

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

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Principle Investigator



19 June 2014 1:45:00 PM

**Project ID #
TV020**

Overview

Timeline

Project start date: Dec 2012
Project end date: June 2016
Percent complete: 68%

Budget / Funding

\$ 1,400,000 total DoE share
\$ 1,420,397 total cost share
FY13 Funding : \$805,910
FY14 Funding : \$445,056

Targets/Barriers

- **\$2.00-\$4.00/gge (2007\$)**
- **Hydrogen Storage**
- **Codes and Standards**
- **Lack of current H₂ 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 H₂ - Ph. 2 Go/No-go

- 57 bar H₂, ambient O₂
- 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 H₂ - Ph. 2 Go/No-go

- Reduce H₂ gas drying purge loss
- Station mechanical compression to 70MPa

Compared to 30 bar H₂ supply

Hydrogen Storage

Adv. composite H₂ 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

Compact Component Arrangements:

Fit SH#2 station within 12m ISO container

- Safety and NFPA 2 code analysis
- Novel component arrangements
- Classified, non-classified zones
- Cooling, power, CSD, H₂ generation

Speed AHJ approval, reduce install cost

Lack of H₂ Refueling Infrastructure Performance and Availability Data

Collect and report SH station performance

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

57 bar, 65 kg/d H₂ Generator

Build 30bar baseline generator

Upgrade H₂ gas components

- 30 bar to 57 bar, 1.5x proof

Build adv. full-scale 65 cell stack

- advanced thinner PEM membrane
- advanced screened electrodes

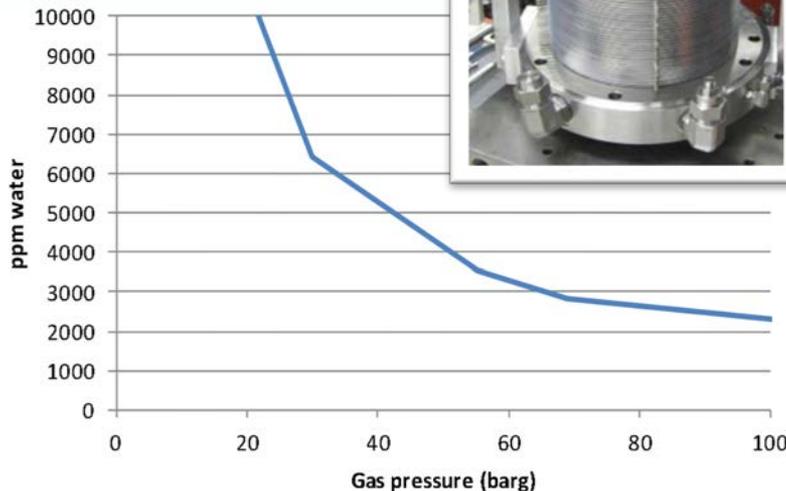
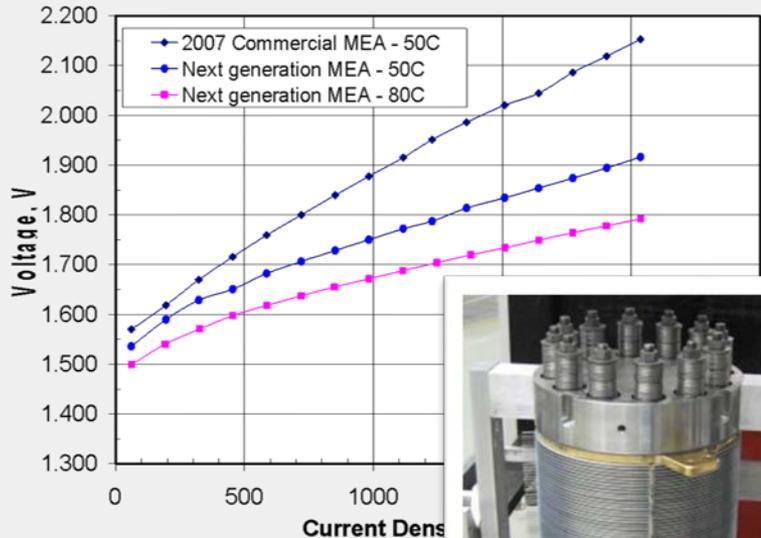
Validate mechanical integrity

Validate voltage reduction

Make 65 kg H₂/day at 57 bar

Goal: 50% less dryer purge loss

Goal: up to 8 kWh/kg H₂ savings



Approach

Upgrade Compression & Composite Storage

Perform differential compressor comparison

- 57 bar input at SunHydro #1
- 30 bar input at SunHydro #2

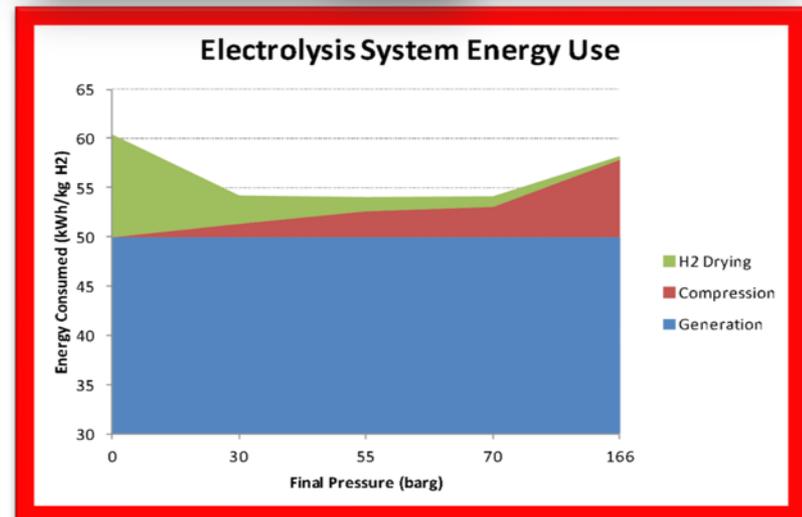
Upgrade/new storage systems,

- SunHydro#1 : add 3 new 280 / 870 bar H2 composite storage tubes to 6 existing 630 to 870 bar tanks
- new installation for SunHydro#2

Goal: SH#1 capacity increase

Goal: kWh/kg reduction

Goal: kg/h increase



Approach

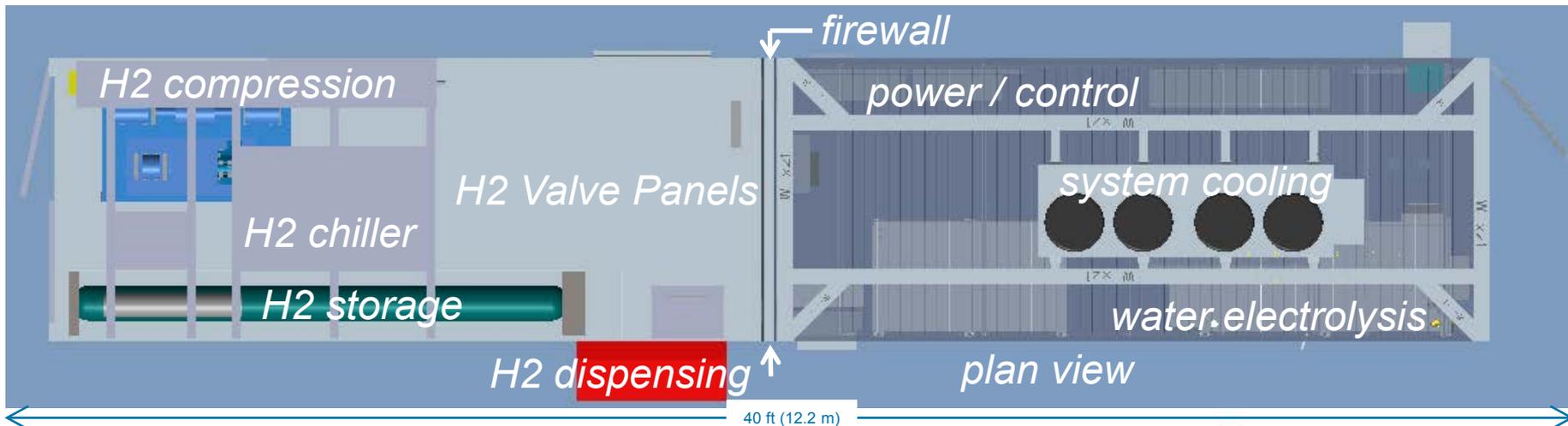
Safety, Code/ Zone Analysis

- Review/update hazard evaluations for station upgrades
- Author safety operations plan
- Diagram EX zone reduction using code-informed compact component arrangements
- Participate in NFPA 2 revisions

Novel Comp. Arrangements

- Non-EX electrolyzer adjacent to EX-rated CSD, in 12m ISO container
- Lightweight 2 h firewalls to demise
- Power, control, thermal in non-EX

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



Approach

Individual site summary for
Sun Hydro #1 & #2

Station instrumentation
install (retrofit & new)

Monitor loads and status of
each H₂ subsystem

Report collected Station data
using H₂ Refueling Station
Templates to Hydrogen Secure
Data Center at NREL.

Quarterly reports: (24 months)

H₂ : kg produced, stored, dispensed, SAE J2719 quality, and costs

Energy: kWh/kg for production, compression, dispensing

Station reliability, maintenance, repairs, service data, and costs

Station Safety incidents, near misses and hydrogen leaks

Data Acquisition/Reporting



Accomplishments and Progress

task	Description	Apr 2014 Progress	Expected Completion Date	Percent Complete
1	57 bar High Eff PEM Stack	<i>High efficiency membrane processing equipment in use Stack built and passed manufacturing ATP</i>	2014Q1	90%
2	57 bar 65 kg/d H ₂ Generator	<i>Baseline Generator built 57 bar upgrade components built, tested, and awaiting installation</i>	2014Q2	85%
3	Composite Storage	<i>Storage tubes on order Delivery significantly delayed Site installation plan and materials ready</i>	2014Q2	50%
4	57 bar input Compressor	<i>Compressor design confirmed for 57 bar Modifications underway for selectable input pressure</i>	2014Q2	75%
5	Safety, Code/ Zone Analysis	<i>NFPA 2 station and onsite generation chapter revisions Local AHJ engaged and working permitting</i>	2014Q3	75%
6	Novel Comp. Arrangements	<i>SunHydro#2 design complete – 2X 20ft containers (generation & compression/storage) Construction underway – container received, generator manufactured, CSD close to complete</i>	2014Q3	70%
7	Data Acquisition System	<i>Data acquisition hardware installed and operating for SH1 Data acquisition hardware prepped for SH2 Data collection software changes for SH2 underway</i>	2014Q3	60%
8	Formal Data Reporting	<i>Data for Sun Hydro #1 reported to NREL for 2013Q4 and 2014Q1</i>	2016Q2	20%

Accomplishments and Progress

Response to 2013 Reviewer's Comments

The investigator should focus more on cost and where it needs to be. / Cost is probably the main obstacle in deploying electrolyzer based fueling stations. More emphasis needs to be placed on cost reduction efforts.

The project seeks to show H2 cost reduction through efficiency improvements, up to 12 kWh/kg potential. The project seeks to reduce infrastructure hardware cost through novel arrangement that minimizes classified electrical equipment. The project seeks to reduce infrastructure installation cost through reduction in required area, site preparation, and separation distances.

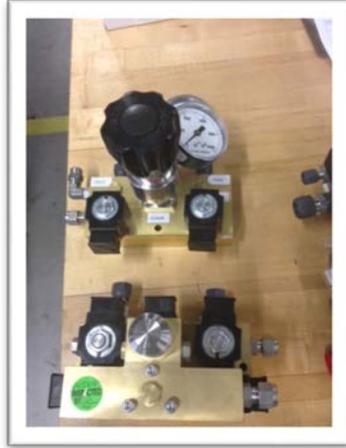
SunHydro LLC and Proton OnSite both share the same ownership. This could restrict the transfer of technology to other electrolyzer and H2 station OEMs.

Learnings from component arrangements are based on open-source building code. Learnings on station reliability will enhance overall data record.

Relevance and impact are limited since this project evaluates one design and one set of components (e.g, just one type of hydraulic compressor and one electrolyzer)

Proton expects the DoE will compare and contrast our evaluation with data from other projects and technologies

Accomplishments and Progress



57 bar, 65 kg/d H₂ Generator

Operating 30bar generator

Upgraded 57bar H₂ components

- H₂ dryer / Phase Separators
- Passed hydro proof test
- Install awaiting station upgrade

Built adv. full-scale 65 cell stack

- Scaled up advanced MEA manufacturing process
- Passed ATP
- Initial voltage higher than predicted based on sub-scale testing

Accomplishments and Progress

Upgrade Compression & Composite Storage

Upgrade/new storage systems

- 6 new 280/870 bar storage tubes on order (3 for SH1, 3 for SH2)
- Delivery delayed 7 months
- Expected install/commission May 2014
- Site prepped for installation

Compressor Design

- Compressor design confirmed for 57bar input
- Software modifications complete and awaiting tube install/commission



Accomplishments and Progress

CSD Container Progress

- Compression, Storage & Dispensing (CSD) Container at 95% Complete
- Final plumbing between skidded components taking place.



2014 AMR TV020

Generation Container Final Model Design

- Design complete
- Fabrication at 35% Complete
- All major and minor components allocated, purchased and ready for integration
- Container received and being modified



13

Accomplishments and Progress

SH1 Data Acquisition

- Panel retrofit installed – PLC, power meters
- Integrates with APCI fueling data delivery (awaiting software update during tube install/commission)
- Local data monitoring

SH1 Data Reporting

- Submitted 2013Q4 and 2014Q1 fueling data to NREL

SH2 Data Acquisition

- Panel items received
- Integrate during SH2 construction
- Software upgraded for discrete cooling energy monitoring

Data Acquisition/Reporting

Item	Data	Units
Date last updated	10/28/2014	m/4/yyyy
Person or other company responsible for Data	Proton On Site	name
General Station Information		
Energy Provider	Proton On Site (P3), Wallingford Electric (grid)	
Site Owner	SunHydro LLC Tom Sullivan	
Unique Station Identifier	SunHydro#1	
Location	Wallingford, CT	City, State
GPS Lat	41.46217	489948
GPS Lon	-72.76483	489948
Ground Breaking Date	7/24/2010	m/4/yyyy
First Public Fueling Date	10/16/2010	m/4/yyyy
Still in Operation (Y/N)	Yes	
Final date of Site Operation		m/4/yyyy
Process Flow Diagram	See SunHydro#1 Process Diagram	
(Production, Refueling, Both Production & Refueling)	Refueling	
Co-Production (H2 & Electricity - No Refueling)		
Co-Production (H2 & Electricity - With Refueling)	Production and Refueling	
Production Method (Reformation, Electrolysis)	Electrolysis	
Production (if applicable)		
Reformation Method		
Reformation Method	Feedstock (for Reformation)	
Electrolyzer Type (PEM, alkaline, etc.)	PEM	
Electrolyzer Brand/Manufacturer	Proton On Site	
Electrolyzer Size	200	kW
Electricity Source (if Electrolyzer, e.g., Grid, PV, Wind, Hydro, etc.)	Grid and PV	
Duration Production Capacity	2.7	kg H2/hour
Intended Production Daily Operation	24	hours/day
Duration Electrical Production Capacity		kW
Output Pressure	20	bar
Compressing and Dispensing		
Compressor type(s), manufacturer(s) and rated pressure(s)	Zetecq-2000 series, Hydro-Fox, 670	type, m/4-bar
Dispensing Capacity per day	65	kg H2/day
Peak Performance Dispensing Capacity per hour	65	kg H2/hour
Method of Processing	Chiller	Description
Process inlet type and temperature	7-20 (<20)	type (<40 C)
Number of Dispenser and Type	SAFARI 2000, N70-F-20, NSF Tank	#/type
Storage		
on-site storage capacity (gaseous)	00	kg
on-site storage capacity (liquid)		kg
1. number of tanks, pressure and capacity	3, 670 bar, 450 kg (nominal) up to 625 kg	#, bar, kg
1. tank description	2000CF composite	#, bar, kg
2. number of tanks, pressure and capacity	2, 670 bar, 200 kg	#, bar, kg
2. tank description	2000CF composite	#, bar, kg
3. number of tanks, pressure and capacity	2, 670 bar, 200 kg	#, bar, kg
3. tank description	2000CF composite	#, bar, kg
4. number of tanks, pressure and capacity	2, 670 bar, 200 kg	#, bar, kg
4. tank description	2000CF composite	#, bar, kg
Other Information		
Survivability (Max Temp, Min Temp)	50, -20	489948 C
Hydrogen Infrastructure Footprint (excluding dispenser)		sq foot
Permanent H2 Storage Footprint (excluding Trailer)	64	sq foot
Removable H2 Storage Footprint (excluding Trailer)		sq foot
Duration Period	00	days
Permit Period	00	days
Construction Period	00	days
Commissioning Period	00	days
Additional Information		



Figure 1. SunHydro #1 Compression, Storage, Dispensing Containerized System



Figure 2. Hydrogen from Proton System Test Facility



Figure 3. Compression and Storage, SunHydro #1



Figure 4. Cold Block and Chiller enable H70 Fast Fill

Collaborations



SunHydro LLC - *Fueling Stations*

- *Owner of SunHydro#1 station in Wallingford CT and SunHydro#2 station in Braintree MA*
- *Cost share provider*



Toyota Motor Sales - *FCHV Vehicles*

- *Provides 12 FCHV-adv cars used at SH#1 and #2*
- *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

2-3Q 57 bar PEM water electrolyzer test*

2-3Q SunHydro#1 storage commission, compressor test*

3-4Q SunHydro#2 arrangements, permitted, commissioned

**Adv stack, 57 bar system eff. Go/No-go Phase 2*

Phase 2 Major Activity

3Q-onward Station Data Acquisition

Project Summary

Relevance: Addresses DoE goal of <\$4/gge, MYPP barriers of H₂ storage, codes, and lack of station performance data

Approach: Validate H₂ fueling infrastructure performance gains of an adv. 57bar PEM water electrolyzer, next-generation 87MPa composite storage tanks, and skid-mounted compact refueling component arrangements with an updated SunHydro#1 station and a fully containerized SunHydro#2 station. Data reporting to 24 months both SunHydro stations with adv. components.

Tech Accomplishments: 57bar stack and system built; SunHydro#1 and #2 advance storage ordered; SH#2 designed and fabrication begun; SH#1 data monitoring underway

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

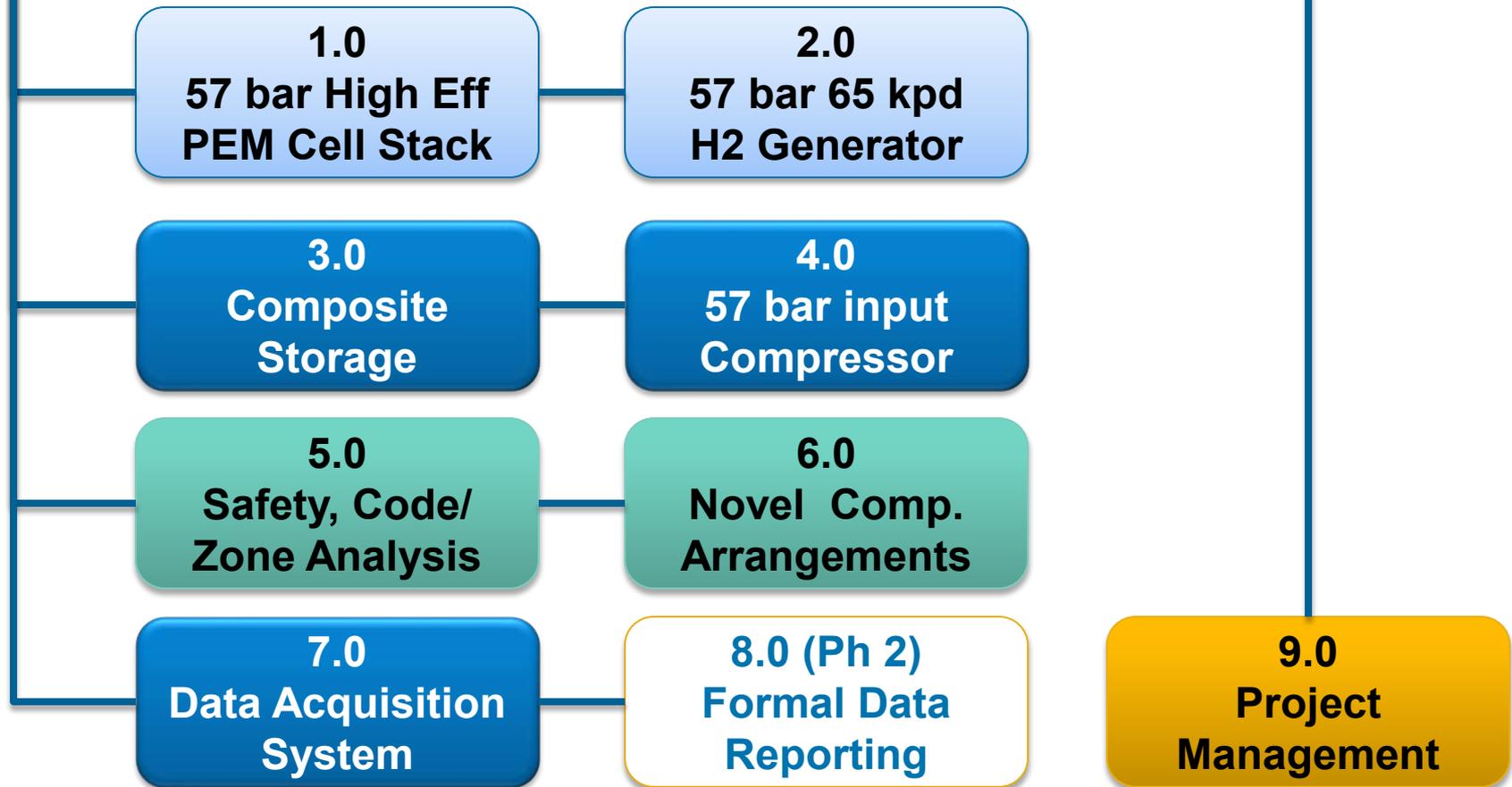
Future Work : Perform adv. PEM test; 57bar electrolyzer install, SH#1 storage upgrade, compressor test, SH#2 install & data monitoring

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Technical Back-Up Slides

Approach

Fueling Tech Validation Tasks

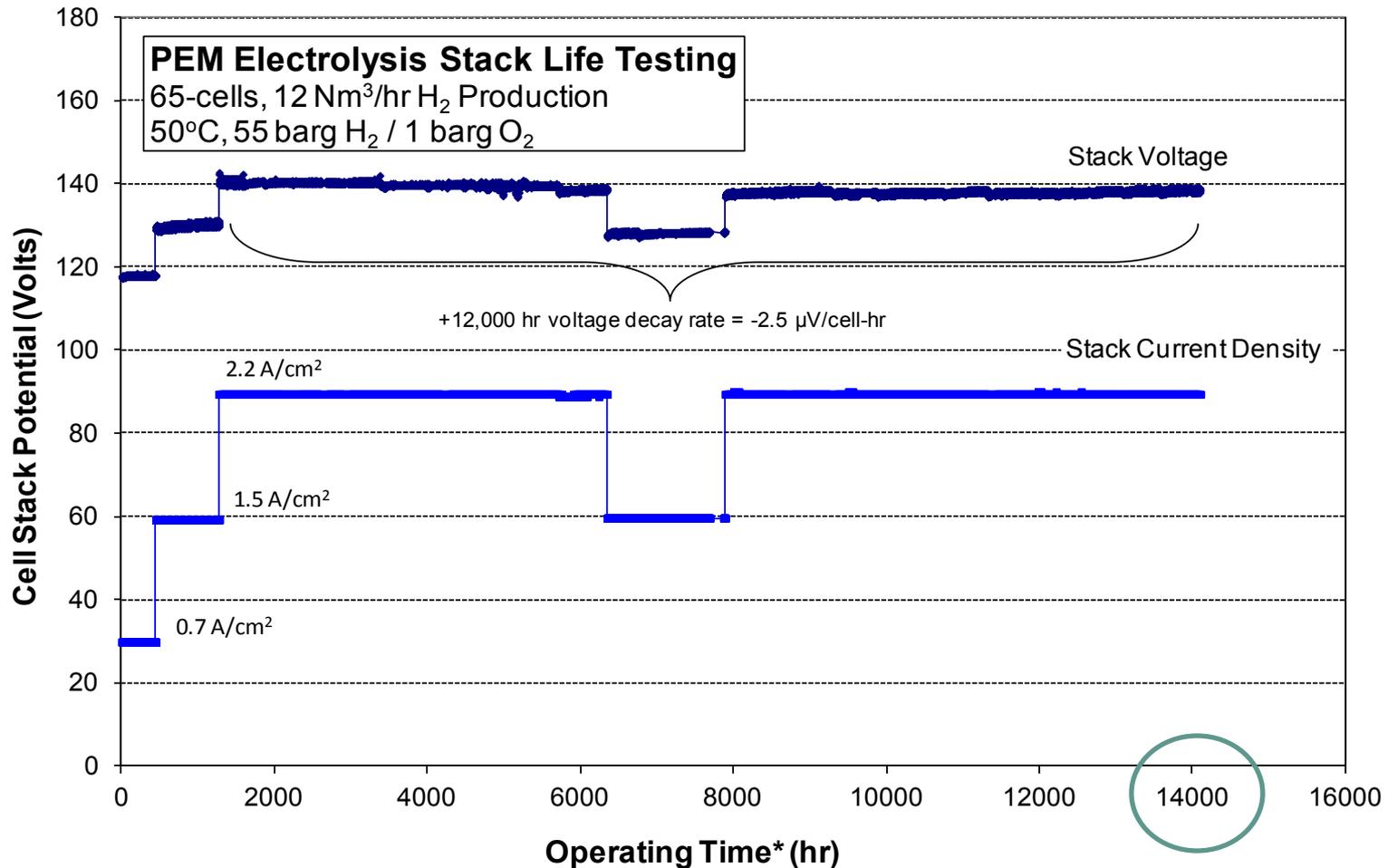


Proton® C Series PEM Electrolysis Stack

- **10 Nm³/hr stack for Navy Life Support Application in 2008**
 - 57 bar H₂ 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 Nm³/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 – Apr 2014



>7000 kg of hydrogen dispensed

>2500 high pressure H2 fills

Serving fleet of 12 FCHV and paratransit



SunHydro #1 Diagram

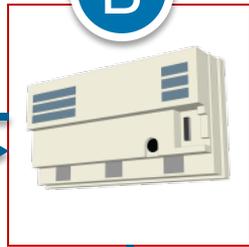
- A. 75 kW photovoltaic array
- B. Net metering / grid connection
- C. 65 kg/d H₂ Generation from H₂O
- D. 30 hp / 87MPa H₂ Compression
- E. 135 kg H₂ Storage @ 83 MPa
- F. H35-Tamb / H70-T-20 Dispensers



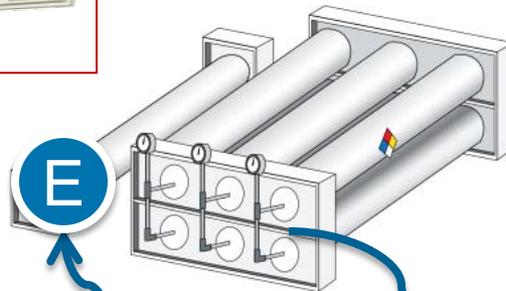
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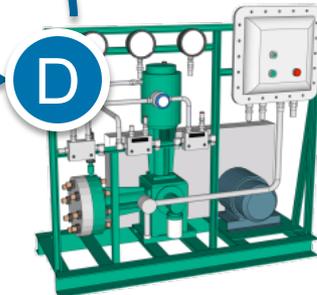
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