International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

Hazards, Mitigation Measures and Statutory Gaps in Green Hydrogen Production, Storage, Transport, and Dispensing - A Review

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Abstract—This paper presents a hazard analysis of green hydrogen (GH_2) produced via electrolysis, covering production, storage, transportation, distribution, and dispensing stages. A total of 25 incidents occurring between 1968 and 2026 were compiled from the Hydrogen Incidents and Accidents Database (HIAD 2.2), H2Tools, the French ARIA database, Nel ASA filings, Korean Supreme Court records, Nature Communications, and verified news sources, and were analyzed to understand root causes and mitigation measures. Explosions accounted for 77% of recorded consequences, with more than 15 fatalities and 40 injuries documented across the dataset. Root cause analysis showed that management factors and system design errors were prominent contributors in 46% of incidents, while the root cause remained unidentified in 23% of cases. Hazards, together with the mitigation measures reported in the literature, were catalogued across the full hydrogen value chain and across four electrolysis production technologies, i.e. Alkaline Water Electrolysis (AWE), Proton Exchange Membrane (PEM), Solid Oxide Electrolysis (SOE), and Anion Exchange Membrane (AEM) electrolysis. The findings reveal an accelerating incident trend after 2018, concentrated in storage and production systems. Available mitigation measures were compared against openly accessible Indian and international standards to identify regulatory gaps, particularly for liquid hydrogen storage, high-pressure dispensing, and emerging electrolyser technologies.

Keywords—green hydrogen; electrolysis; hazards; mitigation gap; Indian standards

I. INTRODUCTION

Green hydrogen produced via electrolysis is a cornerstone of global decarbonization strategies, carrying a near-zero carbon footprint when powered by renewable electricity. However, hydrogen's physical properties — a wide flammability range (4–75% in air), an extremely low minimum ignition energy (0.02 mJ), colorless/odorless characteristics, and the ability to embrittle metals — create substantial safety challenges across the value chain. The global scale-up of GH_2 capacity has accelerated incident scenarios since 2018, yet a uniform safety catalogue is yet to be prepared. An effort is made to at least review and assimilate scattered data on the most common hazards and mitigation measures related to the GH_2 realm, and also to identify statutory gaps based on freely available standards.

II. OBJECTIVE

The primary objective of this review is to identify and summarize the most prevalent safety hazards associated with the green hydrogen (GH_2) value chain, including production, storage, transport, and dispensing. The study systematically examines reported incidents, hazardous scenarios, and root causes to determine the hazards that occur most frequently and pose the greatest safety concerns. In addition, the review catalogs the mitigation measures reported in the literature and industry guidance, evaluates their effectiveness and frequency of application, and identifies mitigation strategies that are less commonly implemented despite their potential safety benefits. Furthermore, the study examines the extent to which these mitigation measures are addressed within currently available standards, regulations, and guidance documents, with particular attention to publicly accessible regulatory resources. By comparing prevalent hazards, existing mitigation practices, and regulatory provisions, the paper identifies gaps in current safety standards and highlights areas were additional guidance, research, or standardization efforts may be required.

III. LITERATURE REVIEW

Several researchers have discussed the fundamental safety hazards associated with green hydrogen production and utilization. [7], [23], and [16] highlight that hydrogen's wide flammability range, low ignition energy, high diffusivity, and tendency to leak present significant safety concerns across the entire hydrogen value chain. These studies emphasize that although green hydrogen is a promising clean energy carrier, its safe deployment requires comprehensive hazard identification and risk management strategies.

A number of studies have focused specifically on storage-related hazards. [3], [19], and [16] discuss challenges associated with high-pressure compressed hydrogen storage and cryogenic liquid hydrogen systems. Their studies identify hydrogen embrittlement, vessel fatigue, boil-off gas accumulation, insulation failure, and cryogenic brittleness as key hazards that may affect storage system integrity, and discuss mitigation measures such as advanced composite storage vessels, improved insulation systems, and material compatibility assessments.

Transportation and distribution safety have been extensively studied by [13] and [6], who focus on hydrogen embrittlement in pipeline materials and the suitability of existing natural gas infrastructure for hydrogen service. Their work suggests that conventional metallic pipelines may degrade under hydrogen exposure and proposes composite materials, specialized sealing systems, and dedicated hydrogen infrastructure as mitigation measures.

Several researchers have examined hazards in hydrogen production technologies. The [11] report discusses operational and commissioning risks in electrolyser facilities, including earthing failures, equipment malfunction, and procedural deficiencies. [19] present an in-depth investigation of a PEM electrolyser failure mechanism caused by water starvation, resulting in membrane degradation and internal hydrogen-oxygen deflagration — together highlighting the importance of process monitoring and operational controls.

Mitigation strategies have received considerable attention: [7],[22], and [16] discuss engineering controls such as leak detectors, ventilation systems, emergency shutdown systems, safety distances, explosion-proof equipment, and automated monitoring — emphasizing that a combination of technical safeguards and operational procedures is necessary to reduce accident likelihood and severity.

Although previous studies have investigated hydrogen hazards, mitigation measures, incident case studies, and regulatory frameworks, these aspects are often examined separately. A consolidated assessment linking frequently occurring hazards, commonly applied mitigation measures, underrepresented mitigation measures, and regulatory coverage across production, storage, transportation, distribution, and dispensing stages remains limited. This study addresses these gaps by systematically comparing hazards, mitigation measures, and gaps in available standards across the complete green hydrogen value chain.

IV. RESEARCH WORK

I. *Data Collection*

Data were collected from two structured sources: (1) a GH_2 (Green Hydrogen) incident register drawn from HIAD 2.1, H2Tools, ARIA, Nel ASA (2019), Korean Supreme Court records, and IMPEL reports, consolidating 25 deduplicated events (1968–2026); and (2) hazard/mitigation tables compiled from peer-reviewed literature (2013–2026) covering storage, transportation, distribution, dispensing, and four production technologies. All 25 incidents met three inclusion criteria: a hydrogen-system initiating cause, documentation in a named primary or secondary source, and sufficient detail to record year, location, consequence, and at least one contributing factor.

II. *Analysis — Graphs and Tables*

1) *Incident Distribution Analysis*

Europe accounts for 48% of incidents, reflecting its longer GH_2 infrastructure history; Asia contributes 28% (largely South Korea, Japan, and China) (Lee et al. 2023); 9 of the 25 incidents occurred in the 2020–2026 period — the highest 7-year concentration on record. Fig 1 shows the GH_2 incident frequency by decade with a linear trend. Explosions dominate at 76% of consequences (Fig 2).

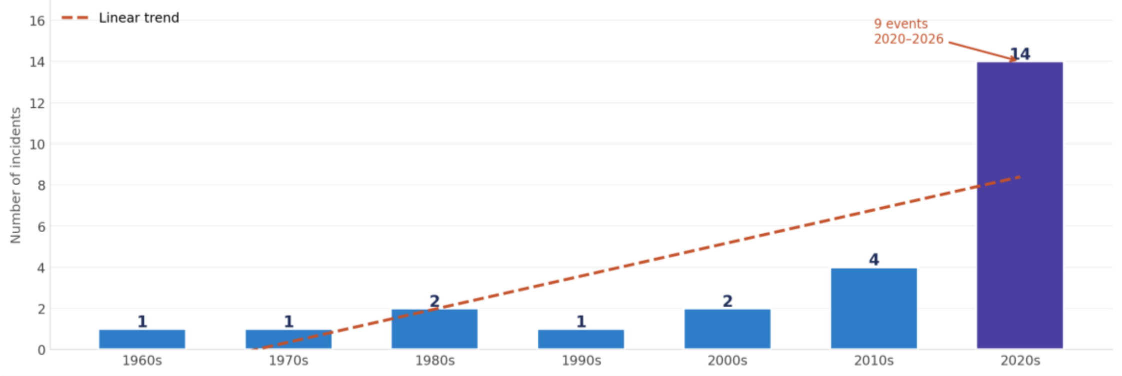

Fig 1. GH_2 incident frequency by decade

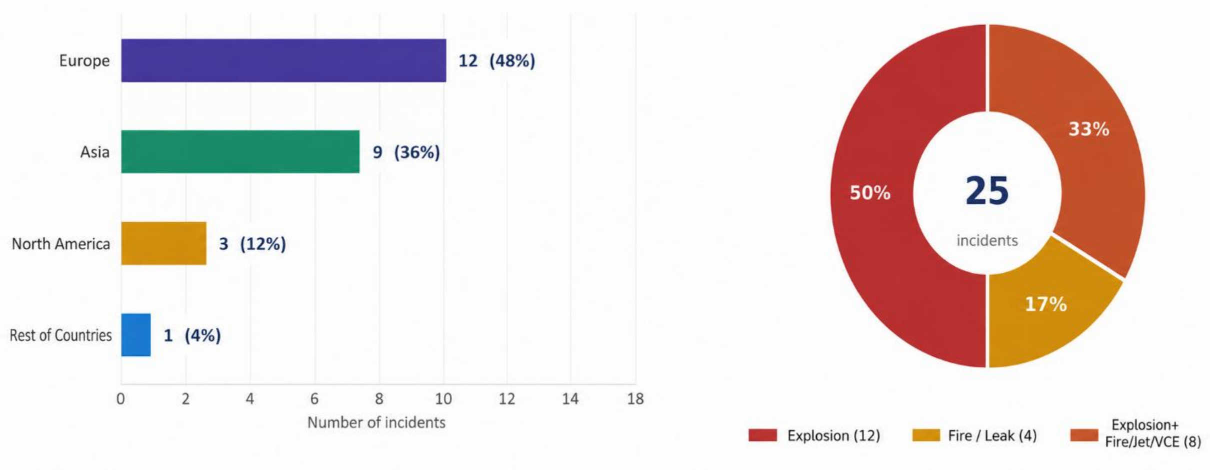

Fig 2. (a) Incidents by region (b) Consequence type distribution

2) *Root Cause Analysis*

As shown in Fig 3, and consistent with classical human-error taxonomies (Reason 1990), management factors and system design errors were the major contributors to hazardous scenarios in the HIAD database, each implicated in 46% of incidents, followed by job factors, and material and installation errors. The root cause remains unidentified in 23% of incidents.

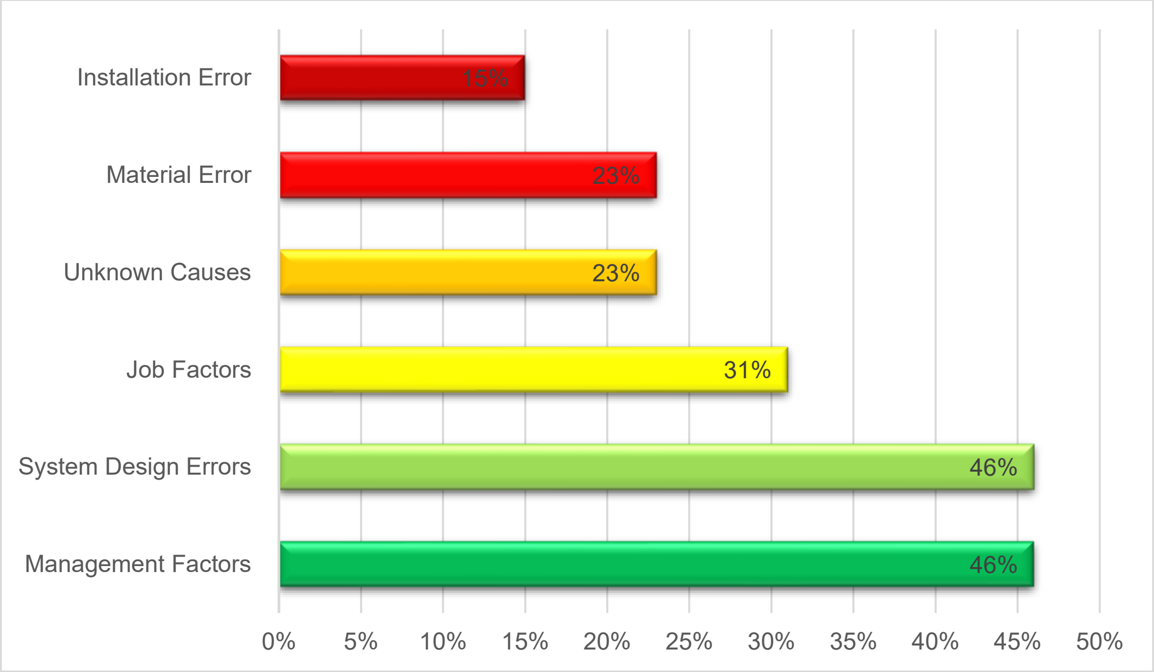

Fig 3. Root cause distribution

Explanation of root cause categories shown in Fig. 3:

- **Management factors:** Organizational failures such as inadequate safety policies, insufficient training, poor supervision, or lack of risk assessment. For example, in the 2019 Gangneung, Korea explosion, the safety management team did not follow the requirement to test hydrogen quality daily, leading to oxygen accumulation in the storage system and a subsequent explosion. In another scenario, failure to establish hydrogen leak inspection procedures led to delayed detection of leakage.
- **System design errors:** Design deficiencies that increase accident likelihood, including missing or inadequate engineered safety devices, poor hazard analysis at the design stage, or absence of protective components. Example: improper placement of pressure relief devices or absence of an oxygen removal unit, resulting in explosive gas mixture formation.
- **Job factors:** Maintenance and operational task-planning failures; inadequate work permits or job procedures leading to unsafe conditions. Example: a valve left partially open during trailer filling due to inadequate procedural controls, causing hydrogen venting and ignition.
- **Material and manufacturing errors:** Incorrect material selection for hydrogen service, quality control failures in manufacture, or diaphragm/membrane defects that fail in service. Example: corrosion or erosion of electrolysis cell internals causing hydrogen ingress into oxygen systems, as seen in the 1975 Laporte Industries UK explosion.
- **Human factors (direct):** Direct procedural deviation or personal error without a clear systemic precondition. Example: an electrician inverting electrode connections during maintenance, causing hydrogen-oxygen system interchange, as occurred in the 2004 China steel plant explosion.
- **Operational factors:** Hazards arising from incorrect operational parameters, out-of-specification conditions, or failure to observe operational limits. Example: deliberate operation of a water electrolyser below the minimum power threshold required for safe membrane separation, allowing oxygen crossover into the hydrogen stream (Gangneung 2019 incident).
- **Maintenance factors:** Failures in scheduled or preventive maintenance activities, including inadequate inspection frequency, failure to detect developing defects, or maintenance-induced damage. Example: a membrane showing signs of deterioration that was not replaced during scheduled maintenance, leading to crossover failure.
- **Environmental factors:** External environmental conditions that affect equipment performance or cause safety failures. Example: a frozen oxygen vent line in sub-zero temperatures (−5 °C) caused oxygen to find an alternative flow path into the hydrogen buffer tank, leading to an explosive mixture (Japan 2007 incident).
- **Installation error:** Construction and commissioning deficiencies, including incorrect assembly of cell stacks or inadequate pre-startup inspection. Example: mechanical deformation of micro-lines during cell stack assembly causing flow restriction, local overheating, membrane destruction, and explosion (Germany alkaline electrolyser incident).

- **Unknown:** Insufficient incident investigation or gaps in mandatory reporting obligations resulted in the root cause being unidentifiable. Example: the 2020 US explosion at a hydrogen fuel plant, for which no public root cause analysis had been released by end-2025.

3) Mitigation Measures with Respect to Indian and International Standards

Hazards related to hydrogen storage are the most extensively documented, followed by hydrogen production, transportation, distribution, and dispensing hazards. Table I lists mitigation measures applicable against hazards during various stages of GH$_2$ generation. Table II further highlights regulatory gaps in Indian standards, particularly for liquid hydrogen storage systems, high-pressure dispensing infrastructure, and emerging electrolyser technologies. Mitigation reference numbers in Table II correspond directly to entries in Table I.

TABLE I. MASTER LIST OF MITIGATION MEASURES

Ref. No.	Mitigation Measure
Storage	
1	FRP pipelines; internal coatings; lower-strength steel (API 5L X52); cathodic protection
2	COPVs; Type 4 CFRP tanks; calibrated pressure relief devices; regular integrity inspections
3	MOF-based insulation; double-shell vacuum-insulated tanks
4	BOG recovery systems; IRAS systems
5	ATEX-certified equipment; fixed H$_2$ detectors; ESD systems; proper grounding; harmonized safety standards
6	Advanced CF/epoxy composite tanks; optimized tank farm pressure management protocols
7	Temperature management systems; pyrophoric materials handling SOPs; inert gas blanketing; nanoscale catalyst doping; hybrid hydride systems
8	High-temperature dehydrogenation with advanced catalyst systems; secondary containment; air monitoring; selective catalysts for NOx suppression
Production (AWE / PEM / SOE / AEM)	
9	Chemical-resistant PPE; emergency eyewash/shower; KOH spill containment SOPs; EPDM gaskets
10	Regular electrode inspection; scheduled replacement; Zirfon® composite diaphragm; corrosion-inhibiting additives
11	Continuous online gas purity monitoring; automatic ESD at ≥2% O$_2$ in H$_2$; scheduled diaphragm integrity testing; Zirfon® membrane
12	Cell voltage control (hard limit ≤1.9 V); advanced catalyst supports (SnO$_2$, TiO$_2$); regular EIS monitoring; catalyst recycling
13	Membrane thickness optimization; differential pressure monitoring and ESD; inlet water deionization; ventilation with H$_2$ detection; water starvation prevention protocols
14	Multi-layer thermal insulation; temperature monitoring with automated interlock; gradual controlled thermal ramp-up; YSZ/LSM advanced ceramics
15	Chemically stabilized polymer backbones; operating temperature control (≤60 °C); reinforced composite membranes; regular conductivity monitoring
Transportation	
16	FRP/stainless steel components; proper ventilation; explosion-proof equipment; H$_2$-specific sensors; burst disc inspection; auto-isolation valves; austenitic stainless steel (FCC structure)
17	Specialized gas detection and ESD; proper grounding; explosion-proof equipment; minimized confined spaces; proper ventilation; ignition source separation ≥3 m
Distribution	
18	Specialized PTFE/PEEK seals and gaskets; LOHC-based distribution; gradual blending ≤20%; dedicated H$_2$ pipelines
19	LOHC transport option; route risk assessment; emergency response planning; leak detection along pipeline
Dispensing	
20	Fixed H$_2$ gas detectors with automatic ESD; ATEX zone 2 equipment; bonding and grounding of all conductive parts; H$_2$-compatible elastomers; 700-bar rated nozzle and hose annual inspection; breakaway couplings
21	Standardized refueling connectors (ISO 17268); safety separation distances; controlled fueling protocols; pressure relief valve testing

[a] *Note: reference numbers in Table I are used in Table II to identify mitigation measures applicable to each hazard.*

TABLE II. GREEN HYDROGEN PRODUCTION HAZARDS, MITIGATION MEASURES (BY REFERENCE NUMBER), APPLICABLE TECHNOLOGIES, AND RELEVANT STANDARDS

Hazard	Mit. Ref.	AWE	PEM	SOE	AEM	Indian Standards	International Standards
Storage hazards							
Hydrogen embrittlement (metals exposed to H$_2$ lose 30–50% tensile strength)	1	✓	✓	✓	✗	SMPV Rules 2016 (Amended 2025) (PESO); OISD safety guidelines	UN GTR No. 13; DOE H2Tools Guidance
High-pressure storage failure (CGH$_2$ 350–700 bar) — vessel rupture risk	2	✓	✓	✗	✗	SMPV Rules 2016 (Amended 2025); PESO pressure vessel approvals	UN GTR No. 13
Cryogenic storage hazards (LH$_2$, −253 °C) — BOG accumulation, insulation failure, burns	3, 4	✗	✗	✗	✗	Static and Mobile Pressure Vessel Rules (cryogenic provisions);	DOE H2Tools LH$_2$ Guidance; NFPA 2

Hazard	Mit. Ref.	AWE	PEM	SOE	AEM	Indian Standards	International Standards
						SMPV Rules 2016 (Amended 2025); PESO cryogenic rules	
Flammability and ignition (LEL 4%, 0.02 mJ MIE) — fire, explosion, DDT in confined spaces	5	✓	✓	✓	✓	SMPV Rules 2016 (Amended 2025); CEA Electricity Safety Regulations; PESO	DOE H2Tools; European Commission JRC Hydrogen Safety Reports; NFPA 2
Compressed gas density limitations (low volumetric density at high pressure, compression energy loss)	6	✓	✓	✗	✗	PESO compliance; SMPV Rules	DOE H2Tools Guidance
Metal hydride storage hazards (pyrophoricity, slow kinetics, 250–400 °C desorption)	7	✗	✗	✗	✗	PESO fire safety; PESO hazardous chemical handling guidance	DOE H2Tools Guidance
LOHC hazards (hydrogenation/dehydrogenation, catalyst poisoning, environmental persistence)	8	✗	✗	✗	✗	PCPIR safety rules; CPCB Emission Standards; PESO chemical handling guidance	European Commission Hydrogen Safety Reports
Production hazards (AWE / PEM / SOE / AEM)							
AWE — caustic KOH exposure (30–40 wt% electrolyte)	9	✓	✗	✗	✗	PESO chemical safety rules	DOE H2Tools Electrolyzer Safety Guidance
AWE — electrode corrosion and degradation (Ni-based anodes in alkaline environment)	10	✓	✗	✗	✗	PESO operational safety guidance	DOE H2Tools Electrolyzer Safety Guidance
AWE — diaphragm deterioration and gas crossover (H_2/O_2 crossover above 4% LFL)	11	✓	✗	✗	✗	PESO operational safety guidance	DOE H2Tools Electrolyzer Safety Guidance; NFPA 2
PEM — precious metal catalyst degradation (Ir anode, Pt cathode dissolution)	12	✗	✓	✗	✗	National Hydrogen Mission guidance	Nature Communications PEM Failure Study; DOE H2Tools
PEM — high-pressure crossover and membrane attack (fluoride release, pinhole failure)	13	✗	✓	✗	✗	National Hydrogen Mission guidance	Nature Communications PEM Failure Study; DOE H2Tools; NFPA 2
SOE — extreme high-temperature operation (700–900 °C; ceramic cracking, electrode delamination)	14	✗	✗	✓	✗	PESO thermal rules [gap: no ceramic-specific IS]	DOE H2Tools High-Temperature Process Safety Guidance
AEM — membrane chemical instability (OH^- attack, membrane lifetime < 2,000 h)	15	✗	✗	✗	✓	National Hydrogen Mission guidance [gap: no AEM membrane standard globally]	DOE H2Tools High-Temperature Process Safety Guidance
Transportation hazards							
Hydrogen embrittlement and cryogenic brittleness in pipeline/tube trailer materials	1, 16	✓	✓	✓	✓	PESO pipeline rules; PNGRB	UN GTR No. 13; DOE H2Tools
Wide flammability range (4–75%), low MIE (0.02 mJ), deflagration-to-detonation transition	5, 17	✓	✓	✓	✓	CEA Safety Regulations; PESO; PNGRB	UN GTR No. 13; DOE H2Tools; NFPA 2
Distribution hazards							
Leakage due to H_2 small molecular size (2.9 Å); pipeline material incompatibility	18	✓	✓	✗	✗	PNGRB	UN GTR No. 13; DOE H2Tools; NFPA 2
Road transport accident risk; high CAPEX for dedicated H_2 pipelines	19	✓	✓	✗	✗	PESO pipeline rules; PNGRB	UN GTR No. 13; DOE H2Tools
Dispensing hazards							
Extremely low ignition energy at dispensing (0.02 mJ); high dispensing pressure (35–70 MPa); static electrical hazard	20	✓	✓	✗	✗	PESO fuel station rules [gap: high-pressure dispensing provisions]	UN GTR No. 13; DOE H2Tools Refueling Station Guidance; NFPA 2
Connector failure; over-pressurization; inadequate venting; cold burns from LH_2 dispenser	21	✓	✓	✗	✗	PESO fuel station rules	UN GTR No. 13; DOE H2Tools Refueling Station Guidance; NFPA 2

Notes:

[b]*(1) ✓ = hazard relevant to that production technology; ✗ = not relevant.*

[c]*(2) Reference numbers correspond to mitigation measures listed in Table I.*

[d]*(3) Standards listed are freely accessible online.*

[e]*(4) Gaps identified in the Indian standards column are marked in square brackets.*

V. FINDINGS AND DISCUSSION

A. Incident Trends and Safety Culture

Management factors and system design errors cause the majority of incidents. The 2019 Gangneung, Korea incident illustrates both errors together: the electrolyser operated below the minimum power threshold (management), and the system lacked an oxygen removal unit (design) (Korean Supreme Court 2025). The last 6 years have shown a sharp rise in incident rates, including Chungju/Busan (late 2024), Ulsan (October 2025), and Colton, California (February 2026). The 2026 Colton fatality resulted in more than 60% of California's 52 hydrogen stations going offline — demonstrating that safety failures now produce systemic supply-chain consequences far beyond the immediate site.

The dominance of management factors and system design errors (46% each) indicates that organizational and engineering deficiencies contribute more significantly to incidents than direct human error (8%). This suggests that improvements in safety management systems, hazard identification during design, and operational oversight may provide greater safety benefits than focusing solely on operator behavior.

B. Production, Storage, Transport and Distribution

The review identified leakage, explosion, flammability-related events, hydrogen embrittlement, and hydrogen-oxygen crossover as the most frequently reported hazards across the green hydrogen value chain. Analysis of the 25 documented incidents showed that explosions were the dominant consequence, accounting for approximately 76–77% of recorded events (Fig. 2b).

Production: The most frequently reported production hazards were hydrogen-oxygen crossover, diaphragm or membrane failure, water starvation, equipment malfunction, and operational errors. AWE systems showed hazards associated with caustic KOH handling and diaphragm crossover, while PEM systems were particularly vulnerable to membrane degradation and hydrogen-oxygen deflagration events.

Storage: Storage exhibited the highest number of documented hazard categories. The most prevalent hazards were high-pressure containment failure, hydrogen embrittlement, cryogenic hazards associated with liquid hydrogen, boil-off gas accumulation, and flammability resulting from leaks. Storage also represented the domain with the largest number of identified mitigation measures and standards references.

Transportation and distribution: The dominant hazards were pipeline embrittlement, leakage through seals and joints, material degradation, and accidental releases during transfer operations. Existing studies consistently identified hydrogen compatibility of pipeline materials as a critical safety concern.

Dispensing: The most frequently reported hazards included dispenser leakage, connector failure, over-pressurization, inadequate venting, and ignition during vehicle refueling operations. Historical hydrogen refueling station incidents indicate that dispensing systems remain vulnerable to leak-related ignition events.

C. Mitigation Measures

Leak detection systems, ventilation, emergency shutdown (ESD) systems, pressure relief devices, safety separation distances, and hydrogen-compatible materials were identified as the most commonly applied mitigation measures across the green hydrogen value chain. The following are gaps identified in the application of mitigation measures during various stages of GH_2 generation.

Gaps in mitigation measures (stage-wise):

- **Production:** Real-time H_2–O_2 crossover monitoring, predictive maintenance for electrolysers, and water starvation detection (PEM) are only partially addressed by measures 11 and 13 in Table I.
- **Storage:** Hydrogen embrittlement monitoring (lifecycle) and BOG (boil-off gas) management for LH_2 storage are addressed by measures 1–4 in Table I, but lifecycle monitoring remains a gap.
- **Transport and distribution:** Continuous degradation monitoring and smart inspection systems for long-distance pipelines are only partially covered by measure 16.
- **Dispensing:** Advanced diagnostics and condition-based maintenance for 70 MPa systems — measure 20 addresses detection but not predictive maintenance.
- **Emerging technologies (LOHC, AEM, SOE):** Technology-specific monitoring and dedicated mitigation approaches are addressed by measures 7, 8, 14, and 15 in Table I, though notable regulatory gaps remain.

D. Regulatory Gap Analysis

Gaps identified in regulatory standards:

- No dedicated AEM membrane safety standard exists globally.
- No ceramic-specific Indian Standard (IS) exists for SOE high-temperature operation.
- Limited lifecycle integrity monitoring requirements exist for cyclic loading of composite pressure vessels (India and globally).

VI. SUGGESTIONS

Further research may be required to close gaps in identifying root causes, ensuring the robustness of mitigation measures, and incorporating lessons learned into regulations:

- Development of a mandatory Indian GH_2 incident reporting system, modelled on HIAD, to reduce the 23% unknown-root-cause rate.
- Cyclic fatigue testing of Type 4 composite cylinders under variable-pressure service representative of intermittent renewable generation, to enhance the safety, durability, and life prediction of Type IV composite hydrogen cylinders operating under intermittent renewable energy conditions.
- Quantitative risk assessment of H_2/O_2 crossover dynamics in AWE/AEM systems at partial load, to assess the applicability of the Gangneung-type failure mode.
- Further empirical characterization of the PEM water-starvation deflagration mode across commercial stack

sizes, to generate empirical data enabling safer stack designs, improved fault detection, optimized operating limits, and stronger safety standards for commercial hydrogen systems.

- Inclusion of mitigation measures related to cryogenic LH_2 storage and 70 MPa pipeline transportation and dispensation in BIS/PESO standards.
- Development of AEM- and SOE-related regulations in India.

VII. STATEMENTS AND DECLARATIONS

Funding: The authors did not receive support from any organization for the submitted work.

Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval: This review did not involve new experiments on human participants or animals; it is based on the analysis of publicly available incident records, regulatory documents, and previously published literature.

Consent to Participate: Not applicable.

Consent to Publish: Applicable.

Data Availability: The data analysed in this review were derived entirely from publicly available sources, including HIAD 2.2 (European Commission Joint Research Centre), H2Tools (Pacific Northwest National Laboratory/U.S. Department of Energy), the ARIA database (French Ministry of Ecological Transition), Nel ASA public filings, Korean Supreme Court records, Nature Communications, and the news sources cited in the reference list. No new datasets were generated. The consolidated incident register and hazard/mitigation tables compiled for this review are available from the corresponding author upon reasonable request.

Author Contributions: All authors contributed to the concept and development of this review paper.

VIII. ACKNOWLEDGMENT

The authors are grateful for the open access to a variety of accident databases maintained by the EU and the generous information openly available on incident investigations. The foundation of this paper is based on these authentic open sources.

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Appendix: List of Abbreviations

Abbreviation	Full Form
AEM	Anion Exchange Membrane
ARIA	Analyze, Recherche et Information sur les Accidents
ASME	American Society of Mechanical Engineers
ATEX	Atmosphères Explosibles (Explosive Atmospheres Directive)
AWE	Alkaline Water Electrolysis
BIS	Bureau of Indian Standards
BOG	Boil-Off Gas
BPVC	Boiler and Pressure Vessel Code (ASME)
CCS	Carbon Capture and Storage
CFRP	Carbon Fiber Reinforced Polymer
CGH_2	Compressed Gaseous Hydrogen
COPV	Composite Overwrapped Pressure Vessel
DDT	Deflagration-to-Detonation Transition
DOE	Department of Energy
EIS	Electrochemical Impedance Spectroscopy
EPDM	Ethylene Propylene Diene Monomer (rubber)
ESD	Emergency Shutdown
FRP	Fiber Reinforced Polymer
GH_2	Green Hydrogen
H_2	Hydrogen
H_2/O_2	Hydrogen/Oxygen
HIAD	Hydrogen Incidents and Accidents Database
HRS	Hydrogen Refueling Station
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IMPEL	European Union Network for Implementation and Enforcement of Environmental Law

ISO	International Organization for Standardization
KOH	Potassium Hydroxide
LEL	Lower Explosive Limit
LH_2	Liquid Hydrogen
LOHC	Liquid Organic Hydrogen Carrier
MIE	Minimum Ignition Energy
mJ	Millijoule
MOF	Metal-Organic Framework
MPa	Megapascal
Mt/yr	Million Tons per Year
MTPA	Million Tons Per Annum
NFPA	National Fire Protection Association
NHM	National Hydrogen Mission
PEM	Proton Exchange Membrane
PESO	Petroleum and Explosives Safety Organization
PNGRB	Petroleum and Natural Gas Regulatory Board
QRA	Quantitative Risk Assessment
RCA	Root Cause Analysis
SAE	SAE International (formerly Society of Automotive Engineers)
SOE	Solid Oxide Electrolysis