H2scan
ADVANCED HYDROGEN SENSING

Hydrogen Sensing Benefits: Safety for Electrolyzers, Pipelines, Batteries, and Other Processes

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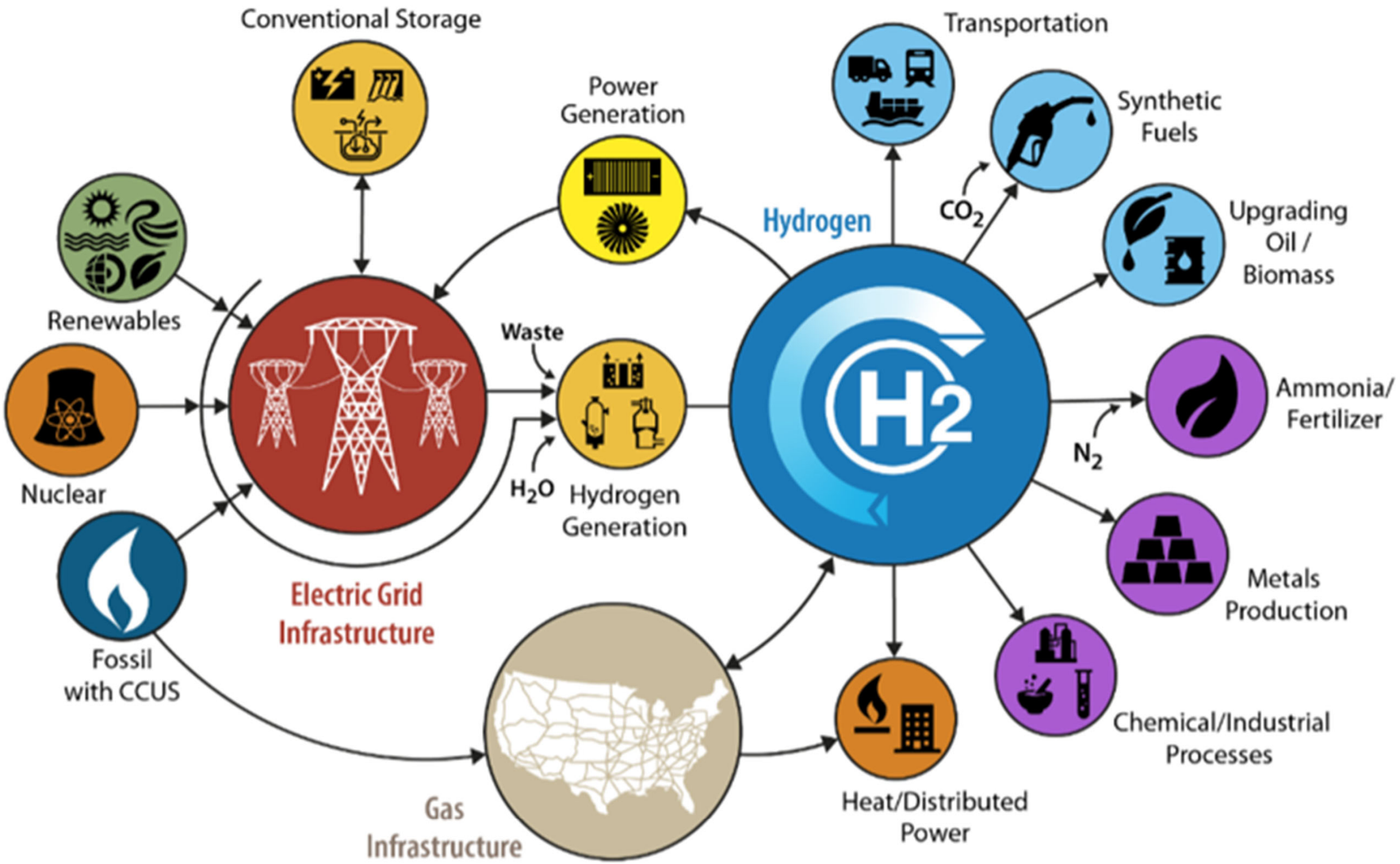
Conceptual H2@scale (hydrogen at scale) energy system



Source: U.S. Department of Energy, *Hydrogen Program Plan*, Figure 3, November 2020
Note: CCUS is carbon capture, utilization, and storage.

Hydrogen Detection in Safety Applications

- Chemical industry:
  - Hydrogen is used in the production of a variety of chemicals, including ammonia, methanol, and fertilizers. Hydrogen gas can leak from equipment and piping, and if it builds up to high concentrations, it can create an explosion hazard.
- Oil and gas industry:
  - Hydrogen is used in oil refineries to remove sulfur from crude oil and to produce gasoline and other fuels. Hydrogen is also used to produce fertilizer from ammonia. As in the chemical industry, hydrogen gas can leak from equipment and piping, creating an explosion hazard.
- Power generation industry:
  - Hydrogen is being used to develop new technologies for power generation, such as fuel cells and gas turbines.
  - Hydrogen fuel cells can generate electricity without producing emissions, and gas turbines can be used to burn hydrogen to generate electricity. Hydrogen can also be used to store energy from renewable sources, such as solar and wind power.

Hydrogen Detection in Safety Applications

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- Transportation industry:
  - Hydrogen is being used to develop fuel cell vehicles, which can emit water vapor but no other pollutants.
  - Hydrogen is also being used to develop hydrogen-powered aircraft and ships. As with other applications, hydrogen gas leaks can create an explosion hazard.

- Electronics industry:
  - Hydrogen is used in the manufacturing of semiconductors and other electronic components. Hydrogen gas leaks can create an explosion hazard and can also damage electronic equipment.
- Standby Power & Energy Storage:
  - Batteries are used in standby power applications such as Uninterruptible Power Systems (UPS), Telecom for cell site and central offices, Utility for Substation, SCADA, Grid Support, and renewable energy applications.
  - Hydrogen cooled Generators

The Challenge of Hydrogen Sensing

- High-temperature environments:
  - Hydrogen molecules can dissociate at high temperatures, which can lead to inaccurate readings.
- High concentrations:
  - High concentrations of hydrogen can also lead to inaccurate readings, as the sensor may become saturated.
- Cross-sensitivity with other gases:
  - Hydrogen sensors can be cross-sensitive to other gases, such as methane and ethane. This means that the sensor may detect these other gases as hydrogen, which can lead to inaccurate readings.
- Requirements from standards and regulations:
  - There are several standards and regulations that specify the requirements for hydrogen measurement. These standards can vary depending on the application, and it can be challenging to ensure that the measurement system meets all the requirements.

Hydrogen Sensor Technology

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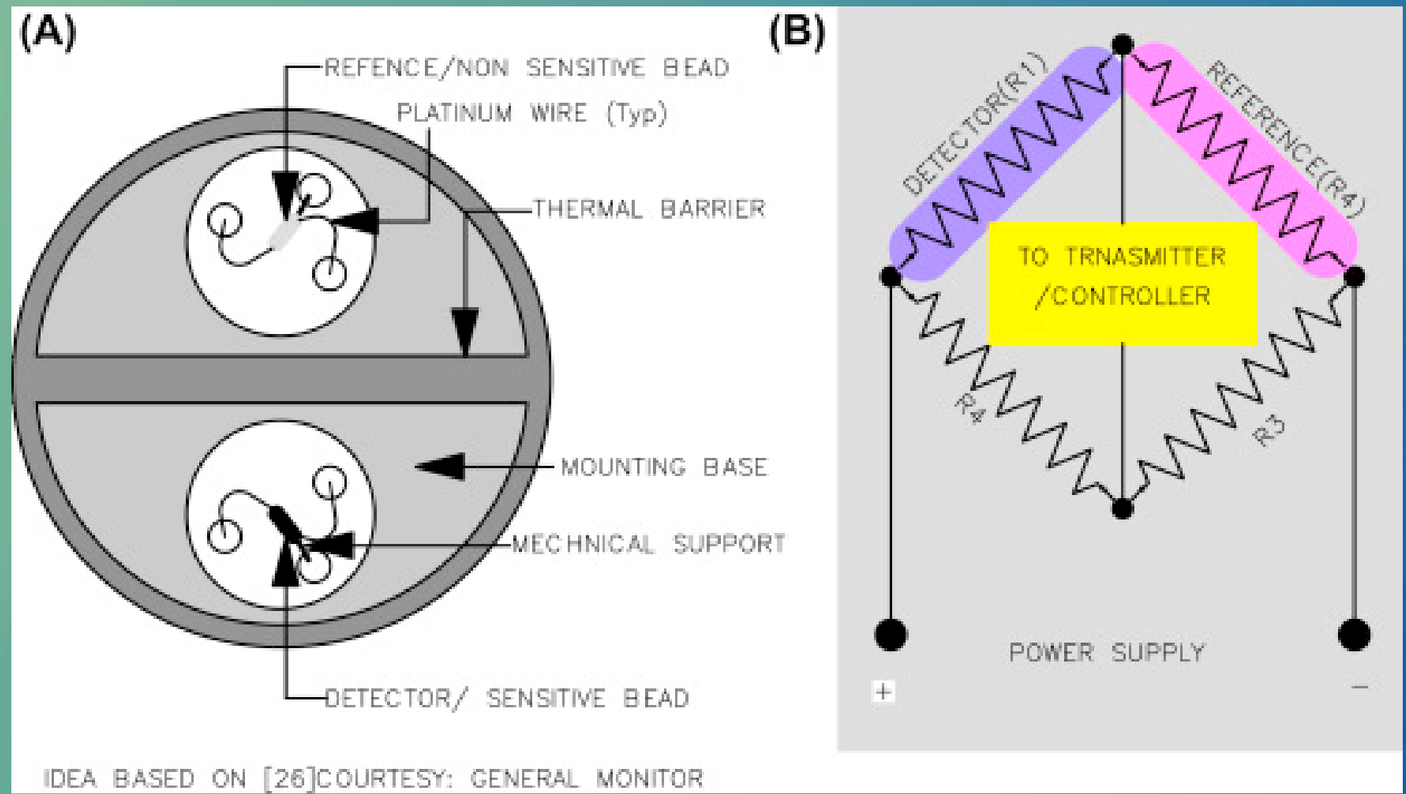
Catalytic bead

- Measures the concentration of hydrogen in a gas mixture by detecting the heat generated when hydrogen reacts with a catalyst.



Hydrogen Sensor Technology

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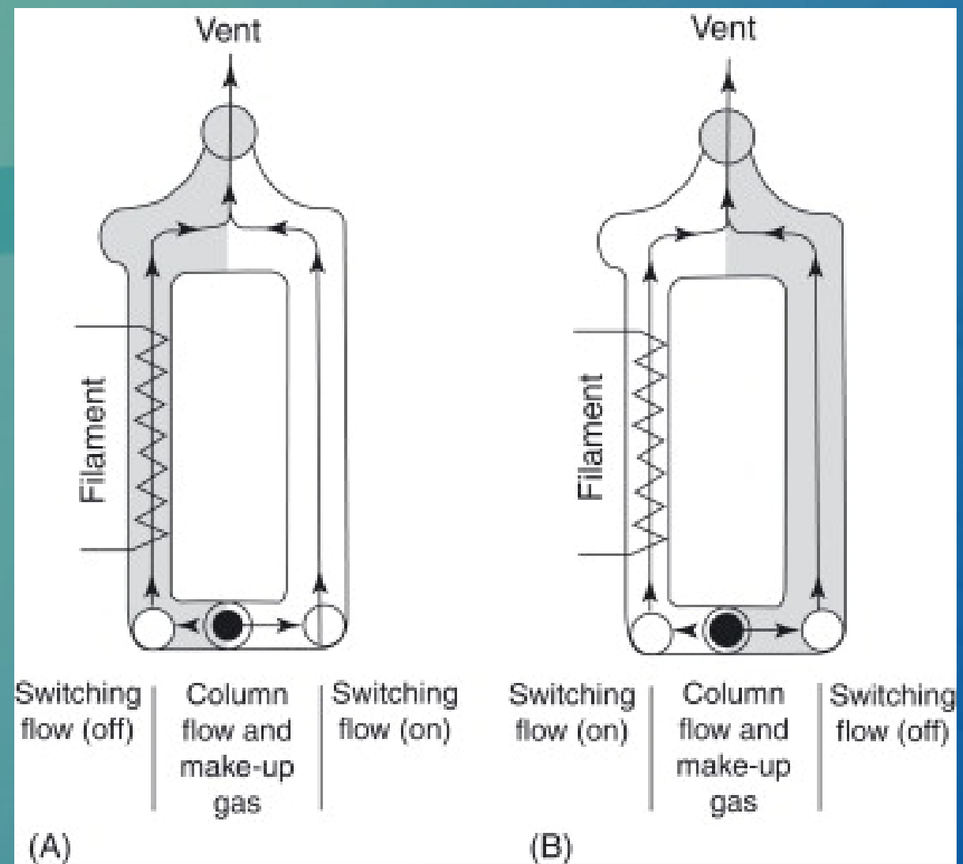
Thermal Conductivity Detector (TCD)

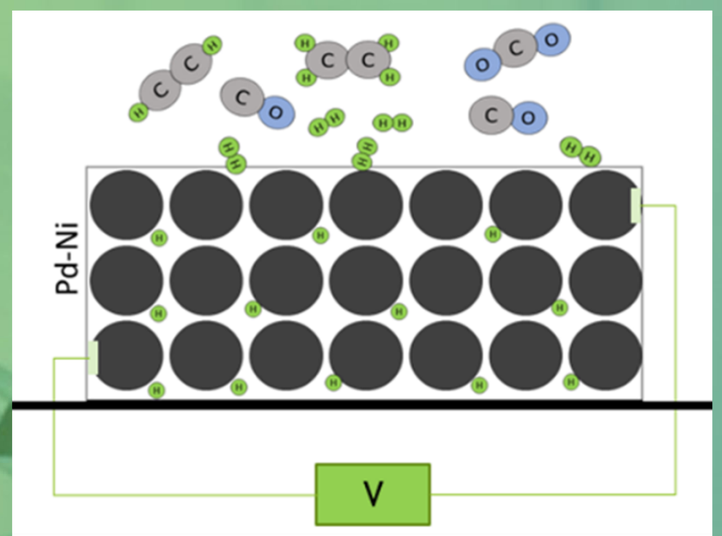
- Measures the concentration of hydrogen in a gas mixture by measuring the thermal conductivity of the mixture.
- Different gasses have different thermal conductivities, and the thermal conductivity of a gas mixture is a weighted average of the thermal conductivities of the individual gasses in the mixture.



Hydrogen Sensor Technology

Solid State Precious Metal

- Uses the catalytic properties of precious metals to detect hydrogen gas.
- Very sensitive to hydrogen and can detect concentrations as low as 1 ppm.
- They are also relatively fast responding and can typically detect hydrogen within a few seconds.
- Relatively durable and have a long lifespan.
- Auto Calibrating



Hydrogen Specific Resistive Sensor Technology

Device resistance changes as a function of H_2 concentration as it permeates the proprietary solid-state substrate

Hydrogen Sensor Maintenance

- Catalytic bead hydrogen sensors:
  - Require regular calibration to ensure accuracy.
  - The frequency of calibration will depend on the operating environment and the required accuracy of the sensor.
  - The catalytic bead should be cleaned or replaced regularly to prevent contamination.
- TCD hydrogen sensors:
  - TCD hydrogen sensors require regular calibration to ensure accuracy.
  - The frequency of calibration will depend on the operating environment and the required accuracy of the sensor.
  - TCD filament should be cleaned or replaced regularly to prevent contamination.
- Solid state precious metal hydrogen sensors:
  - Solid state precious metal hydrogen sensors require less maintenance than TCD and catalytic bead hydrogen sensors.
  - It is important to calibrate them regularly to ensure accuracy.
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Maintenance Requirements

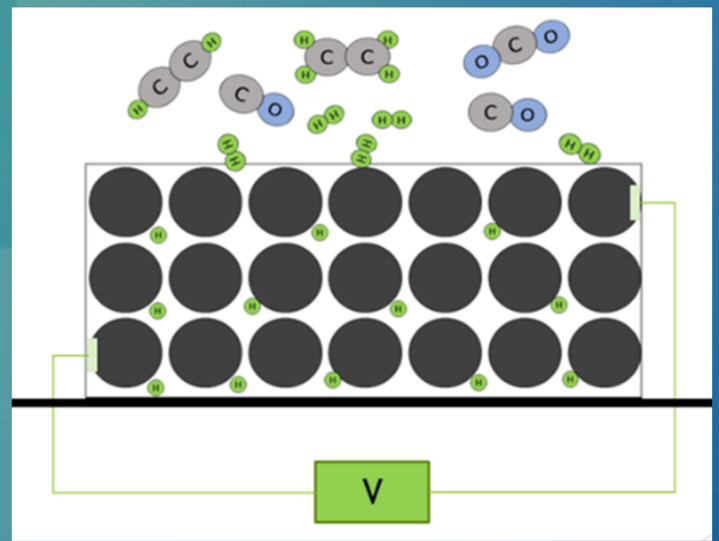
Type of sensor	Maintenance requirements
TCD hydrogen sensor	Regular calibration, cleaning, or replacement of the TCD filament
Catalytic bead hydrogen sensor	Regular calibration, cleaning, or replacement of the catalytic bead
Solid state precious metal hydrogen sensor	Some require calibration / No Calibration / Auto Calibration

H2scan Patented Solid-State Technology Provides Industrialized Hydrogen Sensing

Technology Development

- Solid State Sensor Technology developed by Sandia National Lab and exclusively licensed to H2scan
- Over the last 20 years H2scan commercialized technology and patented new technologies to improve accuracy and eliminate cross gas sensitivities

Hydrogen Specific Resistive Sensor Technology



Device resistance changes as a function of H_2 concentration as it permeates the proprietary solid-state substrate

Outcomes

- Hydrogen specific solid-state sensor that can measure from 5 PPM to 100% H2
- Operates in liquids and gases (oxygen free, multi-component gases streams, and requires no reference or carrier gas)
- Maintains accuracy without periodic calibration
- Industrial temperature range (-40°C to +105°C)
- Life expectancy 10+ years

OSHA & EPA

Federal Regulations:

OSHA

- Hydrogen exposure limits
- Training requirements
- Safety procedures

EPA

- Emission limits for hydrogen production
- Facilities and safety procedures for handling hydrogen in the environment

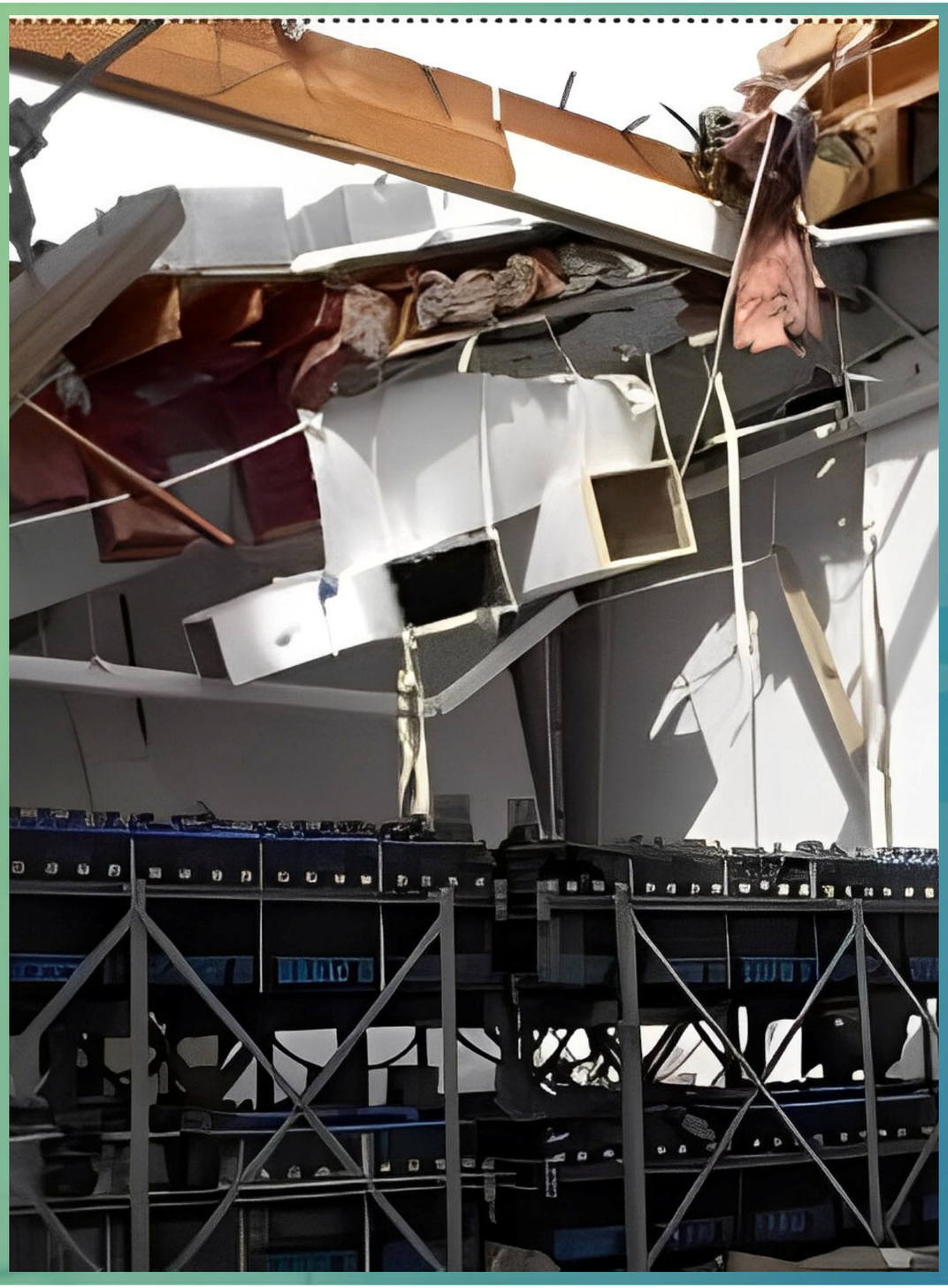
State & Local Fire Code

International Fire Code (IFC)

- IFC Section 2705:
  - Hydrogen fuel cell vehicles: Fuel cell vehicles be parked in designated areas that are properly ventilated and away from ignition sources.
  - Hydrogen fuel cell fueling stations: Fire suppression systems, gas detectors, and emergency shutoff valves.
  - Hydrogen storage: Properly designed and constructed to minimize the risk of leaks and explosions.
- IFC Section 609/Chapter 12:
  - Battery Applications: Rooms and enclosures to be kept below 1% of room volume or 25% of the Lower Explosive Limit (LEL) with a corresponding Hazardous Mitigation Plan (HMP). IEEE 1635/ASHRE-21 is the standard to follow for ventilation requirements.

State & Local Fire Code

- National Fire Protection Association (NFPA)
  - NFPA 2: Hydrogen Technologies Code.
    - The NFPA 2 Hydrogen Technologies Code provides guidance on how to safely design, install, operate, and maintain hydrogen systems.
  - NFPA 855 (Standard for the Installation of Energy Storage Systems):
    - contains language like the IFC where hydrogen needs to be kept below 1% of room volume according to the Hazardous Mitigation Plan (HMP).



International Regulations

In addition to the IFC, there are other international fire codes that contain regulations related to hydrogen safety (to name a few).

Europe:

- **EN 13683:** This standard provides guidance on the safe production, storage, and distribution of hydrogen.
- **EN 1753:** This standard provides guidance on the safe design and operation of hydrogen refueling stations.
- **EN 50632:** This standard provides guidance on the safe installation and operation of hydrogen fuel cell systems.

International Regulations

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Japan:

- **The Fire Service Act:** This act sets out requirements for the prevention and control of fires. Businesses that produce, store, or use hydrogen must comply with these requirements.
- **The Industrial Safety and Health Act:** This act sets out requirements for the safety and health of workers in industrial settings. Businesses that produce, store, or use hydrogen must comply with these requirements.
- **The Japanese Industrial Standards (JIS):** There are a number of JIS standards that relate to hydrogen safety, such as JIS B 8201 (Hydrogen Gas Safety Code) and JIS B 8202 (Hydrogen Refueling Station Safety Code).

Hazardous Mitigation Analysis/Plan

- Monitor hydrogen concentrations.
  - Hydrogen gas monitors should be used to detect hydrogen leaks in industrial and commercial settings.
  - Technologies to detect hydrogen: catalytic sensors, electrochemical sensors, and semiconductor sensors. Ventilate hydrogen-containing areas.
  - Adequate ventilation is essential for preventing the accumulation of hydrogen gas.
- Use proper equipment and procedures.
  - Minimize the risk of leaks.
  - Properly designed and maintained piping and valves, as well as following safe operating procedures.
- Train employees on hydrogen safety.
  - All employees who work with hydrogen should be trained on the safe handling of hydrogen gas.
  - Properties of hydrogen, the hazards of hydrogen, and the safe handling of hydrogen equipment.

Conclusion

- The list of applications is growing based on new technologies either using hydrogen in a process, fuel or creating hydrogen as a by product.
- The application can present challenges based on the environment, concentrations, cross-sensitivities to other gasses and also standards & regulations
- Sites that contain hydrogen may need to create a hazardous mitigation analysis (HMA) and hazardous mitigation plan (HMP). Codes and regulations may change as new revisions are created.
- Sensing and detection technology is evolving. Keep up on new technology that may affect longevity and maintenance requirements and ease of use.