

# The Transition To Hydrogen

## Engineering the Future of Hydrogen Infrastructure

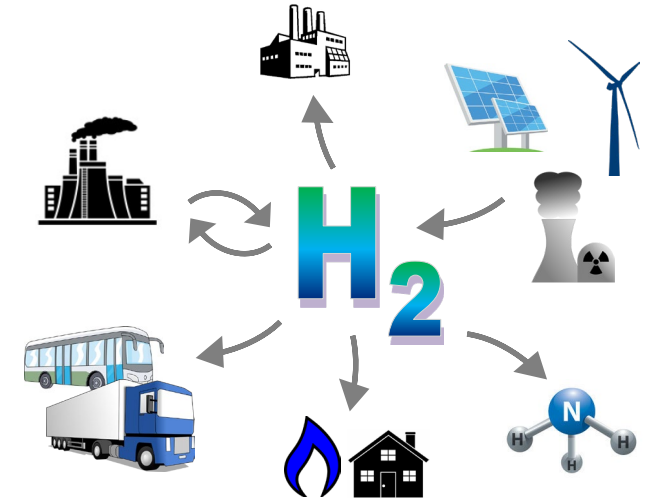
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# Hydrogen Infrastructure

## The Hydrogen Build-Out

- ❖ Start with Safety
  - Leakage
  - Flammability
  - High Pressure
  - Material Embrittlement
  - End User Capabilities and Condition Assessments



# Hydrogen Codes and Regulations

- National Fire Protection Association (NFPA)
  - NFPA 2 – Hydrogen Technologies Code
  - NFPA 70 and 497 – for Hazardous Area Classification
- American Society of Mechanical Engineers (ASME)
  - ASME B31.12 – Hydrogen Piping and Pipelines
- Compressed Gas Association
  - CGA G-5.5 Standard for Hydrogen Vent Systems
- Federal Requirements (Volumes > 10,000 lb)
  - OSHA Process Safety Management Plan (PSM)
  - US EPA Risk Management Plan (RMP) for Offsite Consequence Analysis
  - Chemical Facility Anti-Terrorism Standards (DHS)



# Designing for Safety

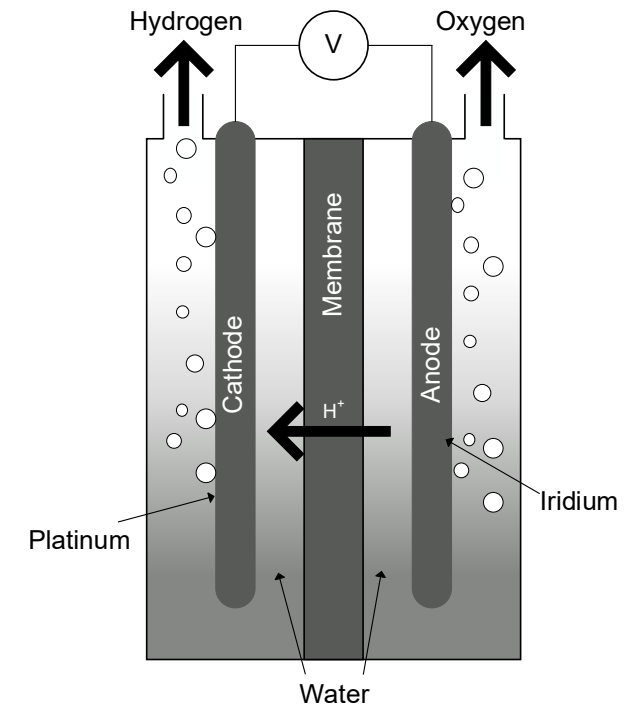
- Ventilation
  - Minimize Hydrogen Concentration in Case of Leakage
  - Venting Hydrogen to Safe Locations
  - Relief Systems
  - Purging
  - Redundancy
- Leak Detection
  - Emergency Shutoff Systems
- Spacing
  - Physical Standoff Distances
  - Volume and Pressure Dependent
- Hazardous Area Classifications
  - Class 1, Division 1 or 2, Group B (for pure hydrogen)

## HAZOP / LOPA

Hazard and Operability Analysis  
Layers of Protection Analysis

# Hydrogen Production

- The New Hydrogen Demand
  - Production methods that minimize CO<sub>2</sub> emissions
    - Electrolysis
    - Carbon capture on traditional methods
    - Methane pyrolysis, thermochemical water splitting, and more
  - Scale-Up of Manufacturing
  - Efficiency Improvements
    - Technology advancements
    - Reduce cost of electricity
  - Purity Requirements



# Hydrogen Facility Siting

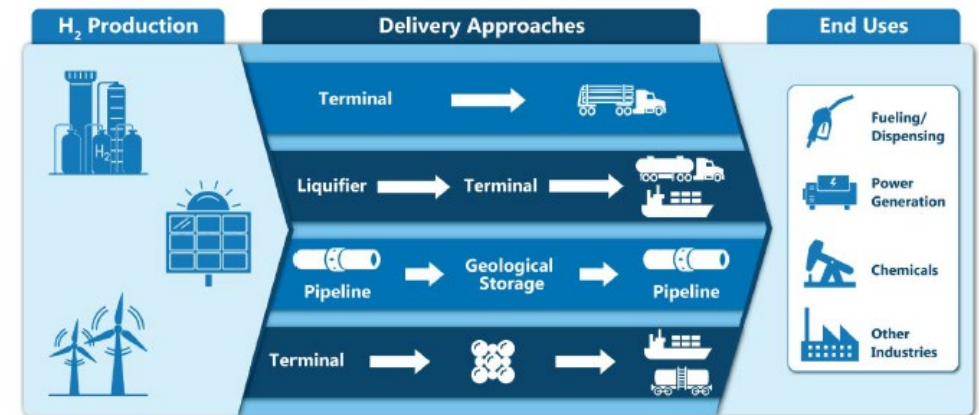
- Site Selection
  - Feedstock Availability
  - Electrical Interconnect
  - Footprint
    - System size
    - Storage
  - Offtake / Use
  - Permitting



Source: Sargent & Lundy

# Hydrogen Transport

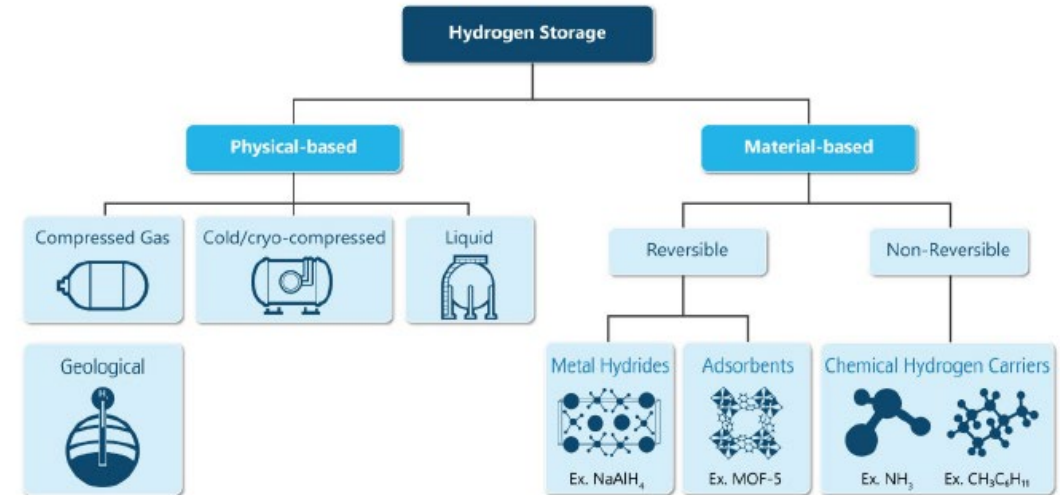
- Trucking
  - High Pressure Gas
  - Liquid
- Hydrogen Pipeline Network
- Alternate Hydrogen Carriers
  - Ammonia, Methanol, Others
- Blending with Natural Gas
  - At point of use
  - Utility scale
  - Energy Content Reduction



Source: DOE

# Hydrogen Storage

- Storage Media Factors
  - Locations of production and use
  - Duration
  - Space
  - Energy for compression or synthesis
  - Offtake and operating basis
- Compressed Gas
  - Vessels (above and below ground)
  - Geologic formations (i.e., salt caverns)
- Cryogenic / Liquid Hydrogen
- Metal Hydrides
- Liquid Ammonia (& other chemical carriers)



Source: DOE



# Aligning the Supply Chain

- Connecting New Producers with New Users
  - Emphasis on safety
  - Adoption across new industries and uses
  - Reductions in cost of hydrogen
  - Development of distribution networks
  - Support decarbonization goals

