

Hydrogen Infrastructure Safety

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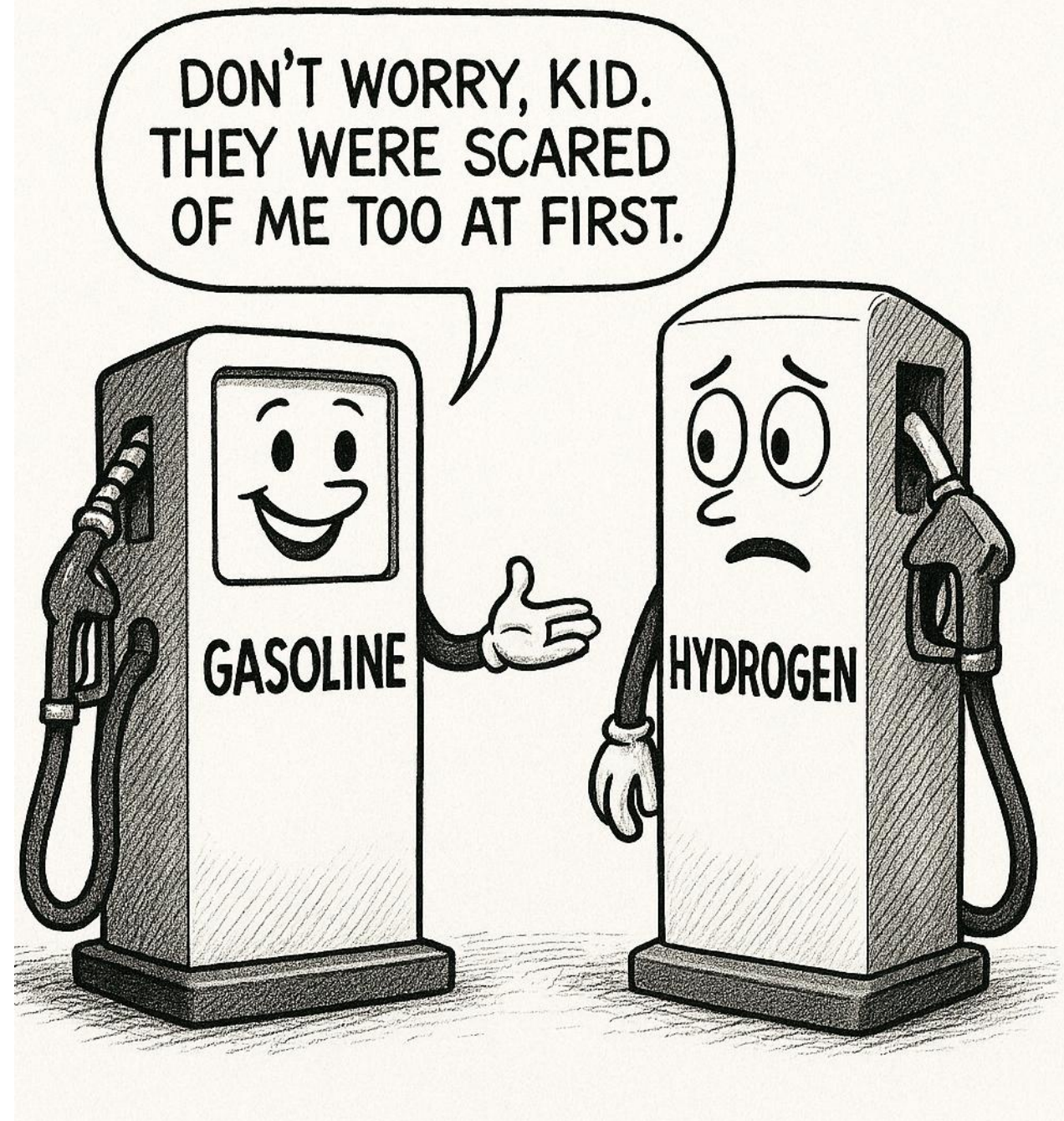


Dawn of the Hydrogen Age

“We have assimilated the dangers of gasoline into our day-to-day lives because the benefits outweigh the risks. And we will do the same with hydrogen.”

— *Peter Lehman, as quoted in Wired Magazine*

Oct 1, 1997



Outline

Why Hydrogen Matters

Safety Fundamentals

Risks in Hydrogen Lifecycle

Mitigation Strategies

Research Gaps

Recommendations

Why Hydrogen Matters?

Technological and Economic Potential

As the hydrogen economy grows, it can create new jobs, industries, and innovations.

Energy Security

Hydrogen can reduce dependence on fossil fuels and can be produced locally from renewable sources.

Decarbonizing Sectors

Hydrogen plays a key role in decarbonizing industries which are difficult to electrify directly.



Clean Energy Source

Hydrogen, when used as a fuel, produces only water vapor as a byproduct, making it a clean and sustainable energy source.

Versatile Energy Carrier

Hydrogen can be used in various sectors, from transportation to industrial applications.

Storage and Transportation

Hydrogen can be stored for extended periods and transported to areas with limited renewable energy generation.

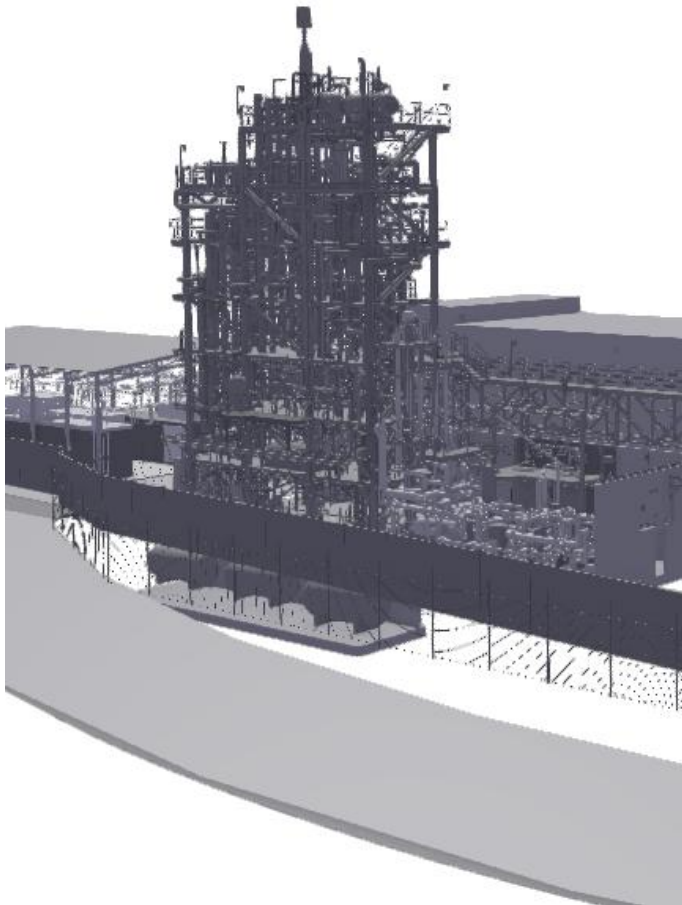
Safety Fundamentals

Property	Hydrogen	Gasoline vapor	Methane
Density (kg/m ³)	0.089	3.5	0.66
Flammability Range (%)	4 – 75 (High Risk)	1.4 – 7.6 (Low Risk)	5 – 15 (Moderate Risk)
Minimum Ignition Energy (mJ)	0.02 (Easily Ignitable)	0.29 (Safer)	0.28 (Safer)
Flame Visibility (Scale 1–5)	1 (Invisible Flame)	5 (Highly Visible)	3 (Moderately Visible)
Laminar flame speed (m/s)	2.5–3 (High)	0.4–0.5 (Slow)	0.35–0.45 (Slow)
Gas Dispersion Rate in Air (cm ² /s)	0.61 (Very fast)	0.05–0.07 (Slow)	0.16 (Moderate)

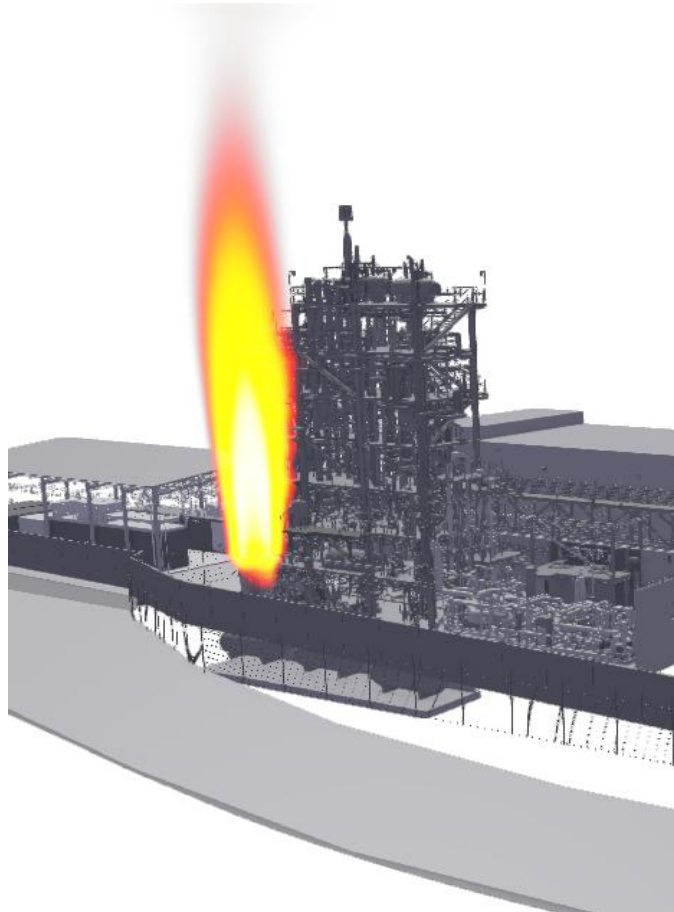
*The flame visibility scale (1–5) used in the table ranks the fuels based on how easily their flames can be seen under normal lighting conditions, with 1 indicating nearly invisible flames and 5 indicating highly visible flames.

Scenarios

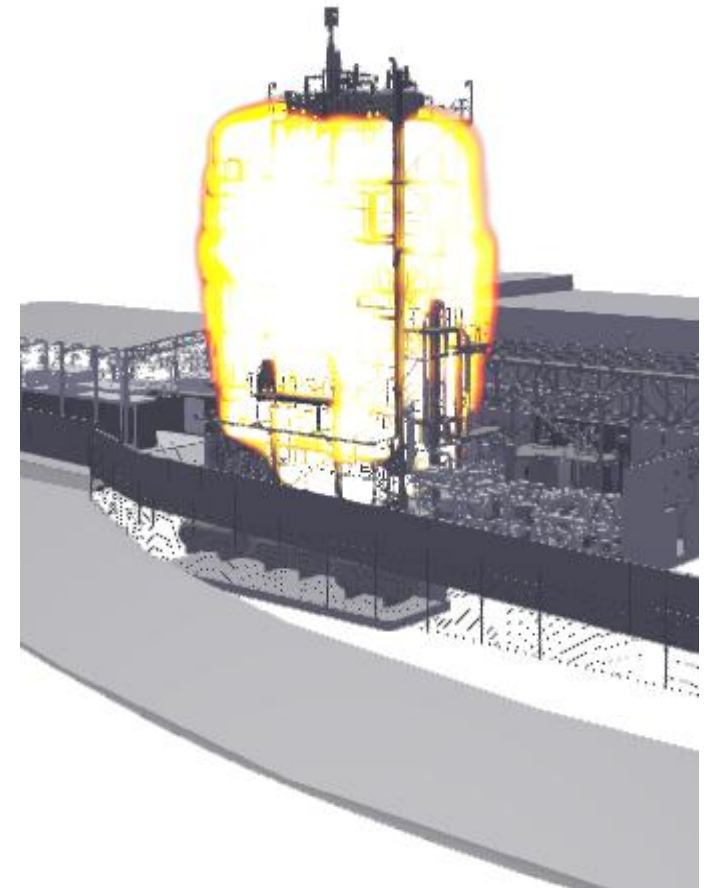
No ignition



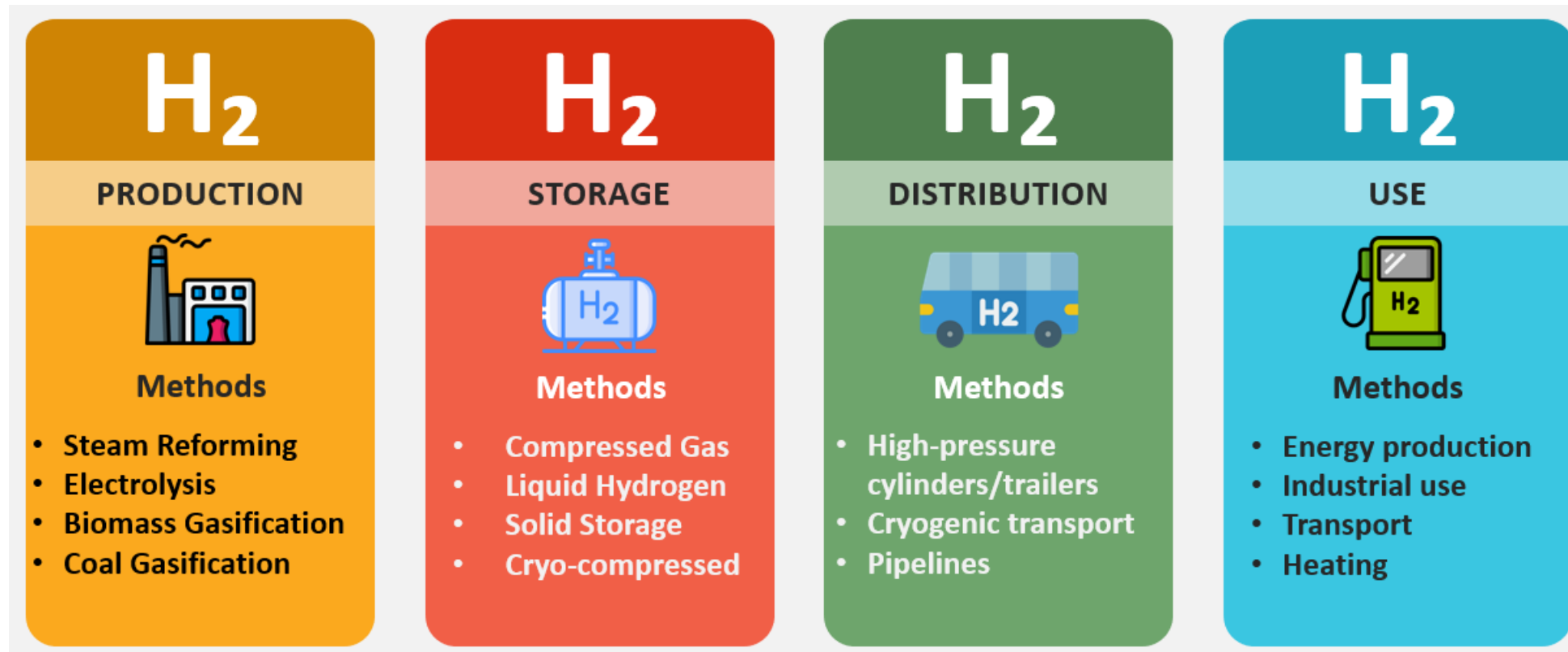
**Direct ignition
Jet flame**



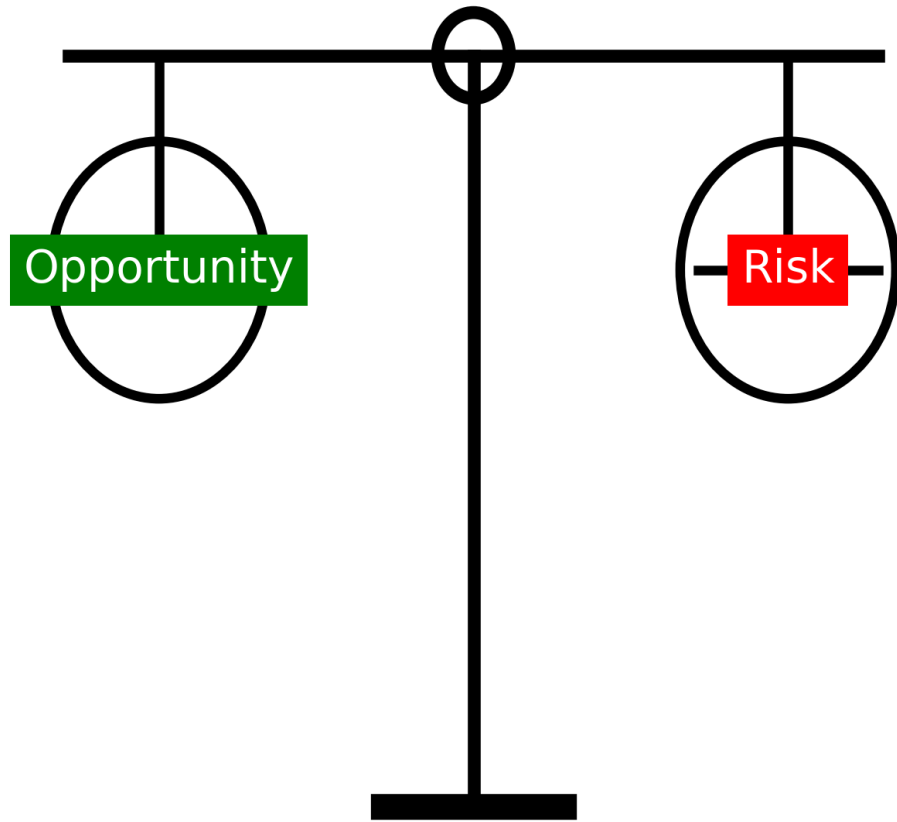
**Delayed ignition
Explosion**



Hydrogen Value Chain



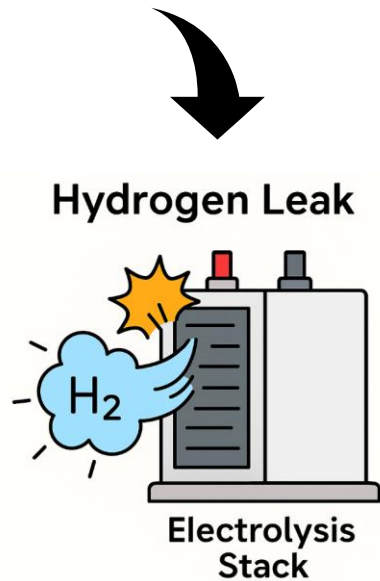
Why Safety Matters



- Properties are different from other gases.
- Large volumes = large exposure risk
- Critical to ask: *what can go wrong?*

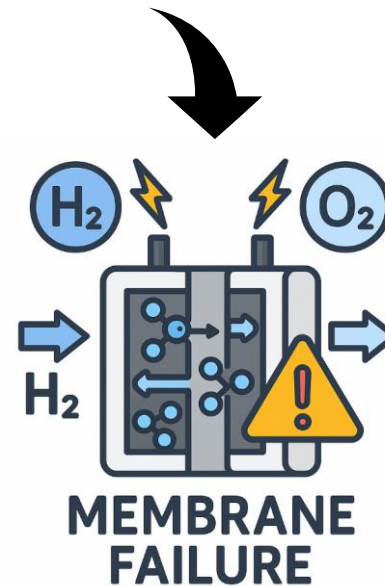
Hydrogen Production Risks

Corrosion, embrittlement,
improper sealing, and
equipment failure



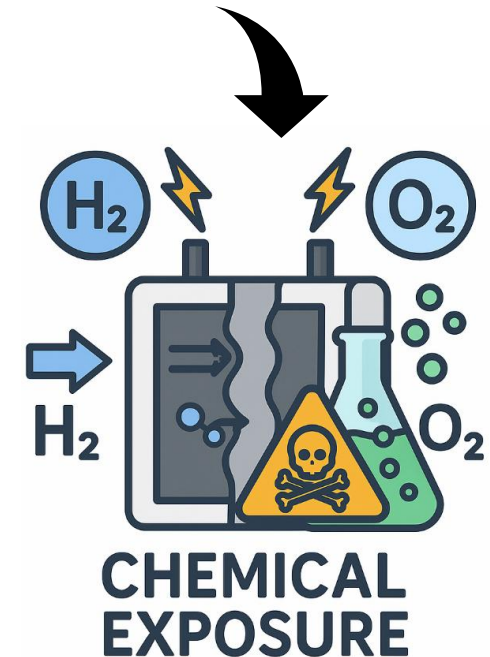
**Explosion, fire, property
damage**

Material fatigue, improper
maintenance, electrolyte
corrosion



**Hazardous gas release, fire,
explosion**

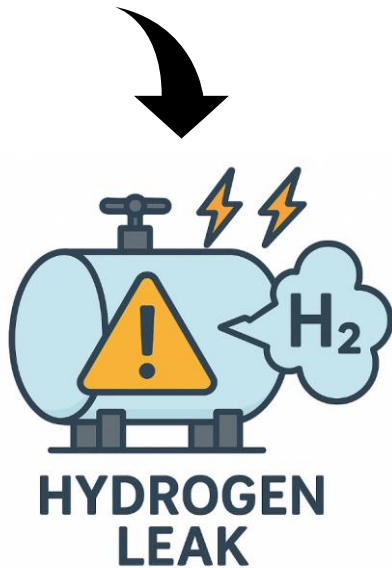
Contact with electrolytes,
improper handling of
materials



**Chemical burns,
environmental contamination**

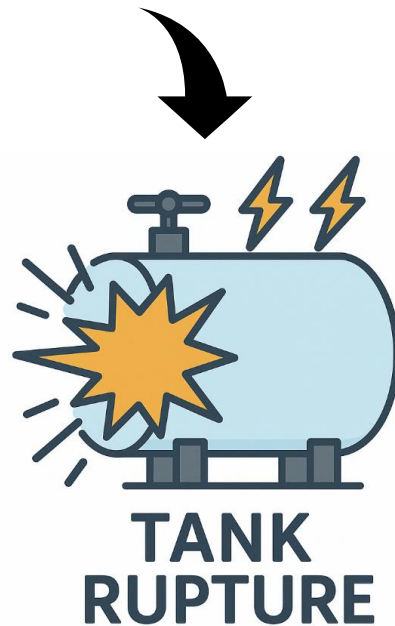
Hydrogen Storage Risks

**Material fatigue, corrosion,
improper sealing,
embrittlement**



**Explosion, fire, property
damage**

**Over-pressurization,
equipment/material failure**



**Explosions, massive hydrogen
release**

**Material brittleness,
temperature fluctuations**



**Structural damage, frostbite
hazards, leaks**

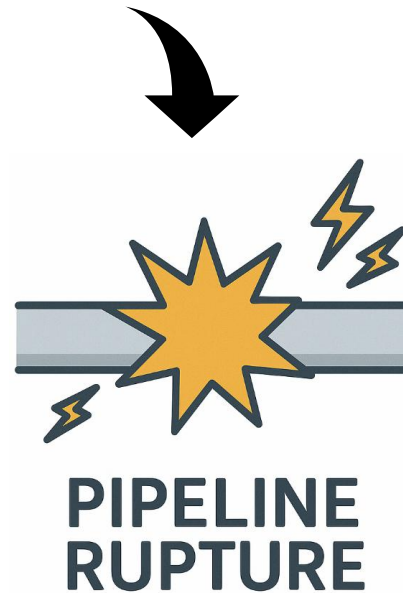
Hydrogen Transport Risks

**Material degradation,
improper sealing, corrosion**



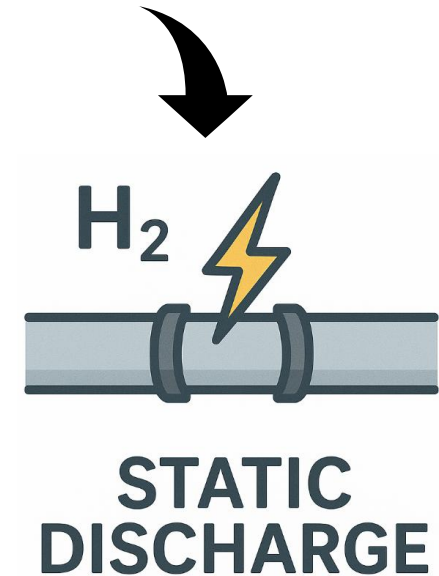
**Fire, explosion, environmental
contamination**

**Hydrogen embrittlement,
corrosion, pressure buildup**



**Explosion, large-scale
hydrogen release**

**Static electricity accumulation
during transport**



**Ignition of hydrogen,
explosion, fire**

Hydrogen Use Risks

Material degradation,
improper sealing, equipment
failure



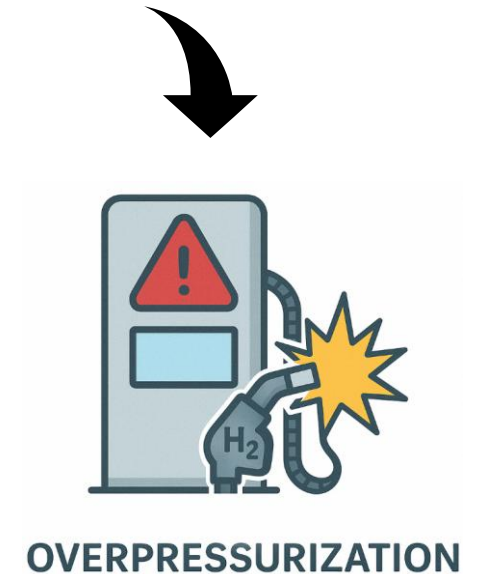
Fire, explosion, asphyxiation,
property damage

Faulty membranes, electrical
faults, improper gas
separation



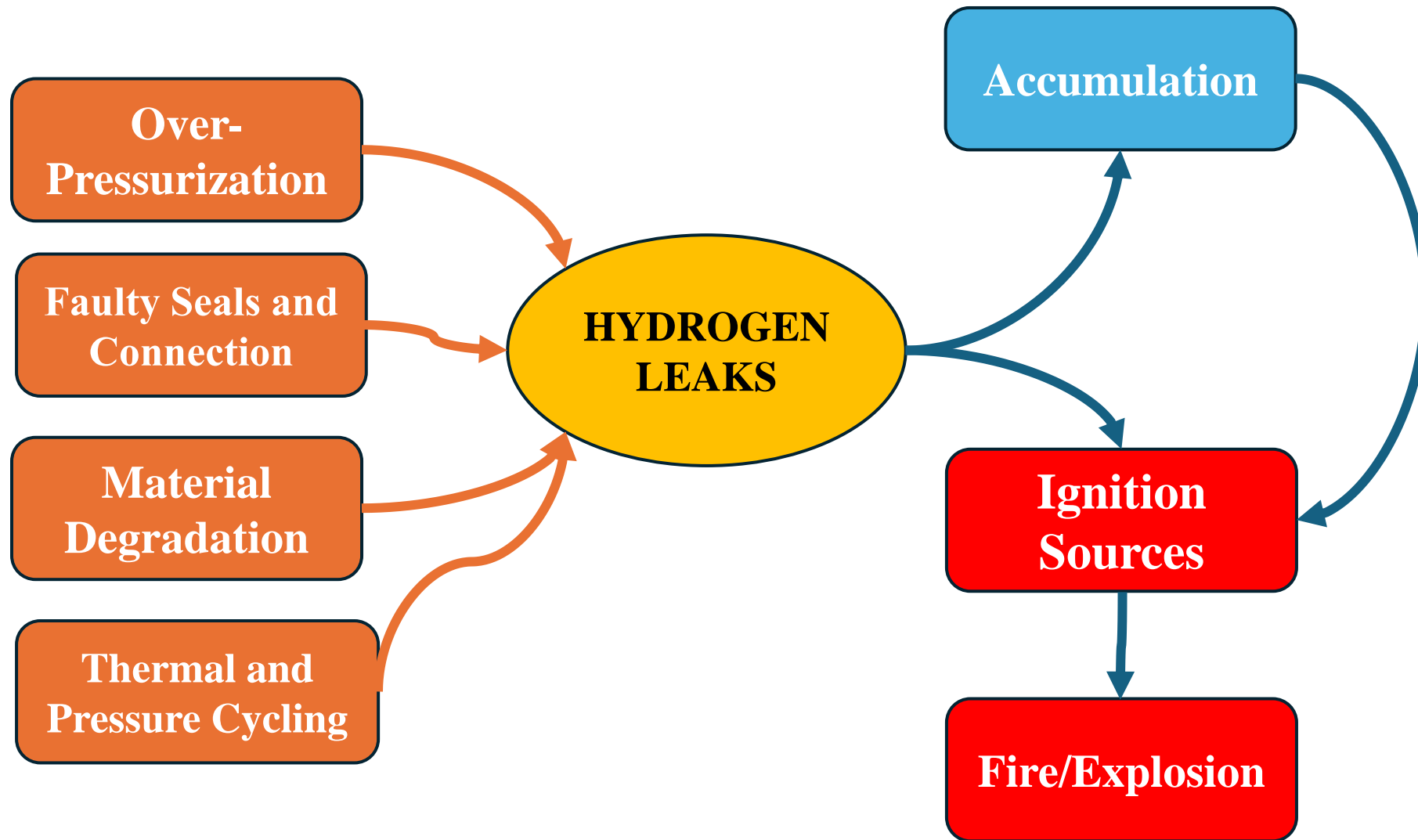
Explosion, fire, equipment
damage, electrical shock

Pressure regulator or valve
failure, faulty containment

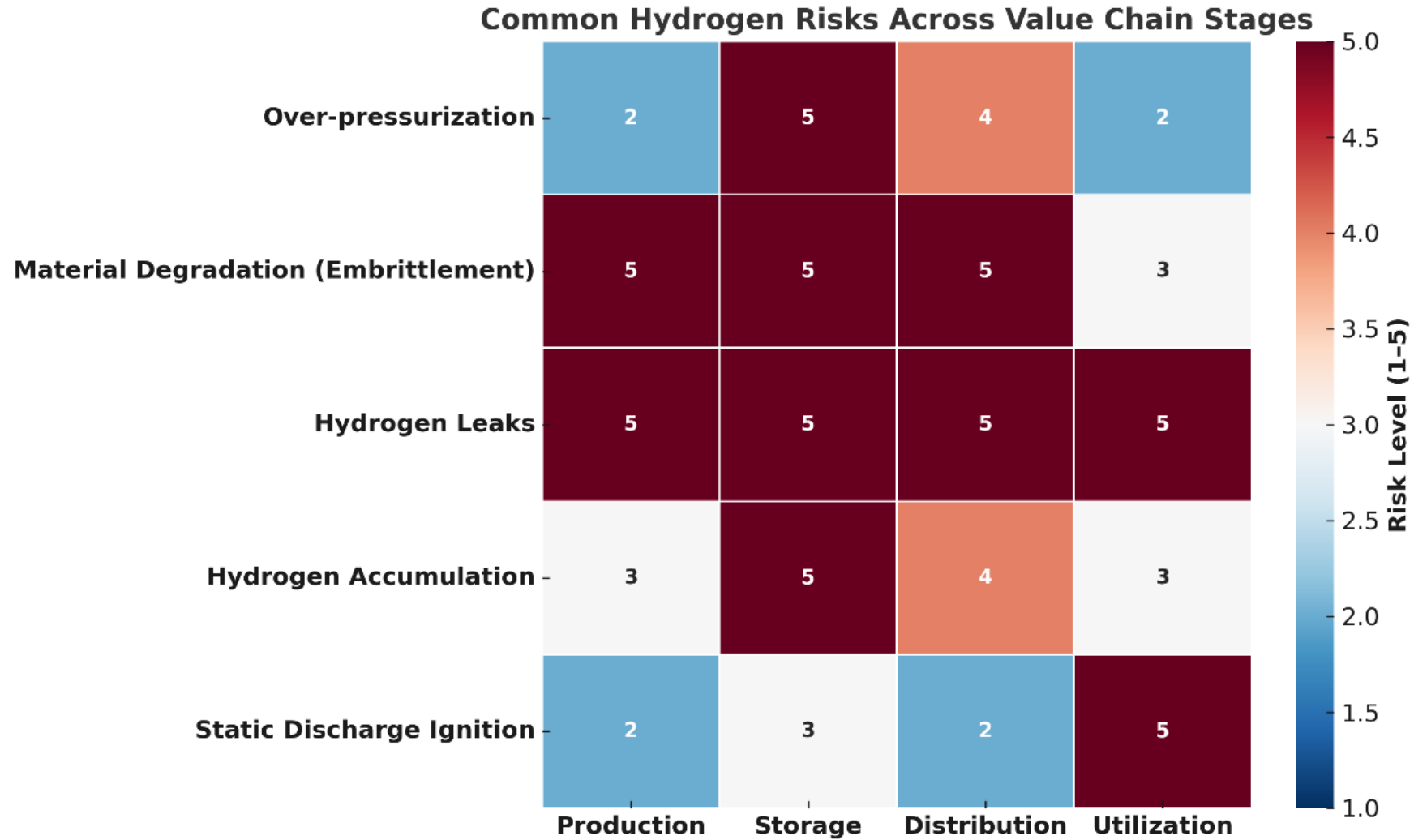


Equipment rupture, explosion,
hydrogen release

Hydrogen Risks



Risks Summary



Mitigation Strategies

✓ **Hydrogen Detection Systems** (Early leak detection and alarms)



✓ **Barrier Systems** (Physical barriers limiting leak propagation and damage such as fire walls, blast walls, safety distances.)



✓ **Emergency Ventilation Systems** (Rapid dispersion of leaked hydrogen, reducing explosion risk)



✓ **Automatic Quick-Release Valves** (Immediate depressurization, preventing rupture or explosions)



✓ **Personnel Training** (Equipping staff with the knowledge and procedures to detect, respond to, and safely manage hydrogen leak scenarios)

Research Gaps

Human Factors & Behavioral Safety

- Limited research on operator training, fatigue, and error
- Emergency response behavior is underexplored

Technology Integration Gaps

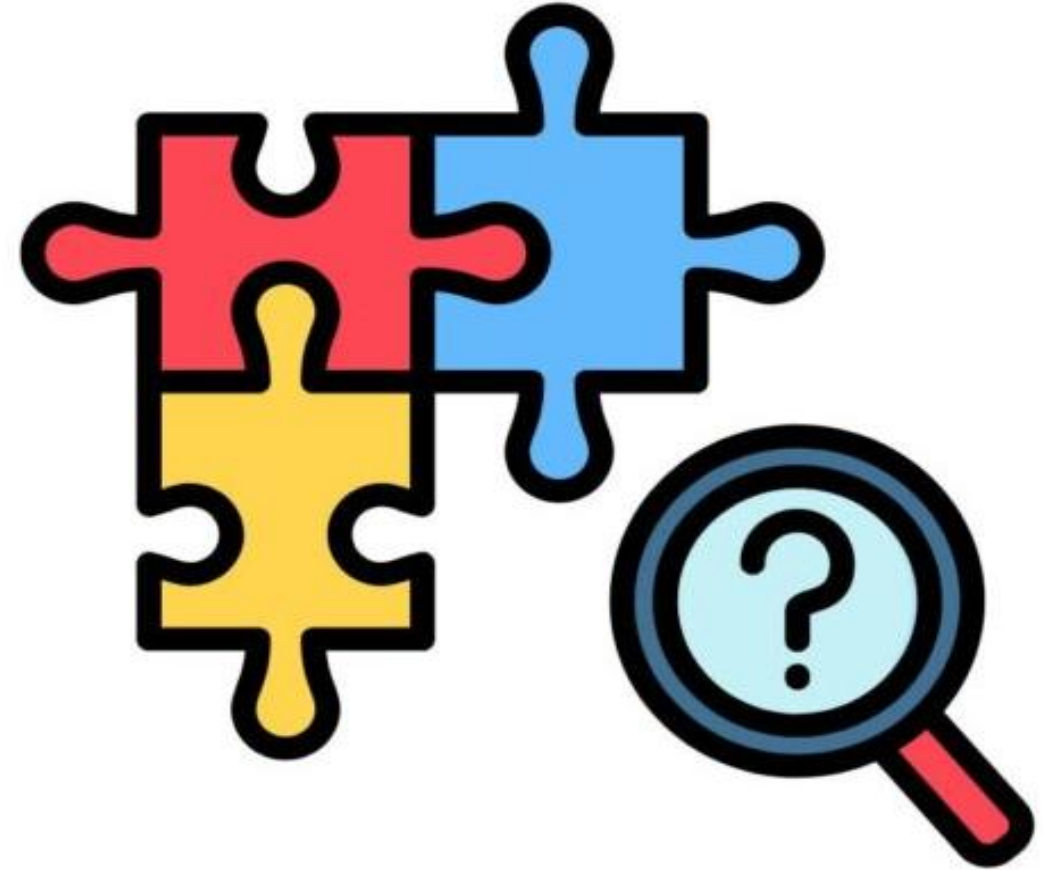
- Underuse of IoT, AI, and Digital Twins for real-time monitoring
- Predictive safety models are still in early stages

Material Durability Uncertainty

- Long-term performance under high pressure & cryogenic conditions
- Risks of embrittlement, corrosion, and degradation persist

Safety Testing & Standards

- Lack of real-world testing data across the lifecycle
- Inconsistent adoption of international safety protocols



Recommendations

Improving Risk Communication

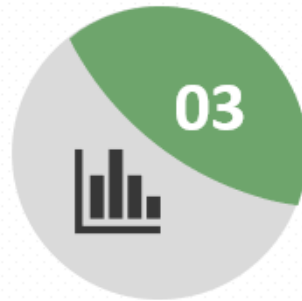
- Standardized Safety Frameworks
- Stakeholder Awareness Campaigns



01

Prioritizing Common Risks

- Hydrogen Leaks
- High-Pressure Failures
- Hydrogen-induced material degradation



03



02

Addressing Research Gaps

- Predictive Risk Modeling
- Combustion Behaviour
- Fire Suppression
- Human Factors

What This Knowledge Can Be Used For

Recognize hydrogen-specific hazards

Identify early warning signs

Integrate hydrogen scenarios into fire and rescue exercises



Contribute to safer adoption of hydrogen in communities and industries

Minimize casualties and property damage through informed decision-making

Conclusions

Hydrogen is clean but not risk-free. Infrastructure must scale with safety.

