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

Larry Moulthrop

Principle Investigator

PROTON ON SITE™

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 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*

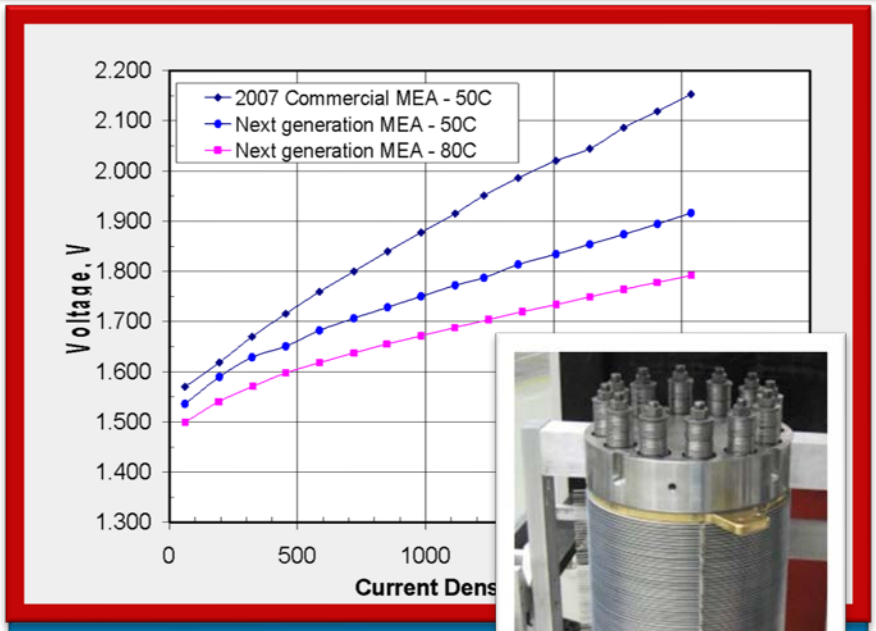
Relevance / Impact

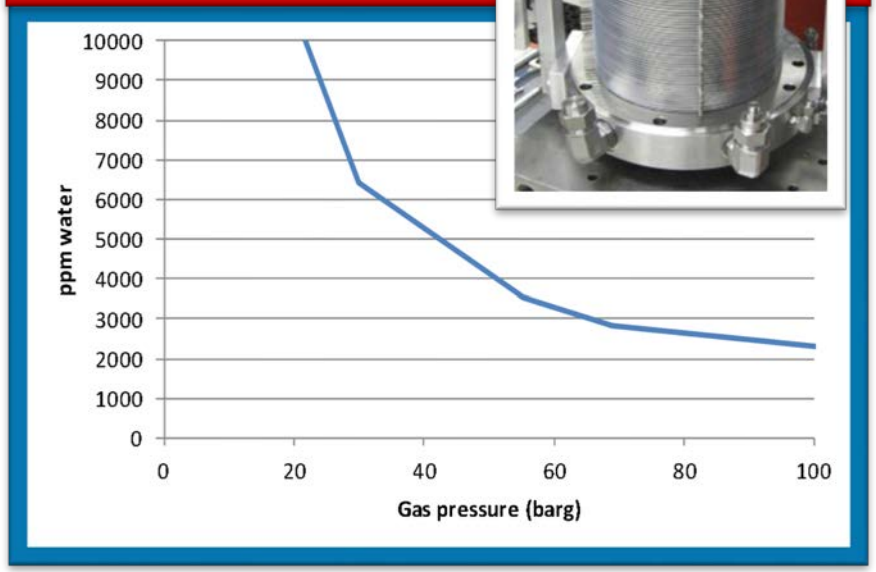
Target / Barriers	Proton team Project Goals
$2.00-$4.00/gge	**Advanced PEM MEAs: (SH#1)** ***Save Up to 8 kWh/kg H_2 - Ph. 2 Go/No-go*** ➢ 57 bar H_2, ambient O_2 ➢ In full-scale 65 cell stack, electrolyzer ***Compared to commercial 30 bar PEM*** **Adv. 57 bar PEM water electrolyzer (SH#1)** ***Save 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 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	**<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





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 H_2 savings**

Approach

Upgrade Compression & Composite Storage

Perform differential compressor comparison

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

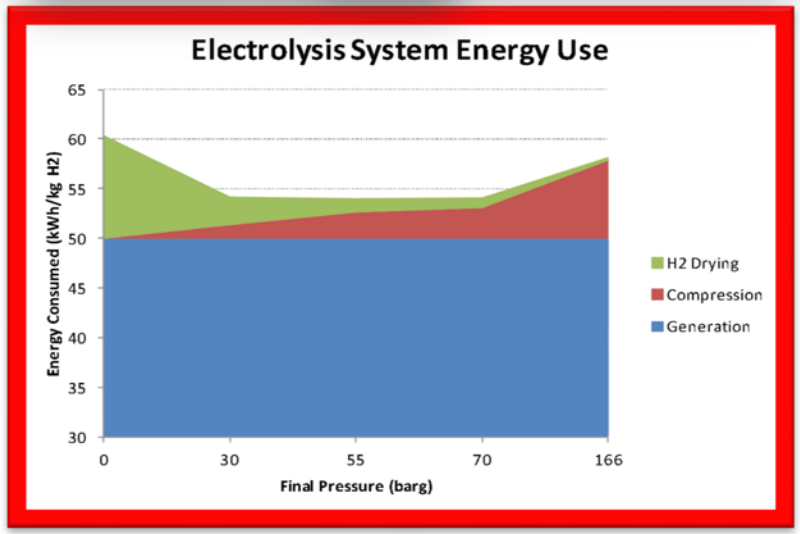
Upgrade/new storage systems,

- 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



PROTON ON SITE

Approach

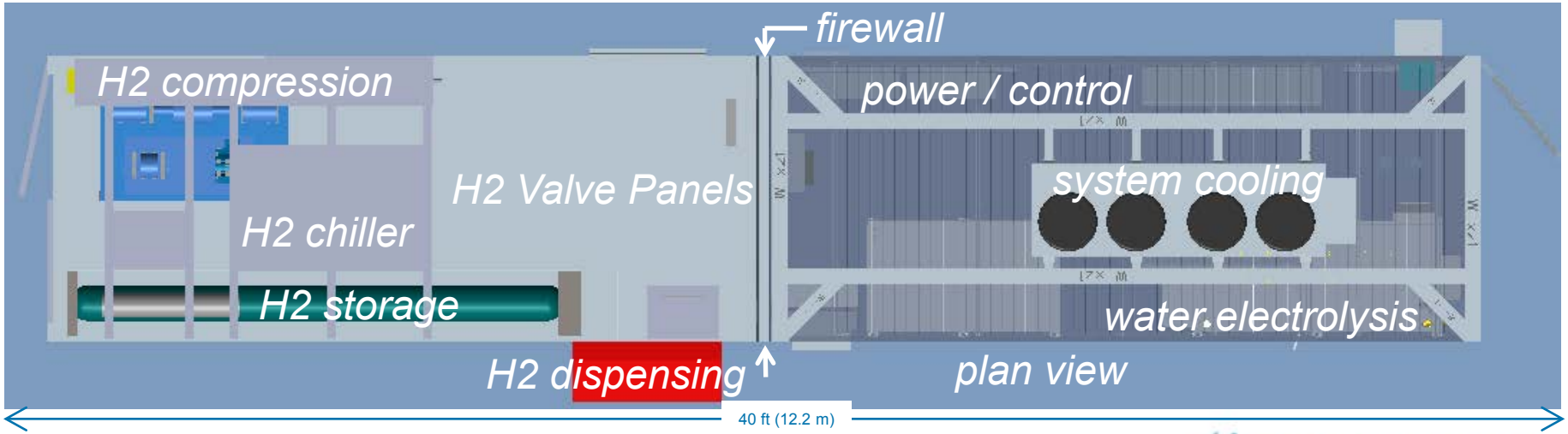
Safety, Code/ Zone Analysis

- 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 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, repairs, service data, and costs
Station Safety incidents, near misses and hydrogen leaks

Accomplishments and Progress

task	Description	Apr 2014 Progress	Expected Completion Date	Percent Complete
1	57 bar High Eff PEM Stack	*High efficiency membrane processing equipment in use* *Stack built and passed manufacturing ATP*	*2014Q1*	*90%*
2	57 bar 65 kg/d H_2 Generator	*Baseline Generator built* *57 bar upgrade components built, tested, and awaiting installation*	*2014Q2*	*85%*
3	Composite Storage	*Storage tubes on order* *Delivery significantly delayed* *Site installation plan and materials ready*	*2014Q2*	*50%*
4	57 bar input Compressor	*Compressor design confirmed for 57 bar* *Modifications underway for selectable input pressure*	*2014Q2*	*75%*
5	Safety, Code/ Zone Analysis	*NFPA 2 station and onsite generation chapter revisions* *Local AHJ engaged and working permitting*	*2014Q3*	*75%*
6	Novel Comp. Arrangements	*SunHydro#2 design complete – 2X 20ft containers (generation & compression/storage)* *Construction underway – container received, generator manufactured, CSD close to complete*	*2014Q3*	*70%*
7	Data Acquisition System	*Data acquisition hardware installed and operating for SH1* *Data acquisition hardware prepped for SH2* *Data collection software changes for SH2 underway*	*2014Q3*	*60%*
8	Formal Data Reporting	*Data for Sun Hydro #1 reported to NREL for 2013Q4 and 2014Q1*	*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.

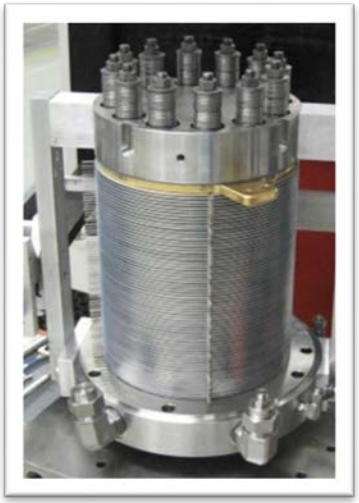
SunHydro LLC and Proton OnSite both share the same ownership. This could restrict the transfer of technology to other electrolyzer and H2 station OEMs.

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

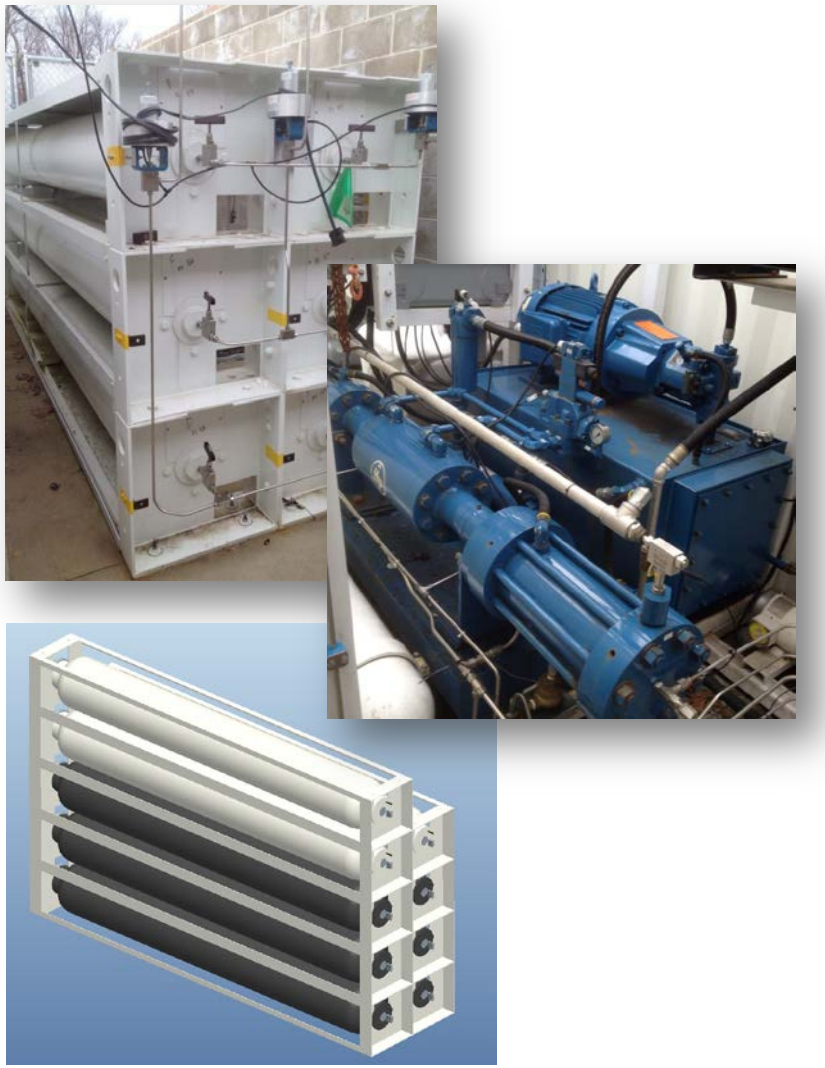
Upgrade Compression & Composite Storage

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



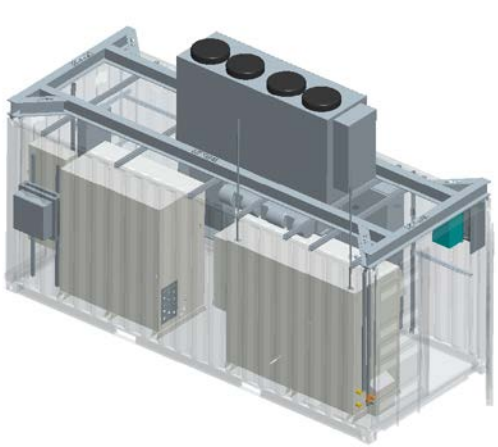
Accomplishments and Progress

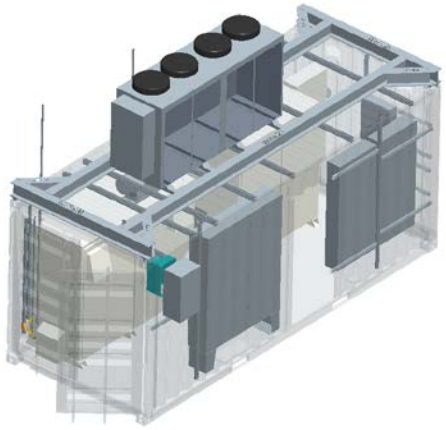
CSD Container Progress

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

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





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

Individual Site Summary

Item	Data	Units
Data last updated	12/5/2013	mm/dd/yyyy
Person and/or company responsible for Data	Proton OnSite	name
General Station Information		
Energy Provider/proton OnSite (PV); Wallingford Electric (grid)		
Site Owner	SunHydro LLC Tom Sullivan	
Unique Station Identifier	SunHydro #1	
Location	Wallingford, CT	City, State
GPS Lat	41.49217	degrees
GPS Lon	-72.79463	degrees
Ground Breaking Date	7/1/2010	mm/dd/yyyy
First Public Fueling Date	10/15/2010	mm/dd/yyyy
Still in Operation (Yes, No)	Yes	
Final date of Site Operation		mm/dd/yyyy
Process Flow Diagram	See SunHydro #1 Process Diagram	
(Production, Refueling, Both Production & Refueling, Co-Production (H2 & Electricity - No Refueling), Co-Production (H2 & Electricity - With Refueling)	Production and Refueling	
Production Method (Reformation, Electrolyzer)	Electrolyzer	
Production (if applicable)		
Reformer Manufacturer		
Reformation Method		
Feedstock (for Reformation)		
Electrolyzer Type (PEM, Alkaline, etc.)	PEM	
Electrolyzer Manufacturer	Proton OnSite	
Electrolyzer Size	200	kW
Electricity Source (if Electrolyzer; e.g., Grid, PV, Wind, Hydro, etc.)	Grid and PV	
Design Production Capacity	2.7	kg H2/hour
Intended Production Daily Operation	24	hours/day
Design Electrical Production Capacity		kW
Output Pressure	30	bar
Compressing and Dispensing		
Compressor type(s), manufacturer(s) and rated pressure(s)	2 stage oil-less piston, Hydro-Pac, 870	type, mfg, bar
Dispensing Capacity per day	65	kg H2/day
Peak Performance Dispensing Capacity per hour	15	kg H2/hour
Method of Pre-cooling	Chiller	Description
Pre-cooling type and temperature	7-2°F (-2°C)	type (deg C)
Number of Dispensers and Type	2 SAE J2601, H70-T-20, NGS Tomb	#-type
Storage		
on-site storage capacity (gaseous)	90	kg
on-site storage capacity (liquid)		kg
1. number of tanks, pressure and capacity	3, 6700 cu. ft, 454 kg (pending upgrade to 1584 kg)	#, bar, kg
1. tank description	Steel/COF composite	
2. number of tanks, pressure and capacity	2, 6700 cu. ft, 300 kg	#, bar, kg
2. tank description	Steel/COF composite	
3. number of tanks, pressure and capacity	2, 6700 cu. ft, 300 kg	#, bar, kg
3. tank description	Steel/COF composite	
4. number of tanks, pressure and capacity	2, 6700 cu. ft, 300 kg	#, bar, kg
4. tank description	Steel/COF composite	
Other Information		
Survivability (Max Temp, Min Temp)	54, -20	degrees C
Hydrogen Infrastructure Footprint (excluding dispenser)	1400	sq feet
Permanent H2 Storage Footprint	64	sq feet
Removable H2 Storage Footprint (example: Trailer)		sq feet
Design Period	120	days
Permit Period	90	days
Construction Period	150	days
Commissioning Period	30	days
Additional information		

igure 1. SunHydro #1 Compression, Storage, Dispensing Containerized Sy

Figure 2. Hydrogen from Proton System Test Facility

L. 40 hp 2-stage compressor
R. 90 kg H2, composite steel tubes

Figure 3. Compression and Storage, SunHydro #1

Cold block in EX zone

R. 20-ton chiller behind 2 hr firewall

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 H_2 storage, codes, and lack of station performance data**

Approach: **Validate H_2 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**

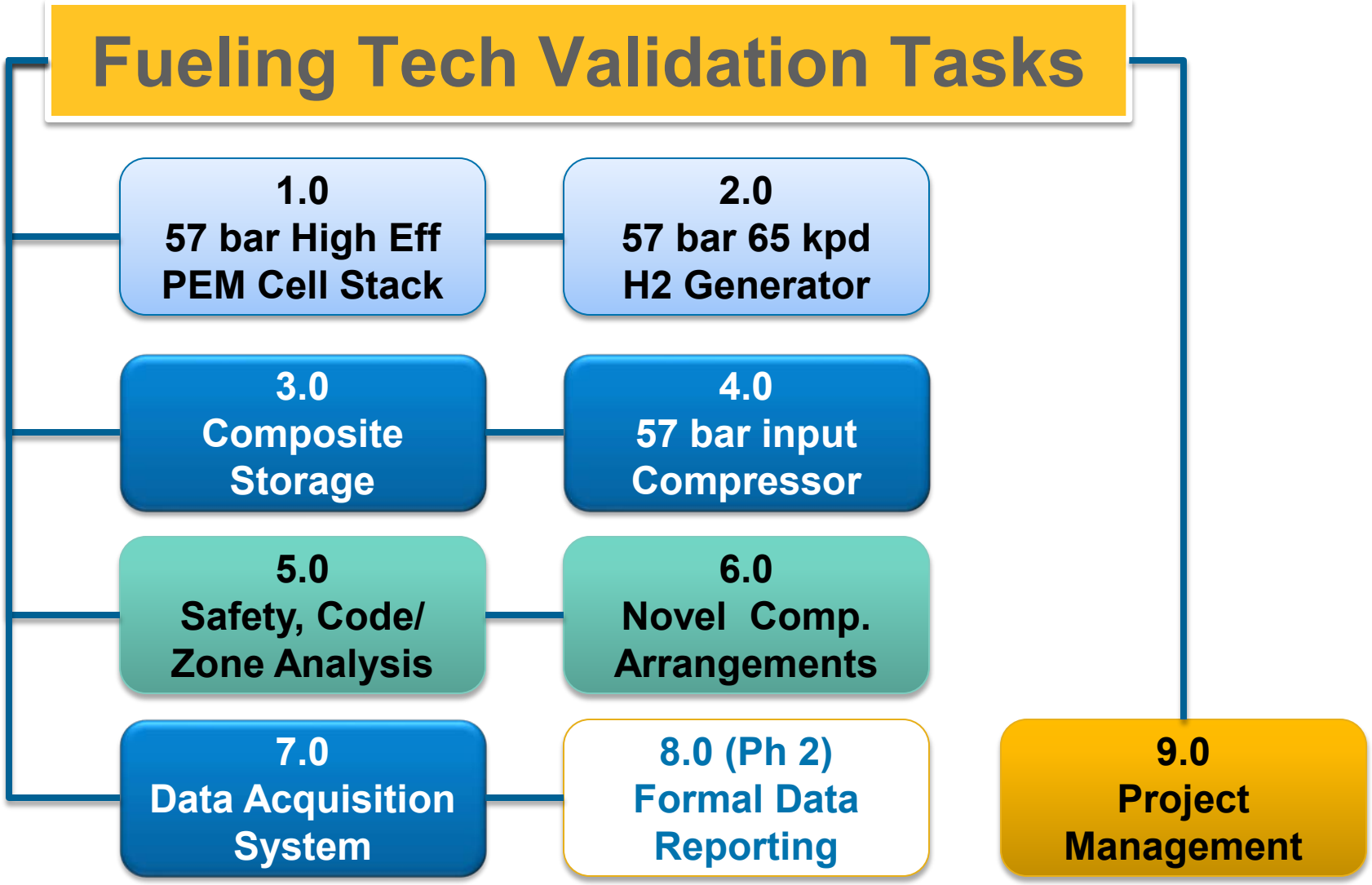
Collaborations: **SunHydro LLC** (stations), **Toyota Motors** (vehicles), **APCI** (supplier storage upgrade and programming)

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

Larry Moulthrop 203-678-2188 LMoulthrop@ Proton OnSite.com

Technical Back-Up Slides

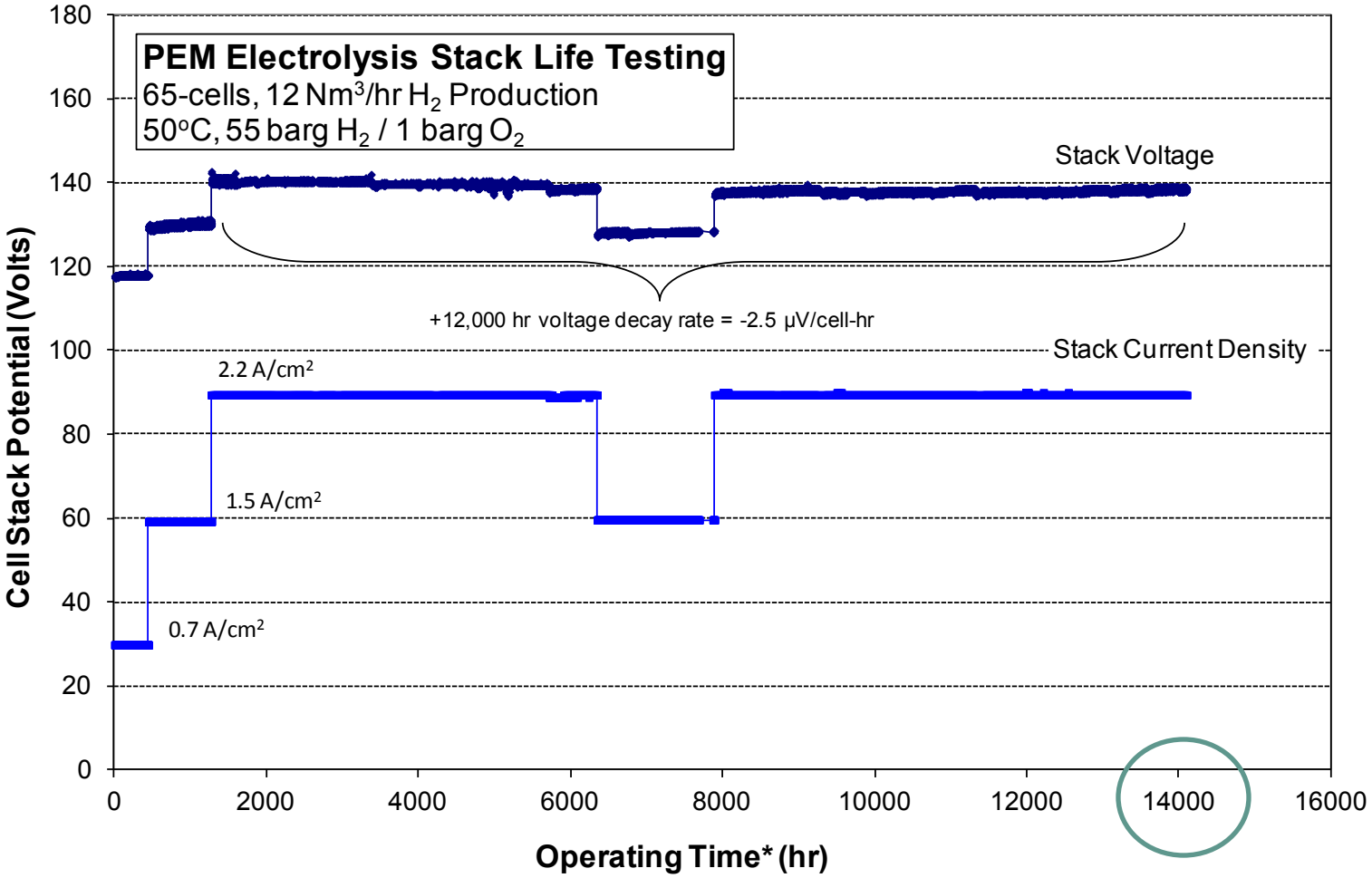
Approach


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 – Apr 2014

>7000 kg of hydrogen dispensed

>2500 high pressure H2 fills

Serving fleet of 12 FCHV and paratransit

PROTON ON SITE

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