Hydrogen Fuel Cell Backup Power Systems (HFC) for ITS Elements– Part 2, Research Project

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Acronyms & Definitions

AHMCT- Advanced Highway Maintenance & Construction Technology

BBS- Battery Back-up System

COTS- Commercial off-the-shelf

EQASI- Electrical Quality Assurance and Source Inspection

HFC- Hydrogen Fuel Cell

K-Bottle- a standardized pressure vessel used for high pressure industrial applications

METS- Materials Engineering and Testing Services

NFPA- National Fire Protection Association

PEM- Proton Exchange Membrane

PSPS- Public Safety Power Shutdown

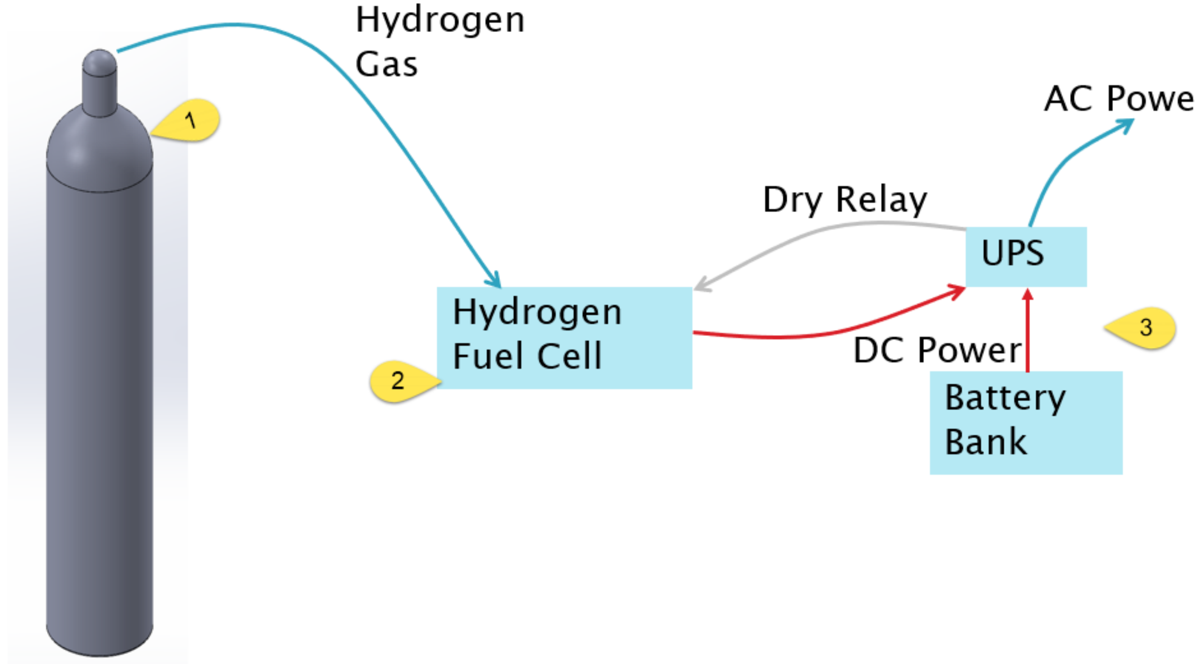
UPS- Uninterruptable Power Supply

Outline

- System overview
  - Typical configuration
  - How it works
- Field testing of HFC units
- Research Tasks
  - Proposed
  - Actual
- Procurement
  - Lessons learned
- Design
  - Foundation
  - HFC connections to Caltrans infrastructure
  - Run-time
- Further Considerations

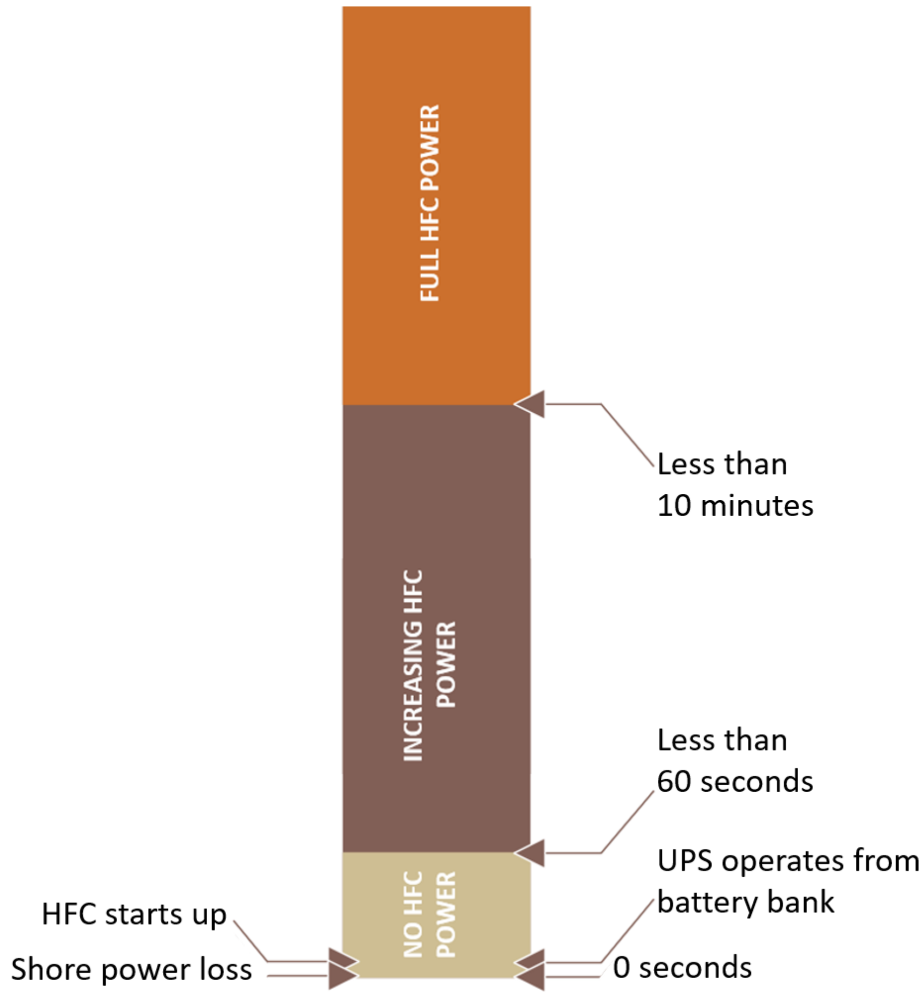
HFC System Overview

1. Hydrogen Fuel Storage (6 to 12 K-Bottles)
2. Fuel Cell
3. Battery Backup System (BBS)
   1. Uninterruptable Power Supply (UPS)
   2. Battery bank



Typical Operations

1. Shore power loss
    1. UPS operates from battery bank
    2. Dry Relay closes
        1. HFC starts up
            1. Dependent on temperature (colder=longer time)
2. Infrastructure runs from battery bank
    1. HFC begins to supply fraction of DC power
3. HFC completes warm-up
    1. HFC supplies required DC power
        1. Supports infrastructure load
        2. Charges batteries



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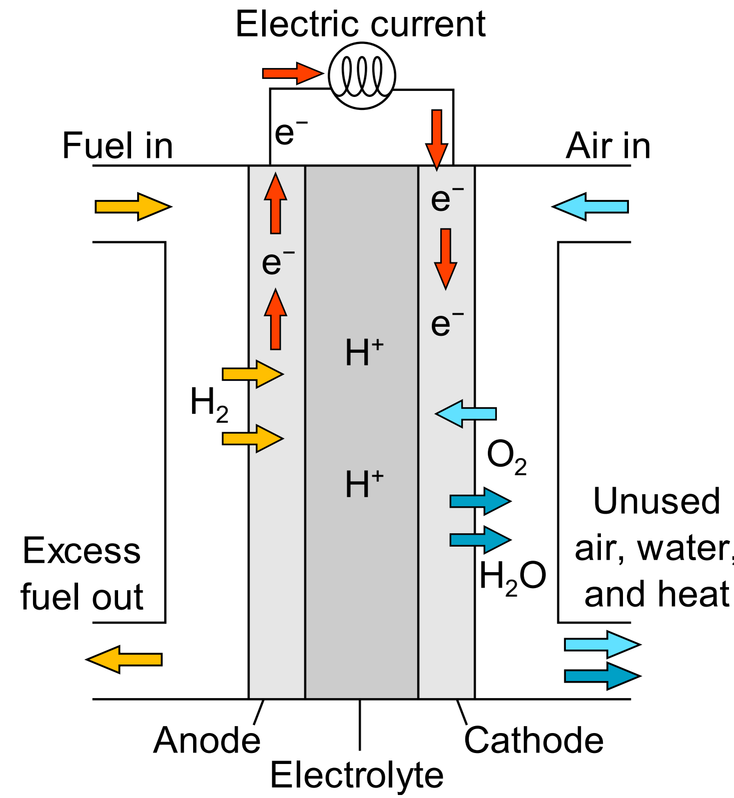
Proton Exchange Membrane HFC

- Hydrogen gas is oxidized to yield hydrogen protons and electrons at anode
  - Electrons traverse external circuit (UPS) generating a current
  - Protons permeate a proton exchange membrane to cathode
- Protons combine with oxygen in air and electrons that have traveled the circuit to form water



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Anode reaction: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode reaction: $O^2 + 4H^+ + 4e^- \rightarrow 2\,H_2O$

Field Testing of HFC

- 1st location
  - San Diego County, California east of Poway
  - 32.9546° latitude, -116.9692° longitude
  - Load- 23 LED traffic lights and a traffic light controller
  - 12 K-bottles
  - Conservative estimate 12 days of uninterrupted back-up power
  - Cabinet is 6 feet above adjacent roadway (circled area)

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Field Testing of HFC

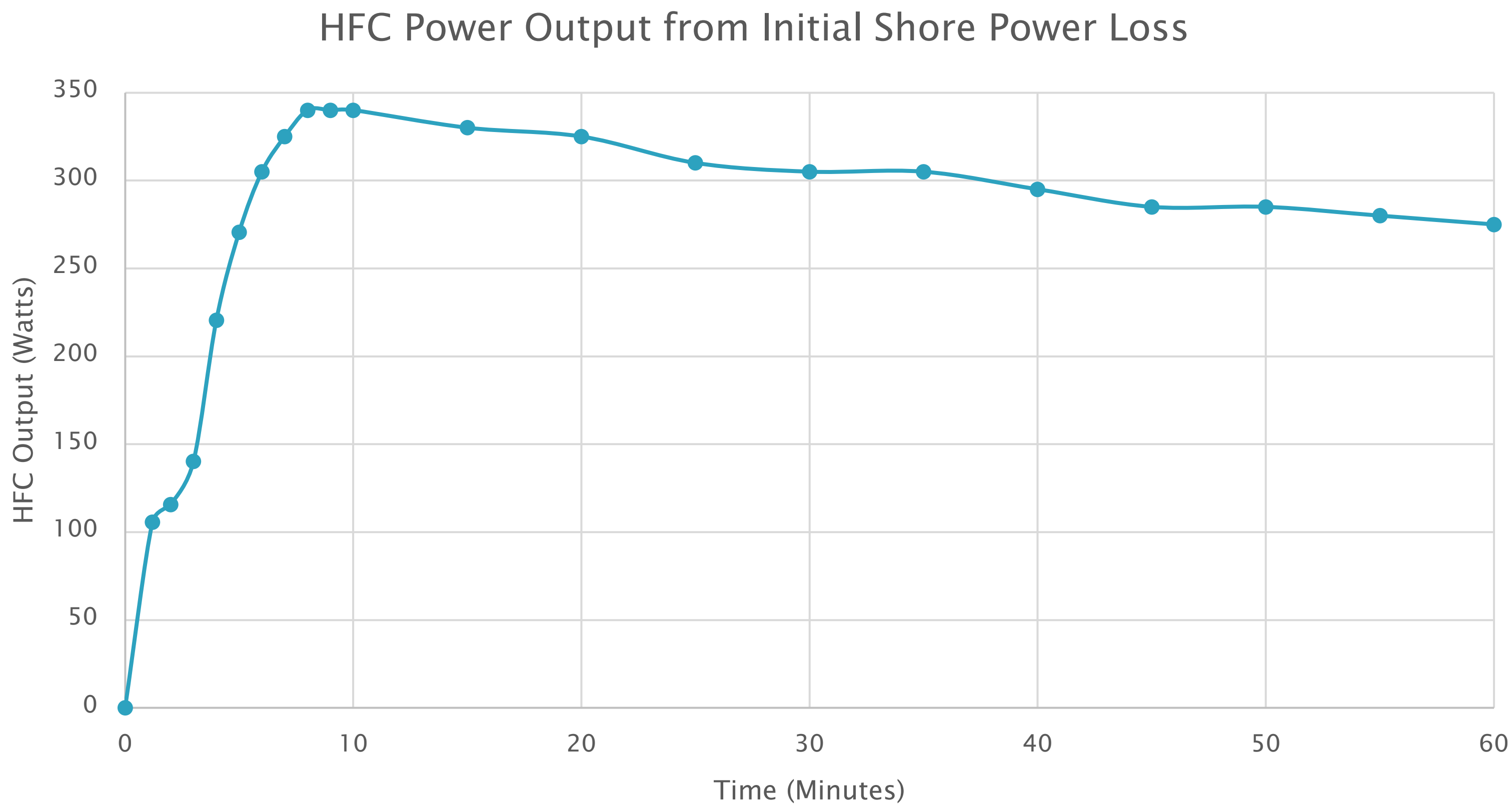
- 2nd location
  - El Dorado County, California northwest of Diamond Springs
  - 38.6985° latitude, -120.8232° longitude
  - Load- 11 LED traffic lights and a traffic light controller
  - 6 K-bottles
  - Conservative estimate 11 days of uninterrupted back-up power
  - Cabinet is behind bollards (circled area)

Testing Setup

Current measurement on output of HFC

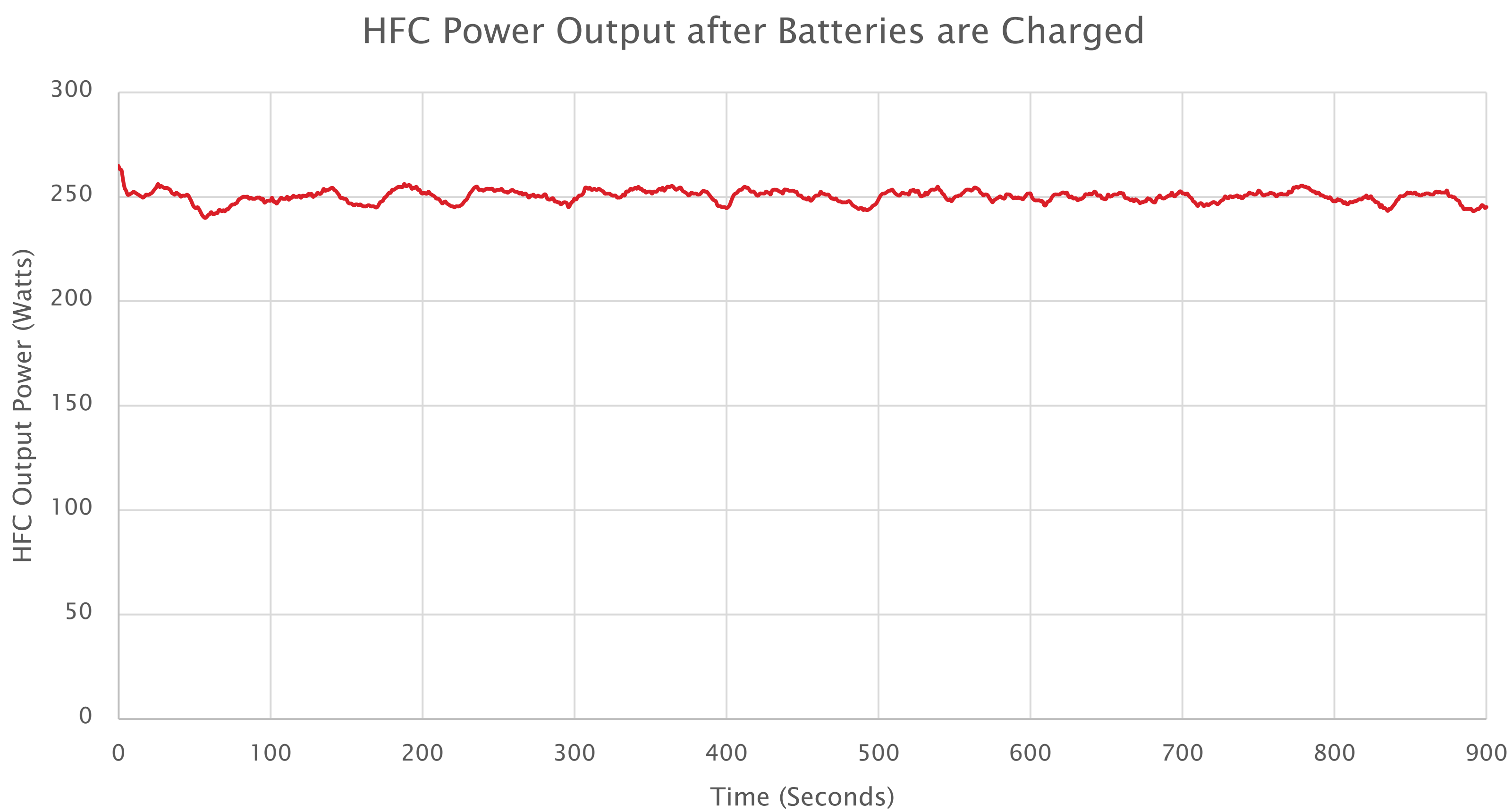
Voltage measurement across terminal block (HFC, Battery Bank, UPS)

HFC Performance



- Warm-up phase- 0 to 8 minutes
- Full power- 9 to 30 minutes
  - Data trends lower as the batteries are recharged and the load decreases to traffic controller and LED lights only

HFC Performance



Research Questions– Proposed

- Procure four commercially available HFC systems
- Document the installation of the HFC systems
- Field testing under actual Caltrans operating conditions
- Document the operation aspects of the HFC system including:
  - Reliability of providing continuous power
  - Time to start
  - Ability to maintain HFC temperature in prescribed limits
  - Performance over time
- Document the maintenance and refueling procedures
- Document the cost of procurement and operations

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Actual Research Tasks

- Developed purchase order for four HFC systems that was eventually cancelled
- Documented the design and system changes necessary to reach a viable HFC system for Caltrans
- Documented the field testing of previously installed HFC systems in California
- Partnered with METS EQASI to perform laboratory testing of a COTS HFC system
- Documented NFPA codes necessary for HFC deployment
- Documented site preparation for a COTS HFC system

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Procurement Lessons Learned

- Quality assurance
  - Require system configured by supplier
  - Require system tested prior to shipment
    - Multiple cold starts
    - Several hours of operation with load at or above your requirements
- System responsibility
  - Who places components?
    - Single cabinet or multiple
    - On-site assembly
  - Who connects components?
    - Electrical connections- dry relay contacts, AC and/or DC
    - Data monitoring- HFC and/or UPS
    - Hydrogen- storage to HFC
  - Who verifies hydrogen system integrity?
  - Who commissions the equipment?
  - Who is responsible for performance/reliability issues?
- Hydrogen storage
  - Rental or lease of bottles
  - Fill in place (K-bottle approximately 140 pounds)
  - Filling contract

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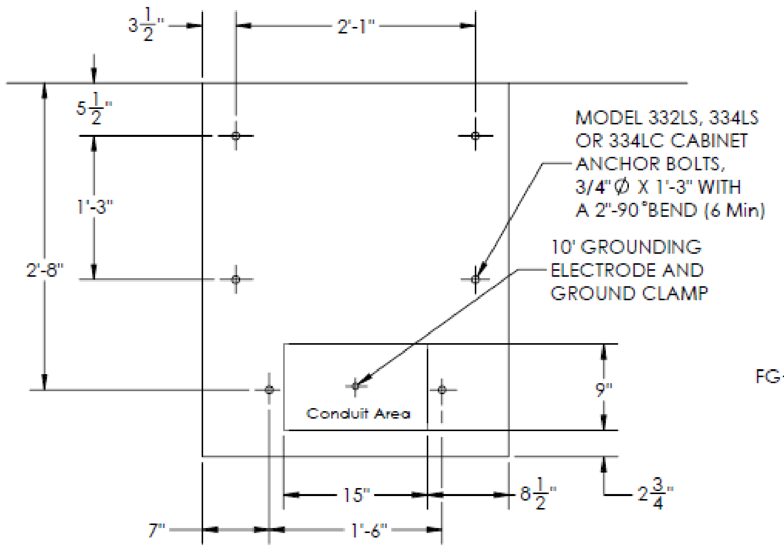
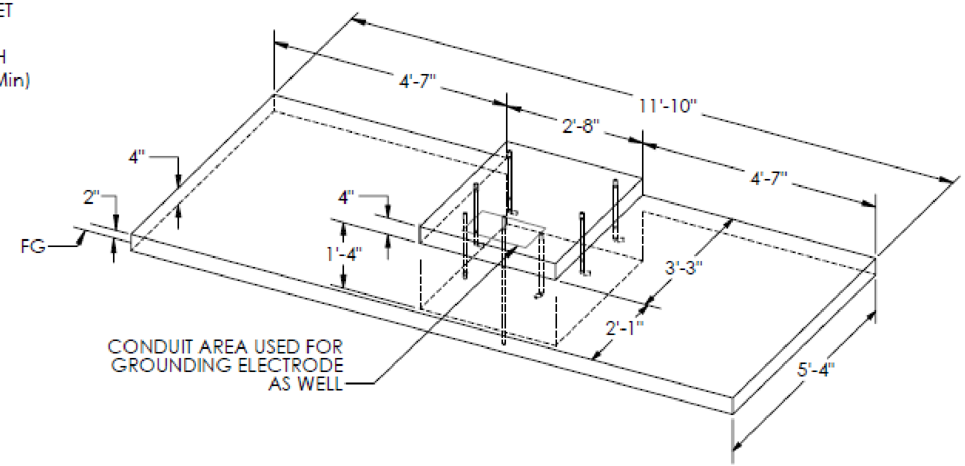
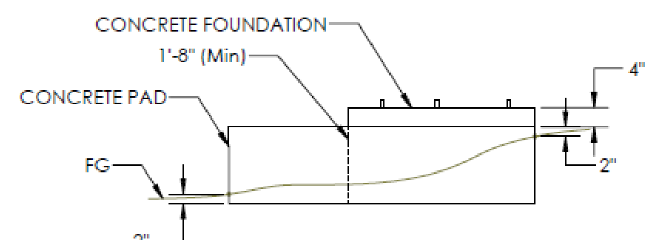
Design– Foundation



ConduitArea, Grounding Rod, and Anchor Bolts
DETAIL A
SCALE 1 : 12



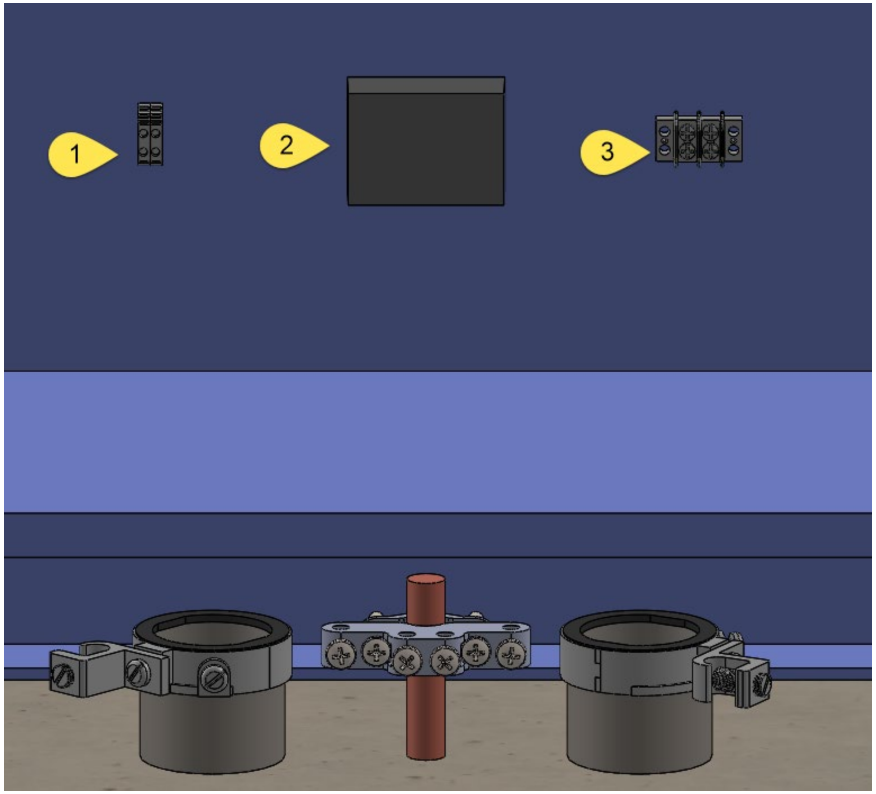
NOTES:
1. Based on 2022 Standard plan ES-3C
2. Modifications are to accomodate a Western Systems Hymax Hydrogen Fuel Cell (HFC)
3. Hidden lines are only shown in the trimetric view for clarity
4. Drawing views are not to scale unless noted
5. Length dimensions are modified for double door acces on HFC Hydrogen fuel storage cabinet
6. Width dimensions are modified to provide 2' of clearance to HFC
7. Conduit location has been modified as shown
8. Grounding rod to be located inside of Conduit Area
9. 2 2" conduits are recommended- 1 for communications, 1 for Power
10. Conduit extends above foundation by 2"
11. Grounding rod extends above foundation by 3"
12. Approximately 32.5 cubic feet of concrete if site is level



SLOPE INSTALLATION
DETAIL B

Design- Connection to Caltrans

1. Terminal block- dry relay contacts
   1. If HFC utilizes existing onsite UPS
   2. Not necessary if UPS is part of HFC system
2. RJ45 surface mount box
3. Terminal block-
   1. DC if HFC utilizes existing onsite UPS
   2. AC if UPS is part of HFC



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Design- HFC Run-Time Calculations

- K-bottle holds .67 kg (1.48#) of Hydrogen
  - 49L (.049 m^3)of storage, 2,400 PSI at Full pressure
  - 13.66 kg/m^3 density of Hydrogen at above conditions
  - (.049 m^3)*(13.66 kg/m^3) = .67 kg (1.48#) of Hydrogen
- 25 kWh of energy per 1 kg of Hydrogen
  - Assume PEM HFC efficiency 50% (30-70% is variation)
- .67 kg of 25 kWh = **16.67 kWh of energy per bottle**
- **Run-time (h)=**

  (# of bottles)*(16.67kWh)/(Load in kW)

Further Site Considerations

- Operating Temperature of HFC verse ambient extremes of proposed location
- Maximum Snow depth of proposed locations
  - Verification of HFC to work if exhaust is covered in snow
- HFC locations relative to southern exposure
  - Locate HFC on south face in colder climates
  - Locate HFC on north face in hotter climates
- Position of hydrogen storage relative to traffic and errant vehicle path

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Unanswered Research Questions

- Long-term testing with 400-watt load, operate until bottles are out of hydrogen
- Verify system protection operates properly
  - Low hydrogen shutoff- protects HFC
  - Hydrogen leak detection- protects public
- Verify extreme weather
  - Ice damming
  - Operations at extreme operating conditions (hot/cold)
- Ability to operate without being reset

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Research Conclusions

- Calculations show ability to mitigate impact of PSPS to transportation systems such as traffic signals
  - Data from previous presentation for ITS node BBS System
    - 4 battery system with 3.7kWh of storage
    - Approximately 12 hours of battery back-up operations
  - A 6 K-bottle system has approximately 100kWh of storage
    - 27 times the energy storage capacity
    - 324 hours or 13.5 days of HFC back-up operations
- Further observations of installed and commissioned COTS hydrogen fuel cell systems are needed
- Further laboratory testing of COTS beyond the work of Justin Ellis and his team at METS EQASI are needed

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