HYDROGEN SAFETY

HIL

Tvisi

Ensuring Safety in Hydrogen-Powered Transportation

By Swapnil Sawant, CEO, Tvisi Motors Limited

#H2leaders

Company Purpose

Tvisi Motors is at the forefront of hydrogen innovation, creating cutting-edge solutions for zero-emission transportation.

Focus areas:

- Software-defined hydrogen vehicles.
- Aftermarket plug-and-play hydrogen range extender kits (H2 REX).

Our Mission:

Accelerate the adoption of hydrogen technology for a cleaner, more sustainable future.

Why Hydrogen?

- Excellent energy carrier
- Nonpolluting
- Economically competitive
- As safe as gasoline
- Used safely for over 50 years
- Produced from a variety of sources

The Need for Hydrogen in Commercial Fleets

Limited Range

Performance Decline

Mass Density

Lengthy Charging Times

Our Product: Aftermarket Plug-and-Play H2 REX Kit for BEVs

H2 REX Kit

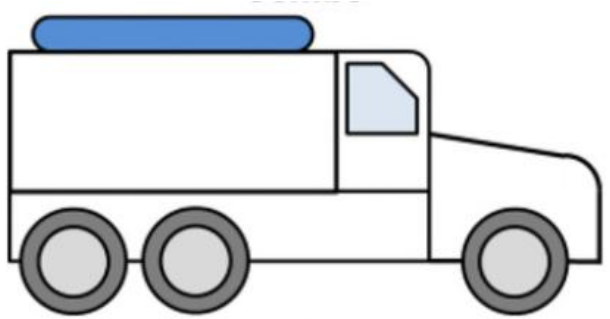
Extended Driving Range

Enhanced Payload Capacity

Reduced Downtime with Fast Refueling

Scalability and Global Market Potential

Placement of Cylinders for Safety concerns



1. **Enhanced Crash Safety**
- Keeps hydrogen cylinders away from common crash zones (front, rear, and sides).
- Reduces risk of impact damage compared to underfloor or rear placements.

2. **Improved Hydrogen Leak Safety**
- Hydrogen is lighter than air, ensuring any leaks disperse quickly into the atmosphere.
- Minimizes the risk of gas accumulation in enclosed spaces like the vehicle cabin or cargo area.

3. **Fire & Thermal Safety**
- Elevated positioning keeps cylinders away from heat sources like the powertrain and battery system.
- Reduces exposure to potential thermal events from the vehicle's drivetrain.

4. **Compliance with Safety Regulations**
- Aligns with global hydrogen vehicle safety standards (ECE R134, ISO 11119).
- Tested for structural integrity, vibration resistance, and crash protection.

5. **Ventilation & Dispersion Efficiency**
- Natural airflow on the rooftop ensures rapid hydrogen dispersion in case of a leak.
- Reduces the need for complex ventilation systems inside the vehicle.

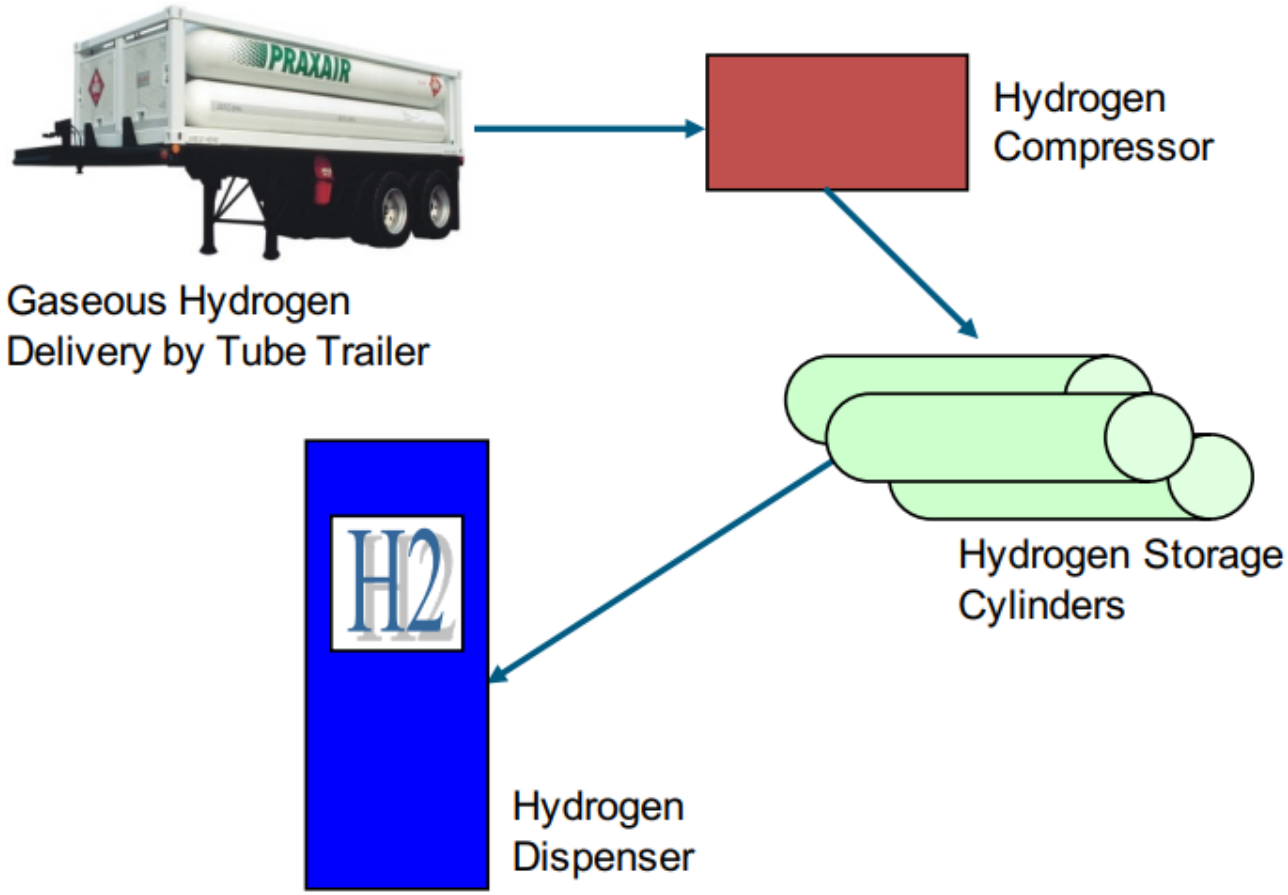
Typical Station Configurations

- Hydrogen can be delivered or made on site
- Liquid delivered → gaseous H_2
- Gaseous delivered or piped → booster compressed gaseous H_2
- Natural gas → gaseous H_2
- Water + electricity → gaseous H_2

Hydrogen Fueling Stations: Gaseous Hydrogen Storage

Gaseous hydrogen is:

- Delivered to fueling station by tube trailer
- Compressed and stored onsite in cylinders
- Piped to dispenser for fueling vehicles



Graphic: Pacific Northwest National Laboratory

The Fundamental Safety Considerations

Ventilation

-Proper ventilation can reduce the likelihood of a flammable mixture of hydrogen forming in an enclosure following a release or leak.

- At a minimum, ventilation rates should be sufficient to dilute a potential hydrogen leak to 25% of the lower flammability limit (LFL) for all operations and credible accident scenarios. -

Passive ventilation features such as roof or eave vents can prevent the buildup of hydrogen in the event of a leak or discharge, but passive ventilation works best for outdoor installations.

- In designing passive ventilation, ceiling and roof configurations should be thoroughly evaluated to ensure that a hydrogen leak will be able to dissipate safely. Inlet openings should be located at floor level in exterior walls, and outlet openings should be located at the highest point of the room in exterior walls or the roof.

Is there a problem here?

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.1, NFPA 2-6.17

Active Ventilation

-If passive ventilation is insufficient, active (mechanical, forced) ventilation can be used to prevent the accumulation of flammable mixtures.

- Equipment used in active ventilation systems (e.g., fan motors, actuators for vents and valves) should have the applicable electrical classification and be approved for hydrogen use.
- If active ventilation systems are relied upon to mitigate gas accumulation hazards, procedures and operational practices should ensure that the system is operational at all times when hydrogen is present or could be accidentally released.
- Hydrogen equipment and systems should be shut down if there is an outage or loss of the ventilation system if LFL quantities of hydrogen could accumulate due to the loss of ventilation. If the hazard is substantial, an automatic shutdown feature may be appropriate. -

Ventilation (passive or active) should be at a rate not less than1 scf/min/ft2 (0.3048 Nm3/min/m2) of floor area over the area of storage or use.

Be aware that no practical indoor ventilation features can quickly disperse hydrogen from a massive release by a pressurized vessel, pipe rupture, or blowdown.

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.2, NFPA 2-6.17

Leak Detection

-Hydrogen leak detection systems may be required by the AHJ or may be installed as a means for enhancing safety of the operation. Leak detection can be achieved by:

- **Providing hydrogen (or flammable gas) detectors in a room or enclosure, or**
- **By monitoring the internal piping pressures and/or flow rates for changes that would suggest a leak is present in the system.**
- **Other methods include providing detectors in close proximity to the exterior piping or locating hydrogen piping within another pipe and monitoring the annulus for leaks.**

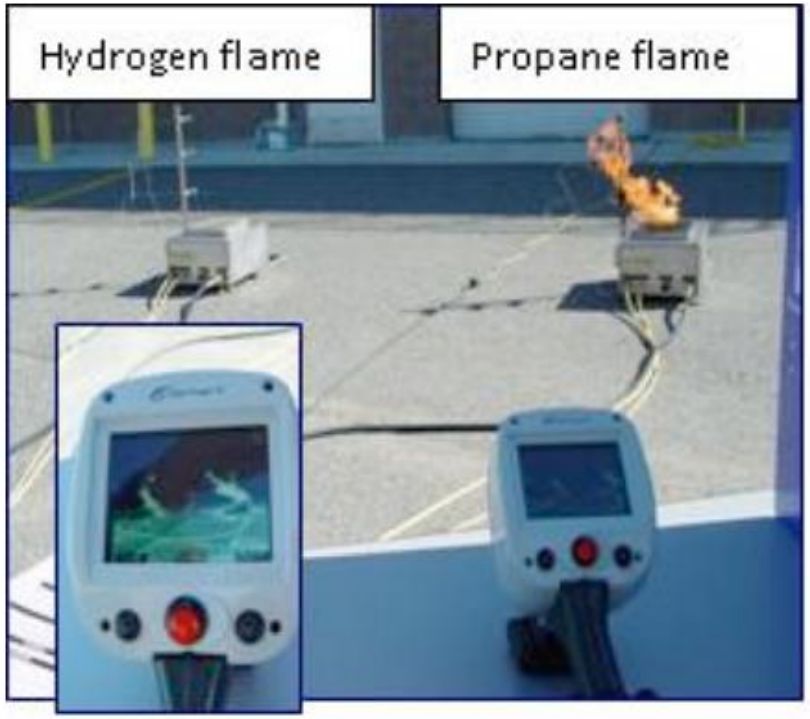
Regardless of the method used, leak detection systems should, at a minimum, incorporate automatic shutoff of the hydrogen source (and startup of a properly-configured active ventilation system, if present) when hydrogen is detected. For systems designed to monitor hydrogen concentrations in rooms or areas, the leak detection system should also warn personnel with visual and audible warnings when the environment is becoming unsafe. Remote notification should also be considered.

Code and Standards: IFC 5003.2.2, NFPA 2-7.1.22

Checking for Leaks

-Hydrogen burns with a pale blue flame that is nearly invisible in daylight. Hydrogen flames also emit low radiant heat, so a person may not feel heat until they are very close to the flame. Best practices include the following:

- **A portable flame detector (e.g., thermal imaging camera) should be used if possible.**
- **Otherwise, listen for venting hydrogen and watch for thermal waves that signal the presence of a flame.**
- **Use a combustible probe (e.g., broom)**
- **Always allow enough time for troubleshooting/debugging a monitoring system before it's used.**
- **Where multiple gases are co-located, always respond in a manner to investigate/ mitigate the most hazardous gas.**



Hydrogen and Propane Flames in Daylight
(Photo courtesy of HAMMER)

Flame Detection

Hydrogen flames are almost invisible to humans, so thermal and optical sensors are used to detect burning hydrogen.

- To cover a large area or volume, many thermal detectors are needed and should be located at or near the site of a potential fire.
- Optical sensors for detecting hydrogen flames can operate in the ultraviolet or infrared spectral region.

Flame detectors should be installed in certain applications (e.g., NFPA 2 requires them near hydrogen dispensers in hydrogen fueling stations). Detectors should provide a rapid and reliable indication of the existence of a hydrogen flame. The system should also:

- Provide for automatic shut-off and isolation of hydrogen sources
- Shut down the system to a safe mode
- Control active ventilation
- Activate audible and visual alarms
- Control access to areas with high concentrations of hydrogen or active fires

Photo courtesy of HAMMER

Code and Standards: IFC 5003.2.2, NFPA 2-7.1.22

Future of Hydrogen Safety & Innovation

Hydrogen safety is evolving with advancements in technology, data analytics, and AI-driven monitoring systems.

At Tvisi Motors, we envision a future where safety is not just reactive but predictive and proactive.

AI-Driven Hydrogen Safety Monitoring

- Real-time Hydrogen Leak Detection
- Automated Emergency Response
- Predictive Maintenance

Autonomous Diagnostics & Predictive Failure Analysis

- Software-Defined Safety Mechanisms
- Thermal Management Enhancements
- Smart Hydrogen Dispensing & Storage

Final message

Hydrogen safety is not just about compliance—it's about innovation. By integrating AI, predictive diagnostics, and digital simulations, we can ensure that hydrogen mobility is as safe, if not safer, than conventional energy sources.

Tvisi Motors is committed to leading this transformation.

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