International Hydrogen Ramp-up Programme – H2Uppp

Development of Roadmap for a Green Hydrogen Cluster in Ramagundam

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Indo-German Energy Forum

Deloitte.

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Deutschland
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Deutschland
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de

Authors:

Mr. Anish Mandal, Deloitte
Mr. Himadri Singha, Deloitte
Mr. Purab Mohapatra, Deloitte

Reviewers:

Mr. Srinivas Cherla, RICH
Mr. Rolf Behrndt, Sr. Hydrogen Expert
Mr. Kumar Abhishek, IGEF-SO
Mr. Karan Arora, IGEF-SO
Mr. Clemens Antretter, IGEF-SO
Ms. Eva Meschede, GIZ
Mr. Abhishek Chaudhary, Tractebel
Mr. Sadasib Mohapatra, Tractebel

Acknowledgements:

Mr. Durgam Satyanarayana, RFCL
Mr. Kamal Katiyar, ACME
Mr. Nilanjan Mahata, ACME

Layout:

Peppermint werbung berlin gmbh, Berlin

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

Jayesh Ranjan IAS
Special Chief Secretary to Government
Commissioner for Industrial Promotion

Industries & Commerce Department
Government of Telangana

Foreword

India's energy transition continues to accelerate. Addressing the COP26 conference in Glasgow, India had announced its goal of achieving 'Net Zero' emission by 2070 reflecting a strong commitment to eliminate the use of fossil fuels. While renewable power generation remains the mainstay of India's decarbonisation efforts, industrial emissions, especially from hard-to-abate sectors, will require other forms of deep decarbonisation such as Green Hydrogen.

India has already embarked on an aspirational journey towards energy self-sufficiency through hydrogen-led decarbonisation. The Government has unveiled 'Green Hydrogen Policy' in February 2022, and in January 2023 the Union Cabinet approved the National Green Hydrogen Mission with an outlay of INR 19,744 crores intended to make India a global hub for Green Hydrogen. Few rounds of bidding have also taken place for disbursement of incentives.

The Government of Telangana is at the forefront in implementing measures to mitigate climate risks, such as making solar energy an integral part of the state's overall energy policy, several programs on biogas and waste to energy, among others. The state has a national subsidy scheme for residential solar grid-connected systems and is also looking forward to developing a hydrogen ecosystem to decarbonize emission intensive industries. To this end, Research and Innovation Circle of Hyderabad (RICH)is working with key industries in the Ramagundam region and other ecosystem enablers and agencies to explore the feasibility of setting up a "Green Hydrogen Valley" in the Ramagundam industrial cluster of Telangana State.

The publication of this report cannot come at a more opportune time as the Indian Government as well as industries have started accepting green hydrogen and its derivatives as potential climate risk abatement measures.The concept of "Green Hydrogen Valley" in a landlocked state like Telangana is expected to be the most effective way to drive hydrogen-led decarbonization.

The success of "Green Hydrogen Valley" lies in multi-stakeholder coordination, fiscal support to initial investors, favorable policy and regulations and implementation of a robust governance mechanism. I hope this report will give an impetus to the development of the "Green Hydrogen Valley" in the state, which can be replicated in other States of the country.

I also express my gratitude to the various contributors for their valuable insights.

(Jayesh Ranjan)

Room No. 24, 3rd Floor, Dr. B.R. Ambedkar Telangana Secretariat, Hyderabad-500 022.
Ph : +91 40 23454449 | Fax : +91 40 23452985 | E-mail : prlsecy-inds@telangana.gov.in | jayesh_ranjan@hotmail.com

Table of Contents

List of Tables

List of Figures

Abbreviations

AEL	Alkaline Electrolysis
AEMEL	Anion Exchange Membrane Electrolysis
AI	Artificial Intelligence
APGPCL	Andhra Pradesh Gas Power Corporation Limited
APR	Annual Performance Review
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage System
BIS	Bureau of Indian Standards
BOP	Balance of Plant
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CGS	Central Generation Station
CII	Confederation of Indian Industry
CKM	Circuit Kilo Meter
COP	Conference of the Parties
CPCB	Central Pollution Control Board
CTE	Consent to Establish
CTO	Consent to operate
DISCOM	Distribution Companies
DPR	Detail Project Report
DRE	Distributed Renewable Energy
DST	Department of Science and Technology
EFST	Environment, Forests, Science, and Technology
EOI	Expression of Interest
EPC	Engineering Procurement and Construction
FEED	Front End Engineering Design
GDAM	Green Day Ahead Market
GDP	Gross Domestic Product
GSDP	Gross State Domestic Product
GST	Good and Service Tax
GTAM	Green Term Ahead Market
GW	Giga-Watts
HEMM	Heavy Earth Moving Machinery
HPA	Hydrogen Purchase Agreement
HRS	Hydrogen Refuelling station
HRSG	Heat Recovery Steam Generator
HSA	Hydrogen Sale Agreement
HSD	High Speed Diesel
I&C	Industry and Commerce
IICT	Indian Institute of Chemical Technology
IITH	Indian Institute of Technology Hyderabad
INR	Indian National Rupee

IOCL	Indian Oil Corporation Limited
ISTS	Inter-State Transmission System
LCOH	Levelized Cost of Hydrogen
LED	Light Emitting Diode
LETFD	Labour Employment Training and Factories Department
LPG	Liquified Petroleum Gas
MHIPL	My Home Industries Pvt. Ltd
MLD	Million Liters per day
MMTPA	Million Metric Tonnes Per Annum
MNRE	Ministry of New and Renewable Energy
MoA	Memorandum of Association
MOC	Ministry of Coal
MU	Million Units (kWh)
MW	Mega-Watt
NG	Natural Gas
NGHM	National Green Hydrogen Mission
NHM	National Hydrogen Mission
NOC	No Objection Certificate
NTPC	National Thermal Power Corporation
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
PEMEL	Proton Exchange Membrane Electrolysis
PERT	Programme Evaluation and Review Technique.
PLI	Production Linked Incentive
PMC	Programme Management Consultant
PMU	Program Management Unit
PNG	Piped Natural Gas
PSP	Pumped Storage Plant
RE	Renewable Energy
RFCL	Ramagundam Fertilizers and Chemicals Limited
RICH	Research and Innovation Circle of Hyderabad
RPO	Renewable Power Obligation
SCCL	Singareni Collieries Company Limited
SGST	State Good and Service Tax
SIGHT	Strategic Interventions for Green Hydrogen Transition
SOEL	Solid Oxide Electrolysis
SPC	Solar Policy Cell
SPCB	State Pollution Control Board
SPP	Solar Power Producer
SPV	Special Purpose Vehicle
T&D	Transmission and Distribution
TPD	Tonnes per Day
TPOA	Third Party Open Access
TPP	Thermal Power Plant

TSNPDCL	Telangana State Northern Power Distribution Company Limited
TGSRTC	Telangana State Road Transport Corporation
TSTRANSCO	Transmission Corporation of Telangana
USD	United States Dollar
VAT	Value Added Tax
VFD	Variable Frequency Drive
VGF	Viability Gap Funding
WPC	Wind Policy Cell
WPP	Wind Power Producer

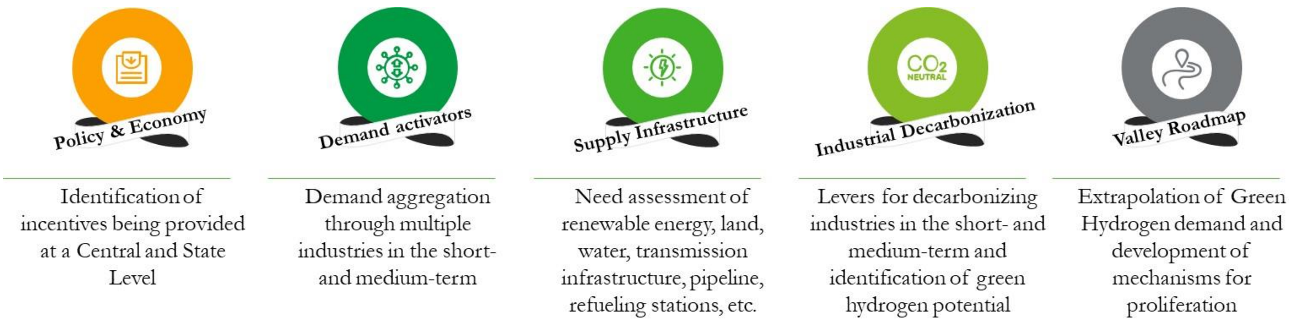
1 Introduction

Globally, green hydrogen and its derivatives have gained wide recognition as decarbonisation agents for multiple facets across industry, chemical, and transport such as shipping and aviation. Many countries have announced hydrogen strategy, roadmap, targets and several support measures. In the last few years, the sector has witnessed a dramatic increase in investment commitment from global developers as well as end-users.

Recognising the importance of green hydrogen as a decarbonisation agent, the Government of India launched the National Hydrogen Mission (NHM), which was followed by the release of the National Green Hydrogen Policy. The government approved the provisions of NHM by sanctioning INR 19,744 crore (~USD 2,379 Mn) outlay in January 2023. The mission aims to take annual green hydrogen production to a minimum of 5 MMTPA by 2030 and capture 10 percent of the global demand (expected to become 100 MMTPA by 2030).[1] In January 2024, the Government (through SECI) has successfully auctioned direct subsidy for green hydrogen production and Production Linked Incentive (PLI) for electrolyser manufacturing. Of late, the Central Government has also announced schemes for using green hydrogen in transport, steel industry and development of hydrogen hubs. In August 2024, the Solar Energy Corporation of India (SECI) has invited proposals for setting up green hydrogen hubs in India under the National Green Hydrogen Mission (NGHM).

Several State Governments, such as Maharashtra, Andhra Pradesh, Uttar Pradesh have also come up with state specific green hydrogen policy. The industrial cluster of Ramagundam in the state of Telangana has been identified as suitable for developing a Hydrogen valley. This region has potential for renewable generation, has availability of land and water, and has some key industries which use hydrogen already, such as fertilizers, refineries, etc. as well as few industries, such as coal mines and glass industry which have future potential of hydrogen use. This set-up minimises hydrogen transportation and hence negates safety concerns and fugitive energy losses.

A hydrogen valley is a defined geographical area where hydrogen serves more than one end sector or application in mobility, industry, and energy. This typically covers all the necessary steps in the hydrogen value chain, from production (and often even dedicated renewable electricity production) to subsequent storage and its transport & distribution to various off takers[2]. Thus, to develop a roadmap for green hydrogen valley, it is critical to identify key success factors which includes aggregation of demand and supply along with provisions for valley creation from a policy and financial support perspectives.



This study will focus on development of a roadmap for hydrogen valley in the Ramagundam region as well as identification of broad industrial decarbonisation levers which include other sources of clean energy and emission abatement measures. The study focuses on the economic view of the state of Telangana followed by the RE landscape in the state and policy measures for RE and Green Hydrogen and derivatives applicable. The policy measures are then followed by the key demand activators in the Hydrogen valley and subsequently the infrastructure required is assessed. Key levers for decarbonizing the industries present in the Ramagundam cluster are identified to understand the role of green hydrogen and a dedicated roadmap for the hydrogen valley is then outlined considering the potential.

Research and Innovation Circle of Hyderabad (RICH) is the key partner for implementation of Green Hydrogen Valley concept and industrial decarbonisation measures in Telangana, especially Ramagundam. RICH with the support of the Department of Science and Technology (DST), initiated discussions with key stakeholders and organized stakeholder consultation event in January 2023 to understand the perspectives of various stakeholders in the Green Hydrogen ecosystem. Through this platform, several industries, research organisations, systems integrators, ecosystem enablers, etc. agreed to formalise a consortium and collaborate on conceptualising a Green Hydrogen valley in the area. The current plan for Green Hydrogen valley focuses on captive markets in a landlocked region. This brings Green Hydrogen valley closer to its ideal state.

[1] Source: India National Hydrogen Mission document

[2] As per the Guidelines for Hydrogen Valley Innovation Cluster by Department of Science and Technology

Key stakeholders include industries like NTPC (National Thermal Power Corporation), RFCL (Ramagundam Fertilizers and Chemicals Limited), AGI-Glaspac, TGSRTC (Telangana State Road Transport Corporation); research organizations like IITH (Indian Institute of Technology Hyderabad), IICT (Indian Institute of Chemical Technology); Systems Integrators like Homi hydrogen, MTAR; Ecosystem enablers like RICH, CII (Confederation of Indian Industry), etc. The discussions helped RICH to identify a couple of use cases that are now being considered for the proposed Green Hydrogen Valley.

i. De-sulphurisation of natural gas feed stock at RFCL
ii. Increased Ammonia production by using Green Hydrogen and Nitrogen as feed at RFCL
iii. Hydrogen blending with LPG in heating for Annealing and Distribution channels at AGI-Glaspac
iv. Hydrogen Fuel cell bus service between Ramagundam and Hyderabad by TGSRTC
v. Blending of H_2 with PNG for residential supply with IOCL
vi. Fuel cell heavy truck for SCCL

It is important to note that this Green Hydrogen Valley is being envisioned with focus on captive markets, in a land locked region. Globally, several valleys are conceptualised with focus on combination of captive use and export.

In this context, GIZ has appointed Deloitte India to develop a roadmap for the proposed green hydrogen valley[3] in Telangana, in the vicinity of Ramagundam. The roadmap shall outline the value chain and the sectors to be included, contributions of each member, infrastructure and financing needs. It will focus on short term (pilot stage), medium term (2030), and long term (beyond 2030) planning horizons. The outcomes of the roadmap could be used to take decisions at a government, industry and investor level, for development of the hydrogen economy in Telangana. The valley would encompass the entire value chain, such as renewable energy, producers of green hydrogen, off-takers (industries, transport, etc.), infrastructure providers, research and development capacities and other services.

[3] Hydrogen "valley" and "cluster" are used interchangeably in this report

2 Overview of economy and policy landscape

2.1 Review of Telangana state economy

Telangana was constituted as a separate state on the 2nd of June 2014. Despite being the youngest state in the country, it has managed to achieve extraordinary growth in this brief period. Telangana's economy is one of the fastest growing state economies in the country. While India's GDP (at current price) increased by only 118.2% from 2014-15 to 2022-23, Telangana achieved a ~156% increase in the GSDP value (at current price) during the same period, making it the 2nd ranking state in terms of the overall GSDP increase during this period. The state's GDP at current prices is estimated at ₹13.13 lakh crore (~USD 158 Bn) in 2022-23, with a growth rate of 16.3% in 2022-23; at Constant prices it was Rs. 7.26 lakh crore, with an increase of ~71% from its 2014-15 value.[4] The service sector is the largest contributor to the economy, accounting for about 62.2% followed by industrial sector at 19.0% and agriculture & allied sectors at 18.8%. **In 2022-23, Telangana was the 8th and 7th highest contributor to the country's GDP at current prices and constant prices respectively.**

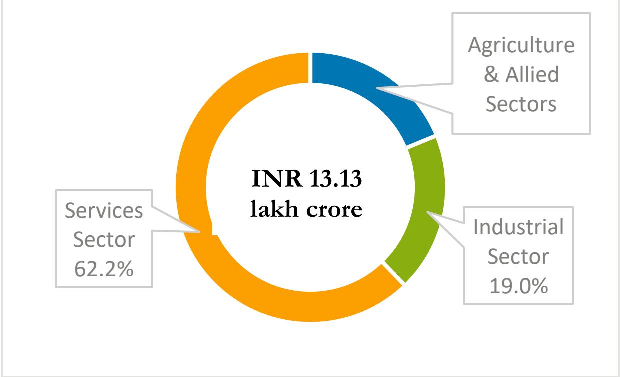


Figure 1: Sector-wise contribution to Gross State Domestic Product of Telangana in FY 23

The increasing trend in GSDP is also mirrored in electricity demand of the state which has grown at a CAGR of ~7.4% from 2014-15[5] to 2022-23[6]. The emissions of the state of Telangana rose from ~15 MT CO_2 (e) in 2014-15 to ~67 MT CO_2 (e) in 2017-18[7] showcasing a positive elasticity between GDP and emissions.

Table 1: GDP trajectory of Telangana (current price)

Year	Telangana GSDP (INR Tn)	India GDP (INR Tn)	Electricity Demand (BU)
2014 - 15	5.05	124.6	39.18
2015 - 16	5.77	137.7	40.65
2016 - 17	6.58	153.9	43.74
2017 - 18	7.50	170.9	50.56
2018 - 19	8.57	188.9	57.57
2019 - 20	9.50	201.0	58.56
2020 - 21	9.41	198.3	57.05
2021 - 22	11.1	234.7	61.22
2022 - 23	13.1	272.1	69.23

Several major manufacturing and services industries are in operation mainly around Hyderabad. Fertilizer, automobiles and auto components industry, mines and minerals, textiles and apparels, pharmaceutical etc. are the main industries in Telangana. The state government is in the process of developing Industrial Parks at different places, for specific groups of industries.

The State also has a progressive industrial policy which emphasises on providing a framework to stabilise and make existing industries more competitive, and also attracting and realising new international and national investments in the industrial sector. The government is also determined to create an ecosystem focusing on enhancing ease of doing business – Telangana is a consistent top performer among states in India in facilitating ease of doing business (ranked within top 3 states consistently).

The Telangana State Government has identified 14 sectors[8] as thrust areas which include several core industries as well as Renewable energy. Every thrust area has its own sectoral policy and a structure of incentives. The Government has also formed high level advisory panels with private sector and academia experts for each of the sectors.

[4] Telangana government, Telangana-Economy-2023, (access here)
[5] Government of Telangana, Telangana State Power Sector – White Paper (access here)
[6] NITI Aayog, India Climate & Energy Dashboard
[7] GHG India Platform, Trend Analysis of GHG emissions of Telangana (access here)
[8] Telangana Industrial Policy (access here)

Some of the key highlights pertaining to Telangana's industrial sector are captured below[9]:

- The state has made continuous efforts for the growth of the industrial sector through its innovative policies, which have resulted in increased investments and employment opportunities. TS-iPASS, the government's flagship initiative, attracted Rs 20,237 crore of investment in 2022-23 (up to Jan 2023) through 2,518 new industries and created employment for 72,908 people.
- During 2021-22, merchandise goods worth Rs. 81,971 crore were exported by the state. Pharmaceutical goods and Organic Chemicals constituted 57.31% of the total goods exported.
- Telangana was included in the Top Achievers category in the latest edition (2020) of Ease of Doing Business rankings which were recently announced in 2022 and since 2016 it has been consistently ranked among the top 3 states in India.
- In the Export Preparedness Index 2021, Telangana scored 100 in the Business environment indicator.
- Innovation and technology are the prime drivers of industrial growth in Telangana. Currently, the state has 78 incubators, accelerators and co-working spaces with a specific focus on emerging technologies. The innovation policy of the state and the incentives provided to the startups are among the best provided within the country.

2.2 Renewable energy policy and regulatory landscape – Central Government

India has committed to being a net zero emitter by 2070. Since it made that pledge at COP 26 in Glasgow in 2021, India's government has unveiled new policies and regulatory action aimed at developing technologies to help the world's most populous nation meet that target.

India's renewable energy sector in India has witnessed huge change in the past 7-8 years. The country plans to achieve 500 GW of renewable energy (RE), including large hydro by 2030. As of December 2023, India's installed RE capacity was ~134 GW (excluding large hydro) and this included ~73 GW of solar (ground mounted and rooftop) and 44 GW of wind energy.

The announced policies and regulations are focused on increasing renewable energy in the energy mix, enhancing commercial viability of new technologies and promoting ease of doing business. Brief description of policy and regulatory impetus offered by the national government is provided below:

2.2.1 Targets of RPO for end consumers

The Government has been driving increased adoption of renewable energy by increasing the renewable purchase obligation (RPO) for the designated consumers. The Ministry of Power, in collaboration with the Bureau of Energy Efficiency (BEE), has issued a notification amending the Energy Conservation Act of 2001 to introduce minimum renewable energy consumption targets for designated consumers until financial year 2029-2030. This amendment is set to come into force on April 1, 2024.

The targets are set as a percentage of the total energy consumption for various designated consumers, including electricity distribution licensees, open-access consumers, and captive users who source electricity independently from distribution licensees. The minimum share of renewable energy is set to progressively increase over the years. In 2024-25, 29.91 per cent of the total energy must come from renewable energy sources. This will gradually rise to 43.33 per cent in 2029-30[10].

Table 2: RPO targets for Renewable Energy from FY25 to FY30

Year	Wind RPO (%)	Hydro RPO (%)	DRE RPO (%)	Other RE (%), mainly Solar	Total RE RPO (%)
FY25	0.67	0.38	1.50	27.35	29.91
FY26	1.45	1.22	2.10	28.24	33.01
FY27	1.97	1.34	2.70	29.94	35.95
FY28	2.45	1.42	3.30	31.64	38.81
FY29	2.95	1.42	3.90	33.10	41.36
FY30	3.48	1.33	4.50	34.02	43.33

Till now, targets are set till 2030. However, directionally, large share of RE in the consumers' energy mix is expected even after 2030. Considering increasing demand of electricity, significant capacity addition through RE sources is

[9] Economic Development of Telangana (access here)

[10] Ministry of Power Order. Renewable Purchase Obligation and Energy Storage Obligation Trajectory till 2029 – 30 (access here)

expected to meet the RPO targets. Both DISCOMs (Distribution Companies) and industrial consumers are expected to increase RE share in the overall energy mix.

2.2.2 Development of Solar Parks and Ultra Mega Solar Power Projects

The Scheme, "Development of Solar Parks and Ultra Mega Solar Power Projects" was rolled out in India in Dec 2014[11] with an objective to help solar park developers to develop large scale solar projects expeditiously. **The scheme has been extended till FY 2025-26 for enabling installation of Solar Projects.**

The scheme aimed at installation of large capacity utility scale and mega projects to overcome roadblocks that are associated with installation of small capacity solar projects like high cost of installation, creation of transmission network for carrying small capacity, creation of infrastructure like land and water, etc.

2.2.3 Waiver of ISTS charges on transmission of electricity

Ministry of Power vide order dated 21.06.2022, has extended the waiver of Inter-State Transmission Charge (ISTS) charges on transmission of electricity generated from solar and wind sources for projects to be commissioned up to 30th June 2025. To encourage the capacity addition in battery storage and pumped storage projects, waiver of ISTS charges shall also be allowed for Hydro Pumped Storage Plant (PSP) and Battery Energy Storage System (BESS) projects if the following conditions are met:

i. At least 70% of the annual electricity generation requirement of pumping of water of the PSP plant is met by use of solar and wind-based generation.

ii. At least 70% of the annual electricity generation requirement of charging of the BESS system is met by use of solar and wind-based generation.

Waiver of transmission charges was also given for trading of electricity generated/supplied from Solar, Wind, PSP and BESS in Green Term Ahead Market (GTAM) and Green Day Ahead Market (GDAM) till 30.06.2023. The landed cost of electricity for any buyer in the power exchanges in India include the market clearing price and the open access charges. Open access charges include the transmission charges (at the central and the state level), wheeling charges (at the distribution company level) and other charges viz. cross subsidy surcharge and additional surcharge. A waiver of ISTS charges provided by the central government can enable a reduction of ~INR 0.4 – 0.5 per kWh of electricity for the buyers.

2.2.4 Green Hydrogen Mission

Union Cabinet approved the National Green Hydrogen Mission in January 2023. The initial outlay for the Mission will be Rs.19,744 crore (~USD 2379 Mn), including an outlay of Rs.17,490 (~USD 2107) crore for the Strategic Interventions for Green Hydrogen Transition (SIGHT) program, Rs.1,466 crore (~USD 177 Mn) for pilot projects, Rs.400 crore (~USD 48 Mn) for R&D, and Rs. 388 crore (~USD 47 Mn) towards other Mission components. MNRE has formulated the scheme guidelines for implementation of the respective components. Within pilot projects Rs. 456 crores (~USD 55 Mn) has been set aside for steel, Rs. 495 crores (~USD 60 Mn) for transport, Rs. 115 crores (~USD 14 Mn) for shipping and Rs. 400 crores (~USD 48 Mn) for other projects.

In addition, The scheme guidelines for SIGHT Mode 2A (aggregation model for Green Ammonia) and Mode 2B (aggregation model for Green Hydrogen) have been notified on 16th January, 2024.

2.2.4.1 Scheme for direct subsidy for green hydrogen production

Under this initiative, direct subsidies are provided to Green Hydrogen developers. The scheme outlines a structured incentive plan, offering financial support to developers based on the amount of Green Hydrogen produced over a span of three years from the commencement of commercial operation. The Bureau of Energy Efficiency (BEE) at the Ministry of Power shall be the Nodal Authority for accreditation of agencies for the monitoring, verification, and certification for green hydrogen production projects.

The incentives are calculated at a specified rate per kilogram of Green Hydrogen produced, with a decreasing cap over the three-year period. In the first year of production, developers can avail a maximum subsidy of Rs 50/kg, which reduces to Rs

---

[11] MNRE (access here)

40/kg in the second year and further decreases to Rs 30/kg in the third year of production. The government has allocated a fund of INR 13,050 Crores (approximately USD 1.7 Billion) for the implementation of this incentive program.[12] The incentive payout in a given year is determined by multiplying the incentive rate for that year (expressed in Rs/kg of Green Hydrogen) by the lower value between the allocated capacity and the actual production during that year. The allocated capacity, a fixed quantity assigned to each successful bidder, remains constant throughout the duration of the Hydrogen Purchase Agreement. The disbursement of incentives occurs on an annual basis, and the successful bidder is eligible to receive the incentive payout after submitting the requisite claim. This scheme not only encourages the growth of the Green Hydrogen sector but also ensures efficient allocation of resources in line with the industry's development trajectory.

SECI is the nodal agency for this scheme and first round of auction took place in December 2023.

The implementation of a subsidy averaging INR 30 per kilogram (as sought by majority of the bidders) has the potential to decrease the Levelized Cost of Hydrogen (LCOH) by USD 0.11 – 0.12 per kilogram[13].

2.2.4.2 Scheme for PLI for electrolyser manufacturing

This subsidy scheme aimed at promoting the production of electrolysers through a Production Linked Incentive (PLI) scheme. It offers incentives based on the production output over a span of five years. The incentives are calculated per kilowatt (kW) of electrolyser produced.

Under this scheme, the base rate incentive starts at INR 4,440 per kW in the first year and is gradually reduced by INR 740 per kW annually for a period of five years, reaching INR 1,480 per kW by the end of the incentive period. The allocation for this scheme stands at INR 4,440 crores (approximately USD 0.5 billion).

The incentive payout is determined by multiplying electrolyser sales volume, the quoted base support rate, performance multiplier, and domestic value addition. This multi-faceted approach ensures that the incentives are linked to the actual performance and contribution of manufacturers to the development of a robust domestic green hydrogen ecosystem.

First round of auction took place in January 2024, and the outcome is indicated below:

Table 3: Status of auction, Tranche – 1 of PLI for electrolyser

S. No	Company	Capacity Allocated (MW)	Max. Incentive Allocation (Rs Cr)
Bucket 1 (Based on Any Stack Technology)			
1.	Reliance	300	444
2.	Ohmium Operations	137	203
3.	John Cockerill Greenko Hydrogen Solutions	300	444
4.	Advait Infratech (Consortium with Rakesh Power Service)	100	148
5.	Matix – Gensol	300	444
6.	L&T Electrolysers	63	93
	Total	**1,200**	**1,776**
Bucket 2 (Based on Indigenously Developed Stack Technology)			
1.	Homi hydrogen	101.5	150
2.	Adani New Industries	198.5	294
	Total	**300**	**444**

The implementation of a subsidy averaging INR 1.5 crore per megawatt can result in a noteworthy impact, leading to a reduction of USD 0.08 – 0.10 per kilogram in the Levelized Cost of Hydrogen (LCOH)[14]. However, the current allocation can only support 1500 MW/year of electrolyser capacity.

2.2.4.3 Green Hydrogen Hubs under NGHM

A key component of the National Green Hydrogen Mission is identification and development of regions capable of supporting large scale production and/or utilization of Hydrogen as Green Hydrogen Hubs. The Mission provides for setting up of two Green Hydrogen hubs in the initial phase. The Ministry of Ports, Shipping and Waterways has identified three major ports viz. Deendayal, Paradip, and V.O. Chidambaranar (Tuticorin) Ports to be developed as hydrogen hubs. Key highlights are:

[12] Scheme guidelines for implementation of SIGHT programme – component II (access here)
[13] Deloitte analysis.
[14] Deloitte analysis.

- The Mission will identify and develop regions capable of supporting large scale production and/or utilization of Hydrogen as Green Hydrogen Hubs.
- Development of necessary infrastructure for such hubs will be supported under the Mission.
- It is planned to set up at least two such Green Hydrogen hubs in the initial phase.
- Outlay of **₹ 200 crore** up to 2025-26 for Hubs and other projects

2.2.5 Green Hydrogen Policy

As part of National Green Hydrogen Mission, the Government has also announced Green Hydrogen Policy in an endeavor to reduce cost of hydrogen production and improve ease of doing business. The policy was notified by MoP dated 17th February 2022.

The policy provisions are:

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

The policy promotes Renewable Energy (RE) generation as RE will be the basic ingredient in making green hydrogen. This in turn will help in meeting the international commitments for clean energy.

2.2.6 Viability Gap Funding for development of Battery Energy Storage Systems (BESS)

The Union Cabinet, chaired by the Hon'ble Prime Minister approved the Scheme for Viability Gap Funding (VGF) for development of Battery Energy Storage Systems (BESS) in September 2023. The approved scheme envisages development of 4,000 MWh of BESS projects by 2030-31, with a financial support of up to 40% of the capital cost as budgetary support in the form of Viability Gap Funding (VGF).

Salient features of the scheme are:

---

[15] Press Information Bureau. The ISTS waiver of Green Hydrogen and Green Ammonia projects extended from 30 June 2025 to 31 Dec 2030. (access here)

- The VGF for development of BESS Scheme, with an initial outlay of Rs.9,400 crore, including a budgetary support of Rs.3,760 crore, signifies the government's commitment to sustainable energy solutions. By offering VGF support, the scheme targets achieving a Levelized Cost of Storage (LCoS) ranging from Rs. 5.50-6.60 per kilowatt-hour (kWh). The VGF shall be disbursed in five tranches linked with the various stages of implementation of BESS projects.
- VGF will be disbursed to BESS developers. The selection of BESS developers for VGF grants will be carried out through a transparent competitive bidding process, promoting a level playing field for both public and private sector entities.
- The projects under the scheme will be approved during a period of 3 years (2023-24 to 2025-26).
- To ensure that the benefits of the scheme reach the consumers, a minimum of 85% of the BESS project capacity will be made available to Distribution Companies (Discoms). This will not only enhance the integration of renewable energy into the electricity grid but also minimize wastage while optimizing the utilization of transmission networks.

The selection of developers under the VGF scheme has not commenced yet, as of 21st May 2024.

2.3 Renewable energy policy and regulatory landscape – Government of Telangana

Telangana has a vast solar potential estimated at 20.41 GW and a wind energy potential of 4.2 GW.[16] Over the past four years, the overall renewable energy capacity has risen from 4.04 GW to 5.11 GW, with more than 90% capacity addition through Solar.

The Telangana government has been proactive in promoting renewable energy through policies like the Solar Policy in 2015 and the Wind Energy Policy in 2016.[17] The state climate action plan also identifies renewable energy as a key pillar for decarbonizing the energy sector.[18]

2.3.1 Telangana state government schemes

Table 4: Schemes by Government of Telangana

Policy	Details
Telangana Solar Power Policy, 2015[19]	**The state has published solar policy in 2015. Key initiatives and support measures are highlighted below:** • Facilitation of expeditious approvals through single window clearance for all Solar Power Projects (SPPs) by Solar Policy Cell (SPC). • Exemption of the wheeling and transmission charges for captive use within the state whereas they will be charged as applicable for third party sale. • Exemption of electricity duty on captive consumption, sale to DISCOMS, and third-party sale for all SPPs established within the state. Additionally, the electricity duty will be waived for new manufacturing facilities and support services related to SPPs. • Exemption on cross subsidy surcharge for five years from the date of commissioning of the SPP located within the state and selling power to third parties within the state. • The Commercial Tax Department will provide 100% refund of VAT/SGST on all inputs required for solar power projects over a duration of 5 years. • The Industries Department will provide 100% refund of Stamp Duty for the acquisition of land intended for establishing solar power projects and/or solar parks. Registration fees must be paid in accordance with regulations. • Captive and Open Access/Scheduled consumers will be allowed to bank 100% of energy throughout the year. Banking charges, set at 2% of the energy delivered at the drawl point, will be adjusted accordingly. The banking period will run from April to March. Banked units cannot be consumed or redeemed during peak months (February to June) and peak hours (6 pm to 10 pm). The Solar Policy was applicable for a period of 5 years (till 2020) and the projects which were commissioned within this period were eligible for a period of 10 years from the CoD.
Telangana Wind Power Policy, 2016 (draft)[20]	**Telangana's Wind policy was notified in 2016. Key highlights of the policy are:**

[16] Industry outlook, opportunity in Telangana (access here)
[17] In draft stage
[18] MoEFCC (access here)
[19] Telangana Solar Power Policy, 2015 (access here)
[20] Telangana Wind Power Policy, 2016 (draft) (access here)

Policy	Details
	• Facilitation of expeditious approvals through single window clearance for all Wind Power Projects (WPPs) by Wind Policy Cell (WPC). • Exemption of the wheeling and transmission charges for captive/group captive use within the state whereas they will be charged as applicable for third party sale. • Exemption of electricity duty on captive/group captive consumption, sale to DISCOMS, and third-party sale for all WPPs established within the state. Additionally, the electricity duty will be waived for new manufacturing facilities and support services related to WPPs. • Exemption on cross subsidy surcharge for five years from the date of commissioning of the WPP located within the state and selling power to third parties within the state. • The Commercial Tax Department will provide 100% refund of VAT/SGST on all inputs required for solar power projects over a duration of 5 years. • The Industries Department will provide 100% refund of Stamp Duty for the acquisition of land intended for establishing wind power projects. Registration fees must be paid in accordance with regulations. • Captive and Open Access/Scheduled consumers will be allowed to bank 100% of energy throughout the year. Banking charges, set at 2% of the energy delivered at the drawl point, will be adjusted accordingly. The banking period will run from April to March. Banked units cannot be consumed or redeemed during peak months (February to June) and peak hours (6 pm to 10 pm).

The state of Telangana is in process of developing an Energy Policy which is expected to revive the flow of funds into the RE sector in the state.

With the increasing GSDP of Telangana, the state's electricity requirement and emissions would have an upward trajectory. It is critical for the state to have dedicated roadmaps for decarbonising the industrial sector and incorporating newer technologies like hydrogen into hard to abate sectors.

3 Concept of Hydrogen Valley in Telangana

From a geographical perspective, the state of Telangana is landlocked and shares borders with Maharashtra, Chhattisgarh, Andhra Pradesh, and Karnataka. Unlike other preferred locations for hydrogen and ammonia production, this state thus has no access to ports. However, the state has clusters of industry which could be potential off-takers for green hydrogen – Ramagundam industrial zone is such an identified cluster with captive demand of hydrogen. Establishing a 'hydrogen valley' could help meeting the localized demand-supply need of hydrogen.

3.1 What is a hydrogen valley?

As per the Guidelines for Hydrogen Valley Innovation Cluster by Department of Science and Technology[21], "a hydrogen valley is a defined geographical area where hydrogen serves more than one end sector or application in mobility, industry, and energy. This typically covers all the necessary steps in the hydrogen value chain, from production (and often even dedicated renewable electricity production) to subsequent storage and its transport & distribution to various off takers".

An illustration of a hydrogen valley innovation cluster is provided below:

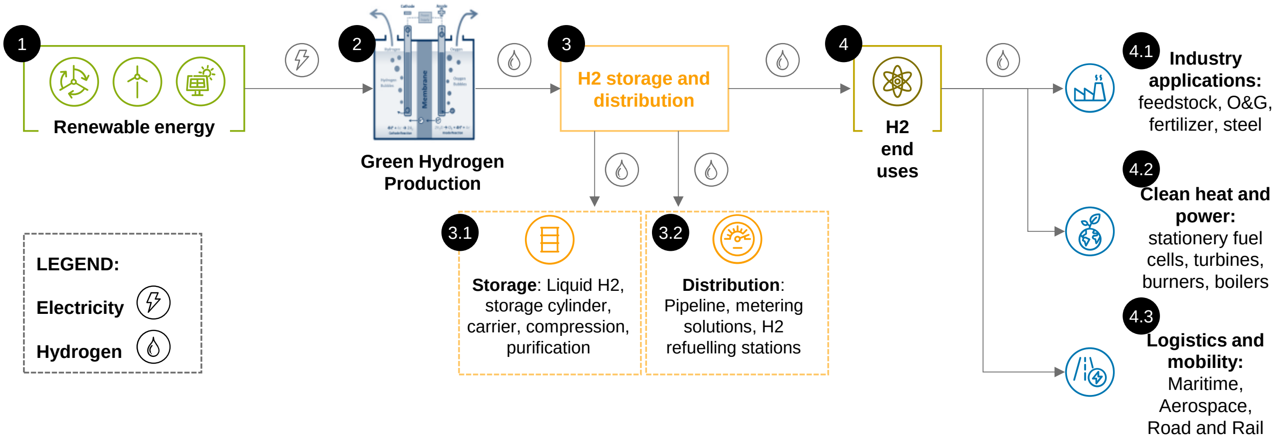


Figure 2: Illustration of a hydrogen valley innovation cluster

3.2 Need of Hydrogen Valley

Hydrogen valleys have multi-faceted utility to accelerate industrial decarbonisation. These are critical element in the organised development of hydrogen in the economy. Valleys are expected to advance the practical application of hydrogen and the use of available resources in most optimal ways. The concept is acknowledged globally as a critical tool for developing locally integrated hydrogen systems.

Valleys reduce the investment risks for a relatively new energy fuel like hydrogen to a great extent. Since it takes a locally concentrated approach, industrial consumers operating in the hard-to-abate sectors near the point of production can be targeted as off-takers – this will provide an offtake certainty. Additionally, the cluster of hydrogen production, transport and consumption can help in establishing a shared infrastructure investment model between producers and consumers/off-takers, thereby reducing investment risk for each party.

Development of valleys would also attract investors of different risk profile to develop integrated hydrogen project. These provide an organised format for the global investors to invest into hydrogen projects. The most notable example is "Hydrogen Hub" program in US – multiple investors have formed consortium to develop the integrated hydrogen hubs.

Furthermore, hydrogen valleys ensure local economic development by generating jobs while ensuring necessary infrastructure development. An offshoot benefit of this is the localisation of industries in the cluster for easy access to hydrogen. Economic and environmental impacts are significant from a well-functioning hydrogen valley.

---

[21] DST, Guidelines for Hydrogen Valley Innovation Cluster (access here)

Examples of Global Hydrogen Hubs/valleys

Europe, USA and Australia have been at the forefront of the hydrogen economy, recognizing the potential of hydrogen as a key enabler for achieving climate neutrality. Several initiatives have been launched across these geographies to develop hydrogen hubs/valleys, integrating production, storage, distribution, and utilization of hydrogen across various sectors. These hubs aim to accelerate the transition to a low-carbon economy, foster innovation, and ensure energy security.

Some of the prominent valleys/hubs, already in operation or under development, are:

Hamburg Green Hydrogen Hub, Germany: Luxcara and Hamburger Energiewerke will establish the Hamburg Green Hydrogen Hub at the Hamburg-Moorburg power plant site. The plan is to build an electrolyser with a capacity of 100 MW and the potential for further expansion. It supplies hydrogen to industries and the port as well as applications in transport in Hamburg and the surrounding area.

HEAVENN, Netherland: Supported by the European Union's Fuel Cells and Hydrogen Joint Undertaking (FCH JU), this project aims to create a fully functioning green hydrogen value chain in the Northern Netherlands, including production, storage, and use in transport, industry, and heating. The concept is based on the deployment and integration of existing and planned project clusters across six locations in the Northern Netherlands, namely Eemshaven, Delfzijl, Zuidwending, Emmen, Hoogeveen and Groningen. HEAVENN is expected to demonstrate the coupling of existing electricity and gas infrastructures at scale, to decarbonise industry, power, transport and heat across the entire region.

Rotterdam Hydrogen Hub, Netherland: The Port Authority of Rotterdam is working with various partners towards the introduction of a large-scale hydrogen network across the port complex, making Rotterdam an international hub for hydrogen production, import, application and transport to other countries in Northwest Europe. The hub will also enable Rotterdam to maintain its position as important energy port for Northwest Europe in the future. The port has taken major steps in bringing the infrastructure, production, storage, supply and demand of hydrogen and/or hydrogen carriers together.

Hydrogen Hubs in USA: Supported by Bipartisan Infrastructure Law, the U.S. DOE is spearheading a major hydrogen hub initiative aimed at accelerating the deployment of hydrogen technologies across the country. The DOE has allocated $8 billion to fund the development of several regional hydrogen hubs, which will serve as key components of the national hydrogen economy. Within USA, prominent regional hub programs are:

- Gulf Coast Hydrogen Hub, Texas
- California Hydrogen Hub, California
- Pacific Northwest Hydrogen Hub, Washington, Oregon
- Appalachian Regional Clean Hydrogen Hub, West Virginia, Ohio
- Heartland Hydrogen Hub, North and South Dakota
- Mid-Atlantic Hydrogen Hub, Pennsylvania

3.3 Suitability of Ramagundam cluster as a "Hydrogen Valley"

Ideally, Hydrogen Valleys should be deployed in areas where there is access to resources for producing hydrogen (i.e., renewable energy, water, land) and close to a consumer base to ensure offtake certainty. All the aspects of the hydrogen valley shown above are largely housed in a single geography which qualifies it as a self-sustaining hub for green hydrogen. Importantly, a valley covers the entire value chain of green hydrogen – RE generation, hydrogen production, storage & transportation and consumption.

Ramagundam cluster can be an ideal location for valley development. Key elements of the valley are indicated below:

Table 5: Key elements of Hydrogen valley

Sl.	Particular	Description
1	Renewable energy	RE can be sourced through a combination of Solar, Wind and BESS. Route of RE sourcing could be captive, Third Party Open Access (TPOA) or GDAM (Green Day ahead market) or GTAM (Green term ahead market).

Sl.	Particular	Description
		Ideally, RE generating plant shall be located within the state only, and captive route is widely recognized as the most attractive route commercially. **Telangana has ~25 GW RE potential**[22], which can be utilized for powering electrolyser.
2	Green hydrogen production	Electrolysis route of hydrogen production is considered for this study. Suitable location and technology should be selected based on demand. This study will evaluate both Alkaline and PEM technology for electrolysis of water. Land availability is not a challenge near the identified industrial cluster of Ramagundam. For initial development of the valley, excess land near Singareni Collieries Company Limited could be made available.
3.1	Hydrogen storage	Hydrogen produced through electrolysis requires to be stored in specific form and pressure for catering to multiple end use applications. There are multiple options for hydrogen storage – liquid H_2, compressed hydrogen. Depending on the demand profiles from end-users, hydrogen storage size will be estimated. Compressed storage tank is the preferred method of storage.
3.2	Hydrogen distribution	Distribution infrastructure will be designed based on demand profile of the end-consumers. For instance, fertilizers require a constant feed of hydrogen to produce ammonia (through Haber-Bosch process) whereas mobility solutions require refuelling stations which can have bulleted delivery to cater to demand from vehicles. Distribution of hydrogen for the cluster can be done through pipelines (for constant feed), or transportation truck (staggered delivery to refuelling stations or to glass manufacturing facility).
4	Hydrogen end uses	Use cases identified in the Ramagundam region are[23]: i. De-sulphurisation of natural gas feed stock at RFCL (Ramagundam Fertilizers and Chemicals Limited) ii. Increased Ammonia production by using Green Hydrogen and Nitrogen as feed at RFCL (details provided in section 3.4.1) iii. Blending with LPG in heating for Annealing and Distribution channels at AGI-Glaspac; in the long run, hydrogen can be blended with NG for furnace operation. (details provided in section 3.4.5) iv. Hydrogen Fuel cell bus service between Ramagundam and Hyderabad by TGSRTC (details provided in section 3.4.2) v. Blending of H_2 with PNG for residential supply with IOCL (as per inputs from RICH) vi. Fuel cell heavy truck for SCCL (details provided in section 3.4.4)
5	Water	Water is a critical component for green hydrogen production. Giga-watt scale electrolyser facilities cannot rely on ground water for operations and usually rely on desalination plants if the facility is near sea and surface water bodies viz. rivers to obtain their feedstock. The Ramagundam cluster has access to surface water from Godavari river which can be utilised for the electrolysers.

In other words, Hydrogen Valleys are "mini-hydrogen ecosystems" with a strong potential to speed up the development of the hydrogen sector in the country. Ramagundam region is poised to become a Hydrogen valley with the availability of all pre-requisites for a Valley development – demand generators, RE potential and water.

3.4 Demand activators in Ramagundam green hydrogen cluster

Based on the study conducted by RICH, the short term (pilot stage), medium term (2030), and long term (beyond 2030) demand in the hydrogen cluster is expected to rise from 2.62 TPD to 75 TPD.

[22] Source: Invest Telangana

[23] As identified by RICH through a DPR for the Hydrogen Valley in Ramagundam. Details of the demand activators are mentioned in the following sections.

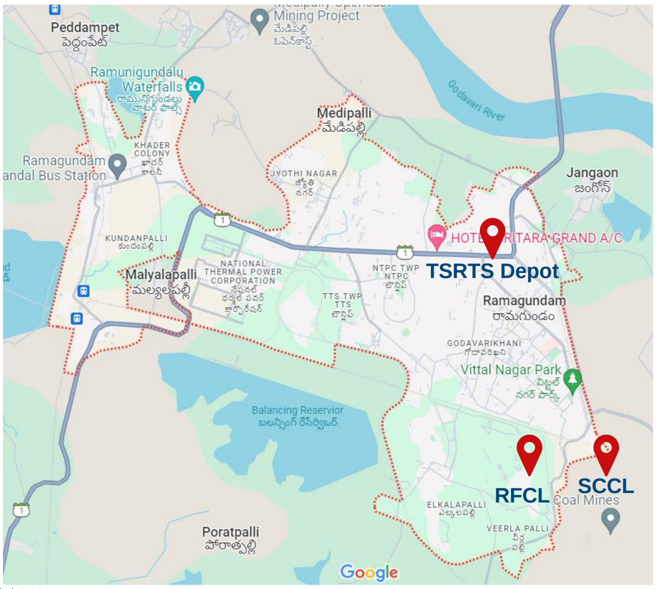


Figure 3: RFCL, SCCL, and TGSRTC Depot in Ramagundam

Figure 4: AGI Glaspac manufacturing facility distance from Ramagundam

Figure 5: MyHome Cements facility distance from Ramagundam

The table below captures the demand from multiple use cases in the cluster.

Table 6: Green Hydrogen demand in Ramagundam cluster

Sl.	Off-taker (sector)	Use case	Current Grey H_2 demand (TPD)	Short-term GH_2 demand (TPD) [Pilot stage]	Medium-term GH_2 demand (TPD) [2030]	Long term GH_2 demand (TPD) [2030 - 2040]
1.	RFCL (Fertilizers)	Ammonia production and NG desulphurisation	383[24]	2	5.5	45
2.	TGSRTC (Transportation)	Hydrogen fuel cell buses	-	0.2	2	8
3.	MyHome (Transportation)	Hydrogen fuel cell trucks	-	0.2	4	10

24 Considering 0.56 kg ammonia required for production of 1 kg of Urea; 12.7 LMT demand of RFCL considered

Sl.	Off-taker (sector)	Use case	Current Grey H_2 demand (TPD)	Short-term GH_2 demand (TPD) [Pilot stage]	Medium-term GH_2 demand (TPD) [2030]	Long term GH_2 demand (TPD) [2030 - 2040]
4.	SCCL (Mining)	Hydrogen fuel cell trucks	-	0.2	2	10
5.	AGI Glaspac (Glass)	Melting furnace	-	0.02	1	2
	Total			**2.62**	14.5	75

In addition to the identified industries, NTPC has an annual grey hydrogen demand of 35 – 40 tonnes[25]

3.4.1 RFCL (Ramagundam Fertilizers and Chemicals Limited)

Ramagundam Fertilizers and Chemicals Limited (RFCL) in Telangana operates an Ammonia Unit with a capacity of 2,200 Metric Tonnes Per Day (MTPD) and a Urea Plant with a capacity of 3,850 MTPD. [26] RFCL aims to produce 12.7 Lakh Metric Tonnes per annum at 100% capacity utilization. The commercial operation of the Ramagundam Unit commenced on March 22, 2021. In the financial year 2022-23, RFCL produced and dispatched significant quantities of neem-coated prilled urea.[27]

Production process of Urea:

1. Fertilizer manufacturing involves two stages: Production of ammonia from NG and production of urea from ammonia.
2. Ammonia is produced from H_2 (derived from NG) and N2 from air through Haber-Bosch process.
3. NG is to be purified by desulphurization process, followed by SMR, Methanation etc. to arrive finally at Ammonia production.
4. In the Urea process, Ammonia (NH_3) and CO_2 are combined to form an intermediate called Carbamite, which is very unstable and precipitates into Urea.
5. The Urea process starts from a high-pressure urea reactor and goes through multiple intermediary stages.
6. Finally, ~99% pure urea in liquid form is sent through the prilling process where in it forms granules of urea. This urea is sent for bagging process as the final step.

A schematic is provided below:

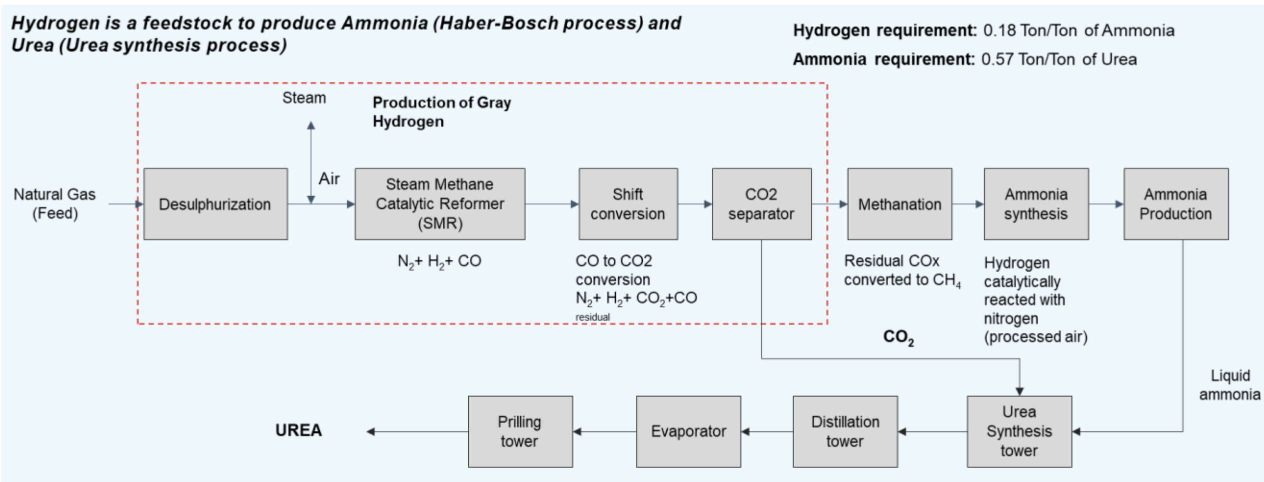


Figure 6: Process flow diagram for Urea production

Opportunity for Green Hydrogen:

Currently, grey hydrogen is used for desulphurisation of Natural Gas (NG) and as a feedstock in the Haber-Bosch process. Green hydrogen can potentially replace grey hydrogen in both of these applications.

---

25 Ramagundam thermal power plant is a 2600 MW capacity TPP, which has a demand of 35-40 tonnes per year
26 PIB, (access here)
27 RFCL, (access here)

- Desulphurisation uses hydrogen to remove sulphur content present in methane/NG. Total daily requirement, in current full capacity, is 2350 NM3/hr; this is equivalent to 5 TPD of hydrogen at 50 bar pressure.
- For Haber-Bosch process, total H_2 requirement is 1.3 Lacs Ton per year. Partial replacement of grey hydrogen with green hydrogen can be explored in the long term.

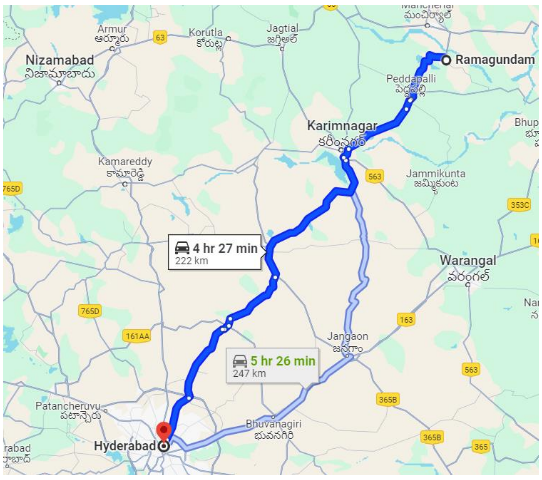
Following table captures the short term and long-term demand of green hydrogen from RFCL:

Table 7: RFCL hydrogen demand and delivery requirements

Particular	Short-term [Pilot stage]	Medium-term [2027 - 2030]	Long-term [2030 - 2040]
Demand	2 TPD	5.5 TPD	45 TPD
Demand rationale	RFCL has agreed to offtake 2 TPD of green hydrogen required for desulphurization for the pilot demonstration,	Considering 100% substitution of grey hydrogen required for desulphurization	Considering 100% substitution of grey hydrogen required for desulphurization (~5 TPD) and 10% substitution in Haber-Bosch process
Delivery options	Pipeline (<1 km)	Pipeline (<1 km)	Pipeline (<1 km)
Infrastructure requirement	Will leverage existing storage capacity	Will leverage existing storage capacity	Will leverage existing storage capacity

3.4.2 TGSRTC (Telangana State Road Transport Corporation)

Telangana State Road Transport Corporation (TGSRTC) operates bus transport services within Telangana, managing a fleet of more than 9000 buses through 98 depots under 11 Regions. TGSRTC plans to achieve its targets of reducing emissions and promoting eco-friendly urban transportation through introduction of a fleet of 50 'Green Metro Luxury' fully air-conditioned electric buses in Hyderabad, with 25 buses already operational[28]. In accordance with their decarbonisation plans they have recently placed order for 50 new E-buses (Battery electric vehicle) from Olectra Greentech.[29]



To boost their effort to reduce emissions, TGSRTC has agreed to be one of the offtakers of Green Hydrogen and has planned to run 2 hydrogen fuel cell based buses as a pilot experiment in the Ramagundam Hyderabad route. By 2030, they plan to increase the Hydrogen cell bus fleet to 200. In the short run, the refuelling will be done in the refuelling station built in the SCCL facility. In the long run it is proposed to build a refuelling station in TGSRTC bus station located at 6.7 kms from the SCCL facility.

Hydrogen Fuel cell vehicles generate electricity using oxygen from air and compressed hydrogen to generate electricity in hydrogen fuel cell. This will power the onboard motor responsible for mobility. In hydrogen powered IC engine, the hydrogen replaces the conventional fuel. For TGSRTC, deployment of fuel cell bus is considered.

Table 8: TGSRTC hydrogen demand and delivery requirements

Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Demand	0.2 TPD	2 TPD	8 TPD
Demand rationale	2 – 3 buses	Estimated for 50 buses	Estimated for 200 buses
Delivery options	Refuelling at SCCL site	Refuelling at TGSRTC depot	Refuelling at TGSRTC depot

[28] Deccan chronicle, 25 Green metro buses in Telangana, (access here)
[29] Mercom india, olectra 550 ebuses in Telangana, (access here)

Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Infrastructure requirement	Hydrogen Refuelling Station (HRS) including accumulator, dispensing station at SCCL end	1 no of HRS of capacity 80 kg/hour (2 TPD) and associated system	4 nos of HRS of capacity 80 kg/hour (2 TPD) and associated system

3.4.3 MyHome (Maha Cement)

MHIPL (My Home Industries Pvt. Ltd), a cement producer in India, is actively engaged in utilizing renewable energy sources and implementing energy-saving projects. The company has shown a commitment to environmental sustainability through initiatives like waste management, conservation of fossil fuels, and reducing carbon footprints. MHIPL has increased its alternate fuel consumption and aims to further boost the utilization of renewable energy sources - the company has a 12.5 MW waste heat recovery-based power plant and established solar power installation of 15 MW in 2006 and 60 MW plant in 2012. These efforts not only help meet the power requirements of the plants but also contribute to reducing carbon emissions significantly. [30]

MyHome plans to run one Hydrogen fuel cell truck to transport cement between their facility at Kodad and the SCCL facility (~80 km) at Ramagundam. In the long term plan MyHome plans to deploy 50 fuel cell trucks.

Table 9: MyHome hydrogen demand and delivery requirements

Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Demand	0.2 TPD	4 TPD	8 - 10 TPD
Demand rationale	Daily requirement for 1 – 2 trucks	Requirement for 20 trucks	Requirement for ~50 trucks
Delivery options	Refuelling at SCCL site	Refuelling at own premise	Refuelling at own premise
Infrastructure requirement	Hydrogen Refuelling Station (HRS) including storage capacity, dispensing station at SCCL end	2 no of HRS of capacity 80 kg/hour (2 TPD) and associated system	4-5 no of HRS of capacity 80 kg/hour (2 TPD) and associated system

3.4.4 SCCL (Singareni Collieries Company Limited)

Singareni Collieries Company Ltd (SCCL) plans to become a 'net zero' energy organization by 2025-2026. SCCL aims to achieve this by increasing its solar power generation capacity to 530 megawatts. By 2024-25, the company aims to generate the entire 700 GWh electricity consumption from its solar power plants. In the first phase, SCCL has completed 224 MW out of the planned 300 MW capacity plants and will commission the remaining 76 MW by June this year, adding another 120 MU energy availability. The second phase involves developing solar plants with a capacity of 230 MW in Bhupalapally, Mandamarri, and other areas by the end of 2025. [31]

SCCL also plans to run a hydrogen fuel cell truck within the facility and has committed to provide land to build Green Hydrogen production facility and also one (1) refuelling station in the short term pilot phase which will be increase to three (3) in the long term.

Table 10: SCCL hydrogen demand and delivery requirements

Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Demand	0.2 TPD	2 TPD	10 TPD
Demand rationale	1 mining truck	20 mining trucks	50 mining truck
Delivery options	Through the HRS located at SCCL facility only	Through the HRS located at SCCL facility only	Through the HRS located at SCCL facility only

[30] Energy business centre, (access here)
[31] The Hindu, SCCL, (access here)

Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Infrastructure requirement	1 HRS of ~1 TPD capacity 1 storage tank of 2 tons capacity	3 HRS 1 TPD capacity	3 HRS 1 TPD capacity

3.4.5 AGI Glaspac

AGI Glaspac is a leading container glass bottle manufacturer in India, specializing in producing high-quality glass containers for critical packaging industries such as food, pharmaceuticals, beverages, and more. The company operates two cutting-edge manufacturing facilities located in Hyderabad and Bhongir, Telangana. These facilities have a combined capacity to melt over 1600 tonnes of glass per day. The company aims to minimize its carbon footprint and significantly increase the utilization of renewable energy by 2030.[32]

In the Glass manufacturing process heat is a major requirement for blending and annealing process where Green Hydrogen has a role to play by substituting conventional fuel such as NG and LPG. A step-by-step process flow for glass manufacturing is provided below:

1. Raw material batch (sand, soda, lime, cullet etc.) is prepared and loaded into the hopper from where it is fed through a conveyor into a continuous melting furnace.
2. The melting furnace (main furnace) is heated by burning either furnace oil, LPG, or other fuel through three high speed burners.
3. Once the raw material is melted, it slowly moves into the distributor channels, which feed the individual glass bottle manufacturing lines.
4. The temperature of these distributor lines is closely controlled using LPG or NG fuel to maintain Glass Homogeneity as each distributor channel is used for manufacturing a different product.
5. At the end of distributor lines the glass is shaped into bottles / containers using blow moulding and the finished product is pushed into annealing chamber where the glass is gradually cooled to ambient temperature.

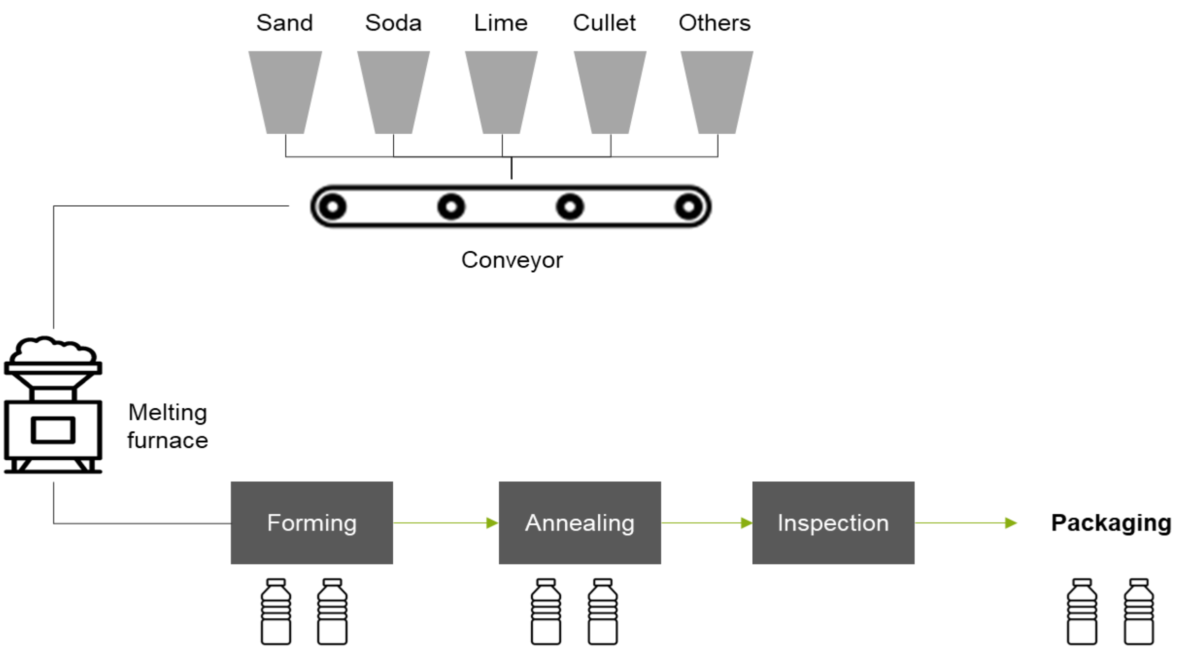


Figure 7: Process flow for container glass manufacturing

[32] Green business energy centre, AGI Glaspac, (access here)

Hydrogen opportunity:

Hydrogen has almost ~3x the calorific value of Natural gas / LPG and is therefore a good fuel for heating purposes. However, controlling a hydrogen flame can pose as a challenge because it has a higher flammability compared to other fuels. Hydrogen can be used to replace NG/LPG either completely or by blending in the Annealing process. Currently, specific thermal energy requirement for AGI is 1100 – 1200 kg/kg of glass production[33], which translates to consumption of ~100kg per ton of production.

In the Pilot phase/ short term AGI Glaspac would offtake 0.02 TPD which will increase to 2 TPD in long term.

Table 11: AGI hydrogen demand and delivery requirements

Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Demand	0.02 TPD	1 TPD	2 TPD
Demand rationale	Blending up to 20% hydrogen into one distributor. Green hydrogen will be supplied in a continuous manner as the furnaces operate 24/7	More blending in 2 – 3 melting furnaces.	More blending in 5 melting furnaces.
Delivery options	By road	By road	By road
Infrastructure requirement	7 - 10 day storage	7 – 10 day storage	7 – 10 day storage

Total demand of hydrogen (~2.6 TPD in the short term and ~75 TPD in the long term) will be met through adequate supply infrastructure in the form of renewable energy, water, pipeline, refuelling stations, etc. The sizing of electrolyser and RE installed capacity are critical which will drive the economics of green hydrogen.

3.4.6 Opportunity of Hydrogen blending

Governments and gas utilities worldwide are seeking to reduce their carbon footprint by injecting green hydrogen directly into a natural gas distribution system, displacing existing fossil fuel consumption. When implemented at relatively low concentrations, less 10% hydrogen by volume, utilities can transition without significantly increasing risks associated with utilization of the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network.

Ramagundam region has City Gas Distribution (CGD) network being operated by Indian Oil Corporation Limited. In future, there could be an opportunity to blend hydrogen in the gas network. In the last 2 -3 years, there have been few instances of hydrogen blending in the CGD network in India:

Project sponsor	Project details
GAIL	Blending of 2%/5% green H_2 in CNG/PNG network at city gas stations of Avantika Gas.
NTPC and Gujarat Gas	Blending of 8% green H_2 in PNG network at NTPC Kawas township in Surat.
Adani Total Gas	Blending of 8% green H_2 in PNG network at Ahmedabad, targeting 4,000 residential and commercial customers, with pilot expected to commence in H1FY25

[33] https://energy.greenbusinesscentre.com/energyawards/enepresent22/General/AGI%20Glaspac.pdf

IGL	Blending green H_2 in the PNG network of IGL, and exploring the potential for green H_2 plants and electrolyzers.

All of the above projects are in pilot scale. The goal of these projects is to see physical impact of H_2 on pipeline infra and equipment. Hydrogen causes embrittlement in metals, due to which normal gas pipelines have a tolerance level (up to 20% blending is cited to be possible with no major risks). While dedicated H_2 pipelines with specialized materials & coatings can be set up, but sizable costs are involved and, hence, good volume visibility over the long term and scale is required.

Apart from material condition impact, blending is expected to increase the price of delivered PNG. Currently at ~USD 4.5/kg estimated green H_2 cost, every 5% blending can lead to 5 – 6% increase in delivered PNG price.

	Green H_2 PNG blending cost at USD 4.5/kg price					
	kCal/kg	SCM/kg	Retail price (Rs/SCM)	Retail price (Rs/kg)	Price (Rs/Mn Cal)	Change
Green H_2	28500	11.2	32.9	369	12.9	
PNG	12000	1.4	51.0	71.4	6.0	
H_2 blend	5%	PNG RSP			6.3	**6%**
H_2 blend	10%	PNG RSP			6.7	**12%**
H_2 blend	15%	PNG RSP			7.0	**18%**
H_2 blend	20%	PNG RSP			7.4	**24%**

Note: RSP – Retail Selling Price; prices of PNG are as per prevailing price.

Infrastructure requirement:

Hydrogen is blended normally in the transmission network, which is made of steel. The blending infrastructure includes electrolyser system (mostly decentralized), hydrogen storage and blending skid.

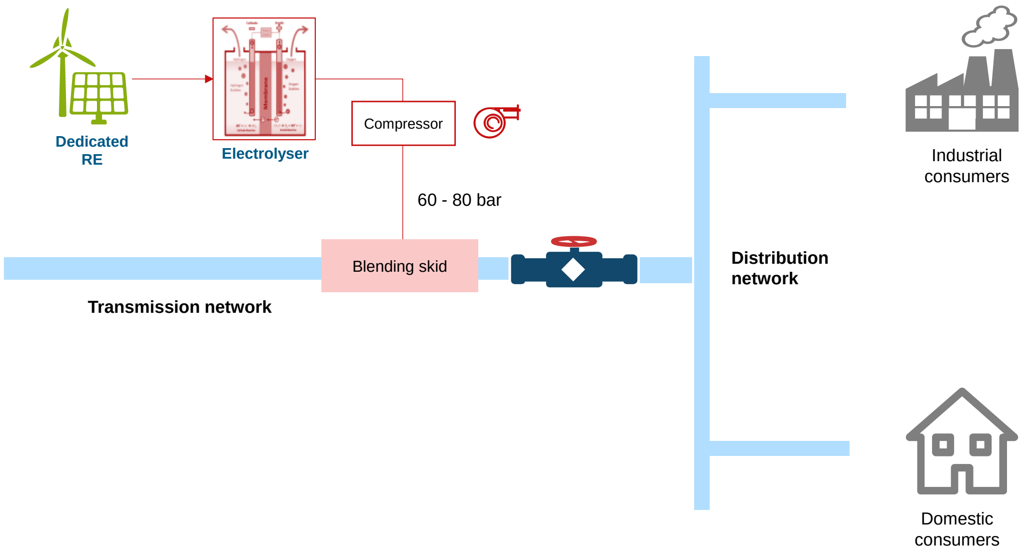
- Electrolyser system: Depending on the blending percentage, a decentralized electrolyser system is installed. This may vary from KW scale to MW scale.
- Compressor and Storage: Compressed hydrogen storage (steel tank) is provided with a capacity of 8-10 hours of storage.
- **Blending skid**: The blending skid is basically a Pressure Reducing Skid (PRS), which ensures accurate injection & blending of hydrogen and prevention of leakages and/or permeation. Accurate injection and blending of hydrogen are essential to ensure that the blended gas meets the desired specifications and is safe to use. This requires precise control over the flow rate and composition of both natural gas and hydrogen, as well as careful monitoring of the blending process to ensure that the two gases are thoroughly mixed.

  The critical components of the blending skid are the pressure regulator, flow regulator, leak and flame detection system, Programmable Logic Control (PLC) system, control valves and associate instrumentations. Preventing leakage of hydrogen is crucial to ensure the safety of the distribution network and the surrounding environment. Therefore, the blending system must be designed with appropriate materials and components, including seals and valves that can withstand the corrosive properties of hydrogen. Regular maintenance and monitoring of the distribution system are also necessary to detect any leaks or potential safety hazards.

The PRS broadly will have following components

- **Inbuilt Safety** : Being a high-pressure section two level safeties are incorporated at first stage regulator i.e. Safety shutoff loop & full capacity safety relief valve to safeguard the further equipment's in case of malfunction of the regulator.
- **Pressure Regulator** : The pressure regulator reduces the pressure of the high-pressure hydrogen gas to the required level for injection into the natural gas pipeline.
- **Pressure Gauge** : The pressure gauge measures the pressure of the hydrogen gas before and after the pressure regulator.
- **Safety Relief Valve** : The safety relief valve is a safety device that opens automatically to relieve pressure in case of an overpressure event.
- **Filter** : A filter is typically used to remove any impurities or moisture from the hydrogen gas before it enters the natural gas pipeline.

- **Flow Meter** : A flow meter is used to measure the flow rate of the hydrogen gas entering the natural gas pipeline.
- **Control System** : A control system is used to monitor and control the operation of the PRS.



In the context of the Ramagundam Hydrogen valley, the blending pilot can be initiated in the IOCL PNG network with ~5% blending by volume, which is inline with the other pilots undertaken in India. However, the cost of delivered PNG price may increase by 5-6% with ~5% blending.

3.5 Sustainability dimensions along the project value chain

Any responsible investor should consider specific sustainability dimensions along the project value chain for undertaking socio-economic and environmental impact studies.

Table 12: Sustainability dimensions along the project value chain

Dimensions	**Key issues**	**Description**
Energy, Emissions and Climate change	GHG emissions	• Reduce total CO_2 equivalent emissions per ton of product • Reduce Scope 2 and 3 emissions • Develop and prioritize a list of viable greenhouse gas reduction capital projects.
	Energy Management	• Reduce Specific Energy Consumption by implementing energy efficiency measures and potential fuel shift
	Air Quality	• Maintain a clean air quality with continuous monitoring mechanism
	Water Management	• Identify and evaluate a list of viable water reuse/ reduction projects. • Develop integrated water resource management plans to ensure sustainable withdrawals and discharges.
Workplace & Communities	Workforce Health and Safety	• Train and certify compliance with the Environmental, Health, Safety, and Security Policy for all employees annually
	Process Safety, Emergency Preparedness, & Response	• Train the employees and workers on process safety and emergency response; develop SOPs and make those accessible to everyone.
	Training and Development	• Develop training programs and design growth paths for employees
	Inclusion, Diversity, & Equity	• Increase representation of females in leadership roles

		• Train on inclusion, diversity and equity matters for all employees annually. • Develop pathways for traditionally underrepresented employee groups with the ultimate goal of increasing the hiring and promotion of underrepresented groups. • Increase engagement and support with local communities and expand the corporate giving philosophy to include environmental sustainability
	Safety & Environmental Stewardship of Chemicals	• Identify and complete safety critical equipment inspections per schedule
Ethics & Governance	Ethics	• Train and certify compliance with the Code of Corporate Conduct for all employees annually. • Train and certify compliance with the Anti-corruption Compliance Policy for all employees annually
	Reporting, Management of Legal & Regulatory Environment	• Begin to report and disclose Company data in accordance with the Task Force on Climate-related Financial Disclosures (TCFD) framework for climate related risks and opportunities, in addition to the Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB) • Engage suppliers and service providers that annually represent 50% of the Company's total procurement and supply chain expenditures and assess their ESG performance and commitment.

Each of the above dimensions are aligned with UN SDGs and investors should focus on prioritizing the above issues and work closely with stakeholders to address those along the project value chain.

Implementation of the hydrogen valley will help in achieving the above sustainability dimensions; however, it will also come with the risk of Hydrogen leakage across the end-use categories:

Area	Impact of the hydrogen valley
CO_2 reduction	Implementation of hydrogen valley would avoid the CO_2 emission by substituting the fossil based fuel: • Short term : 0.01 Mn ton CO_2 • Medium term: 0.05 Mn ton CO_2 • Long term: 0.27 Mn ton CO_2
Risk of Hydrogen leakage	Hydrogen leakage is a major challenge in developing and implementing a hydrogen ecosystem. This will require implementation of comprehensive solution that prevents leakages and/or permeation, which includes: • Inbuilt safety features to control the operation of pressure regulator • Safety/pressure relief valve • Adequate valves and sealing arrangement • Flame and gas leakage detector

3.6 Infrastructure for green hydrogen valley in Ramagundam

The supply side infrastructure include following elements:

- RE Power and energy storage
- Electrolyser system (stack and Balance of Plant)
- Hydrogen storage
- Distribution infrastructure – pipeline, trucks etc.
- Hydrogen refuelling stations.

Based on the RE profile in the Telangana region, RE capacity, energy storage and electrolyser size will be optimized in order to achieve lowest Levelized cost of Hydrogen (LCOH). An optimization modelling technique was adopted to determine the sizing of RE and electrolyser.

3.6.1 Optimisation model for RE and electrolyser sizing

Optimal electrolyser and RE sizing is critical to ensure that the hydrogen produced in the valley is cost competitive with respect to the willingness to pay of the identified off-takers. The optimization model minimizes the annualized fixed cost and the operational expenses (grid power usage).

The output of the electrolyser is fixed in the short, medium, and long term at ~2.62 TPD, 14.5 TPD, and ~75 TPD respectively. The boundary conditions allow the optimizer to match the daily hydrogen production from the electrolyser with the daily requirement. It is assumed that the hydrogen produced is compressed and stored in a storage tank for further transfer.

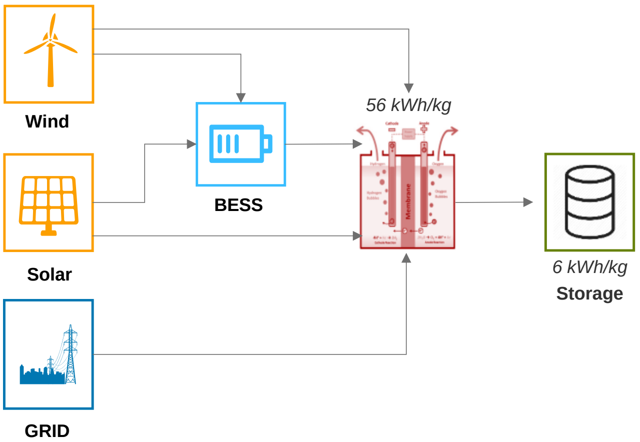


Figure 8: Hydrogen production setup and associated energy consumption

Recently, MNRE has issued the definition for green hydrogen having emission threshold of 2 kg CO_2 equivalent / kg H_2 as 12-month average[34]. As per the notification, well to gate emissions include water treatment, electrolysis, gas purification, drying and compression of hydrogen processes thus, some amount of grid power will be permissible, based on grid emission intensity, for green hydrogen production.

For the Ramagundam hydrogen valley, two production setups have been evaluated for determining the LCOH.

- **Option 1**: Hydrogen production with permissible grid power procurement (4 – 5% as per India's current gid emission intensity[35]). If the emission intensity of Telangana state is considered, ~4.5% of the electricity can be taken from the grid.[36] [37]
- **Option 2**: Hydrogen production with no grid procurement

The optimization model leveraged excel based open solver application. The objective function of the optimization model minimizes the annualized fixed cost and the operational expenditure, as illustrated below:

$$\boldsymbol{Objective\ function = Min\ (AFC(Solar, Wind, BESS, Electrolyser) + Opex(Electricity\ from\ grid))}$$

Major annual cost elements are tabulated below.

[34] PIB. India announces definition of Green Hydrogen (access here)
[35] Considering grid intensity of 711 gCO_2/kWh of electricity produced in India
[36] Considering grid emission intensity of 736 gCO_2/kWh of electricity procured by TSNPDCL in tariff filings for FY24. (access here)
[37] Grid electricity will help in optimization of BESS and electrolyser size

Table 13: Key assumptions for annual cost of hydrogen production

Sl.	Particular	Capital expenditure	Annualized fixed cost input (time period)
1.	Solar Generation unit	INR 4.5 – 5 Cr/MW	~INR 0.59 Cr/MW (25 years)
2.	Wind Generation unit	INR 7 – 7.5 Cr/MW	~INR 0.88 Cr/MW (25 years)
3.	BESS (2 hours)	INR 3.5 Cr/MW	~INR 0.58 Cr/MW (12 years)
4.	Alkaline electrolyser	INR 7 – 7.5 Cr/MW	~INR 1.04 Cr/MW (Short-term) ~INR 0.78 Cr/MW (Medium-term) ~INR 0.68 Cr/MW (Long-term)[38]; (25 years)

Other assumptions for the optimisation model are:

- Annual escalation of grid tariff (from TSNPDCL) is considered as 1%[39].
- The quantum of electricity that can be procured from the grid depends on the emission intensity of the grid and the emission threshold as per MNRE norms.
- The minimum electrolyser loading is assumed to be 50%.
- Round trip efficiency of BESS is assumed to be 85%.
- Power procurement from GDAM (Green Day Ahead Market) has not been considered for the valley due to implementation challenges such as scheduling and probability of getting cleared on a daily basis.
- With the availability of pipeline to supply hydrogen to RFCL (largest demand activator), hydrogen storage capacity of 3 days has been considered for all other applications.
- **Route of RE procurement**: Group captive/Captive RE route of RE procurement has been considered to minimize landed cost of electricity by avoiding cross subsidy surcharges (CS) and additional surcharges (AS).
- **Grid tariff** from the state's Discom is calculated to be ~INR 7.22/kWh in the short-term and ~INR 7.67/kWh in the medium- and long-term.

With the help of above stated assumptions, the optimization model provides us with the sizing (of RE, electrolyser) required to meet the valley's daily green hydrogen needs. The cost of hydrogen generation is further represented through the Levelized Cost of Hydrogen (LCOH) which accounts for the hydrogen production cost for the setup throughout the life of the project.

The assumptions for the LCOH model are provided below:

Description	Unit	Assumption
Operation phase assumptions		
Project Life	Years	25
Production Capacity		
Electrolyser capacity	MW	As per the optimisation results
Electrolyser efficiency	%	0.68
Electrolyser CUF	%	70 – 80% (as per outcome of optimisation model)
Electricity required for H_2 production (including BOP)	KWh / Kg H_2	56
Additional electricity required for compression and storing	KWh / Kg H_2	6
O&M expenses		
First year O&M expense	% of capital cost	1.5%
Annual escalation	%	4.0%
Stack lifetime between refurbishes	Years	10
Refurbishment costs	% of capital cost	30.0%
Water usage assumptions		

[38] Considering a 25% reduction in Capital expenditure by 2030 from 2024 figures and 35% for electrolysers beyond 2030
[39] The tariffs have been adequately levelized for a 25-year period at the WACC of the electrolyser facility (~8.63%)

Description	Unit	Assumption
Water requirement for GH_2 (DM+cooling)	Litre / Kg of H_2	42
Water cost	INR / Litre	0.08
Landed cost of electricity (Levelized)	INR / KWh	As per RE sizing obtained from optimization
Depreciation		
Maximum depreciation (SLM method for book depreciation)	%	100%
Tax depreciation rate (WDV method)	%	15%
Depreciation timeline for refurbishment costs	Years	5
Financing Assumptions		
Capital Structure		
Debt: Equity	%	70:30
Return on equity (post tax)	%	12%
USD to INR exchange rate	INR / USD	83
Exchange Rate Variation	%	0%
Domestic loan details		
Repayment period	Years	10
Interest rate during construction	%	9%
Interest rate post commissioning	%	9%
Loan processing fee	%	0%
Refurbishment loan details		
Repayment period	Years	5
Interest rate	%	10%
Corporate tax rate	%	25.17%
Working Capital Assumptions		
Debtor days	days	30
Creditor days	days	30
Interest on working capital	%	11%

3.6.1.1 *Option 1: Hydrogen production with permissible grid power procurement*

The southern region in India has the best wind generation profile in India and second-best solar power generation profile after northern India (including Rajasthan). Based on the daily hydrogen demand, RE and electrolyser system are sized, so that electrolyser works with the minimum loading (50%) and is adequately ramped up during high RE generation hours to meet the daily demand.

The key outputs from the optimizer for the short- and long-term demand of hydrogen in the valley are captured below.

Table 14: Techno-economic assessment for Option 1

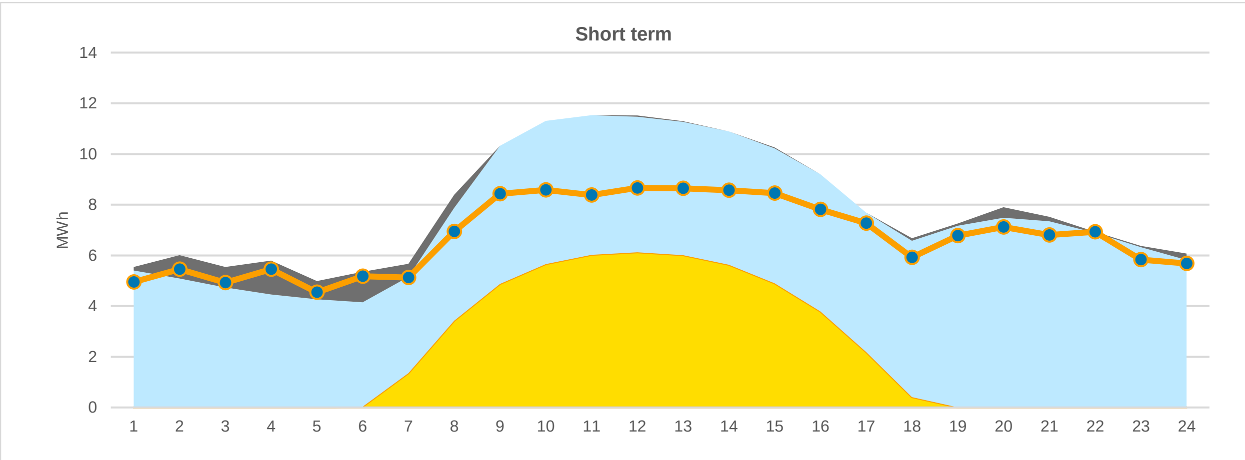
Particular \ Timeframe		Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
	Electrolyser capacity (MW)	8.68	48.05	252.60
	Solar (MW)	7.49	41.43	215.89
	Wind (MW)	15.74	87.12	447.48
	Grid power usage (%)	4.5%	4.5%	4.5%

Particular / Timeframe		Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
	Electrolyser CUF (%)	78.0%	78.0%	76.7%
	BESS 2 hour (MW)	0.00	0.00	0.00
	H_2 Storage (MT)	0.00	0.00	0.00
	Landed cost of electricity (INR/kWh)	4.14	4.16	4.15
	LCOH (USD/kg)	4.22	4.25	3.96
	Monthly operational expenses (INR Cr)	**2.14 – 2.30**	**12 – 13**	**60 – 65**

Note:

- The electrolyser sizing is done considering the monthly averages. The model captures the best and worst RE generation months and it determines sizing considering these days as well. The model also matches green hydrogen production with the valley's green hydrogen requirements on a daily basis.
- The above RE mix is an optimized configuration. However, actual mix may change based on availability of sites and transmission network.
- The operational expense of the hydrogen production unit consists of the O&M expense and the electricity consumed to run the electrolysis process. This amount will be the monthly cash outflow by the valley operator.

The loading of the electrolyser vis-à-vis the RE power generation, grid power usage and BESS discharge are shown below for the short- and long-term hydrogen demand.



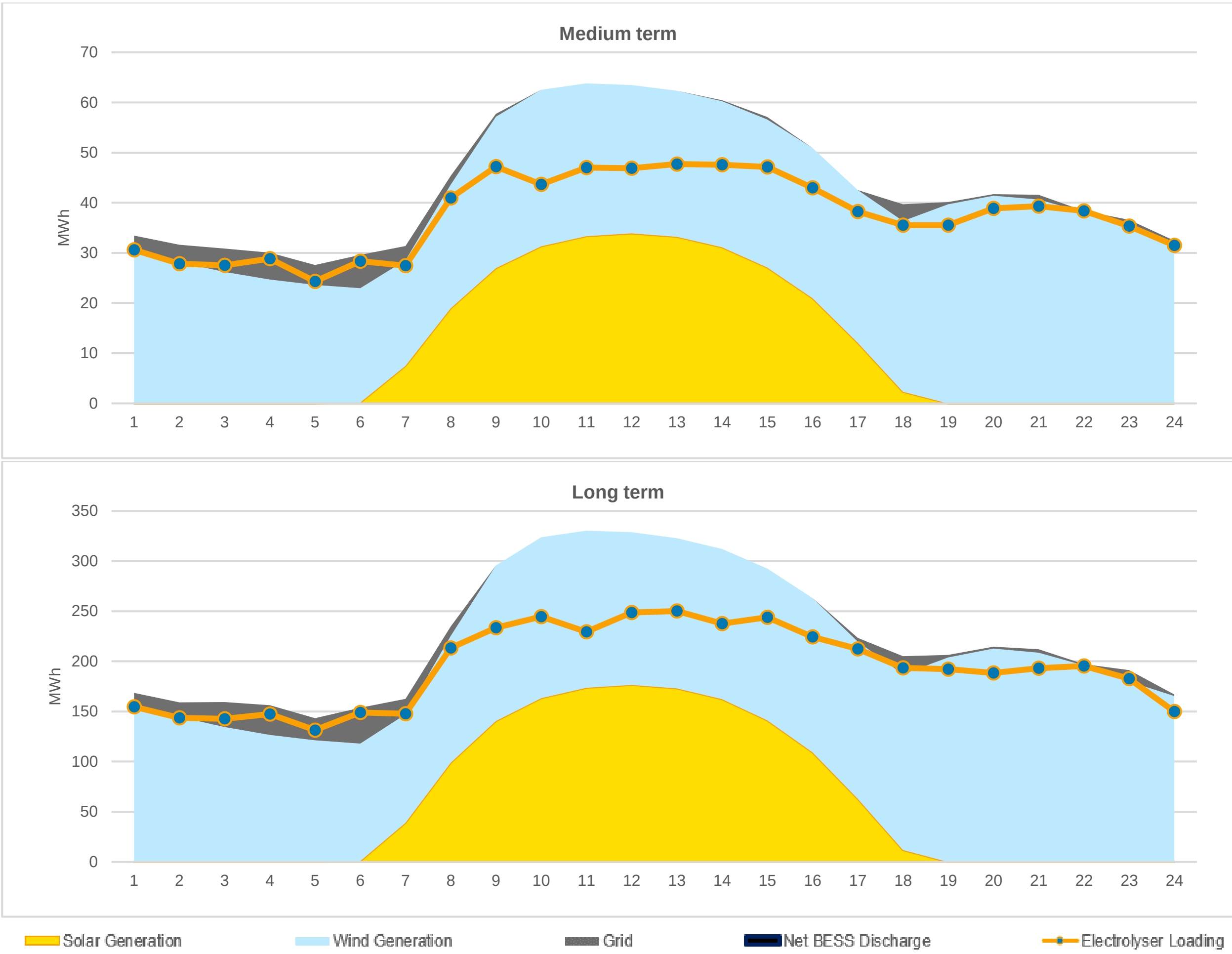


Figure 9: Electrolyser loading, RE generation and net battery discharge under option 1

3.6.1.2 Option 2: Hydrogen production with no grid procurement

In place of diversifying the power procurement mix for the electrolyser with RE sources and grid, an off-grid solution can also be developed to reduce reliance on the grid. Given the strong RE generation profiles in Southern India, the hydrogen valley in Telangana can opt for such a solution.

Table 15: Techno-economic assessment under Option 2

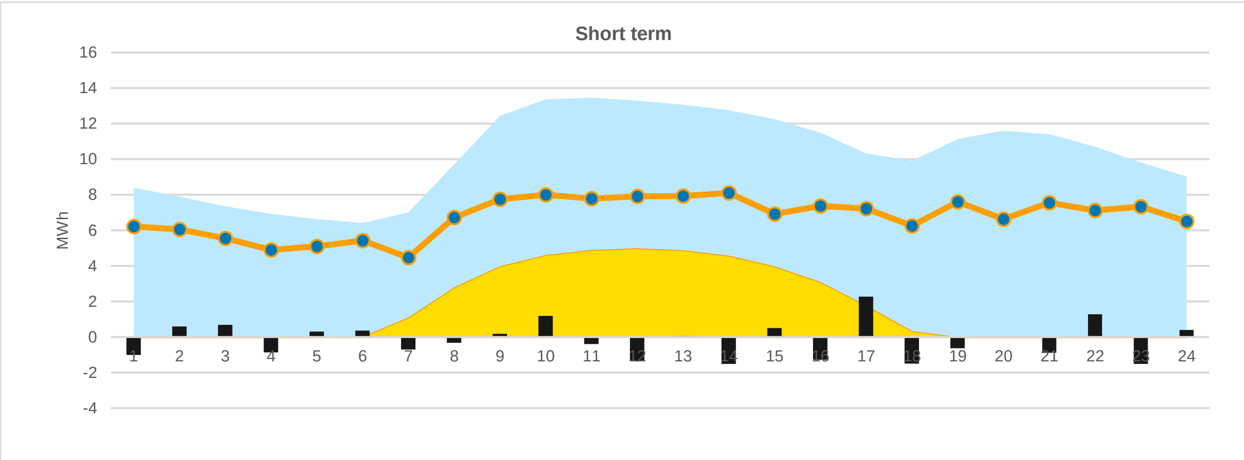
Timeframe / Particular	Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
Electrolyser capacity (MW)	8.10	44.85	231.34
Solar (MW)	6.10	33.77	169.15
Wind (MW)	24.44	135.25	705.06
Grid power usage (%)	0.00%	0.00%	0.00%
Electrolyser CUF (%)	83.5%	83.5%	83.8%
BESS 2 hour (MW)	4.05	22.42	110.70

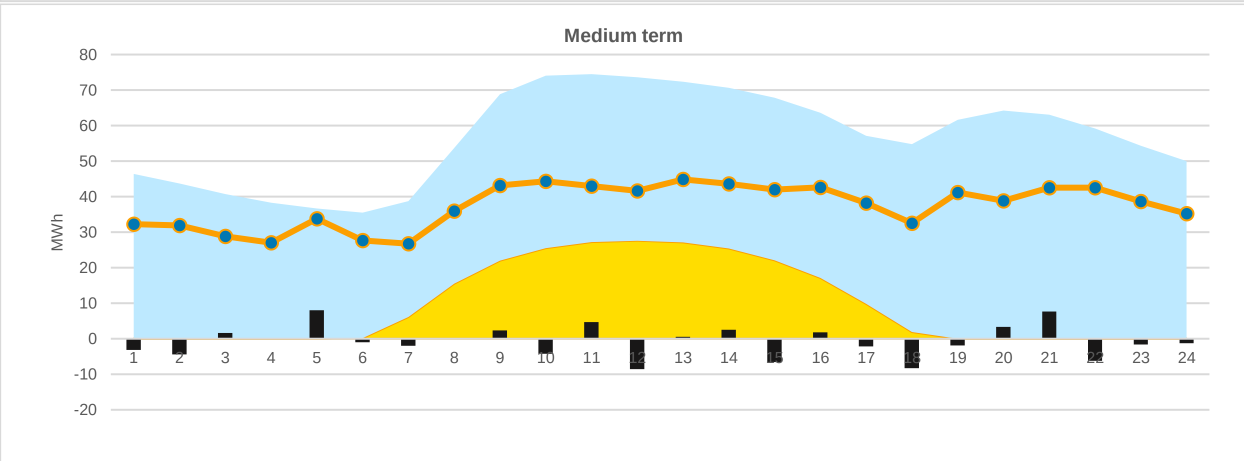
Particular / Timeframe		Short-term [Pilot stage]	Medium-term [2030]	Long-term [2030 - 2040]
	H_2 Storage (MT)	0.00	0.00	0.00
	Landed cost of electricity (INR/kWh)	5.60	5.60	5.60
	LCOH (USD/kg)	5.13	5.18	4.87
	Monthly operational expenses (INR Cr)	**2.85 – 3**	**15.5 – 17**	**80 - 85**

Note:

- The electrolyser sizing is done considering the monthly averages. The model captures the best and worst RE generation months and it determines sizing considering these days as well. The model also matches green hydrogen production with the valley's green hydrogen requirements on a daily basis.
- The above RE mix is an optimized configuration. However, actual mix may change based on availability of sites and transmission network.
- The operational expense of the hydrogen production unit consists of the O&M expense and the electricity consumed to run the electrolysis process. This amount will be the monthly cash outflow by the valley operator.

The loading of the electrolyser vis-à-vis the RE power generation, grid power usage and BESS discharge are shown below for the short- and long-term hydrogen demand.





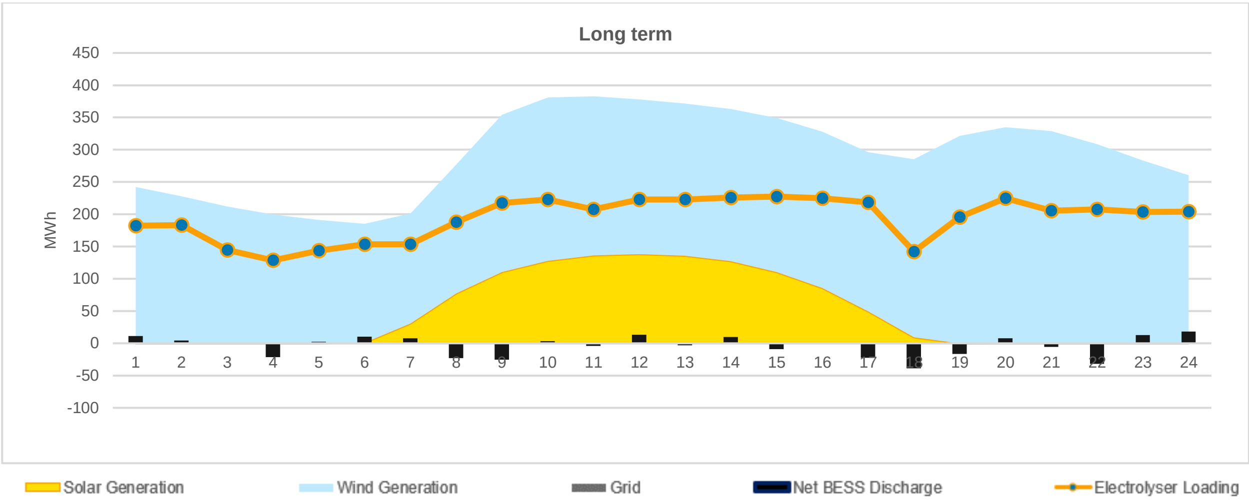


Figure 10: Electrolyser loading, RE generation and net battery discharge under option 2

In Option 1, the permissible grid power (~4.5%) manages the intermittency of RE generation, which obviates the requirement of BESS and also minimizes the landed cost of electricity. In the Option 2, BESS is required to manage the variability of RE, which increases the landed cost of electricity.

3.6.2 Land requirement for hydrogen production in the valley

The hydrogen production facility in the short-term (pilot phase) has been planned within SCCL's facilities. One of the key advantages for the location is its proximity to RFCL (less than 1 km) which is the largest off-taker. In the long term also, RFCL is expected to be the largest off-taker with 45 TPD demand out of total demand of 75 TPD. Therefore, expansion for future capacity in the SCCL facility is the most preferred option.

The land required for production of hydrogen in the short, medium, and long-term is captured below[40].

Table 16: Land requirement for electrolyser system

Power procurement	Timeframe	Electrolyser sizing (MW)	Land required (acres)
Option 1: RE + Permissible grid power	Short	8.68	0.21
	Medium	48.05	1.15
	Long	252.60	6.06
Option 2: Off-grid (RE + BESS)	Short	8.10	0.19
	Medium	44.85	1.08
	Long	231.34	5.55

In the short-term, the land required for the electrolyser system is around 0.2 acres which would need to be demarcated in the SCCL premises. Given the strategic location of SCCL and RFCL in close proximity, the electrolyser capacity expansion should also take place near the SCCL premise. The land required for ~200 – 250 MW electrolyser system would be 5.5 – 6.5 acres. The stated quantum of land is only for the electrolyser facilities and doesn't account for the land required to establish the RE capacities in the short to long term.

[40] 24 acres of land is required per GW of electrolyser

As per the Environment Sustainability report 2021 – 22 by Ministry of Coal, SCCL Ramagundam has ~933 ha (~2300 acres) of land under lease of which 13% is the active mining area and 67% of the land is reclaimed area[41].

Therefore, the area required for the hydrogen plant can be accommodated in SCCL land, even in the long term. However, land acquisition must be initiated with appropriate arrangement (e.g. leasing).

In addition, the transport sector off-takers viz. TGSRTC, MyHome would require setting up refuelling stations for operating their hydrogen fueled vehicles. For TGSRTC, the hydrogen refuelling station can be installed in the SCCL facility or the nearest TGSRTC bus depot/ station which is ~6.5 – 7 kms away from the SCCL premises. **The green hydrogen produced in the facility can be transported to the refuelling stations through tankers through cascaded deliveries.**

3.6.3 Water requirement for hydrogen production in the valley

Water is the key feedstock for the electrolysis process. The usage of river water from Godavari is recommended for electrolysis process. The water storage is 25 km away from the SCCL premises which is expected to be the prime source of water for the electrolyser. The quantum of water required for the electrolyser basis daily hydrogen requirement is captured below.

Table 17: Water requirement in the hydrogen valley

Timeframe	Daily H_2 requirement	Water requirement (Mn liters/day)
Short	2.62 TPD	0.12 – 0.15
Medium	14.5 TPD	0.7 – 0.8
Long	75 TPD	3.5 – 4.1

Note: DM water and treated cooling water requirement per kg of green hydrogen is 10 kg and 25 - 35 kg respectively. Total raw water requirement is expected to be 45 – 50 kg per kg of H_2

Considering the large amount of water required, for electrolysis and cooling, sourcing is envisaged from Godavari river. The requirement for the project can be met from the Sripada Yellampalli barrage Project.

Sripada Yellampalli Project is an irrigation project located at Yellampalli Village of Ramagundam. It is the fourth largest on the Godavari River. Water requirement of few of the recent large scale projects, such as Ramagundam 1600 MW thermal power project, has been allocated from this project.

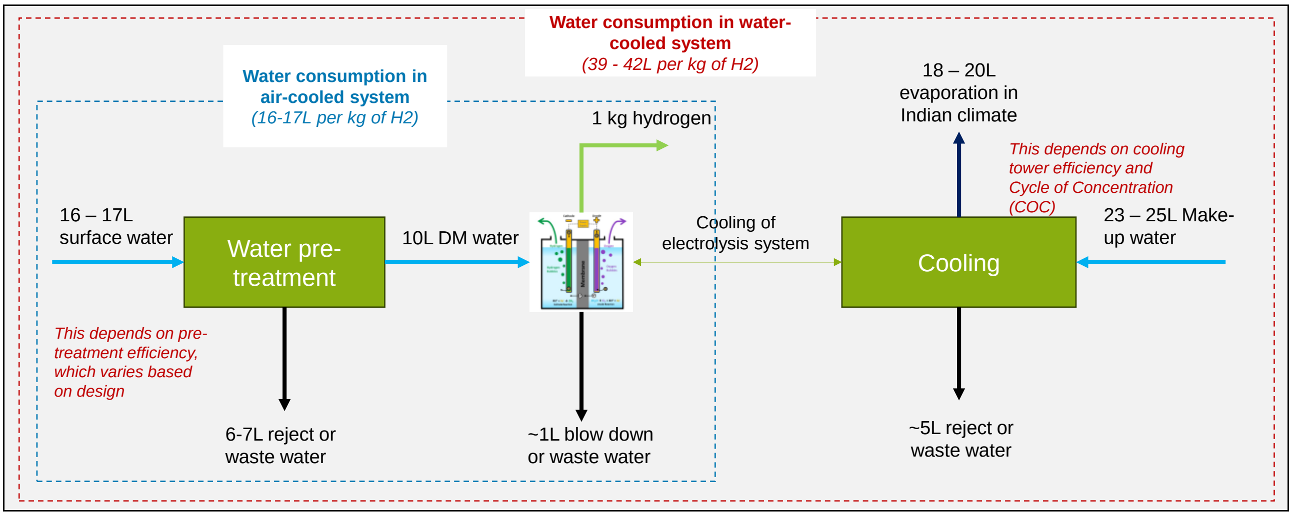
Water storage availability in the reservoir is indicated below:

Reservoir	Water storage (Thousand Million Cubic Ft)	Distance from SCCL facility (km)	Remark
Sripada Yellampalli	~20	~25	Sufficient storage capacity is available, which can provide water to Hydrogen valley.

Source: Andhra Pradesh Water Resources Information and Management System

Illustration of water requirement in Hydrogen production:

[41] Ministry of Coal. Status of environmental sustainability in coal mines 2021 – 2022 (access here)



Source: Deloitte analysis

3.6.4 Transmission infrastructure in Telangana

As on FY23, the transmission utility of the state TSTRANCO has 25 Nos. of 400kV Substations, 101 Nos. of 220kV Substations, 250 Nos. of 132kV Substations and 27849 CKM of EHT lines. The utility had transmission losses of ~2.52%. TSTRANSCO serves the installed capacity of ~18.5 GW in the state comprising of 4042.5 MW of Thermal, 2430.60 MW of Hydel, 11.16 MW of Mini Hydel, 1200 MW of Singareni TPP, 1000 MW of Chhattisgarh Power, 76.31 MW of Interstate Hydel, 24.51MW of APGPCL, 2502 MW of CGS Share, 5595 MW of NCE, 807.31 MW of IPP's and 839.45 MW of Sembcorp (TPCIL)[42].

As per the APR (Annual Performance Review) filed by TSTRANSCO for FY22[43], availability was 99.98%. However, as per the MYT (Multi-year tariff) of TRANSCO filed with TSERC in 2020[44], the utility was approved to provide availability of 99.99%. Thus, the transmission utility of the state has ample coverage to provide services to the public and private entities (on both generation and consumption fronts).

In light of the growing demand of the state and the expected consumer category wise growth in the state, TSTRANSCO has outlined resource plans amounting to ~INR 1,616 Crores for sub-stations and transmission lines[45]. The resource plans for period FY2025 – FY2030 are as follows:

Table 18: Envisaged resource planning by TSTRANSCO for control period FY25 – 29

Period	Sub-stations (nos.)			Lines (Ckm)		
	400 kV	220 kV	132 kV	400 kV	220 kV	132 kV
FY25	0	5	13	0	99.00	441.03
FY26	1	1	4	0	318.00	548.30
FY27	0	2	5	0	4.00	202.50
FY28	0	3	12	0	28.00	231.60
FY29	0	1	1	0	0	190.80
Total	**1**	**12**	**35**	**0**	**449.00**	**1614.23**

It is assumed that the RE capacity required to power the electrolyser in the hydrogen valley would be installed in the state's RE rich regions. The RE installation would be connected to the state transmission network. The STU would carry out a load flow study for the assessing the augmentation requirement and execute the transmission system addition. Once operational,

42 TSTRANSCO Resource Plan Petition (access here)
43 TSTRANSCO, ANNUAL PERFORMANCE REVIEW OF TRANSMISSION CORPORATION OF TELANGANA LIMITED (access here)
44 TSERC, AGGREGATE REVENUE REQUIREMENT AND TRANSMISSION TARIFF FOR 4 TH CONTROL PERIOD (FY 2019-20 TO FY 2023-24) (access here)
45 The resource plan includes power transformer augmentation, reactors/ capacitors, and bay extensions as well.

the transmission charges would be borne by the valley developer. The LCOE would be calculated including the state transmission charges of the state of Telangana, as decided by the State Electricity Regulatory Commission.

It should be noted that Telangana State Electricity Regulatory Commission (TSERC) has unveiled new regulations for its consumers to promote green energy across the State. As per the Regulation, termed as TSERC's (Terms and Conditions of Open Access) Regulation, 2024, consumers with a contracted or sanctioned load of 100 kW or more are eligible for Green Energy Open Access (GEOA). This Regulation shall extend to whole of Telangana State.

As per the Commission, this Regulation shall apply to open access users (including captive users and GEOA users) for use of intra-State transmission system (In-STS) or distribution system in the Telangana State, including when such system is used in conjunction with inter-State transmission system. These regulations align with the GEOA guidelines released by the Ministry of Power in June 2023. The duration of the consumer's use of the intra-state transmission or distribution system determines their category viz. long-term (7 to 25 years), medium-term (one month to seven years), or short-term (less than a month).

In this analysis, valley developer is assumed to source RE through captive route to reduce the landed cost of electricity (few charges like Cross Subsidy Surcharge, Additional Surcharge would not be applicable). The state of Telangana has sufficient RE potential – 21 GW solar and 24 GW wind; it has a vast solar potential with average solar insolation of nearly 5.5 kWh/m2 for more than 300 sunshine days.

Some of the potential RE rich locations are Medak, Mahbubnagar, Adilabad, Khammam, Nalgonda etc. If RE is sourced from any other region (e.g., AP or Karnataka or Tamil Nadu), additional transmission charge will be added in the landed cost of electricity.

Therefore, the valley developer has an option to leverage the favourable open access policy of Telangana. RE capacity requirement would be ~1 GW (Solar + Wind), which can be met through intra-state transmission network. Charges applicable would be as per the regulations defined by the State Electricity Regulatory Commission.

3.6.5 Additional infrastructure required in the hydrogen valley for envisaged demands

Apart from the RE, electrolyser system and hydrogen storage, additional infrastructure is required to develop and operate the valley, as illustrated below:

Table 19: Additional infrastructure requirement in short and long term

Infrastructure requirement	Timeline			Remark
	Short-term demand	Medium-term demand	Long term demand	
Water pipeline	Can be arranged from Municipality (~0.1 MLD)	~25 km water pipeline from Godavari to SCCL H_2 plant site for ~1 MLD	~4 MLD water connection in the long run	For pilot project, water can also be arranged through the Municipal corporation. There is an existing pipeline from Godavari to RFCL and SCCL; an evaluation is required if that pipeline can be used for additional water in the medium term
Hydrogen Pipeline	**~1 km** pipeline with capacity **~100 kg/hour** from plant site to RFCL facility at 50 bar pressure	~1 km pipeline with capacity ~250 kg/hour from plant site to RFCL facility at 50 bar pressure	~1 km pipeline with capacity ~1900 kg/hour from plant site to RFCL facility at 50 bar pressure	Enhanced capacity can be augmented in the future based on actual requirement
Hydrogen Storage	**~1.2 Ton**	~18 Ton	~60 Ton	Considering demand from industries other than RFCL.
Hydrogen Refuelling station (HRS)	1 refuelling station in SCCL site	8 refuelling station in SCCL site, MyHome site and TGSRTC depot	25 – 28 refuelling station in SCCL site, TGSRTC depot and Kodad (MyHome cement plant)	In the short term, 1 TPD HRS will be deployed; in the medium and long term 2 TPD HRS would be deployed
Truck for Hydrogen transportation	Hydrogen truck **(Tube Trailer)** will be deployed to transport H_2			GH_2 supply is cost competitive up to **approx. 500 km distance**

Infrastructure requirement	Timeline			Remark
	Short-term demand	Medium-term demand	Long term demand	
	to AGI Glaspac plant located at a distance of 240 km			

Supply side infrastructures are required to be built in gradual manner as hydrogen demand and electrolyser capacity increases. Setting-up pipelines, Hydrogen Refuelling Systems (HRS) and deployment of tube trailer or transport trucks are critical to activate the use cases.

4 Roadmap for hydrogen valley in Ramagundam

While hydrogen valleys bear benefits to the development of the hydrogen economy, there are several factors to consider before establishing a hydrogen valley, which include identification of land, arranging investment, the availability of technology and infrastructure, availability of ecosystem players etc.

4.1 Key success factors for Hydrogen Valley development

- **Location identification**: Selecting the right location to establish a hydrogen hub is one of the most critical factors to consider in its development. The location must have renewable energy sources to generate electricity, water sources and a concentration of demand centres.

- **Concentrated demand with offtake certainty**: The valley should consist of credible off-takers from end-use industries that serve as a direct market for the product in a cost-competitive manner. A concentrated demand would serve as the foundation of a hydrogen valley. This will also help in optimization of capital cost through sharing of infrastructure.

- **Availability of funding sources and sponsorship**: This is probably the most important factor for valley development. Hydrogen production and development of associated infrastructure is very capital intensive. This includes production, storage, transportation, and distribution to consumers. A mix of public and private funding sources is crucial to scale up hydrogen valley development. Ideally, a hydrogen valley should have a project sponsor—an organizing entity that identifies various stakeholders and brings them together around the vision for the project. The sponsor is not only a coordinator and organizer, but also an investor and risk-taking leader that is willing to catalyze the valley by investing in pilot projects as a first step to encourage other actors to co-invest[46]. The sponsor (also an investor) paves the way in this manner, demonstrating the project's viability while gaining the interest of other potential investors towards the project. The necessary infrastructure (such as pipelines, storage tanks, and refuelling stations) is set up through these investments, improving the project viability.

- **Creation of a business case**: A techno-economic business case to establish viability is also critical. It is necessary to compare the costs associated with using hydrogen against traditional fuels or applications as well as the "willingness to pay" of end consumers. The business case also helps to identify gaps in the economic parameters, which can potentially be addressed through subsidies and incentives. The sizing and scale-up strategy can be done based on techno-economic business case.

- **Policy and incentive support:** Many of the barriers for hydrogen adoption — including its high cost, the uncertainty about future demand and market development, and the lack of a formal market—can be resolved through favourable policies and regulations. A mix of financial (incentives, subsidies etc.) and non-financial (mandates, ease of doing business etc.) policy measures can provide considerable support to green hydrogen adoption. For example, specific subsidies in the form of capital grant, waiver of electricity charges as well as setting roadmaps, strategies, and targets help create confidence among investor community.

  Finally, regulations are also an important part of creating a formal hydrogen economy. Bodies that regulate the use of hydrogen will formalize standards for hydrogen applications, technical standards (e.g., pressure at which hydrogen must be kept for storage & fueling), and safety.

The roadmap shall factor in the above success factors and provide the basis for decision-making for the formation of an integrated Hydrogen valley. It will outline the necessary SPV structure, the governance structures and capacity to be created, need of infrastructure development, investment required and ecosystem players to be onboarded. The roadmap will also elaborate on the ways to engage key stakeholders.

4.2 Framework for roadmap development

This roadmap framework outlines a structured approach to developing a "Hydrogen Valley" factoring in the key elements of feasibility, policy, partnerships, technology, infrastructure and investment. It is critical to successfully develop a vision for the valley development, followed by implementation of a pilot hydrogen project, followed by scaling-up to a large-scale deployment. Implementation of pilot project is necessary to instill confidence among investors and stakeholders. The requisite activities for developing the roadmap are illustrated below:

[46] Engie: Hydrogen Valleys: A Gateway to the Coming Hydrogen Revolution

1 Pre-Pilot stage

1. Preparation of objective, vision and strategy for the GH2 valley in Ramagundam
2. Identification of key stakeholders for the valley
3. Development of communication and awareness campaign for the green hydrogen valley
4. Engagement with stakeholders to identify requirements and delivery needs
5. High-level feasibility study to gauge the willingness to pay for green hydrogen
6. Designing pilot for green hydrogen valley and funds mobilization

2 Pilot stage

1. Commissioning of pilot project at SCCL facility
2. Modification of general operations of end users to integrate green hydrogen from pilot plant
3. Operational efficiency building for hydrogen production and transportation to end users
4. Testing of the pilot projects and reporting key findings of the pilot projects
5. Roadshows and workshops to disseminate pilot project findings
6. Identifying key skills and capacity development required among stakeholders

3 Post-pilot scaling

1. Development of operating and commercial model for the hydrogen valley
2. Infrastructure development for the valley in line with demand activators
3. Skill and capacity development
4. Governance mechanism for instituting implementation of the valley elements

Key activities and timelines for each of the stages are elaborated in the sections that follow.

4.2.1 Pre-pilot stage

With the geographical landscape and congregation of multiple industries in the Ramagundam region, a hydrogen valley could be a critical catalyst for their decarbonisation vision of multiple stakeholders from the public and private stakeholders. In line with the country's sustainability targets, the Ramagundam region of the state of Telangana can have an aspirational vision for hydrogen-led decarbonisation:

> ***Vision:***
>
> To develop a self-sustaining hydrogen valley in Ramagundam region, focused on centralized hydrogen production and catalyzing the decarbonisation initiatives of multiple industries present in and around the region.

Research and Innovation Centre of Hyderabad (RICH) has already conceptualized an aspirational vision and identified key stakeholders for the green hydrogen valley in Ramagundam region spreading across multiple industries. Each industry has specific use-cases for hydrogen or its derivatives which either is integrated into their process (viz. fertilisers) or as agent for substituting fossil fuel (furnace fuel or diesel). Key consumers identified in the valley for off-take are:

Off-taker	RFCL	TGSRTC	MyHome	SCCL	AGI Glaspac
Sector/ Industry	Fertilisers	Transportation	Transportation	Transportation	Glass

The demand from each of these off-takers has been elaborated in Section 3.4. RICH has conducted consultations with the offtakers and has developed the foundation for pilot project to kick-start the hydrogen economy in the region. High-level schematic of the valley has been shown below.

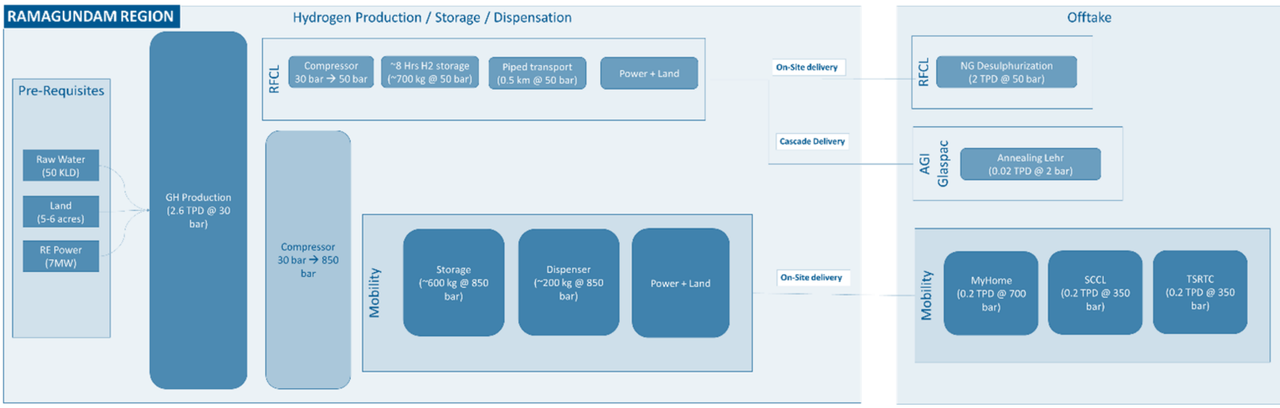


Figure 11: Ramagundam region green hydrogen valley schematic[47]

Setting up the vision for Ramagundam Hydrogen Valley and initial assessment of use cases and demand of green hydrogen would be the foundation for the pilot project and scaling-up to commercial scale.

RICH has also developed a communication and awareness program for the off takers through regular interactions and focused group discussions; it has also captured their willingness to pay for green hydrogen. The initial study has highlighted specific requisites for the pilot phase implementation.

4.2.2 Pilot project development of Hydrogen Valley

After the pre-pilot studies, the next step is to conceptualize, design and develop the pilot project. This PFR has estimated demand from each industry for the pilot stage and additional infrastructure required to meet that hydrogen demand.

Table 20: Infrastructure requirement across multiple off-takers in the pilot stage

Particular	RFCL	TGSRTC	MyHome	SCCL	AGI Glaspac	IOCL (NG line)
Hydrogen demand (TPD)	2.0	0.2	0.2	0.2	0.02	Not considered
Centralized electrolyser	8 – 9 MW Alkaline					
Centralized Hydrogen storage	~1.2 Tons at the outlet of electrolyser					
RE	6 – 7.5 MW (Solar), 16 – 25 MW (Wind); BESS will not be required if 4 – 4.5% power is sourced from the Grid					
Hydrogen refuelling system	One HRS at the SCCL premise with capacity 200 kg/hr (average capacity required for TGSRTC, MyHome and SCCL is 0.6 TPD)					
Fuel Cell Bus		2 – 3 Buses				
Fuel Cell Truck			1 Heavy duty truck	1 Heavy duty truck		
Tube trailer					1 tube trailer for transportation	
Specific infrastructure	1 km Hydrogen pipeline (50 bar, SS, Schedule 40, welded) ~1 Ton SS storage tank, 200 bar and associated compressor				Storage tank at the AGI Glaspac site - ~200 kg SS tank	

[47] RICH

4.2.2.1 Key interventions required from each of Consumers[48]

Consumer	Interventions required
RFCL	• Commissioning of a ~1 km pipeline from green hydrogen generation plant to ammonia synthesis unit • Incremental retrofitting for blending of green hydrogen for desulphurization • Commissioning of Hydrogen storage tank at plant end, if required
TGSRTC	• Launching 2 Fuel Cell based Electric Vehicle
MyHome	• Launching of 1 Fuel Cell Electric Truck
SCCL	• Launching of 1 Fuel Cell Electric Truck • Commissioning of Green Hydrogen plant • Commissioning of Hydrogen Refuelling System
AGI Glas	• Retrofitting of distributor fuel line to blend hydrogen with natural gas • Commissioning of a Hydrogen storage tank for 7 – 10 days[49]

4.2.2.2 Selection of Nodal Agency for Pilot project development

Selection of pilot project developer is the first step to initiate the valley development.

Option 1: Singareni Collieries Company Limited (SCCL) could be proposed as the nodal agency/ valley developer for pilot project development.

Option 2: Any other organization may be selected through competitive bidding

Interaction between various stakeholders and nodal agency is illustrated below:

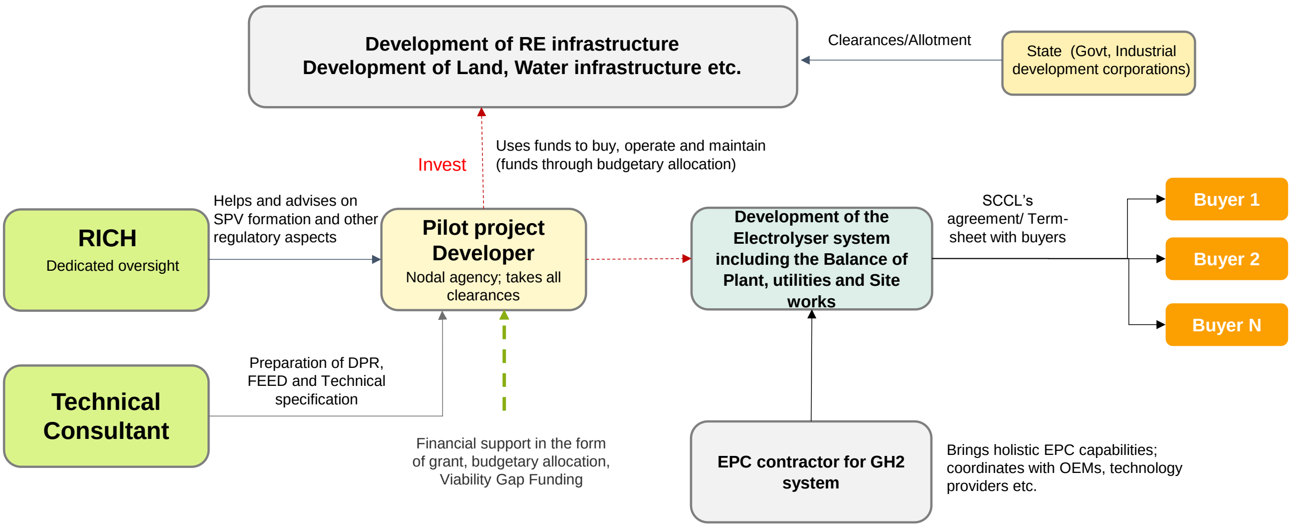


Figure 12: Schematic of interaction between various stakeholders and nodal agency

Process efficiencies and the realized decarbonisation of the off-takers shall be captured by RICH through a pilot assessment report. The learnings from the pilot program shall be disseminated to larger industry players through roadshows and workshops to ensure larger participation from other industries. Increased participation by other industries can help the valley to grow beyond 75 TPD green hydrogen demand.

[48] Based on inputs received from Stakeholder consultation organized by RICH
[49] Considering weekly frequency of Tube Trailer

With the finalization of the DPR, SCCL or the Valley developer can float a tender to invite developers for the pilot green hydrogen facility. In parallel, the identified off-takers would modify their internal processes and operations to integrate green hydrogen in their facilities.

4.2.2.3 Key activities with timeline for the Pilot stage

Key activities for pilot stage as well as the involvement of the key stakeholders are indicated below:

Sl.	Activity/ Initiative	Responsible	Accountable	Consulted	Informed	FY25	FY26	FY27
1.	Create SPV for valley development (SCCL or any other)	Valley developer	DoE, Govt of Telangana (GoT), Valley developer	RICH, Department of Finance, GoT				
2.	Prepare a detail DPR for the valley along with financial feasibility assessment (support required for financial feasibility)	Valley developer		RICH				
3.	Finalize the proposal for Government support and take approval	Valley developer	Department of Finance, GoT	RICH				
4.	Obtain all statutory clearances as indicated in the DPR	Valley developer	GoT	RICH				
5.	Finalize Hydrogen selling and purchase agreements/term sheets	Valley developer		RICH, End Consumers	DoE, GoT			
6.	Set up the RE plant (additional quantum from the existing excess capacity)	Valley developer		RICH				
7.	Conduct technical study for Hydrogen plant and associated infrastructure (FEED including HRS set up)	Valley developer	Technical Consultant	RICH				
8.	Float RFP for Hydrogen plant developer including the HRS	Valley developer		RICH				
9.	Float RFP for logistic partner for road transport of compressed H_2	Valley developer		RICH				
10.	Selection of Hydrogen plant developer/EPC contractor	Valley developer		RICH				
11.	Erection, Commissioning and completion of trial run	EPC contractor	Valley developer	RICH				
12.	Appoint agency for certification of the green hydrogen	SCCL		RICH				
13.	Ensure infrastructural changes in the end-consumer end	End-Users		Valley developer, RICH				
14.	Acquire water connection as identified in the DPR	SCCL						
15.	Assess skills need/ gap with industry and educational institutes	RICH	Valley developer					
16.	Develop programs for reskilling in existing industries to support hydrogen value chains	RICH	Valley developer					
17.	Identify the training and certification need and develop a plan	RICH	Valley developer					
18.	Successful commencement of the Pilot phase of valley operation							

Post preparation of the PFR, the nodal agency (SCCL for the pilot phase) is expected to initiate development of a DPR and appoint technical consultant for preparation of FEED study. The DPR will focus on detailed techno-economic assessment, including assessment of investment required and the need of Government support. This will be followed by floating of RFP for Hydrogen plant EPC contractor, HRS supplier and associated infrastructure developer.

In parallel, SCCL or the valley developer will obtain all statutory clearances and initiate green hydrogen certification program; RICH could be entrusted with development of a capacity building plan, including the training program.

4.2.3 Post-pilot scaling up of Hydrogen Valley

Pilot project development is expected to develop the initial ecosystem and establish the functioning of the hydrogen valley in a smaller scale. Scaling up of the pilot project by aggregating more demand and infrastructural development could further enhance the commercial viability of the valley.

Three major pillars for "scaling up" are commercial model development, infrastructure development, and skills and capacity building. Along with them, engagement with key stakeholders through inter-ministerial collaboration, routine monitoring and governance and arrangement of funding are critical success factors for valley development.

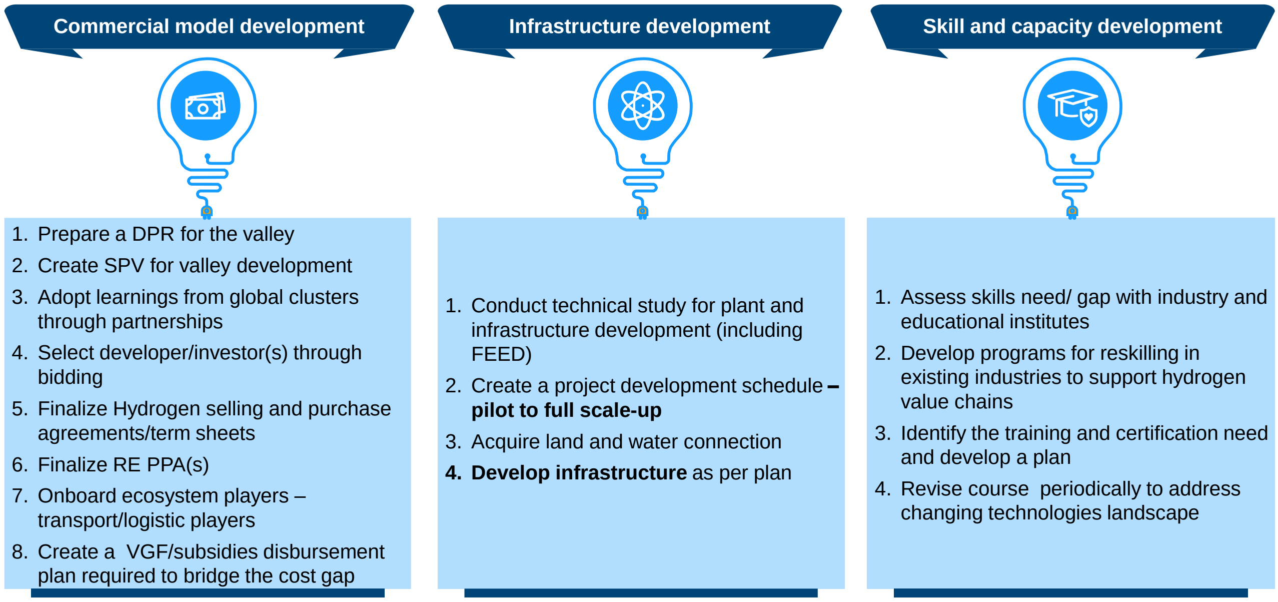


Figure 13: Three pillars for hydrogen valley development in Ramagundam

The outlined steps under each of the success factors need to be executed with assignment of responsibility to appropriate implementing agency/ state department in consultation with public and private stakeholders in a timeframe of 5 -10 years (FY27 onwards), depending actual market development and offtake demand certainty.

Multiple departments of the Government of Telangana are required to be involved to ensure smooth implementation of the roadmap ranging from Department of Energy, Planning, Transport, Industry and Commerce, etc.

Key activities for scaling up of Hydrogen valley and associated stakeholders are indicated below:

Table 21: Timeline for implementation of identified initiatives and stakeholder role identification

Sl.	Activity/ Initiative	Responsible	Accountable	Consulted	Informed	FY28		FY29		FY30	
1.	Create SPV for valley development	RICH	DoE, Govt of Telangana	Dept of I&C, SCCL							
2.	Prepare a detail DPR for the valley along with financial feasibility assessment (support required for financial feasibility)	SPV									
3.	Finalize the proposal for Government support and take approval	SPV	Department of Finance, GoT								
4.	Obtain all statutory clearances as indicated in the DPR	SPV	GoT	RICH							
5.	Acquire Water linkages as per the DPR	SPV	Dept of Water Resources, GoT								
6.	Finalize Hydrogen purchase agreements/term sheets with the end consumers (this shall be part of RFP for selection of valley developer)	SPV		End consumers	Developers						
7.	Float the RFP for selection of valley developer, including the criterial for technical and commercial evaluation	SPV		RICH							
8.	Conduct bidding and select the Hydrogen Valley developer	SPV		RICH							
9.	Transfer the SPV to the selected developer	SPV		DoE, D-I&C							
10.	Signing of Hydrogen Selling Agreement (back to back)	SPV		End-consumers, DoE, D-I&C							
11.	Conduct technical study for Hydrogen plant and associated infrastructure (FEED including HRS set up)	SPV									
12.	Finalize RE procurement model and the PPAs	SPV									
13.	Onboard Hydrogen plant developer	SPV									
14.	Onboard ecosystem players – transport/logistic players	SPV									
15.	Erection, Commissioning and completion of trial run	EPC contractor	SPV								
16.	Appoint agency for certification of the green hydrogen	SPV		RICH							
17.	Ensure infrastructural changes in the end-consumer end	End-Users		SPV, RICH							
18.	Assess skills need/ gap with industry and educational institutes	RICH		SPV							
19.	Develop programs for reskilling in existing industries	RICH	SPV								

Sl.	Activity/ Initiative	Responsible	Accountable	Consulted	Informed	FY28	FY29	FY30
	to support hydrogen value chains							
20.	Identify the training and certification need and develop a plan	RICH	SPV					
21.	Successful commencement of the valley operation	SPV						

Note: I&C – Industry and Commerce, LETFD: Labour Employment Training and Factories Department, EFST: Environment, Forests, Science, and Technology
This schedule is to meet the medium-term demand

Key takeaways:

- Timely completion of above activities are critical to complete the scaling up of Hydrogen Valley infrastructure. The activities may undergo a phasing approach as per the demand certainty.
- The Government of Telangana, in association with RICH, should form the SPV, prepare the DPR for large scale operation, obtain all clearances, sign the Hydrogen Purchase Agreements (HPA) with offtakers and conduct the bidding process to select the valley developer.
- The valley developer will be the anchor investor which would bring all the ecosystem partners. The developer will be responsible for technical and FEED study, complete the financial closure, onboard contractors and ecosystem players, obtain certification and operate the hydrogen valley in a sustainable manner.
- The Government of Telangana will be an important enabler to expedite all clearances and statutory approvals

4.2.4 Operating and commercial model for the hydrogen valley

Creation of an SPV (Special Purpose Vehicle) is the first step towards implementation of the valley. It should be created with dedicated oversight from RICH to initiate the development of the valley work, take necessary approvals, onboard key stakeholders and finalize the initial term-sheets with the offtakers. The interactions among all the participants are illustrated below.

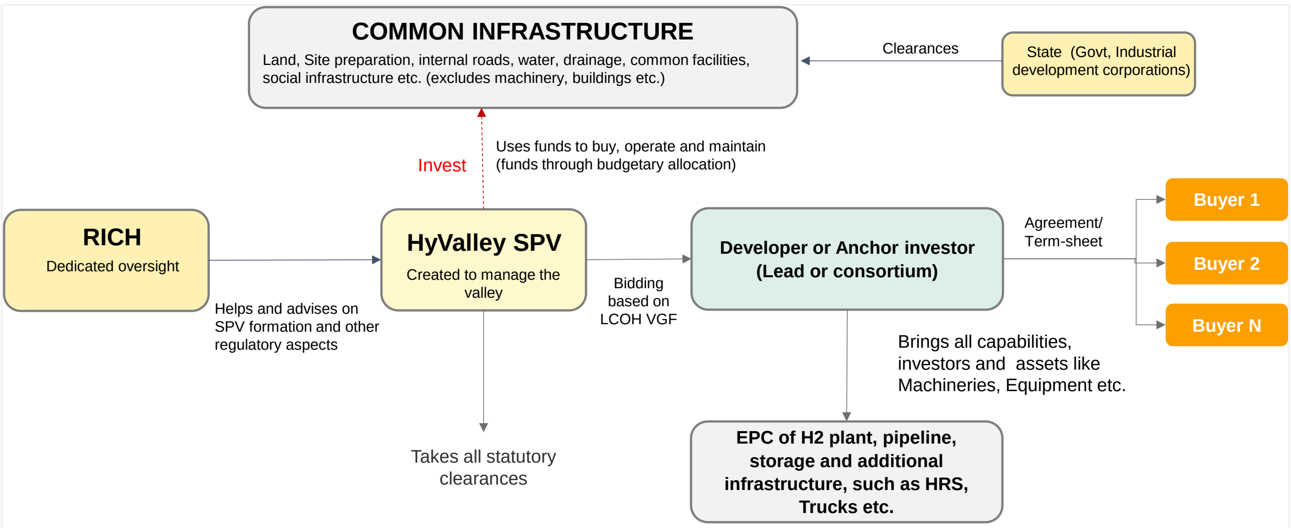


Figure 14: Operating and Commercial model for Hydrogen valley

As illustrated above, SPV will take up following activities:

- Identification and procurement of the site to set-up the centralized production facility
- Obtaining all statutory clearances and regulatory permits/ licenses/ approvals from central and state government
- Establishing few common infrastructure, such as road, drainage, fencing etc.

- Concluding the term-sheets with key offtakers.

With all clearance on hand, the SPV would conduct a bidding for selecting developers/ anchor investors based on the VGF sought by the bidders on LCOH (INR/kg). Individual or consortium bidders should be allowed to participate in the tenders floated by the SPV on behalf of RICH and upon selection of successful bidders, the SPV would transfer the SPV to the selected bidder for initiating the EPC of H_2 plants, pipelines, storage, and additional infrastructure such as refuelling stations. The SPV will also create a fund[50] for disbursing the VGF.

Table 22: Key aspects and stakeholders for the Hydrogen Valley

Sl.	Particular	Details
1.	Location	Ramagundam, Telangana
2.	Setup	Joint (PPP preferable)
3.	Feedstock source	Hybrid renewable project (Solar+Wind+BESS)
4.	Lead partner	SPV
5.	Partners	**Off-takers:** SCCL, NTPC, TGSRTC, MyHome, RFCL, AGI Glaspac
6.	Facilitators	**Valley Developer (system integrator)**, **RE generator** (for captive arrangement), **Utilities (state specific), PMC/ Engineering consultant, Funding agencies**
7.	Government entities	RICH, TGREDCO, DST, Dept of Finance, Industry and Commerce Department (for approvals and land allotment), Energy Department

4.2.4.1 Clearances and regulatory compliances required for valley development

- **Consent to Establish (CTE) is the primary clearance for entities intending to setup any project in India**. Meanwhile, the Consent to operate (CTO) serves as a legal consent that entities have to apply after establishing the unit and meeting conditions of CTE. The respective State Pollution Control Board (SBCB) grants both these consents with different validity duration. Central Pollution Control Board (CPCB) has categorized all industrial sectors/projects under Red, Orange, Green and White categories based on predetermined pollution index under prevailing legislation. The process for securing Consent to establish (CTE) and Consent to Operate (CTO) seeks filing of application with the concerned SPCB. Applicants are required to facilitate mandatory documents and scrutiny fees for this purpose. While the SPV should be responsible for obtaining the CTE, CTO can be obtained by the selected bidder. Following documents are required for CTE:
  - Site plan of the production unit/project
  - Detail Project Report (DPR)
  - Land documentation such as Registration deed/ Lease deed
  - Details of air pollution control/ Water Pollution control equipment
  - MOA /Partnership Deed, if any
- Several other regulatory approvals and permits have to be obtained by the SPV, as indicated below:
  - Factory licenses depending on the product and chemical to be manufactured, as per Factories Act, 1948
  - Environmental clearance from MoEFCC
  - Approval for Power and water connections
  - NOC from State Pollution Control Board (SPCB)

The SPV should ensure that the above clearances are in place before the bidding process to identify the anchor investor for valley development.

4.2.4.2 Finalisation of term-sheets between SPV and off takers

As the next step, the SPV will sign the off-take agreements and term sheets with all potential offtakers of green hydrogen. Salient clauses of the term sheet are indicated below:

[50] Fund to be developed via budgetary allocation by the Finance Department

Table 23: Illustration of representative term-sheet between SPV and off-takers

Key clauses	Description
Parties	*Seller:* valley developer *Buyer:* End consumer
Price & Quantity	To be decided between supplier and individual consumer
Delivery of Products	• Seller delivers the contract quantity during the Delivery Period of the HPA at the agreed quality specifications. • Delivery will be enforced by contractual warranties, penalties, and termination rights.
Delivery point and change in title	• A delivery point will be specified in the contract • Customers will be responsible to manage the product logistics "behind" the Delivery Point
Delivery schedule	• Seller will deliver the annual quantity of Product in a mutually agreed delivery schedule
Handling of the product	• Seller is responsible for the Product transport and logistics up to delivery to the Delivery Point. • Transport and logistics shall take place in compliance with all applicable safety regulations.
Product specification	Product will have to comply with technical product specifications upon delivery. • Purity: > 99.999 % (vol.) • Oxygen content: < 2 ppm • Dew point: ≤ (-) 71 °C @ atm
Production process	• In addition, production process should comply with India's Green Hydrogen Standard. • Compliance with technical specification and green hydrogen standard will be enforced by contractual warranties, penalties, and termination rights.
Certification	• The Seller will have to prove compliance with the requirements as per green hydrogen standards. Certification of production needs to be furnished to the buyer

Contract price and payment	• The off-taker shall pay Seller the contract price for duly delivered Product quantities. The contract price includes
	  • Product price
	  • Transport charge
	  • Taxes and duties
	• Payment terms will be mutually decided; Late payments shall accrue interest at a rate specified in the Agreement.

"Take or Pay" obligation	• The agreement should contain a "take or pay" provision

Contractual penalty for supplier	• Seller's key obligations under the HPA will be secured by contractual penalties. This includes:
	  • Failure to deliver
	  • Deviation of Product from agreed specifications

Termination rights for Supplier	• The developer will have an extraordinary right of termination without notice in the event of sustained and/or recurring non-compliance.
Performance bond	• In order to ensure due payment of the contractual penalty, the Seller will provide a performance bond to secure due performance of all obligations of the Seller under the HPA
Force Majeure	• Neither HPA sellers nor HSA customers shall be liable for any failure to perform, or delay in performing, any of its obligations under this agreement to the extent that the failure or delay results from a Force Majeure Event.
Taxes, Duties and Charges	• Seller will bear all product-, and export related taxes and other levies in India and will bear the commercial risk of an increase of such taxes and levies
Amendment of HPA due to Regulatory Changes	• The off-taker may request an amendment of the HPA if laws and regulations relevant for the performance of the HPA change.
Liability	• HPA Sellers have agreed to indemnify and hold harmless the off-taker, its affiliates, employees, officers, customers (including HSA Customers) from and against all claims actions, damages, suits, liabilities, obligations, Taxes, Duties, costs, fees and charges

Key clauses	Description
	resulting from a Defect or any other negligent or willful breach of any obligation under this Agreement.

Note: Above clauses are standard industry terms and conditions. These may be customized for the valley development.

4.2.4.3 Bidding for selection of Developer

As a next step, the SPV should invite global bids for 'Selection of Green Hydrogen Developers for Setting up Production Facilities in Telangana Hydrogen Valley'. Selection of developer(s) shall be done in a transparent manner as per guidelines prepared by the SPV. Guidelines for conducting the bidding process is illustrated below:

- Develop the pre-qualification criteria for selection and issue a global Expression of Interest (EOI)/Request for Selection (RfS)
- Bidders could be a single party or a consortium of parties.
- The scope will be setting up of green hydrogen production facilities, associated infrastructure including pipelines, HRS as well as bringing logistics partners.
- Bidding can be based on LCOH or VGF against LCOH stipulated by the SPV; SPV can indicate the LCOH based on the "Willingness to pay" of the off-takers.
- Bidders are required to submit the following documents with their response, as part of response to RfS:
    - Construction/Implementation Plan
    - Clearances/ approvals required from various Government departments/ Local Bodies
    - Timelines/ PERT chart of major construction activities
    - Timelines for applying for/obtaining various clearances/ approvals
    - Investment break-up
    - Potential of new job creation

Once the bidder is selected, the SPV will be transferred to the bidder to initiate the implementation work.

4.2.5 Infrastructure development

Implementation of project would involve several activities, of which some are pre-project activities and others are related to physical execution of the project. The total project including offsite facilities will be executed on EPC basis with the help of reputed EPC contractor who will provide services for detailed engineering, procurement, construction and supervision of pre-commissioning & commissioning activities. The infrastructure required in the medium- and long-term timeframes in the valley are shown below:

Table 24: Infrastructure development requirement in the valley across timeframes

Particular	Requirement
Electrolyser system and utilities	Medium term – 45 – 48 MW Long term – 230 – 255 MW
RE and BESS	Medium term – 34 – 42 MW (solar), 85 – 135 MW (wind), up to 22 MW (2 hr BESS) depending on drawl of grid electricity Long term – 170 – 215 MW (solar), 450 – 705 MW (wind), up to 111 MW (2 hr BESS) depending on drawl of grid electricity
Hydrogen storage	Medium term – 18 tons Long term – 60 tons
HRS	Medium term – 2 HRS Long term – 3 HRS
Pipeline	**Medium and Long term:** • 1 km pipeline from SCCL to RFCL (SS 316); • ~25 km carbon steel pipeline from Sripada Yellampalli storage to SCCL
Fuel Cell Bus	Medium term: 50 buses Long term: 200 buses
Fuel Cell Truck	Medium term: 40 trucks

Particular	Requirement
	Long term: 100 trucks
Tube trailer	One tube trailer

Development of infrastructure starts with the pre-FEED and FEED study. These studies will be undertaken by the developer and will take 10 – 12 months before the commencement of procurement and construction. The key activities under pre-FEED and FEED are shown below.

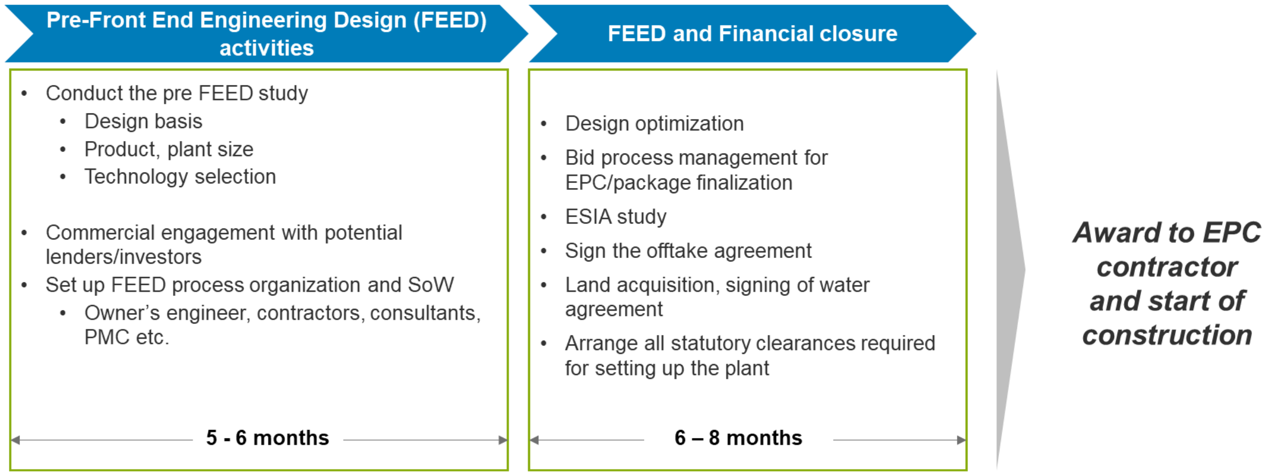


Figure 15: Key activities outlined under pre-FEED and FEED activities

EPC contractor will be responsible for carrying out Detailed Engineering of all facilities inside the complex and construction of the plant within budget, quality, Safety and given schedule. Developer and a PMC team will overview/monitor the performance of EPC contractor. Commissioning and guarantee test will be the responsibility of the OEM of hydrogen electrolyser.

4.2.5.1 Technology selection for Infrastructure development

The Selection of the main technologies for the hydrogen valley is based on available technology maturity, technical performance, and market availability of those technologies.

Hydrogen Generation System (Electrolyser Unit)

Electrolysis is the process of splitting water into hydrogen and oxygen using electricity. This reaction takes place in a unit called an electrolyser. Electrolyser consists of an anode and a cathode separated by an electrolyte which acts as an electrical insulator and ionic conductor.

Water electrolysis technologies can be classified according to the applied electrolyte. The main water electrolysis technologies are Alkaline Electrolysis (AEL), Proton Exchange Membrane Electrolysis (PEMEL), Solid Oxide Electrolysis (SOEL) and Anion Exchange Membrane Electrolysis (AEMEL).

Globally two technologies are relatively mature – alkaline and PEM; alkaline is more prevalent but PEM is bridging the gap.

A. Alkaline electrolysis technology

Alkaline electrolysis technology is the most prevalent technology at present and also the most mature. The main benefit of this technology is its liquid electro-catalyst, which negates the need for costly metal materials. Alkaline electrolysis cells can be configured in large stacks and are known for their long-term stability and lifetime. However, the issue faced with alkaline technology is low pressure of operations which leads to requirement of four stage compression for generated hydrogen as well as long ramp-up times which is relatively unsuitable for operations with intermittent renewable power. Thus, **alkaline cells may be suitable where power variability is limited**. Further, companies in Norway and China have developed high pressure alkaline systems to reduce compression needs.

However, due to limited or no use of precious metal, cost of alkaline electrolyser is the cheapest available in the market (USD 500 – 600 per KW).

B. Proton Exchange Membrane (PEM) electrolysis

Proton Exchange Membrane (PEM) electrolysis is suited more for RE intermittency vs alkaline and since PEM operates at higher pressure, there is no need for hydrogen compression. However, PEM efficiency levels are lower than alkaline and it is **costlier than alkaline electrolysers** due to

- Use of costly rare earth materials. The cathode and anode of PEM stack are created by depositing platinum or Iridium on either side of a relatively costly NAFION membrane
- The porous transport layer (PTL) is built using titanium which is costly as well. In contrast, alkaline uses nickel which is widely available and of lower cost.

The presence of precious metals makes PEM costlier, by about 40-50% more than alkaline electrolysers. Chinese alkaline electrolysers are the lowest cost due to higher scale, mature/developed electrolyser ecosystem and also relatively low labour costs compared to developed countries.

Other electrolyser technologies are also attempting to address the shortfalls in the current technologies, largely solid oxide electrolyser cell (SOEC) and anion exchange membrane (AEM) . These technologies are currently under advance prototype or demonstration phase and are not commercially ready yet.

Based on the technological assessment, market maturity, economics and global references, it is suggested to adopt alkaline based electrolyser technology for the proposed 'hydrogen valley' project. Renewable electricity will be provided with a combination of solar, wind and BESS to limit the variation.

Hydrogen Storage

Hydrogen is lightweight (about 0.09gm/litre) or low density molecule, which results in low energy density for pure hydrogen at room temperature. It needs to be compressed to store at room temperature. Hydrogen can be stored as a compressed gas, liquid, or as a part of a chemical structure. Different types of hydrogen storage options are illustrated below:

A. Compressed Gas Storage

a. Tubular Cascade/ Skids:

Type I pressure tubes are used in cascade skids. Generally, each cascade skids consist of 6 to 8 nos. of tubes. Tubes are made of metals like carbon steel and low alloy steel, and they are mostly used in industry and are available in market with water volume of 2- 3 m^3.

Figure 16: Hydrogen Tube Cascade/ Skid (representative image)

b. Underground Storage Vessel:

Hydrogen can be stored in pressure vessel in a purposely built underground cavity. The advantage of this technology is low capex compared to other high pressure storage technologies. However, it is not yet commercialized for large scale application, and design is largely dependent on project location geotechnical data.

c. Spherical/Bullet Storage:

Hydrogen tanks that are available in the market are mostly cylindrical. Although this common tank geometry offers good utilisation of the installation space, the potential for weight reduction has been limited. For physical reasons, the required wall thickness in the cylindrical area of the tanks is twice as high as in the spherical area. Thus, the spherical design contains an enormous potential in terms of material and thus weight and cost savings.

Figure 17: Hydrogen spherical storage (representative image)

d. Mounded Bullets Storage:

The concept of mounded storage was brought into sharp focus by the Mexico City GAS Distribution Terminal disaster in November 1984, where 16000 m^3 of LPG was stored in 6 spheres and 48 horizontal vessels. Mounded storage usually stores combustible liquids under atmosphere and liquefied gases under high pressure in horizontal cylindrical vessels placed near ground level and covered with suitable backfill. The vessels shall be installed above the highest known ground water table; the soil cover usually protrudes above grade as an earth mound; hence the term "mounded storage".

Figure 18: Mounded bullet storage (representative image)

B. Liquid Storage

a. Hydrogen Liquefaction:

Storing hydrogen in the liquid form requires approximately 6 – 12 kWh/kg- H_2 energy which is 6 to 12 times higher than that needed for high-pressure hydrogen gas compression. Hydrogen liquefaction temperature is -253 deg C and the process of liquefaction is energy intensive. Supply chain system of Liquid hydrogen is yet to evolve.

C. Solid State storage (as chemical structure)

a. Metal Hydrides Storage:

Hydrogen can be chemically stored by absorbing or reacting with other chemical compounds such as metals or "organic substances." Metal hydrides are one of the most common types of hydrogen chemical storage that can store hydrogen at high densities that can exceed that of liquid hydrogen. The challenges of storing hydrogen in a chemical form are mostly relative to the hydrogenation and dehydrogenation processes considering high temperature and pressure requirements which might be an obstacle to their application in large-scale energy storage applications.

Based on requirement, safety, technical maturity, and market availability, the preferred hydrogen storage type is Mounded Bullet Storage. Mounded Bullet Storage has additional safety associated with it when compared to the other above-ground storage options. The purpose of mound is to protect the vessel against external events such as radiation in case of fire, flying objects and sabotage. The advantages of mounded storage are:

- Very low possibility of "Boiling Liquid Expanding Vapour Explosion". As in case of early fire, flame impingement or bullet heating, the mound surrounding the bullets will protect the vessel.
- The vessel is protected against heat radiation from a nearby fire, pressure wave originating from an explosion, impact by flying object and sabotage.
- It satisfies environmental and aesthetic requirements.
- It results in reduced site area due to less stringent inter-spacing requirements.
- The safety distance to the site boundary can be reduced considerably.
- Extensive water deluge systems are not required.

Hydrogen Refuelling Station (HRS)

The process of refuelling at a hydrogen station is similar to that of a conventional petrol station, with some details that make the experience a little different. This is because hydrogen is supplied at high pressure and, as it is an extremely light gas, the connection between the vehicle's receptacle or connection point and the pump must be watertight. In a Hydrogen Refuelling Station (HRS), the hydrogen is pumped into the vehicle's fuel tank, which powers the fuel cell that generates the electricity needed to drive the vehicle. The only waste product produced is water vapour, which is expelled through the exhaust pipe.

Key components of a Hydrogen Refuelling Station are described below:

- **Receiving Hydrogen Supply**: Hydrogen refuelling stations receive their supply of hydrogen gas through various means. This can include delivery via tanker trucks or pipelines.
- **Compression and storage**: Once the hydrogen is received, it is stored on-site at the station. Typically, hydrogen is compressed and stored in high-pressure tanks. Storage is controlled by specially designed valves, fittings and electrical controls to ensure safe refuelling and controlled H_2 flow rate. This is the most common method for storing hydrogen at refuelling stations. Liquefaction is not preferred due to its high energy intensity.
- **Cooler:** The supply requires that the hydrogen be refrigerated. This ensures H_2 is dispensed safely and efficiently (H_2 starts warming up on expansion hence cooling necessary)
- **Dispensing**: When a hydrogen fuel cell vehicle arrives at the station for refuelling, the dispensing process begins. The vehicle is parked in the designated refuelling area, and the driver connects the fueling nozzle to the vehicle's receptacle. The hydrogen is then dispensed from the station's storage tanks into the vehicle's fuel tank. This process is similar to refuelling a gasoline or diesel vehicle, though it can take a few minutes longer due to the high pressure at which hydrogen is stored.
- **Monitoring and Control:** Throughout the refuelling process, the station's systems monitor various parameters such as pressure, temperature, and flow rate to ensure a safe and efficient transfer of hydrogen.
- **Safety Measures**: Safety is a top priority at hydrogen refuelling stations. They are equipped with various safety features, including sensors to detect leaks, emergency shutdown systems, and protocols for responding to emergencies. In addition, before fueling begins, there is typically a communication process between the station and the vehicle to ensure compatibility and safety. This can involve authentication protocols to ensure the vehicle is authorized to refuel, as well as checks for leaks and other safety measures.
- **Maintenance and Inspections**: Regular maintenance and inspections are crucial for the safe and reliable operation of hydrogen refuelling stations. This includes checks on equipment, storage tanks, dispensers, and safety systems.

- Overall, the operation of a hydrogen refuelling station involves a careful balance of safety, efficiency, and convenience to provide fuel for hydrogen fuel cell vehicles, contributing to the growth of a cleaner and more sustainable transportation ecosystem.

Unlike conventional filling stations, hydrogen is sold by the kg, not by the litre, and the refuelling time for a conventional bus or truck - which usually has a capacity of between 30 and 37.5 kilos - is 10 - 15 minutes.

A schematic of HRS is provided below:

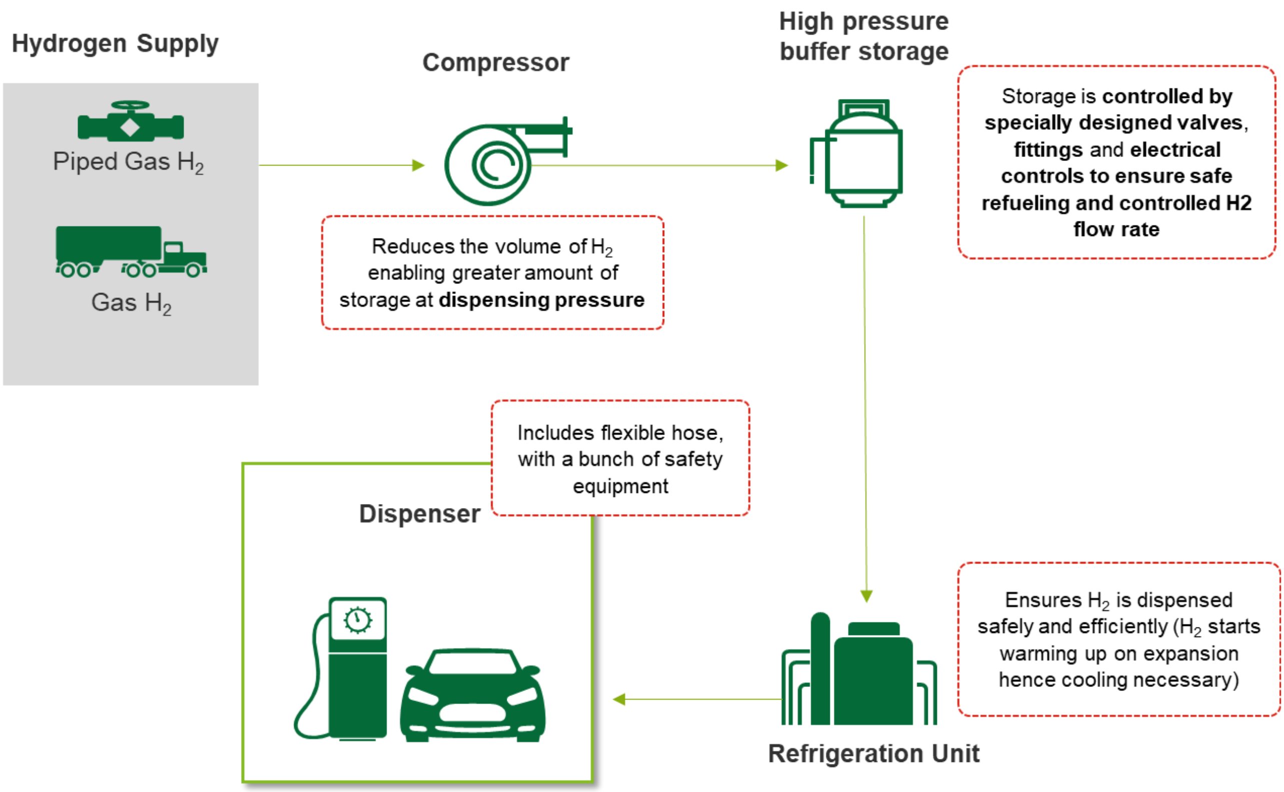


Figure 19: Schematic for a 1 TPD HRS

4.2.6 Skill and Capacity development

Green Hydrogen is a relatively new technology, even for potential stakeholders and investors to explore. The sector needs handholding in terms of capacity building and skills development in various upstream and downstream jobs. Therefore, it is important to identify appropriate skills and avenues that are required for successful implementation and sustained operation of the valley. It is also necessary to explore existing skills and capacities in hydrogen value chain linkage (e.g. RFCL) which can be leveraged in valley development.

This study has taken a value chain view to identify the current skill gaps and recommend on the future roadmap. The methodology is illustrated below:

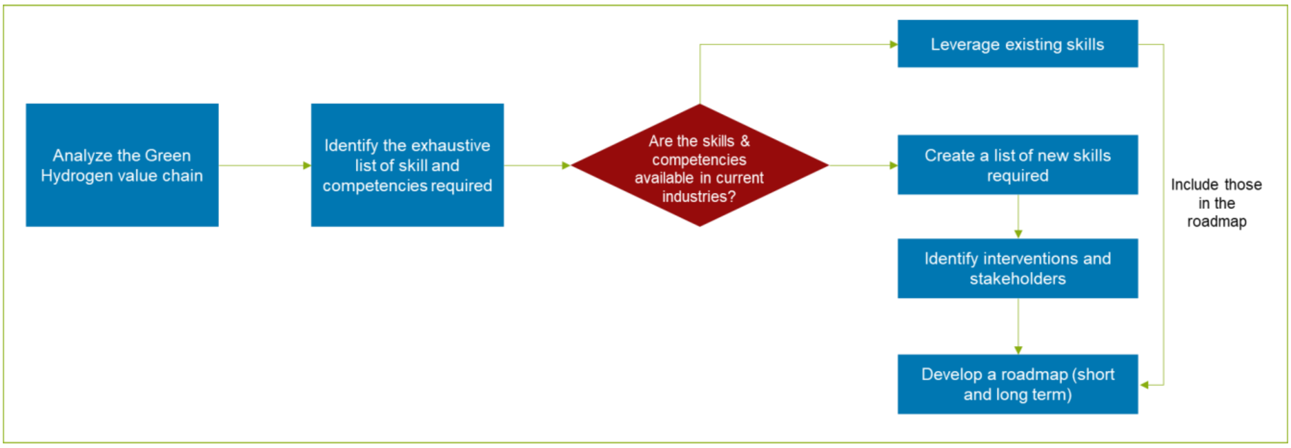


Figure 20: Skill and capacity building framework

4.2.6.1 Mapping of skills and competencies along the value chain

While certain existing skillsets and capabilities can be leveraged from existing industries (fertilizer, refinery etc.), several new capabilities need to be developed. An illustrative analysis of current state of skill availability in the country is provided below:

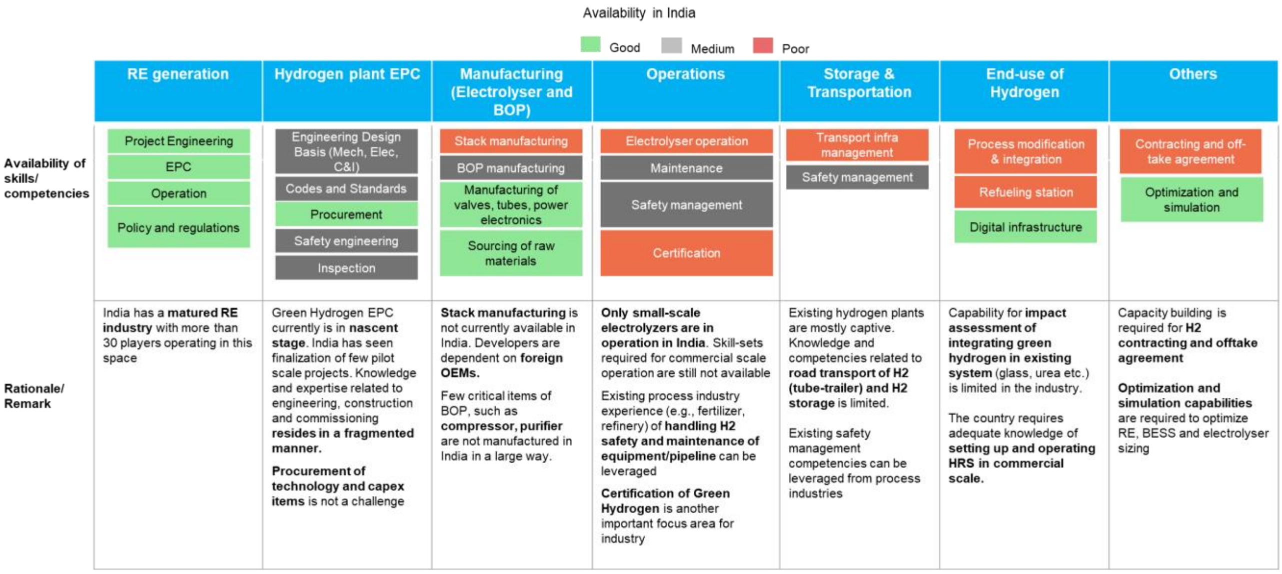


Figure 21: Skill map along the green hydrogen value chain

Upstream of Hydrogen production:

- India has significant capability in RE project development, procurement and manufacturing of solar cell and module, plant operation and handling policy and regulatory complexities associated with RE industry. The Government regulations are clearly laid out, and, currently, more than 30 developers are active in India in the RE project development.
- Till date construction of green hydrogen plant is limited to small scale pilot plants only. Therefore, engineering, construction and commissioning capabilities are yet to be matured. While few global engineering companies have these capabilities, knowledge dissemination to domestic EPC companies is yet to happen.
- India has recently held auction for production linked incentives (PLI) for electrolyser manufacturing, and several organizations have participated in the auction process. However, the current capacity of stack manufacturing is very limited. In the BOP segment, only a few manufacturers have capabilities for critical equipment like hydrogen compressor, purifier etc.

Operations of Hydrogen plant:

- Currently, only a few pilot-scale green hydrogen plants are in operation. Widespread adoption of green hydrogen plants requires handholding from technology providers and OEMs.
- Capabilities related to maintenance and safety measures for handling hydrogen can be leveraged from existing process industries, such as refineries, fertilizer, chlor-alkali etc.
- Certification of green hydrogen is a critical aspect. The developers and operators should be aware of national as well as international certification guidelines. In addition, adequate capabilities should be developed to create more number of certification agencies.

Storage, transportation and distribution:

- Most of the existing hydrogen plants in process industries are captive, with limited exposure to transportation and storage. Therefore, knowledge and competencies related to road transport and H_2 storage (cascade, bullet etc.) are limited.
- Adequate knowledge is also required for assessment of pipeline integrity and blending of hydrogen in natural gas pipeline.

Downstream industry application:

- Use of hydrogen in the downstream industry would require knowledge to assess impact due to process change and layout changes. Considering the nascent state of the industry, additional technical capabilities need to be developed in the user industries.
- Ecosystem should be available for manufacturing and deployment of Hydrogen Refuelling Stations in the country.

Others:

- Developers and Off-takers should build commercial capabilities to conclude Hydrogen supply and purchase contracts, with familiarization of key contractual terms and conditions. However, existing experience of gas contracting can be leveraged for concluding hydrogen agreements.

4.2.6.2 Roadmap for skill development

A trained and skilled workforce is a prerequisite for achieving the objectives of scaling up local clean hydrogen production and establishing resilient hydrogen ecosystems. Telangana Hydrogen Valley will be the first of its kind hydrogen valley where all ecosystem players are located in a single geography. Gradual ramping up of the size of hydrogen production and consumption will require skilled and trained workforce. There will be a requirement of reskilling and upskilling.

In the above context, a roadmap is prepared which identifies a range of continuous actions to ensure success of the valley operation, focused on:

- Building a pipeline of skilled, adaptable workers for the hydrogen industry in collaboration with OEMs, industry players, research institute, multilaterals etc.
- Creation of a knowledge pool with easy access to all ecosystem players
- Creation of a policy framework to support reskilling and upskilling of workforce

Detail action points for development of the skill and capacity building roadmap is provided below.

Roadmap objective: Build a pipeline of skilled and adaptable workers for the hydrogen industry

Table 25: Roadmap for Skill and capacity building

Action point	Focus areas						Responsible party	Consulted party
	Engineering, Construction and Commissioning	Operation, storage, H_2 transport	Safety Management	Certification	HRS, Fuel Cell, Transport	Process modification		
Design Modular training program on following areas, optimally choosing mode of delivery – online and offline							Government of Telangana, RICH	GIZ or any multilateral
Hydrogen technology	✓	✓						OEMs
Hydrogen storage, pipeline integrity		✓				✓		OEMs, Research institutes
SOPs for safe hydrogen handling	✓	✓	✓			✓		OEMs, Research institutes, Industry players
Codes and standards								Research institutes, BIS
Sizing and engineering design, equipment specification	✓							Global engineering players
Certification mechanism				✓				Certification agencies
HRS, fuel cell					✓			HRS, Fuel Cell OEMs
Transportation SOPs					✓			Gas traders, Industry players
Establish a governing body responsible for enforcing and regularly updating the training standards related to hydrogen							Government of Telangana, RICH	
Prepare skilling plans in anticipation of hydrogen development							Government of Telangana, RICH	
Develop a supportive policy framework and implement funding mechanisms for reskilling and upskilling of workforce							Government of Telangana, RICH	
Develop a centralized online platform serving as a hub for a wide range of hydrogen-related training and resources (existing e-infrastructure can be leveraged)							Government of Telangana, RICH	
Set-up a Centre of Excellence (CoE) acting as an intellectual hub for Hydrogen related aspects							Government of Telangana, RICH	

4.3 Investment phasing and viability gap funding

Based on the activity timeline, investment phasing for the valley has been estimated for different phases based on level of penetration and requirement of infrastructure.

4.3.1 Investment need assessment for the Valley

Investment will depend on infrastructure requirement, which is an outcome of level of hydrogen penetration by each end-consumer. Infrastructure requirement, capital expenditure assumptions and investment requirement are illustrated below:

Table 26: Infrastructure requirement in each phase

Focus areas	Unit	Timeline		
		Pilot Project (2024-27)	Medium term (2027-2030)	Long term demand (2030 - 40)
Electrolyser system and utilities	MW	8.68	48.05	252.60
Solar	MW	7.49	41.43	215.89
Wind	MW	15.74	87.12	447.48
Hydrogen storage	Ton	1.24	18	60
HRS - 2 TPD	Nos	1	8	28
Hydrogen Pipeline	km	1	1	1
Fuel Cell Bus	Nos	2	50	200
Fuel Cell Truck	Nos	2	40	100
Tube trailer	Nos	1	1	2

Note: the above figures are cumulative

Table 27: Assumptions for capital expenditure

Focus areas	Unit	Timeline		
		Pilot Project (2024-27)	Medium term (2027 - 30)	Long term demand (2030 - 40)
Electrolyser system and utilities	USD/MW	800000	600000	520000
Solar	INR Cr/MW	4.5	4.5	4.5
Wind	INR Cr/MW	7.5	7.5	7.5
Hydrogen storage	INR Cr/Ton	8	8	8
HRS - 2 TPD	INR Cr/No	35	30	25
Pipeline	INR Cr/km	3	3	3
Fuel Cell Bus	INR Cr/No	2.5	2	1.8
Fuel Cell Truck	INR Cr/No	3.0	3.0	2.5
Tube trailer	INR Cr/No	2.0	2.0	1.8

Source: Industry benchmark

Note:

- HRS cost is the EPC cost inclusive of Hydrogen Compression system at 500 Bar, Hydrogen Storage System, Hydrogen Pressure Reduction System and Hydrogen Dispenser Unit. Land cost is not significant and is assumed to be provided from existing landbank of respective entities (e.g. SCCL, TGSRTC, MyHome)
- Current capex of Fuel cell truck is $350 – 400k. This is expected to reduce with higher uptake, cost reduction of battery and more OEMs getting into manufacturing of FCEV.
- Fuel Cell Bus prices are as per latest OEM price in India.
- Cost of Hydrogen Tube Trailer is $250 – 300k.

Table 28: Investment requirement for valley development

Focus areas	Unit	Timeline		
		Pilot Project (2024-27)	Medium term (2027 - 30)	Long term demand (2030-40)
Electrolyser system and utilities	INR Cr	58	239	1090
Solar	INR Cr	34	186	972
Wind	INR Cr	118	653	3356
Hydrogen storage	INR Cr	10	144	480
HRS - 2 TPD	INR Cr	35	240	700
Pipeline	INR Cr	3	3	3
Fuel Cell Bus	INR Cr	5	100	360
Fuel Cell Truck	INR Cr	6	120	250
Tube trailer	INR Cr	2	2	4
Total (Cumulative)	**INR Cr**	**270**	**1688**	**7214**
Capex requirement for each Phase	**INR Cr**	**270**	**1418**	**5526**
	USD Million	**33**	**171**	**666**

4.3.2 Impact of Green Hydrogen transition on end consumers

The willingness to pay for green hydrogen would vary based on the industry of the off-takers.

Table 29: Willingness to Pay be end-consumers

	Short-term		Medium-term		Long-term	
Off-takers	Willingness to pay for GH_2 (USD/kg)	LCOH (Cost of production)	Willingness to pay for GH_2 (USD/kg)	LCOH (Cost of production)	Willingness to pay for GH_2 (USD/kg)	LCOH (Cost of production)
RFCL	2.92	4.22	3.07	4.25	3.06	3.96
TGSRTC	4.50	4.22	4.73	4.25	4.71	3.96
MyHome	4.50	4.22	4.73	4.25	4.71	3.96
SCCL	4.50	4.22	4.73	4.25	4.71	3.96
AGI Glaspac	1.70	4.22	1.79	4.25	1.78	3.96

Note:

- Impact on transport is exclusive of HRS cost; additional cost due to HRS would be US$ 0.50 – 0.60 per kg of Hydrogen (applicable for TGSRTC, MyHome, and SCCL).
- For AGI Glaspac, additional cost of transportation and storage will be 0.8 – 1.0 per kg
- The Willingness to Pay figures are derived based on consultation with stakeholders. The willingness to pay in the medium- and long-term has been raised as per the crude oil price escalation outlook globally. The cost gap between green hydrogen and alternative fuels should be bridged (completely or partially) by deploying suitable incentive and VGF mechanism.

The gap between delivered cost of Hydrogen and Willingness to Pay should be bridged through either Viability Gap Funding (disbursed annually) or support in the form of capital grant or subsidy in the initial years. **In a status-quo scenario, annual fund requirement for bridging the cost gap is indicated below:**

	Annual VGF requirement to bridge the cost gap (INR Cr/Year)		
Off-takers	Short Term	Medium Term	Long Term
RFCL	6 – 10	18 – 22	120 – 125
TGSRTC	0 – 1	0 – 1	0 – 1
MyHome	0 – 1	0 – 1	0 – 1
SCCL	0 – 1	0 – 1	0 – 1
AGI Glaspac	0 – 1	6 – 8	12 – 14
Total	**6 – 12**	**24 – 33**	**132 – 142**

It has been observed that, purely from operational cost, ease of transition for the transport sector is higher than fertilizer or glass sector. However, additional capex is required by all the end consumers to become operation-ready to ensure the transition.

4.3.3 Scope of Government support and Viability Gap funding

Government support and incentives play an important role in bridging the cost gap between green hydrogen and alternative fuel and ensure commercial viability of the hydrogen valley. Following avenues can be explored for providing Government subsidies:

Table 30: Potential policy support measures

Policy support	Impact and rationale
Capital grant for Hydrogen production and allied infrastructure	Any incentive in the form of capital grant can reduce the delivered LCOH. This grant can be tailormade by the state government for the valley development.
Waiver of electricity charges	Waiver of State Transmission charges and electricity duty can optimize the LCOE used for water electrolysis. Other charges, such as Cross Subsidy Surcharge, Additional Surcharge are already waived off for captive configuration.
Equity infusion from the Government	Equity infusion from the State Government can reduce the burden on the developer/anchor investor and optimise the return expectation.
Other incentive	Tax exemption for valley developer and operator can further improve the risk-profile of the project, which can optimize the LCOH

Announcement of above incentives could improve the attractiveness of the project and optimize the delivered LCOH to the end consumers.

Table 31: VGF impact and requirement for short term

Type of incentive	Incentive offered	Impact on LCOH (USD/kg) (reduction)	Amount of subsidy/VGF/ Equity (INR Cr)
Capital grant on Hydrogen production and allied infrastructure	10% capital grant	0.10	8 -10
	20% capital grant	0.20	16 - 20
	30% capital grant	0.30	24 - 28
Waiver of transmission charge	Waiver for 10 years	0.25 – 0.30	35 - 40
	Waiver for 5 years	0.15 – 0.18	18 - 20
Equity infusion	30% equity infusion	0.05 – 0.10	20 - 25

Table 32: VGF impact and requirement for medium term

Type of incentive	Incentive offered	Impact on LCOH (USD/kg) (reduction)	Amount of subsidy/VGF/ Equity (INR Cr)
Capital grant on Hydrogen production and allied infrastructure	10% capital grant	0.10	30 - 35
	20% capital grant	0.20	60 - 70
	30% capital grant	0.30	90 - 105

Waiver of transmission charge	Waiver for 10 years	0.25 – 0.30	200 - 250
	Waiver for 5 years	0.15 – 0.18	100 - 125
Equity infusion	Not Considered		

Table 33: VGF impact and requirement for long term

Type of incentive	Incentive offered	Impact on LCOH (USD/kg) (reduction)	Amount of subsidy/VGF/ Equity (INR Cr)
Capital grant on Hydrogen production and allied infrastructure	10% capital grant	0.10	100 - 120
	20% capital grant	0.20	200 - 240
	30% capital grant	0.30	300 - 360
Waiver of transmission charge	Waiver for 10 years	0.25 – 0.30	1100 - 1200
	Waiver for 5 years	0.15 – 0.18	550 - 600
Equity infusion	Not Considered		

The end consumers/industry players may require capital grant for the additional infrastructure required to enable a hydrogen led transition. Therefore, additional subsidies may be required for additional infrastructure required to enable commercial viability of the valley, as illustrated below:

Focus areas	Unit	Timeline		
		Pilot Project (2024-27)	Medium term (2027 - 30)	Long term demand (2030-40)
HRS - 2 TPD	INR Cr	35	240	700
Fuel Cell Bus	INR Cr	5	100	360
Fuel Cell Truck	INR Cr	6	120	250
Tube trailer	INR Cr	2	2	4
Total (Cumulative)	INR Cr	~48	~462	~1315
Capex and grant for each phase	INR Cr	~48	~422	~853
Capex grant @10%	INR Cr	~5	~42	~85
Capex grant @20%	INR Cr	~10	~84	~170
Capex grant @30%	INR Cr	~15	~126	~255

4.4 Ecosystem players along the Green Hydrogen value chain

Ecosystem players will play an important role in the valley development. An indicative list of ecosystem players are provided below:

Table 34: Mapping of ecosystem players along the green hydrogen value chain

Value chain	Ecosystem players	
	Short term (pilot phase)	Long term
RE generation	Cleantech Solar, Cleanmax, Amplus Power, Fourth Partner etc.	Greenko, Azure Power, Renew Power, Sterlite, Amp Energy etc.
Valley developer (system integrator)	Linde, NTPC, Avaada, ACME Group etc. (shall be selected through bidding)	
Electrolyser plant	Domestic: L&T, Gensol-Matrix, Reliance, Greenko-John Cockerill International: NEL, Thyssenkrupp	
Utilities and infrastructure	Tata Projects, L&T, Thermax, ISGEC etc.	
Storage tank	Linde	
HRS	Linde, Cummins, Air Liquid, Air Product, Praxair etc.	
Transportation service provider	Mysore Ammonia, Local service provider	
Certification agency	TUV SUD, DNV, CetifHy	
PMC/Engineering Consultant	Fichtner, Black & Veatch, Mott Macdonald	

4.5 Scope of German players in the valley development

In recent years, several German and European companies have shown strong interest for Indian market in the Green Hydrogen value chain. They could be potential collaborators for valley development.

Table 35: Mapping of German ecosystem players along the green hydrogen value chain

Value chain	German Ecosystem players	Remark
Valley developer (system integrator)	Linde, RWE, HH2E AG	The firms have adequate development experience and can leverage it to participate in the bid for valley developer
Electrolyser plant OEMs	Thyssenkrupp nucera, Siemens, Sunfire, H-TEC Systems, OHS	
Utilities and infrastructure	None	Indian players will be more competitive due to better local presence and understanding
Storage tank	Linde, Hensoldt	Both are leader in designing and supplying Hydrogen storage solution
HRS	Linde, Elringklinger, Maximator Hydrogen, Sera	Linde is one of the leading HRS producers in the world
Certification agency	TUV SUD	One of the leading certifying agency
PMC/Engineering Consultant	Fichtner, EMCEL, Hynergy GmbH	
Technology partner	Fraunhofer	One of the leading research organisation in the energy space
Component OEMs	Siemens Atlas Copco BOSCH Hartmann Valves	These players are leaders in their respective fields; many of their products, such as compressor, fittings would have use in Hydrogen ecosystem

The collaboration can create a win-win situation for both valley stakeholders and the collaborating entity by pooling expertise and technological superiority from the partners across the green hydrogen value chain.

Collaboration opportunities with German and other European ecosystem players in development of the Hydrogen valley

Given Europe's leadership in hydrogen technology, especially in valley development, the Government of Telangana may explore collaboration opportunities with ecosystem players to leverage their expertise in the areas of technology transfer, engineering and project development, equipment supply, knowledge sharing, best practices adoption, and training.

Knowledge Sharing and adoption of Best Practices

- **Workshops and Seminars:** Hosting joint workshops and seminars with European/German experts can help in sharing best practices and lessons learned from Germany's hydrogen hubs.
- **Case Studies and Success stories:** The implementing agency can collaborate with European/German institutions to analyze case studies of successful hydrogen hubs in Germany, providing a blueprint for the state's own Hydrogen Valley.
- **Academic Collaboration:** Partnerships between Telangana's universities and European academic institutions can foster exchange programs for students and researchers, enhancing knowledge transfer.
- **Sustainability and Environmental Practices:** Collaboration can focus on integrating Europe's/Germany's best practices in sustainability, ensuring that hydrogen production in Telangana is environmentally friendly.

- **Engineering and Project Development:**
    - **Engineering and system integration:** The implementing agency can collaborate with German engineering firms for the design, development and integration of hydrogen production, storage, and distribution infrastructure.
- **Training and Capacity Building:**
    - **Skill Development Programs**: European/German institutions can collaborate with Telangana's skill development institutions to design and deliver specialized training programs in hydrogen technologies, valley development and operation of the valley.
    - **Technical Training:** On-site training sessions or through virtual platforms can be organized for Telangana's engineers and technical staff to enhance their expertise in hydrogen technologies and allied infrastructure

Implementation strategy and way forward:

- **Establish a bilateral Task Force**: Establish a bilateral task force comprising representatives from the Government of Telangana, European/German companies, research institutions, and relevant stakeholders. This task force will be responsible for identifying specific areas of collaboration, setting priorities, and ensuring smooth communication between both parties.
- **Memorandum of Understanding (MoU):** Signing MoUs between Government of Telangana and European ecosystem players can formalise the partnership, outlining specific areas of collaboration, roles, and responsibilities. These MoUs should cover areas such as engineering collaboration, knowledge exchange, and training initiatives.
- **Funding and Investment support**: Explore funding opportunities from bilateral cooperation programs. Jointly seeking grants or subsidies from European Union funds dedicated to green energy could also be beneficial.
- **Monitoring and Evaluation**: Establishing a robust monitoring and evaluation framework will ensure that the collaboration yields the desired outcomes, with periodic reviews and course corrections as needed.

By collaborating with European ecosystem players, the Government of Telangana can accelerate the development of the Hydrogen Valley that is technologically advanced, sustainable, and scalable. This partnership will contribute to the state's energy transition and position the state of Telangana as a leader in hydrogen initiatives in India.

4.6 Governance mechanism for valley implementation

Successful implementation of the valley will hinge on deployment of a robust governance system, enabled by multidisciplinary collaboration between diverse stakeholders. An illustration of the mechanism is provided below.

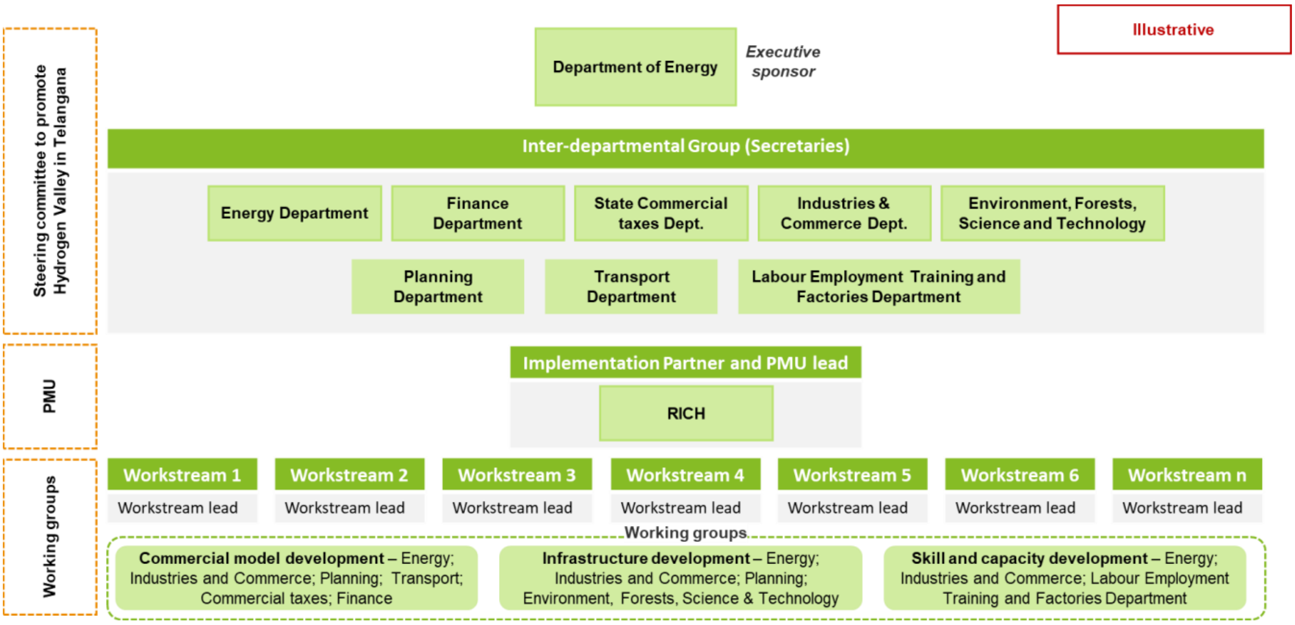


Figure 22: Governance mechanism for valley implementation

Salient points of the governance mechanism are:

- Department of Energy, Government of Telangana may be the executive sponsor for the valley development
- Various inter-departmental groups may be required to be formed for effective collaboration
- RICH may act the implementation partner as well as the Program Management Unit (PMU). RICH will be responsible for Project planning, coordinating implementation, Risk management and monitoring and knowledge management.
- The entire implementation work should be broken up in multiple workstream and each workstream should be assigned with individual workstream lead

5 Risk and mitigation measures

While water electrolysis is an established process, developing hydrogen projects comes with various risks. To ensure successful project development, it's crucial to identify and mitigate these risks effectively. Captured below is an overview of major risks associated with hydrogen project development and potential mitigation measures:

Table 36: Identification of Risks and mitigation plans

Risk	Description	Mitigation measures
Technical and Safety Risks	• Hydrogen is highly flammable and can be challenging to handle safely, leading to potential accidents and infrastructure damage • Deployment of Hydrogen Refuelling System may lead to public safety risk	Employ rigorous safety protocols, invest in advanced leak detection systems, and implement robust emergency response plans. Additionally, use advanced materials and designs for hydrogen storage and transportation infrastructure to minimize risks
Offtake risk	• Green H_2 merchant market is not established. Also, cost of green hydrogen is much higher than grey hydrogen, leading to limited voluntary purchase interest from consumers due to this unfavourable economics. • Developers prefer a long term offtake contract (>10 years), while off takers prefer short term contract (2-3 years) • All the above lead to unpredictable cash flow for the developers	SPV should negotiate long term contract with consumers.
Technology risk	• Green hydrogen is nascent technology; while certain technologies are mature (e.g. alkaline electrolysis), experience on commercial scale deployment is limited	Select OEM with proven experience and good pedigree. Lead developer/anchor investor should have prior experience of developing green hydrogen projects.
Operational risk	• Non-performance of hydrogen process and equipment (e.g., load factors, conversion efficiency, leakage) poses significant operational risk. • Limited availability of historical data makes it difficult to predict performance.	Developer should focus on skill and capacity building by training O&M officials by the OEM and in the initial years; developer may also explore outsourcing the annual maintenance contract to the OEM.
Counterparty default risk	• Default of the buying counterparty on its obligations (disappearance, questioning of contract) • Default of the electricity supplier and the equipment supplier	Developer should deploy suitable payment security mechanism as part of the off-take agreement. Developer may consider signing multiple small contracts to diversify default risk.
Construction risk	• Non-performance of contractor	Selection of the EPC contractor should be done through proper due diligence. Selection of contractor should incorporate completion guarantees, conduct due diligence on previous records etc.

6 Key recommendations

A systematic analysis carried out in this study uncovers several opportunities that strongly support the viability of hydrogen valleys in the Ramagundam region. With an active participation from stakeholders, the region has potential to create future demand of hydrogen.

However, in the initial years, commercial viability of hydrogen could be a challenge for few end-consumers, such a fertiliser and glass industries. In addition, higher initial investment by both valley developer as well as by end-consumers, continuous supply of water, non-availability of transport infrastructure of hydrogen, limited availability of capable and trained workforce are some of the major challenges for valley development.

Overcoming these barriers requires strategic initiatives, such as providing fiscal incentives, providing favourable renewable energy policy regime, investing in workforce development, and implementing pilot projects. Policymakers and government stakeholders along with ecosystem players can play pivotal roles in addressing the major issues. Key recommendations for successful development of the Ramagundam valley are depicted below.

Table 37: Key recommendations

Recommendation	Responsibility
DPR preparation: A detailed project report comprising of plot-plan, technical requirements, project scheduling and commercial aspects of valley development should be prepared prior to commencement of pilot project.	The implementation partner (e.g., RICH)
Development of a strategy or policy roadmap: Clear production and consumption targets along with timelines are essential for providing industry stakeholders with a sense of direction. Currently, the state of Telangana doesn't have any hydrogen policy; developing a hydrogen policy with a clear direction for hydrogen valley development could be an important step.	Government of Telangana, Department of Energy
Selection of the implementation partner for valley development: Implementation partner must be identified as the first step of valley development. It will be responsible for end-to-end monitoring of the progress. For example, RICH has adequate capability and expertise to oversee the development and progress of hydrogen valley. Other entities may also be evaluated	Department of Energy, Government of Telangana
Providing fiscal incentives: Fiscal incentives may include capital grant, subsidies, tax credits, tax exemptions, rebates, and low-interest loans aimed at incentivizing private sector investments in valley development. These are critical instruments to drive investment. The State Government may provide tailormade incentives to the valley developer in addition to what is allowed as per industrial policy. Budgetary allocation should be made for the "Hydrogen Valley" development.	Government of Telangana, Department of Energy and Department of Finance.
Phasing of valley development: The valley development should be divided into multiple phases, beginning with a "Pilot Project", with a clear visibility of "Pilot to Scale-up" strategy. A clear roadmap to aggregate demand and ramping up of hydrogen production capacity should be in place.	The implementation partner (e.g., RICH)
Collaboration with ecosystem players: Success of valley development is hinged on collaborating with ecosystem players with diverse expertise (e.g., hydrogen production, HRS suppliers, logistics service providers etc.). Engaging ecosystem players at right time and incorporating feedbacks from them is a critical success factor for valley development	This is a multi-stakeholder activity. Implementation partner could be the nodal agency for engaging with stakeholders
Collaboration with European/German ecosystem players: Given Europe's leadership in hydrogen technology, especially in valley development, the Government of Telangana may explore collaboration opportunities with ecosystem players to leverage their expertise in the areas of technology transfer, engineering and project development, equipment supply, knowledge sharing, best practices adoption, and training.	RICH, Government of Telangana

Recommendation	Responsibility
Workforce development: Investing in workforce development programs and training of workforce is critical for successful operation of the valley. The aim is to develop education and training for the technical jobs that will be needed in the hydrogen industry, for example maintenance of hydrogen equipment, hydrogen handling and safety, HAZOP study, reconversion of workers from other industry etc. Dedicated budget should be allocated towards workforce development and training	Implementation Partner
Selection of valley developer: Selection of the valley developer or anchor investor is one of the critical milestones for valley development. Preparation of an RFP document and standard Hydrogen purchase and selling agreement, followed by a global competitive bidding should be initiated within the stipulated timeframe. This will expedite the pace of development.	Implementation Partner
Waiver of state transmission charges: Transmission charges waivers can help in reduction of delivered electricity costs for the hydrogen facility thus bridging the gap between the LCOH and willingness to pay of multiple demand activators. ISTS charges are waived off for hydrogen production units as per the central regulations and similar waiver can be provided in the state as well.	Department of Energy, Telangana

7 Conclusion

As the pressure to reach net zero mounts from investors, regulators, customers, and other stakeholder groups and the demand for low-carbon products and solutions grows, “harder-to-abate” sectors are rightfully seeking pathways to achieve meaningful emissions reduction while preserving value for shareholders. Hydrogen valleys present a relatively preferable option for industry in the near term to demonstrate action on climate change.

While Government subsidy plays an important role in kickstarting a hydrogen valley, business case for cross-sector collaboration may emerge even without government support. This would include involving the right partners, securing demand amongst diverse end-uses, engaging the value chain players, structuring agreements between valley developer and off takers, and adequate coordination amongst various stakeholders. Industries must embrace collective ecosystem approaches to make the business model more commercially viable.

The Green Hydrogen valley in Ramagundam region is expected to be the regional market maker for Green Hydrogen ecosystem in Telangana. This can be a successful model, which can also be replicated in other regions. However, willingness to pay for certain sectors is lower than the current cost of production of Green Hydrogen, which needs to be bridged through funding support. Further, implementation of an appropriate governance mechanism and onboarding of ecosystem players are critical success factors for valley development.

Selection of right anchor investor or developer is critical to bring the right expertise through coordination with all ecosystem players. RICH (or the implementation partner) has a larger role to play by creating the Special Purpose Vehicle (SPV), obtaining necessary statutory approvals, selection of valley developer, setting up a governance mechanism and development of a capacity building plan.

The success of valley project will ultimately be driven by how well valley sponsors are able to navigate the complexity surrounding valley development. This will include sending the right demand signals to ecosystem collaborators, making near-term investment decisions for bottom-line impact down the road, and reorienting mid- and long-term business goals and capital expenditure to lower emissions.

In addition to dedicated hydrogen valley, this study has briefly examined the holistic industrial decarbonisation initiatives to reduce emission footprint in the Ramagundam industrial cluster. There is no single solution to industrial decarbonisation, and a broad portfolio of options should be exercised by companies to reduce carbon footprint. Each industry sector will have different levers for decarbonisation, depending on technical feasibility, economics and scalability. For example, Fertiliser – Green Hydrogen, Renewable energy and CCUS; Cement – CCUS and Renewable energy; Glass – Renewable energy, Green Hydrogen and recycling; Mining – Renewable energy, Green Hydrogen etc.

8 Annexure

8.1 Industrial decarbonisation roadmap in Ramagundam cluster

Industrial decarbonisation is seen as the most important lever for meeting the country's climate targets. There is no single solution to industrial decarbonisation; a broad portfolio of options is being exercised or explored by industrial companies to reduce emission.

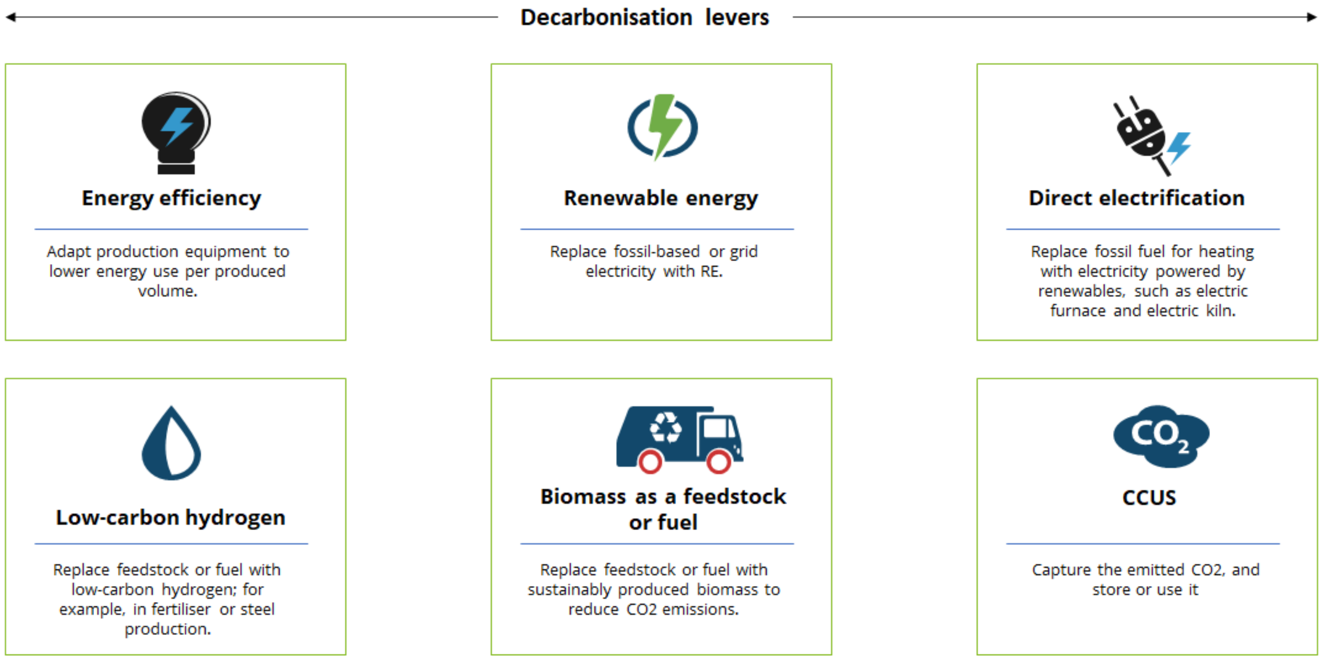


Figure 23: Decarbonisation levers for industrial companies

Energy efficiency: Energy efficiency is a continuous process; manufacturers are focusing on operations excellence and adoption of digital monitoring tool to manage energy consumption. Emission reduction potential from energy efficiency measures is 5 – 15%[51]. Industries in the matured sectors typically have already seen improvements and can thus be expected to be at the low end of the range, whereas industries in evolving sectors may be at the high end.

Renewable energy: Transition to renewables is becoming the most preferred options for most of the energy intensive industries to decarbonize the electricity (Scope 1 and 2 emissions). With reforms in regulations in policies, such as green open access, increase in renewable corporate PPAs through third party mode or group captive mode is clearly visible. As of March 2024, India has ~20 GW of C&I renewable installed capacity[52]. Many industries and corporates also prefer buying renewable energy certificates to discount carbon emission. Major drivers for corporates to shift to RE include declining cost of renewables, emergence of energy storage to enable round-the-clock power and favourable regulations towards Renewables.

Direct electrification: Many industrial manufacturers have started focusing on electrification of process heat to leverage low-carbon electricity in place of fossil fuel (coal, NG etc.). For example, many furnace applications which use fossil fuel directly (e.g., steel, foundry etc.) are getting replaced with electric furnaces powered by RE.

Low carbon hydrogen: Use of low carbon hydrogen (mainly green) is being explored as a decarbonisation agent in refineries, fertilizer and Steel sectors. There is a fast-growing acknowledgement that energy systems cannot be decarbonized by greening electrons (RE) alone; low-carbon hydrogen is emerging as a "Decarbonisation Agent" for the hard-to-abate sectors.

Carbon Capture, Utilisation and Storage (CCUS): CCUS is the most preferred decarbonisation option in Cement sector; limited uptake is visible in Steel and Fertilizer industries. Currently, India is only operating few pilot scale projects in the Steel and Chemical sectors; both downstream carbon utilization and carbon storage will be critical to achieve scale.

---

[51] Source: Industry input, Deloitte analysis
[52] India RE Navigator (access here)

Biomass as a feedstock: Biomass as an alternative fuel is gaining traction to reduce fossil fuel emission. Currently, majority of biomass used in the industrial sectors is in the Paper and Food industries. Going forward, some uptake is expected in the Steel and Cement sectors (co-firing with coal); however, key considerations include changes in the plant design and establishment of a reliable supply chain.

8.1.1 Decarbonisation roadmap for RFCL

Urea is produced by combining liquid ammonia and carbon dioxide (CO_2) during urea synthesis. The CO_2 generated during ammonia production is further used during Urea synthesis. Ammonia is commonly produced through the Haber-Bosch process, combining hydrogen (currently typically sourced from natural gas) with nitrogen from the air to form NH_3. Current production process is emission intensive, as illustrated below:

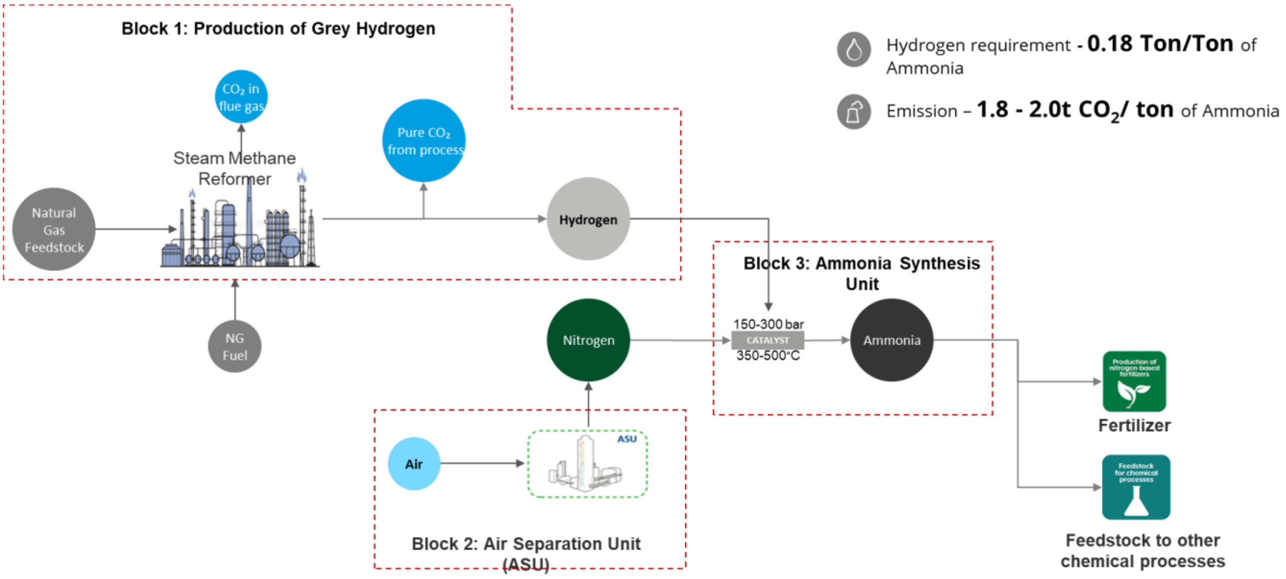


Figure 24: Ammonia production technology

8.1.1.1 *Current status of emission and initiatives taken by RFCL*

RFCL has already undertaken several decarbonisation measures in the form of enhancing energy efficiency. A brief description on current emission and initiatives is provided below:

Table 38: Current status of RFCL's decarbonisation initiatives

Title	Description
Total CO_2 emission	• 500 – 550 tons per day
Total energy consumption	• ~5 GCal/ton of Urea • ~50 MW electricity per day
Sources of CO_2 emission	• Ammonia Unit – Primary reformer • Flare • Gas turbine • Heat recovery steam generator • Utility boiler
Current decarbonisation initiatives	**Energy efficiency** • Use of VFD in rotary equipment, wherever possible, such as Ammonia plant – NG compressor, ID/FD fans of Primary reformer, select pumps in Urea plant • Use of Heat Recovery Steam Generator (HRSG) **Renewable Energy** • No use of RE; entire electricity is from captive power plant or GRID **Green Hydrogen and CCS** - None

8.1.1.2 Decarbonisation levers and roadmap for RFCL

Replacing natural gas as a feedstock for ammonia production with green hydrogen theoretically offers the potential to produce carbon-free nitrogen fertilizers. Other measures include improvement in energy efficiency, substituting grid power with Renewable Energy, biomass cofiring in the utility boilers and deployment of CCS, as illustrated below:

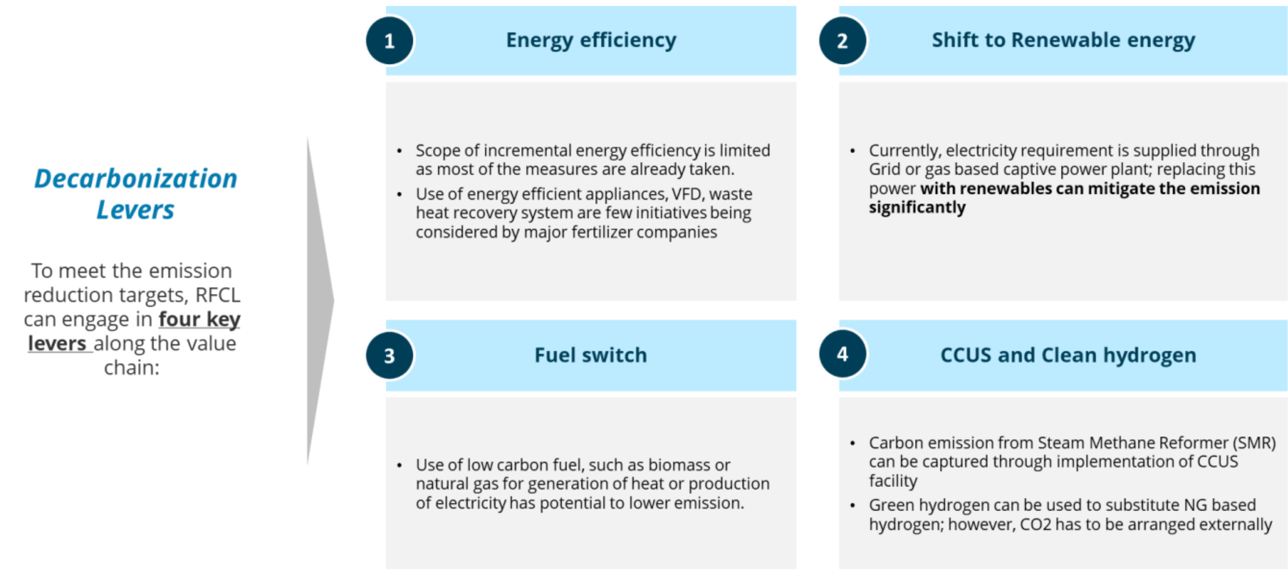


Figure 25: Decarbonisation levers for RFCL

It is important to note that RFCL manufactures Urea, which has carbon it's molecular structure. Typically, the carbon in urea's molecule is obtained by re-using the carbon dioxide (CO_2) emitted by natural gas-based ammonia production (later the CO_2 gets emitted in the field when mixed with soil). Using CO_2 from other sources is theoretically an option, but it implies a prohibitive cost increase in addition to green ammonia costs. In the vicinity of the RFCL plant, NTPC operates its 2600 MW Ramagundam Thermal Power Station. Therefore, in the long run, sourcing CO_2 from NTPC Ramagundam could potentially help to enable adoption of green hydrogen.

RFCL can undertake decarbonisation initiatives in a gradual manner along energy efficiency, adoption of renewable energy, green hydrogen and CCUS. Some of the interventions could yield immediate impact ('Quick wins') on emission footprint, as illustrated below:

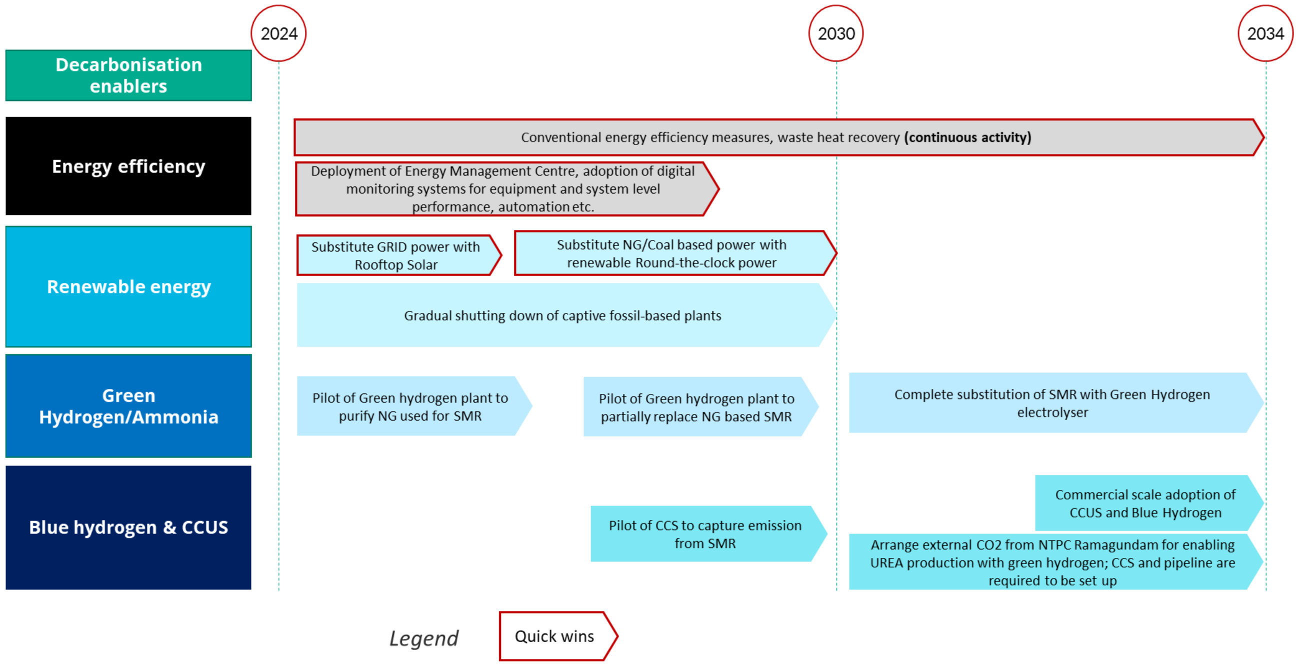


Figure 26: Decarbonisation roadmap for RFCL

8.1.2 Decarbonisation roadmap for SCCL

Emissions within mining can be broken down into two broad types: Scope 1 (emissions from diesel) and Scope 2 (emissions from electricity generation). Today, typically, 50 - 60 percent of CO_2 emissions come from diesel used in mobile equipment, with another 40 to 50 percent from nonrenewable electricity.

8.1.2.1 Current status of emission and initiatives taken by SCCL

SCCL has already undertaken several decarbonisation measures in the form of RE adoption, use of energy efficient appliances, VFD etc. A brief description on current emission and initiatives is provided below:

Table 39: Current status of decarbonisation initiatives taken by SCCL

Title	Description
Total energy consumption	• Grid electricity ~350 MU per year; additional 350 MU is sourced from captive RE plants
Sources of CO_2 emission	• Use of GRID electricity (350 MU) • Use of HSD for HEMM in Open Cast Mine
Current decarbonisation initiatives	**Energy efficiency** • Use of energy efficient appliances (5 Star Rating of BEE) in all mines, official buildings and quarters of SCCL • Latest Technology adoption for various Plant & Machineries used in Coal Handling Plants such as VFD, efficient drives etc. **Renewable Energy** • 50% power is sourced from RE • Rooftop solar installed in various buildings **Hydrogen and fleet electrification** The following Proposals are being worked out: • Electrification of HEMM • Use Case of Green Hydrogen for Off Road Trucks

8.1.2.2 Decarbonisation levers and roadmap for SCCL

Multiple efforts will be required to address the principal sources of emissions and to decarbonize. Such actions include a move toward fleet decarbonisation as well as a switch to green electricity. The following options are at varying states of technological readiness; several are already cost-positive today or will be by 2030.

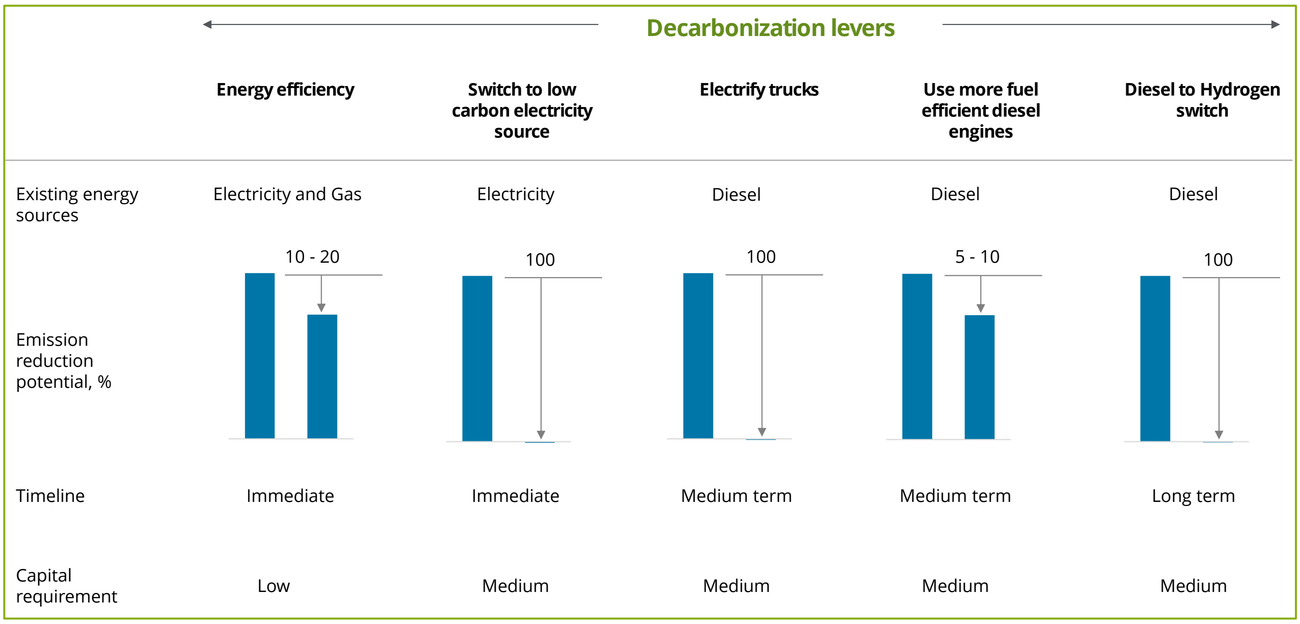


Figure 27: Decarbonisation levers for SCCL

SCCL can undertake decarbonisation initiatives in a gradual manner along energy efficiency, adoption of renewable energy, and green hydrogen use in mining trucks. Some of the interventions could yield immediate impact ('Quick wins') on emission footprint, as illustrated below:

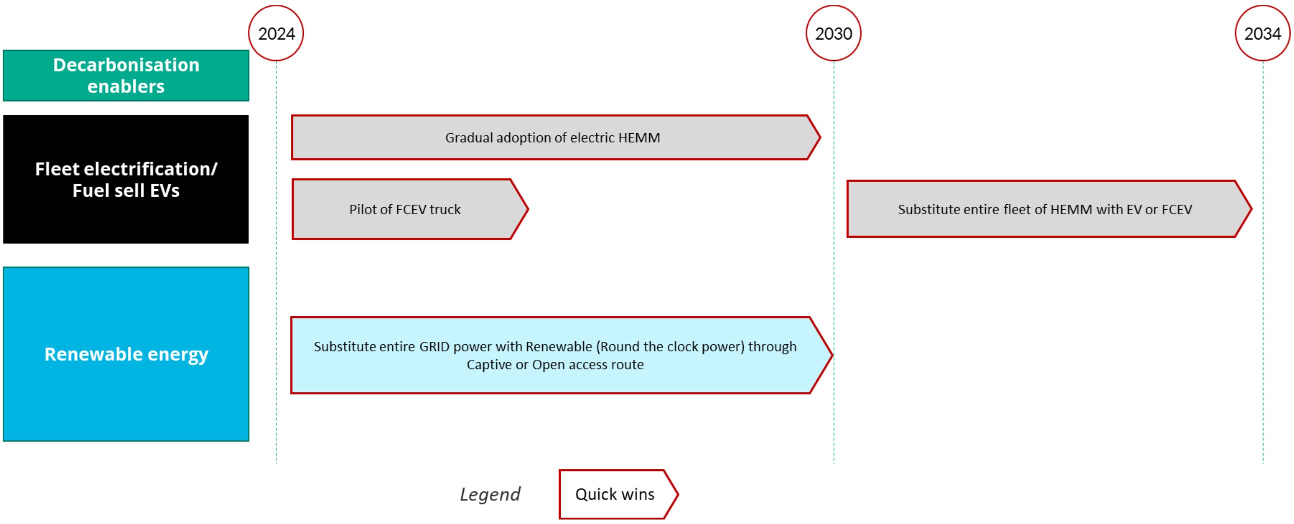


Figure 28: Decarbonisation roadmap for SCCL

8.1.3 Decarbonisation roadmap for AGI Glaspac

Glass industry is one of the major energy intensive industries globally. In addition to the typical challenges of sustainably producing high-quality glass at optimized costs, the glass industry is facing new challenges towards achieving **carbon-neutrality and circularity.**

The path to the industrial production of low-carbon glass still faces many obstacles. The most significant one being the **switch to renewable energy sources**. Two main contenders - electricity and hydrogen – are being tested and developed by many players in the industry. Other options such as biogas and biofuels are also under investigation.

Melting and Forming processes are most energy intensive process along the value chain as they use high temperature heat (+400 deg C). Some of the levers that can drive decarbonisation in glass manufacturing are illustrated below:

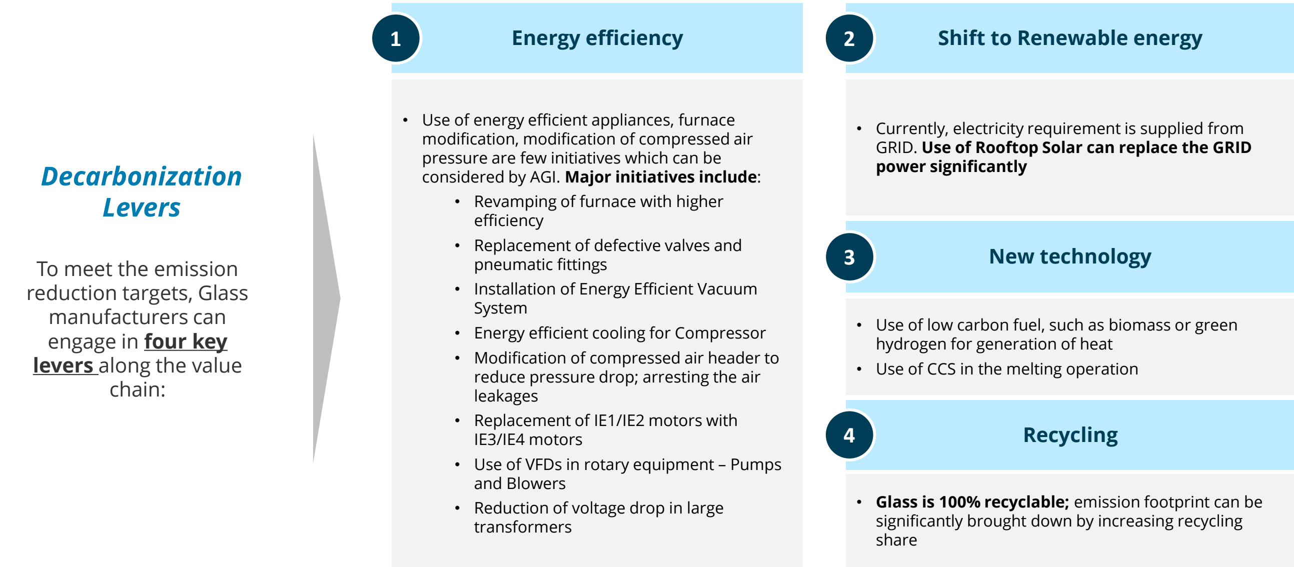


Figure 29: Decarbonisation levers for AGI

Several Indian glass manufacturers have taken initiatives to reduce emission footprint, such as:

- Signing of Renewable PPA with RE developers in a group captive mode.
- Deployment of rooftop solar in glass factories
- One large manufacturer has **piloted Hydrogen use in the furnace for glass production in Germany**. Once successful, the furnace in India, which is being run on natural gas, **would shift to hydrogen in a progressive manner**
- Energy Saving initiative across plants which include installing energy efficient motors and systems, use of energy efficient electrical equipment (such as LED bulb instead of fluorescent lamp), installation of Digital Energy meters for monitoring Power Consumption at the equipment level.
- Deployment of AI modelling for furnaces to reduce fuel consumption.

In similar line, AGI Glaspac can undertake decarbonisation initiatives in a gradual manner along energy efficiency, adoption of renewable energy, recycling, and green hydrogen use in furnace. Some of the interventions could yield immediate impact ('Quick wins') on emission footprint, as illustrated below:

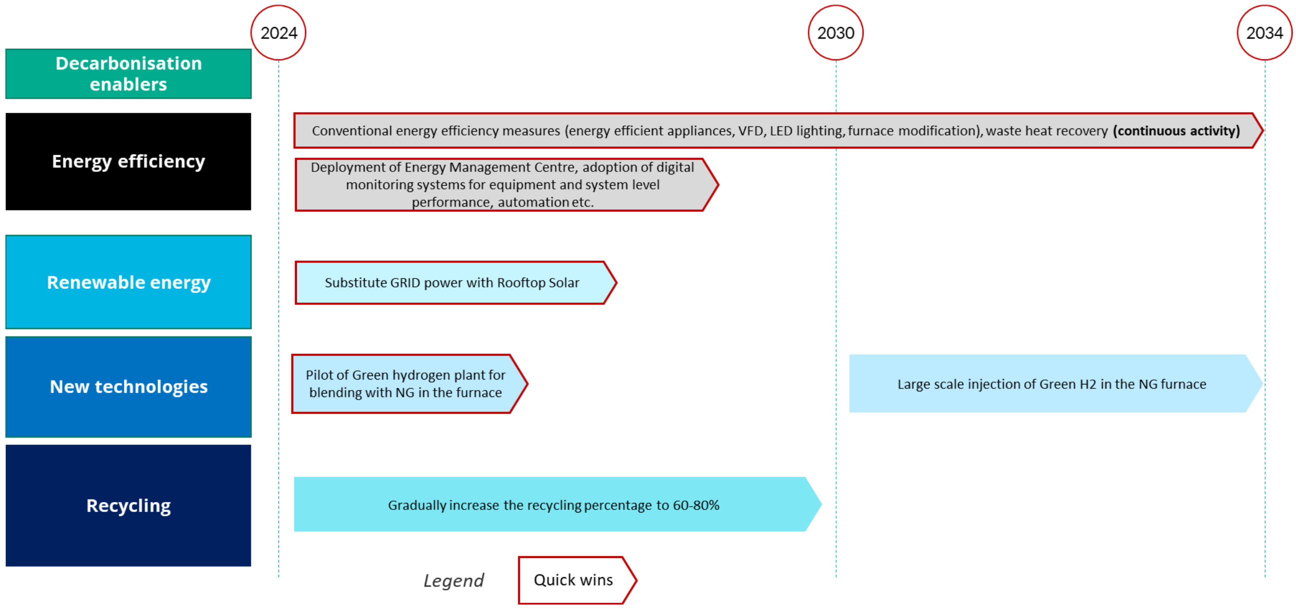


Figure 30: Decarbonisation roadmap for AGI

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Deutschland
T +49 228 44 60-0
F +49 228 44 60-17 66

E info@giz.de

Dag-Hammarskjöld-Weg 1-5

65760 Eschborn, Deutschland

T +49 61 96 79-0

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.