Validation of an Advanced High Pressure PEM Electrolyzer and Composite Hydrogen Storage, with Data Reporting, for SunHydro Stations

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7 June 2016 ***6:30 PM***

Project ID # TV020

Overview

Timeline

***Project start date*: Dec 2012**
***Project end date*: June 2017**
***Percent complete*: 95%**

Budget / Funding

Total spent (3/31/16): $ 2,679,258
Total project value: $ 2,810,544
Cost Share Percentage: 50%

Targets/Barriers

- **$2.00-$4.00/gge (2007$)**
- **Hydrogen Storage**
- **Codes and Standards**
- **Lack of current H_2 Refueling Infrastructure Performance and Availability Data**

Proton's Partners / Collaborators / Interactors

Air Products & Chemicals - *Composite Storage / control* - *Supplier*
SunHydro LLC - *Fueling Stations* - *Collaborator*
Toyota Motor Sales - *FCHV Vehicles* - *Interactor*

Relevance / Impact

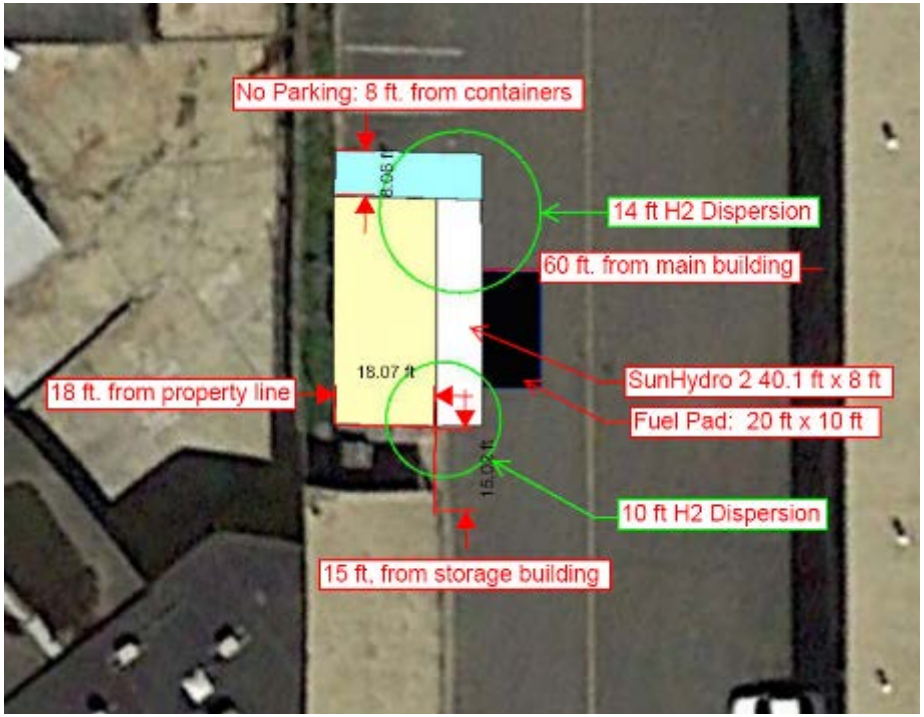
Target / Barriers	Proton team Project Goals
$2.00-$4.00/gge	**Advanced PEM MEAs: (SH#1)** ***Save Up to 8 kWh/kg H_2 - Ph. 2 Go/No-go*** ➢ 57 bar H_2, ambient O_2 ➢ In full-scale 65 cell stack, electrolyzer ***Compared to commercial 30 bar PEM*** **Adv. 57 bar PEM water electrolyzer (SH#1)** ***Save up to 3.6 kWh/kg H_2 - Ph. 2 Go/No-go*** ➢ Reduce H_2 gas drying purge loss ➢ Station mechanical compression to 70MPa ***Compared to 30 bar H_2 supply***
Hydrogen Storage	**Adv. composite H_2 storage (SH#1 and #2)** ***Double useable storage per unit volume*** ➢ Cycle from 28 to 87MPa ***Compared to first generation storage tubes***

Relevance / Impact

Target / Barriers	Proton team Project Goals
Codes and Standards	**<u>Compact Component Arrangements</u>:** ***Fit SH#2 station within 12m ISO container*** ➢ Safety and NFPA 2 code analysis ➢ Novel component arrangements ➢ Classified, non-classified zones ➢ Cooling, power, CSD, H_2 generation ***Speed AHJ approval, reduce install cost***
Lack of H_2 Refueling Infrastructure Performance and Availability Data	**<u>Collect and report SH station performance</u>** ***Validate advanced technologies reliability*** ➢ SunHydro #1 station, SunHydro #2 station ➢ Energy use, # fills, kg dispensed, capacity ➢ Maintenance type and frequency, issues ➢ "%Uptime", any safety or customer issues ***Up to 24 months of station data***

Approach

Safety Analysis for Novel Component Arrangement



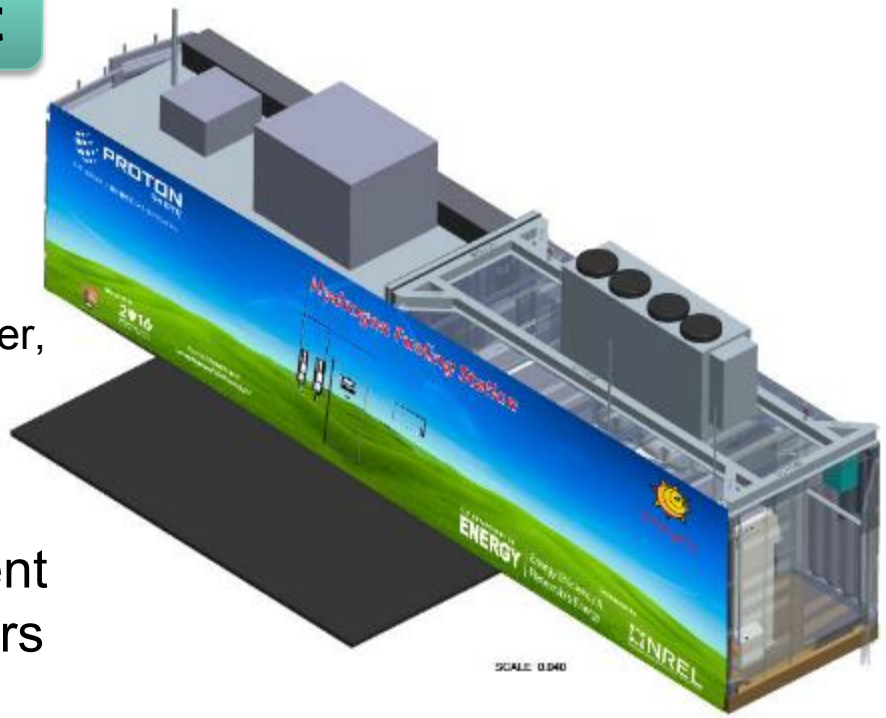
- Hazardous Operations Analysis
  - Identify process hazards that could lead to safety related consequences
  - Recommend ways for reducing risk of events associated with identified hazards
  - Covers H2 generation, compression, storage, and dispensing, HVAC, and siting
- Code Compliance Matrix
  - Diagrams EX zone reduction using code-informed compact component arrangements
  - Implements NFPA 2:2016 revisions
  - Utilized for siting containerized fueling station in Washington, D.C.
  - Enables means to streamline permitting and reduce installation costs

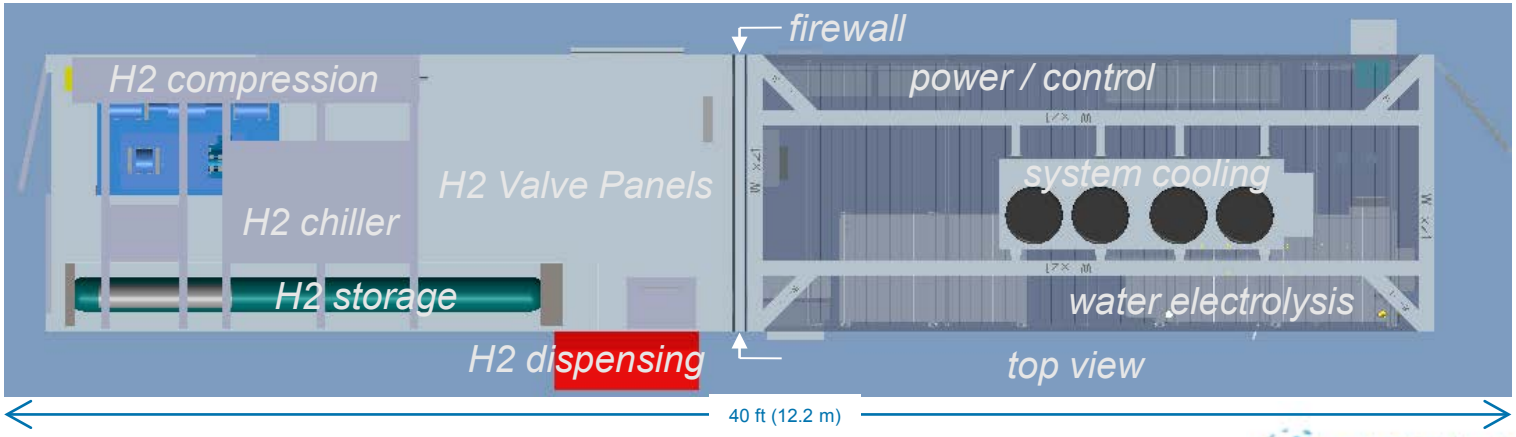
Approach

Novel Component Arrangement

***Goal*: 12m station package, reliable, maintainable, permitted**

- 6m ISO Container (x2)
  - Non-EX container houses electrolyzer, power, and controls
  - EX-rated container houses compression, storage, chilling, and dispensing equipment
- Lightweight 2 hr. firewall allows adjacent placement of EX and non-EX containers





Approach

Individual site summary for Sun Hydro #1 & #2

Station instrumentation install (retrofit & new)

Monitor loads and status of each H_2 subsystem

Report collected Station data using H_2 Refueling Station Templates to Hydrogen Secure Data Center at NREL.

Data Acquisition/Reporting

Quarterly reports: (>24 months)

H2: kg produced, stored, dispensed, SAE J2719 quality, and costs
Energy: kWh/kg for production, compression, dispensing
Station reliability, maintenance, service data, and costs
Station Safety incidents, near misses and hydrogen leaks

Accomplishments and Progress

task	Description	Apr 2016 Progress	Expected Completion Date	Percent Complete
1	57 bar High Eff PEM Stack	*Lessons learned from scale-up of process have been collected* *Stack has operated continuously as needed throughout year*	*2014Q1*	*100%*
2	57 bar 65 kg/d H_2 Generator	*57 bar upgrade components proof tested and installed* *57 bar system operated throughout year to support data collection* *57 bar dryer system tuned and optimized for energy savings*	*2014Q3*	*100%*
3	Composite Storage	*Storage tube qualification completed* *Tubes delivered, installed, and commissioned* *Upgraded performance demonstrated*	*2014Q2*	*100%*
4	57 bar input Compressor	*Modifications for selectable input pressure completed* *Efficiency improvement with higher input pressure demonstrated*	*2014Q3*	*100%*
5	Safety, Code/ Zone Analysis	*State of MA permit issued, DC permit pending*	*2016Q2*	*98%*
6	Novel Comp. Arrangements	*SunHydro#2 design complete – 2X 20ft containers (generation & compression/storage)* *Container construction complete – installation in DC*	*2016Q2*	*98%*
7	Data Acquisition System	*Data acquisition hardware installed and operating for SH1* *Data acquisition hardware installed for SH2* *Data collection software changes for SH2 complete*	*2015Q4*	*100%*
8	Formal Data Reporting	*Data for Sun Hydro #1 reported to NREL for each quarter since 2013 Q4. Data for Sun Hydro #2 coincident with installation.*	*2017Q2*	*65%*

Accomplishments and Progress

Response to 2015 Reviewer's Comments

It is not entirely clear how broad the benefit of this project will be, beyond helping one company build two stations.

The project benefits include relative contribution of higher H2 generation pressure in reducing mechanical compression cost, field validation of Type II ground storage cylinders and a compact fueling station design optimized with the latest code compliances, and station data that highlights infrastructure development needs.

It would be good to see a discussion of how the project is supported by, and will support, automakers that are introducing fuel cell vehicles on the East Coast.

There are discussions happening regarding the future commercial use of the SH station in CT. Use of the SH station in DC is scheduled to begin in June 2016.

The project provides little or no detail about station costs.

The station costs include the energy to run the mechanical compressor, the electrolyzer, HVAC equipment, dispensing equipment, and lights and safety equipment, measured in $/kWh. Costs vary by month based upon station use and uptime with an average of $7.50/kg

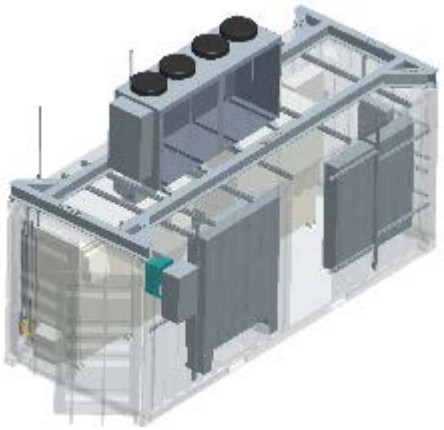
Accomplishments and Progress

CSD Container Complete

- Compression, Storage & Dispensing (CSD) Container complete, including all internal plumbing and wiring
- Received at Proton
- Prepped to ship to DC

Generation Container Complete

- Hydrogen Generation Container complete, including plumbing, ventilation, and power, safety, and control panels
- Built at Proton
- Prepped to ship to DC



Accomplishments and Progress

SH1 Data Acquisition

- Adapted reports to incorporate integrated data collecting with APCI

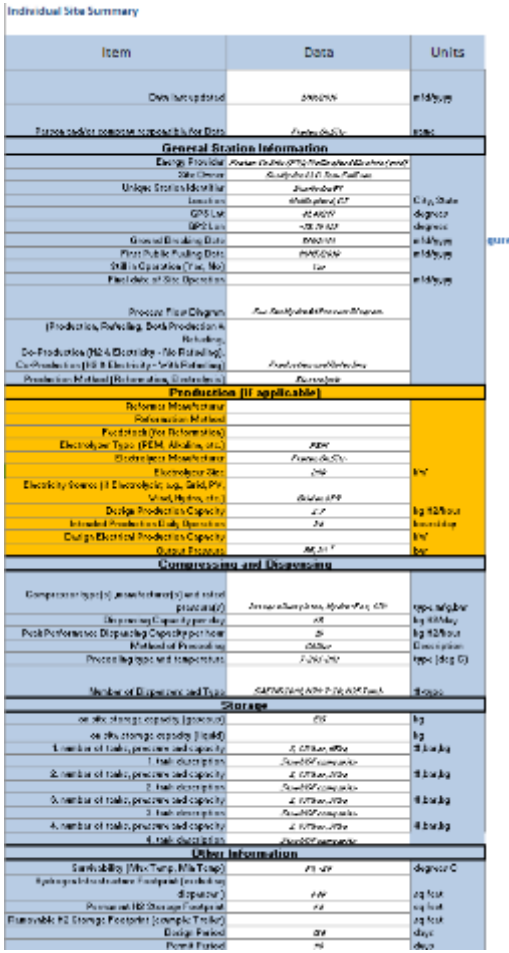
SH1 Data Reporting

- Submitted reports since 2013Q4
- Improving procedures to ensure data reflects true fueling operation with the instrumented H_2 generator
- Showing 4-8 kWh/kg reduction (5-10%)

SH2 Data Acquisition

- Equipment tested and installed
- Data collection scheduled to begin in June 2016

Data Acquisition/Reporting


Individual Site Summary

Item	Data	Units
Date last updated		m/d/yyyy
Person and/or company responsible for Data		name
General Station Information		
Energy Provider		
Site Owner		
Unique Station Identifier		
Location		City, State
GPS Lat		degrees
GPS Lon		degrees
General Opening Date		m/d/yyyy
First Public Fueling Date		m/d/yyyy
Still in Operation (Yes, No)		
Final date of Site Operation		m/d/yyyy
Process Flow Diagram		
(Production, Refueling, Both Production & Refueling, Co-Production (H2 & Electricity - No Refueling), Co-Production (H2 & Electricity - With Refueling), Production Method (Reformation, Electrolysis))		
Production (if applicable)		
Reformer Manufacturer		
Reformation Method		
Feedstock (For Reformation)		
Electrolyzer Type (PEM, Alkaline, etc.)	PEM	
Electrolyzer Manufacturer		
Electrolyzer Size		kW
Electricity Source (If Electrolysis: e.g., Grid, PV, Wind, Hydro, etc.)		
Design Production Capacity		kg H2/hour
Intended Production Daily Operation		hours/day
Design Electrical Production Capacity		kW
Output Pressure		bar
Compression and Dispensing		
Compressor type(s), manufacturer(s) and rated pressure(s)		type; mfg/pwr
Dispensing Capacity per day		kg H2/day
Peak Performance: Dispensing Capacity per hour		kg H2/hour
Method of Pressurization		Description
Processing gases and temperature		type; deg C
Number of Dispensers and Type		#; type
Storage		
on site storage capacity (gaseous)		kg
on site storage capacity (liquid)		kg
1. number of tanks, pressure and capacity		# tanks/kg
1. tank description		
2. number of tanks, pressure and capacity		# tanks/kg
2. tank description		
3. number of tanks, pressure and capacity		# tanks/kg
3. tank description		
4. number of tanks, pressure and capacity		# tanks/kg
4. tank description		
Other Information		
Survivability (Min Temp, Max Temp)		degrees C
Hydrogen Infrastructure Footprint (excluding dispenser)		sq feet
Permanent H2 Storage Footprint		sq feet
Expandable H2 Storage Footprint (example: Trailer)		sq feet
Design Period		days
Permit Period		days

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Collaborations

Department of Energy, NREL and NPS - Installation and Operations

- *NPS Siting, A&E, Construction, O&M of SunHydro #2 through the NREL Station case study project*

SunHydro LLC *Fueling Stations*

- *Owner of SunHydro#1 station in Wallingford CT and SunHydro#2 station in Brentwood Washington DC*
- *Cost share provider*

Toyota Motor Sales - *FCHV Vehicles*

- *Provided FCHV-adv cars used at SH#1*
- *No cost lease with SunHydro LLC*

Air Products & Chemicals – *Storage/control*

- *Supplier of advanced storage, commissioning*
- *Supplier of programming and dispensing data services*

Future Work

Balance Phase 1 Major Activity

2Q'16 SunHydro#2 commissioning

-ACCOMPLISHED-

Phase 2 Major Activity

Ongoing **Station data acquisition and reporting**

Support NREL Hydrogen Station Case Study Project, provide lesson's learned and potential design improvements for site selection, A&E, construction, and M&O from Proton's perspective.

Project Summary

Relevance: **Addresses DoE goal of <$4/gge, MYPP barriers of H_2 storage, codes, and lack of station performance data**

Approach: **Adv. 57bar PEM water electrolyzer, next-generation 87MPa composite storage tanks, and skid-mounted compact refueling component arrangements with SunHydro#1 and SunHydro#2 stations. Data reporting 36+ months for both SunHydro stations with adv. components.**

Tech Accomplishments: **57bar stack and system built and tested; SunHydro#1 and #2 advance storage installed; SH#1 data monitoring and energy measurements ongoing; 8 kWh/kg energy reduction; SunHydro#2 installation**

Collaborations: **SunHydro LLC** (stations), **Toyota Motors** (vehicles), **APCI** (supplier storage upgrade and programming)

Future Work : **SH#2 install, data reporting for SH#1 and SH#2**

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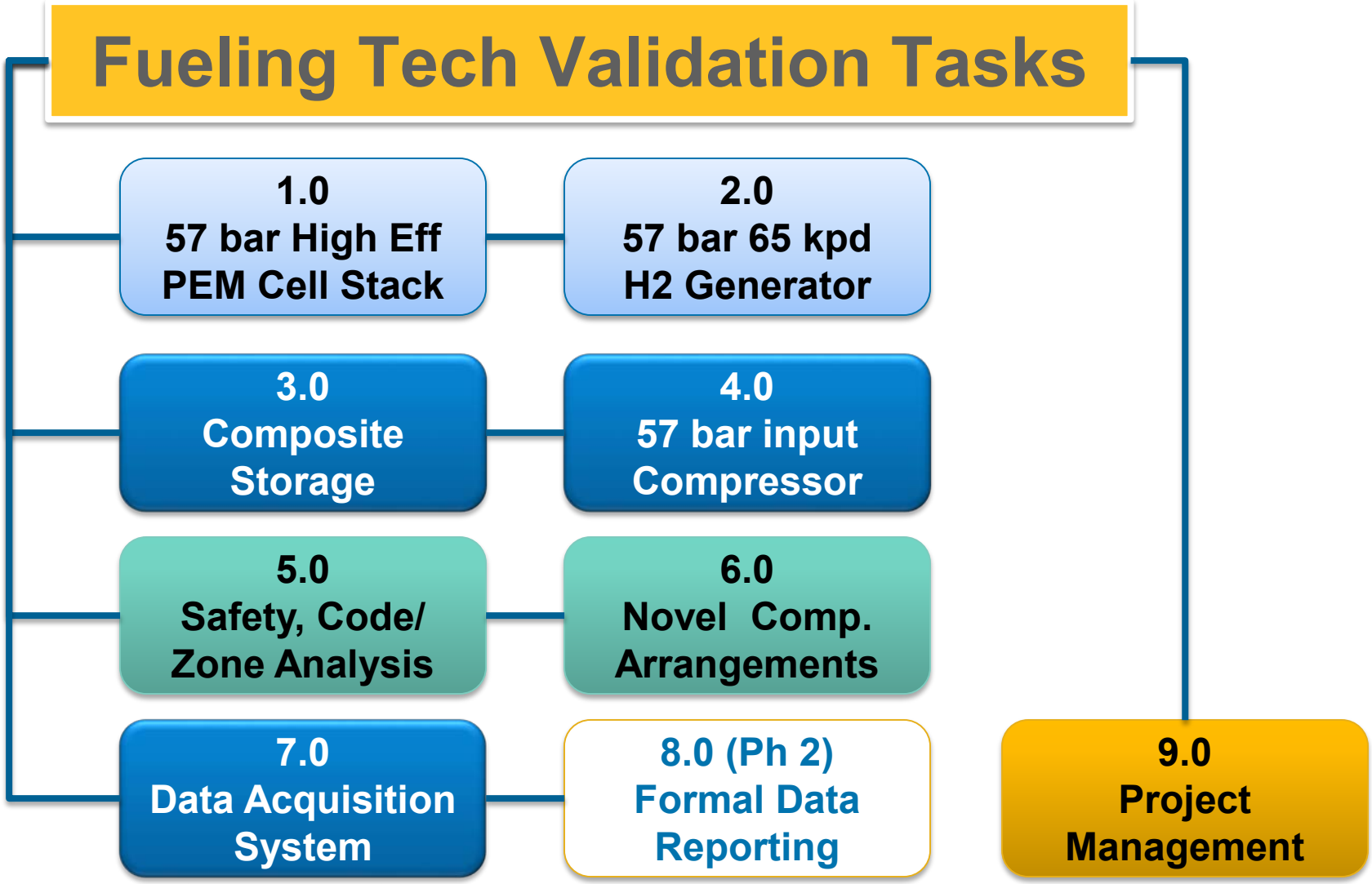
Technical Back-Up Slides

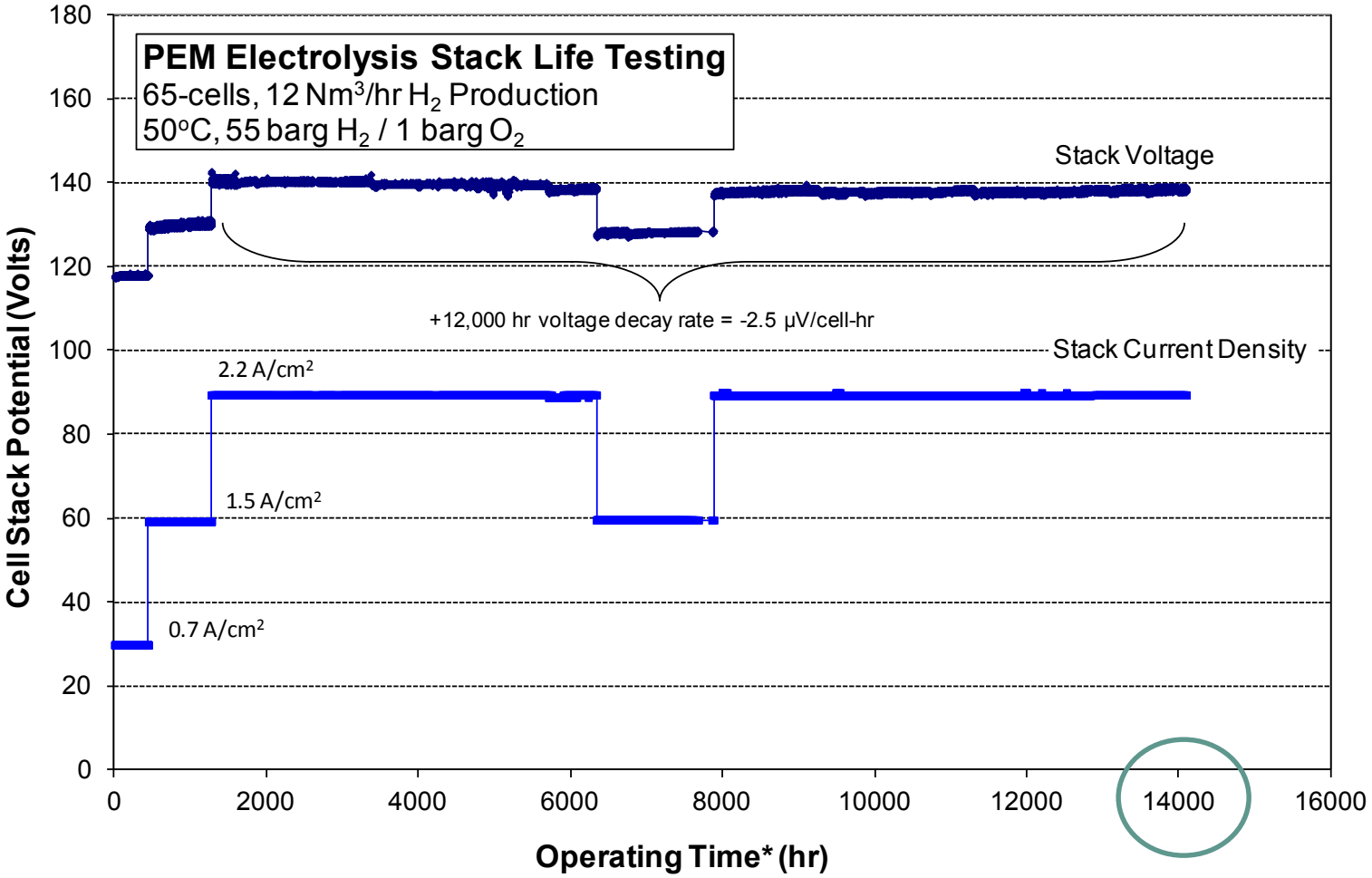
Approach


Fueling Tech Validation Tasks
1.0
57 bar High Eff
PEM Cell Stack
2.0
57 bar 65 kpd
H2 Generator
3.0
Composite
Storage
4.0
57 bar input
Compressor
5.0
Safety, Code/
Zone Analysis
6.0
Novel Comp.
Arrangements
7.0
Data Acquisition
System
8.0 (Ph 2)
Formal Data
Reporting
9.0
Project
Management

Proton® C Series PEM Electrolysis Stack

- **10 Nm^3/hr stack for Navy Life Support Application in 2008**
  - 57 bar H_2 differential pressure
  - Over 1 million cell-hrs of validation
  - Currently in serial production
  - Over 18 months on-board submarines
- **Derivative 30 bar version in 2009**
  - Basis of C-Series 30 Nm^3/hr commercial product design
  - Over 1.5 Million cell-hrs of customer field experience to date

PEM Electrolysis Life Testing – 'Mature'



*Note: Non-operating time and restarts removed from graph

SunHydro #1 Operations

Jan 2011 – Dec 2015

>14,000 kg of hydrogen dispensed

>3,600 high pressure H2 fills

Serving fleet of 12 FCHV and paratransit

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SunHydro #1 Diagram

A. 75 kW photovoltaic array
B. Net metering / grid connection
C. 65 kg/d H_2 Generation from H_2O
D. 30 hp / 87MPa H_2 Compression
E. 135 kg H_2 Storage @ 83 MPa
F. H35-Tamb / H70-T-20 Dispensers