11th AMAI Alkali Industry Conference
11-12 February 2026, New Delhi

Hydrogen Safety and Clean Energy Transition :

technology, policy and financial interventions

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India's Hydrogen Story –
Establishing a decarbonized energy system

National Green Hydrogen Mission

Launched by Hon'ble Prime Minister Narendra Modi on 15th August 2021
Approved in Jan 2023; Initial outlay: ₹19,744 crore (FY 2022-23 to 2029-30)

India – The next big moment

Green hydrogen, a green and sustainable energy carrier, will play an integral role in reducing carbon emissions and reducing energy imports, achieving India's net zero ambitions by 2070; making India a global hub for production, usage and export

Mission Objectives and Outcomes by 2030

- At least 5 MMT GH_2 Annual Production
- 60-100 GW Electrolyser capacity
- 125 GW RE Capacity for GH_2 Generation
- 50 MMT per annum of CO2 emission averted
- ₹ 1 lakh Crore Import Savings
- ₹ 8 Lakh Crore Investment
- 6 Lakh Green Jobs

Safety is the most important determining factor after electricity prices for success of the hydrogen economy

Safety issues can be a 'deal breaker'; must be addressed for successful technology acceptance and deployment

Production of H2 is determined by thermodynamics, while hydrogen safety is determined by kinetics

Understanding Hydrogen

UNIQUE PROPERTIES OF HYDROGEN: A CHALLENGE AND AN OPPORTUNITY

CO_2 Emission Free

Non-Toxic

Very small molecule

Colourless
Odourless
Tasteless

Invisible flame

Less Radiant heat

14 times lighter than air

Range of flammable conc. (4 -75 %) 10 times higher than petrol

Easily ignited ; (15 times less energy required than NG @stoichiometric conc)
Even a weak ESD (Vs<2kV) from the human body can ignite the hydrogen–air mixt

Prone to deflagration-to-detonation transition (DDT)

Laminar burning velocity about 3 m/s. 10 times faster than methane
Can accelerate from 18 to 300m/s under confined, turbulent env; prone to flashback; flame instability due to high diffusivity

Negative Joule Thomson coefficient - T_{hyd} rises on expansion above T_{inv} of 202 K and P_{abs} of zero (significant if already near T_{ign} of 580 C after mixing with surrounding gas)

Comparison with Other Fuels

Property	Hydrogen	Natural Gas	Gasoline
Colour	No	No	Yes
Toxicity	None	Some	High
Odour	Odour-less	Mercaptan	Yes
Buoyancy Relative to Air	14X Lighter	2X Lighter	3.75X Heavier
Energy by Weight wrt gasoline	120-132 MJ/kg 2.8X >	~1.2X >	43MJ/kg
Energy by Volume wrt Gasoline	4X< 8-10 MJ/L (LH2) < 5.7 X 5.6 MJ/L (GH2 @700 bar)	1.5X <	32 MJ/L

NATURAL GAS, [COMPRESSED]

NFPA 704 Hazard Placards

- Red = Flammability
- Blue = Health
- Yellow = Reactivity
- White = Special Precautions

Gaseous Hydrogen

Liquid Hydrogen

Hydrogen Vapour Cloud Explosions: credible scenario

- Often the most credible **catastrophic explosion hazard** on a plant site
- Fires are more frequent, but typically cause **less widespread damage**
- Can occur **externally (unconfined)** or **internally (within enclosures)**
- Internal events are often **vented deflagrations**; terminology is secondary
- Typically a deflagration, but **DDT is possible** under certain conditions
- **High-reactivity fuels** (e.g., hydrogen) are of particular concern

Factors affecting VCE

- **Flame speed** (primary driver of overpressure)
- **Congestion and confinement** (equipment density, walls, decks)
- **Fuel reactivity** (burning velocity)
- **Flame travel distance / length scale**
- **Energy release** at elevated flame speeds
- **Deflagration vs. detonation behavior**
  - Deflagration: blast driven by cloud within confined/congested zones only
  - Detonation: can propagate beyond confined areas
- **Gas cloud geometry and distance to target (standoff)**

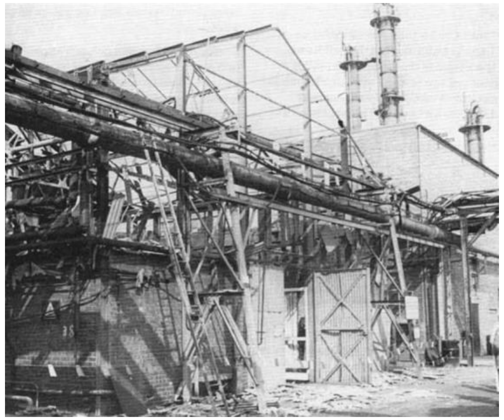
Hydrogen VCs do not always disperse or ignite immediately

12% H_2 (ER = 0.33)

Baker Risk

Technology Interventions

Learning from Hydrogen Accidents



Explosion at Laporte Industries, Ilford London, 1975

Electrolytor - corrosion and clogging of cell seals, H_2 cross-over and explosion in O_2 separator

Hydrogen tank explosion, Gangneung South Korea, 2019

Spark ignition of Hydrogen in buffer tank

Hydrogen air explosion in Ammonia plant

Hydro Herøya, Porsgrunn Norway 1985

Expl in purification chamber, substantial jet fire

https://elementalexpirations.wordpress.com/2017/07/19/hydrogen-explosion-at-the-n1-factory-in-heroya-norway/

Hydrogen explosión & Jet fire, Santa Clara, California, June 2019

A major uncontrolled release of high-pressure hydrogen at the Air Products hydrogen trailer transfill facility; unauthorized repair to leaking valve & miscomm between 2 drivers filling trailer

https://h2tools.org/sites/default/files/2021-06/AP_Santa_Clara_Incident_Review_Report_Rev1.pdf

HRS explosion at Kjørbo, June 2019

A leakage and subsequent explosion at the Hydrogen Fuelling Station

Hydrogen incidents: Lessons learnt

Safety principles derived from the actions required to prevent an escalation of a prototypical hydrogen accident

Analysis of 426 Hydrogen accidents/ incidents

Common cause : **Design of hydrogen system** or the **selection of materials not compatible** with hydrogen services
SP0 : Poor design of hydrogen system and material selection (proposed)
SP 9: **Lack of training of operators/plant personnel and lack of understanding** of hydrogen hazards is a key area which need further improvement.
SP 10 : **Lack of a system to report near misses/incidents** and **apply learning from it** for further development of a safety plan

- Ensure **inherently safety design** - an effective means to prevent incidents
- Perform a throughout **quantitative risk assessment (QRA) during the design phase and before any process or equipment change**
- **Embed Human & Organisational factors**
- **Life cycle analysis**

https://www.fch.europa.eu/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects_Re-lease1p31_20190705.pdf

Preventive barriers or Risk reducing measures

Number	Safety Principle	Explosion/ Protection Tier
1	Limit hydrogen inventories, especially indoors, to what is strictly necessary	1st Tier
2	Avoid or limit formation of flammable mixture by applying appropriate ventilation systems, for instance	
3	Carry out ATEX zoning analysis (Zone 0, 1 or 2) *based on the likelihood of a potentially explosive atm being present*	
4	Combine hydrogen leak or fire detection and countermeasures	2nd Tier
5	Avoid ignition sources using proper materials or installations in the different ATEX zones, remove electrical systems or provide electrical grounding, etc.	
6	Avoid congestion, reduce turbulence promoting flow obstacles (volumetric blockage ratio) in respective ATEX zones	3rd Tier
7	Avoid confinement. Place storage in the free, or use large openings which are also supporting natural ventilation	
8	Provide efficient passive barriers in case of active barriers deactivation by whatever reason	
9	Train and educate staff in hydrogen safety	Organisational Safety Principles
10	Report near misses, incidents and accidents to suitable databases and include lessons learned in your safety plan	

Systems Safety Analysis and **Quantitative Risk assessments, informed by lessons learnt from previous incidents, play a crucial role in identifying and mitigating risks associated with hydrogen handling, storage, and transportation.**

AMAI : Alkali Industry Proactive Measures

The Alkali Manufacturers Association of India (AMAI) has established a **Chlorine Emergency Response Network (CERN)** that has been extended to cover the handling of other chlor-alkali products, including hydrogen, to mitigate emergencies during transport and on-site.

- Increasing focus on zero-accident goals, as it moves toward utilizing advanced technologies and, in some cases, green hydrogen initiatives.

Policy & Regulatory

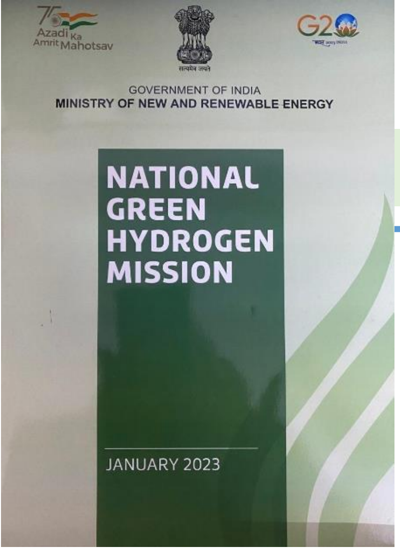
NGHM GOVERNANCE STRUCTURE

Inter-Ministerial Governance: An Empowered Group (EG) chaired by the Cabinet Secretary, Secretaries from various Ministries/Departments of GoI and experts from the industry, to guide the mission and facilitate policy interventions.

Advisory Group: Chaired by the **Principal Scientific Adviser (PSA)**, with experts from various fields to advise the Empowered Group on scientific and technological matters.

Mission Secretariat: Headquartered in the **MNRE**, the secretariat is responsible for the day-to-day implementation, monitoring, and program management.

Sectoral Implementation: Various Central and State Government agencies, along with PSUs (like NTPC), are assigned specific roles in implementing projects, including the development of green hydrogen hubs at ports (e.g., Deendayal, V.O. Chidambaranar, Paradip).



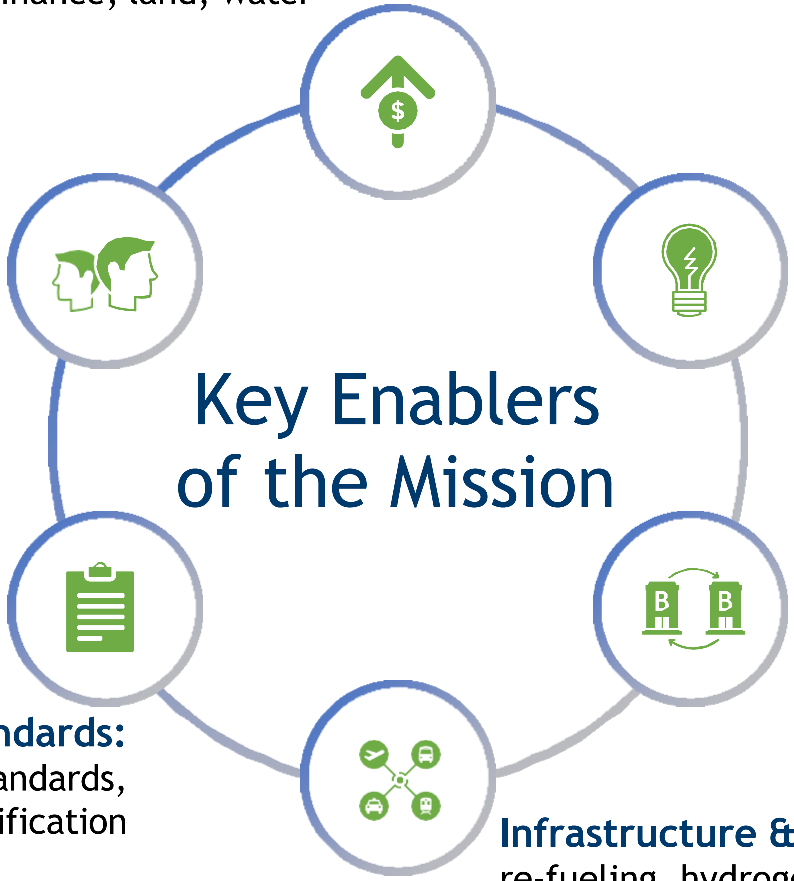
National Green Hydrogen Mission

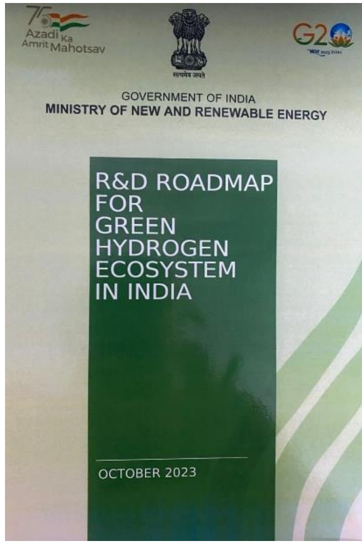
Major Activities (Outlay: ₹ 19,744 Crore)

Resources for banking, storage, transmission, finance, land, water

Skill Development & Public awareness: Coordinated skilling program and online portal

R&D: Result-oriented, time-bound, including through PPP

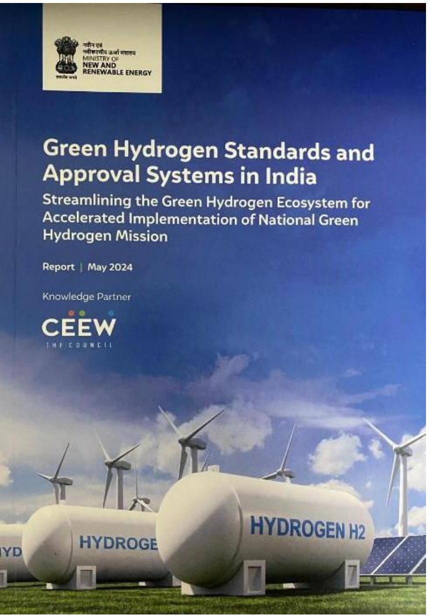




Ease of doing business: Simpler procedures, taxation, SEZ, commercial issues, single window

Regulations & Standards: Testing facilities, standards, regulations, safety & certification

Infrastructure & Supply Chain: Ports, re-fueling, hydrogen hubs, pipelines



Key Regulations and Frameworks

- **Green Hydrogen Policy** 17th Feb 2022
- **Safety Standards:** 128 standards released for hydrogen across value chain
- **Green Hydrogen Standard:** 29th April 2025 ;

Green Hydrogen Policy Highlights:

- **Definition of green hydrogen and ammonia**: produced via RE -powered electrolysis of water or from biomass.
- **Waivers on inter-state transmission charges**: 25-years for projects commissioned before June 30, 2025.
- **Open access for RE sourcing** within 15 days.
- **Allows RE banking** for up to 30 days.
- Prioritizes **connectivity to the interstate transmission system** (ISTS).
- **Allocates land in RE parks** for green hydrogen/ammonia production.
- Permits manufacturers to **establish bunkers near ports for export**.
- Counts **RE consumed towards Renewable Purchase Obligation (RPO) compliance**.
- Establishes a **single portal for statutory clearances**.
- May **aggregate demand** for consolidated procurement bids.

Hydrogen safety governed by

Explosives Act 1884, the Gas Cylinder Rules (GCR) 2016, Static and Mobile Pressure Vessels (Unfired) (SMPV(U)) Rules 2016, and Manufacture, Storage and Import of Hazardous Chemical Rules (MSIHC) Rules 1989

Nodal Ministries / Deptts and Agencies for Implementation

Nodal Regulatory Bodies & Ministries

Ministry of New and Renewable Energy (MNRE): Nodal ministry for implementing NGHM, defining GH2 standards, and overseeing strategies.

Bureau of Energy Efficiency (BEE): Nodal authority for accrediting agencies responsible for monitoring, verification, and certification of GH2 projects.

Ministry of Power (MoP): Responsible for policies ensuring RE supply for hydrogen production, including open access and banking regulations.

Petroleum and Natural Gas Regulatory Board (PNGRB): Regulates the transportation of hydrogen via pipelines and city gas distribution networks.

Ministry of Road Transport and Highways (MoRTH): Responsible for standards related to hydrogen-powered mobility.

Safety and Technical Standards Bodies

Petroleum and Explosives Safety Organisation (PESO): Regulates the storage, transportation, and safety aspects of hydrogen, particularly for high-pressure storage and fuel stations.

Bureau of Indian Standards (BIS): Sets technical standards and specifications for hydrogen production, quality, and equipment.

Oil Industry Safety Directorate (OISD): Involved in developing safety standards for hydrogen handling in industrial settings.

Implementation and Monitoring Agencies

Solar Energy Corporation of India Limited (SECI): Acts as the implementing agency for competitive bidding for green hydrogen and green ammonia production.

Grid Controller of India Limited: Manages the grid connectivity and open access for renewable energy needed for hydrogen projects.

State Pollution Control Boards (SPCB): Grant 'Consent to Establish' (CTE) and 'Consent to Operate' (CTO) for GH2 projects

Safety Panel & Centre

National Hydrogen Safety Panel (NHSP) set up in Sept 2025 to prioritise of safety across the value chain to build greater public confidence in new technologies in the Green Hydrogen ecosystem; provide expertise and advise AG to NGHM and staekeholders

Centre for Hydrogen Safety (CHS) Nodal Institute for Hydrogen Safety- provide technical support to stakeholders cross value chain

Ministry of Skill Development and Entrepreneurship (MSDE) : Responsible for skill development alongwith Skill Council for Green Jobs

Automotive Research Association of India (ARAI) under MHI: Scheme Implementing Agency (SIA) and technical partner for monitoring, testing, and facilitating the adoption of green hydrogen in vehicles

https://nghm.mnre.gov.in/regulations?cat=21&language=en

Green Hydrogen Certification of India (GHCI)

notified on 29th April 2025

- **GHCI GHCI mandates** : GH2 production must use RE with emissions ≤ 2 kgCO_2e/kg H_2.
- A "well-to-gate" certification approach, where producers must track emissions from water treatment to compression.
- Entails rigorous, on-site verification to ensure compliance.
- **Certification mandatory** for all GH2 projects in India that:
  - ✓ Supply to the domestic market
  - ✓ Seek Central or State government support/incentives
  - ✓ Export majority of production but retain a portion for domestic use
- **Exemption:** 100% export-oriented units **without incentives** are **exempt** from GHCI certification but must comply with the destination country's reporting norms.

Green Hydrogen Standard for India

Emissions shall not be greater than
2.0 kg CO_2 eq per kg H_2

GH2 Produced through electrolysis

- Non-biogenic GHG emissions include water treatment, electrolysis, gas purification, drying & compression of H_2
- As an average over a 12-month period

GH2 Produced from biomass conversion

- Non-biogenic GHG emissions include Biomass processing, heat/steam generation, conversion of biomass to H_2, gas purification, drying and compression of H_2
- As an average over a 12-month period

National Hydrogen Safety Panel (NHSP)

Set up in September 2025 under the advice of Advisory group of NGHM chaired by PSA

Aim: Prioritisation of safety across the value chain to build greater public confidence in new technologies in the Green Hydrogen ecosystem, through

- *R&D, skill development, standards and testing protocols.*
- *Sharing of expertise and development of knowledge base on safety aspects of Hydrogen and Fuel Cell technologies*
- *Development of standards and safety regulations in consonance with globally accepted safety norms, to build trust among users with robust quality and reliability requirements.*

Development and harmonization of Hydrogen safety standards across value chain including identification of global best practices

Identify and suggest topics for research / testing on Hydrogen safety including areas for future investigation

Identify gaps in safety practices in the country and recommend areas for improvement

Suggest measures to promote awareness, training, and knowledge-sharing regarding Hydrogen safety among target groups

Engage with stakeholders to ensure safety considerations are integrated across the Hydrogen value chain

Recommend RCS, protocols and model guidelines commissioning for and operation of Hydrogen projects in the country

Any other task assigned by Empowered Group, Advisory Group or MNRE

Sharing expertise and building knowledge database pertaining to the safe use and handling of hydrogen

https://nghm.mnre.gov.in/hydrogen-resources.php

RD&D in Green Hydrogen & Safety related challenges

- Applied RD&D & Safety Analysis related to Green Hydrogen production, transportation, storage, handling and applications
- Indigenous development of affordable and reliable safety equipment such as sensors, leak detectors, fire detectors, etc.
- Safety protocols and guidelines for handling Hydrogen in various industrial and consumer applications including laboratories.
- Investigate materials compatibility with Hydrogen to prevent embrittlement and other safety issues.
- Incubation & Startups.

Testing & Standardisation

- Co-ordinate and collaborate with existing Hydrogen testing Centres in India to carry out safety related tests
- Establish test centres for safety equipment, monitoring and detection systems, etc.
- Development of India specific codes and standards in Hydrogen safety.
- Co-ordination with related agencies such as BIS, PESO, DPIIT, OISD etc.
- Process Safety and Risk Management.

Centre for Hydrogen Safety

(CHS)

Skill Development & Capacity Building

- World class resource pool of Hydrogen Safety Engineers and Experts
- National & International conferences and workshops.
- Training programs: introductory courses to advanced training for professionals.
- First responder trainings
- Knowledge repository
- Disaster response and best practices for lab and industry safety

Outreach activities

- Networking and collaborate with academia/research institutes
- awareness creation towards adoption of safety related best practices by all stakeholders.
- International collaborations to share best practices and align training standards with global norms.
- Facilitate national/international visits for knowledge sharing and creating awareness.
- Provide inputs to policy makers: MNRE, MOPNG, PESO, OISD, BIS.

Key Financial Interventions under NGHM & Mission Outcomes

Financial Incentives	Ecosystem Development
➢ **Electrolyser Manufacturing** 3000 MW capacity awarded to 15 companies ➢ **GH2 production capacity** 8,62,000 TPA awarded to 18 companies ➢ **Green Ammonia for Fertilizers** Projectwise e- Reverse auction for 7,24,000 TPA concluded; ➢ **Green Hydrogen for Refineries** 2,00,000 TPA capacity allocated; 10,000 TPA awarded by IOCL; result announced by BPCL and HPCL for 5,000 TPA capacity each; rest 22,000 TPA under tendering	✓ **Pilot Projects** **Transport:** 5 projects with 37 Hydrogen fuelled vehicles (10 Buses and 27 Trucks), 9 HRS, 10 different routes in the country **Steel:** 5 projects for use of GH2 in steel sector - DRI using 100 % Hydrogen using vertical Shaft, Blast Furnace and Injection of Hydrogen in vertical shaft based DRI **Shipping:** Negotiations ongoing for the tender “Development of bunkering and refuelling facility for Green Methanol (750m3) on Pilot basis at VOCPA; **Research & Development**: 23 projects awarded ✓ **Testing facilities:** 3 testing facilities finalised ✓ **Skill Development**: 43 courses developed, 81 master trainers and 335 trainers aligned; 5000+ participants trained ✓ **Regulations and Standards:** 164 standards recommended, and 128 standards adopted/ published ✓ **Green Hydrogen Certification Scheme for India** has been issued on 29th April 2025. ✓ Inclusion of HVIC in revised scheme of GH2 Hubs

thank you

questions?