International Conference on Green Hydrogen

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R&D Strategies for Hydrogen Safety

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India’s Hydrogen Story – Establishing a decarbonized energy system

National Hydrogen Energy Mission

Launched by Hon’ble Prime Minister Narendra Modi on 15th August 2021

A clean and sustainable energy source
to reduce carbon emission and replace energy imports

India – The next big moment

Make India a **global hub for production and export** of green hydrogen

Target of production of
5 MT of Green hydrogen by 2030;
25 MT by 2047

National Green Hydrogen Mission approved, 17th Feb 2023

Green hydrogen, will play an integral role in achieving India’s net zero ambitions by 2070

Transitioning to hydrogen fuel through
- **Innovation**
- adopting stringent **safety standards**

Make hydrogen fuel technology **competitive** and **affordable** to the masses

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	2.8X > Gasoline	~1.2X > Gasoline	43MJ/kg
Energy by Volume	4X < Gasoline	1.5X < Gasoline	120MJ/ Gallon

NFPA 704 Hazard Placards
- Red = Flammability
- Blue = Health
- Yellow = Reactivity
- White = Special Precautions

Gaseous Hydrogen

Liquid Hydrogen

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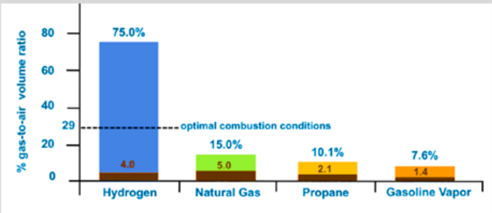
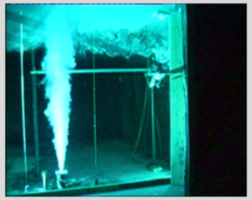
UNIQUE PROPERTIES OF HYDROGEN: A CHALLENGE AND AN OPPORTUNITY

Flammable Limits

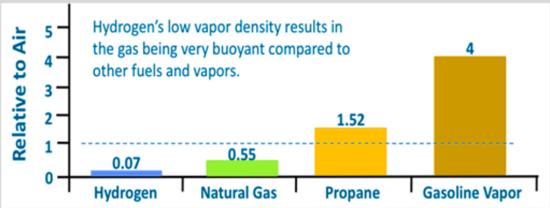


Hydrogen leaks

Hydrogen has a low density causing it to disperse upwards and generate flammable gas layers against the ceiling



Vapor Density



Auto-ignition temperature (hot surfaces)

Hydrogen	580 °C
Methane	537 °C
Propane	493 °C
Acetone	535 °C
Ethanol	363 °C
Petrol	ca 250 °C
Diesel	ca 220 °C

CO_2 Emission Free

Colourless

Odourless

Tasteless

Invisible flame

Non-Toxic

Less Radiant heat

Very small molecule

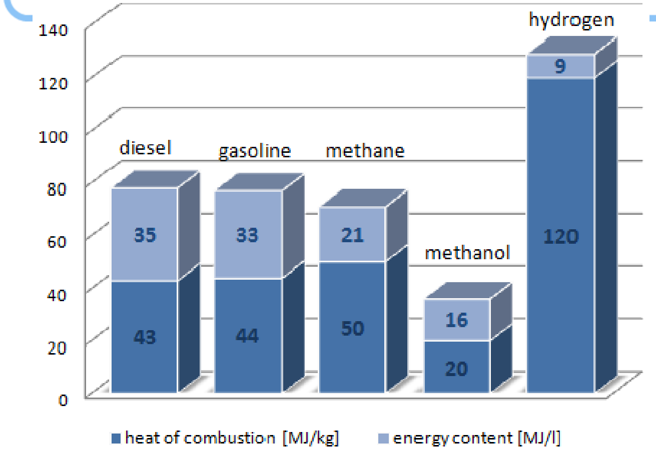
Easily ignited (15 times less energy required than NG @stoichiometric conc)

14 times lighter than air

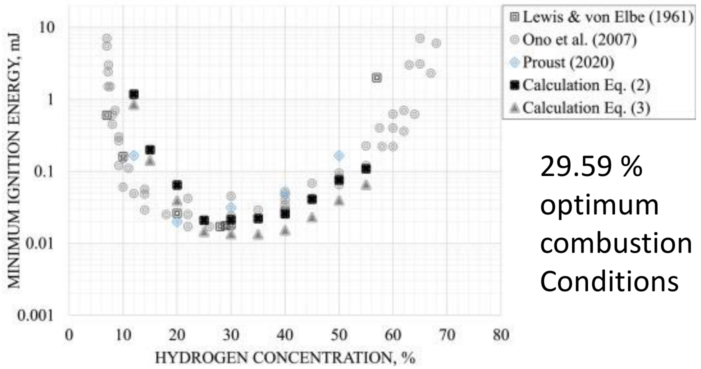
Prone to deflagration-to-detonation transition (DDT)

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

Negative Joule Thomson coefficient (significant if already near ign T)



Min Ignition Energy



29.59 % optimum combustion Conditions

% Volume of H_2 in air	Flammability limits of Hydrogen
8	not robust enough to propagate a flame throughout an entire mixture
9	downward propagating flames have a lean limit
7.5–8	horizontal propagating flames have a lean limit
4	upward propagating flames have a lean limit

Why is Hydrogen Safety Important?

Relatively new endeavour - proper methods of handling, storage, transport and use are often not well understood across the various world communities

Insufficient knowledge about critical safety aspects - represents a bottleneck for industry, authorities, end-users and the general public

Hydrogen related accidents could negatively impact the public's perception of hydrogen systems as a viable, safe, and clean alternative to conventional energy systems

For successful hydrogen technology acceptance and its deployment

Safety issues must be addressed

Accelerate early transition

Large and widespread use of H2

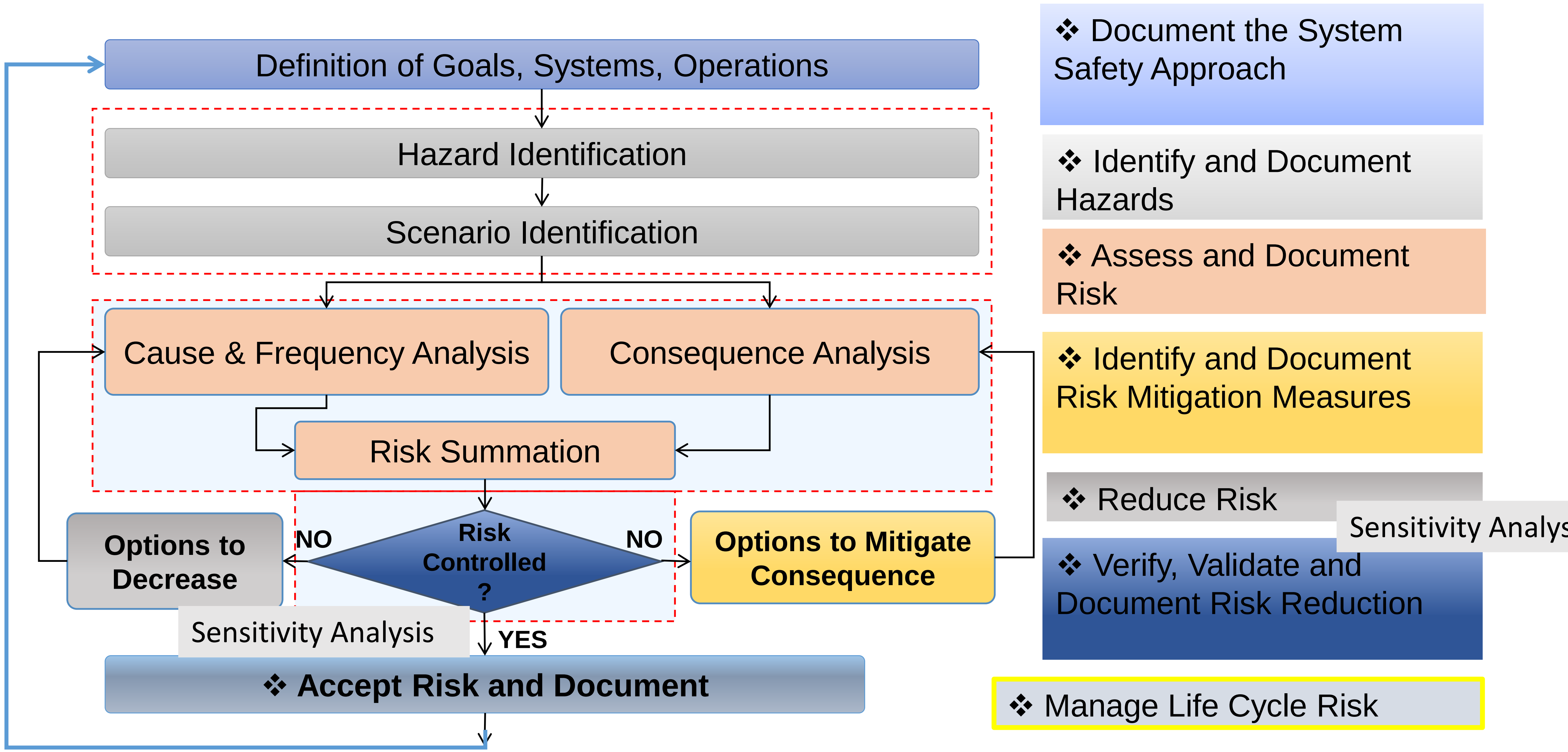
Rapid progress of technologies

Hydrogen Infrastructure design

Foundation for hydrogen standards

A SYSTEMS PROBLEM: COMPLEX WITH UNCERTAINTIES REQUIRES RIGOROUS SYSTEMS SAFETY ANALYSIS

Quantitative Risk Assessment as an Integral Part of Systems Safety Analysis



R&D in QRA : Identification on gaps in Hydrogen Safety

Enable consistent, rigorous and acceptable Safety analysis

Use QRA

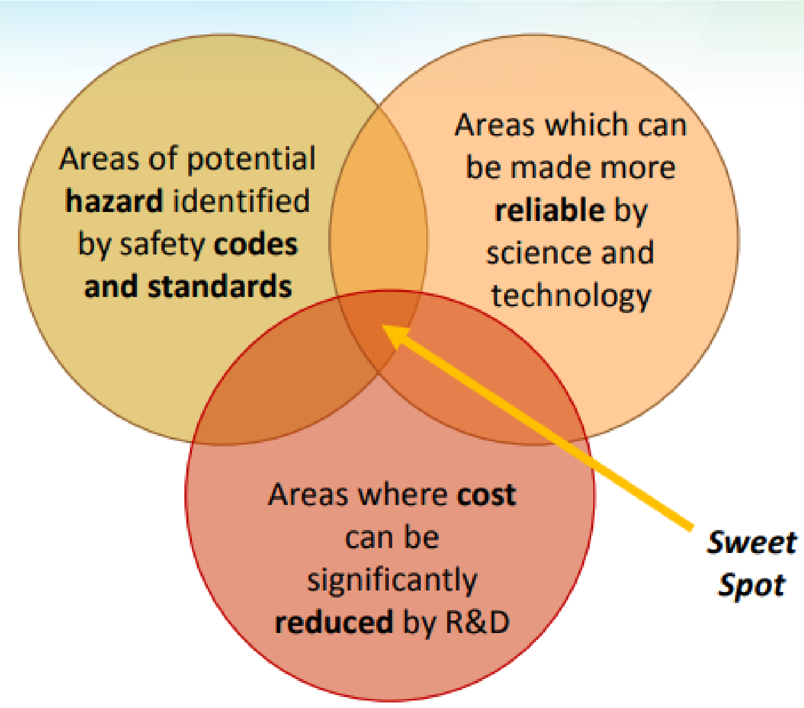
- to calculate risk associated with key Hydrogen infrastructure – support safety, reduce barriers
- Enhance reliability and reduce costs for hydrogen technologies
- State of the art risk methods incorporating materials , scientific computing and data analytics concepts
- Industry sensitisation and participation early in R&D

Behaviour R&D:
Development and validation of models to accurately predict hazards and harm from accident scenarios

Risk R&D:
Development of integrated methods and algorithms for enabling consistent, traceable and rigorous QRA

Science based Regulations, Safety Codes & Standards:
Apply QRA and behaviour models to real problems in Hydrogen infrastructure and emerging technologies

Developing methods, data and tools for hydrogen safety and RCS



Sandia National Labs

Potential Impacts of Use of QRA

- Developing science-based, risk-informed codes & standards
- Production, Transport , Delivery, Storage & Applications
- Address critical barriers for industry related to limited availability and access to safety

Research Gaps Identified in International Workshops

Sandia National Labs

Research Priorities

- Quantitative Risk Assessment (QRA) Tools (23%)
  - Want user-friendly and industry focused QRA software tool
  - Second highest priority is guidance for using risk in decision making
- Reduced Model Tools (15%)
  - Effects of barrier walls on flame and overpressure behavior
  - Consolidation of research and tools
- Indoor (13%)
  - Behavior of cryo jets, improved understanding of H2 indoors
- Unintended Release-Liquid (11%)
- Unintended Release-Gas (8%)
- Storage (8%)
- Integration Platforms (7%)
- Hydrogen Safety Training (7%)
- Materials Compatibility/Sensors (7%)
- Applications (2%)

Hydrogen Compatible Materials Workshop

- Data and Phenomenology
  - Measurements of fatigue properties and causes of fatigue (15 votes)
  - Database for properties structural materials in H2 (12 votes)
  - Influence of welds on H2 compatibility (11 votes)
  - Crack initiation (4 votes)
  - Structural materials qualification for P/T for portable power (4 votes)
- Technology Development
  - Better containment materials: high strength, low cost, long life (8 votes)
  - Better H2 compressors (5 votes)
  - Non-destructive testing (5 votes)
  - Life assessment and leak-before-break criteria (4 votes)
- Codes and Standards
  - Testing protocols for materials evaluation (10 votes)
  - Criteria for engineering acceptance (9 votes)
  - List of acceptable materials (5 votes)
  - Design requirements for portable power (4 votes)
  - No international standard for >35 MPa (4 votes)
  - Variation in C&S relating to production/distribution/dispensing (4 votes)

Broad research areas for India

- Review of the risk assessment tools for predicting and preventing process accidents in the hydrogen industry
- Approaches to managing human factors in hydrogen production, transmission and application - Human reliability analysis, Human factors lab
- Recent advancement of experimental techniques and measurement diagnostics for risk and reliability analysis of hydrogen handling
- Advanced computational simulations and modelling software for hydrogen accidents' consequence modelling (e.g. fire, explosion, thermal radiation) - predicting leak frequencies and ignition frequencies allow for estimating risks and comparing those to acceptance criteria.
- Sensing and monitoring advancement toward hydrogen safety
- Machine learning applications and data-driven models in risk assessment and management of hydrogen process

Hydrogen safety: focused Research areas

Potential Research Topics based on knowledge gaps

•**Hydrogen explosion modelling refinement:** more accurate modelling of hydrogen explosions to better understand blast waves, flame speeds, and other explosion characteristics.

•**Development and evaluation of wide area hydrogen sensing technology**: Current sensing technology is limited in its ability to detect hydrogen leaks, especially in large areas such as refuelling stations.

•**Hydrogen effects on materials, specifically fatigue loading**: The long-term effects of hydrogen exposure on materials, including fatigue loading, need to be better understood to ensure the safe use of hydrogen in various applications.

•**Hydrogen gas cabinets**: need more information on the design and operation of hydrogen gas cabinets to prevent hydrogen leaks and ensure safe storage.

•**Hydrogen deflagrations in partially enclosed areas**: The behaviour of hydrogen deflagrations in partially enclosed areas is not well understood, which is critical for designing safe hydrogen storage and transportation systems.

Potential Research Topics based on knowledge gaps

- **Pressure relief device reliability:** There is a need for more reliable pressure relief devices to prevent overpressure and potential explosions.
- **Confined release mitigation strategies**: There is a need for more effective strategies to mitigate the consequences of confined hydrogen releases.
- **Design, installation, testing, and maintenance of hydrogen detection systems**: There is a need for standardized guidelines for the design, installation, testing, and maintenance of hydrogen detection systems.
- **Ignition limits/criteria for large leak (dynamic) scenarios**: There is a need for more information on ignition limits and criteria for large hydrogen leaks to prevent explosions and ensure the safe use of hydrogen.
- **Hydrogen safety study on infrastructure:** There is a need for a comprehensive study of hydrogen safety in infrastructure, including fuelling stations, storage facilities, and transportation systems.
- **Fire barrier effectiveness**: The effectiveness of fire barriers in preventing the spread of hydrogen fires needs to be better understood to ensure the safe use of hydrogen in various applications.

Investing in research and development in these areas mentioned below is crucial to ensure the safe and effective use of hydrogen in various applications, ultimately leading to a sustainable future.

Blending Hydrogen into Natural Gas Pipeline Networks: addressing Key Issues and challenges

- Lifecycle assessment
- Impact on End-use Systems
- Safety assessment
- Leakage assessment
- Material compatibility and durability assessment
- Material Embrittlement
- Modelling of Hydrogen injection into NG pipelines
- Codes and Standards Assessment for Hydrogen Blends into the Natural Gas Infrastructure
- Current status and Novel approaches

Safe storage of hydrogen

For liquefied hydrogen (LH2)

- BLEVEs of storage vessels
- releases of LH2 on & underwater
- combustion and dispersion of clouds developing from LH2 pools
- ignition by electrostatic charging during releases of LH2 and
- effect of temperature on combustion properties of H2 and
- LH2 jet fires

For gaseous hydrogen (GH2)

- gas cloud build-up in ventilated rooms
- a study on the properties of GH2 jet fires
- spontaneous ignition and flame propagation in congested environments including deflagration-to-detonation transition (DDT)
- tunnel safety
- explosion mitigation

Determination of the Safety Integrity Level of hydrogen systems to determine the requirements for instrumented risk reduction measures

PS&RM FOR A HYDROGEN ECONOMY

Safe generation of hydrogen

- Electrolyser and component performance, quality, manufacturing, and safety
- Green H2 production project design, construction, and operation (including Ventilation, Leak Detection: H2 sensors, Electrical Equipment Consideration, Outdoor separation and varying pressure, Selection of materials)
- Hydrogen uses in Industrial applications
- Green H2 certification and trade related regulation

Safe transport / utilization of hydrogen

- Measurement of Green H2 production and utilization
- Safety response due to normal and hazardous environmental condition
- Emergency Response
- Safety requirements for retrofitting of green hydrogen in the existing infrastructure of refineries and fertilizer sector
- Safety aspects (fire explosion hazards, QRA, impact radius, hazardous area classification, etc.) for blended hydrogen for transportation, utilisation
- Principle and approaches for the safety assessment of hydrogen vehicles

Risk Acceptance Criteria for Hydrogen

- Developed based on societal and individual risk
- Consensus of all stakeholders is necessary
- Enables comparison of risk levels calculated from QRA studies
- Risk reducing measures need to be identified and put in place

Basis for selection of individual risk guidelines:

- Established safety goals and their quantification
- Risk to individuals should not substantially increase their existing risk from other unintentional injuries

Benefits of a risk informed approach:

- Provides a defensible technical basis for specifying separation distances for hydrogen facilities.
- Risk acceptance criteria established for all groups of people exposed to accidents

Linear risk integral versus length

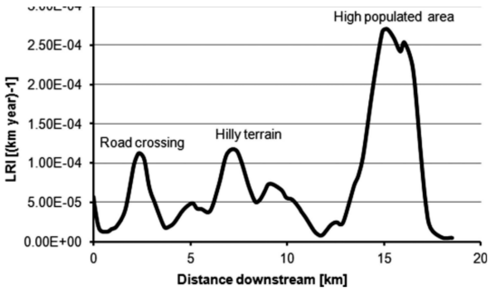


Figure 4. Societal Risk of a pipeline: LRI curve over pipe distance

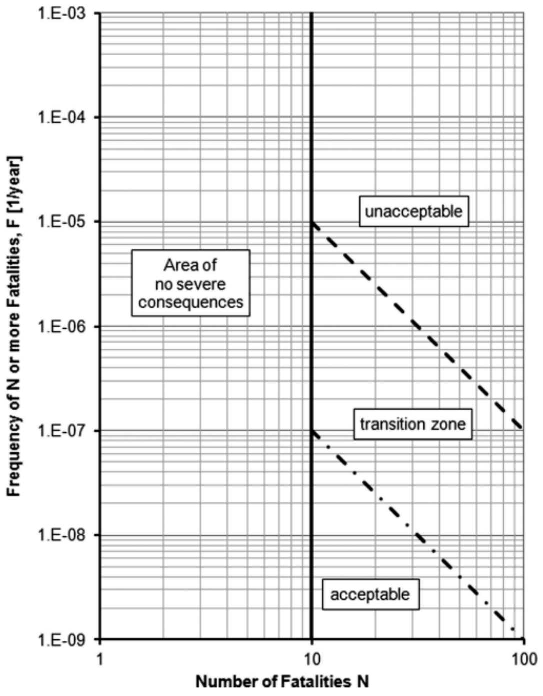


Figure 3. Societal Risk criteria in Switzerland, Swissgas 2010

Different groups for Criteria

Group	Affected People	Risk Management
Third Party	People living and working in the vicinity of the refuelling station or visiting/travelling	Both societal and individual(geographical) risk measures should be considered
Second party	Refuelling station customers	These people will be exposed to the risks at the refuelling station for a limited period of time, while visiting the facilities. Therefore, the risk contribution to each individual will be very low. However, it would be unreasonable to use this as an argument for not considering this risk
First party	Hydrogen refuelling station personnel	A higher risk level will be considered acceptable for this group than for Third party.

Human Factor Design For User Friendly Hydrogen Installations

ISO 13407 is the standard for human-centered design processes for interactive systems

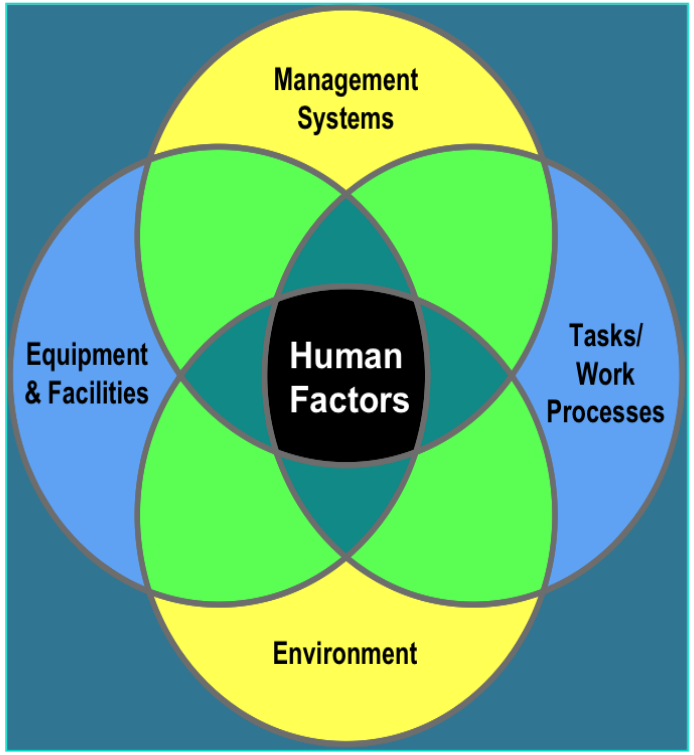
- Human factors and ergonomics should be integrated into interactive systems design
- The aim is to enhance effectiveness and efficiency, improve working conditions, and counteract adverse effects on human health, safety, and performance

Design Considerations:

- Pivotal events triggered by humans should be recognized
- Facility and organizational systems should be designed to reduce human fatigue.
- Accessibility and ergonomic design should be considered.

Recommendation:

- Design new hydrogen systems in India with human tendencies in mind.

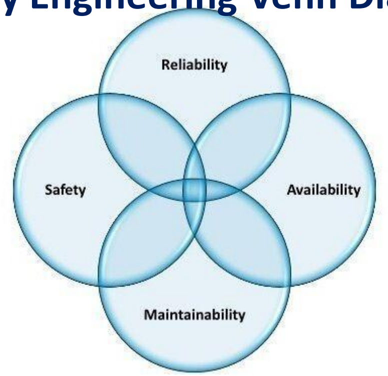


Human factor integration

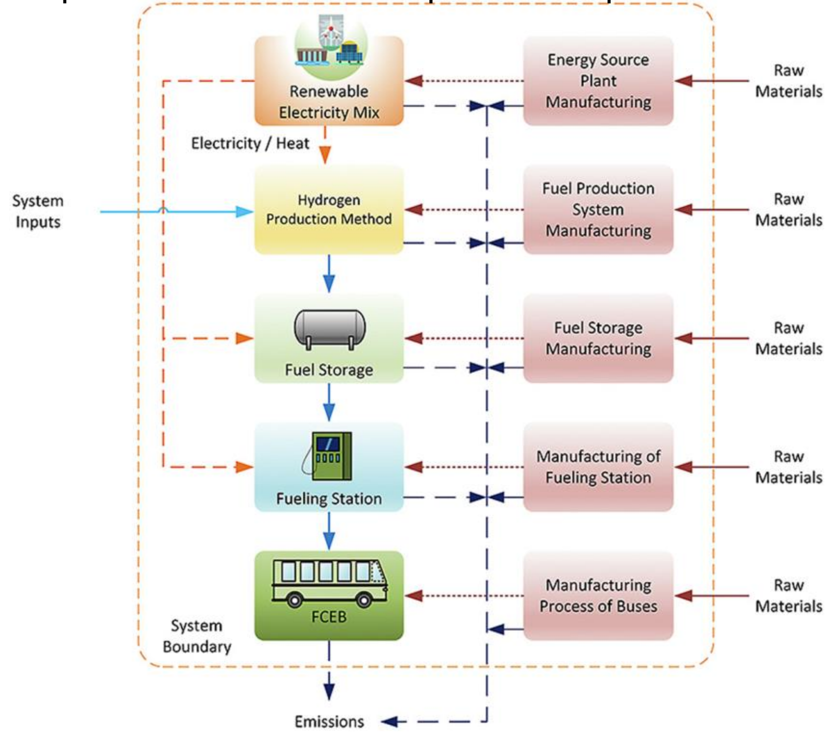
Reliability, Availability, Maintainability and Safety(RAMS)

- The reliability of hydrogen infrastructures significantly contributes to the price of hydrogen.
- It can be enhanced by improving the reliability of individual components through reliability engineering programs.
- This will decrease the maintenance cost, increase the time the system is available, accelerate component developments, and reduce the failure rate.

Reliability Engineering Venn Diagram

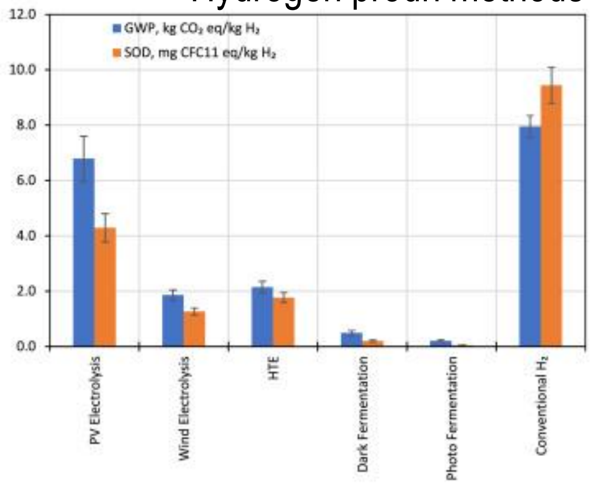


A life cycle impact analysis of various hydrogen production methods for public transportation sector

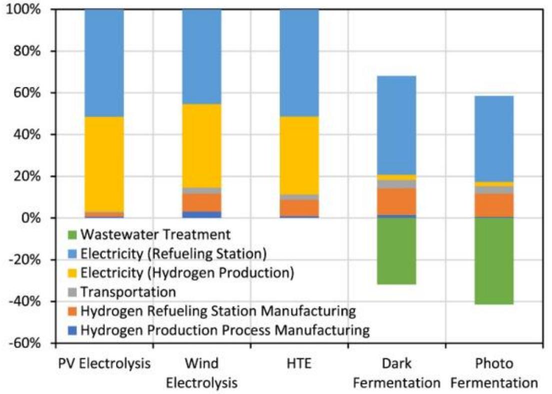


Life Cycle Analysis (LCA)

GWP and strat. O_3 depl (SOD) for Hydrogen prodn methods



Pathway contributions to global warming potential (GWP)

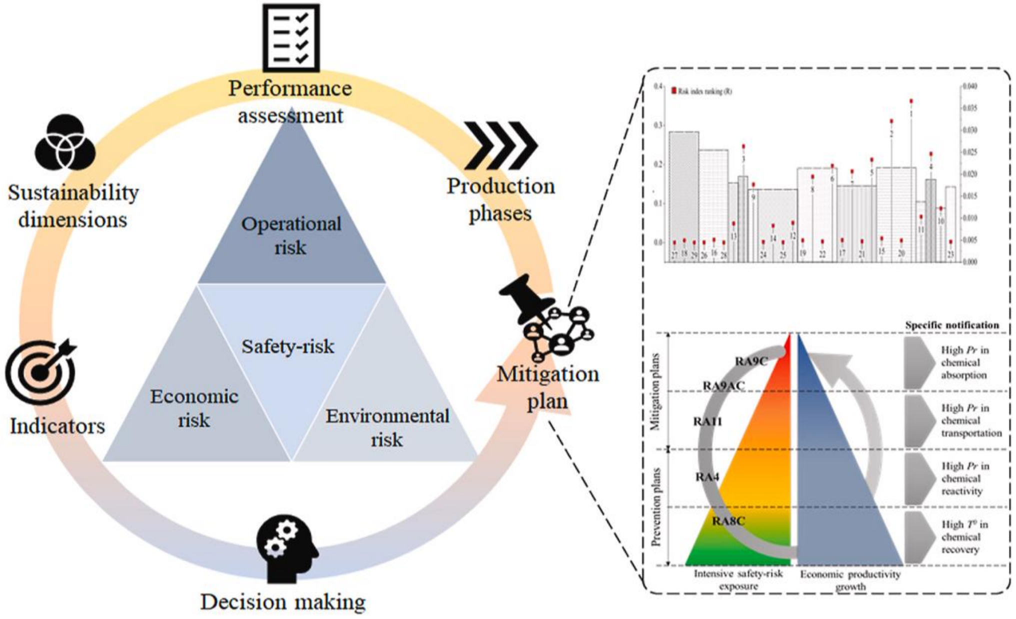


https://www.sciencedirect.com/science/article/pii/S0360319922042665#fig2

Big Data, Data Analytics and Tools for Hydrogen Safety Analysis

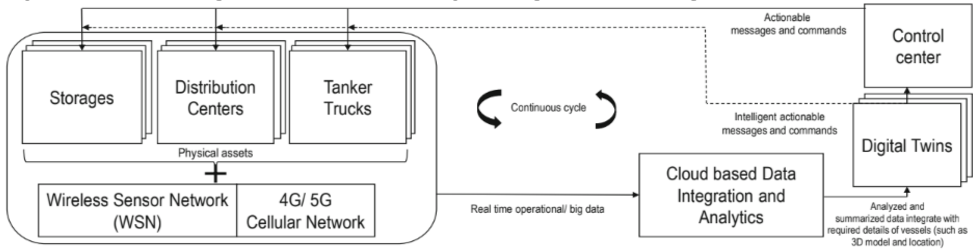
- Data analytics can be used for preparation of digital twins that utilizes the internet of things, software simulation, and data analytics to create a digital replica of a physical object or system.
- Digital twins have the potential to significantly transform condition monitoring and maintenance operations.

Fuzzy and Bayesian approach are proposed to deal with uncertainty in data



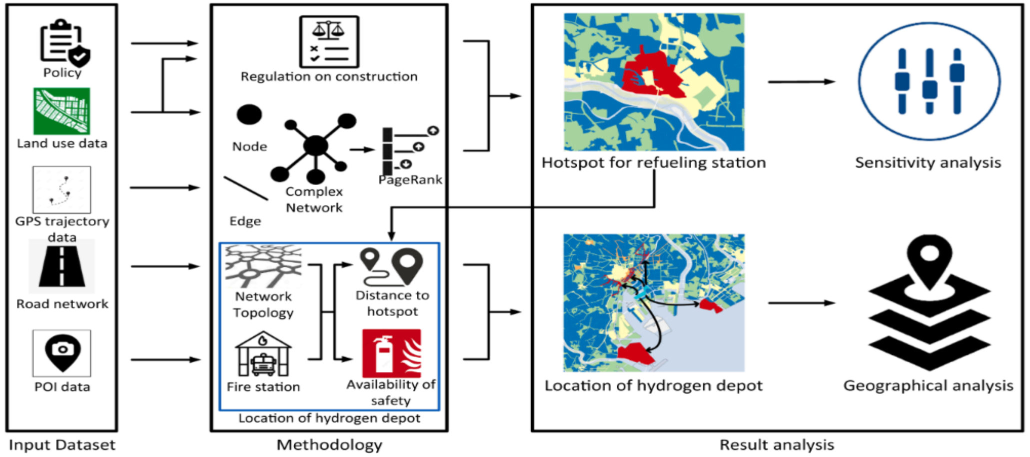
R-index ranked to suggest a priority procedure of optimal mitigation in resolving high potential risk occurrence and reducing uncertain safety factors, environmental impact, and economic loss.

Deployment of digital twins in hydrogen storage and transportation



Digital Twins of the hydrogen vessel in India

Locating priority of hydrogen facilities based on multiple big data fusions.



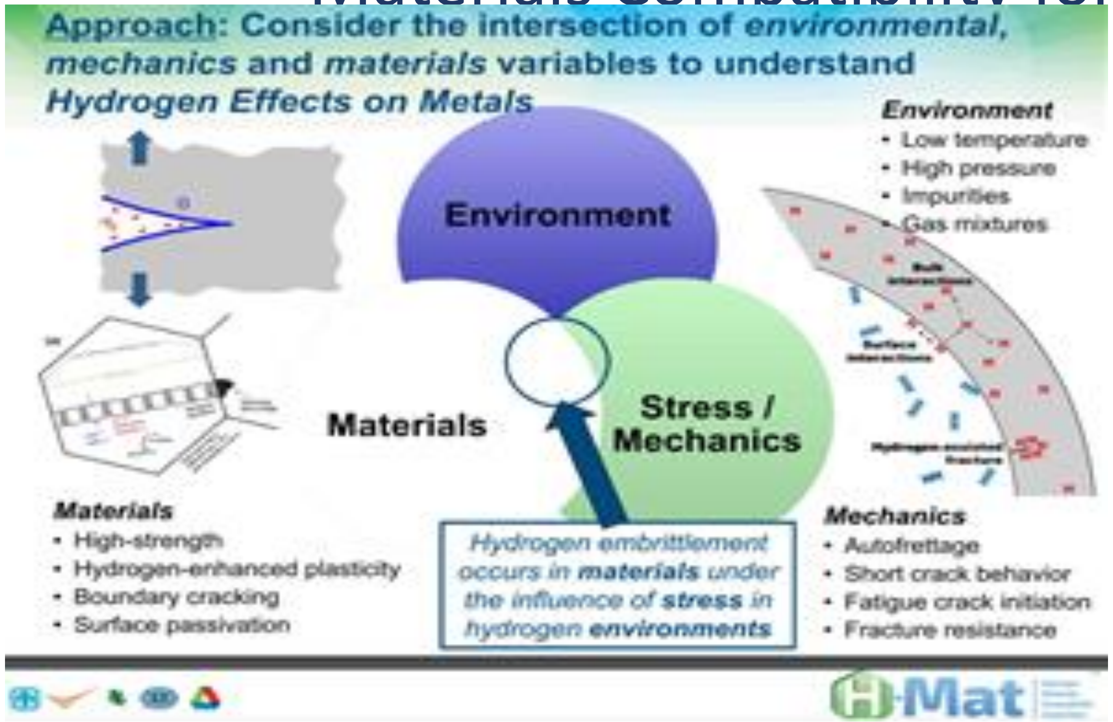
E Lab - For calculation of risk associated to various categories in complex systems virtually

For introducing new technology such as hydrogen fuels, helpful to narrow down uncertainty. Investigation of unusual behavior and near-misses, which represent unidentified failure scenarios, is therefore critical.

To make accident prevention more flexible and interactive, India needs e-Lab

https://elab.hysafer.ulster.ac.uk/

Materials Compatibility for Safety in Hydrogen service



https://www.osti.gov/servlets/purl/1786298

Titanium electrolyser before and after the accident

- Loss of integrity of hydrogen equipment including hydrogen damages are due to

  Embrittlement

  Blistering

  Metal hydride formation
- May lead to catastrophic fire and explosion consequences.

Fracture face of Hot dip galvanized high strength steel anchor rods

https://hyresponder.eu/wp-content/uploads/2021/04/Lecture-1-slides.pdf

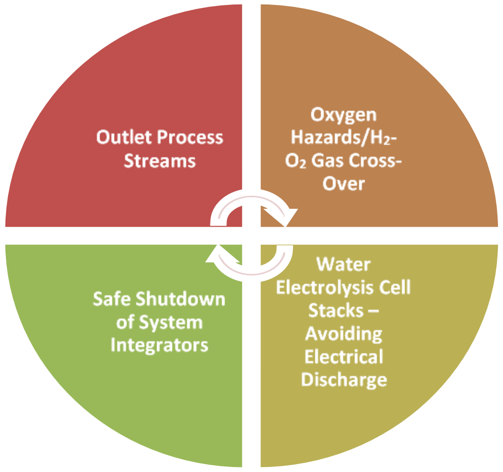
Materials Compatibility for Safety in Hydrogen service

Non-metals Suitability for Hydrogen Service (ISO/PDTR 15916:2014)

Component	Description	Exemplary material grades
Compressed hydrogen pressure vessels	Type IV	**Polymer liner:** High-density polyethylene (HDPE), Polyamide (PA); **composite vessel:** glass or carbon fiber, epoxy resin
Pipelines	High-pressure distribution (>10 MPa)	**Polymer liner:** HDPE, PA
Piping, tubing	Low-pressure distribution (<10 MPa)	HDPE, Polypropylene (PP), Poly(vinyl chloride) (PVC), Chlorinated poly(vinyl chloride) (CPVC)
Mechanical compressors	Seals and coatings	Polytetrafluoroethylene (PTFE), Polyetheretherketone (PEEK)
Dispensing hoses		Nitrile rubber, Fluoroelastomer (FKM), Polycarbonate (PC)
Flange connectors (low-pressure <10 MPa)	O-rings, gaskets	Nitrile rubber, FKM, PTFE
Threaded connectors (high-pressure >10 MPa)	O-rings	Nitrile rubber, FKM
Valves	Pistons	PEEK
	O-rings, fittings, etc.	Nitrile rubber, FKM, PTFE
	Seals and gaskets	PTFE, FKM, nitrile rubber, PEEK, PA, Ethylene propylene copolymer (EPM), fluorosilicone, silicone, Neoprene (CR)
	Valve seats	PA, PTFE, Polychlorotrifluoroethylene (PCTFE), Polyimide (PI)

Adoption of Best Practices for Hydrogen Systems

- The development and design of hydrogen systems should make knowledge available and utilize experiences and learnings from the Hydrogen Safety Panel work and other practices.
- Safety practices for hydrogen systems should include safety culture, safety planning, incident procedures, and communications.
- A safety plan for each hydrogen facility should include the nature of work, organizational policies and procedures, identification of safety and vulnerabilities, risk reduction plan, operating procedures, equipment, and mechanical integrity, management of procedures, project safety documentation, personnel training, safety reviews, safety events and lessons learned, emergency response, and self-audits.



Example : Electrolyser safety

Regulation, Codes and Standards (RCS)

Requirements

- Adoption of international codes and standards and development of consistent national standards are essential for achieving a successful hydrogen economy.
- Harmonisation with international standards is necessary for efficient use of hydrogen-related equipment built in other countries.
- Consensual rules to enable the reduction of risks to people and assets to an acceptable level and protect the environment from damage due to hydrogen operation.
- Learning from countries that are pioneers in hydrogen sector development can assist industries to enhance their skills.
- Facilitation of permitting procedures is possible with the development of regulatory authorities and licensing agencies.

Global efforts

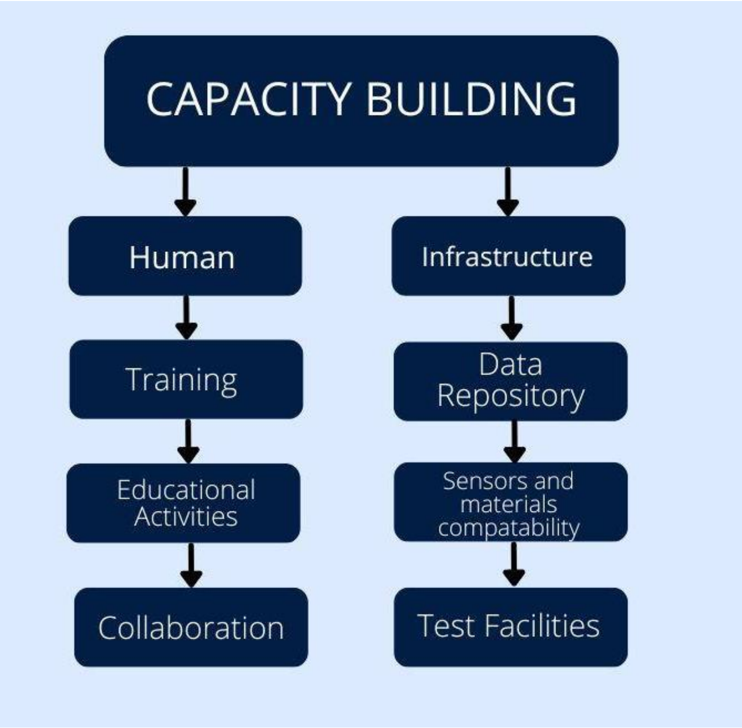
- Collaborations between industry, governments, and safety experts are required to develop hydrogen codes and standards.
- The development of digital platforms and data-based tools has been initiated to assist in the development of consistent procedures for hydrogen safety.
- Standard bodies such as ISO, IEC, NFPA, ASME, CGA, and IMDG are developing standards and codes for various hydrogen-related applications.
- Codes and standards for vehicles, fuel delivery and storage, parking facilities, refueling interfaces, stationary and portable fuel cells, and hydrogen generators have been created, reviewed, and distributed.

Approach to RCS Development

S No	Approach to RCS Development	Provider
1	Evidence-based technical input to standard development organizations (like ISO) to ensure standard requirements are technically sound.	International Association for Hydrogen Safety (HySafe) and IEA HIA (International Energy Agency Hydrogen Implementing Agreement) Task on hydrogen safety
2	Risk-informed approach to hydrogen codes and standards that has been implemented at international (ISO/TC197) and country (NFPA 2 and NFPA 55) levels.	
3	Development of a hazard assessment toolkit for hydrogen applications that will translate fundamental scientific findings into practical formulas and will contain risk metrics relevant to decision making for safety and codes and standards.	

CAPACITY BUILDING

The successful adoption of a Hydrogen economy requires sufficient skilled workforce for the hydrogen.
Appropriate training of the workforce & other stakeholders - emergency responders, regulators, is essential to eliminate barriers
Dissemination of guidelines will help updating industry to create units of competency and qualifications with the growth of infrastructure.



Training related to production, storage, transportation and deployment

Identification and development of well equipped training procedures

Training to all employees, workers and supervisors.

Emergency responders need to be specially trained

Regular Drills based on emergency response plan - periodically revised

First responders should be aware of the building layout and any unique characteristics.

A walkthrough of the entire facility along with material storage should be a necessary drill.

CFD & VR VISUALISATION FOR RISK COMMUNICATION & TRAINING

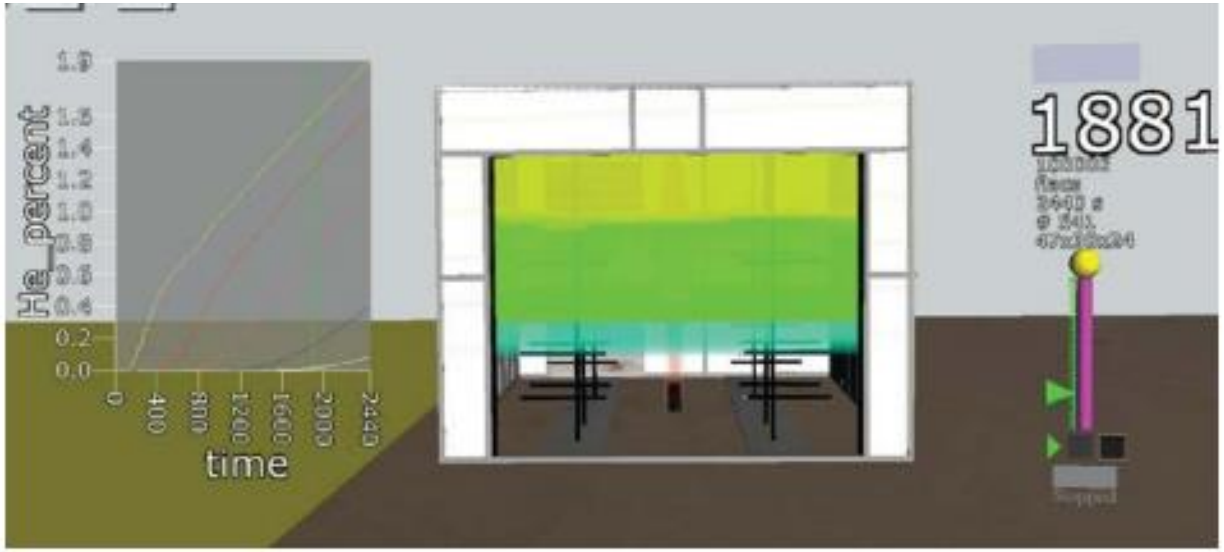


Figure 3 VRSafety visualization of dispersion simulation (CEA Garage test 5, 0.05 g/s He injected into a garage sized enclosure). The gas is released centrally on the floor (see red plume from black cylinder) and the different colours show gas concentrations. To the right the progress bar can be seen, illustrating that this is a FLACS simulation 1881s after start of the release. To the left gas concentrations at 6 sensors can be seen, the green vertical line shows the current time in the animation.

Release in a garage (Experiments with Helium)

A powerful toolbox for

- safety training and risk communication to first-responders, employees, media and other stakeholders
- lessons learned from incidents and accidents,
- Emergency control Centre, and
- to demonstrate what went wrong and how mitigation could have prevented accidents from happening.

Explosion in a refueling station (Shell Benchmark scenario)

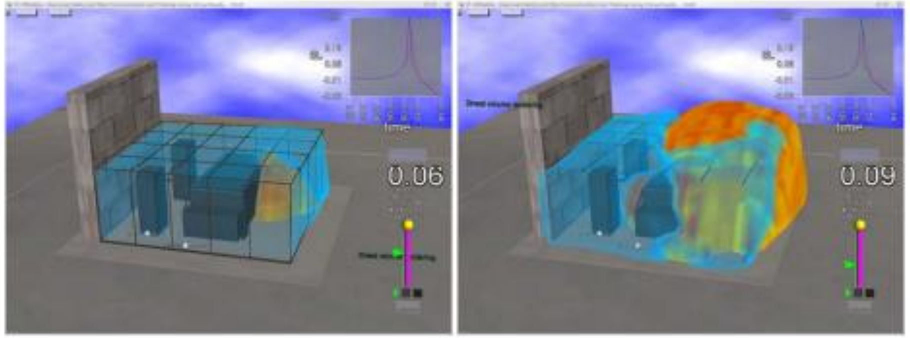


Figure 4 VRSafety visualization of explosion in a mock-up hydrogen refueling station, ignition point is chosen on the left-rear corner of the car and pictures after 60 and 90 ms are shown. Both the flame and the unburnt gas cloud (semi-transparent blue) are visualized, and transient explosion pressure is shown at two chosen locations (white probes).

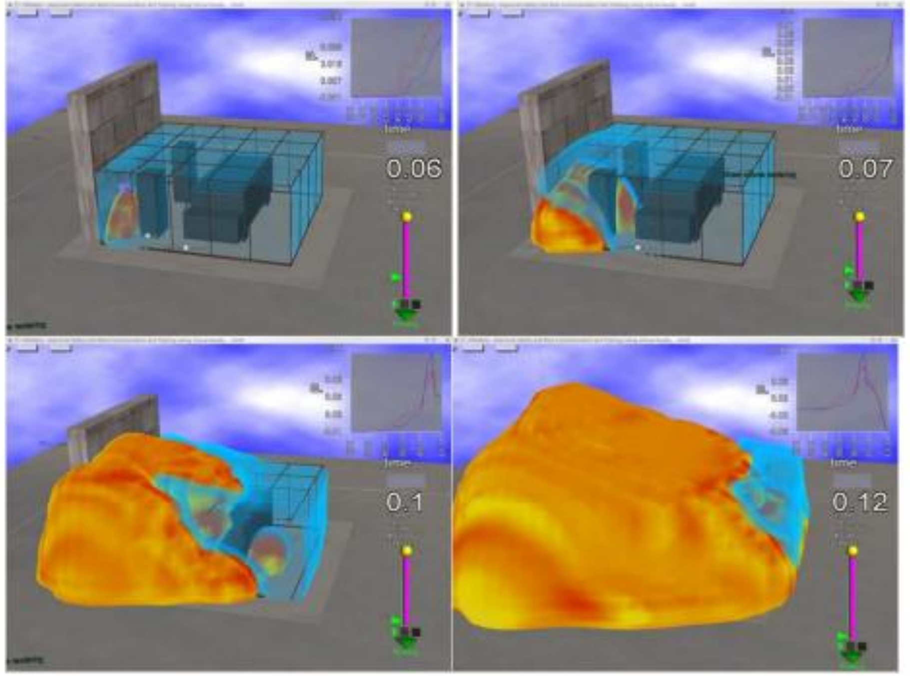
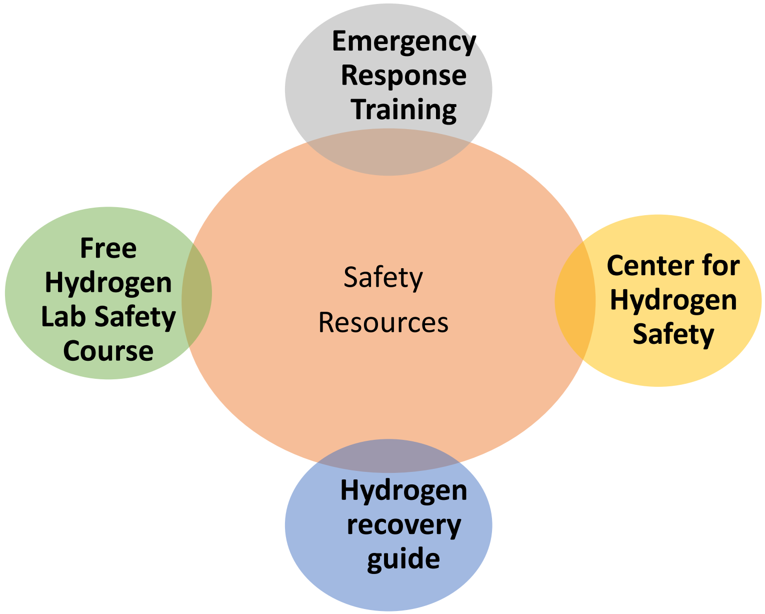


Figure 5 One of the possibilities unique for VRSafety is the interactive simulation with FLACS during a session. The above pictures show how ignition point is moved to the lower left corner of the enclosure and a new explosion simulation is started. The total simulation time is around 5 minutes, which can using the parallel version of FLACS.

Hydrogen Safety Resources and Database Management

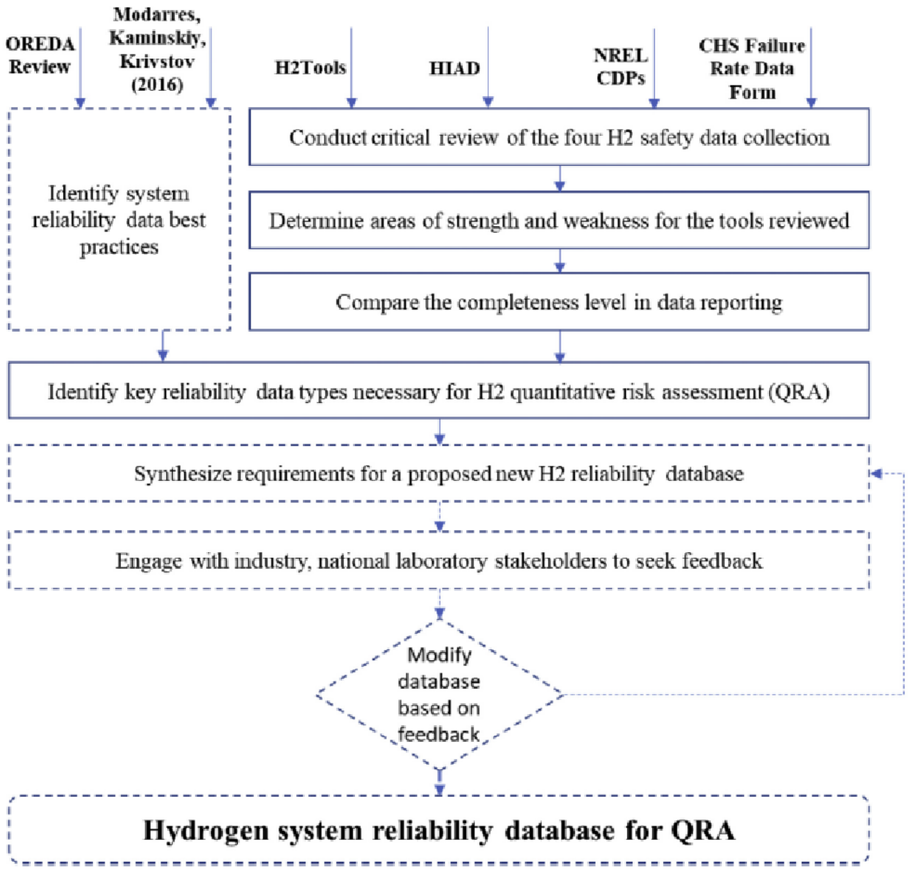
- Hydrogen safety database can help in development and sustainability of hydrogen value-chain.
- Digital platforms & data-based tools are essential for developing consistent procedures for hydrogen safety in different sectors.
- Database management is necessary to enable wider, safer deployment of hydrogen infrastructure and value-chain.



A CoE in Hydrogen Safety in India to engage with national, international laboratories, research institutions, industries and other stakeholders to develop a comprehensive reliable database for hydrogen safety systems and identify best practices for hydrogen safety data collection.

Resources Algorithm

Methodology for review and analysis of hydrogen safety data collection tools



CoE in Process Safety & Risk Management for a Hydrogen economy


THE ECONOMIC TIMES Industry

Nayara Energy inks MoU with IIT-Delhi and Gexcon to strengthen process safety & risk management

Nayara Energy Inks Memorandum Of Understanding With IIT-Delhi And Gexcon To Strengthen Process Safety & Risk Management To Set Up Centre Of Excellence (COE)

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BUSINESSFAST

Nayara Energy inks MoU with IIT-Delhi and Gexcon to strengthen process safety & risk management

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NP News Patrolling

A unique Centre of Excellence in Process Safety and Risk Management for a Hydrogen Economy, set up in IITD

Vision

To establish a world class process safety Institute to help reduce accidents and ensure high levels of process risk management, so that the rapid growth in Indian economy is sustainable

Mission

To promote process safety and minimise industrial accidents in the country, as also to carry out research in Safety of renewables including Hydrogen, develop safety protocols and standards in line with international norms and best practices.

FOR A HYDROGEN ECONOMY

IIT DELHI

CoE in PS & RM – H2 : Stakeholders

Industries

- Chemical Process Industries
- Petrochemicals
- Energy (Renewables, Oil & Gas, Hydrogen, LNG)
- Pharma
- Food & Beverages
- Transportation
- Mechanical Equipment Manufacturing

R & D Centers

- CSIR
- BARC
- DRDO
- DST

Academia / Research Institutes

- IITs
- NITs
- IISERs
- Other Universities

Government / Regulatory / Finance

- MNRE
- MoEF & CC
- NDMA
- CPCB
- PESO
- OISD
- IRDAI
- Banking Institute
- Insurance Companies

Area of Expertise

Capacity Building

- Programs in Process Safety
  - ✓ Masters
  - ✓ PhD
- Training Programs
  - ✓ Process Safety and Risk Management
  - ✓ Explosions Science
  - ✓ Process Hazard Analysis
  - ✓ Advanced Process Safety Tools
- Fire and Explosion Testing

Hydrogen Safety

Consultancy Services

- Safety Audits
- Process Hazards Analysis
- Process Safety and Risk Management
- Regulatory Compliance
- Modelling Studies
- Incident Investigations

CoE Verticals

R&D

Process/Hydrogen Safety

- Use of **advanced CFD tools**, AR&VR
- Developing and maintaining **data base of accidents** with root cause analysis
- **R&D Projects** related to safety of Industrial, hydrogen, pilot plant process

Consultancy

- System safety Analysis
- Process Hazard Analysis
- Process Safety and Risk Management
- Safety Audits
- Regulatory Compliance
- Modelling Studies
- Incidents/Accidents Studies

Capacity Building

- PhD and Masters course
- Virtual Training Reality (VR) Programs
- Process Safety and Risk Management;
- Advanced Process Safety Tools;
- Process Hazard Analysis
- Explosions Science

Development of Safety standards

Provide inputs for adoption of International Standards and Adaption to Indian conditions

CoE Key Activities

- Process/Technical Safety and Risk Management
- Dispersion Modelling, Explosion Modelling, Fire Modelling
- Gas and Dust Explosion
- Safety Regulatory Compliance
- Occupational Health and Safety
- Incident Investigation
- Share information and knowledge on process safety management and safety studies through technical support.
- Hydrogen technical safety and risk management.

Design and Certification *

- Tests Related to Certification and Classification
- Specialized Testing and Research
- Certification of Equipment Intended for Use in Explosive Atmospheres
- Explosion Mitigation Systems Testing

*Based on projected availability of labs/ land for setting up test facility at one of the IITD campuses

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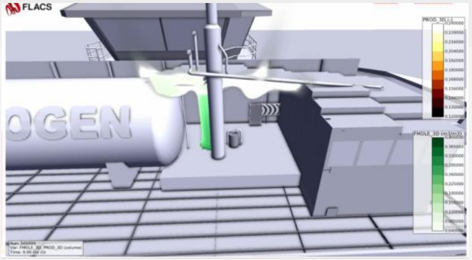
Computational Facility

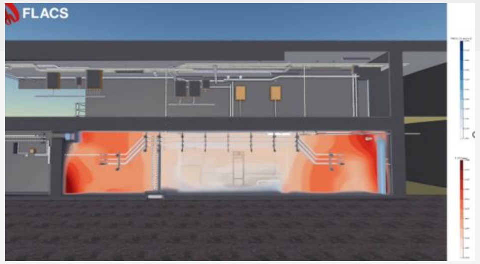
Applications of FLACS developed by KP Gexcon

Simulation vs. live test

Hydrogen Dispersion and Explosion Deck



Hydrogen Dispersion Simulation in a Battery Room



CoE is equipped with the world-class software and hardware which offers a wide variety of analytical solutions to help you understand and manage your challenges. These include tools in consequence modelling, quantitative risk analysis (QRA) and pre-incident planning.

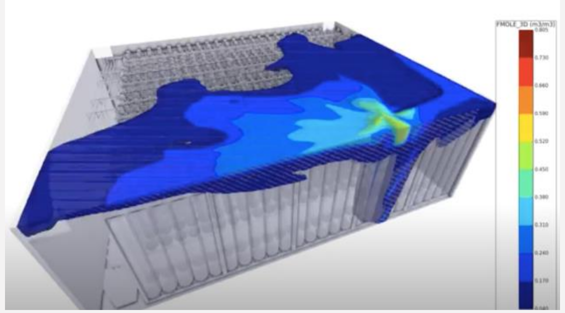
Software

- FLACS
- EFFECTS
- RISKCURVES
- SHELL FRED
- SHELL SHEPHERD
- SHELL PIPA

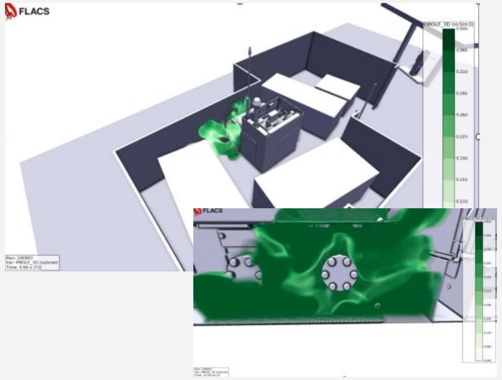
Hardware

- High Performance Computing System (HPC)
- Virtual Reality /Augmented Reality (VR /AR)

Hydrogen Dispersion Simulation in a Room



Hydrogen Dispersion from Fuelling Station



PS&RM
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Advanced Safety Assessment

CFD
RSC
EFF
SHPD
FRED
FREQ

Process/ Hydrogen Advanced Safety

3D Consequence Analysis and Quantitative Risk Assessment

- Safety Training Using 3D CFD CA with VR
- Risk communication and analysis (societal and environmental risk)
- Understanding the accident and its consequence
- Process risk analysis and safety reviews for regulatory compliance
- Support for the design of installations: safety distances, layout optimization of ventilation
- Gas detection optimization study
- Dispersion, explosion, and fire simulations
- Sizing/verification and optimization of structures and equipment

Virtual Reality (VR) Training Tool

- VR- In Safety Training
- VR – In Risk communication
- VR – In Understanding the accident

Pre-Incident Planning

PIPA

Hydrogen Safety Systematic Approach

A commitment to utilizing available knowledge and technology to achieve success.

BASIC SAFETY
- Safety Related
- Technical Data
- Safety Plans and Project Designs
- Site Safety Evaluations

EMERGENCY RESPONSE TRAINING
- Awareness Training
- National Hydrogen and Fuel Cell Emergency Response Training

Hydrogen Safety Systematic Approach

SAFETY IN DESIGN AND OPERATIONS
- Facility Design Considerations
- Storage and Piping
- Operating Procedures
- Equipment Maintenance
- Laboratory Safety

SAFETY PRACTICES
- Safety Culture
- Safety Planning
- Incident Procedures
- Communications

Safe Implementation of Hydrogen Technologies

Knowledge partner - support in hydrogen safety from production to dispensing through storage and transportation, in India.

Pre Project

Safety Planning

Safety Training

Early Design

Review Project/Facility Early Designs.

Review Risk Analysis

Early Operations

Onsite Safety Evaluations

Support

Identify Safety Gaps

Incident Fact finding and Investigations

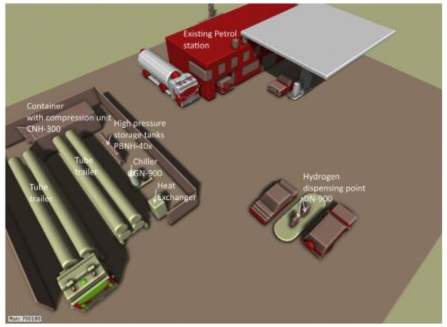
Early Concept Support

Successful Project Implementation

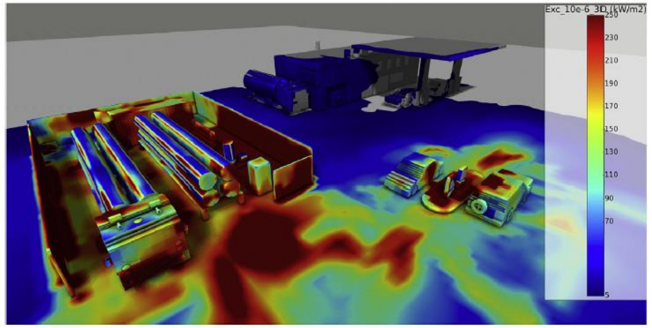
3D Risk Management – Case Study

QRA part of the 3DRM concept for a filling station. The analysis combines event frequencies with consequences from fire and explosion scenarios simulated with the CFD tool FLACS Hydrogen. The fire scenarios are limited to jet fires, and the explosion scenarios are limited to deflagrations.

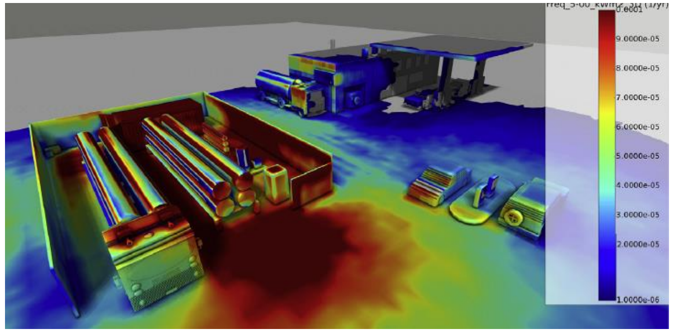
- System definition
- Fault and Event Tree
- Dispersion simulation
- Fire simulation
- Explosion simulations
- Risk calculations
- Human vulnerability model



Layout



Heat radiation contours with frequency exceeding 10-6 yr-1.



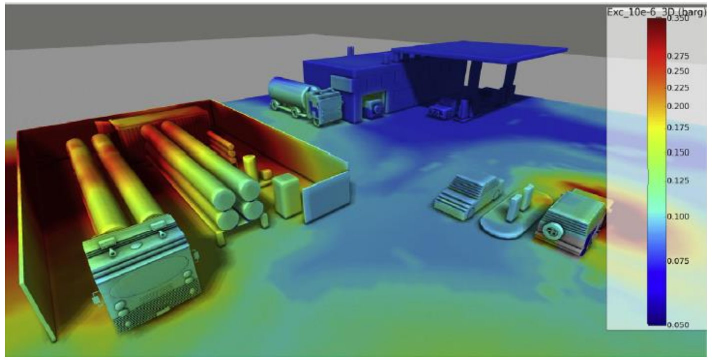
Frequency contours, from 10-06 to 10-04 yr-1, for 5 kW m-2 radiation load

Table 1 – Summary of release locations and release rates.

Process units and scenarios	Pressure [bar g]	Representative internal diameter [m]	Release rate [kg s^{-1}]
Container with compressor unit	207	19.00	3.55
High pressure storage tanks	1034	7.16	2.00
Tube trailer	207	12.60	1.59
Dispenser	700	7.16	1.50

Table 2 – Summary of frequencies [yr^{-1}] for the risk analysis.

Process units and scenarios	Number	Releases	Jet fires	Explosion
Container with compressor unit	1	2.3E-03	5.1E-05	2.6E-05
High pressure storage tanks	2	1.1E-03	2.5E-05	1.3E-05
Tube trailer	2	2.2E-03	5.2E-05	2.6E-05
Dispenser	1	7.1E-04	3.8E-05	1.9E-05
Total	6	2.3E-03	5.1E-05	2.6E-05

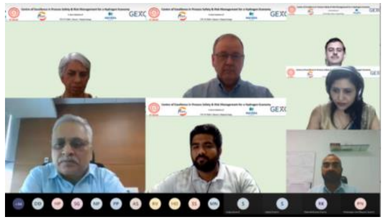


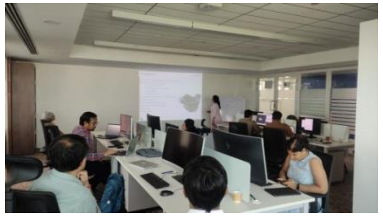
Explosion overpressure contours (up to 300 mbar) for frequency exceeding 10-6 yr-1.

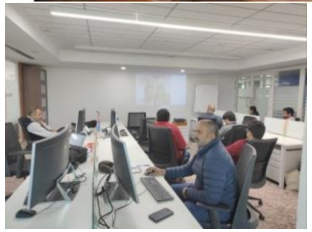
https://www.chegg.com/homework-help/questions-and-answers/event-tree-fictitious-safety-system-natural-gas-reactor-designed-prevent-damage-hydrogen-r-q73329556

Training programs 2022

- Half Day Training program on “Process Safety Management and Risk Management” & “Hydrogen Safety” held c[illegible]
- Online Training Program on PSM for Senior Management For Nayara Energy held on 1st and 2nd April 2022.
- One Day Training Program on “Process Safety Management and Risk Management” held on 4th April 2022.
- One Day Training Program on “Process Safety Management and Risk Management” on 6th April 2022 in NIA, Pune
- FLACS - I (Flame Acceleration Simulator) 6-Days Introductory Certificate Course 28th November- 3rd December 2022.
- A two-day program on ‘Hydrogen blending and its transportation in NG pipelines’, 13th–14th December 2022.







More than 300 participants from organizations like DRDO, IOCL, IITD, HEMRL, NCL, ARDE, ACEM, Nayara Energy, GAIL, EIL

Training programs 2023

- FLACS - I (Flame Acceleration Simulator) 6-Days Introductory Certificate Course, 20th – 25th February 2023
- Training program for GAIL ‘Role of Hydrogen in Emerging Economy’ , 22-23rd March 2023

More than 60 participants from organizations like Nayara Energy, GAIL, EIL

Upcoming Training programs

- Continuing program on Process Safety for PTA / speciality chemicals, GAIL
- Training Program for IOCL on ‘Hydrogen safety’
- VR based Training Program for Emergency responders, under planning for NFC Nagpur
- Certificate programs with IISC , BEST cluster
- Training program for Railways, under discussion

Creating Eco-System for Hydrogen Safety in India and world

Role of different stakeholders

Building a strong pool of experts and knowledge engineers

Government and regulatory Bodies

MNRE, MOPNG, PESO, OISD

Articulate the gaps and framing **protocols and policies to meet international standards**.

- Advocating for **harmonisation of international standards** to reduce technical barriers to trade.
- Help Regulatory authorities to **upgrade Indian Standards with international standards**

International collaboration

Norway, France, UK, Germany and others

Enabling **sharing of knowledge, collaborations and investment** to support and develop hydrogen safety tools, research and test trial projects, Regulation & safety standards

Industries/ R&D Centers/ Knowledge Consultants

NEERI, NCL, IOCL, RIL, SRI, ONGC

- Develop new **innovative solutions**
- **Human Capacity Building**
- Educating and deploy personnel for the safe handling and transportation of hydrogen.
- Enabling investment to support **development of hydrogen safety tools, research and testing trial projects**.

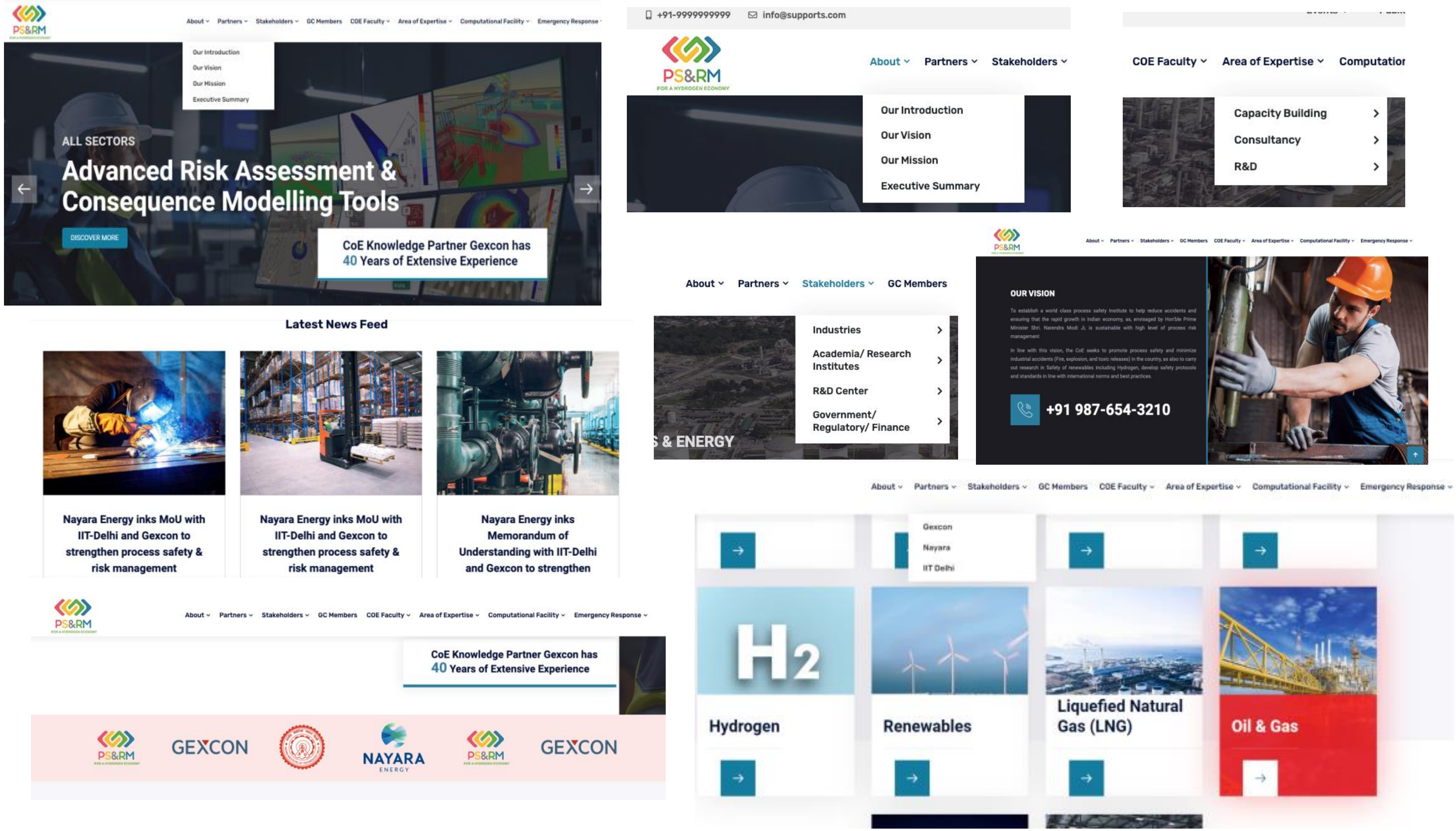
Academic Institutions

Bergen & Norwegian Universities, INERIS, Brunel Univ, Sheffield, MKOPSC

- Develop **higher education and research**-Leading to master and doctoral programs.
- **Skilling personnel** for deployment in the hydrogen sector.
- Develop **expertise in forensic audits of accidents**

CoE website

https://www.coepsrmh2-iitd.in/



“True progress in managing risk which can be made only if the people affected by the problem are part of the solution.”

Thank You