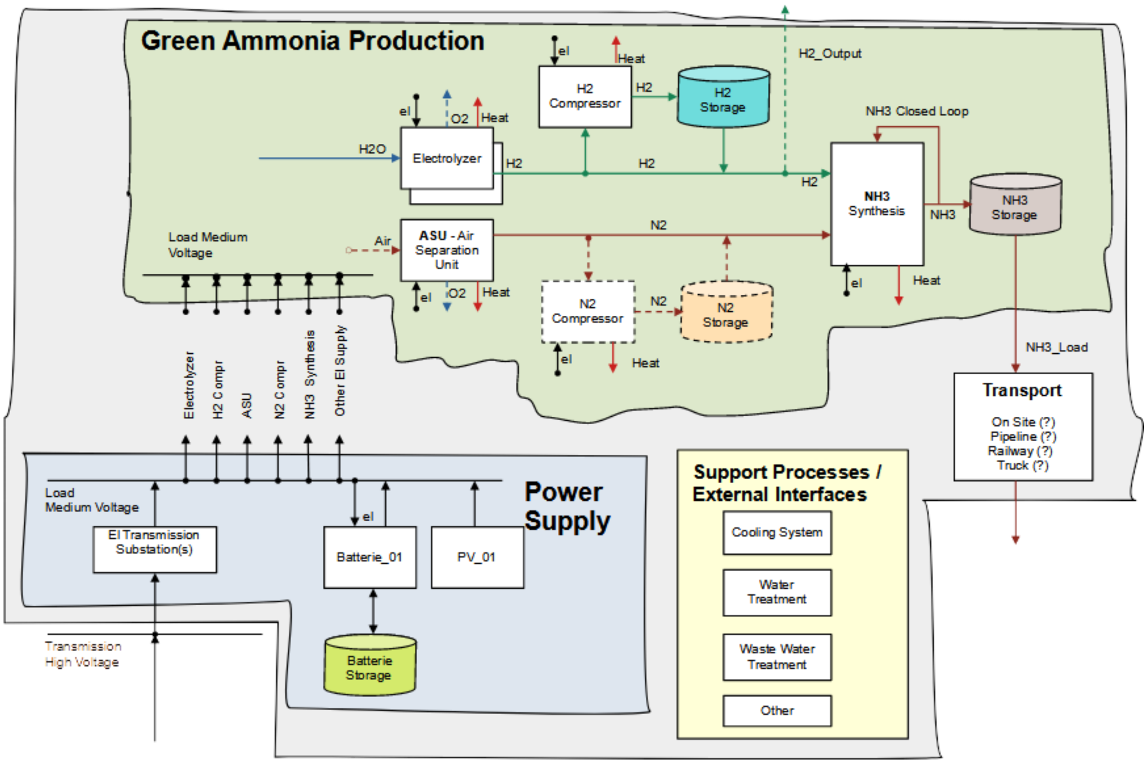
At the **Intermediate Workshop** (see section 2.2.3) conducted on 27 March 2023, the collected data set was presented, and remaining data gaps were discussed. Validations and aspects of high importance as identified from the preliminary analysis were also discussed with the participants and clarifications sought. Additionally, also major sensitivities were identified together to be further analysed with different scenarios.

FS received a finalized and complete version of the data set on 3 April 2023 based on which the system optimisation calculations were executed. At the **System Optimisation Workshop** (see section 2.12.4) on 11 May 2023, FS presented and discussed the optimisation results with the workshop participants. From these results the parametrization of the specific CapEx figure for the ammonia synthesis system component was identified as a major sensitivity as well as uncertainty about the optimum system design. FS calculated thus afterwards further scenarios covering these uncertainties and submitted the final results from all optimisation calculations on 16 May 2023.

2.12.2 System Overview Workshop

At the system Overview Workshops, the participants discussed options for power input, bypass products (for example hydrogen, heat, oxygen), definitions, assumptions and available/required input data per system component and major dependencies and uncertainties, for developing a common high-level understanding of system core processes and boundaries. At the end, a refined version of the main system components and system composition as to be represented in the DSO was developed along the following block diagram (Figure-6).

Figure 6: Block diagram of the system as updated with the System Overview Workshop



As a main outcome from the System Overview Workshop, the system design was adjusted regarding following aspects:

- An PV-based power generation option in the format of a generation profile (2590 full load hours per year) in combination with a constant PV tariff was added, in addition to a predefined power supply profile (with 6735 full load hours and a minimum load of 25%) combined by several Variable Renewable Energies (VRE), as defined, and provided by NTPCREL. Also, the VRE profile was assumed to be supplied at a constant tariff. With the DSO the model determines the optimum volume/capacity from each power supply profile in the manner of a take or pay option.
- Two technology options regarding electrolysis technology are parametrised and included into the model: PEM and AEL technology. With the DSO the model determines the optimum capacity and employment of both technology options.

2.12.3 Intermediate Workshop

Based on the preliminary analysis of data collected and system components specified so far, at the Intermediate Workshop, input data and assumptions were presented that were received, amended, validated, or clarified since the last workshop (e.g., regarding hydrogen storage and compression, regarding batteries, etc.) and were discussed and checked together during the workshop. For instance, it was agreed to not assume an identical tariff for both power supply sources, VRE and PV. Transport options for ammonia were assumed to be temporally decoupled and independent from ammonia production, and a NH_3 storage component serves as interface for the further process chain. Regarding the storage of hydrogen and nitrogen it was assumed, that current solutions are based on separate storages, but future options with a combined storage of both materials will be developed.

An aspect of high importance was how to consider water and wastewater related processes. Although ammonia production based on renewables energies saves huge amounts of water resources (cooling water) compared to processes based on thermal power plants, nevertheless the provision of sufficient water supply is a major challenge for a large green ammonia plant of this size. However, the effects of water and wastewater related processes on the overall costs and on the optimised design of core systems like electrolysis and ammonia synthesis are low. The optimisation will thus not consider an explicit water supply component but will implicitly provide optimal capacities and optimised flows for efficient water related processes.

At the intermediate workshop it was also decided that the economic usage of any byproducts of the plant, like heat, oxygen and surplus hydrogen is unlikely or at least not clearly enough recognizable at this prefeasibility stage to be explicitly considered in determining the economically optimum system design with the model.

Furthermore, at the Intermediate Workshop, parameters and aspects that might be potentially sensitive to the optimal system design were discussed and identified, like the specific CapEx for the ammonia synthesis capacity, and different options and parametrizations of power supply and of electrolyser technologies. These considerations served as basis for defining different scenarios (see section 2.2.10.1) of system optimisation.

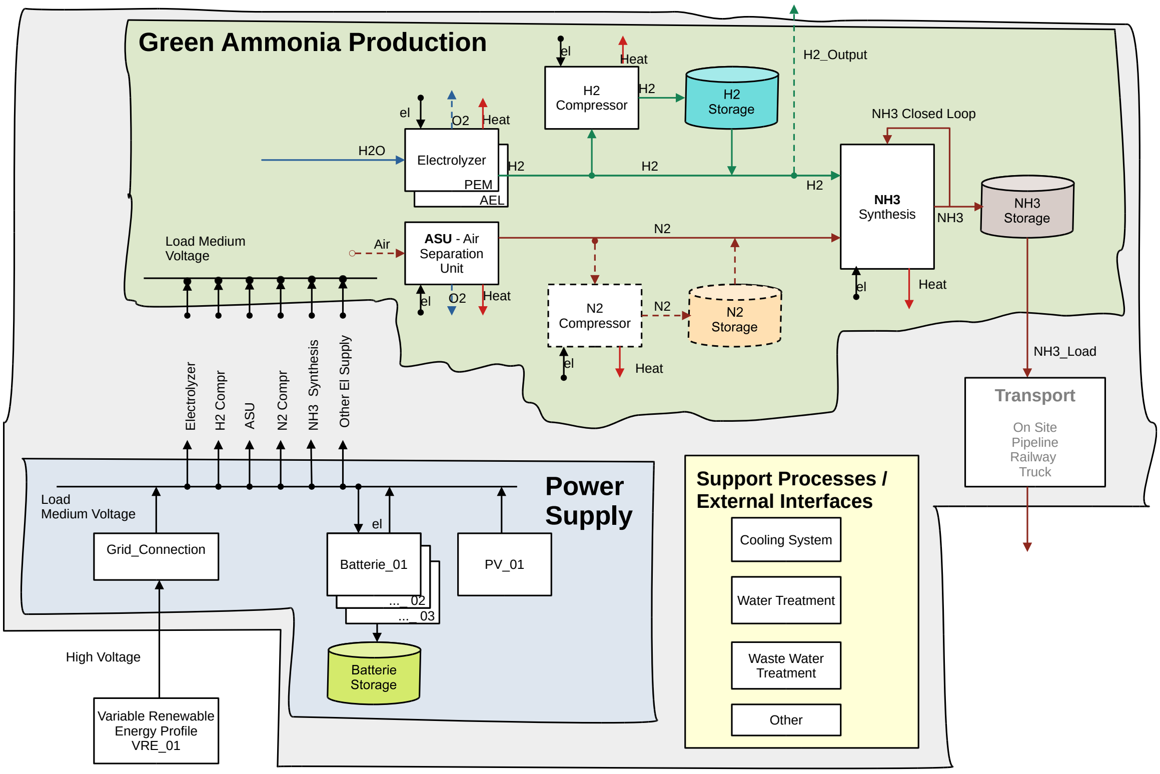
2.12.4 System Optimisation Workshop

At the system optimisation workshop, an overview about the final main system and model specifications was presented, as well as about the six scenarios (see section 2.2.10.1) that were defined and specified up to that point. Then the belonging system optimisation results (see section 2.2.12) were presented.

2.12.5 System Specifications

The final system design that was represented with the H2 optimiser is shown below.

Figure 7: System Overview in its final stage



In the following, some major specifications of the system design are presented, as they were considered by the H2 optimiser for all scenarios.

2.12.6 General Parameters and Assumptions

- currencies:
  - base currency of the model: Indian Rupees (INR)
  - 1 USD = 82.7 INR
  - 1 EUR = 1.1 USD
- contingency factor on all system component costs: 20%
- annual availability of the whole plant: 91%
  - annual amount of ammonia to be produced by the plant:
  - 1000 tons per day x 365 days/year x 91% availability = 332,150 [t_ NH_3/a]
- project timeline:
  - NPV_Base_Year: 2023
  - Project_Commercial_Start_of_Operation: 2026
  - Project Lifetime: 25 years
- discount rate: 8%

2.12.7 Power Options

- VRE (Variable Renewable Energy) supply profile:
  4000 INR/MWh, 6735 h/a full load hours, minimum 25% load:
- PV-based power generation:
  3000 INR/MWh, 2590 h/a full load hours

Both power supply options to be considered via an hourly supply profile and via a constant tariff. The model determines the optimum volume/capacity from each (fixed predefined) power supply profile, in the manner like a take or pay option.

2.12.8 Storage Options

Table 8: Storage options considered

	base_unit	storage_volume [base_unit]	specific CAPEX [Mio INR/base_unit]	specific annual fix OPEX [% of CAPEX/year]	lifetime [years]	maximum output [storage content per hour]
battery_01	MWh	to be optimized	38.8	2.5%	15	1
battery_02	MWh	to be optimized	24.2	2.5%	15	0.25
battery_03	MWh	to be optimized	21.7	2.5%	15	0.125
h2_storage	t_h2	to be optimized	96.8	2.0%	25	unlimited
nh3_storage	t_nh3	to be optimized minimum 10000	0.086	3.0%	25	unlimited

2.12.9 Electrolysis Options

Both, PEM and AEL electrolysis are considered by the H2 optimiser, with the following specifications (plus an extra variation within scenario 4, see in red colour):

Table 9: Electrolysis options considered

Parameter	Unit	PEM	AEL	AEL in scenario #4
BoL_efficiency	[MWh/t_h2]	55.5	52.0	52.0
EoL_efficiency	[MWh/t_h2]	60.4	58.0	58.0
specific CAPEX	[Mio USD/(t_h2/h)]	70	60	60
specific CAPEX_stack	[Mio USD/(t_h2/h)]	10	10	10
specific fix OPEX	[annually as percentage of CAPE)	2%	4%	2%
lifetime electrolyzer	[years]	25	25	25
lifetime stacks	[years]	10	10	10
as a result (of discount rate, lifetime, currency exchange rate):				
specific CAPEX annuity	[Mio INR/a/(t_h2/h)]	651	558	558
specific fix OPEX annuity	[Mio INR/a/(t_h2/h)]	139	238	119
specific total annuity	[Mio INR/a/(t_h2/h)]	790	796	677

2.12.10 Scenario and Run Definitions

2.12.10.1 Scenario Definitions

At the System Optimisation Workshop, the results for the first six defined scenarios were presented (see scenarios 1 to 6 in following table). After this Workshop, further 3 scenarios (scenarios 7 to 9) for further variations of the specific CapEx figure of the ammonia synthesis component were added. Table 2.8 shows the in total nine scenarios calculated with the H2 optimiser.

Table 10: Scenarios defined and calculated with the H2 optimiser

Item	Unit	scenario No. 1	2	3	4	5	6	7	8	9
scenario characterisation	-	base case	synthesis high CAPEX	synthesis low CAPEX	AEL OPEX only 2%	no PEM	no AEL	nh3_capex_350_usd	nh3_capex_550_usd	nh3_capex_800_usd
spec_nh3_capex_usd	[USD/(t_nh3/a)]	650	1000	143.835	650	650	650	350	550	800
spec_annual_fix_OPEX_AEL	[% of CAPEX / a]	4%	4%	4%	2%	4%	4%	4%	4%	4%
PEM included?	-	yes	yes	yes	yes	no	yes	yes	yes	yes
AEL included?	-	yes	yes	yes	yes	yes	no	yes	yes	yes
results included in India_1000TPD_Green_NH3_**m124a**_...[xyz].csv		**yes**	**yes**	**yes**	no	no	no	no	no	no
results included in India_1000TPD_Green_NH3_**m124b**_...[xyz].csv		**yes**	no	no	**yes**	**yes**	**yes**	no	no	no
results included in India_1000TPD_Green_NH3_**m125**_...[xyz].csv		**yes**	**yes**	**yes**	no	no	no	**yes**	**yes**	**yes**

The yellow colour marks the only difference from which a certain scenario differs from the base case scenario number 1.

Scenarios 1 to 3 and 7 to 9 cover in total 6 different assumptions for the specific ammonia synthesis CAPEX. Those figures are 143.835, 350, 550, 650 (base case), 800 and 1,000 USD per t_ NH_3 per year.

The further scenarios 4 to 6 consider different assumptions for the electrolysers. With scenario 4, the specific annual fixed OPEX is assumed to be only 2% of specific CAPEX, instead of 4% in the base case. And with the scenarios 5 and 6 one of both electrolyser types is completely excluded from the system (by definition).

2.12.11 Run Definitions

In addition, Table 2.8 does in the last three rows also list the three different H2 optimiser runs. Those runs are named m124a, m124b and m125. Each run generates its (in total 5) output csv-files. And each run does include a different set of scenarios calculated. Not all scenarios are calculated with a single run, for a) preventing the output files becoming too big and b) for comparing those scenarios with a certain run that shall become comparable among the same output files.
The 5 output files of each run have the following names and contents:
Each run created the following 5 output csv-files with the following content:

- …_overview.csv overall run results
- …_result_agg_value.csv all annual results
- …_result_ts_value.csv hourly results (i.e., per timestep "ts")
- …_result_ts_value_sparse.csv like hourly results, but excl. time steps with value = 0
- …_result_ts_storage_value_sparse.csv hourly results focused solely on all storage-related values

2.12.12 Fichtner H2-Optimiser Approach

The Fichtner H2 Optimiser used for Dynamic Simulation and Optimisation of the green ammonia plant consists of a linear optimisation model, that represents all identified main system components, their capacities, and activities and their intercorrelations and processes. That means, it calculates all material and energy flows along the ammonia production value chain for all hours of a representative year. And it calculates all the capacities of all the system components that are required for such production. All these variables are determined in a way, where all the costs resulting from the installation and utilisation of all represented system components are minimized while generating the pre-defined annual amount of green ammonia. Thereby costs may either result from the installation of capacities and are thus independent on how much and in which hours the capacities are utilised. Within one year, these so-called "capacity costs" consist of an annualized CAPEX part and of an annual fixed OPEX part. Or in addition to these capacity costs, costs may depend/vary on the quantity of materials and energy flows through the system components and are thus called "variable costs". For the system analysed for this project the only variable costs to be considered in the model are costs for utilizing power, i.e., per kWh of electricity.

The amount of available electricity in each hour and its price/tariff (assumed to be constant in each hour) are thus a major determination of how an optimised system design will be operating in each hour, how much capacity will be required of each component and particularly, how much and which kind of storage components are recommended for buffering any inflexible generation constraints - as resulting from hourly varying renewable power supply - with cost-optimised storage solutions.

For both types of electrolysers, AEL and PEM, it is assumed, that the electrolyser capacity investment needs to be able to allow a maximum hydrogen generation in the first year, which is then linearly slightly degrading due to slight energy efficiency deterioration of the electrolyser until stack replacement. The annual and hourly amounts of hydrogen (and consequently ammonia) produced and the amounts of inputs (electricity, air, water, etc.) required for this are however calculated based on an average year, i.e., for a year just in-between the year with the best (BoL: begin of life) and the worst (EoL: end of life) electrical efficiencies. Also, the electrical grid connection capacity (i.e., substation capacity) that is required is calculated in a way where sufficient power is supplied to the electrolyser even in its worst year (EoL) with lowest electrical efficiency.

2.12.13 Optimised System Results

All results[1] are included in the output csv-files of the model runs number 124a, 124b and 125. Some explanations about the results regarding scenarios 1 to 6 are given below, further are given in the Optimisation Workshop presentation. Items and parameters are explained in section 2.2.13.

2.12.13.1 Overview about main results

Following most important results and insights were gained from the optimisation in all 9 scenarios calculated[2]:

- Power sources: VRE is the only power source used in all scenarios; no PV power is chosen.
- Storage: Apart from predefined nh3_storage (10,000 t_nh3), h2_storage is the only kind of storage found to be optimal for the system. In some scenarios, which have an underlying assumption of a relatively low specific CAPEX for ammonia synthesis, if even no h2_storage at all is found to be optimal. In any case, no batteries are employed in any of the scenarios.
- Electrolysers: In the assumed base case parametrisation, the optimum system employs both electrolyser types together. The reason for this is: AEL with its slightly higher electrical efficiency is used for a kind of "base load" employment, to avoid electricity costs compared to PEM employment. In base load mode (i.e., at high annual full load hours), when relatively much annual electricity is consumed, the electricity costs have a relatively higher importance than in peak load mode (i.e., at low annual full load hours), where it is more cost efficient to avoid high specific capacity costs. Avoiding high specific capacity costs is the slight advantage of PEM {957,374,070 INR/a/(installed_th2/h)} over AEL {983,514,913 INR/a/(installed_th2/h)}. As Figure 8 shows, both effects are only slightly effective/differing, but finally outpace each other at a certain point of annual full load hours.

The Figure 8 shows the specific costs of electrolysis per generated hydrogen, in dependency on the amount of annual full load hours of the two electrolyser types. As can also be seen in the figure, in scenario 4 these specific costs are lower for AEL due to assumed lower specific fixed OPEX. Therefore, in scenario 4, AEL is clearly superior to PEM. Whereas in the base case (scenario 1), it depends on the amount of full load hours on which electrolyser type is superiorly to be employed, i.e., which electrolyser is cheaper to be used than the other type.

[1] All economic figures resulting from the model are expressed in Indian Rupees INR_{2023}.

[2] For further details see also the Presentation of Optimisation Workshop in Annex 1

Figure 8: Specific costs of electrolysis per generated hydrogen, in dependence on the amount of annual full load hours of the two electrolyser types

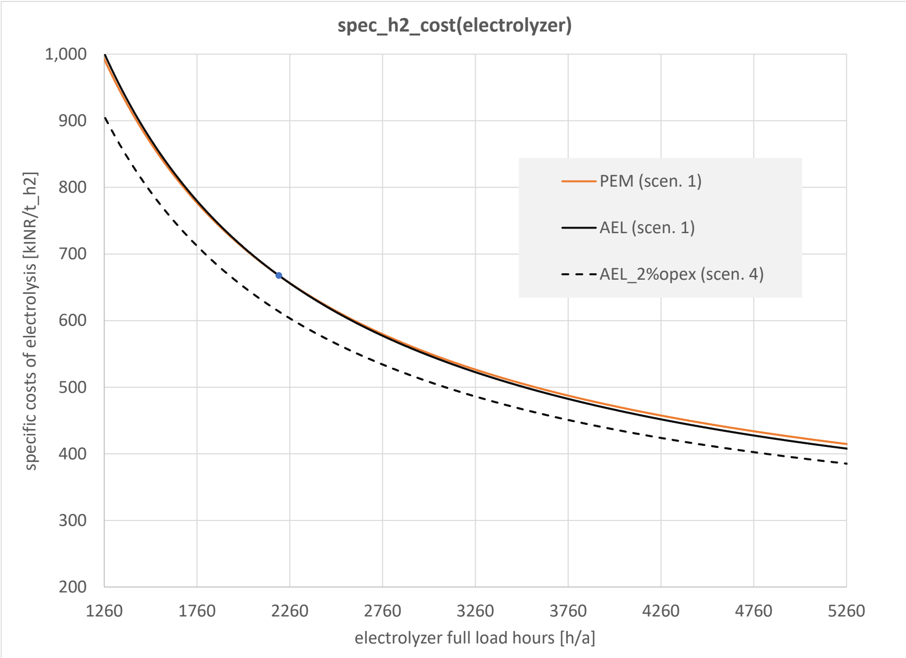
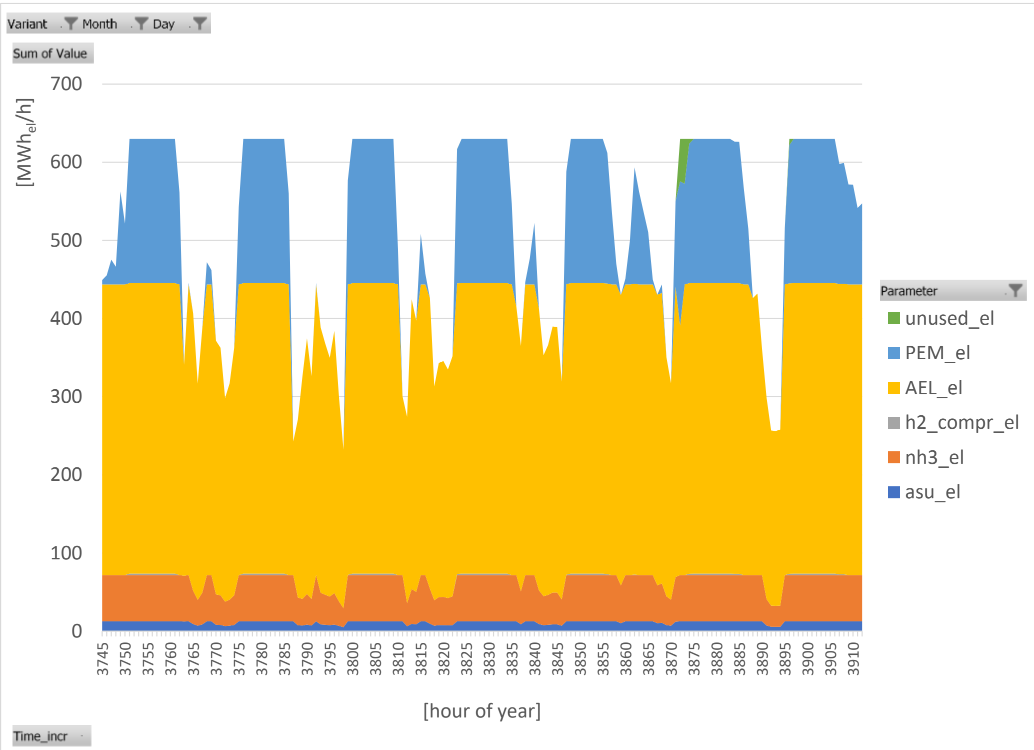


Figure 9: Hourly electricity consumption per system component for an exemplarily week, scenario 2



Therefore, the model determines that a combination of both electrolyser types should be employed in optimal case, given the underlying base case cost assumptions for both electrolysers. In this combination, AEL is preferably used for covering base load and PEM is preferably used for covering peak load of the hydrogen generation process. This becomes clearly visible when looking into the hourly electricity consumption of the plant's component along an exemplary week, see Figure 9.

As Figure 8 shows, the costs of employing one or the other electrolyser are almost the same under base case assumptions. Cost differences for both electrolyser types are then insignificant in comparison to the generally inherent uncertainty in the cost figure assumptions. Scenario 4 demonstrates that already a changed assumption from 4% to 2% of specific fixed OPEX for the AEL electrolyser would result in a clear advantage for the AEL technology.

2.12.13.2 Capacities

Following capacities were determined to be optimum among the first 6 scenarios:

Table 11: Optimum system component capacities

[MW]	Scenario 1	2	3	4	5	6
elect_capacity	**685.8**	**688.9**	**685.2**	**684.5**	**684.4**	**701.4**
asu_n2	13.5	12.6	13.7	13.5	13.6	13.5
PEM_h2	178.9	200.7	166.7			623.8
AEL_h2	429.5	414.6	440.0	606.9	606.6	
h2_compr_h2	0.4	1.8		0.5	0.4	0.5
nh3_nh3	63.4	59.2	64.7	63.7	63.9	63.7

Following electrical capacities were determined to be optimum among the first 6 scenarios:

Table 12: Optimum electrical capacities of system components

System Component	Scenario 1	2	3	4	5	6	Unit
capacity							
vre_01_el	629.3	632.3	628.6	624.2	624.1	653.4	[MW]
grid_connection	626.8	629.7	626.1	621.7	621.6	650.8	[MW]
asu_n2	44.9	41.9	45.8	45.0	45.2	45.0	[t_n2/h]
PEM_h2	3.0	3.3	2.8			10.3	[t_h2/h]
PEM_stack_h2	3.0	3.3	2.8			10.3	[t_h2/h]
AEL_h2	7.4	7.1	7.6	10.5	10.5		[t_h2/h]
AEL_stack_h2	7.4	7.1	7.6	10.5	10.5		[t_h2/h]
h2_compr_h2	0.2	1.0		0.2	0.2	0.2	[t_h2/h]
h2_storage	2.4	11.2		2.6	2.2	2.6	[t_h2]
nh3_storage	10,000	10,000	10,000	10,000	10,000	10,000	[t_nh3]
nh3_nh3	52.9	49.4	53.9	53.0	53.2	53.0	[t_nh3/h]
nh3_nh3	*1269.0*	*1184.8*	*1294.4*	*1273.0*	*1277.3*	*1273.1*	*[tpd nh3]*

2.12.13.3 Amounts of hydrogen and ammonia production

Table 13 shows annual and hourly amount figures of hydrogen and ammonia production from the two electrolyser types and from the ammonia synthesis process.

Table 13: Annual and hourly amounts of hydrogen and ammonia production

capacities and volumes by component	Scenario 1	2	3	4	5	6	Unit
PEM_h2							
capacity	3.0	3.3	2.8			10.3	[t_h2/h]
x_avg	1.3	1.5	1.2			7.6	[t_h2/h]
x_avg_with_avail	1.2	1.4	1.1			6.9	[t_h2/h]
x_max	2.8	3.2	2.6			9.9	[t_h2/h]
x_min						2.2	[t_h2/h]
x_sum	11,702	13,123	10,840			66,430	[t_h2/a]
x_sum_with_avail	10,649	11,942	9,864			60,451	[t_h2/a]
AEL_h2							
capacity	7.4	7.1	7.6	10.5	10.5		[t_h2/h]
x_avg	6.2	6.1	6.3	7.6	7.6		[t_h2/h]
x_avg_with_avail	5.7	5.5	5.8	6.9	6.9		[t_h2/h]
x_max	7.0	6.8	7.2	9.9	9.9		[t_h2/h]
x_min	2.3	1.6	2.5	2.2	2.2		[t_h2/h]
x_sum	54,728	53,307	55,590	66,430	66,430		[t_h2/a]
x_sum_with_avail	49,802	48,510	50,587	60,451	60,451		[t_h2/a]
nh3_nh3							
capacity	52.9	49.4	53.9	53.0	53.2	53.0	[t_nh3/h]
x_avg	41.7	41.7	41.7	41.7	41.7	41.7	[t_nh3/h]
x_avg_with_avail	37.9	37.9	37.9	37.9	37.9	37.9	[t_nh3/h]
x_max	52.9	49.4	53.9	53.0	53.2	53.0	[t_nh3/h]
x_min	13.7	13.7	13.7	13.6	13.6	13.6	[t_nh3/h]
x_sum	365,000	365,000	365,000	365,000	365,000	365,000	[t_nh3/a]
x_sum_with_avail	332,150	332,150	332,150	332,150	332,150	332,150	[t_nh3/a]

2.12.13.4 System costs

Table 15 provides an overview about major cost figures and cost efficiencies (levelised costs) per scenario 1 to 6. The total annuity is composed of total annual capacity costs and total annual variable costs (i.e., electricity costs). Calculating total annuity under the consideration of a plant availability restriction (see "…_with_avail") is the kind of cost item that is minimized per each scenario configuration.

Table 14: Cost overview per scenario

Item	Comment
spec_nh3_capex_usd	
prj_initial_capex	
total_annuity	
total_annuity_with_avail	**= minimized objective value**
annual_capacity_cost	total_annual_capacity_costs..
annual_capacity_cost_excl_storage	.. of which
annual_capacity_cost_storage	.. of which
annual_var_cost	
annual_var_cost_with_avail	
levl_h2_cost	includes only costs/components required for hydrogen generation, inclusive any batteries and h2_storage
lcoa	levelized cost of ammonia

Following Figure 10 shows the breakdown of levelised costs of ammonia production given in [INR/t_nh3] for the three scenarios 1, 5, and 6. These scenarios differ only by allowing once both electrolysers to be included into the system (scenario 1), once only the AEL electrolyser to be included (scenario 5) and once only the PEM electrolyser to be included (scenario 6).

Table 15: Overview about major cost figures and cost efficiencies (levelised costs)

	Scenario						
Item	1	2	3	4	5	6	Unit
spec_nh3_capex_usd	650	1,000	143.84	650	650	650	[USD/(t_nh3/a)]
prj_initial_capex	110,935,046,110	126,162,376,679	87,156,372,394	108,797,407,337	108,812,775,740	118,164,316,344	[INR]
total_annuity	31,508,482,009	33,427,707,943	28,576,711,765	30,313,236,947	31,558,881,835	31,949,978,824	[INR/a]
total_annuity_with_avail	**29,982,726,807**	**31,894,795,554**	**27,052,641,742**	**28,799,873,144**	**30,045,681,098**	**30,365,779,700**	**[INR/a]**
annual_capacity_cost	14,555,646,431	16,395,348,069	11,642,600,397	13,498,083,578	14,745,540,311	14,347,766,334	[INR/a]
annual_capacity_cost_excl_storage	14,396,084,652	16,118,674,304	11,514,338,329	13,335,137,271	14,587,966,793	14,184,971,372	[INR/a]
annual_capacity_cost_storage	159,561,779	276,673,764	128,262,067	162,946,307	157,573,517	162,794,961	[INR/a]
annual_var_cost	16,952,835,578	17,032,359,873	16,934,111,368	16,815,153,369	16,813,341,524	17,602,212,490	[INR/a]
annual_var_cost_with_avail	15,427,080,376	15,499,447,485	15,410,041,345	15,301,789,566	15,300,140,787	16,018,013,366	[INR/a]
levl_h2_cost	425,546	430,217	424,480	405,736	426,153	431,639	[INR/t_h2]
lcoa	90,269	96,025	81,447	86,707	90,458	91,422	[INR/t_nh3]

The annual capacity costs listed in Table 14 are further broken down by system component in Table 16

Table 16: Cost breakdown of annual costs per scenario

	Scenario					
Cost Breakdown [INR/a]	1	2	3	4	5	6
annual_capacity_cost						
grid_connection	146,552,360	147,239,825	146,390,495	145,362,137	145,346,474	152,166,036
asu_n2	421,482,291	393,544,307	429,925,363	422,839,165	424,256,623	422,852,102
PEM_h2	2,339,078,512	2,623,489,983	2,180,072,414			8,155,998,584
PEM_stack_h2	496,855,197	557,268,439	463,079,928			1,732,455,862
AEL_h2	5,894,693,698	5,690,255,281	6,037,838,431	7,082,581,550	8,324,742,162	
AEL_stack_h2	1,389,239,369	1,341,058,087	1,422,975,184	1,962,865,277	1,961,944,104	
h2_compr_h2	13,041,130	57,804,023		14,451,305	12,212,714	14,347,535
h2_storage	31,299,712	148,411,697		34,684,239	29,311,450	34,532,894
nh3_nh3	3,695,142,095	5,308,014,359	834,056,514	3,707,037,836	3,719,464,714	3,707,151,253
nh3_storage	128,262,067	128,262,067	128,262,067	128,262,067	128,262,067	128,262,067
annual_elec_cost_with_avail						
vre_01_el	15,427,080,376	15,499,447,485	15,410,041,345	15,301,789,566	15,300,140,787	16,018,013,366
Grand Total	**29,982,726,807**	**31,894,795,554**	**27,052,641,742**	**28,799,873,144**	**30,045,681,098**	**30,365,779,700**

Figure 10: Breakdown of Levelised Cost of Ammonia (LCOA) per scenarios 1, 5 and 6 given in [INR/t_nh3]

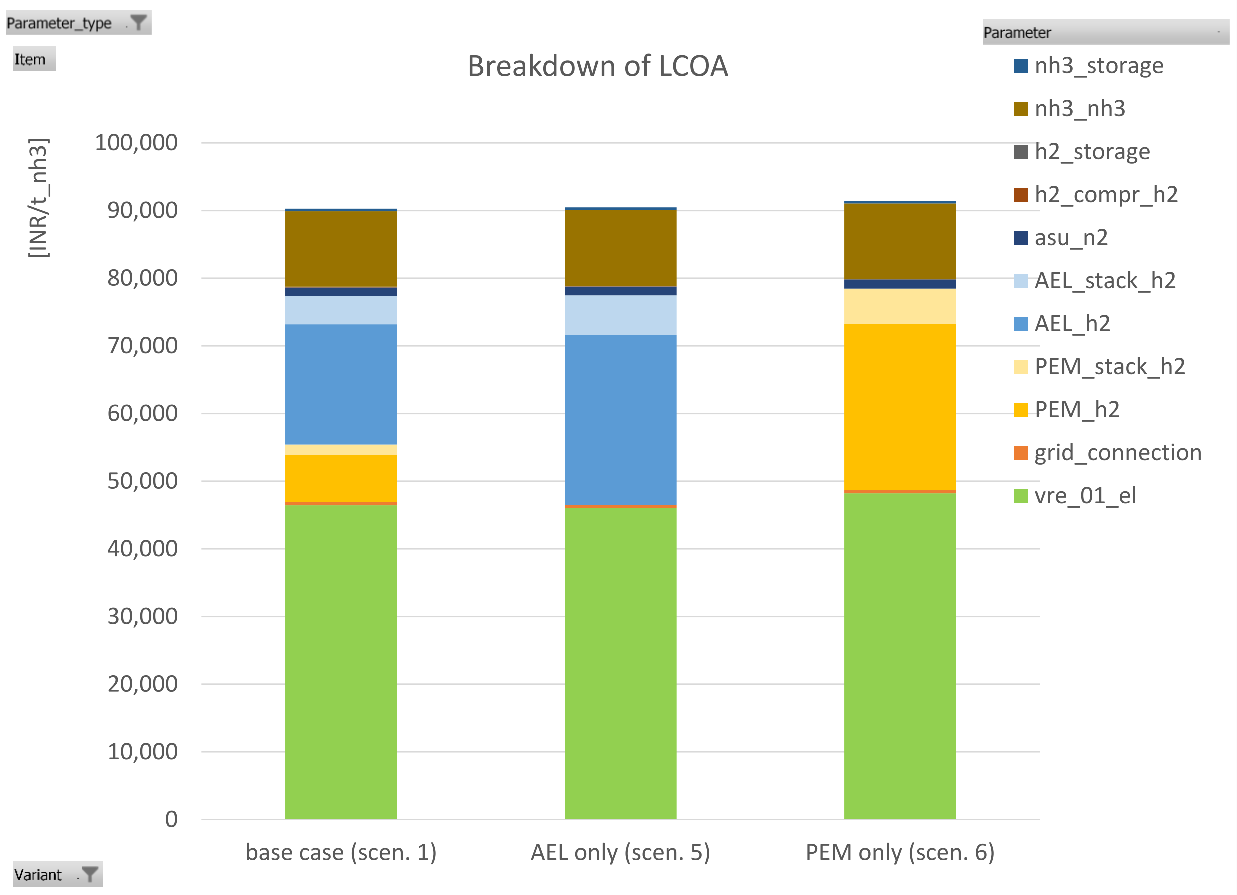


Table 17: Breakdown of Levelised Cost of Ammonia (LCOA) per scenario 1, 5 and 6 given in [INR/t_nh3]

	base case (scen. 1)	AEL only (scen. 5)	PEM only (scen. 6)
vre_01_el	46,446	46,064	48,225
grid_connection	441	438	458
PEM_h2	7,042		24,555
PEM_stack_h2	1,496		5,216
AEL_h2	17,747	25,063	
AEL_stack_h2	4,183	5,907	
asu_n2	1,269	1,277	1,273
h2_compr_h2	39	37	43
h2_storage	94	88	104
nh3_nh3	11,125	11,198	11,161
nh3_storage	386	386	386
Grand Total	**90,269**	**90,458**	**91,422**

Following main conclusions can be drawn from this Figure 13 and from the belonging Table 17

- A combined AEL and PEM utilisation (scenario 1) brings only very low advantage over sole AEL or PEM utilisation (scenarios 5 or 6)
- Electricity costs (see the item vre_01_el) contribute little more than half to LCOA.

2.12.14 Model Items and Parameters

For interpretation of the model results produced with the csv files, the following model items are explained in the following.

2.12.14.1 Model items

```
uncovered_el        # uncovered electricity load in [MW]
unused_el           # not used electricity in [MW]
supply_el           # electricity supply
load_el             # electricity load
vre_01_el           # by NTPC predefined normalized power supply profile from
variable renewable energy sources
vre_01_eln          # normalized VRE power generation profile in %
pv_01_el            # PV power generation in [MW]
pv_01_eln           # normalized PV power generation profile in %
grid_connection     # grid connection point with substation [MW] transforming from
high to medium voltage
PEM_h2              # hydrogen output from PEM in [t per h]
PEM_stack_h2        # hydrogen output related to PEM stack in [t per h]
PEM_el              # power input to PEM in [MW]
PEM_o2              # oxygen output from PEM in [t per h]
PEM_h2o             # water input to PEM in [t per h]
AEL_h2              # hydrogen output from AEL in [t per h]
AEL_stack_h2        # hydrogen output related to AEL stack in [t per h]
AEL_el              # power input to AEL in [MW]
AEL_o2              # oxygen output from AEL in [t per h]
AEL_h2o             # water input to AEL in [t per h]
h2_compr_h2         # h2 input to h2 compression in [t per h]
h2_compr_el         # power input to h2 compression in [MW]
h2_load             # h2 output from h2 subsystem (incl. h2_storage) in [t per h]
asu_n2              # n2 output from ASU in [t per h]
asu_O2              # O2 output from ASU in [t per h]
asu_air_input       # air input to ASU in [t per h]
asu_el              # power input to ASU in [MW]
n2_load             # n2 output from n2 subsystem in [t per h]
nh3_nh3             # nh3 output from ammonia synthesis in [t per h]
nh3_h2              # h2 input to ammonia synthesis in [t per h]
nh3_n2              # n2 input to ammonia synthesis in [t per h]
nh3_el              # power input to ammonia synthesis in [MW]
nh3_outp            # ammonia output after ammonia storage
sum_battery_inp     # sum of input into all batteries
sum_battery_outp    # sum of output from all batteries
battery_01_storage  # battery (type1) storage in MWh
battery_02_storage  # battery (type2) storage in MWh
battery_03_storage  # battery (type3) storage in MWh
h2_storage          # h2 storage in [t_H2].
nh3_storage         # nh3 storage in [t_nh3]
```

2.12.14.2 Parameters

The above listed items are contingently (as applicable) assigned with inter alia the following parameters-

- hourly or annual flows (incl. annual sums, maximum or minimum values, storage load and unload flows, etc)

  → x, x_sum, x_max, x_min, x_load, x_unload

These values can be expressed without or with consideration of the annual plant availability constraint, the latter case earmarked with the suffix "_with_avail"; hourly flows can also be named as with x_value, while x_cost represents hourly variable costs (i.e., hourly electricity costs)

- capacity (e.g., in tons per hour or MW, for storage in tons or in MWh)
- prefix "prj" stands for project and refers to values summarized over the whole project
- prefix "sum" stands for summation over one year
- levelised costs
  - "levl_cost" are the cost of the respective component/item levelised over the output belonging to this respective item/component;
  - "levl_h2_cost" refer to the levelised costs of hydrogen and sum up all costs in the value chain up to hydrogen production and(!) storage and levelised these costs over the amount of hydrogen produced;
  - "lcoa" refer to levelised cost of ammonia
- capacity costs can be either expressed specific (i.e., per capacity unit), expressed with the prefix "spec", or in total without such prefix
- capacity costs consist of CapEx and fix_OpEx values and with the prefix "annual" they are expressed as annuities

annual_var_cost refers to annual variable costs, which are annual electricity costs only in this system; they are distinguished whether they are calculated with or without considering the availability constraint (_with_avail, as introduced above).

2.13 Description of Sub-systems and Equipment

2.13.1 Techno-economic details about all relevant sub-systems and storages

The expected Capex of the relevant sub-systems and storages is indicated in Chapter 6. The sizing (capacities) of the sub-systems is shown in sub-clause 2.3 (f). The Opex of the sub-systems other than the electrolyser is assumed to be about 3% of the Capex per annum. Besides the maintenance cost, other costs will be incurred due to replacement of spent adsorbent in instrument air dryer and ASU air dryer, spent resins in the Demineraliser plant.

Refer to section 2.2 – Dynamic simulation and optimisation.

2.13.2 Techno-economic details about electrolyser stack and ammonia synthesis catalyst

It must be noted that the electrolysers comprise of stack, Balance of plant such as gas separators, radiator coolers, and purification system. The purification is required to remove impurities such as Oxygen and moisture that enter the Hydrogen stream during the electrolysis process. The purity of H_2 at electrolyser outlet is typically 99.9% consisting of impurities like moisture saturated at 30 bar g, and O_2 of up to 1000 ppm. At outlet of purification system, the moisture content and Oxygen level will be $\leq$ 5 ppm. The purification system consists of adsorbents and catalysts that will require periodic replacement at an average interval of 5 years. The replacement quantities are approx. 15 Tons for spent catalyst (in the De-oxo unit) and 36 Tons of spent adsorbent in the H_2 dryer unit.

2.13.2.1 Ammonia synthesis catalyst

From the table below, conventional promoted Iron catalyst seems to be cost effective with catalyst life of ~ 10 yrs. But for the cost and stability issue, Ruthenium based catalyst is desirable with low impurity levels prevalent in the green Ammonia plant. KBR is already using this in one of their technologies. The type of catalyst must be discussed with the Licensors during the project implementation phase.

Table 18: Comparsion of Ammonia Synthesis Processes

Comparison of SMR-Based Ammonia Synthesis Processes With Commercial Iron-Based and Ruthenium-Based Catalysts.				
	IRON			RUTHENIUM
	Fe_3O_4	Fe_3O_4 with Co	$Fe_{1-x}O$	Ru–Ba–K/AC
Year	1913	1979	1986	1992
Temperature (°C)	360–520	350–500	300–500	325–450
Pressure (bar)	120–450	100–300	100–250	70–100
Energy consumption (GJ/t_{NH3})	28	28	27–28	26–27
H_2:N_2 ratio	2–3	2–3	2–3	1.5–2
Catalyst lifetime (y)	>14	–	6–10	≤10
Relative activity	1.0	1.2	1.5	2–10
Thermal stability	High	Medium/Low	Medium	Low
Relative catalyst cost	1.0	1.5	1.1	150–230

2.13.2.2 Catalyst manufacturers

- *Clariant* (Amomax 10, Amomax 10 plus, Amomax Casale)
- *Haldor Topsoe* (KM1/KM1R/KM 111/KMR 111)
- *Johnson Matthey* (Katalco 35 and 74)
- *KBR* (Ruthenium Catalyst for low pressure in KAAP™ process)

2.13.2.3 Catalyst life & replacement quantity/cost

Approx. 400Tons of catalyst must be replaced once in 10 years. The replacement cost of Catalyst is likely to be ~INR 1650/kg (without import duty and IGST).

2.13.3 Ammonia plant material and energy balance in flow chart

Refer to Annexure 2, 3

2.13.4 Nitrogen ASU material and Energy balance

Refer to Annexure 1

2.13.5 Process flow scheme detailing all processes, equipment, interconnections

Refer to Annexure -4

2.13.6 Risk and safety studies

Refer to Chapter 3 – Safety and Risk Mitigation

2.13.7 Utilities

All plant equipment including their capacities required for utility supply are identified in the table below.

Table 19: Plant utlities

Sr.no	*Utility*	*Unit*	*Qty*	*Usage Pattern*
1	Compressed air (Service & Instrument air) @ 7 bar	Nm^3/h	1500	Continuous
2	Demin water (including Electrolysers consumption)	m^3/h	130	Continuous
3	Sweet Cooling water circulation rate	m^3/h	5255	Continuous
4	DM water (makeup for Sweet Cooling Water Circuit)	m^3/h	negligible	Continuous
5	Service and Potable water	m^3/h	5 to 10	Intermittent
6	Utility Nitrogen @ 7bar	Nm^3/h	~1000	Intermittent
7	Process steam LP @ 3.5 bar	TPH	10	Continuous
8	Process steam MP @ 35 bar	TPH	2.5	Continuous
9	Firefighting water	m^3/h	190	Intermittent
10	Wastewater Generation	m^3/h	~10	Continuous
11	Assist Gas (LPG/NG) for Ammonia plant (10 kg/h) & storage (130 kg/h) flares. To be confirmed by vendor A PGHRU unit is not required if the flare flame is self-sustaining with purge gas and the Ammonia storage flare can be sustained by purge gas itself, instead of LPG/NG. This will be confirmed by the vendor during detailed engineering.	Kg/h	140	Continuous

Feasibility of arranging necessary utilities other than power and water at the project site for the life of the project

All the required utilities will be produced at the site for the life of the project. The main utilities other than power and water, are Instrument air, utility Nitrogen, steam, etc.

2.13.8 Offsite systems

2.13.8.1 Cooling system

Since the main source of water supply to the plant is assumed to be from borewells, it will be essential to reduce the overall consumption. Cooling system is necessary for –

1. Condensing the steam after expansion in the steam turbine
2. Colling of STG auxiliary systems such as lube oil, generator, vacuum pumps, and hydraulic oil.
3. Electrolyser stack and other BoP systems
4. process heat exchangers in the Ammonia plant
5. Heat exchangers in the ASU (Air compressor, N2 Compressor)
6. Cooling requirements in the BoP (such as utility air compressor, H2 storage compressor)

Refer to Annexure 6 for details.

To minimise the water consumption Air Cooled Condenser (ACC) is adopted for condensing the expanded steam discharged from the turbine. The ACC will also be designed to function during the turbine bypass scenario.

For all other cooling systems, closed loop radiator cooling is assumed. The circulating water in the coolers will be demineralised to avoid corrosion.

2.13.8.2 Hydrogen storage facilities on-site and at storage terminal

On-site storage of Hydrogen at site is limited to meet 30 minutes requirement of the plant (~1.7 tons, net). This is for operational flexibility, and to minimise transient fluctuations. Hydrogen storage is not envisaged at the transport terminal.

2.13.8.3 Ammonia storage tanks, refrigeration system, flare and supporting infrastructure at on-site and at storage terminal

Ammonia at (-)33 °C from the LP separator is transferred by ammonia transfer pumps into 2 x 5000 MT capacity atmospheric pressure buffer tanks having double-walled construction.

Boil-off from the buffer storage tanks is recovered and treated in a Boil-off Gas system where it is compressed and refrigerated, and subsequently transferred to the storage tank.

During normal operation of the plant, the unreacted gases/tail gases released in the Ammonia synthesis are sent to the flare. During an emergency condition where the Boil off Gas system is either unavailable (due to unscheduled outage) or overheating of the stored product due to fire, the Ammonia vapours from the storage tanks will be directed to the flare stack.

A flare having a stack height of 70m, with a safety clearance of 90m radius, is considered for flare which will be designed in accordance with API 521- Pressure-Relieving and Depressurizing Systems.

Storage Terminal:

Ammonia from the cross-country pipeline will be received at high pressures and temperature in the storage terminal. It is therefore transferred to surge vessels/bullets (the necessity to be determined during detailed engineering) and subsequently condensed and refrigerated to cryogenic conditions before transfer into 2x10000 Ton capacity storage tanks of Double-Wall Double-Integrity type construction. Boil-off from the storage tanks is sent to ammonia knockout drum through a blower followed by flashing in the flash drum, uncondensed ammonia vapours are then compressed and condensed.

Ammonia from the storage will be transferred to the ship/vessel using Ammonia loading pumps. Such pumps could be either of canned type (suitable for mounting outside the tank) or of the submersible type where it will be fully submerged inside the storage tank containing liquid Ammonia. The capacity of the transfer pump will be determined once details such as the ship capacity and turnaround time in the port are available.

Provision for a third storage tank also of 10000 Tons storage capacity is available in the layout. The refrigeration area includes compressor house, flash tanks. Area for Electrical switchyard, control room, fire water storage and raw water storage, fire pump house, parking area is considered. Considering the criticality of the terminal, dual source of power supply (from the Discom) to the terminal is envisaged. This will ensure that power supply to the Boil off gas recovery system is always available. An emergency DG set of ~700 kW capacity running on biofuel is envisaged for the storage terminal as additional back-up power for the boil off gas recovery system.

In the event of a complete failure of the boil off gas recovery system, it is likely that ammonia vapours will be generated in significant quantities. To avoid release of toxic Ammonia into the atmosphere, the vapours will be flared in a flare stack of 60 m height. A safety radius of 30 m around the flare stack is considered. Flare sizing will be carried out in accordance with API 521- Pressure-Relieving and Depressurizing Systems.

2.13.8.4 Oxygen handling system and potential end-use cases

Oxygen will be produced at the anode of electrolysers and from the ASU during normal operation. The quantity of Oxygen released during normal operation is as follows-

1. From Electrolysers: 81 TPH of O2. The main contaminants in the oxygen will be H2 and moisture, both in trace quantities.
2. From ASU: 16 TPH of O2 having a purity of 95%. The main contaminants being Argon and Nitrogen.

Recovery of oxygen is justified if there is a large buyer located in the vicinity of the plant. From the details gathered during the site visit, it appears that there is no large consumer (such as steel manufacturing plant) nearby.

Another potential use of Oxygen could be in the aeration tanks of large municipality sewage treatment plants. However, existing sewage treatments plants are designed for using air (not oxygen directly). Therefore, the aeration system in the plants must be suitably modified before using oxygen directly.

Use of Oxygen for medical purposes is not envisaged due to the stringent purity requirements of medical grade Oxygen.

In view of the above, the recovery and purification of Oxygen is not considered for the Feasibility. The Oxygen produced in the Electrolysers and ASU is proposed to be vented safely.

2.13.9 Effluent list and Effluent Treatment Plant

2.13.10 Desalination Plant:

Table 20: Liquid waste generated in saline water treatment plant

Liquid waste generated in Saline water Treatment Plant				
Parameters	*Reject flow from RO*	*Dirty backwash from MGF filters*	*Dirty Backwash from ACF Filters*	*Dirty Backwash from UF system*
Flow- m^3/hr	274			37
Flow- m^3/day	6576	444	216	880
TDS-mg/lit	95454	60000	60000	60000
TDS -kg/day	627699	26661	12932	52783
TSS -mg/lit	0.5	185	155	54
TSS-Kg/day	3	82	33	48
Flow- m^3/day	*8116*			

The above total quantity of liquid wastes will be discharged to the adjacent salt pan area after obtaining the requisite approvals.

Table 21: Sludge Generation from saline water Treatment plant

Sludge Generation from saline water Treatment plant					
Parameters	*Sludge flow from Lamella clarifier*	*Thickened sludge from Gravity thickener*	*Supernatant from Gravity Thickener*	*Dewatered sludge from Centrifuge*	*Supernatant from Centrifuge*
Flow- m^3/hr	14	2	13	1	4
Flow- m^3/day	347	46	301	6	39
TSS -mg/lit	4515	30900	520	214000	1791
TSS-Kg/day	1567	1410	157	1340	71
Total, Kg/day	*4545*				

A contractor must be identified to periodically collect the above identified solid waste from the plant and dispose them offsite.

2.13.10.1 Intermittent waste generated

Table 22: Intermittent waste generated from water treatment plant

	Flow rate(m^3/h)	*Remarks*
RO CIP waste	30	Once in four to five months
UF CI waste	15	Once in four to five months
MB regeneration waste	15	Once in a week

The intermittent wastes generated as shown above will collected and neutralized in a neutralisation pit located in the desalination plant. The treated wastes will then be disposed offsite to comply with the state pollution control board requirements.

i) Electrolysers:

There is no liquid waste generated during the normal operation of the electrolysers. Intermittent liquid wastes (only demineralised water in case of PEM or dilute caustic lye in case of Alkaline type) in small quantities will be generated.

ii) Boiler Blow-down:

The estimated boiler blowdown effluent quantity is 525 kg/h. Of this, about 100 kg/h is the actual blowdown while the remaining quantity is the water used for quenching the blowdown to approx. 40°C before discharging to the neutralization system.

To reduce the quantity of liquid effluent due to blowdown, it is possible to cool the blowdown using the closed loop cooling system. This will limit the blowdown quantity to 100 kg/hr only. The best option viz., direct quenching or cooling in the closed loop system) will be identified during detailed engineering.

Table 23: Contaminants and Concentrations Range

Sl. no.	*Contaminants*	*Concentration range (mg/l)*
1	Phosphorus	10
2	Dissolved solids	100
3	Suspended solids	10
4	Free Ammonia	2
5	Ammoniacal nitrogen	2
6	Oil	30

2.13.11 Ammonia/ ASU Plant

The gaseous emissions, both continuous and intermittent, generated in the Ammonia plant and their disposal method is shown the table below –

Table 24: Typical gaseous effluents for ASU and Ammonia plant

Typical gaseous effluents for ASU and Ammonia plant.					
Sl. no.	*Gaseous effluents*	*Composition*	*Qty (kg/h)*	*Disposal point*	*Remarks*
1	ASU waste gas vent	N2= 1 %, O2= 94.8 %, Ar= 4.2 %	15500	Vent stack	Continuous
2	Tail Gas from PGHRU	H2= 5.4 %, N2= 84.13 %, NH_3= 9.9 %, Ar= 0.57 %	425 to 1070	Flare stack	Continuous
3	Emergency vent-syngas compressor	H2= 74.84 %, N2= 25.13 %, Ar= 0.03 %	57000	Flare stack	Intermittent
4	Emergency vent-synloop	H2= 56.71 %, N2= 27.98 %, NH_3= 15.05 Ar= 0.26 %	57000	Flare stack	Intermittent

The liquid emissions, both continuous and intermittent, generated in the Ammonia plant and their disposal method is shown the table below –

Table 25: Typical liquid effluents from Ammonia plant

Typical liquid effluents from Ammonia plant					
Sl no.	*Liquid effluents*	*Composition*	*Qty*	*Disposal point*	*Remarks*
1	Suspended solids	100 – 15000 mg/l	-	Neutralization pit	
2	Dissolved solids	1000 – 3000 mg/l	-	Neutralization pit	
3	Ammoniacal nitrogen	200 – 1500 mg/l	-	Neutralization pit	
4	Oily water	Oil= 1% avg, 10 % max, NH_3 = 10000 PPM max	5 m^3/h	Oil separator, then to neutralization pot	Assumed to be continuous
5	Boiler blowdown	Hydrazine, Phosphates in ppm level	100 kg/h	Neutralization pit	Continuous
6	Sweet Water-Cooling system blow down				
7	Domestic sewage	BOD, TSS	25 m^3/day	STP	Treated in STP
8	Leakages and floor washings	Ammonia traces	100 m^3/day	Neutralization pit	
9	Spent lubricant		~ 20 m^3/year	Disposed through external agency	Qty and interval depends on Lubricant quality, life, and maintenance
10	Process Condensate (Separator, KO pot drains etc)	Traces of Ammonia	< 5 m^3/h	Neutralization pit	

The total quantity of continuously generated effluent is approx. 10 m3/h. This will be discharged to a neutralization pit located adjacent to the Ammonia plant. After suitable treatment, the composition of the liquid wastes must comply with the requirements mentioned in Table 1- Tolerance Limits for Industrial Effluents of IS 2490-Part 1. The liquid effluents will be discharged from a common point (common point for both demineralisation plant and Ammonia plant neutralised effluents). This will help in monitoring and recording the total quantity of effluents discharged from the plant along with the discharged effluent parameters. Such records must be furnished periodically to the state pollution control board.

The solid waste generated in the plant (other than the desalination plant) are intermittent and as shown in the table below. Solid waste is generated intermittently and will be disposed offsite by an external agency.

Table 26: Typical solid waste from plant

Typical solid wastes from plant				
Sl no.	Solid waste	Qty	Disposal point	Remarks
1	Spent catalyst replacement -Ammonia synthesis - 10 yrs life	400 Tons	Offsite	Disposed through agency
2	Spent MS/Alumina (ASU air dryer) -10 yrs	85 Tons		
3	Spent Alumina- Inst Air dryer – 2 yrs	1800 kg		
4	Spent resin-DM plant - 5 yrs life	TBA		
5	Spent catalyst in De-Oxo plant (Hydrogen plant) – 5 yrs	15 Tons		
6	Spent adsorbent (H2 dryer unit) – 5 yrs	36 Tons	Offsite	

2.14 Material and Energy balance

The main material and energy flows are named, quantified and their characteristic operating conditions furnished in this section.

2.14.1 Overall material and energy balance

Overview of essential energy and material flows: This overview provides the essential energy and material flows. It does not include the utilities and the water systems.

Figure 11: Overall material and energy balance diagram

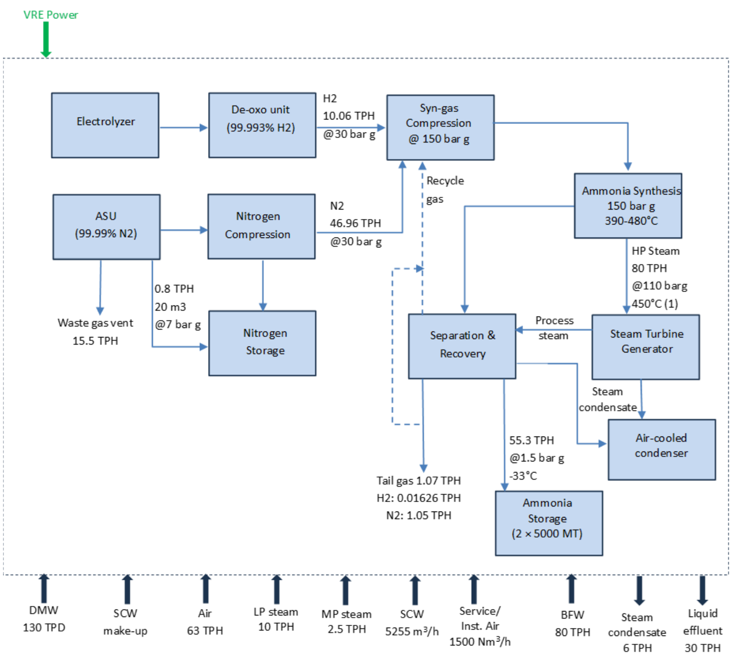
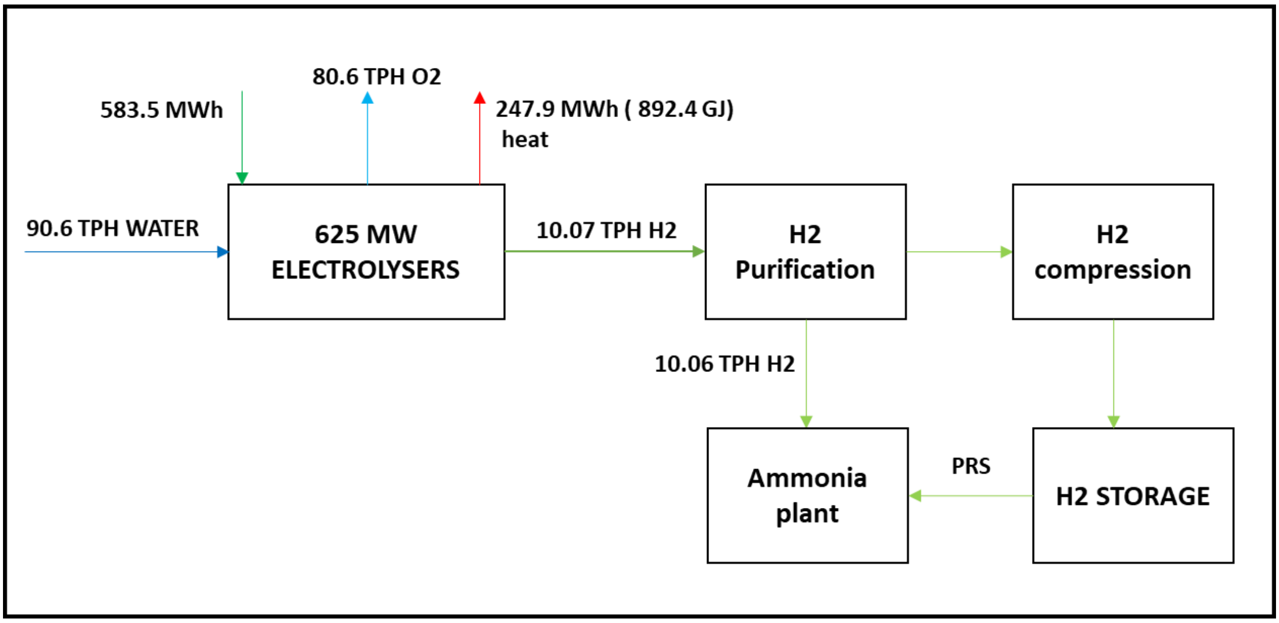


Table 27: Inventory of operating resources and utilities

Parameters	Quantity	Supply pressure, bar g	Supply temperature, °C
Ammonia converter catalyst, m^3	180	-	-
Borewell water, m^3/h	425	Atm.	Ambient
Demineralised water, m^3/h	130	4 (min) / 5.5 (nor) / 6 (max)	Ambient
Service & potable water, m^3/h	80	Atm.	
Sweet Cooling water, m^3/h	5225	3.5	32
Makeup for Sweet Cooling Water Circuit, m^3/h	negligible	3.5	32
Compressed air (Service & Instrumentation air), Nm^3/h	1500	7	Ambient
Utility nitrogen, Nm^3/h	1000	7	Ambient
LP steam, TPH	10	3.5	148
MP steam, TPH	2.5	35	244
Flare assist gas (LPG/NG), kg/h	140	-	Ambient

2.14.2 Hydrogen balance

Figure 12: Process Flow Scheme of Hydrogen generation and storage



i. Configuration of hydrogen generation, compression, and storage units:

Based on the assessment in the study, it is observed that both PEM and pressurised Alkaline type electrolysers have the required characteristics to meet the requirement for hydrogen generation. This option will also avoid the use of a booster compressor. To optimise the number of electrolysers, it is proposed to install electrolysers of ~625 MW capacity assuming all are of PEM type. The total number of electrolysers to be installed will depend on the unit capacity offered by the OEM. The largest unit capacity currently available is 5MW. The PEM type electrolyser can supply Hydrogen at a pressure of 30 bar g to the suction of the syngas compressors.

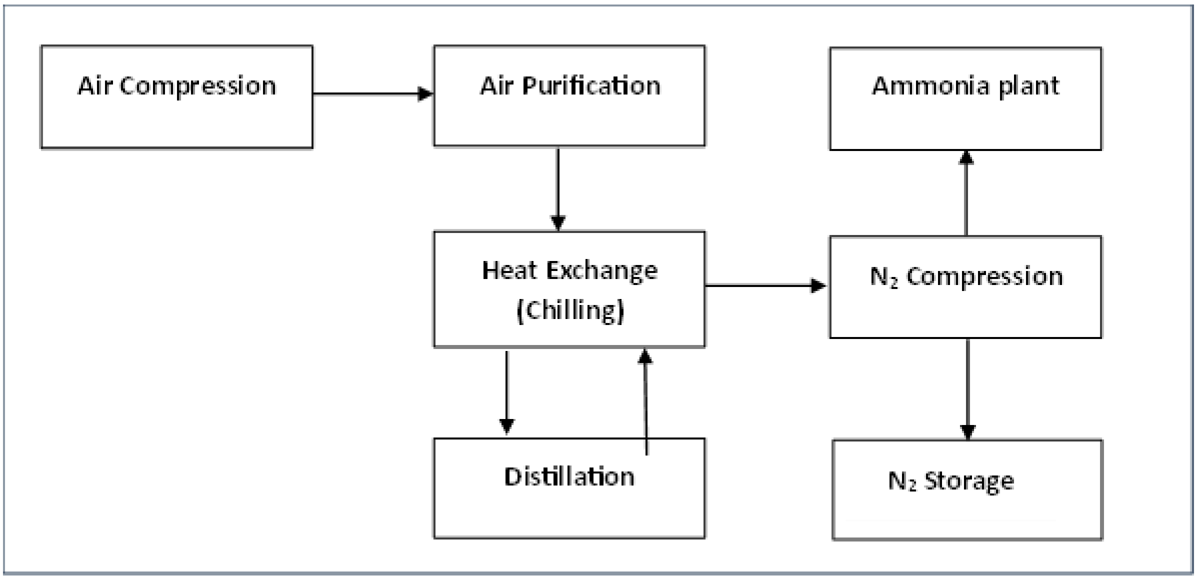
The purity of the hydrogen produced during the electrolysis process is low as it contains moisture, and oxygen as impurities. Before the gas is delivered to the ammonia plant, the hydrogen gas is purified. The selection of the purification equipment will be governed by the purity requirements of the Ammonia production process. The maximum permissible impurities in the feed Hydrogen are specified by the Licensor and is typically as follows –

- Oxygen : 5 PPM (max)
- Moisture : 5 PPM (max)

The dynamic simulation study has indicated that Hydrogen storage is required in a high Ammonia plant capex scenario. Further, it has been assumed that the Ammonia plant can operate with a VRE power supply and is flexible in terms of turn down/ ramp rates. However, this will require discussions with the selected technology Licensor during the plant implementation phase. In the Feasibility study, a minimum Hydrogen storage requirement is considered for operational safety reasons (to minimise transient disturbance in Hydrogen supply from Electrolyser). A net storage of 1.7 Tons of gaseous storage at 40 bar g pressure is envisaged.

2.14.3 Nitrogen balance

Figure 13: Process Flow Scheme of nitrogen generation, compression, and storage units



i. Configuration of nitrogen generation, compression, and storage units:

A Nitrogen plant of capacity 48 TPH @99.99% purity is envisaged. Cryogenic technology-based Air Separation Unit is selected for producing Nitrogen of the required purity. Since the byproduct Oxygen having a purity of 94% has no commercial value, it is vented. The Air separation unit configuration is based on Single High pressure cryogenic column since nitrogen is the desired product. The feasibility of Single/two column for achieving the purity will be checked with the vendor. The turndown capacity of ASU is low with an operating range of 60 to 100%. Argon and Oxygen are the main impurities. Oxygen less than 5 ppm is possible with additional column. However, the combined Nitrogen and Hydrogen in the synthesis gas contains less than 5ppm Oxygen (4 ppm), which is adequate. ASU configuration mainly includes the following components.

Air compression: The feed stream of ambient air is first filtered and then compressed to a medium pressure level of about 6 bar by the main air compressor. Subsequently, the air stream is cooled to approximately ambient temperature.

Air purification: After pre-cooling, the air stream is purified in an adsorber. Water, carbon dioxide and other trace components that would freeze out in the cryogenic part of the ASU are removed here.

Heat exchange: The air stream after purification is cooled in a heat exchanger and liquified partially and then expanded in an expansion turbine. The cooling of this high-pressure air stream resulting from the expansion corresponds to the cooling duty required for the cryogenic process of air separation.

Distillation: The cooled air stream is fed into the cryogenic rectification part of the ASU where the two main components of air - nitrogen and oxygen, are separated by means of cryogenic distillation. The separation process is based on the slightly different boiling temperatures of nitrogen and oxygen.

Nitrogen compression**:** The gaseous nitrogen generated at 5.6 kg/cm^2 pressure must be compressed to 30 kg/cm^2 g before mixing with hydrogen from Electrolyser for compression in Syngas compressor for Ammonia synthesis.

Nitrogen storage: A portion of Liquid Nitrogen (~800 kgs/hr) drawn from Cryogenic ASU unit is stored in Liquid Nitrogen storage Tank (20 m^3 with effective gas volume of ~ 140000 Nm^3) at 7 bar (pumped from ASU at higher pressure) and it is gasified using ambient air finned coil for feeding to Utility Nitrogen header.

Refer to Annexure 1- for details.

ii. Usage of nitrogen for ammonia production:

The ASU supplies nitrogen of the required purity required for the Ammonia synthesis loop. The ASU unit will be designed to operate in tandem with the downstream ammonia unit. The requirement of nitrogen for the ammonia production plant is as follows (Refer to Annexure 2- for details):
Nitrogen as raw material to produce ammonia = 46955 kg/h
Utility nitrogen required for purging activities in the ammonia circuit is shown below –

Continuous

- Seal gas for Syn gas compressor: ~60 Nm^3/hr
- Ammonia Storage tank inerting through Vacuum breather valve: ~60 to 150 Nm^3/hr
- Flare seal purge to prevent ingress of air: ~15 Nm^3/hr

Intermittent

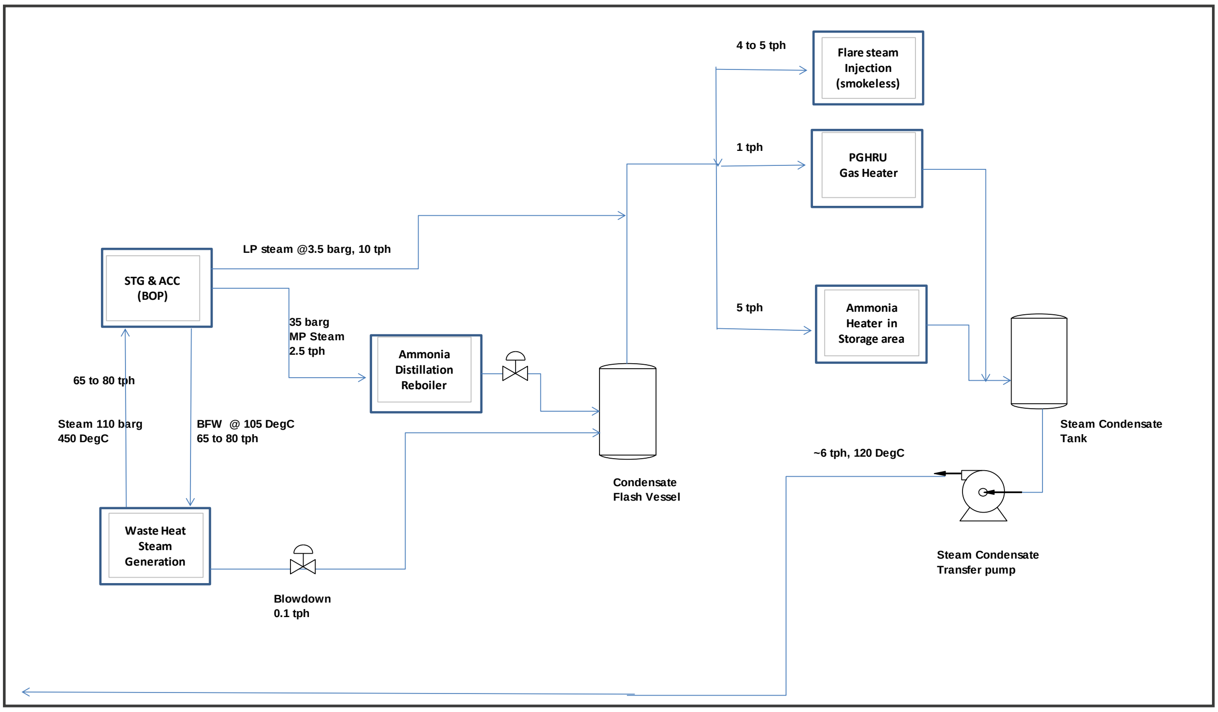
- Start-up/shutdown purge requirement
- Start-up heating of syn loop and catalyst reduction along with Hydrogen
- Ammonia storage tank commissioning initial purge to displace air.

iii. Usage of nitrogen in the hydrogen circuit for purging activities:

Tentative requirement of nitrogen for purging per electrolyser is 200 Nm^3 which is required intermittently.

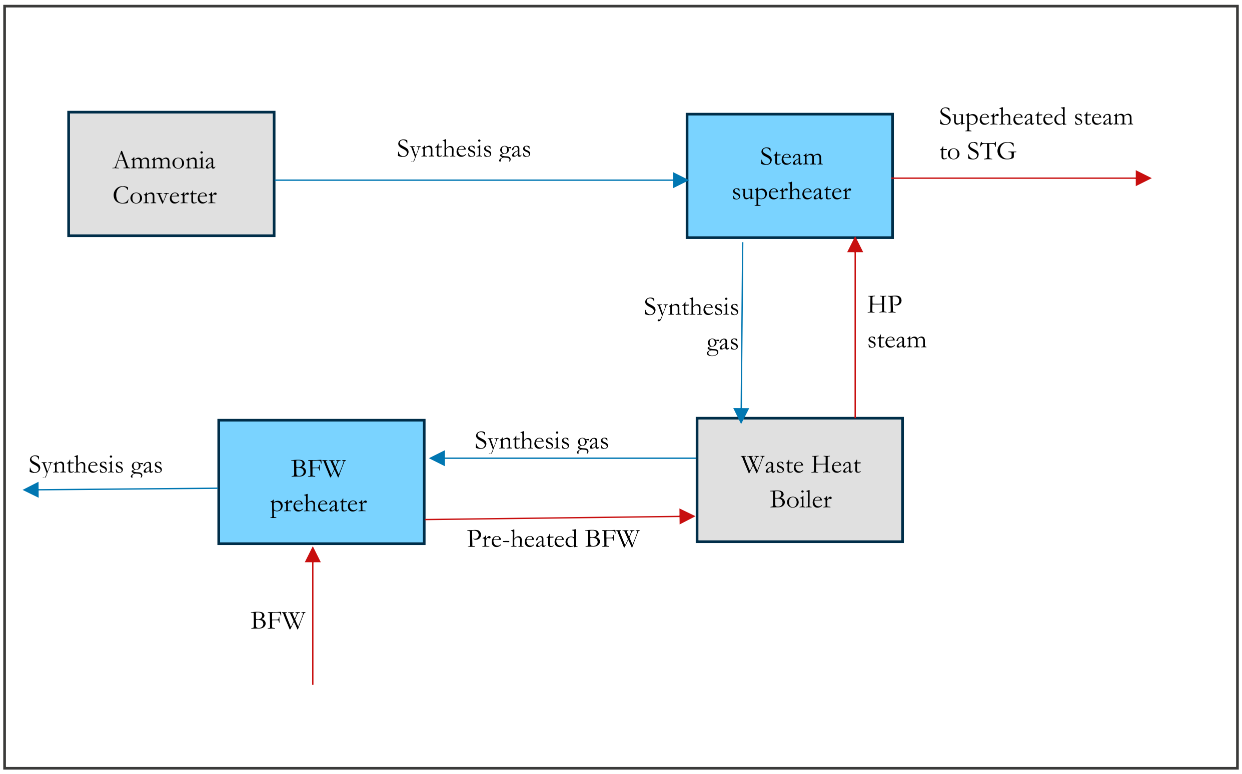
2.14.4 Water and steam balance

Figure 14: Process flow scheme for feedwater, steam, and condensate balance



i. Configuration of steam generation and heat exchangers:

Figure 15: Process flow scheme of steam generation



The Haber-Bosch process being exothermic releases heat that is recovered through a waste heat recovery boiler to produce high pressure superheated steam. The steam generation system consists of BFW preheater, Waste heat boiler and a superheater. Boiler feed water, coming from the BOP system is pre-heated in BFW preheater by hot synthesis gas and then enters Waste heat boiler, where the HP steam @110 bar g is generated. Subsequently, the produced HP steam is superheated in Steam superheater to a temperature of 450°C. The steam generation capacity is 80 TPH. Steam generation for this flow configuration is expected in the range of 65 to 80 tph, depending on the recycle condition, catalyst activity and ageing. The steam is expanded in an extraction-condensing type steam turbine to generate ~15MW power.

Refer to Annexure-3 for details.

The steam generation quantity in the range of 65 to 80 TPH, depends on the recycle condition, catalyst activity and ageing. Also steam generation will vary with licensors loop configuration and heat recovery options. Steam production also varies with plant load ramping (within permissible limit). The variation may not be proportional and depends on the stability of converter conditions and space velocity, which will vary. The STG however has an operating range of 25-100% (with throttle control) and therefore the variation in the steam generation quantity will not have any impact.

2.14.5 Energy balance

Green Ammonia Plant:

As per the input from the OEMs, at low turndown ratio of the ammonia plant, the energy is lost due to the limitation of the compressors which need to be operate on anti-surge demanding high energy consumption. At 10% turndown, the power required for the ammonia plant is about 90% of the power at full load. However, the efficiency of the electrolysers increases at part loads. Efficiency of the electrolysis at part load increases between 100-30%. At lower loads, viz., 30-10%, the efficiency once again reduces. This is an aspect of electro-chemistry, where the efficiency of the electrochemical reaction (the voltage efficiency) increases at part loads. The actual efficiency curves will be provided by the vendor during detailed engineering. Therefore, the overall efficiency of the system comprising of electrolysers, ASU and the Ammonia loop does not deteriorate while operating at part loads. Refer Annexure 7 for Plant load list.

3 Safety and Risk Mitigation

3.1 Safety provisions

Applicable codes and standards

1.	NFPA 2: 2020	Hydrogen Technologies Code.
2.	IS 4544: 2000	Ammonia – Code of Safety.
3.	NFPA 704	Standard System for the Identification of the Hazards of Materials for Emergency Response.

3.1.1 Hazard identification

In a green Ammonia plant the hazard categories are as follows -

- Major leakages of Hydrogen from Electrolysers, interconnecting pipework, compressors, and hydrogen storage vessels
- Major leakages of Ammonia from process vessels, pipelines, or storage tank
- Leakages of Explosive/flammable gas from the process vessel (mainly due to H_2 and NH_3)

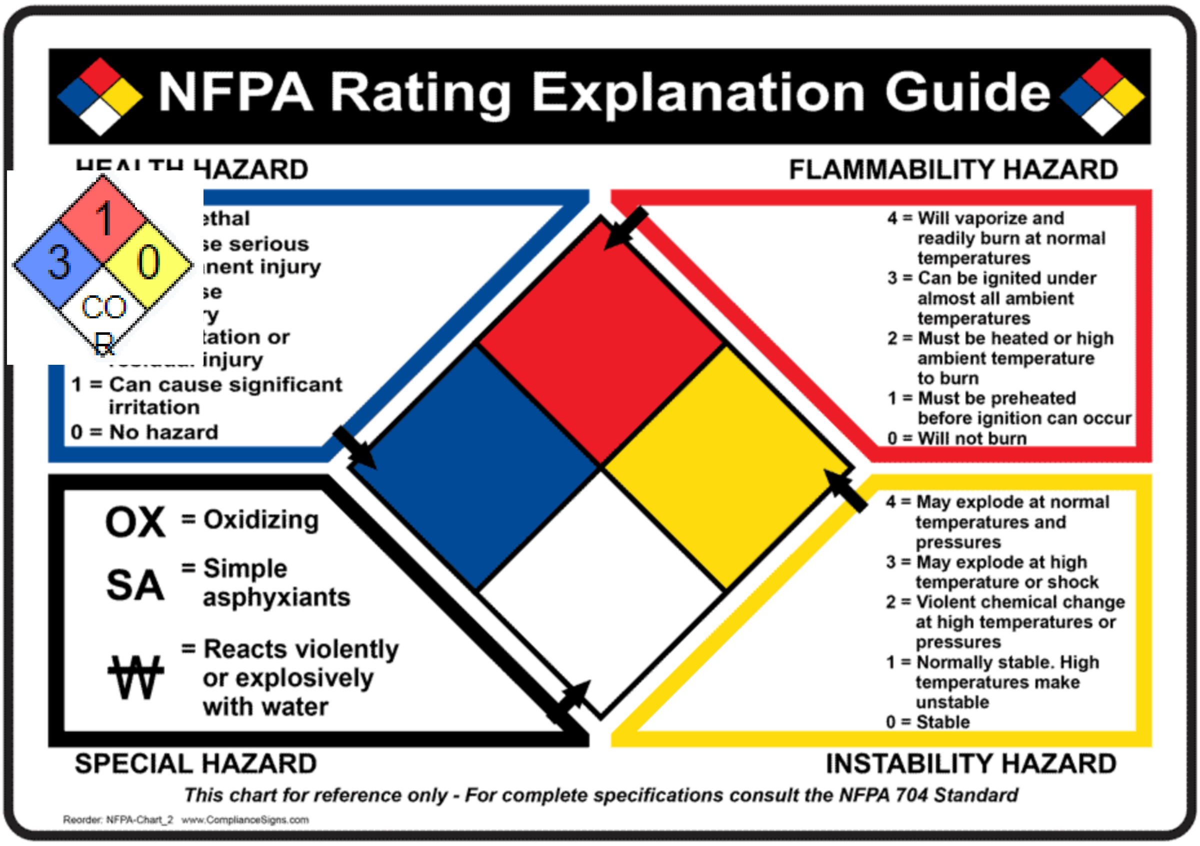
The following table identifies the hazard nature as per FEI (Fire and Explosion Index) and TI (Toxicity Index) as defined in "Major Hazard Control" an ILO publication.

Table 28: hazard nature as per FEI (Fire and Explosion Index) and TI (Toxicity Index)

Sl.no	*Process area*	*FEI*	*TI*
1	Air Separation Unit	Oxygen Fire/Explosion hazard	NIL
2	Hydrogen compression and storage	Hydrogen leak/explosion	NIL
3	Nitrogen Storage& Compression	NIL	NIL
4	Synthesis gas Compression	Hydrogen Leak Fire	NIL
5	Ammonia Synthesis	Hydrogen and Ammonia leak Fire and Explosion	Toxic release of Ammonia in syngas
6	Ammonia separation	Fire risk due to separated Hydrogen in recycle gas	Toxic release of Ammonia
7	Ammonia Refrigeration	NIL	Toxic release of Ammonia
8	Ammonia Storage	NIL	Toxic release of Ammonia
9	Ammonia transportation	NIL	Toxic release of Ammonia

The hazard classification as per NFPA for gaseous Hydrogen and Ammonia are shown below.

3.1.2 Hydrogen



3.1.3 Ammonia

NFPA 704 safety square for anhydrous ammonia is shown below.

an cause severe or permanent injuries,
: 1 – must is preheated before ignition can occur.
– stable compound.

- Special hazard: COR – corrosive base.

Root causes and consequences of the risks in an Ammonia plant are shown in the table below.

Table 29: Root cause and consequence of risk in ammonia plant

1.	Fire/Explosion Risks	• Glands/seal leaks in valves, pumps, compressors handling hydrogen, nitrogen gas, synthesis gas etc. • Hose/pipe failure, leakage from flanged joints carrying combustible gases, vapours, liquids

2.	High/Low Temperature Exposure Risks	• Burns due to contact with hot surfaces of pipelines, equipment etc. or leaking steam lines, process fluids at high temperature. • Frost bite due to contact with anhydrous liquid ammonia at (-)33 °C. • Burns due to contact with pyrophoric catalyst
3.	Toxic chemicals Exposure Risks	• Asphyxia due to inhalation of simple asphyxiants like N_2, H_2 and Chemical asphyxiants like NH_3. • Acute toxicity due to inhalation of catalyst dusts containing heavy metals like Ni, Cr, Co, Mo, Fe, Zn, Alumina etc and silica gel molecular sieves, insulation fibres/dusts.
4.	Corrosive/ Radioactive Chemicals Exposure Risks	• Severe burns, damage to eyes, skin, and body tissues due to contact with anhydrous ammonia. • Damages to eyes, skin, and body tissues due to contact with acid (HCl and NaOH) in the water treatment plant

The risk mitigation measures are identified based on the understanding of the risks and consequences associated with the two major hazards viz., gaseous Hydrogen (highly flammable) and Ammonia (highly toxic).

As Hydrogen is colourless, odourless, tasteless, and non-toxic, it is necessary to utilise a combination of flame detectors and gas detection equipment when using or handling hydrogen gas. A mapping will be carried out once the layout is in an advanced stage to determine the locations for mounting the flame detectors and gas detectors. Commercially available Hydrogen flame detectors can detect a Hydrogen flame at ~30m. The detector must be immune to sources of interference to prevent false alarms due to. sources such as welding work or hot CO_2 emissions. Further, the sensitive detection must ensure that the detector does not falsely set off an alarm for fires emanating from other areas.

The flame detectors must be complemented by a reliable gas detection system that will act as an early warning area monitor for detecting high-pressure gas leaks in an outdoor environment. Present day technology uses an ultrasonic acoustic sensor that will respond immediately since it registers the sound of leaking gas instead of measuring the concentration of accumulated gas clouds. As gas escapes, leaks must be immediately detected in the surrounding area, regardless of the wind direction. Loud process areas generate noise which is mostly in the audible spectrum. Gas leaks from pressurized vessels or pipe flanges & valves operating above 10 bar g generate both audible sound and inaudible ultrasound. A detector tuned to measure in the ultrasound spectrum can easily identify gas leaks with a leak rate of up to 100 g/sec in a 20 m radius circle. As the Hydrogen production and use is at a pressure greater than 10 bar g, the use of ultrasonic acoustic sensors is recommended for Hydrogen leak detection.

Ammonia leak detection from the cross-country pipeline will be detected using a Distributed Acoustic system (DAS) which is also based on the principle of detecting ultrasonic sound generated by a leak. This will be complemented by other systems that work on internal leak detection system. This is based on Real Time Transient Model employing volume balance principle for continuous monitoring. Pressure and temperature transmitters are provided at inlet and outlet of the pipe for leak detection. Number of temperature and pressure transmitters are provided based on actual site requirements for accurate leak detection. A combination of DAS and the internal leak detection system will ensure that the pipeline is monitored round the clock and any leak is detected without any delay.

The risk of fire and explosion risk from Ammonia is generally quite low. Ammonia can however form flammable mixtures in air within certain limits (16 to 25 percent by volume). The presence of oil, or a mixture of ammonia with other combustible materials, will increase the fire hazard. The explosive range of ammonia is broadened by admixture of oxygen replacing air, and by temperature and pressure higher than atmospheric pressure.

Outside storage tanks will be located at least 15 m away from buildings or adjacent to blank masonry building walls. The location should be away from any flammable liquid storage. Dyke of adequate size should be constructed around the storage tank to contain large scale spillage along with the water used to dilute the spill.

Fire protection system will be designed in accordance with local/international standards. It will consist of a network of hydrants to ensure coverage of all the assets. A high velocity spray system will be provided for the transformers in the substation. Sprinkler system will be provided for the warehouse /stores. The manned areas will be provided with smoke detectors and alarm system. Portable fire extinguishers will be provided to fight the fire in the manned areas. Flooding system using inert gas can be considered for the control room during the project implementation phase.

3.2 Template for risk and safety studies

3.2.1 HAZOP

3.2.1.1 Introduction

Hazard and Operability (HAZOP) analysis is a technique used to identify potential hazards and operability problems in a process plant. Ammonia is produced through Haber Bosch process which operates under high pressures and temperatures. The reactants and products are hazardous to handle since they are either flammable/explosive or toxic. Hence the Hazop study is essential to identify the process safety risks and provide for mitigation measures upfront, so that these can be incorporated into the project during design and implementation and for safe operation and maintenance.

3.2.1.2 Methodology

The Hazop study must be carried out during the implementation stage based on the engineering P&IDs The P&IDs are the starting point for Hazop. The analysis will be carried out section-by-section. Each section (or node) will be tested for the following conditions:

- ✓ Temperature too high
- ✓ Temperature too low
- ✓ Pressure too high
- ✓ Pressure too low
- ✓ Level too high
- ✓ Level too low
- ✓ Mass flow rate too high
- ✓ Mass flow rate too low
- ✓ Other conditions: leakage, impurity in reactants, toxicity, explosion hazard etc.

For each of the above conditions, the causes and consequences will be identified. Mitigation measures will be incorporated, and a risk class (arrived at after implementation of mitigation measures) will be shown. The risk class is determined from a combination of two factors:

-Severity (graded S0 to S4, with S4 being the least severe and S0 being the most severe)
-Frequency (graded F0 to F4 with F4 being the least frequent and F0 being the most frequent)

From the combination table of severity and frequency, the risk class is derived.

The risk classes (or ratings) are as follows:

E2	Desirable
E1	Acceptable
D	Undesirable
C	Unacceptable
B	Danger-STOP
A	Catastrophe

The mitigation measures (or risk reduction measures) will be selected as appropriate for the identified risks and all such risks are reduced and maintained as E2 (desirable) or E1 (acceptable).

The nodes are selected based on P&IDs where controls, section of piping, valves, and equipment are present.

3.2.2 HAZID

A hazard identification (HAZID) study is a procedure used to uncover and identify hazards in the workplace. Its purpose is to determine the adverse effects of exposure to a hazard while also providing suggestions for mitigating risks.

The HAZID study technique is one of a range of techniques. It is selected, when appropriate, during the lifecycle of an operating site from conception to abandonment. The primary role of HAZID study is to identify hazards and scenarios which may have the potential to result in an incident of a degree of seriousness. It is not the purpose of the study to assess risk. However, the study team members can be expected to use their own experienced judgement to present their findings organized according to a preliminary rough risk ranking. The intent of the study method is, by taking an organized and exhaustive approach within a formalized structure, to identify as far as possible all hazards of note. Possible causes of initiating events and their outcomes are recorded, and recommendations made.

The composition and numbers of members within a study team will vary with the type of study. The core of the team can be expected to be reinforced by representatives of the leading engineering and operating disciplines appropriate to the aspects and phases of the development being studied and to the activities which will take place on it.

3.2.2.1 Steps to conduct a HAZID study

- Groundwork:

This step involves collecting all relevant information regarding the project including blueprints, understanding the client's standards and expectations, and forming an effective study team. The team should include a study leader, a person to record the discussions, and an experienced HAZID study team.

- Terms of Reference (TOR) and Preparation:

The prepared TOR should be developed for each study and agreed upon with concerned stakeholders. The TOR should include among other things:

a) The objective, scope, guidewords, methodology, and breakdown of HAZID sessions
b) Reference documents
c) Schedule and deliverables
d) Details of personnel attending the workshop

- Workshop Sessions:

The sessions include a review of study TOR and recording of sessions, ground rules, review of facilities and operations. The duration of the workshop may vary depending on the scope of the study.

- Reporting:

The HAZID study report becomes a permanent record that can be referred by those not a part of the team. Client-approved worksheets and recording methods should be used to record the workshop sessions.

3.2.2.2 QRA

A Quantitative Risk Assessment (QRA) is a formal and systematic risk analysis approach to quantifying the risks associated with the operation of an engineering process. A QRA is an essential tool to support the understanding of exposure of risk to employees, the environment, company assets and its reputation. A QRA also helps to make cost effective decisions and manages the risks for the entire asset lifecycle.

Objectives of QRA:

- To identify the hazards associated with a facility.
- To determine the potential frequencies and consequences of the identified hazards
- To determine the system availability of the protection systems
- To quantify the risks associated with a facility (e.g., Risk Contours, Individual Risk Per Annum (IRPA), Potential Loss of Life (PLL) and F-N Plots).

The typical procedure to perform a QRA consists of the following steps:

- Identify relevant activities, units, and processes.
- Define Loss of Containment scenarios (LoCs)
- Assess the consequences (both effects and damage) for all LoCs.
- Assess the failure frequencies and probabilities of all LoCs.
- Calculate and present risk (e.g., IR contours, SR f-N curve, etc.)
- Evaluate and analyse risk.

3.3 Emergency provisions

The following emergency provisions will be made available within the plant –

1. Emergency power supply during an extended power outage
2. Flare system designed to take care of process upsets and emergency situations.
3. Fire station with trained staff to handle local fires and large-scale spillages.
4. First-aid provision at site
5. Quick evacuation of injured personnel to nearby hospital(s) for serious injuries

4 Operational Management

4.1 Turn down philosophy

a) Comparison of turning down the plant vs bigger storage of hydrogen and energy
Refer section 2.2 for details.

b) Effect of turn down on equipment life and OPEX.
The new generation Ammonia plants are being designed to have high turndown capability (10% to 100%). Therefore, operating such a plant at high turn-down will neither impact the equipment life nor Opex. The electrolysers are designed to operate at very low loads up to 10% (for PEM) and 30% (for Alkaline type) without any impact on equipment life. However, the impact on stack life due to the VRE profile will be studied by the OEM especially for the Alkaline type, before providing warranties for annual degradation (stack replacement life). The power consumption of the electrolyser stack will reduce at part loads and will therefore compensate for the efficiency loss of the Ammonia plant at part loads.

4.2 Hot and cold start-up philosophy

<u>Green Ammonia plant</u>

<u>Cold startup:</u>

- Ensure Cooling Water, Instrument air, power supply systems are ready and lined-up.
- Start Hydrogen and Nitrogen Supply system (Hydrogen compressor and ASU system)
- Purge Syn Gas compressor and Syn loop with Nitrogen till Oxygen level is 0.5% by vol.

- Displace the nitrogen in the syngas compressor with Hydrogen-Nitrogen mixture (3:1).
- Start the Syn Gas compressor in recycle mode and pressurize gradually as per licensor/vendor recommendation. Slightly open the discharge valve bypass and purge the Syn loop with Syn gas, till nitrogen is displaced.
- Compressor pressurization @14 bar g/hr till 150 bar is reached when leak checked, reduce the pressure to 84 bar g for starting catalyst reduction. Start the start-up heater.
- Recycle loop is brought in line with small make-up Syn gas feed and venting (through flare). Moisture should be limited to 3000 ppm to avoid poisoning. Reduction is complete when the converter inlet and outlet Hydrogen levels are same.
- Converter heating rate 25 to 30 °C/hr till 340°C and at 2 to 3° C/hr above 340 up to 410°C when hot spot is anticipated. Pressure is raised to 150 Barg in 3.5 bar/min increment.
- Ammonia formation gradually increases as the catalyst reduction is nearing completion. A typical time versus Ammonia load for pre-reduced (~30 hr) and unreduced catalyst (~7 days) is given in the curve to achieve full capacity.

The graph below compares catalysts with percentage full ammonia production rates versus time elapsed.

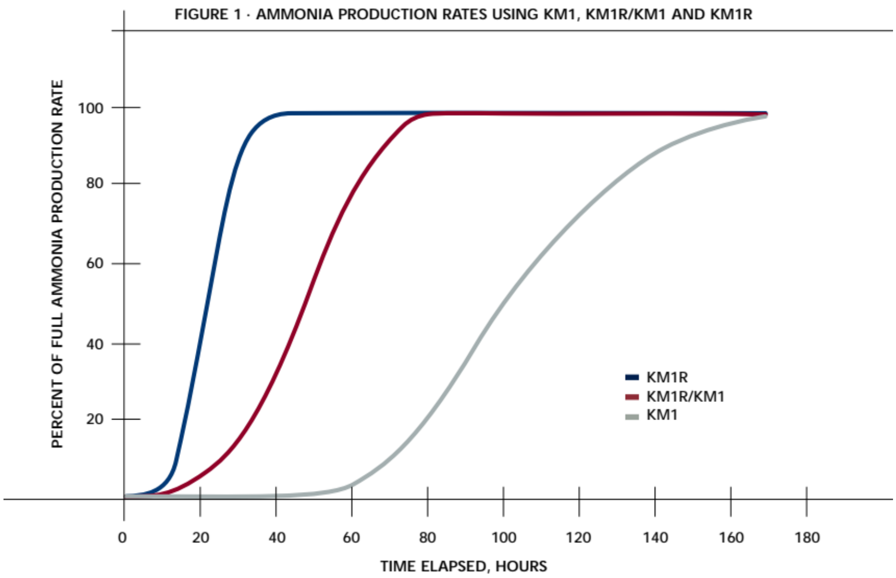
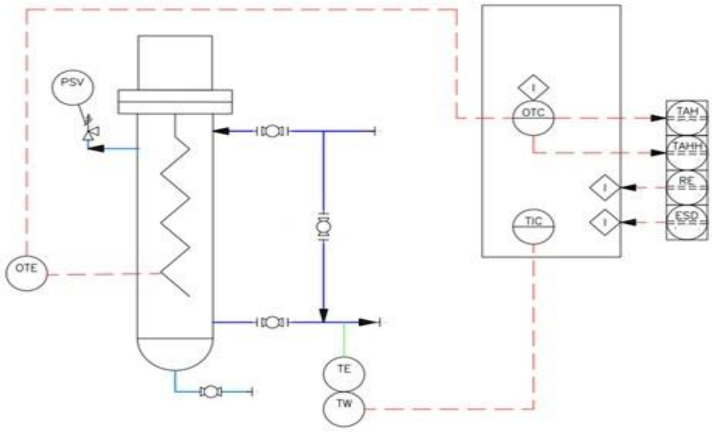


Figure 16: Typical Ammonia synthesis loop start-up heater arrangement



However, the detailed start-up procedure will be given by Licensor.

Hot startup:

- The first curve (KM1R) in the above graph is the typical startup time and rate for a pre-reduced catalyst.
- If the catalyst temperature is maintained above 390 °C , the Ammonia synthesis starts immediately. If the temperature drops down, reheating is required to reach 390 ° C and duration depends on Initial temperature.

Ammonia synthesis loop start-up heater arrangement:

When the ammonia plant is started up from cold, it is necessary to preheat the converter and its catalyst mass by circulating hot gas through it from an external heater. At each start-up or reheating, the heater will be in continuous operation for a period ranging between 5 (for a pre-reduced catalyst) and 250 hours (first commissioning with unreduced catalyst or loading of unreduced catalyst after annual turnaround and catalyst change). The cold startup is longer for unreduced catalyst and shorter for pre-reduced catalyst.

In the electrical start-up heater (4.2MW), power is regulated in six steps by means of contactors connecting the individual sections in star or delta configurations. The general arrangement of the electric heater, comprising three sections and three supply transformers. Each section is independent of the others, and this improves reliability. If one section fails, the plant can be started using the remaining two sections. However, this extends the start-up time slightly. Furthermore, one spare heater section can function as a common spare for all the three installed sections. The electric heater will be positioned either horizontally or be vertically attached to the adjacent converter structure. A general arrangement is shown below, which will vary according to the licensor. The startup heater is in loop with the converter located internally (CASALE) or externally (KBR, Haldor Topsoe) depending on the licensor.

Air Separation Unit (ASU)

- Ensure CW, Instrument air, power systems are ready and lined-up.
- Cooling water to be circulated to the compressor intercoolers.

- The air purification unit is prepared for use by isolating the adsorption bed to be initially used for operation during start-up. The unit's block valves are allowed to set up for purification in one bed and regeneration in another bed.
- The expansion valve on the high-pressure column as well as on the low-pressure column must be cracked open.
- After confirming all the instrumentation in the working order, the process air compressor is started up by activating electrical switch.
- After confirming that the compressor is functioning normally, the compressor's discharge is allowed to enter the air purification system while the entire discharge system increases up to operating pressure.
- The discharge pressure is kept at the operating level using the expansion valve on the HP column.
- After ensuring the steady operation of air compressor, purification system and HP column the turbo expander is put on stream and once proper functioning of the turbo expander is confirmed and that the temperature is slowly decreasing, most of the compressor's discharge will be sent to the expander by throttling on the HP column expansion valve.
- The above step is maintained until the liquid level in the sump of HP column reaches maximum design level. Once this is reached, the feed to the expander is reduced while opening the HP expansion valve.
- Samples are checked routinely to confirm the purity of the streams at this stage.
- Once the stream purity levels are established and liquid levels are controlled and maintained at a constant level, the transfer of product nitrogen to the storage tank is carried out.

Normal Shutdown:

Green Ammonia Plant

- Plant load is reduced gradually (10 to 20%/hr) till minimum turndown is reached and syngas compressor is stopped, Syn loop is gradually depressurized and converter is cooled (max 50 deg. C/hr) keeping the recycle compressor in operation, and when the converter temperature reaches around 50 deg. C, Nitrogen is introduced into the Syn loop to purge the system and converter is boxed up at a slight positive pressure. Air/Oxygen should not ingress into converter catalyst, which is in reduced state. It takes around 8 to 10 hr to achieve shutdown.
- If converter catalyst is to be unloaded, gradual oxidation of catalyst must be done, before catalyst discharge, since the reduced catalyst is pyrophoric.

Emergency shutdown:

Green Ammonia Plant

- If the plant trips due to Cooling water failure, Instrument air failure/ Syngas compressor trip, interruption in Nitrogen/Hydrogen supply, or any safety/fire hazard, the trip action is initiated, and the Converter is isolated in hot condition to help restarting quickly. If the converter temperature drops below 370°C due to longer waiting period, then start up heater may be required to reheat the catalyst to 370°C and above.
- The start-up time in such conditions depends upon the temperature level, and the required heating rate (25 to 30 °C/hr).

4.3 Basic open loop and closed control systems involved

Process control system

The process control system for the three major equipment/systems of the plant are described below -

Green Ammonia plant

The main process control systems are -

- Hydrogen and Nitrogen ratio control to achieve desired Ammonia conversion (based on the input Hydrogen and Nitrogen measurement and process gas analysis at the inlet of the Ammonia converter.
- Syn Gas compressor discharge pressure control by varying the driver load.
- Synthesis loop pressure control by means of make-up gas/recycle compressor, inert reduction by purge gas etc.
- Converter bed temperature monitoring and control by adjusting the load, quench /intercooler temperature control etc.

Some of the important conditions that will lead to the total or partial trip of the plant are as follows:

- Cooling water failure
- Instrument air failure
- Power failure
- Syn gas compressor trip
- Refrigeration compressor trip leading to syngas loop shutdown.
- Low level in waste heat boiler drum trips syngas loop
- High level in HP separator trips syngas loop

Air Separation Unit (ASU)

The main process control systems are –

- The process air compressor discharge flow control by adjusting air input to the compressor.
- The product supply pressure control by the valve at the product outlet to maintain the product purity by means of adjusting the backup supply of product i.e., from the nitrogen storage tank.
- Distillation column pressure control by adjusting product nitrogen valve in case of rapid consumption/decrease in nitrogen supply.

Some of the important conditions that will lead to the total or partial trip of the plant are as follows:

- Cooling water failure
- Instrument air failure
- Power failure
- Product air compressor trip
- High level in liquid nitrogen storage tank
- Main heat-exchanger failure

Electrolyser Unit

The main process control systems are –

- The electrolyser cell pressure control by adjusting water input to the cell.
- The hydrogen product purity control by means of venting of gas with impurities.

Some of the important conditions that will lead to the total or partial trip of the plant are as follows:

- Power failure
- Demineralised water supply failure
- Cooling water failure
- Instrument air supply failure.

4.4 Operation-control and monitoring, level of automation

4.4.1 Control System Configuration

4.4.1.1 General

The Distributed Control System (DCS) shall be provided for safe, reliable, and efficient operation of the proposed Plants. In general, all the I&C systems/ equipment should be of modern and compact design, incorporating proven technology and modern industrial practice. The design of the control systems and related equipment shall adhere to the principle of 'Fail Safe' operation wherever safety of personnel / plant equipment is involved. 'Fail Safe' operation signifies that the loss of signal, loss of excitation or failure of any component shall not cause a hazardous condition.

4.4.1.2 Requirements of DCS

- The plant control system configuration shall be as per drawing no. FCE-20122125-CI-DWG-ARC-4100-001. The control system (DCS) shall be of the latest version (software & Hardware) available in the market at the time of supply, preferably on the same hardware and software platform.
- The overall operational control and supervision of Ammonia Plant, Hydrogen plant, Nitrogen plant, Power plant, Ammonia storage at plant area, De-salination plant/DM plant, Balance of Plant (BOP) and associated electrical system shall be carried out from the proposed plant DCS.
- Two Large Video Screens (LVS) of size 80" Inch shall be provided at Central control room. This monitor shall be connected to the operator station. Space provisions shall also be considered for the future. Large video screens, complete with projectors, screens, control units (graphical generators) & associated accessories shall be supplied as per standard specifications. LVS as a backup for control & operation, in case all OWS are blackout. The control unit of LVS shall be the same as the operator workstation without the TFT monitor. Facility of projecting a particular display on a selectable area of the screen upon activation of a predefined event shall be provided.
- Sequence of Event (SOE) for each unit shall be provided.
- A Historical Storage and Retrieval system shall be provided.
- If DCS is server based then server shall be hot redundant and shall be independent of the historian, MIS, engineering station or operator station. In case of failure of the redundant servers, the operator station graphics shall continue to run normally and DCS operator should be able to monitor and control the process normally from at least one operator station.
- Processor modules, power supply modules, communication modules & network interface cards and serial interface to other control systems shall be redundant. The individual measurements (dual or triple) shall be wired to separate input modules.
- The system will be designed in such a manner that in the event of failure of the primary controller, the entire configuration of the failed controller will be instantaneously and automatically transferred to the back-up controller without operator's intervention. Mode changeover in either direction will bump less and procedure less.
- The communication sub system will be a real time reliable communication network between control processors, operator stations, printers, and engineering stations.

4.4.1.3 Machine Monitoring System

The condition monitoring system (Bentley Nevada series 3500 or equivalent) shall be supplied for all the critical and essential services as required by the process. This system shall be interfaced with DCS for continuous monitoring, logging, and alarm purposes. The equipment shall be classified and complied with application design below.

CRITICAL

- Syngas Hydrogen compressors
- Hydrogen storage compressors
- Steam turbine and Steam turbine generator
- Electric motors driving critical machinery.
- Boiler Feed Pump and motor

ESSENTIAL

- Fin fans
- Cooling tower fans
- Primary cooling water pumps
- Centrifugal pumps with driver capacity greater than or equal to 500 KW
- Centrifuge

4.4.1.4 Human Machine Interface (HMI)

It consists of One Engineering workstations, Six Operator workstations (dual monitors), One Historian PC and One Electrical system PC with Two numbers of A3/A4 LaserJet printers. These workstations shall be provided with 24" LED monitors, Qwerty keyboards. Engineering stations shall have logic builder licenses to develop logic for drives and equipment. Among the six OWS, one for Ammonia plant, one for electrolysers, one for ASU, one for power plant, one for plant BOP and one for systems like pipeline monitoring, Ammonia storage terminal etc. has been envisaged. However, the workstation shall have the facility to adopt multiple monitors configuration, so that the monitors can be increased as per process requirement.

4.4.1.5 Redundant Master and Slave Clock System shall be provided to synchronise all the systems with GPS clock.

4.4.1.6 Other Control System's Communication

- Vendor Packaged PLC and other plant's control systems/devices shall be interfaced to this proposed plant DCS system. The interfacing between the various control systems with plant DCS will be achieved through redundant Optical Fiber Cable (OFC) through appropriate communication protocols by analysing the individual plant's control system's available protocols.
- Packaged equipment like Electrolysers and Air separation units shall have its own microprocessor-based PLC for its control & operation. However, it shall be interfaced with the plant DCS with redundant FO network to monitor the operations as well shall have facility to control the packaged items from main DCS (only Start/Stop from DCS, all other permissive and interlocks to be implemented in local control systems)
- Fire detection and protection system will be a separate independent control system but interfaced with plant DCS through redundant ethernet network.

4.4.1.7 Asset Management System

The Asset Management System shall be provided for collecting and archiving data from the self-diagnostic functions of field instruments using adequate protocol. The AMS will be fully integrated with the DCS, and the user can run the AMS application from the dedicated workstation.

The AMS will read HART information from field devices. The system will be provided with read-write password protection to download parameter settings into the devices. Failure of the AMS system will not inhibit the functionality of the DCS.

The AMS will be capable of interrogating all HART devices and providing similar notification upon abnormal conditions defined during detailed design.

Alarms generated by the AMS will be displayed on the operator console on HMI graphics. The AMS can be accessed from maintenance and engineering workstations.

4.4.1.8 Remote Communication

Since the Ammonia storage terminal at the port area is approximately 180km from the proposed Ammonia plant location, it is envisaged to have its own dedicated control system for operation and control. This control system will be interfaced with the main plant DCS through wireless satellite communications like OPC / GSM technologies (as shown in Dwg.01 & Dwg.02). Suitable Trans-Receiving hardware will be utilised at both transmitting & the receiving end and the data will be fetched into the DCS system for further utilisation. Amongst the two available options, GSM technology is preferred. It will help in getting data directly from remote control system to the plant DCS.

DCS will have this facility to adapt OPC/GSM technologies and the following functionalities-

- Display of all input points under alarm/first out alarm connected to or generated by other PLC/third party control system on the main operator console.
- Generate shutdown reports on the logging printer of Programable Logic Circuits.
- To receive certain operating commands from the operator console for the operation of output devices connected to another PLC/third party device.
- To display diagnostic messages of another PLC/third party device.

4.4.2 Field Instrument Specification/ Requirements

All Instrument devices shall utilise "smart" type electronics using HART Protocol such as smart transmitters, smart positioners for Control Valves, smart gas detectors and analysers, etc. The standardized instruments shall be provided and utilised for the measurements of process variables (Pressure, Temperature, Level and Flow).

- All field instruments shall be suitable for installation in the hazardous area and climatic conditions as specified.
- All parts subject to moisture, fungus growth, or insect attack shall be treated with suitable coating to inhibit such attack. Suitable weather protection, IP65 (as minimum) shall be provided. Sunshades shall be provided.
- All field instruments shall be certified Zone-2, Gas Group IIC, and Temperature class T3, as a minimum.
- Field mounted off-line instruments shall be suitable for mounting on a (2") pipe stanchion, except when installed in local panels.
- Capable of calibrating & configuring on-line locally & remotely by using a HART handheld communicator or Asset Management System (AMS) software, including write protection feature.
- Electronic devices shall be selected and installed such that the electromagnetic interference (EMI), including radio-frequency interference (RFI), shall not interfere with their function.
- All transmitters shall be complete with integral indicators and shall be installed so that these can be readable from grade or platform. Local indicators shall be provided where transmitter indication is not available locally.

4.4.2.1 Signal Transmission

Conventional Hardwire interface for all field instruments to the plant DCS shall be implemented. All field transmitters shall be compatible with HART protocol.

Instrument analog signals except for special signals shall be as follows:

- The electronic transmitters connected to the DCS, and process control application shall be preferably based on 4-20mA HART protocol.
- All transmitters shall be indicating type.
- In case of HART instrumentation, electronic signals used for process measurement will be analog 4-20mA (2 wires).

All control signals like digital inputs shall be 24VDC and digital outputs shall have interposing relays and shall be potential free with contact rating of 5A/240V. The voltage rating of wetted digital outputs shall be according to the field instruments ratings.

4.4.2.2 Critical Measurements

For critical measurements, 2oo3 voting logics are envisaged to accomplish Main Check philosophy. Some of the critical process variables like Hydrogen flow, Nitrogen flow, Ammonia flow, Ammonia storage tank level etc. shall be measured in this philosophy. Some critical measurements are-

i. <u>Level instruments</u>

a. The level measurement for special type application like Liquid Ammonia in Cryogenic tanks will be of Radar / displacer type instruments with high accuracy (2oo3 voting). Radar type of non-contact type is envisaged. It shall be easy for maintenance and replacement.

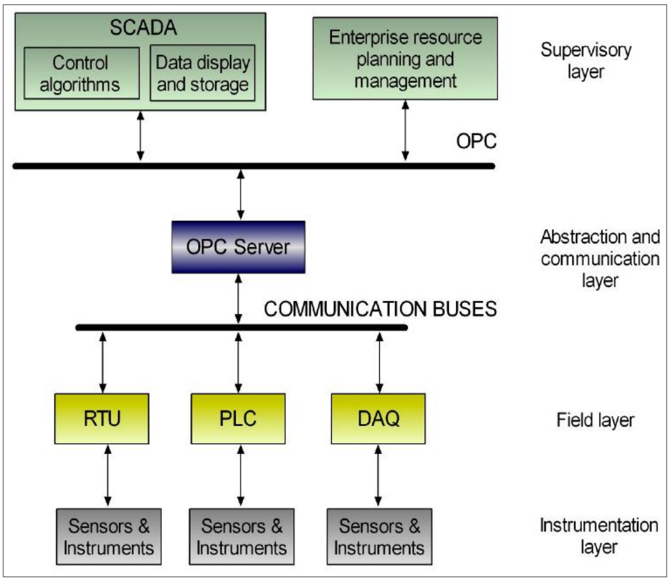


Figure 17: OPC remote communication system

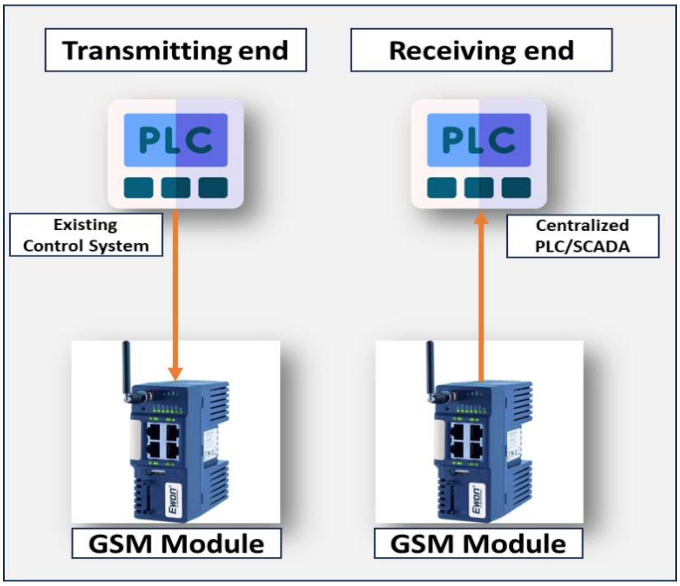


Figure 18: GSM remote communication system

b. Level switches will generally be 'displacer' type with external cage type.

c. All level gauges / transmitters will be provided with drain connection at ground level. Gauge glasses will normally be reflex or transparent type depending upon service, with overall length not exceeding 1500 mm. All gauge glasses will be provided with graduated suitable scale. Wherever necessary, standpipes or float chambers will be provided.

ii. Flow instruments

Flow measurement will be carried out using Mass flowmeter / Magnetic flowmeter / Ultrasonic flowmeter. Flow transmitter's displaying unit shall be integral / separate mounted with signal type isolated 4-20 mA with HART protocol. Coriolis type mass flowmeter will be preferred for liquid ammonia & Hydrogen flow. 2oo3 voting shall be considered for this measurement.

iii. Gas Detectors (if applicable):

Gas detectors will be of standard make and have a voltage level of 24 VDC with isolated 4-20 mA output. The detectors will be wall/frame mounted and display gas concentration, alarm, fault and status information via backlit LCD and LEDs. This can be locally tested and calibrated periodically.

Ultrasonic acoustic type leak detectors are envisaged for detecting hydrogen leakage.

iv. Ammonia Leak Detection System

A standalone leak detection system with dedicated PLC shall be provided for detection of leaks in the Ammonia transfer pipeline from plant to offsite storage terminal at the port.

4.4.3 Quality Control Laboratory

To run the Green Ammonia plant, a quality control laboratory is required to monitor and ensure Product quality and performance of various sections of the plant. The following list identifies some of the typical recommended laboratory Instruments for an Ammonia plant.

1. Gas Chromatograph (to analysis feed and process gas at various locations of the plant)

2. Atomic absorption spectrophotometer (to analyse trace metal ions in product, condensate etc.)
3. pH, conductivity meters
4. Karl Fischer Moisture analyzer
5. Portable Dissolved Oxygen analyzer
6. Dissolved Silica analyser (for HP Steam and for drum water)
7. Dissolved Sodium analyser (for steam and condensate)
8. Automatic potentiometric titrator
9. Oil testing centrifuge with microprocessor control
10. Water testing instruments
11. Steam testing instruments
12. High Volume sampler
13. Digital Density meter
14. Viscosity meter

Note: The detailed list will be provided by the EPC contractor/ licensor.

4.5 Performance guarantee clauses

4.5.1 Green Ammonia Plant

The Licensor/EPC contractor gives performance guarantee for the design and performance of the unit to achieve the desired capacity of the unit and specific consumptions stated.
Typically, the following conditions must be fulfilled before start-up of the plant-

- Erection of equipment in the plant is in accordance with the Process Flow Diagrams (PFD) & Layout.
- Pressure testing to be done for the full plant as per the respective pressure rating.

Erection is considered to be complete based on approved drawings/ agreed terms and conditions of work order / Purchase order. Once the above conditions are fulfilled, the preliminary acceptance of the plant is done by owner and then performance guarantee test is performed by Licensor/EPC contractor.
After pre commissioning, commissioning a stable run for 15 days is considered after which, performance guarantee run is planned for minimum 72 hr of continuous run at designed capacity. A guarantee run of 96 hours could be discussed with the Licensor during the project implementation stage. The results obtained are analysed and documented for review and acceptance within acceptable tolerance. If any shortfall is observed, the Licensor/EPC contractor takes corrective action and rerun the guaranteed test to achieve the desired results.

Following are the parameters generally covered for guarantee:

- Ammonia flow rate (TPH)
- Specific consumption figures (tons per ton of Ammonia produced)
  - Hydrogen
  - Nitrogen
  - Power
  - Steam Generated
  - Steam Utilised
  - Cooling water
- Product Ammonia purity, water content, oil content
- Stream days: 330 days (min)

4.5.2 Air Separation Unit (ASU)

The Licensor/EPC contractor provides performance guarantee for the design and performance of the unit to achieve the desired capacity of the unit and specific consumptions stated.
At first the following conditions shall be fulfilled before the start-up of the plant:

- Erection of equipment in the plant shall be in accordance with the Process Flow Diagrams (PFD) & Layout
- Pressure testing to be done for the full plant as per the respective pressure rating.

Once the above conditions are fulfilled, the preliminary acceptance of the plant is completed by owner, the performance guarantee test is performed by Licensor/EPC contractor.
After pre commissioning, commissioning and stabilization, performance guarantee run is planned for minimum 72 hr of continuous run at designed capacity. The results obtained are analysed and documented for review and acceptance within acceptable tolerance. If any shortfall is observed, the Licensor/EPC contractor takes corrective actions and rerun the guaranteed test to achieve the desired results.
Following are the parameters generally covered for guarantee:

- Plant capacity (TPD) – gaseous flows and liquid N_2 product
- Specific consumption figures (tons per ton of Nitrogen produced)
- Power requirements
- Product Nitrogen purity
- Stream days: 330 days (min)

4.5.3 Electrolyser Unit

The guaranteed parameters for the electrolysers are-

- Power Consumption of the stack – Beginning of Life and End of Life
- Power consumption of the Electrolyser Balance of Plant systems – Beginning of Life
- Hydrogen gas purity
- Hydrogen gas pressure
- Demineralissed water consumption
- Annual availability (or alternatively the annual production quantity of Hydrogen)

5 Personnel and Manpower

5.1 Indicative Staffing

The plant staffing comprises of operators, maintenance technicians, supervisors, engineers and support function staff like administration, procurement, accounts, etc. The summary table below indicates the requirements for individual plant sections for the individual shifts and the general shift also. The requirements of the individual plants are indicated separately.

5.1.1 Overall manpower for regular operation and maintenance of the plant:

Table 30: Overall manpower for regular operation and maintenance of the plant

	Shifts	*Relieving*	*General shift*	*Total*
Ammonia, ASU & H2 Plant	51	17	31	99
Hydrogen plant maintenance	12	4	9	25
Desalination/Demineralisation Plant	3	1	11	15
Substation & plant electrical	9	3	5	12
Power plant	15	5	2	22
Offsite Storage facility	3	1	3	7
Overall manpower	*93*	*31*	*61*	*185*

Note:

1. The staffing for HSE, general administration, laboratory, engineering services, stores, is covered under Ammonia, ASU
2. The above summary table does not cover personnel required for plant security since this will be generally outsourced and the requirements will be confirmed after carrying out a security assessment study.
3. The above table has excluded manpower requirement for gardening/landscaping, janitorial services, canteen, etc. since they are generally outsourced.
4. The manpower for the Offsite storage facility will be physically located far away from the main plant O&M team.

5.1.2 Ammonia, ASU and H2 plant – staffing requirement

Table 31: Ammonia, ASU and H2 plant – Staffing Requirement

Departments	Designation	Manpower Requirements				Min. Qualifications	Min. Experience (yrs.)
		Shifts	Relieving	General shift	Total		
Operations	Production – Field operators	15	5	-	20	B.Sc. (Chem)/Dip Chem Engg	3 - 4
	Panel operators –Control room	9	3	-	12	B.Sc. (Chem)/Dip Chem Engg	5 – 6
	Production - Asst Shift in charge	6	2	-	8	B.E/ B.Tech (Chem)	2 – 3
	Production - Shift in charge	3	1	-	4	B.E/B.Tech (Chem)	5 - 6
	Laboratory	3	1	2	6	B.Sc./ M.Sc. (Chem)	3 - 5
Maintenance	Maintenance staff -Mech	6	2	2	10	DME /ITI	3 - 6
	Maintenance staff – Electrical	6	2	2	10	DEE/DE &I/ITI	3 - 6
	Maintenance staff – Control & Instrumentation	3	1	1	5	Diploma	5
	Maintenance Engineers (Mech +E&I) + Head	-	-	5	5	BE/B.Tech in Mech/EEE/E&I	3 - 10
Plant Superintendent		-	-	1	-	BE/B.Tech Chem	10 - 15
Plant head		-	-	1	1	BE/BTech	15
HSE	Safety Engineers			2	2	P.G Diploma in Industrial Safety	5-10
	Firemen	3	1		4	Diploma in Fire Safety & Hazards Management	5-10
Engineering	Engineering services	-	-	5	5	BE/B.Tech Chem/Mech	3 – 5

Administration	Admin/ Stores/ Accounts	-	-	10	10		
	Total Manpower	*51*	*17*	*31*	*99*		

Notes:

1. The Plant head and the Plant superintendent will be responsible for the entire plant.
2. Engineering services & Administration (stores, Accounts, etc) will be common for the entire plant.
3. The responsibilities of the Operations personnel will cover the Hydrogen plant, BoP, storage area, flare stack, and Ammonia transfer system.
4. The responsibilities of the maintenance personnel will cover the BoP, storage area, flare stack, and Ammonia transfer system.
5. The laboratory will service the water treatment plant, Effluent treatment plant, Hydrogen plant and Balance of Plant also.
6. The Plant head / Plant superintendent will have sole responsibility for the plant safety. Responsibilities related to safety for various sections of the plant for different shifts will be identified from within the O&M team.

5.1.3 Hydrogen plant maintenance

Table 32: Hydrogen production plant maintenance - Staffing requirements

Departments	*Designation*	*Manpower Requirements*				*Min. Qualifications*	*Min. Experience (yrs.)*
		Shifts	*Relieving*	*General shift*	*Total*		
Maintenance	Maintenance staff -Mech	6	2	2	10	DME /ITI	3 - 6
	Maintenance staff – E&I	6	2	2	10	DEE/DE &I/ITI	3 - 6
	Maintenance Engineers (Mech +E&I) + Head	-	-	5	5	BE/B.Tech in Mech/EEE/E&I	3 - 10
	Total Manpower	*12*	*4*	*9*	*25*		

Note: The above manpower requirement will be revisited during the project implementation phase depending on the scope of work in Service Agreement signed with the electrolyser Vendor. This will cause a reduction in the number of maintenance personnel if comprehensive maintenance is covered in the service agreement.

5.1.4 Desalination/ Demineralisation plant

Table 33: Desalination/ Demineralisation Plant - Staffing requirements

Departments	*Designation*	*Manpower*				*Min. Qualifications*	*Min. Experience (yrs.)*
		Shifts	*Relieving*	*General shift*	*Total*		
Operations	Engineer -Operations & MIS	-	-	1	1	B.Tech Chem	10

	Operators -Shift in charge	3	1	-	4		5 – 6
	Helpers	-	-	3	3	12th std	5 - 6
Maintenance	Engineer -Maintenance	-	-	1	1	B.Tech Mech	10
	Electrician	-	-	1	1	C license holder	3 - 6
	Fitter	-	-	1	1		3 - 10
	PLC/instrument technician	-	-	1	1	Polytechnic /Diploma holders	3 - 5
	Helpers	-	-	3	3	12th std	3 - 5
	Total Manpower	*3*	*1*	*11*	*15*		

Note:

1. The O&M personnel will cover the service water, drinking water, and ETP also.

5.1.5 Substation & Electrical facilities- Manpower requirements:

Table 34: Substation & Electrical facilities - Staffing requirements

Departments	*Designation*	*Manpower*				*Min. Qualifications*	*Min. Experience (yrs.)*
		Shifts	*Relieving*	*General shift*	*Total*		
Operations	Substation Supervisor/Shift in charge	3	1	-	4	B.Tech Electrical	10
	Operators (for substation & electrical facilities)	6	2	-	8	DEE	5 – 10
Maintenance	Engineer -Maintenance			1	1	C license holder	10
	Electrician	-	-	2	2	DEE	3 - 6
	Helpers	-	-	2	2	12th std	3 - 5
	Total Manpower	*9*	*3*	*5*	*17*		

5.1.6 Power plant manpower requirements:

Table 35: Power Plant - Staffing requirements

Departments	*Designation*	*Manpower Requirement*	*Min. Qualifications*	*Min. Experience*

		Shifts	*Relieving*	*General shift*	*Total*		*(yrs.)*
Operations	Head -Operations	-	-	1	1	B.E - Mech	15
	Engineer -DCS operator	3	1	-	4	B.E - Mech	5
	Field Engineer	3	1	-	4	Diploma- Mech	5
Maintenance	Head -Maintenance	-	-	1	1	B.E - Mech	20
	Engineer -Mech	3	1	-	4	B.E - Mech	5
	Fitter- Mech	3	1	-	4	ITI	5
	Helper	3	1	-	4	10th pass	5
	Total Manpower	*15*	*5*	*2*	*22*		

Notes:

1. The O&M personnel will cover the Boiler Feed water system, Condensate system, Air Cooled Condenser besides the STG.
2. The O&M team will also be responsible for the STG building EOT crane & HVAC systems.

5.1.7 Offsite storage facility manpower requirement:

Table 36: Offsite Storage Facility Staffing Requirement.

Departments	*Designation*	*Manpower Requirements*				*Min. Qualifications*	*Min. Experience (yrs.)*
		Shifts	*Relieving*	*General shift*	*Total*		
	Operators	3	1	-	4	DME/DEE	5 – 6
Maintenance	Maintenance staff -Mech	-	-	1	1	DME /ITI	3 - 6
	Maintenance staff – E&I	-	-	1	1	DEE/DE &I/ITI	3 - 6
Administration	Admin/ Stores/ Accounts	-	-	1	1		
	Total Manpower	*3*	*1*	*3*	*7*		

5.2 Maintenance Requirements

The maintenance requirements for different sections of the plant will be identified based on the inputs provided by the Licensor/OEMs. Effective maintenance must ensure that the planned availability of the plant is achieved or exceeded.

The major plant subsystems such as ASU, Electrolysers, Water treatment plant, Substation and the BoP must be maintained to achieve the overall availability of the Ammonia plant (≥ 91%).

In certain cases, such as the Electrolysers, the maintenance of the plant may have to be outsourced to the OEM due to potential Intellectual Property (IP) issues.

Separate service contracts will also be necessary for –

a. Major maintenance/overhaul of the centrifugal compressors (in ASU and the Ammonia plant)
b. Major maintenance/overhaul of the STG
c. Replacement of stack for the electrolysers.

5.3 Local availability of personnel

Local availability of personnel for the O&M phase of the plant is assumed considering the location of plant in the highly industrialised state of Gujarat. The state has several fertilizer and production facilities such as GNFC, GSFC, and IFFCO and therefore trained manpower in the vicinity will be available. Further, Gujarat is poised to be a hub for green Hydrogen also.

In the nearby areas of Kutch and Saurashtra there are medium and large desal plants operated by corporates like Reliance, Nayara Energy, Sanghi Cements, Adani, Tata Power, Tata Chemicals. Therefore, a critical mass of trained manpower for the water treatment plant is assumed to be available in the vicinity.

5.4 Training and qualification needs

Training requirements of plant O&M personnel must be assessed periodically to identify gaps especially in areas related to safety in the production and handling of Hydrogen and Ammonia. Safety audits (by external/third party agencies) must also be conducted regularly to ensure that the safety and quality requirements are being adequately met.

Refresher courses to enable upgradation of the knowledge and skill sets of the O&M team must be conducted. Such courses can be conducted by specialist training institutes or OEMs.

5.5 Local training institutes

National Power Training Institute (NPTI) – Provides training in O&M of power stations and all other aspects of Electrical Energy Systems including Transmission, Sub-Transmission and Distribution.
Besides the above there are many training institutes in India (48 institutes as on 1 July 2020) recognized by the Ministry of Power. These institutes training in the areas of generation, electrical power systems, transmission, distribution, and electrical safety.

National Skills Training Institutes (NSTI) – Such institutes are present in almost every state of India and provide training for welders, fitters, electricians, etc.

Ammonia Safety & Training Institute (ASTI) – It is a non-profit American organization that conducts training related to Ammonia safety in many countries including India.

Ammonia Energy Association (AEA)- The association regularly conducts conferences and seminars related to Ammonia production and applications related to Ammonia. The support of the Indian chapter of AEA can be taken for training/refresher courses.

Center for Hydrogen Safety – Non-profit entity

TUV-SUD- They conduct training courses related to Hydrogen safety in India.

Indian Institute of Fire Engineering – resource pool for trained staff and for training/consulting services

National Academy of Fire and Safety Engineering, Nagpur, Maharashtra state – Accredited by the government of India.

6 Financial analysis and Techno-economic assessment

6.1 Capital Cost Estimate

6.1.1 General

The project cost estimates have been worked out on the following basis.

i. Estimates have been prepared and presented based on market prices prevailing as on date and based on internal database.

ii. The following taxes and duties are considered in the Project cost for the equipment:

- GST: 18%
- Freight & forwarding: 5%
- Pre-Operate Expense & PMC: 1.5%

Preliminary Project Costs summary of major heads are as follows:

Table 37: Cost Summary of Major heads

Key Description	Capacity/Size	Cost (INR Million)
Electrolysers (PEM)	623 MW	38240.00
Air Separation Unit	48 TPH	3466.00
Nitrogen booster compressors	2 * 48 TPH	735.00
Ammonia Plant (1300 TPD capacity)	1300 TPD	8483.00
STG & ACC (~15MW capacity)	15MW	200.00
Desalination/Demineralization plant		450.00
H2 Storage Vessels	5 Tons net storage at 40 bar	260.00
Buffer storage of Ammonia (including refrigerating and boil off gas recovery unit)	2 x 5000 Tons storage capacity	800.00
Flare Stack		120.00
Ammonia cross-country pipeline	180 kilometers	1075.00
Balance of Plant - Mechanical		970.00
Electrical Substation		2360.00
Electrical Balance of Plant		270.00
Civil works		6500.00
Control & Instrumentation works		25.00
Offsite storage terminal	2 x10,000 Tons storage capacity	1630.00
Contingency factor		20%
GST Rate		18%
Land Development rate		1%
Freight & forwarding rate		5%

Pre-Operate Expense & PMC		1.5%
Total CAPEX (including Contingency, GST & Land Development, and freight rate)		**99985.17**
Interest during construction (IDC)		**12598.13**
Total Capital cost for 1000 TPD Ammonia plant		**112583.30**

Table 38: Financial parameters considered for the calculation

Description	Unit	Value
Debt: Equity Ratio		70:30
Interest on Loan	%	9
Repayment period (including Moratorium)	Years	17
Moratorium Period	Years	3
Design useful life of the plant	Years	25
Useful life of Stack	Years	10
Annual availability of overall system	%	91
Electricity Cost	INR/kWh	4
Maintenance cost (Electrolyser)	%	2% of Capex
Maintenance cost (Balance of System)	%	3% of Capex
Escalation on O&M (y-o-y)	%	3
Escalation on Manpower Cost (y-o-y)	%	5
Depreciation for Stack	%	10
Depreciation for Balance of System for first 15 years	%	5
Depreciation for Balance of System from 16th year	%	2.5

6.2 Opex Estimate

Fixed O&M costs are as follows –

Table 39: Operation expenses of the Ammonia production

Description	Unit	Value
Fixed Cost (for the Project lifetime)		
Interest on loan	INR (in million)	52030.28
Return on Equity	INR (in million)	170453.67
Depreciation	INR (in million)	119710.15
Interest on working capital	INR (in million)	4824.94
O&M expenses	INR (in million)	99447.11
Total Fixed Cost	INR (in million)	**446466.15**
Variable Cost (for the Project lifetime)	INR (in million)	

Cost of electricity	INR (in million)	348592.40
Chemical/Solid Waste Cost	INR (in million)	2138.18
Total variable cost	INR (in million)	**350730.58**
Total cost of Production	INR (in million)	**797196.72**
Levelised Cost of Ammonia	INR/kg	**98.89**

6.3 Cost of Generation

Based on the parameter considered the levelised cost of generation of green ammonia is INR 98.89/kg. It is observed that the cost of electricity is one of the major components of the overall cost of ammonia as shown in the breakup cost in Figure 19. The above tables show the fixed costs and variable cost components of Ammonia production including the CAPEX and the annual maintenance expenses. The payback period for the project is 7.96 years and the Project IRR and NPV pre-tax and post-tax is shown in table below.

Figure 19: Breakup cost of Ammonia production

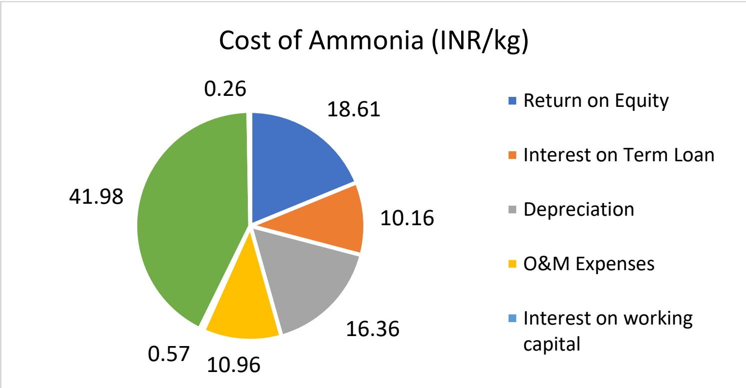


Table 40: IRR and NPV of the project

S.No	IRR	NPV (INR Million)
Pre-Tax (Overall Project)	12.60%	39784.67
Post-Tax (Overall Project)	11.35%	27628.71
Equity	13.95%	

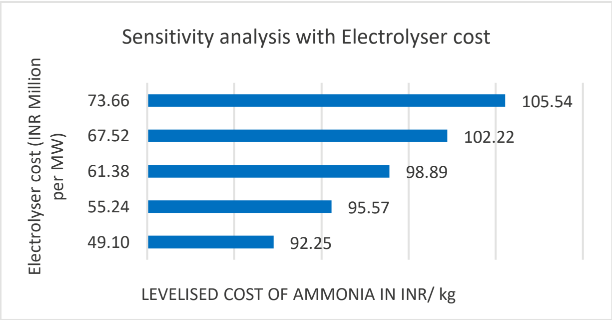
6.4 Utilisation of Oxygen

Utilisation of oxygen has not been considered for the purpose of achieving a second revenue stream. See Chapter 2 on System Design- section 2.3 (g) for further details.

6.5 Cost sensitivity analysis

Sensitivity analysis for levelised cost of generation for Ammonia with variation in Electrolyser cost, electricity cost, rate of interest is presented below. It is observed that the variation in electricity cost has a significant impact on the LCoA. With a 10% increase in the electricity cost, the LCoA varies from INR 98.89/kg to INR 103.09/kg. Similarly, with 10% increase in the Electrolyser cost the LCoA varies from INR 98.89/kg to INR 102.22/kg. With increase in the rate of interest from 9% to 10% LCoA increase from INR 98.89/kg to INR 100.43/kg.

Figure 20: LCoA (INR/kg) with change in Electrolyser cost. & change in electricity cost.



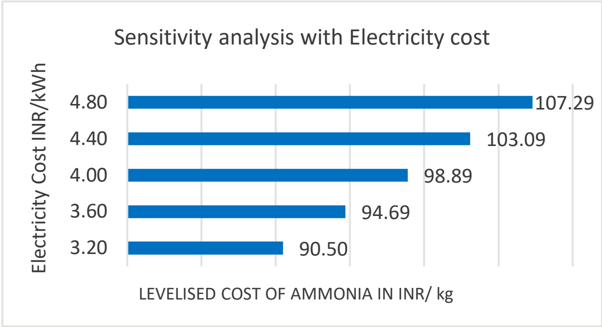
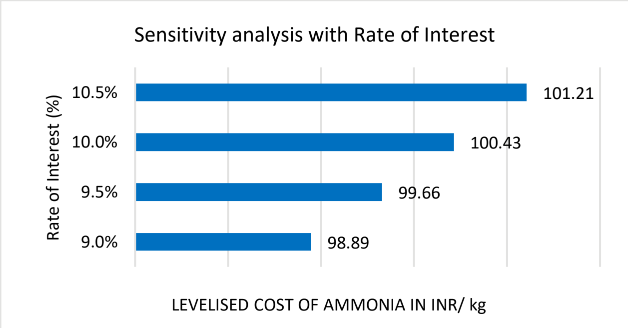


Figure 21: LCoA (INR/kg) with change in Rate of Interest



7 Vendor/ bidder selections

7.1 Potential OEMs

Refer section 2.1 Broad Design Concept for potential electrolyser OEMs.

Potential OEMs for ASU are -

1) LINDE
2) Jyotech
3) SIAD Macchine Impianti
4) AirLiquide -Praxair **
5) INOX Air products **

Note: ** function based on Build, Own and Operate model.

7.2 Potential FEED Contractors, technology providers

7.2.1 Ammonia Technology providers

1) Haldor Topsoe
2) KBR.
3) ThyssenKrupp Uhde.
4) Casale.
5) LINDE
6) Stamicarbon

7.2.2 EPC contractors

1) Engineers India Limited (EIL)
2) Technip Energies
3) Toyo Engineering Corporation
4) Maire Tecnimont
5) McDermott International
6) Wood
7) FLUOR Corporation
8) Projects & Development India Ltd
9) Larsen and Toubro

8 Project implementation strategy

8.1 Level of indigenisation

There are presently no mandates regarding the extent of indigenisation required for electrolysers. However, such a mandate cannot be ruled out in future. Presently, there are several OEMs with the capability to manufacture electrolysers either partly with import of critical items like stacks, or fully in the country. Therefore, even if indigenization is mandated subsequently, there is unlikely to be any impact on the price or delivery schedule.

Most of the remaining equipment /systems are already being manufactured locally and have achieved 100% indigenisation.

8.2 Licensing and statutory clearances

The producer will typically require the following permits and clearances to establish a green Ammonia plant –

1. Environmental and Regulatory clearances
   The applicant (producer) must obtain environmental clearances such as Pollution No Objection Certificate (NOC), waste management certificates, permits for usage of ground water etc., from the Ministry of Environment, Forest, and Climate change (MOEF & CC).

2. Industrial licenses
   The company must also apply for appropriate industrial licenses as the plant will utilise hazardous chemicals for production of Ammonia. Such licenses will be granted by the Department for Promotion of Industry and Internal Trade G2B.

3. Land use Permits
   The producer must have proof of ownership of land to seek the Land use permits. The applicant must produce evidence in the form of either the rent agreement or the lease agreement.

4. Building permits
   The plant must also receive structural and fire safety certificates from the municipal authorities before occupancy /commencing any operations.

5. Electricity permits
   The applicant must ensure that they have a proper electricity connection (from SLDC) to carry out the plant operations.

6. Pollution Board permits
   The company must obtain clearances from the central and state pollution control board before discharging emissions into the surrounding water or air.

7. Tax Registrations
   The company also must obtain all the tax permits, including the GST registration, TDS registration and PAN card for the business.

Besides the producer, the EPC contractor will also require permits and clearances, and these are described subsequently.

8.3 Project schedule

The overall project schedule is shown in the attached as Annexure 5.

The total project schedule is assumed to be 26 months of which broadly consists of two major activities viz., FEED phase for 8 months followed by the Implementation phase of 18 months. The completion of FEED phase coincides with the FID (Final Investment Date).

The six (6) months preceding the commencement of FEED will be utilised for the following activities –

i. Carry out assessment of the borewell capacity (to check suitability for availability of water for 25 years)
ii. Carry out geotechnical investigation at few critical locations (STG building, Syngas compressor location, storage tank location), which can be provided to the EPC bidders.
iii. Carry out Rapid EIA to identify if there are any environmentally sensitive locations nearby that can either become showstoppers or impact the project schedule/cost.
iv. Draft PPA (discussions and agreement on key contract and commercial terms)
v. Commence survey of routing for cross country Ammonia transfer piping from plant to storage location near port
vi. Identify land near port and commence action to acquire the land parcel; once completed, commence route survey for piping from storage location to port.
vii. Commence Pre-FEED and identify Technology Licensor (for the Ammonia plant) and FEED contractor.
viii. Identify suppliers of other major equipment and long lead items such as Electrolysers, ASU, and Power transformers
ix. Obtain technical inputs required for submitting application to MOEF.
x. Preliminary discussions with CTU for obtaining ISTS waiver and discussions with SLDC/STU for connectivity approval.

8.4 Long lead items in project

Long lead items in the project are identified in the table below.

Table 41: Long lead items in the project

Item	Indian Make	Imported	Lead Time	Remarks
Electrolysers	X	X		Current manufacturing capacity of domestic vendors ranges from 100MW to 500MW per annum. However, most OEMs are planning to ramp-up the production capacity over the next two years based on market conditions. Delivery of electrolysers is expected to be staggered over a period of 12-18 months. So, award of supply contract must happen soon after project FID. Since over 100 numbers of electrolysers must be supplied, it is expected that they will be delivered in batches and installed at site progressively. The last batch of electrolysers is likely to be delivered in 18 months, which would be installed and hooked up to the piping and electrical system already completed.
STG & auxiliaries	X		9-12 months	
Air-cooled condenser (for the STG)	X		12 months	
Syn Gas compressor / Nitrogen Compressor		X	8 to 12 months	
Refrigeration compressor	X	X	6 to 8 months	

Item	Indian Make	Imported	Lead Time	Remarks
Recycle Compressor	X		6 to 8 Months	
DCS control system and Shutdown system	X	X	8 to 12 months	
Process Gas analysers /Safety gas monitors		X	6 to 8 months	
ASU Nitrogen Generator	X	X	8 to 12 months	
Ammonia Converter with Catalyst	X	X	> 12 months	
Flare System	X	X	12 months	
Ammonia Storage system	X	X	>12 months	

8.5 Schedule risk

The project completion schedule can be extended due to the following –

1. Delay in scaling up of domestic Electrolyser manufacturers – If the domestic vendors are unable to scaleup the production capacity as expected, the delivery schedule of the electrolysers will extend beyond 18 months. Import of electrolysers is unlikely to be a solution because of the expected increase in demand for electrolysers in every major economy. Further, imported electrolysers will result in a higher Capex due to higher cost of freight and imposition of import duties.
2. Surge in international demand for green Ammonia plants – The supply of green Ammonia plant will be dependent on capacity constraints faced by major licensors like KBR, Linde, Haldor Topsoe, etc. whose current focus is on meeting the rising demand from Europe and North America.

Due to the above, the completion of the project could extend from 26 months to 32-34 months. To mitigate the schedule risk, it might be necessary to book a few manufacturing slots by issuing a Limited Notice to proceed (LNTP) to the electrolyser vendor. Similarly, LNTP can be issued to the Ammonia Licensor to commence the Basic Engineering Design Package.

8.6 Quality control recommendations

Managing quality requires the adoption of proven techniques that enable project teams to look at areas where there may be potential problems.

Rigorous implementation /follow-up of the Shop Quality Plans and Field Quality Plans will be necessary to ensure high levels of quality starting from the material procurement phase, through manufacture and till installation.

Typical Strategies used for quality control in project management include:

a) Employing a third-party specialist agency to maintain independent oversight of quality aspects.
b) Project planning, tracking, review, corrective action, and audit
c) Project budgeting, tracking and cost control.

d) Cause and effect diagrams
e) Checklists

8.7 Applicable permits/approvals

Table 8.2 Applicable permits/approvals

Sl. No.	Licenses/ Registration	Approval Authority	Remarks
1	IEC Code	Ministry of Commerce and Industry, GOI	If export/deemed export is considered
2	SIA Certificate (Secretariat Industry Assistance)/ Industrial Entrepreneurs' Memorandum	Ministry of Commerce and Industry, GOI	
3	Trade License	Municipal Corporation, Gujarat Govt	
4	CHEMEXCIL Membership (large scale manufacturer Exporter)	Ministry of Commerce and Industry, GOI	IF EPCG is availed siting import substitution
5	GST registration -	Commercial Taxes Department	
6	Professional Tax Registration - Gujarat	Commercial Taxes Department	
7	Central Excise Registration	Ministry of Finance - Department of Revenue, GOI	
8	EPCG Registration	DGFT, Ministry of Commerce and Industry, GOI	For availing customs duty exemptions for import of capital goods (import substitution of Ammonia)
9	Environmental Clearance	Ministry of Environment, Forest and Climate Change, GOI	
10	Environmental Impact Assessment Study	Govt. Approved Consultant	
11	Sanction for Temporary Power Supply	Electricity Department, Gujarat	
12	Sanction of water supply	Gujarat Water Board	
13	Layout drawing approval from Inspector of factories, Gujarat	Inspector of factories, Gujrat	
14	Sanction for Permanent Power Supply	Electricity Department, Gujarat	
15	Power Purchase Agreement	Electricity Department Gujarat	
16	Consent order for Air and water Act	Pollution Control Board, Gujarat	
17	Drawing approval for Boiler (Syngas Loop)	CIB, Gujarat	
18	Drawing approval for Electrical Inspectorate	Electrical Inspectorate, Gujarat	
19	Registration and License under Contract Abolition and Regulation Act	Inspection of Factories, Gujarat	
20	Registration under PF Act	PF Dept Gujarat, Region	
21	Registration under ESI Act	ESIC, Gujarat Region	
22	Registration of wireless equipment	Dept of Telecommunications, GOI	
23	Contract Labor License, Form 5	Labor Commissioner	
24	License as per SMPV rules (Pressure vessels and Compressed gas cylinder/ storage act)	Chief Controller of Explosives	Ammonia and Hydrogen handling & storage and design as per Indian Standard 2825

Annexures

Please access Annexures in the digital version by scanning the QR code

Deutsche Gesellschaft für
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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.