Ocean Observatories Initiative

Coastal & Global Scale Nodes

Hydrogen Safety

CP01 Mooring Timeline:

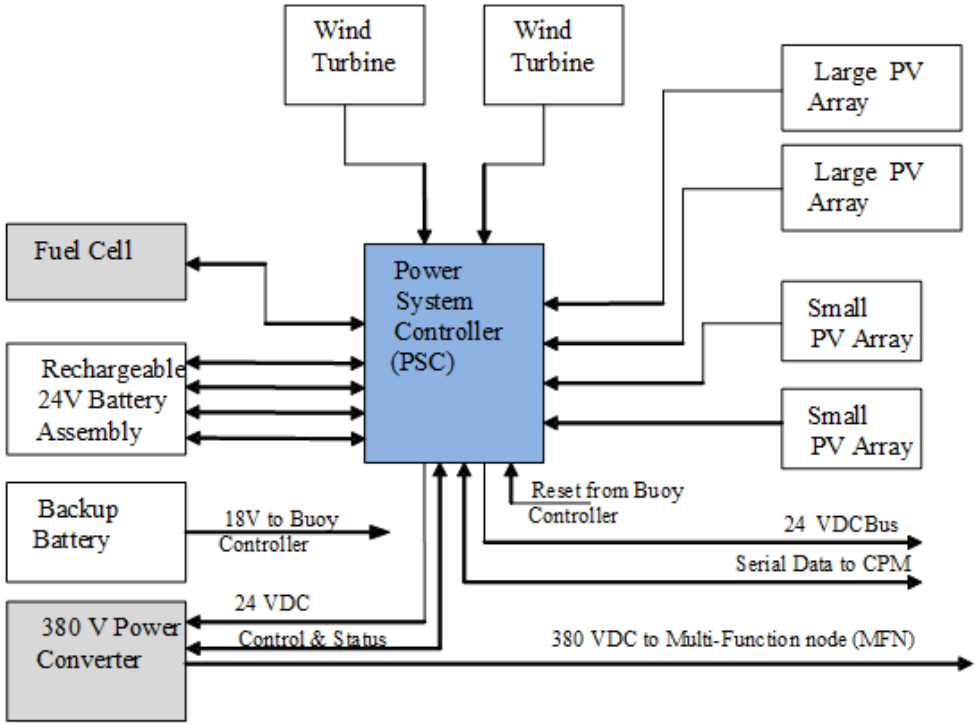
- 21 November 2013: CP01CNSM was deployed and transitioned to shore controlled operations.
- 17 Feb. 2014: After nearly 3 months of operation, at 13:15:53-13:50:00 (UTC), CP01CNSM, ended communications to shore, except for its XEOS Beacon providing location information.
- 18 April 2014: Recovery of Mooring on Pioneer II Cruise
  - Signs of a Catastrophic Event, thought to have been caused by “a purposeful event,” were seen from a distance during the cruise on 16 April 2014.
  - Clear Signs of an Internal Explosion Upon Recovery onto the *Knorr* on 18 April 2014.
  - 19-21 April 2014: Further On Shore Analysis Uncovers Likely Failure Sequence.

Mooring System Architecture

- Parallel Platform Controllers
- Parallel Telemetry
  - Inmarsat
  - Iridium Data
  - Iridium SBD
- Power System:
  - Renewable Inputs
    - Wind
    - Solar
    - Fuel Cell
  - Monitors Battery Status
  - Controls Charge Cycles

Mooring System Architecture

- Power Sub-System Description
  - Power System Block Diagram
  - Battery Bank: 24 Volt Bus, 840 Ahr Capacity



Internal Process

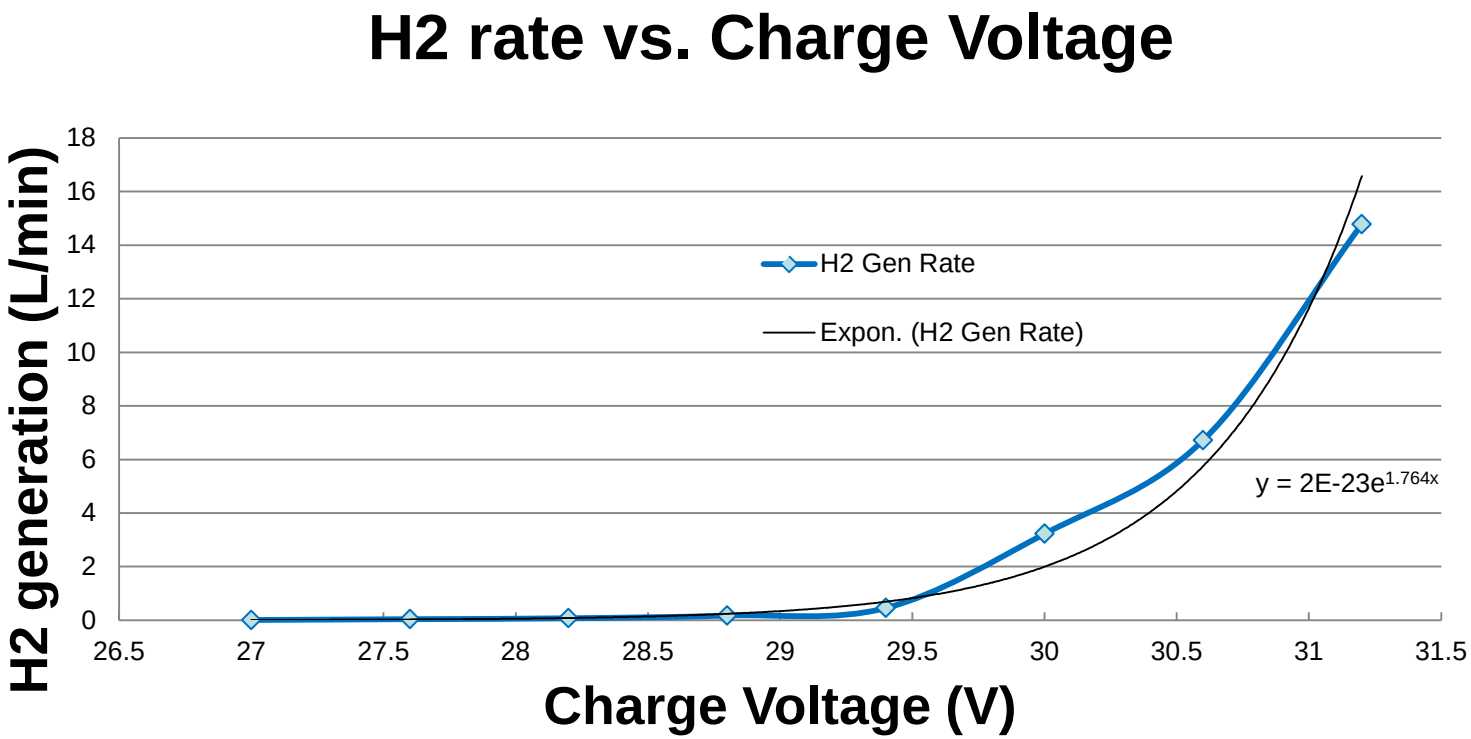
Engineering Investigation:

- Failure Analysis Report: FAR – 00008
- Outside Consultation:
  - Buoy Subject Matter Experts
    - Specific Detailed Reports
  - Alternative Power Subject Matter Experts
    - System Review
  - Sensor Manufacturers
    - Sensor Capability
  - Battery Manufacturer
    - Hydrogen Generation Rates
- Investigation of Previous Events:
  - Data Buoy Operations Safety Paper

Root Cause: Lack of adequate ventilation, compounded by excessive Hydrogen generation during battery charge cycles

Failure Analysis: Potential H2 Generation

- H2 Generation goes up exponentially with terminal voltage

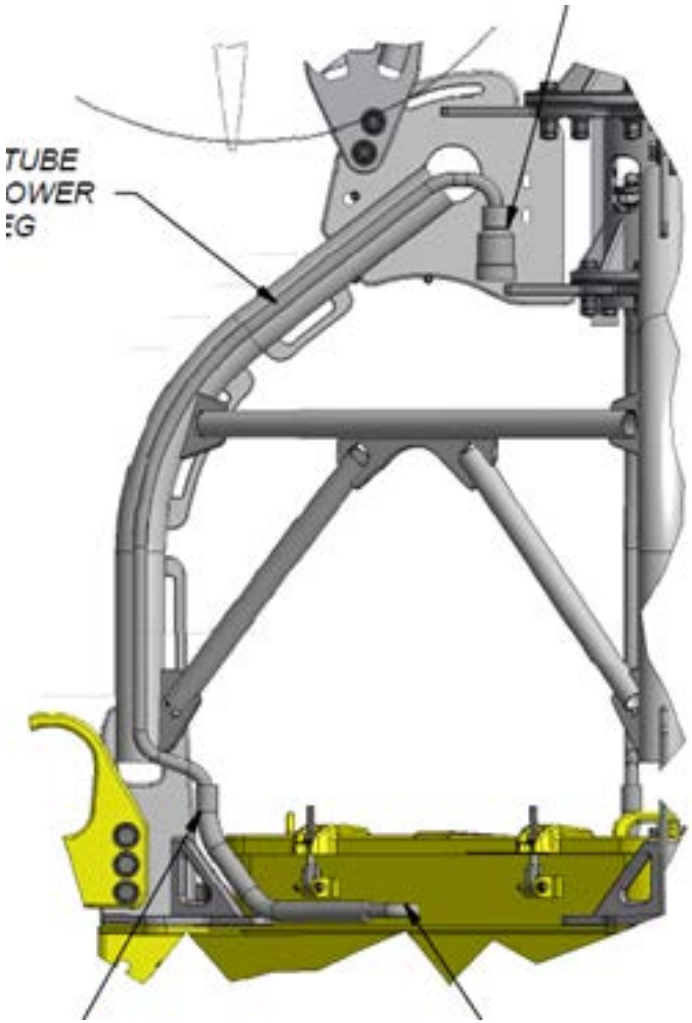


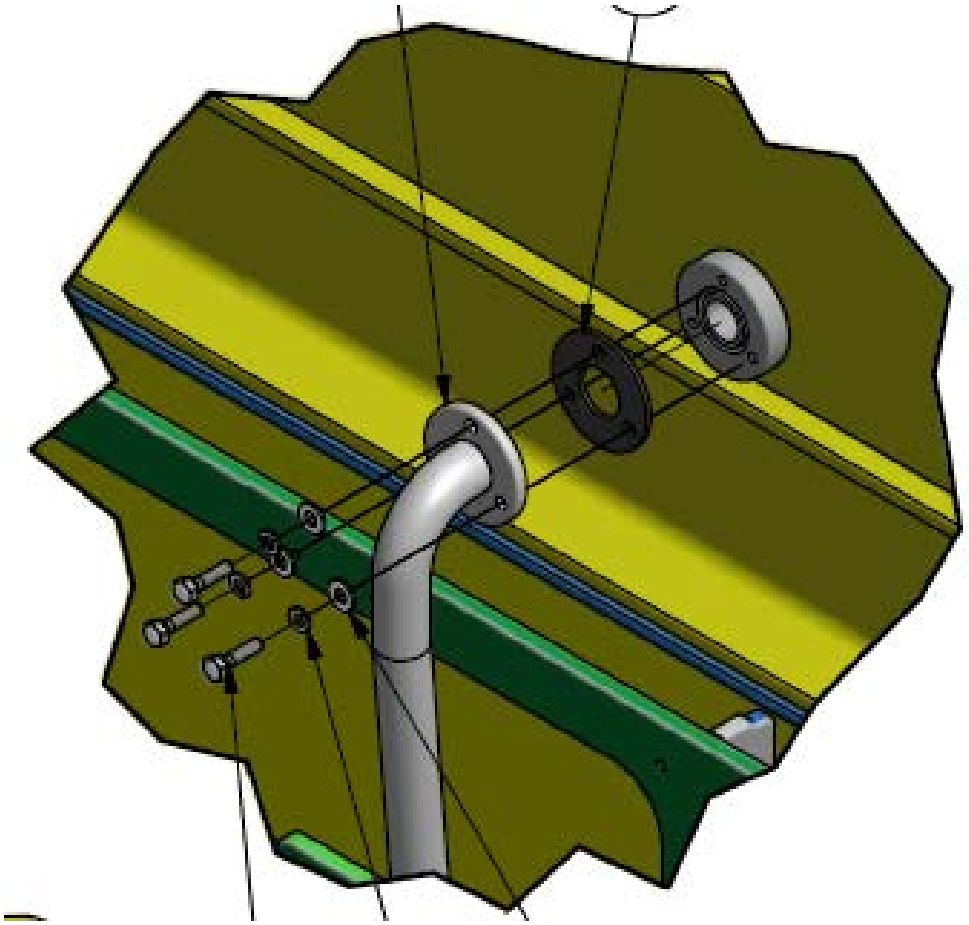
Mitigation Solutions:

Multi-Disciplinary Approach:

- Mechanical:
  - Design and Test Passive Ventilation System
  - Mount Hydrogen Sensors
- Software:
  - Integrate Hydrogen Sensor Data
  - On Board Monitoring
  - OMC Display
- Electrical:
  - Sensor Integration with Data Collection
  - Modify Battery Charging Algorithm to Minimize Hydrogen Production
  - Institute Battery Over Voltage Prevention
- Operational:
  - Remote System Monitoring
  - Handling and Recovery Procedures

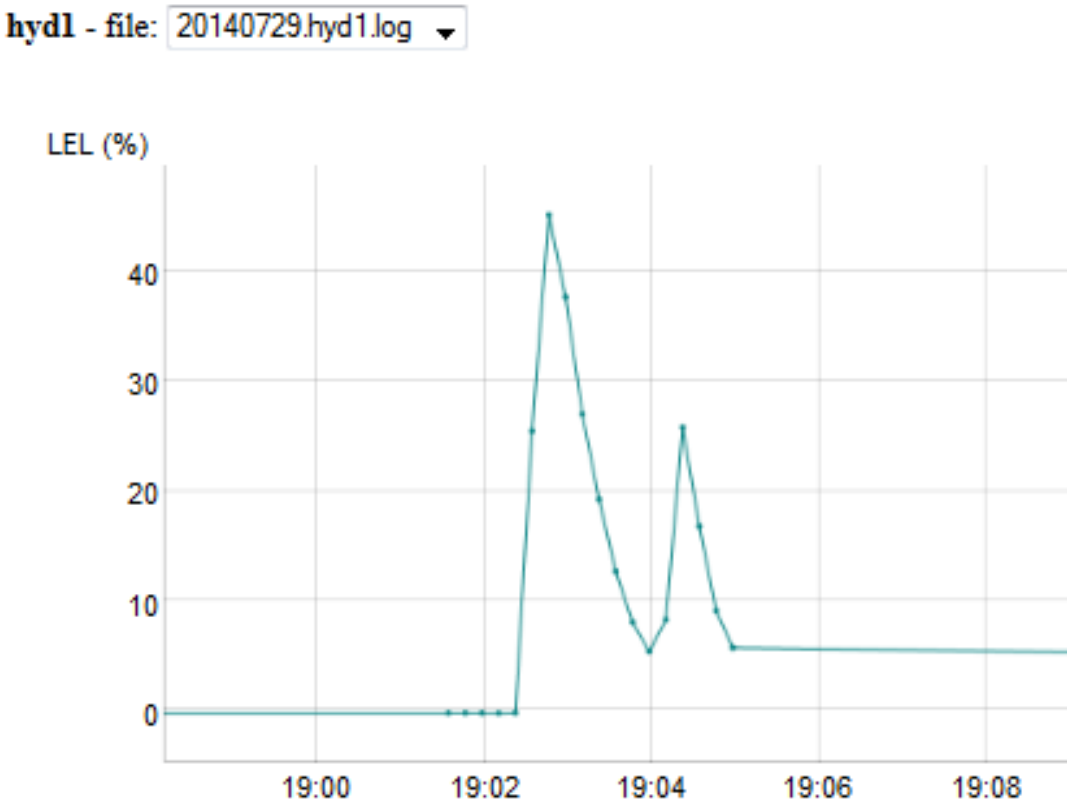
Mitigation Solution: Vent Implementation





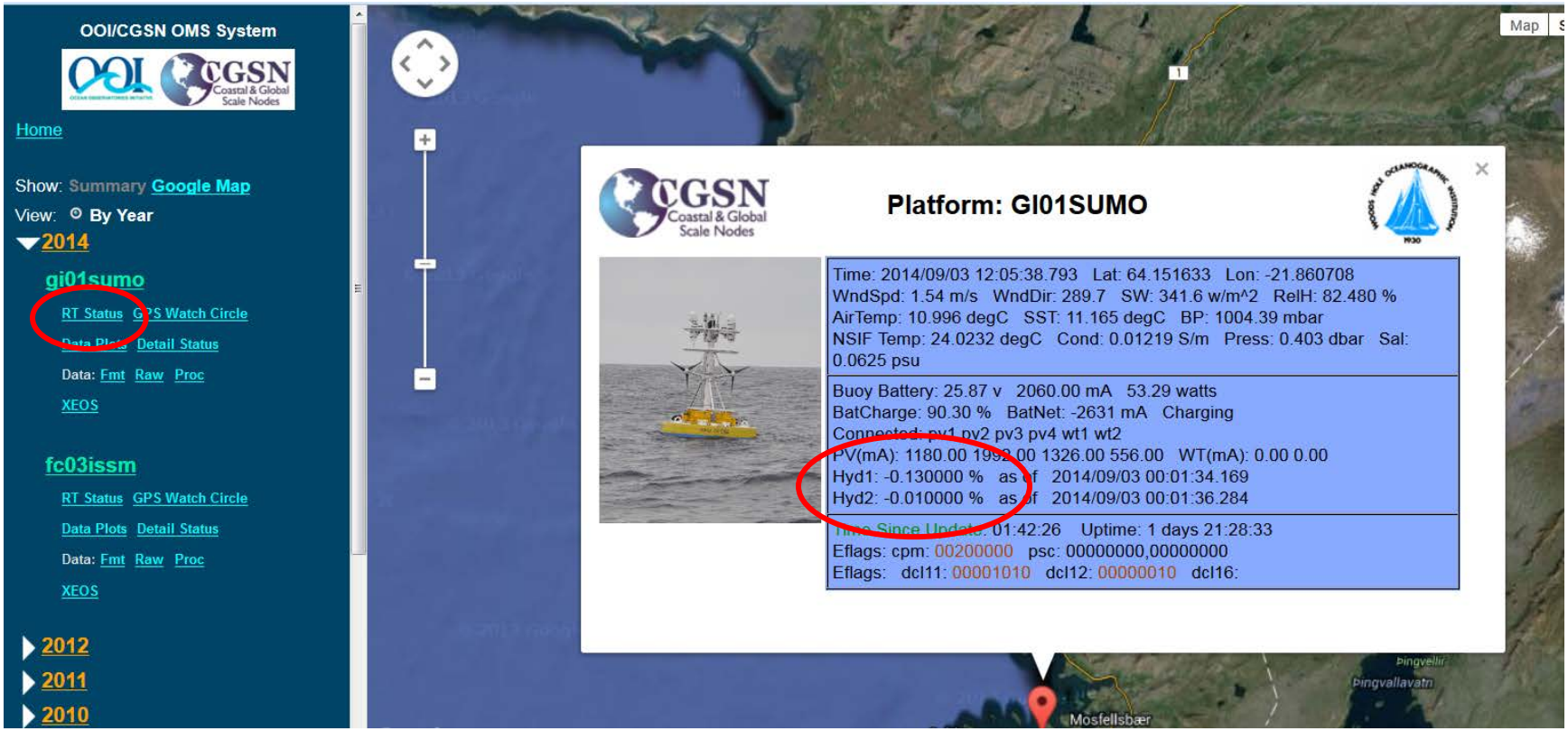
Mitigation Solution: Electrical

- **Sensor Selection:** RKI Instruments M2A
  - Hydrogen Specific



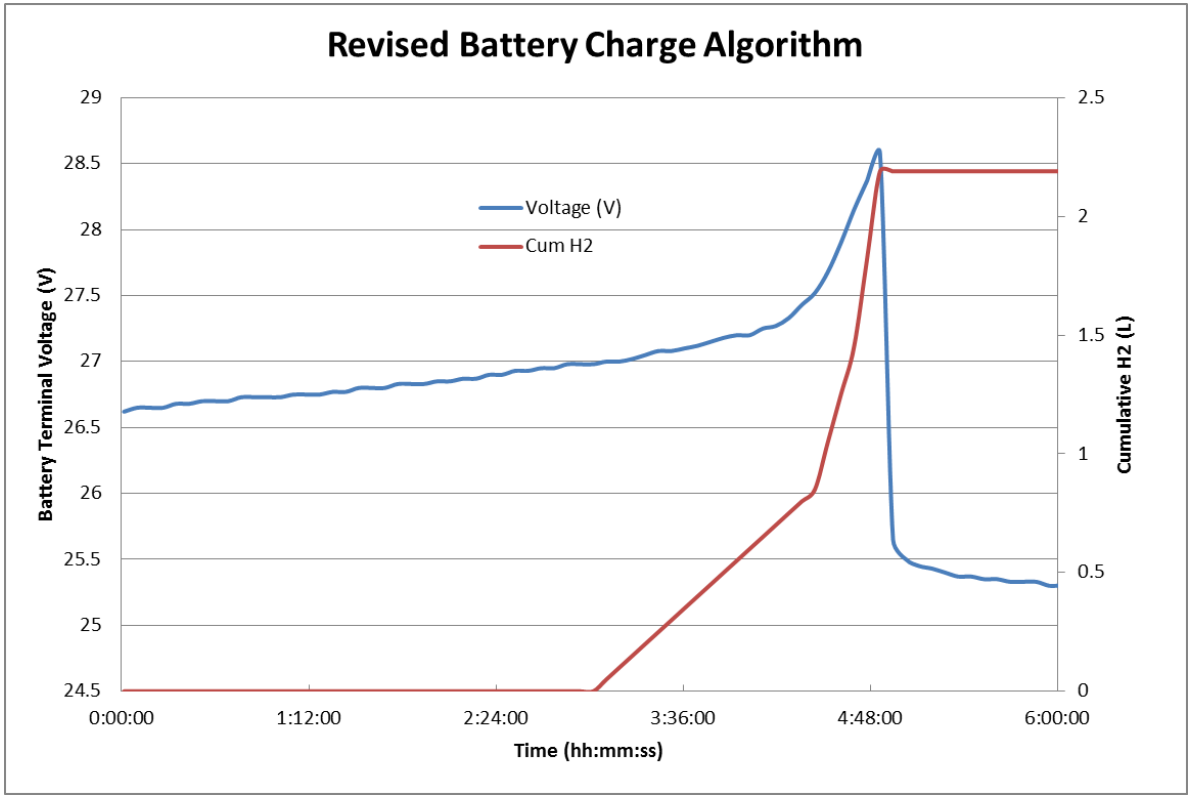
Mitigation Solution: Software

Remote Monitoring:



Mitigation Solution: Reduce H2 Generation

- H2 Accumulation During a Charge Cycle
- Bulk of H2 Production is During the Charge Duty Cycle
  - Each individual cycle should not create an explosive concentration of H2



Mitigation Solution: Operational

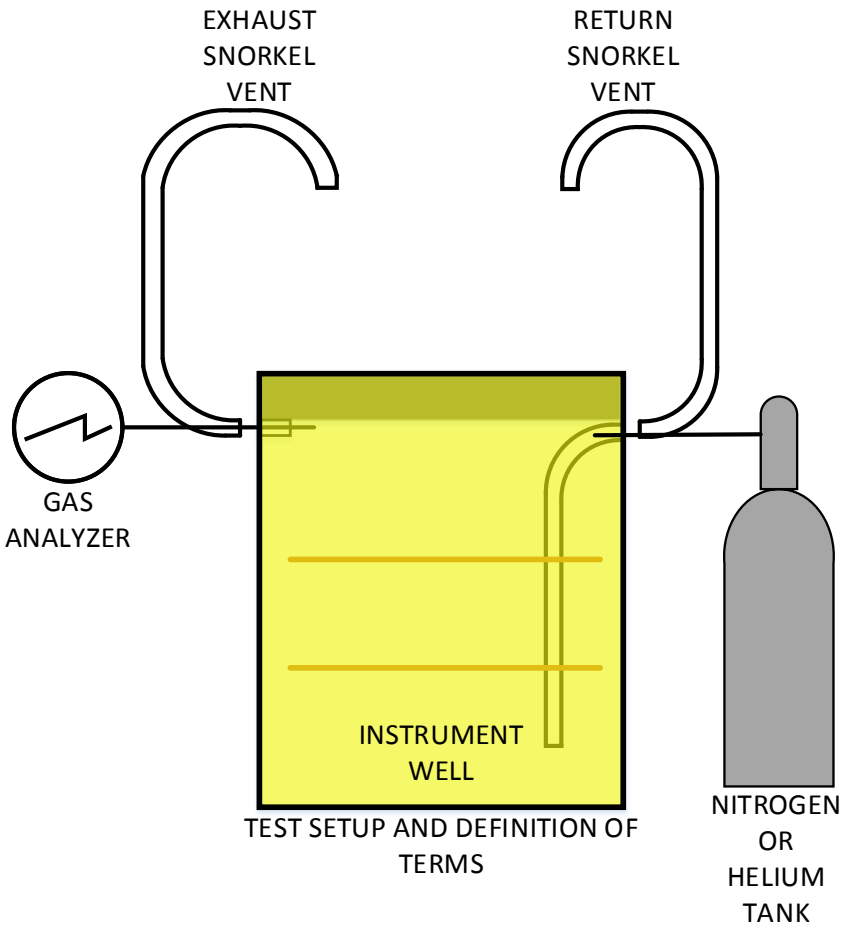
Recovery Procedure:

Objective:

- Connect Ground Strap
- Verify Hydrogen Dissipation to < 1% Concentration / 10% LEL
- Purge Hydrogen and Oxygen from well

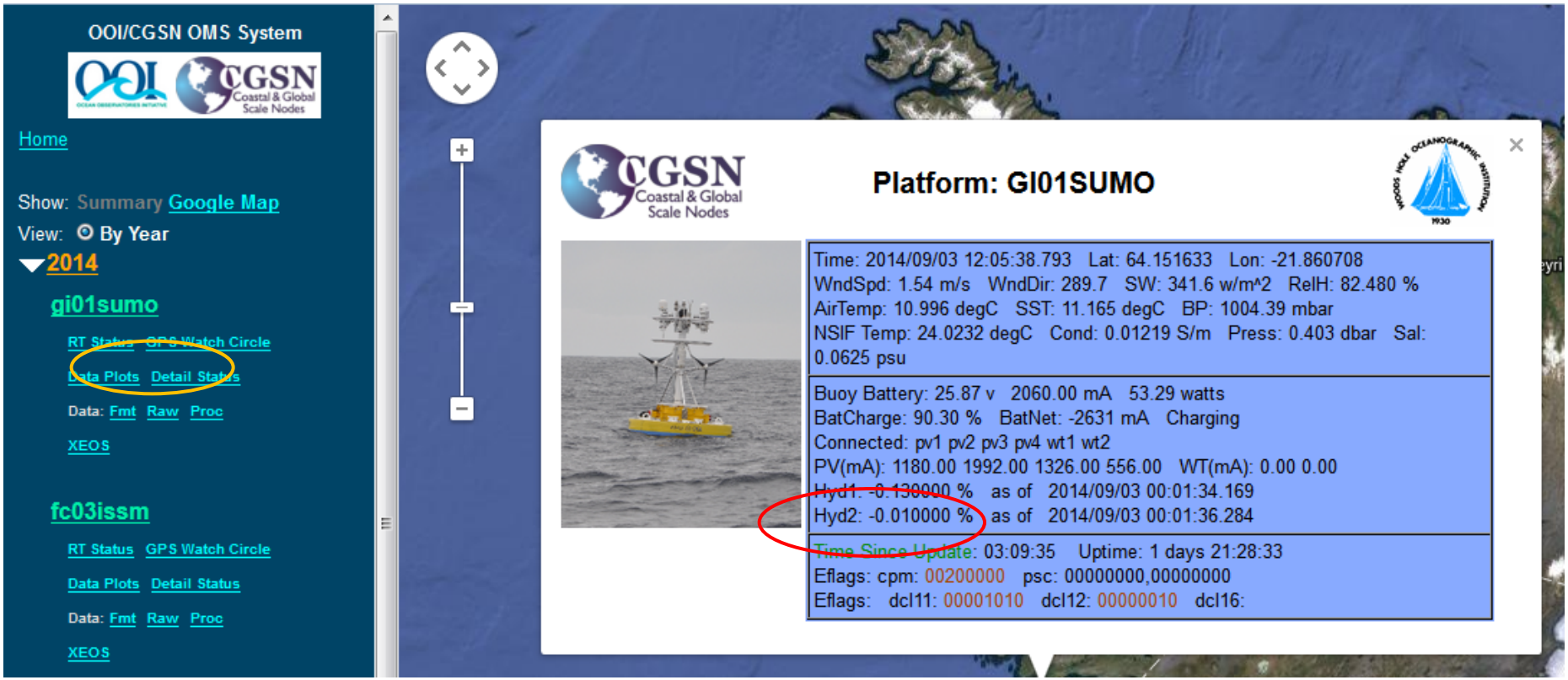
Procedure:

- Insert Gas Analyzer Monitor port
- Flood Container With Nitrogen
- Verify Hydrogen Dissipation to < 1% Concentration / 10% LEL

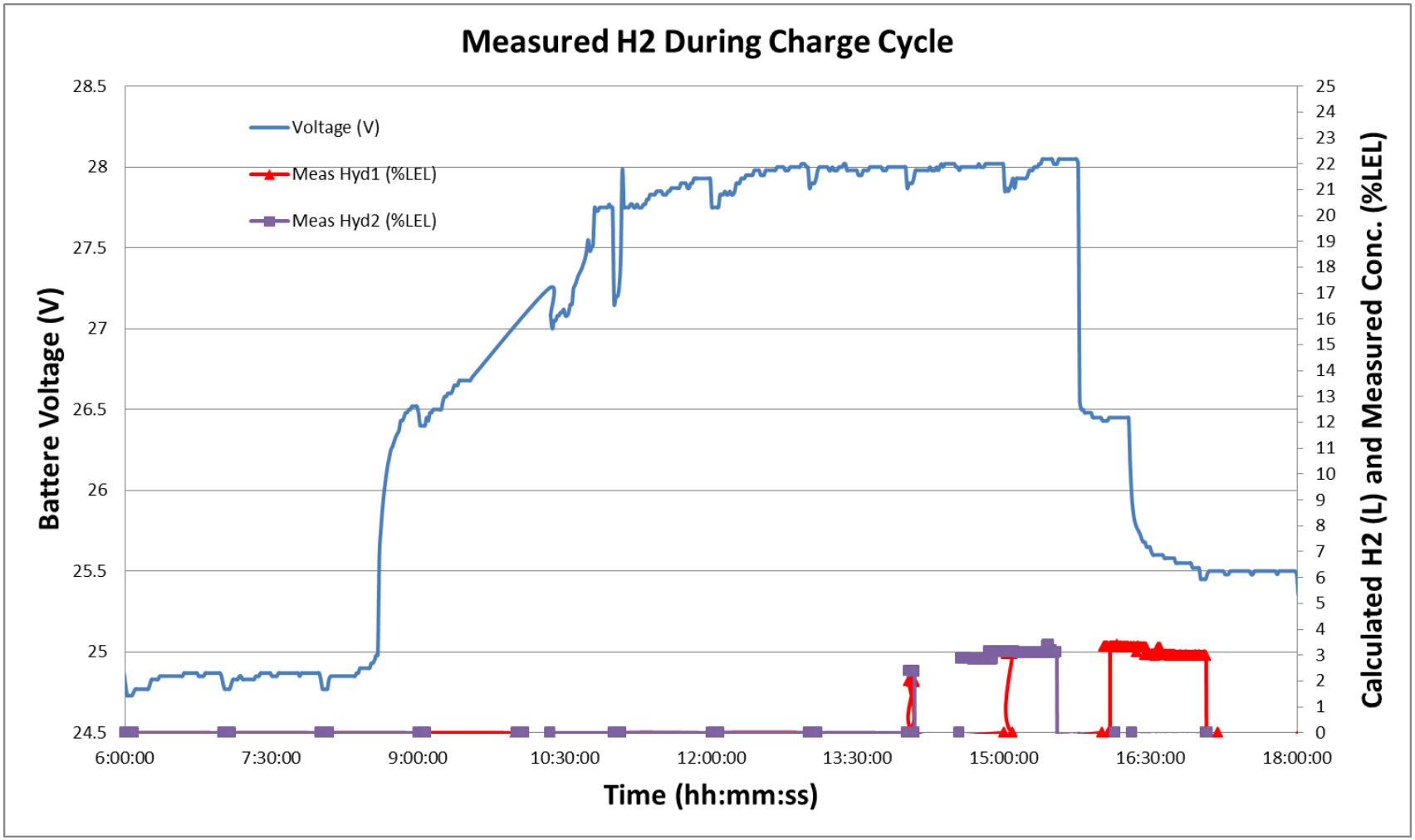


TEST SETUP AND DEFINITION OF TERMS

Recovery Procedure: Monitoring



Recovery Procedure: Monitoring



Recovery Procedure: Decision Making

Normal Monitoring Operation:

1. Data Connection to Shore:
    1. If H2 level > 25% LEL, override charge inputs
    2. If H2 level < 25% LEL, allow normal operation

Recovery Prep: With Communication

1. Disable charging inputs 48-72 hours prior to recovery
2. Communicate H2 levels to recovery team
    1. If H2 level < 10% LEL, follow “Active Mooring” procedure
        1. Recover mooring as normal
        2. Follow “Secure For Transit” step
    2. If H2 level > 10% LEL, follow “Unknown Mooring” procedure

Recovery Prep: Without Communication

1. Attempt LOS communication path
    1. If successful, determine mooring state
2. Visual inspection for signs of blocked ventilation, clear if possible
3. Secure wind turbines if spinning
    1. Allow as much time as feasible prior to “Unknown Mooring” procedure

Recovery Procedure: Unknown Mooring Scenario

Recovery Prep: On Site

Determine if small boat operations are viable:

1. Yes: Assemble following equipment
    1. RKI Instruments Eagle 2 Gas Analyzer
    2. Q size Nitrogen tank
    3. Gas Regulator
    4. Long ½” tubing
    5. Continue with “Unknown Mooring” recovery procedure from small boat platform
2. No: Continue with “Unknown Mooring” recovery procedure

Recovery Procedure: Unknown Mooring Scenario

Recovery: Grounding

This step is designed to prevent any accidental sparks due to Electro-Static Discharge (ESD)

1. Prior to mooring chassis making contact with the deck:
2. Clamp the grounding strap to the instrument well chassis
3. Clamp the other end to ship rail or deck
4. Secure mooring with minimal strapping

Recovery Procedure: Unknown Mooring Scenario

Recovery: Determine Hydrogen Level

This step is to determine if there is a volatile mixture inside the instrument well

1. Remove plastic caps from the “Monitor” and “Purge” ports on the instrument well junction box
2. Insert Gas Analyzer plastic tube into “Monitor” port
    1. If <10% LEL: Recover mooring
    2. If >10% LEL:
        1. Continue monitoring
        2. Continue to purge step

Recovery Procedure: Unknown Mooring Scenario

Recovery: Purge

This step is to clear any accumulated Hydrogen, and Oxygen from the instrument well

1. Continue monitoring H2 levels with Gas Analyzer
2. Connect tubing to “Purge” port
3. Open cylinder valve
4. Adjust regulator to 2-4 psi
5. Purge until H2 < 10% LEL
6. Secure mooring

Recovery Procedure: Unknown Mooring Scenario

Recovery: Prepare for Transit

This step is to prevent any accumulation of Hydrogen during return transit

1. Shut down mooring:
    1. Insert shut down magnet
2. Remove vent valves from tower assembly
3. Monitor H2 levels with Gas Analyzer daily
4. Open instrument well, remove battery connections