Fuel Cells in Telecom and Protection Considerations

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Overview

- Types of Fuel Cells Used in Telecom
  - Backup
    - Generator Replacement / Battery RunTime Extension
    - Primarily PEM Technology
  - Primary
    - Low Cost of Natural Gas vs High Cost of Electricity
    - Primarily Solid Oxide Technology
- Electrical Protection
  - DC and AC Surge Protection Strategies & Pros/Cons
    - DC Surge Arrestors
    - DC-DC Isolation Converters
    - AC Surge Arrestors
  - Communications Cables Surge Protection
  - Lightning Zone of Protection
  - Grounding
    - Metallic Piping
    - Metallic Enclosures
- Physical Protection of Hydrogen Fuel Sources

Why Primary Solid Oxide Fuel Cells?

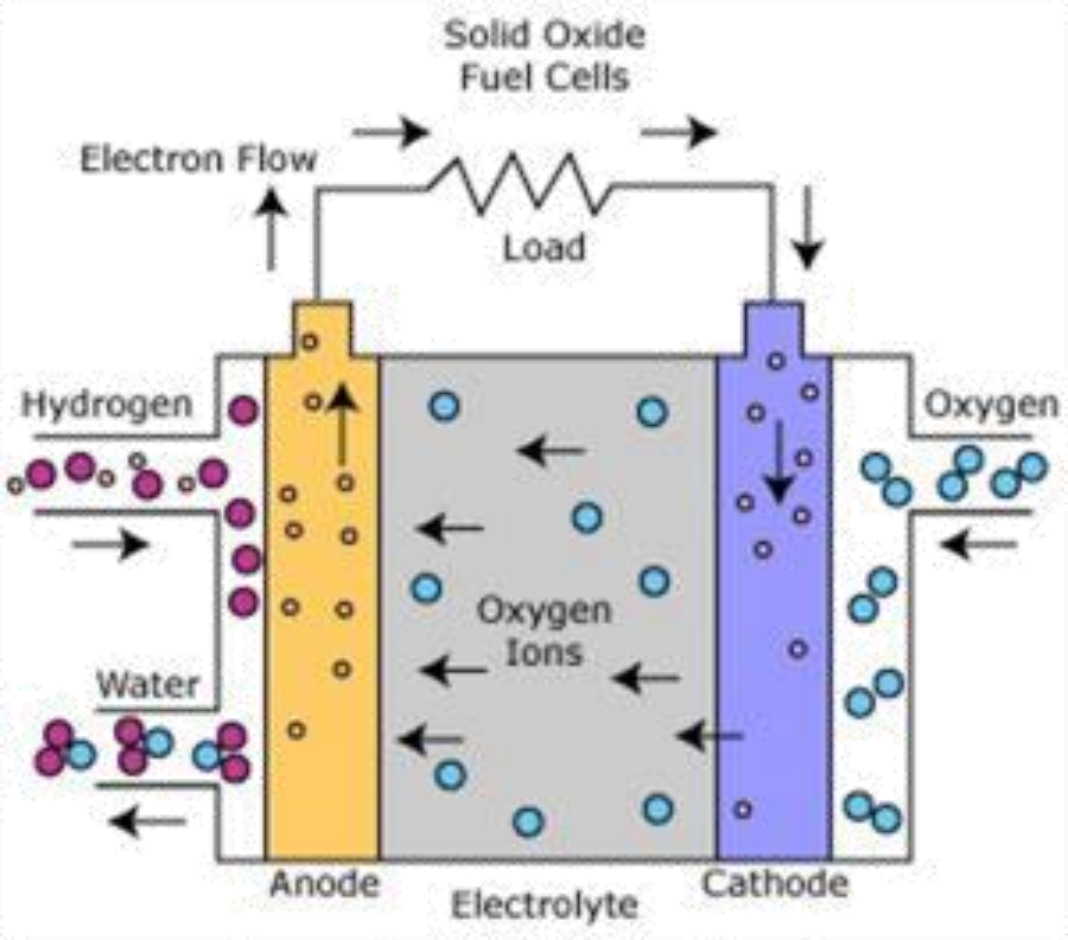
- High $ of Electricity vs Low $ of Natural Gas
  - Time of Use High Electric Rates Possible
  - Mostly NE U.S. and California

High Electricity $ vs Other Options

State	Electric ¢/kWh	Natural Gas ¢/ft³	Diesel $/gal	Diesel Engine ¢/kWh produced	Gas Turbine ¢/kWh produced	Fuel Cell ¢/kWh produced
National Avg	10.45	1.10	2.15	15.80	13.34	10.64
New Jersey	14.01	0.97	2.01	14.81	11.55	9.55
Vermont	14.58	1.47	2.31	16.92	17.46	13.72
California	15.23	1.15	2.46	17.97	13.90	11.05
New Hampshire	15.25	1.63	2.38	17.41	19.24	15.07
Massachusetts	15.34	1.45	2.30	16.88	17.24	13.56
Rhode Island	15.57	1.51	2.29	16.85	17.90	13.06
New York	16.25	1.25	2.47	18.04	15.01	11.89
Connecticut	16.98	1.41	2.39	17.48	16.79	13.23
Alaska	17.58	0.91	2.21	16.24	11.22	9.02
Hawaii	33.53	4.75	4.35	31.13	53.97	41.14

Note that the electric production costs for engine-alternators, turbines, and fuel cells include amortized equipment cost, + maintenance, + fuel costs (the latter is typically more than 90% of the cost shown)

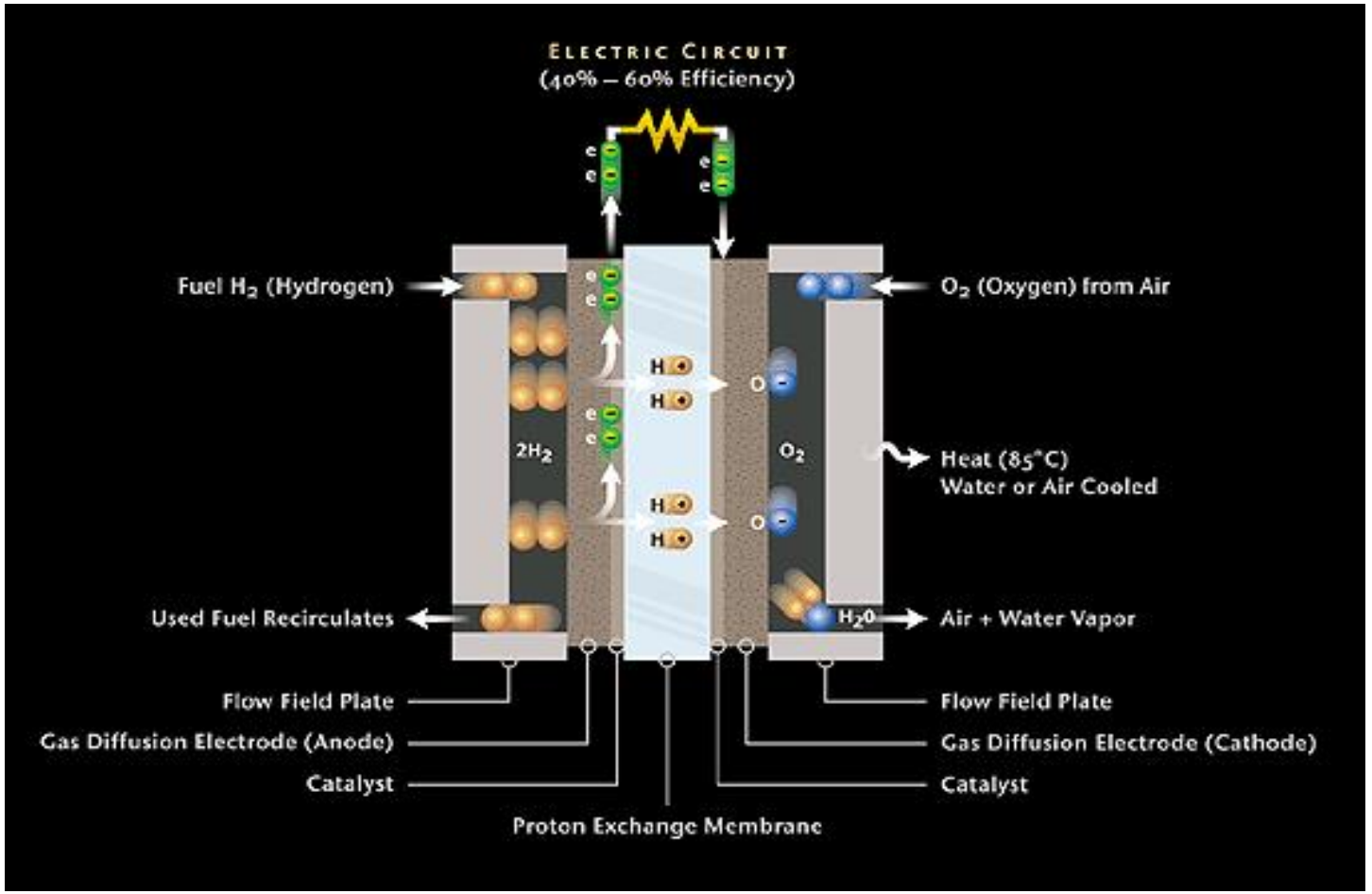
How a Solid Oxide Fuel Cell Works



Fuel Cell Output

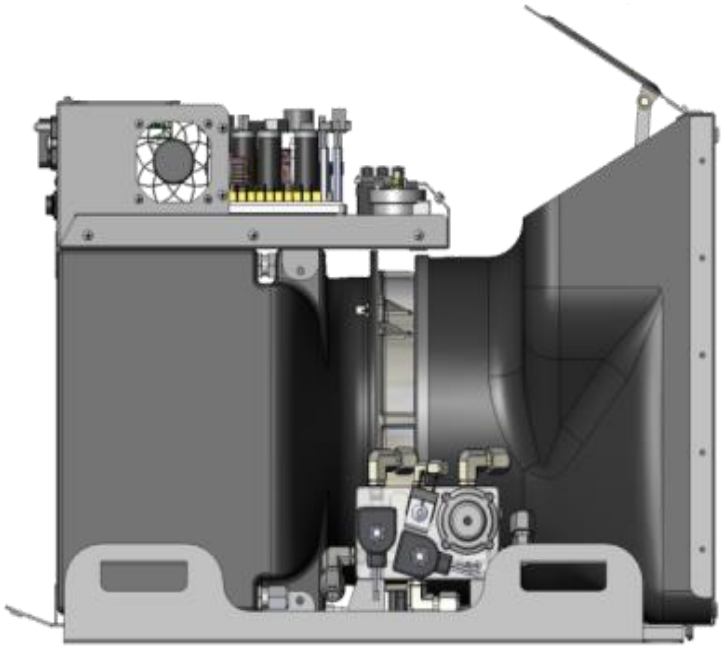
- All Fuel Cell Output is DC Electricity & H_2O Vapor
  - For Prime Fuel Cells, DC Typically Inverted Back to AC
    - Heat in Output Vapor Can be Used for Other Things
      - However, Often Used Primarily to Steam Reform the Fuel
  - For Backup PEM Cells:
    - Direct DC Tie to Bus at Slightly Lower Voltage Than Rectifiers
      - If Fuel Cell Outdoors, Will Need DC Surge Protection
      - Could Have Inverter Off -48 VDC Plant For Any AC Loads
        - » e.g., Tower Lights, Air-Conditioning, etc.
    - 100% Inverted Output to Power Rectifiers (Like a Traditional Standby Engine-Alternator) When AC Power Lost

How a PEM Fuel Cell Works



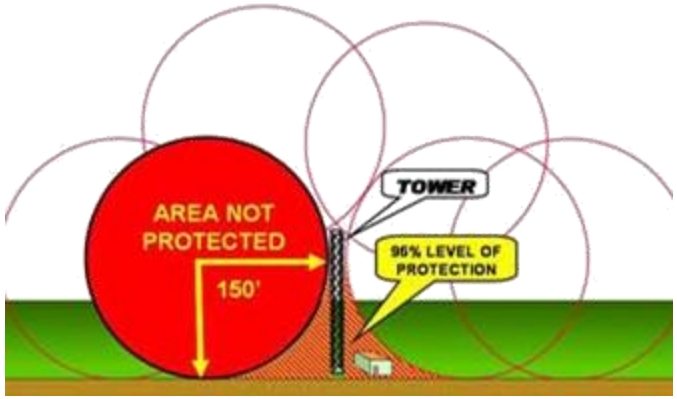
A PEM Fuel Cell Stack

Example 5 kW PEM Fuel Cell



PEM Fuel Cell H_2 Storage Options

Lightning Protection for H_2



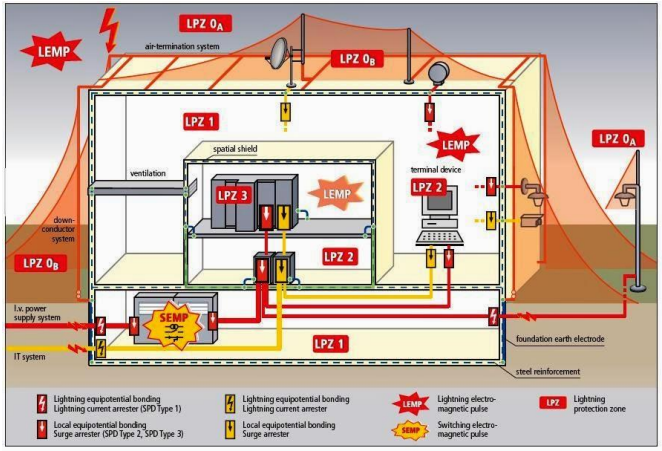
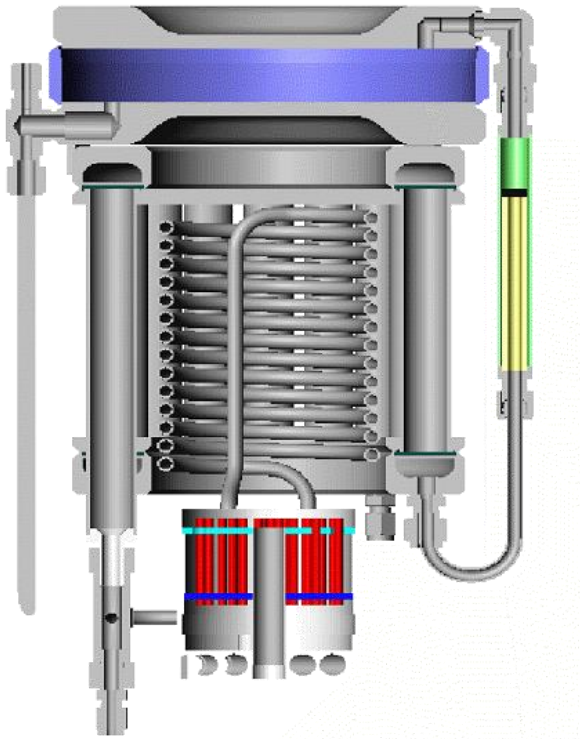


Fig. 7.1.1 Lightning protection zones concept according to IEC 62305-4 (EN 62305-4)

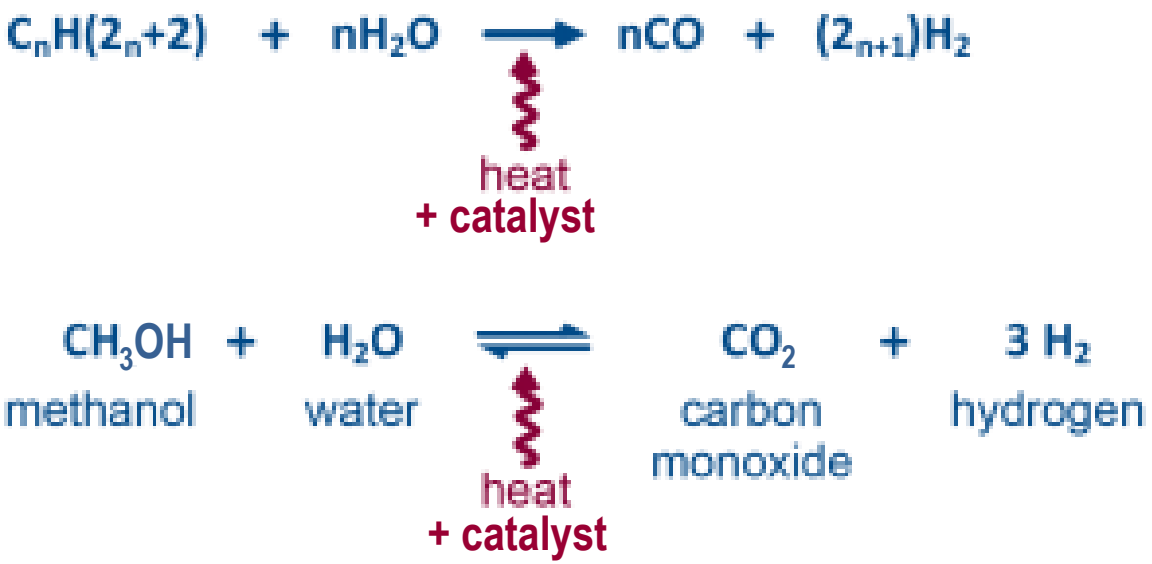
Hydrogen vs Reformers

- Startup Times
  - 10-60 seconds for pure Hydrogen
    - Bridging Battery or SuperCap Needed if Tied Directly to DC Bus
  - 15-60 minutes for Reformed Fuels
    - Methanol-Water Mix
    - Natural Gas
    - Propane

Example Reformers



Steam Reformation of Gaseous Hydrocarbons or Methanol-H_2O Mix



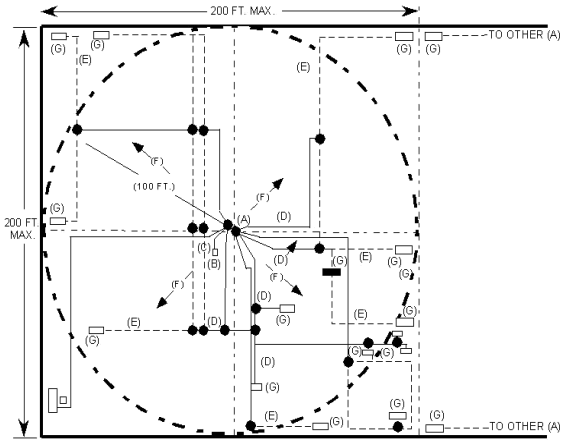
Fuel Cells May be Modular (n+1)

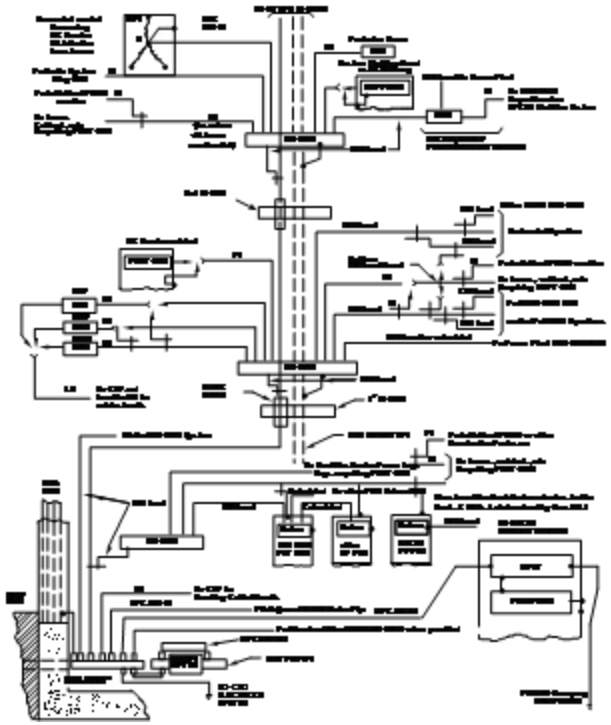
Grounding Outdoor Fuel Cells

- Ground it Outdoors to the Building Ground Electrode System Right Before it Enters the Building
  - Or, if it Never Enters the Building, Simply Bond to the Ground Electrode System Already There
- Ground any Metallic Cabinets for the Fuel Cell or Tanks to the Outdoor Ground Electrodes

Indoor Fuel Cell Grounding

- Bond Metal to the DC or AC Grounding System of the Building





Additional Fuel Cell Grounding Rules

- Per the NEC, Gaseous Fuel Piping that is Near Electrical Wiring ("Likely to Become Energized" in NEC Terms) is Required to be Bonded to the Grounding System
  - NFPA 853 Requires All Fuel Cell Fuel Piping to be Grounded
  - IFGC Requires Bonding Around Mechanical Joints Unless Conductivity Tested

Why/When do DC Ckts Need SPDs?

- All Copper/Entering Leaving a Building or Electronics Cabinet Historically Has Had Surge Protection
  - TVSS for AC
  - 5-pin Protectors for Twisted Pairs
  - Coax Arrestors for GPS Sync
- Historically DC Never Left the Building / Cabinet
  - It Sometimes Does Now!
    - RRH
    - PoE
    - Backhaul Provider Powering
    - **<u>Outdoor Fuel Cells and Their Metallic Tanks/Piping</u>**

Clamping Voltage(s) for DC SPDs

- Choose it Pretty Close to DC Plant Voltages
  - 60-90 V DC for Nominal -48 VDC Plant (Which Normally Operates from -52.08 to -55.2 V)
    - NEBS GR-1089 Pulls from ATIS-0600315, Which Allows Momentary (50 μs) Transients from 75-100 V, and < 10 ms Transients from 62.5 – 75 VDC
  - 30-45VDC for Nominal 24 VDC Plant (Which Normally Operates from 26.4 to 27.25 V)
    - ATIS-0600315 Has Not Yet Recommended Transient Testing/Levels for Nominal 24 VDC-Powered Equipment
  - Too High of a Clamping Voltage Will Allow Damage to All the Other Electronics Connected to the DC Plant
  - Highly Capacitive Nature of Batteries on DC Plants with them Prevents Most Initial Surges From Being Very Large

Commercially Available DC Ckt SPDs

- Lower-Current (e.g., 5-20 A) SAD and/or MOV Series Arrestors
- Higher Current SAD and/or MOV Parallel Arrestors
- Large MOVs

DC-DC Converters for Protection?

- DC-DC Converters Can Help With Surge Protection
  - Especially if It is Isolated (Has a Transformer)
    - Transformer Windings Are Natural Current Surge Impeders
    - All Step Up and Same Voltage Converters are Isolated, but Not Necessarily so for Step-Down Converters
    - Even if Non-Isolated, Electronic Components Give Some Protection
      - The Converters May be Much Less $ than the Equipment Being Protected
        - » i.e., The Converters Become a Sacrificial SPD
  - The Converters Can Serve as Secondary Surge Protection
    - An SPD is the Primary, But Any Let-Through Gets Suppressed by the Converter

Communications Cables SPDs

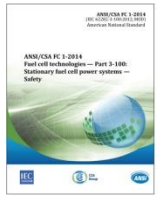
- When a Backup Fuel Cell is Outdoors, there has to be Communication Between the DC Plant or AC Fail Alarms and the Fuel Cell to Tell it When to Start

More Fuel Cell Electrical Protection

- Properly Labeled Full Disconnect (Similar to EPO) Required by NEC
- Warning Sign Noting that Fuel Cell Contains Energy Storage is Required by NEC If there is a Transition Battery or SuperCap

Fuel Cell Physical Protection

- NFPA 55 (LPG and H_2), NFPA 54 (natural gas), NFPA 30 (methanol), NFPA 853, ANSI FC-1
  - Location
    - Fuel Cell itself located 5’ from other flammable or hazardous chemicals
    - Indoor Fuel Cell in Separate 1-h Fire-Rated Enclosure/room
    - Outdoor Fuel-bearing Components located 15’ from Bldg openings, including HVAC intakes
      - 10’ if fuel cell ≤ 50 kW
      - Indoor Reformer Exhausts min 50’ from Ventilation, Door, and Window Openings
    - Accessible to Fire Dept & Maintenance personnel
    - Locate Exhaust vents Away From Building Openings
      - Don’t Direct Exhaust onto Walkways
    - Indoor Reformers must be Located in Negative or Neutral Pressure Room
  - Resistant to Rain/Snow/Ice, Freezing temperatures, Wind, Seismic events, and Lightning
  - Liquid Fuel systems (e.g. Methanol) shall be Curbed/Diked
    - Require Fire Detection & Suppression Systems, Auto Shutoff, and Leak Detection
    - Require an accessible Fire Hydrant
      - Or Another AHJ-Approved Plan for Remote Sites



More From Aforementioned Codes

- Piping must have 2 Shutoff Valves Within 6’ of Fuel Cell if Fuel Storage and Fuel Cell Separated by > 6’
  - Auto Shutoff Valve with Detection Required for Outdoor Fuel Storage with Indoor Fuel Cell
  - If Fuel Cell not in 1-hr Fire-Rated Room, Shutoff Outside Room
- Indoor Ventilation Rate of 1 cfm/ft^2 of floor area, min of 150 cfm
  - Combustible Detectors Required in enclosure for Indoor systems; Unless Fuel is Methanol, or is Natural Gas & Fuel Cell < 50 kW
    - Combustible Detector Activates Alarm at 25% of LFL & Shuts Down Fuel Cell at 60% of LFL
- Roofing Material for Rooftop Installs Either Non-Combustible or Class A
  - Reformers Generally Prohibited from Rooftops
    - Exceptions for Specific Rooftop “Listings”
- Reformers Indoors Limited to Max 5 gal Liquid Fuel at all times
  - Must Have Leak Detection Between Primary Fuel Supply and Reformer
    - Auto Shutoff Valve Outside Building Activated by Sensing of ≥ 25% of LFL
  - If Outdoor Tank is Higher than Reformer, Automatic Isolation Valve Required
  - Must have CO Detector
- Natural Ventilation can be used if Verified Safe, but if Mechanical Ventilation used, it must have Interlock with Shutdown(s)

OSHA® Hydrogen Storage Rules

- Compressed Gas Cylinders Periodically Inspected
- 15’ Combustibles Clearance Around Cylinders
  - Includes Dry Weeds/Grass
- H_2 Storage < 3,000 ft^3 Inside Any Building Space
  - Inlet Ventilation Opening(s) Near Floor in Exterior Wall
    - Outlet Up High
    - Inlet/Outlet Openings Min of 1 ft^2 / 1000 ft^3 of Room Volume
  - 20’ Min from Stored Flammables (e.g., oil, Cardboard, etc.)
  - 25’ Min from People and Electrical Eqpt
  - 50’ Min from any Other Flammable Gas Storage and HVAC or Compressor Air Intakes
    - Can Have More than 1 Tank of < 3,000 ft^3 if Separated by ≥ 50’

More OSHA Hydrogen Rules

- 3,000-15,000 ft^3 Can Be Indoors in Separate Rm
  - NFPA 55 Lowers the Threshold for Needing Fire-Rated Wall Separation to 400 ft^3
- >15,000 ft^3 In Separate Bldg or Outdoors
- Hydrogen Flammable Gas Warning Placard

OSHA Outdoor H_2 Tank Setbacks

Exposure	Subtype	<3,000 ft³	3,000-15,000 ft³	>15,000 ft³
Building or structure	a. Wood frame construction b. Heavy timber or ordinary c. Fire-resistive construction	a. 10' b. 0 c. 0	a. 25' b. 10' c. 0	a. 50' b. 25' c. 0
Wall openings	a. Not above any part of system b. Above any part of a system	a. 10' b. 25'		
Flammable liquid ASTs	a. 0-1000 gallons b. >1000 gallons	a. 10' b. 25'	a. 25' b. 50'	
Flammable liquids USTs <1000 gal	a. Tank b. Vent or fill opening of tank	a. 10' b. 25'		
Flammable liquids USTs >1000 gal	a. Tank b. Vent or fill opening of tank	a. 20' b. 25'		
Other Pressurized Gas Storage	a. low pressure: 0-15,000 ft³ b. high pressure: >15,000 ft³	a. 10' b. 25'	a. 25' b. 50'	
Electrical Equipment		25'		
Inlets to air compressors or HVAC		50'		

OSHA Outdoor Methanol Tanks Separation Rules

- Min 3’ Separation from Other Combustible Fuel Tanks
  - And Not Less than 1/6 their Diameter
    - And Not Less Than ½ the Diameter of Smaller Tank When Smaller Tank is < ½ Diameter of Larger Tank
  - More Special Rules When Locating Near LPG Tank
  - Fluid Level Cannot Drop Below Max Flood Stage for Area, Unless Diked to Ward Off FloodWaters
- Min 1’ Separation from Building Walls
- Min 3’ Separation from Property Line

Other OSHA Outdoor Methanol Tank Rules

- Methanol to be Stored at Approx Atmospheric Pressure
  - Vents are Required
    - May be Open if Tank < 1000 gal
      - Otherwise they are Normally Closed (Vent on Pressure) or Have Flame Arrestors
    - Where Vents are Near Buildings, Walkways, or Streets, the Must Vent at Least 12’ High
      - Vents Min 5’ From Building Openings
    - Vent Not Required for Interstitial Space (NFPA 30)
    - Vent at least 1¼” and as Big as Largest Tank Opening (NFPA 30)
- Tank Supports Shall be of Concrete, Masonry, or Horizontal Wood Beams No Taller than 12”
  - Steel Supports Must Have Fire Protection
- Fire Extinguisher 25-75’ Away
- Per IFC, Need Operational Permit for > 10 gal

Indoor OSHA Methanol Storage Rules

- Max 25 gal Stored Indoors in Portable Containers

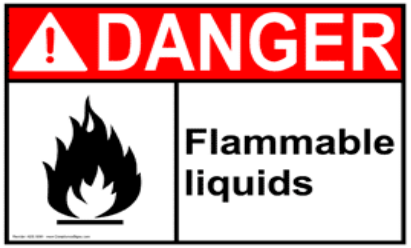
  - Can be Up To 60 gal if In Flammables Cabinet
    - IFC Allows Up to 120 gal in Flammables Cabinet if No Individual Container > 60 gal
    - NFPA 30 Allows even More
  - Larger Quantities Allowed in Specialized Storage Rms
    - If More than 60 gal, Need Fire Extinguisher Outside Room, but Less than 10’ from Door
    - Howevever, Fill Port has to be Outside per IFC
  - IFC Requires Operational Permit for > 5 gal

Methanol Transport to MountainTops

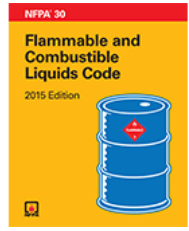
- Transfer from Portable Containers to Permanent Tanks 25’ From Other Operations or Separation by Firewall
  - Drainage for Spill Control
  - Natural or Forced Ventilation to Ensure No More Than 10% of LFL
  - If Both Containers are Metal, they Must be Bonded During Transfer

More IFC Rules for Methanol

- Need Spill Control for Individual Tanks > 55 gal, or for combined Tank Storage > 1000 gal
- Piping must be Pressure-Tested After Install and Before Use
- Piping Protected from Damage
  - Including Vehicular Outdoors
- Vaulted Tanks Need Liquid and Vapor Detection
- In Addition to NFPA 704 and No Smoking Signs, A Flammable Liquid Sign is also Needed
  - Fill Procedures must be Posted
- Overfill Prevention Required
  - Max Fill is 95%



More NFPA 30 Rules for Methanol



- 1100 gals max if Adjacent to Building
  - Wall Must have 2-hr Fire Rating Minimum
  - No Above-Grade Building Openings Within 10’ and No Below-Grade Building Openings Within 50’
- If > 1100 gals
  - 5’ separation
  - 50’ from Property Lines
  - 10’ from Street/Alley/Walkway
- For Tanks > 60 Gals, all Tank Materials are Non-Combustible (e.g., Steel)

IFC & IFGC Fuel Storage Rules

- No More than 1000 ft^3 of H_2 (150 lbs Methanol/LPG) Indoors w/Non-Sprinkler Fire Suppression
  - Increases to 2000 ft^3 of H_2 (or 300 lbs of Methanol/LPG) with Sprinkler System
  - Increases to 4000 ft^3 of H_2 (or 600 lbs of Methanol/LPG) with Sprinkler System & Fire Containing Cabinet
  - If there is an Outdoor Area that Has Fire Suppression/ Control, Can Store up to 3000 ft^3 of H_2 (or 300 lbs of Methanol/LPG) per Control Area
  - Values Above can be Exceeded if AHJ Allows it With Approved Emergency Plan (NFPA 55)
- Any Pressure-Handling Component must Withstand Pressures, Seismic, and Exposure
  - Emergency Shutoff Valves at the Source with Signage
  - Piping must Indicate Material conveyed and Direction Every 20' Minimum
  - Pressure Relief Devices are Required, Directed Up, Protected from Freezing, Accessible/Inspectible, and Free of Debris/Obstructions
  - Above Grade Piping (Approved for H_2 - usually Stainless Steel) Visibly Exposed
  - All Piping Installations Inspected and Pressure-Tested Prior to Turnup
  - Piping Going Through Concrete/Brick Walls has to be Protected from Settling
  - Protect Buried and Through-Wall Piping from Corrosion
- NFPA 704 and No Smoking Signage

How Dangerous is Hydrogen

- Myth

- Reality