HYDROGEN GENERATION, HANDLING & SAFETY MANAGENMENT

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FOCUSED WORKSHOP ON HYDROGEN HANDLING & TRANSPORTATION IN REFINERIES

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PRPC

Current and Future hydrogen demand in India

- Current demand for hydrogen in India is around 6.7 MMTPA.
- Around 99.5% of the current total demand is from Ammonia (Fertilizers) and Refineries, wherein hydrogen is used as feedstock.
- Distributed applications such as hydrogen peroxide, food processing, specialty chemicals, float Glass, power plants, pharma etc. contributes to less than 0.5% of total demand.
- Demand from power and mobility sector is expected to start materializing post 2025 onwards.

Overall H_2 demand is expected to grow at ~5% (CAGR) till 2025, which may grow at CAGR of ~6% by 2030 in case of high adoption

Hydrogen Production Pathways

Production from fossil fuels

- Reforming of hydrocarbons
  - ✓ Steam Reforming of Natural gas, Naphtha
  - ✓ Partial oxidation of Natural gas/ oil
  - ✓ Auto-thermal reforming
- Coal gasification

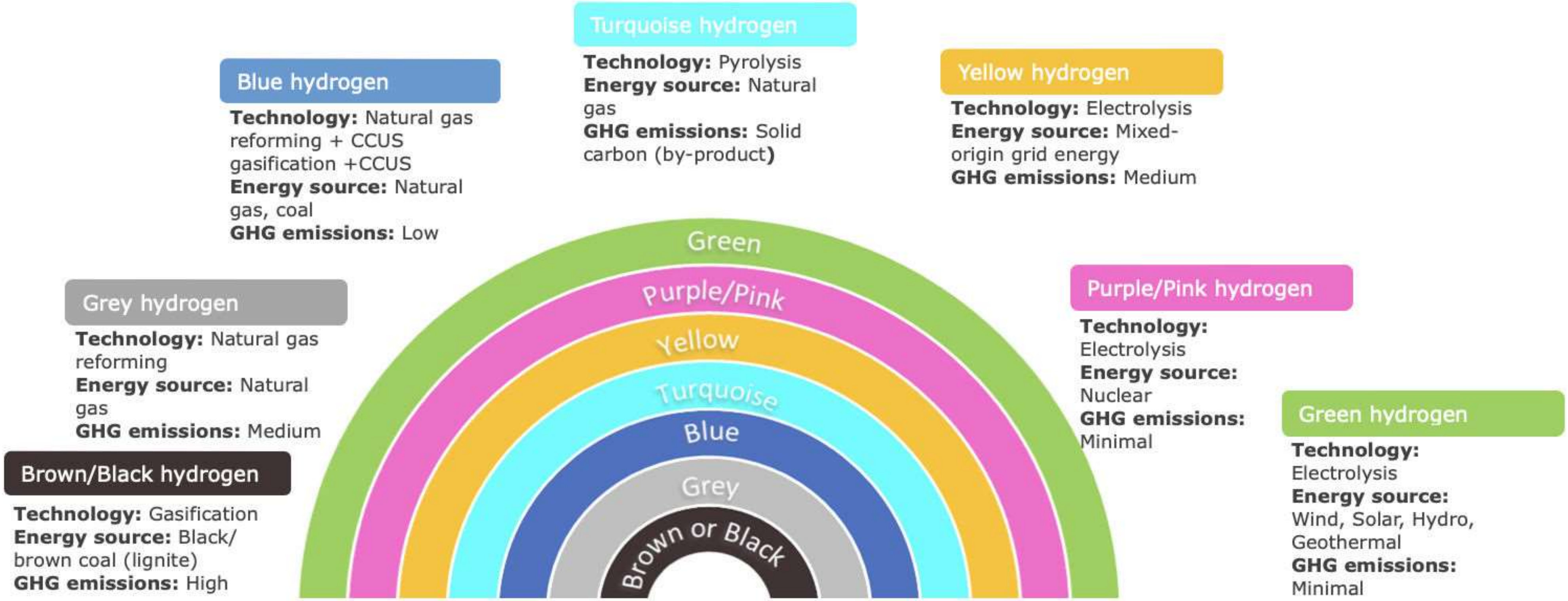
Splitting of water

- Electrolysis of water
  - ✓ Proton Exchange Membrane electrolysis
  - ✓ Alkaline electrolysis
  - ✓ Solid oxide electrolysis
- Thermo-chemical water splitting

Renewable hydrogen

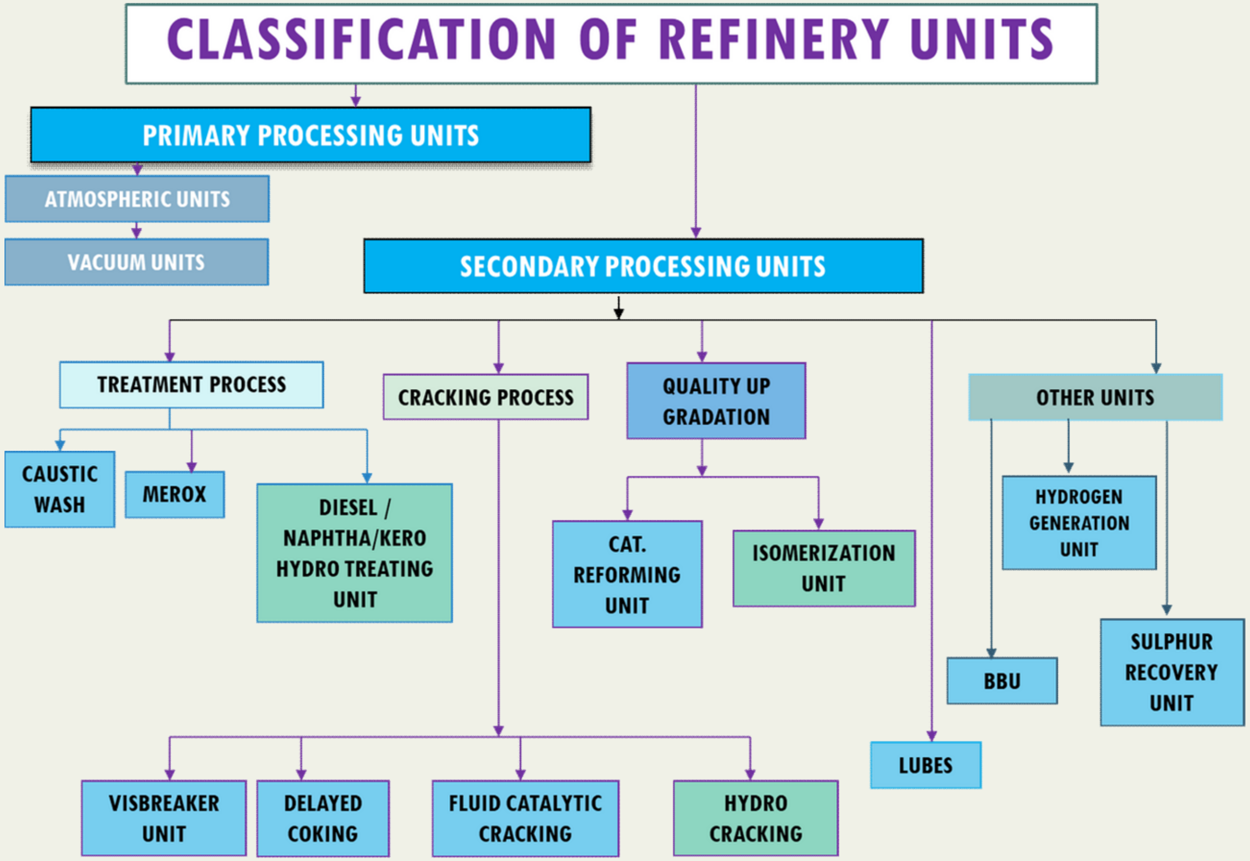
- Renewable energy-based water electrolysis
- Biomass gasification
- Reforming of biogas
- Dark fermentation
- Microbial electrolysis cell
- Thermo-chemical solar water splitting
- Photo-catalytic/ photo-electrochemical water splitting

THE HYDROGEN RAINBOW



- **Roadmap for decarbonizing hydrogen production :** Grey → Blue → Green
- Turquoise Hydrogen is an emerging "**bridge technology**" offering low emissions with lower energy costs & provides pragmatic mid-term solution.
- Purple / Pink Hydrogen is gaining traction where **nuclear power** is abundant (e.g., France, Japan).
- **CCUS : Carbon Capture, Utilization, and Storage** a set of technologies that capture CO2 emissions from sources like power plants. The captured CO2 is either utilized to create products or stored underground in geological formations.

CLASSIFICATION OF REFINERY UNITS



Primary Processing
- Initial crude separation
- Atmospheric distillation
- Vacuum distillation

Treatment Processes
- Caustic wash
- Merox units
- Hydrotreating (DHT)

Cracking Operations
- FCC units
- Hydrocracking
- Visbreaking/coking

Quality Upgradation
- Catalytic reforming
- Isomerization
- Hydrogen generation

HYDROGEN AT REFINERY COMPLEX

Hydrogen Generation (HGU)

Hydrogen Generation (HGU)
Steam methane reforming produces high-purity hydrogen from natural gas.

Catalytic Reforming

Byproduct hydrogen recovered from naphtha reforming operations.

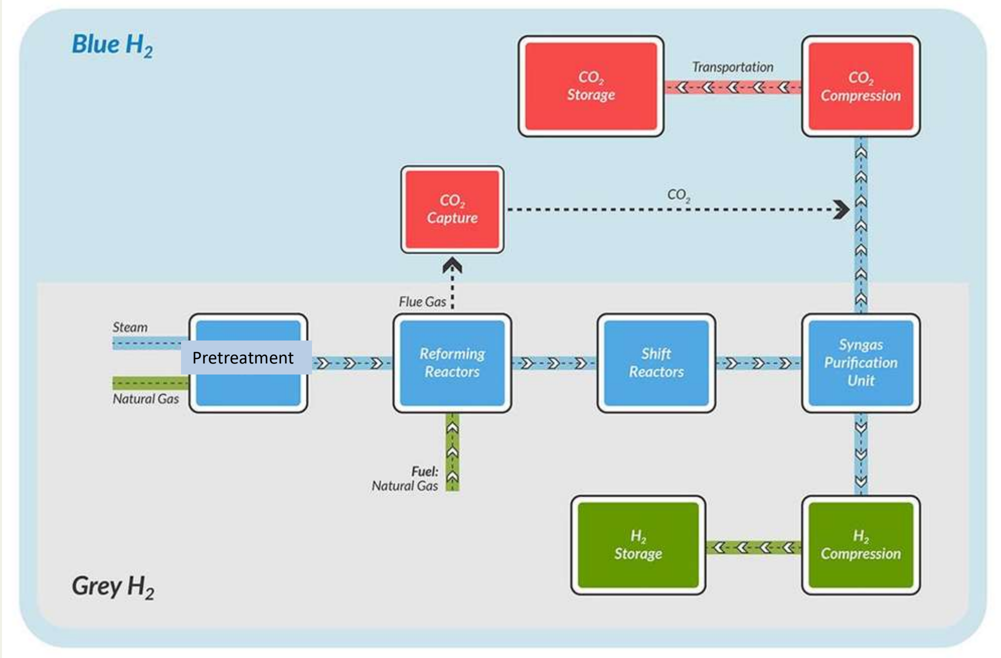
Hydrogen Distribution

Network supplies hydrotreating, hydrocracking, and petrochemical units.

Typical hydrogen consumption ranges from 1-1.5% of crude throughput. Efficient hydrogen management is critical for both operational economics and process safety.

STEAM METHANE REFORMING (SMR)

- Steam methane reforming remains the dominant hydrogen production technology globally, with 70-85% total efficiency.
- The process operates at high temperatures(800-930°C) and moderate pressures (25-28 bar), converting methane and steam into synthesis gas containing hydrogen, carbon monoxide, and carbon dioxide.



Process Conditions

- Temperature: 800-930°C
- Pressure: 25 -28 bar
- Efficiency: 70-85%
- Output: 75% H_2, 11% CO, 6% CH_4

Key Advantages

- Proven technology at scale
- High hydrogen purity achievable
- Flexible capacity range
- Established supply chain

PARTIAL OXIDATION (POX)

Partial oxidation involves reacting hydrocarbons with substoichiometric oxygen to produce hydrogen-rich syngas in an exothermic process. This technology is particularly suitable for heavy feedstocks with high carbon-to-hydrogen ratios and can handle feedstocks with sulfur content up to 400 ppm in catalytic POX systems.

Thermal POX (TPOX)

Operates at temperatures above 1,200°C without catalysts, requiring pure oxygen to avoid nitrogen contamination

Catalytic POX (CPOX)

Reduces operating temperature to 800-900°C using catalysts, improving efficiency but with sulfur sensitivity concerns

70-80%

Efficiency

Lower than SMR due to higher temperatures and heat recovery challenges

400

Sulfur Tolerance (ppm)

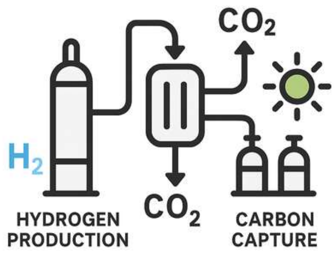
Maximum sulfur content in catalytic POX feedstocks

1,200°C

TPOX Temperature

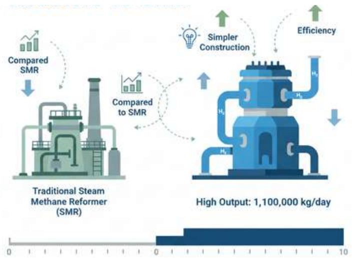
Operating temperature for thermal partial oxidation

ATR KEY ADVANTAGES



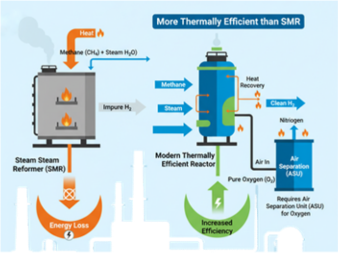
Carbon Capture Integration

Carbon Capture Integration Enables 90-99% CO_2 capture at lower CAPEX, preferred for blue hydrogen



Scale Economy

Reactors scale to 1,100,000 kg/day H_2 with simpler construction than SMR



Energy Efficiency

More thermally efficient than SMR but requires Air Separation Unit for oxygen

- Topsoe's SynCOR™ technology, backed by 70 years of operational experience, operates at low steam-to-carbon ratios and maximizes single-line capacity.
- Johnson Matthey's MAXERGY™ technology integrates ATR with Gas Heated Reformer (GHR), achieving up to 99% CO_2 capture with the lowest levelized cost of hydrogen commercially available.

INDUSTRIAL ELECTROLYZER DEPLOYMENTS

Neste Rotterdam, Netherlands

World's largest 2.6 MW SOEC high-temperature electrolyzer, producing over 60 kg/h of green hydrogen.

Galp Sines, Portugal

Europe's largest 100 MW PEM electrolyzer system, replacing 20% of grey hydrogen and cutting 110,000 tonnes/year CO_2 emissions by early 2026.

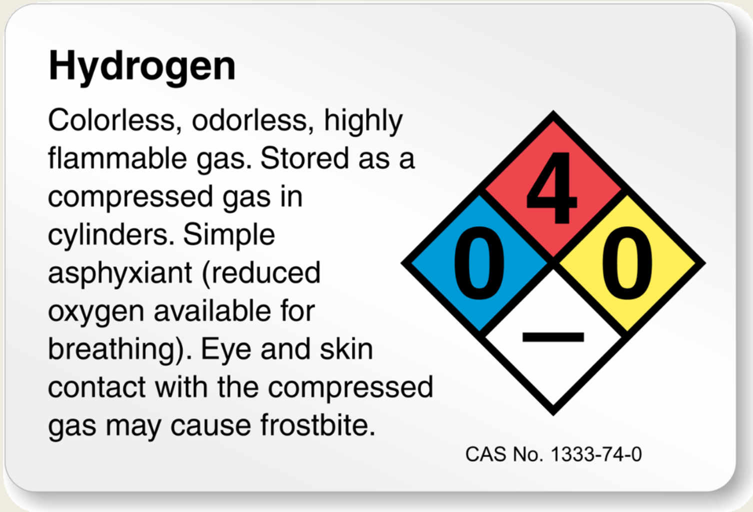
These deployments demonstrate industrial-scale viability of electrolysis technologies in refinery applications, paving the way for broader adoption across the sector.

The Combustion Reaction

The combustion reaction of hydrogen is highly exothermic, releasing significant energy:

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g) - 249 \text{ kJ/mol}$$

This powerful reaction demonstrates why hydrogen must be handled with extreme care. The energy released during combustion can lead to fires and explosions if not properly controlled.



Why Hydrogen is Dangerous in Refinery

Hydrogen presents unique and severe hazards in petroleum refining environments. Its widespread use across multiple process units, combined with its physical and chemical properties, creates multiple pathways for catastrophic incidents.

Extensive High-Pressure Service

Hydrotreaters, hydrocrackers, and reformers operate with hydrogen under extreme pressure and temperature conditions, significantly increasing leak probability and explosion severity upon ignition.

Small Molecule Leak Paths

Hydrogen's small molecular size enables penetration through gaskets, mechanical seals, and threaded connections. Being lighter than air, it rapidly rises and accumulates beneath roofs, canopies, and overhead structures.

Invisible Flame Hazard

Hydrogen burns with an nearly invisible flame in daylight, making fire detection extremely difficult. The flame propagates upward with minimal radiant heat signature, providing little warning to personnel.

Ultra-Low Ignition Energy

Static electrical discharge or contact with hot surfaces readily ignites hydrogen due to its exceptionally low minimum ignition energy (0.02 mJ). Ordinary friction or process equipment surfaces can serve as ignition sources.

Material Embrittlement & HTHA

High-Temperature Hydrogen Attack (HTHA) and hydrogen embrittlement degrade steel integrity over time, potentially causing sudden catastrophic failure of pressure vessels, piping systems, and welded joints without visible warning.

Negative Joule Thomson Coefficient

Hydrogen has a negative Joule-Thomson coefficient at room temperature, meaning it heats up during expansion instead of cooling. So throttling hydrogen at normal conditions increases its temperature rather than reducing it.

The combination of these factors demands rigorous leak detection systems, continuous monitoring, comprehensive material selection and strict confined space entry protocols in all hydrogen service areas.

High Flammability Characteristics

Hydrogen mixtures with air or oxygen are highly flammable over a broad composition range, making them extremely dangerous in industrial settings.

4%

Lower Flammability Limit in Air

75%

Upper Flammability Limit in Air

94%

Upper Flammability Limit in Oxygen

Critical Safety Note: Hydrogen flames are nearly invisible, which significantly increases the risk of accidental burns. Special detection methods must be employed to identify hydrogen fires.

Leakage, Diffusion, and Buoyancy

01

Leakage Propensity

Hydrogen has low molecular weight and low viscosity, making it prone to leakage. The leakage rate is roughly 50 times that of water and 10 times that of nitrogen.

02

Rapid Diffusion

Hydrogen diffuses nearly four times faster than air, meaning a hydrogen leak can spread quickly throughout an area. Air turbulence further increases diffusion rates.

03

Buoyancy Advantage

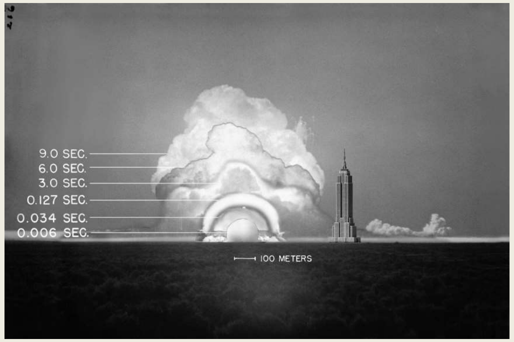
Due to its extreme lightness, hydrogen tends to disperse upwards, reducing the risk of accumulation at ground level where personnel work.

Asphyxiation Risk

While hydrogen is **non-toxic** and environmentally benign, it presents a **serious asphyxiation hazard** in confined spaces. When hydrogen accumulates in enclosed areas, it displaces oxygen, reducing the oxygen concentration below safe breathing levels.

Workers entering confined spaces where hydrogen may be present **must use proper atmospheric monitoring equipment** and **follow confined space entry procedures** to prevent oxygen deficiency incidents.

Detonation: Supersonic Combustion



Detonation represents the **most severe form of hydrogen combustion**, where the flame and shock wave travel at supersonic speeds, creating extreme overpressures and devastating consequences.

Supersonic Propagation

Detonation velocities range from **1700-3000 m/s** for gas explosions, and **4000-10300 m/s** for solid explosives.

Extreme Pressure

Pressure ratio across a detonation wave is about **20 (300 psi at atmospheric pressure)**. When striking obstacles, ratios reach 40-60.

Confined Spaces

A confined hydrogen-air mixture can be detonated by a relatively small ignition source, making containment critical.

General Safety Approach

Hazard Elimination

Design systems to eliminate hazards through adequate ventilation, leak prevention, and ignition source control.

Fail-Safe Design

Implement redundant safety features and automated shut-off controls to prevent hazardous failures.

Automated Detection

Deploy leak detection, ventilation, alarm, and shutdown devices to detect and respond to abnormal conditions.

Safety programs aim to minimize accidents and reduce their severity through comprehensive, layered protection strategies.

Automatic Safety Devices

Leak Detection Systems

Automated hydrogen gas detectors continuously monitor for leaks, providing early warning before dangerous concentrations accumulate.

Ventilation Controls

Automated ventilation systems activate when hydrogen is detected, rapidly dispersing accumulated gas to safe levels.

Alarm Systems

Multi-stage alarm systems alert personnel to abnormal conditions, allowing for evacuation and emergency response.

Shutdown Devices

Automated shutdown systems isolate hydrogen sources and stop flow when dangerous conditions are detected.

Regulatory Framework

Hydrogen safety in India is governed by comprehensive regulations ensuring proper handling, storage, and use.

1

Explosives Act, 1884

Foundational legislation governing explosive substances including hydrogen. Under the Explosives Act, 1884, hydrogen—being a flammable and potentially explosive gas—**is regulated by PESO** for its safe manufacture, storage, and transport.

2

SMPV(U) Rules, 2016

Static and Mobile Pressure Vessels (Unfired) Rules for storage vessels. They require PESO approval, **certified vessels**, and adherence to **safety distances**, **pressure testing**, and **maintenance** to ensure hydrogen is stored and handled safely under pressure.

3

Gas Cylinder Rules, 2016

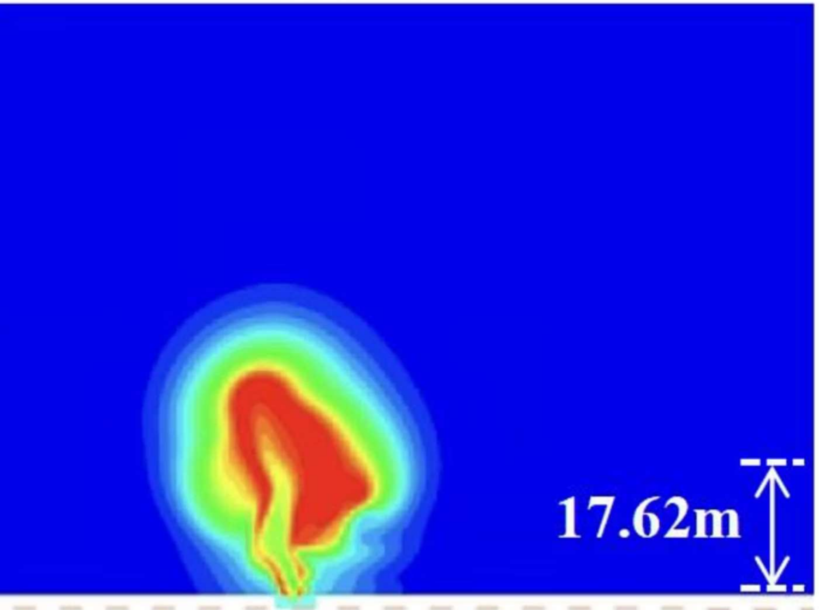
Specific regulations for gas cylinder manufacturing, testing, and handling. They mandate PESO approval, **use of approved cylinder designs** and materials, and **strict safety distances**, **labeling**, and **testing** to prevent leaks and explosions during hydrogen handling.

4

MSIHC Rules, 1989

Manufacture, Storage and Import of Hazardous Chemicals Rules classify hydrogen as a hazardous and flammable chemical. They require **risk assessment, on-site and off-site emergency plans**, and **safety audits** for industries handling hydrogen, ensuring prevention and control of major accidents during its manufacture, storage, or transport.

A license (Form LS1A) is required under SMPV(U) Rules, 2016 for hydrogen storage vessels. The license is issued by PESO.



Fire Suppression: Critical Don'ts

Never Use Water or DCP

Do not use water, dry chemical powder (DCP), or other conventional media to extinguish hydrogen fires. Hydrogen fires require specialized extinguishing methods.

The correct approach is to **cut off the hydrogen supply** and allow the fire to burn out safely in a controlled manner. Attempting to extinguish the fire prematurely can lead to dangerous re-ignition or explosion.

Handling and Storage Precautions

Essential Practices

- Use **non-sparking tools** exclusively in hydrogen handling areas to prevent ignition from static electricity or friction
- Ensure **proper ventilation** in storage and processing areas to prevent accumulation of explosive mixtures
- Store cylinders and containers **securely** in well-ventilated, designated areas away from ignition sources
- Keep hydrogen separated from **incompatible materials** and oxidizers

Leak Detection and Prevention

Install Gas Detectors

Deploy hydrogen gas detectors in all storage, processing, and transport areas. Regularly calibrate and maintain for accurate monitoring.

Regular Inspections

Conduct systematic inspections of pipelines, valves, and fittings to identify and repair leaks promptly.

Leak Detection Solutions

Use leak detection solutions (e.g., soapy water) to check for hydrogen leaks in connections and joints during maintenance.

Operational Precautions

1

System Purging

Purge hydrogen systems with inert gases (e.g., nitrogen) before maintenance to eliminate residual hydrogen and reduce fire risks.

2

Pressure Control

Avoid abrupt pressure changes in hydrogen systems, as they can lead to leaks or equipment failure.

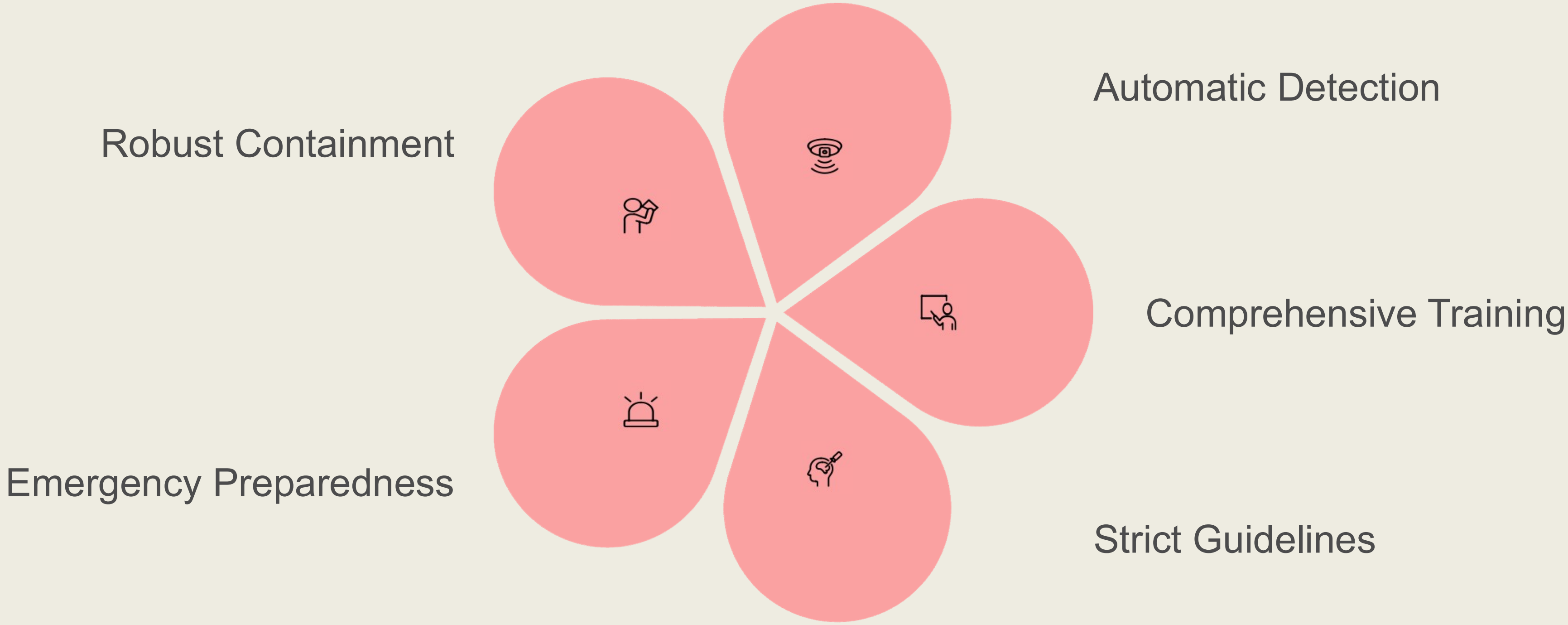
3

Hot Work Permits

Implement strict hot work permit system for any activities involving open flames, welding, or spark-producing equipment.

Conclusion: Safe Hydrogen Operations

Hydrogen is an efficient and clean energy source that plays a vital role in modern refinery operations. However, it presents unique safety challenges due to its flammability, undetectability by human senses, and rapid diffusion characteristics.



Proper safety measures, including robust containment, automatic detection systems, comprehensive training programs, and strict operational guidelines, are essential to ensuring safe hydrogen usage in industrial and commercial applications. By following these protocols, we can harness hydrogen's benefits while minimizing risks.

OISD-STD-241 : Technical Overview & Regulatory Scope

Regulatory Authority

Issued by the **Oil Industry Safety Directorate (OISD)** under the Ministry of Petroleum & Natural Gas, establishing India's first comprehensive safety code for hydrogen infrastructure.

Legal Foundation

Anchored in national statutes including **Static & Mobile Pressure Vessel Rules 2024**, **Gas Cylinder Rules 2024**, and subject to **PESO** (Petroleum and Explosives Safety Organisation) oversight.

Complete Value Chain

Covers production via electrolyzers, storage (GH_2/LH_2), pipeline and road transport, hydrogen–natural gas blending, and dispensing stations with unified safety protocols.

Strategic Objectives

- Enables safe hydrogen deployment in India's decarbonization roadmap
- Harmonizes with international standards: ASME B31.12, IS 2825, and ISO/TR 15916
- Applies to all stakeholders: manufacturers, operators, owners, suppliers, and regulatory bodies

Compliance Framework

- **QRA**: Quantitative Risk Assessment
- **IMS**: Integrated Management Systems
- **ERDMP**: Emergency Response & Disaster Management Plan
- Mandatory competency training programs

OISD-STD-241 : Risk Control, Fire Protection & Transport Safe

Comprehensive regulatory framework ensuring safe handling, storage, and transportation through systematic risk assessment, fire prevention protocols, and road transport safety management systems.

Risk Assessment (Clause 13)

Independent Quantitative Risk Assessment (QRA) required to identify failure scenarios, model dispersion and radiation, and quantify risk against acceptance criteria.

- Mandatory review after major incidents or every 5 years
- Mitigate risks through engineering controls and layout optimization
- Achieve As Low As Reasonably Practicable (ALARP) risk levels

Fire Protection (Clause 15)

Core principle: Isolate fuel source before extinguishing flames. Strict ignition control through permit-to-work systems (OISD-STD-105) and designated no-smoking zones.

- Use Water spray/mist cooling
- Passive Fire Protection (PFP) on critical infrastructure
- Continuous gas detection

Road Transport (Clause 16)

Tube trailers must comply with Gas Cylinder Rules 2024 (PESO). Road Transport Safety Management System (RTSMS) is mandatory for all operations.

- Journey Management Plan (JMP) with pre-approved routes and designated halt points
- Vehicle Tracking System (VTS) for real-time monitoring
- Comprehensive safety audits for drivers and transport equipment

Gaseous Hydrogen System

- Non- Bulk hydrogen

Individual cylinders, vessels, or tanks of compressed hydrogen gas typically found in storage with the valves shut and protective caps in place.

A non-bulk GH2 system can include interconnected cylinders, vessels, or tanks that have been manifolded or connected for use providing the aggregate volume of individual systems does not exceed 5000 scf (141.6 Nm3).

- Bulk hydrogen Installations

A gaseous hydrogen system with a storage capacity of more than 141.6Nm3 of compressed hydrogen gas.

GENERAL INSTALLATION REQUIREMENTS

- Ensure compliance with regulations, licensor instructions, and this standard during installation.
- Installers follow both manufacturer's instructions and standard guidelines.
- Approval needed for any deviation from manufacturer's instructions.
- Obtain regulatory approvals before installation.
- Entity implements safety management system aligned with OISD-GDN-206 or equivalent.

Separation Distances

In case of hydrogen, criteria for separation distances for bulk hydrogen systems are based on maximum allowable working pressure and pipe dimeter instead of conventional approach of system volume.

- Minimum Distance to the exposure (separation distances) for non-bulk hydrogen shall be as per Table 7.2.2.3.2 of NFPA-2 or equivalent standard.
- Minimum Distance to the exposure (separation distances) for bulk hydrogen shall be as per table- Table 7.3.2.3.1.2 (B) a, b, and c of NFPA-2 or equivalent standard.

- Determination of actual separation distances, however, shall be predicated upon a comprehensive risk analysis of the installation also in accordance with prevailing regulations. The selection of the greater distance shall be made.

Pressure relief and Vent systems

- The pressure-relief device must handle required pressure levels to safeguard vessel and piping systems.
- Design of the pressure-relief device should ensure pressure release during emergencies or abnormal conditions.
- Pressurized systems and equipment must be shielded from excessive temperature and pressure using self-destructive or resealable devices.
- Supplemental safety devices like rupture disks can be added based on capacity and usage to protect against high pressures, set at 110% of MAWP.
- Pressure relief devices are activated by pressure or other parameters and categorized as reclosing (e.g., valves) or non-re-closing (e.g., rupture disks, fusible plugs).
- Installation of isolation valves in the relief path is prohibited.
- Guidelines for covering the aspects for hydrogen vent system design, material selection, sizing, installation, operation, maintenance, separation distances, and location shall be in accordance with CGA- 5.5.

Other features of OISD-STD-241

- Electrolysers up to 5 MW must follow IS 16509 for design, installation, operation, and maintenance.
- Adhere to IS 61010-1:2010 for fire prevention.
- Enclosures with hazardous liquids must:
  - ✓ Contain 110% of maximum liquid volume.
  - ✓ Include a leak detection system to prevent containment loss.

NFPA 2:Transport & Infrastructure

Transportation & Fueling Interfaces

- Requirements for tube trailers, tankers, and mobile storage when connecting to stationary systems.
- Tube trailers, consisting of manifolded cylinders mounted on a transport vehicle are generally permitted.
- Setback distances for transfer points and vehicle fueling zones established to prevent fire spread.
- All hydrogen systems must be physically secured against unauthorized entry or tampering

Infrastructure & Site Safety

- Defines control areas and separation distances between hydrogen systems, occupied buildings, and property lines.
- Allows risk-based alternative siting if quantitative risk assessment (QRA) shows equivalent protection.
- Emphasizes integration with fire protection systems, emergency shutdown, and signage.
- Coordination required with electrical classification (NFPA 70) and ventilation systems.
- Hydrogen Equipment Enclosures must be enclosed on three sides with a roof and not normally occupied. If near electrical gear, they need a 1-hour fire wall; if personnel entry is possible, oxygen monitoring and alarms are required

NFPA 2 provides the Technical backbone for hydrogen safety, ensuring that production, storage, transfer, and fueling systems are **engineered, located, and operated** to prevent ignition, leakage, or catastrophic failure — enabling the **safe growth of the hydrogen economy**

Core International Hydrogen Safety Standards

Code / Standard	Issuing Body	Scope / Focus	Latest Edition
NFPA 2	NFPA (USA)	Hydrogen Technologies Code – design, safety distances, venting	2023 NFPA
ISO/TR 15916	ISO	General safety principles for hydrogen systems	2020
ISO 14687	ISO	Hydrogen fuel quality & impurities	2025
ASME B31.12	ASME	Hydrogen piping & pipeline systems	2019
API RP 941	API	Steels for hydrogen service, HTHA prevention	2020 Addendum
ISO 19880-1	ISO	Hydrogen refueling stations – general requirements	2020

Storage & Transport Safety Codes

- ISO 19884 – Stationary GH_2 storage (350–900 bar)
- ISO 9809 / ISO 11119 – Cylinders up to 70 MPa
- UN Model Regulations – UN 1049 / 1966 (Class 2.1)
- ADR / IMDG / IATA – Mode-specific compliance

Hydrogen Refueling & Mobility Standards

- ISO 19880-1 (2020): Refueling design & operation
- SAE J2601 (2020, 2023): Fueling protocols for 35/70 MPa
- ISO 19881 (2025): Onboard storage safety
- CGA G-5 series: Handling, venting & safety guidance

PESO Licensing and Safety Provisions

- Form H (2025): Online licensing for hydrogen stations
- SMPV Licenses: LS-1A (storage), LS-2 (tank transport)
- Double block & bleed, vent stack design, gas detection

Recent Updates (2024–25)

- ISO 14687 (2025) – new fuel purity limits
- IEC 60079-14 (2024) – updated inspection norms
- OISD-241 (2024) – hydrogen-specific code
- PESO (May 2025) – digital licensing workflow

References

- NFPA 2 (2023)
- ISO/TR 15916 (2020)
- ASME B31.12 (2019)
- API RP 941 (2020)
- IEC 60079 Series (2020–24)
- ISO 19880-1 (2020)
- OISD-241 (2024)
- PESO Rules (2016)
- BIS IS 18538, IS 16061, IS 16509
- NGHM Guidelines (2024–25)

Thank You

Thank you for your attention and engagement during this presentation on Hydrogen Safety. We value your commitment to safety and innovation in this critical field.