



## 2016 DOE Hydrogen Program and Vehicle Technologies Program AMR

# CSULA Hydrogen Refueling Facility Performance Evaluation and Optimization

Project ID: tv024\_blekhman



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California State  
University, Los Angeles  
*prepared April, 2016*

# Overview



## Timeline

- Start: 10/01/2012
- End: 12/31/2016

75% complete

## Budget

- Expenditure of Government Funds
  - FY13-14 \$165,000
  - FY15-16 ~\$93,000
- Total project funding
  - DOE \$400,000
  - Contractor \$400,000

## Partners

- California State University, Los Angeles— [Project lead](#)
- Hydrogenics Corp.
- Crystallogly, [Consulting](#)

## Barriers

### Hydrogen Production and Delivery

- Reduce the cost of compression, storage, and dispensing at refueling stations
- Research and develop low-cost, highly efficient hydrogen production technologies

### Technology Validation

- Validate complete systems of integrated hydrogen and fuel cell technologies for transportation, infrastructure and electricity generation applications under real-world operating conditions.

### Education

- Educate key audiences to facilitate near-term demonstration, commercialization, and long-term market acceptance.



# Project Objectives

- The project objective is to test, collect data, and validate hydrogen refueling architecture deployed at CSULA and its individual components in a real-world operating environment. The performance evaluations data will be provided to the National Fuel Cell Technology Evaluation Center (NFCTEC) at NREL.
- Academic objectives
  - Contribute to the development of new industry standards
  - Develop and implement fueling station system performance optimization
  - Conduct outreach and training activities promoting the project and hydrogen and fuel cell technologies
  - Provide a living-lab environment for engineering and technology students pursuing interests in hydrogen and fuel cell technologies



# Tasks: Phase 1

Task 1. Develop data acquisition (DAQ) for station performance with existing capability

Task 2. Design and implement enhanced data acquisition (DAQ) for station performance evaluation

Task 3. Enable hydrogen purity testing and reporting

**COMPLETED**



# Tasks: Phases 2 and 3

Task 4. Regular data collection and reporting after completing Task 2

Task 5. Conduct outreach and training activities for public and government and engage students in station related activities.

**COMPLETED**

Task 6. Data reporting update and station performance optimization after completing Task 4

Task 7. Evaluate station utilization and assess the need for station upgrades and enhanced performance



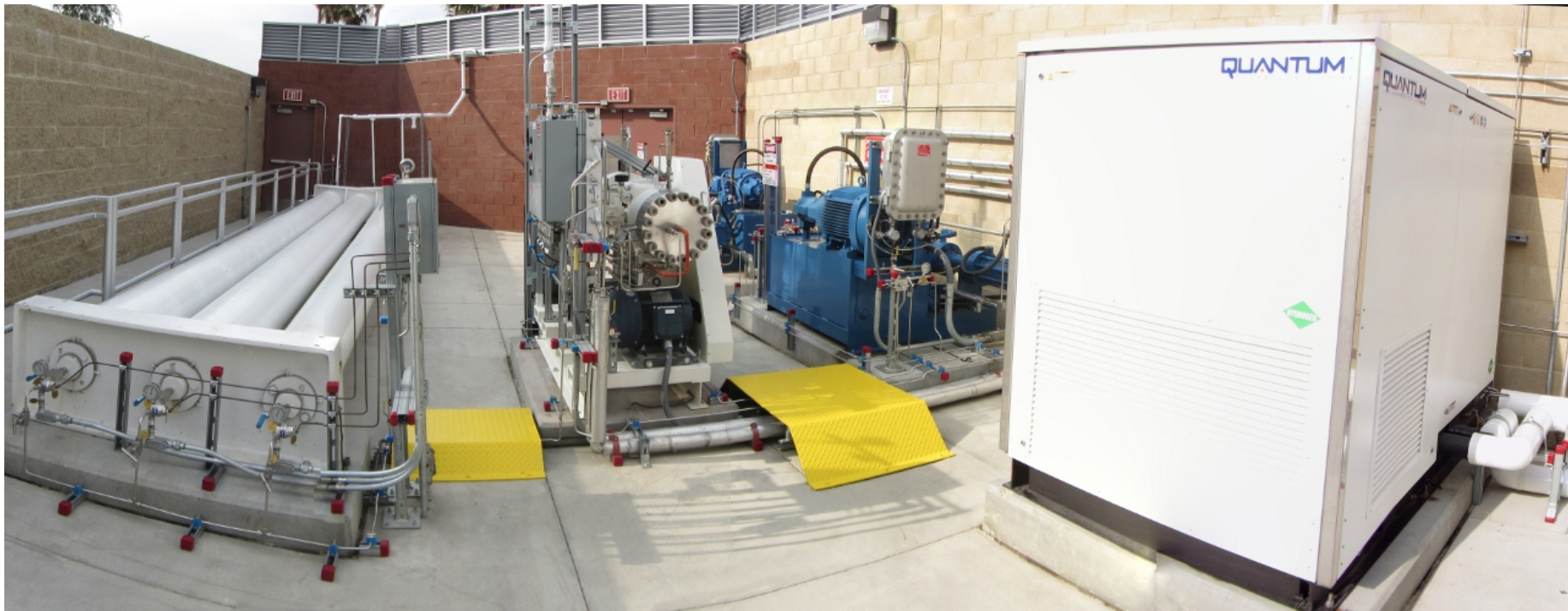
# CSULA Hydrogen Station

Production: 60 kg/day, Hydrogenics Electrolyzer

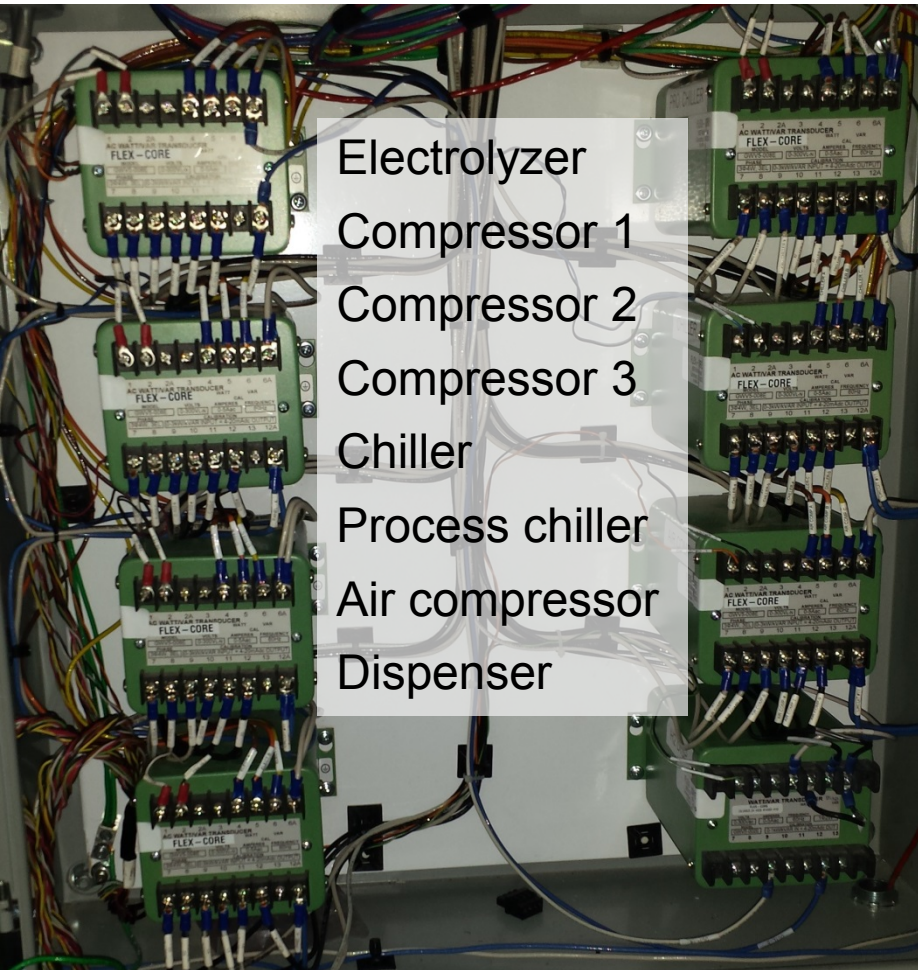
Storage: 60 kg, high pressure buffer ~10kg

Pressure: 5,000 and 10,000 psi

Capacity: 15-20 fuel cell vehicles per day



# Approach/Strategy: Facility Power Meters



- Electrolyzer
- Compressor 1
- Compressor 2
- Compressor 3
- Chiller
- Process chiller
- Air compressor
- Dispenser

Facility Power Meters Junction Box

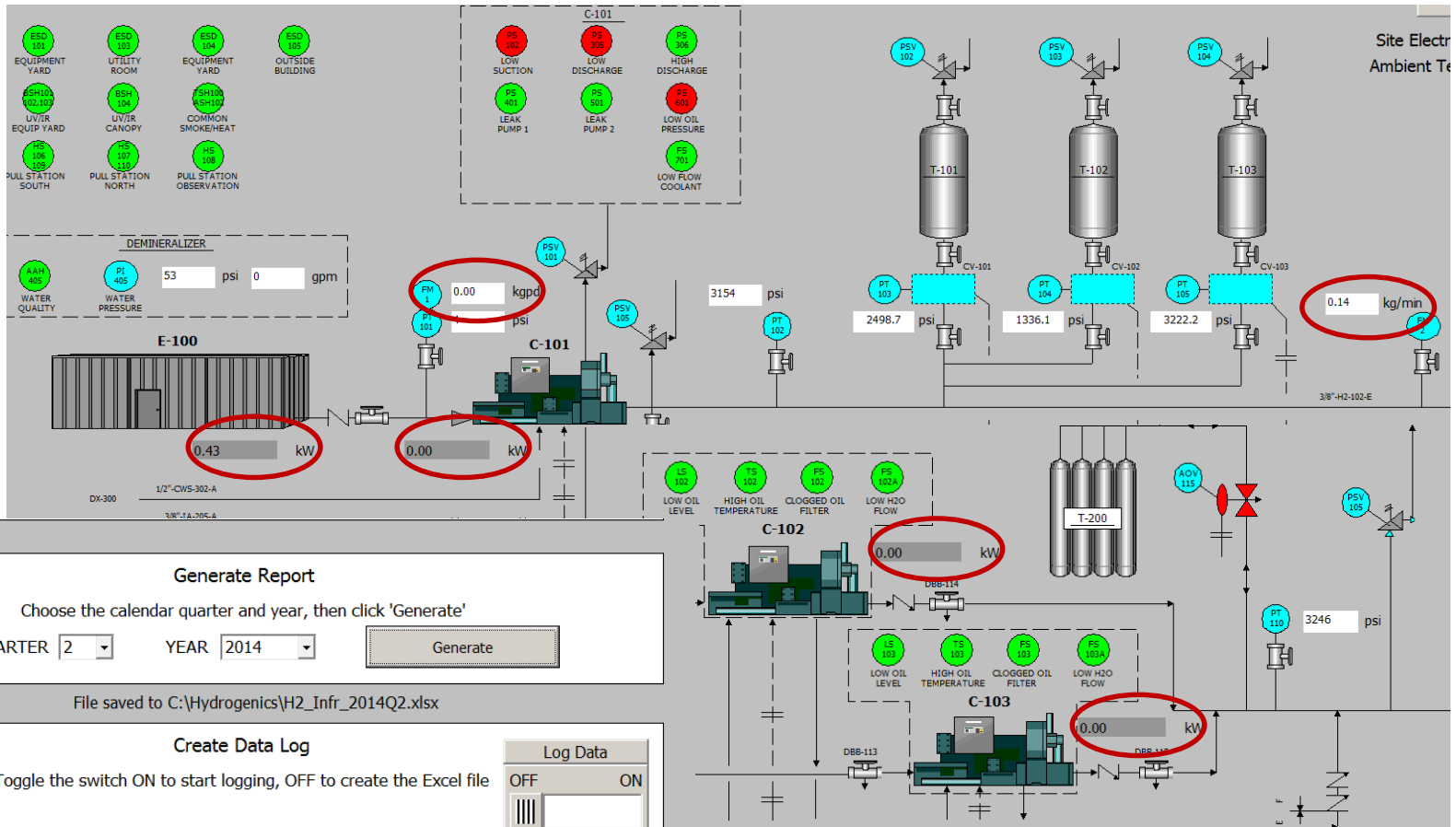


Facility Master Meter:  
Base load  
(above)  
Electrolyzer on  
(right)





# Accomplishments: Readings in the Interface





# Accomplishments: Reports Regularly Submitted



	A	B	C	D	E	F
4	Calendar Quarter (ex. 2011Q2)		2015Q4			
5	Site Name		CSULA			
6	Precooling Description		Chiller			
7	Manufacturer/ Model		Quantum/70MPa			
8	Precooling Temperature		-20			
9						
10	<b>Data should be from reporting quarter</b>					
11	Monthly Data Table		Month			
12	Category	Units	Month1	Month2	Month3	
13	250 or 350 Bar Dispensing					
14	Hydrogen Dispensed at 250 or 350 bar	kg	0.00	113.36	69.81	
15	250 or 350 bar Energy Cost	dollars	\$ -	\$ 9.35	\$ 10.62	
16	Total Energy Consumed in Dispensing 350 bar	MJ	0.00	305.93	347.65	
17	Dispenser Electronics	MJ	0.00	191.89	136.90	
18	350 Precool Energy Consumed	MJ	0.00	114.04	210.75	
19	Specific Energy Consumed	MJ/(kg H2 processed)	#DIV/0!	2.70	4.98	
20	700 Bar Dispensing					
21	Hydrogen Dispensed at 700 bar	kg	120.25	107.63	129.18	
22	700 bar Energy Cost	dollars	\$ 11.73	\$ 11.43	\$ 11.92	
23	Total Energy Consumed in Dispensing 700 bar	MJ	383.78	374.07	390.24	
24	Energy Consumed in Precooling 350 and 700 bar	MJ	254.87	222.30	600.76	
25	Dispenser Electronics	MJ	383.78	182.18	253.34	
26	700 Precool Energy Consumed	MJ	254.87	108.27	390.01	
	Compression 1 350	Compression 2 700	Compression 3 700	Dispensing	Fuel Log	

NREL required report submissions:  
 2014 Q3, Q4  
 2015 Q1, Q2, Q3, Q4

Hydrogen purity tests regularly performed and submitted.  
 Typical: 99.99868%

# Accomplishments: Added Hydrogen Storage Data

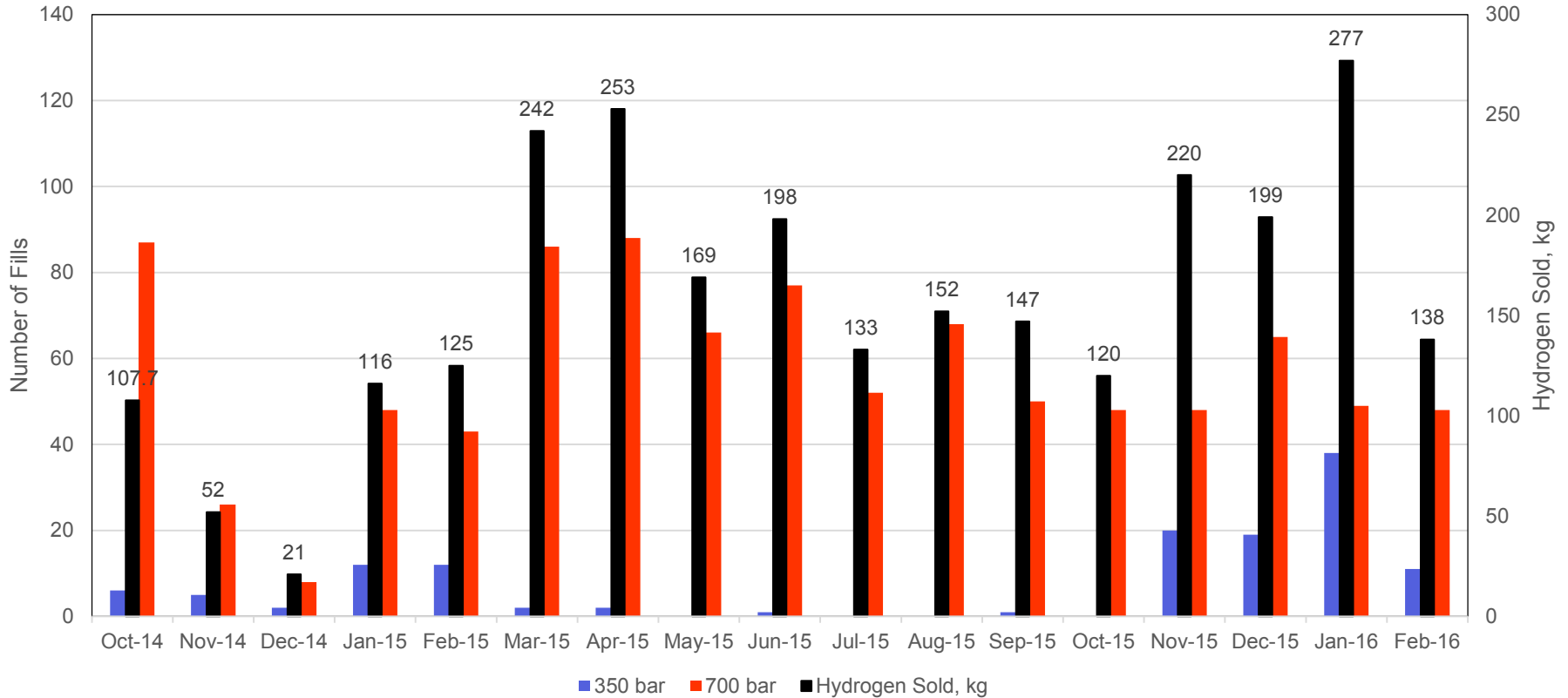


Calendar Quarter (ex. 2011Q2)		2015Q4									
Site Name		CSULA									
Data should be from reporting quarter		Record any hydrogen taken away as negative number (Example: Tube trailer leaves w/ H2 left)									
		Tank Volume (m <sup>3</sup> ): 0.767			Tank Volume (m <sup>3</sup> ): 0.767			Tank Volume (m <sup>3</sup> ): 0.767			
		H2 tanks1			H2 tanks2			H2 tanks3			Liquid tank
Date (record at least monthly)	Ambient Temperature (deg C)	Hydrogen Cost (dollars)	Nominal Pressure (psi)	storage amount (kg)	Nominal Pressure (psi)	storage amount (kg)	Nominal Pressure (psi)	storage amount (kg)	storage amount (kg)	Total Storage Amount (kg)	
10/1/15 11:59 PM	22.3437901		5781.462402	20.586	5730.76709	20.405	5681.98584	20.232		61.223	
10/2/15 11:59 PM	21.6203995		5785.365723	20.650	5607.864258	20.017	5737.129883	20.478		61.146	
10/3/15 11:59 PM	20.7161598		5775.807617	20.680	5603.963379	20.065	5732.700195	20.525		61.270	
10/4/15 11:59 PM	17.8045006		5697.590332	20.604	5527.891602	19.990	5662.47998	20.477		61.071	
10/5/15 11:59 PM	18.1390705		5808.579102	20.981	5543.495605	20.024	5631.446777	20.341		61.346	
10/6/15 11:59 PM	19.8752193		5855.603027	21.026	5859.504395	21.040	5678.084473	20.388		62.454	
10/7/15 11:59 PM	21.4486008		5894.790039	21.053	5900.430664	21.073	5715.143555	20.412		62.539	
10/8/15 11:59 PM	24.4868393		5764.105957	20.376	5687.817871	20.107	5795.118164	20.486		60.969	
10/9/15 11:59 PM	27.8325291		5806.821777	20.299	5584.45752	19.522	5697.024414	19.915		59.736	
10/10/15 11:59 PM	27.9681702		5801.145508	20.270	5849.751465	20.440	5678.242676	19.841		60.551	
10/11/15 11:59 PM	27.4256306		5787.316406	20.258	5836.080078	20.429	5666.379395	19.835		60.522	
10/12/15 11:59 PM	29.4239998		5847.785156	20.335	5602.030273	19.480	5775.614746	20.084		59.898	
10/13/15 11:59 PM	24.9841805		5750.433105	20.294	5518.138672	19.474	5693.688965	20.094		59.862	
10/14/15 11:59 PM	22.2624092		4597.473633	16.375	5758.057617	20.508	5436.214844	19.362		56.245	
10/15/15 7:25 PM	22.89538		5518.333496	19.612	5713.194824	20.305	5826.327148	20.707		60.625	
10/16/15 11:59 PM	21.2134895		5880.942871	21.021	5594.015625	19.995	5885.039063	21.035		62.051	
10/17/15 11:59 PM	21.7017803		5871.365723	20.952	5588.358887	19.942	5877.041992	20.972		61.865	

Per NREL request, daily storage data has been added to the NREL file. Data for three storage tanks is recorded.



# Fueling Events

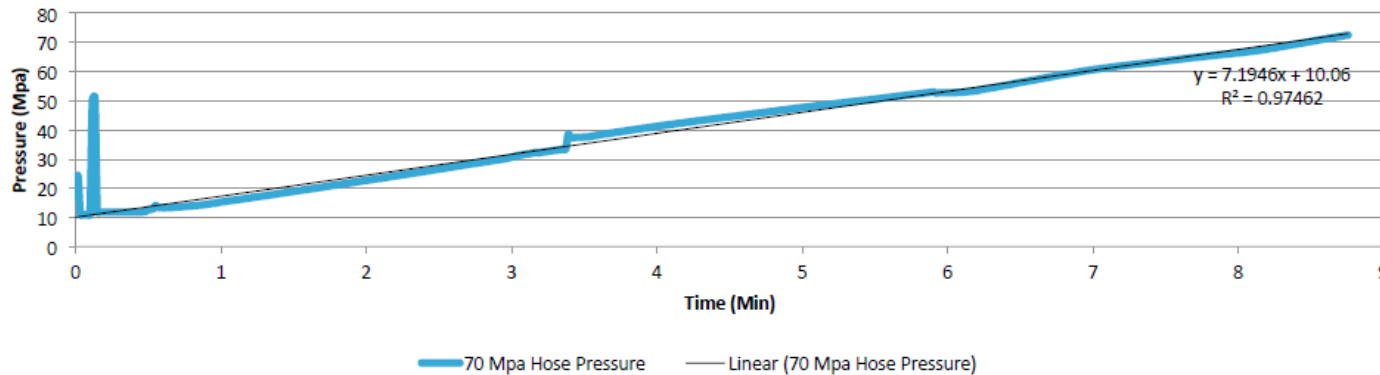


The chart demonstrates:  
 Fueling events, maximum in January 2016 at 277kg  
 700 bar fills are dominant



# Station Upgrades toward J2601 Compliance

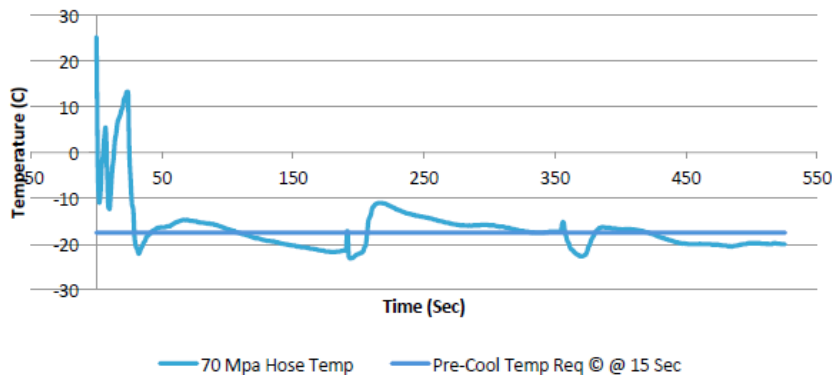
APRR Pressure Profile



Tamb=21.6 degC,

Station software was reprogrammed to follow J2601 2010 Class B pressure corridors. In this example, target APRR= 7.52Mpa/Min, actual APRR = 7.45Mpa/Min with start-up and leak check allowance. Performance is in compliance with J2601 2010 Class B.

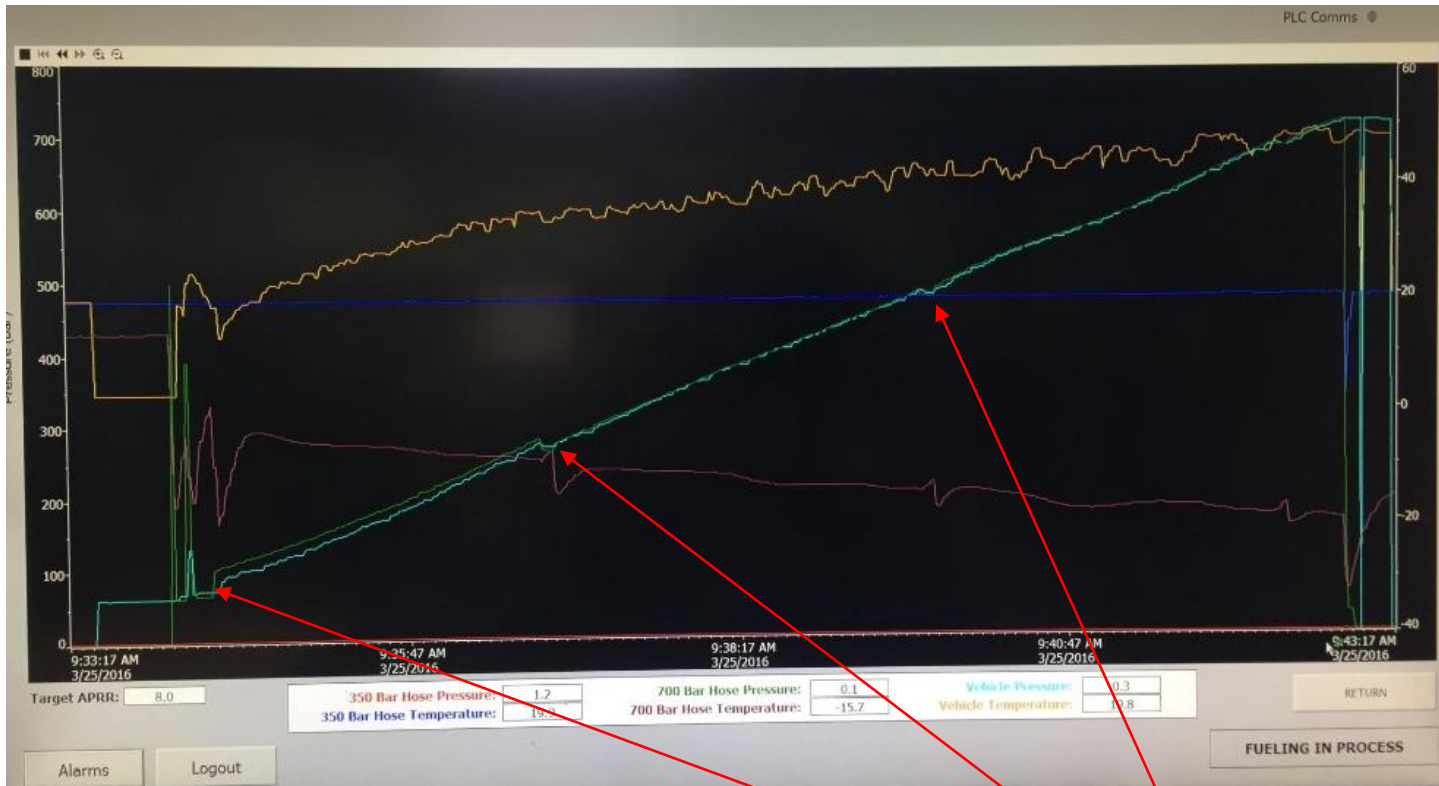
Pre-cooling Performance



Total mass average temp with startup and leak check allowance is -17.7C on this fill, in compliance with J2601 2014 F70-T20 stations.

Figures and data analysis by Crystallogy

# Real Time Performance Implemented



Each fueling event is logged and displayed real time

Safety leak tests are clearly identifiable, 2015 upgrade



# Additional Upgrades



Electrolyzer in line hydrogen purity analyzer: moisture and oxygen content. Manual operation.



Flow control valve venting port re-routing for external venting. Prevents accumulation and alarm triggering.





# Additional Upgrades

Steps to meet retail model:

-Vending machine (left)

-Point of Sale (right), works in both secured chip and strip





# Collaborations: Dispensing Meter Type 2016 Re-Approval

CSULA receives second seal of approval for sale of hydrogen on per kg basis as for 2016. Testing was conducted in collaboration with the California Department of Weights and Measures, CAFCP and CARB.



Testing equipment at CSULA Station  
Right, yellow sticker- seal of approval







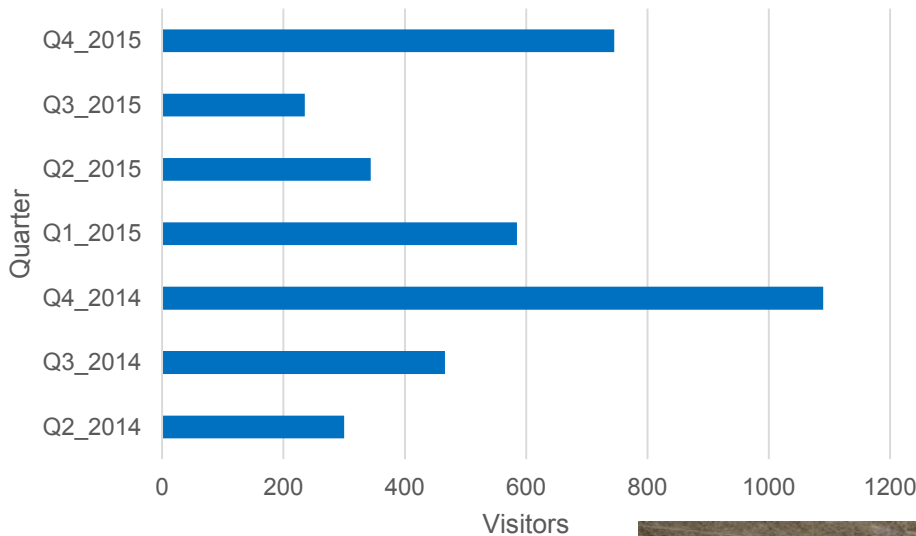
# Collaborations: HyStEP



Hosted HyStEP (DOE-Sandia funded/built) device testing as it arrived to California. Hosted training workshop for Station Developer/Operator Group Mtg. Dec 2015



# Outreach

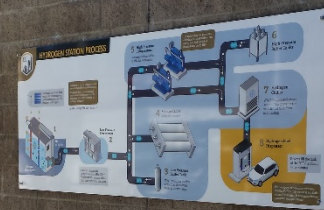


## 85% Educational outreach

- 50% High School
- 10% Cal State LA
- 5% Community Colleges
- 5% K-8
- 11% Combined
- 5% Environmental Educators

Students, government, industry, professional meetings, media.

Number of visitors (right) to CSULA hydrogen station, total 3765



Developed educational poster



# Future Work



Continue regular data collection and reporting of NREL data

Conduct outreach and training activities for public and government and engage students in station related activities.

Continue hydrogen purity testing

Evaluate station utilization and assess the need for station upgrades and enhanced performance

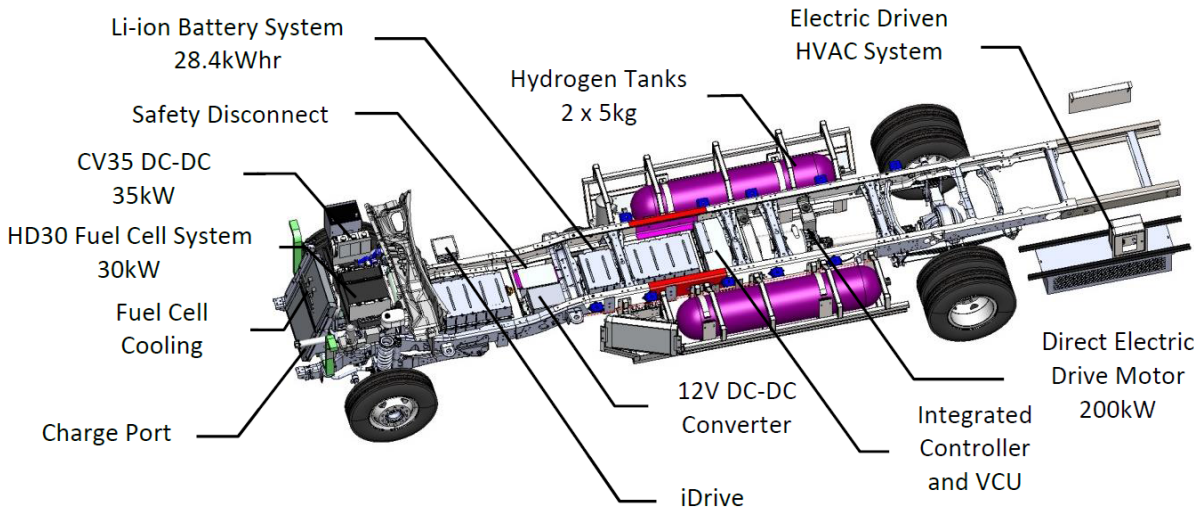
Two Hyundai fuel cell vehicles are deployed as CSULA Campus Safety vehicles



# Future Work and Collaborations: Fuel Cell Shuttle Bus Program

Partners: CALSTART, US Hybrid, Cal State LA (2 buses), SunLine (2 buses)

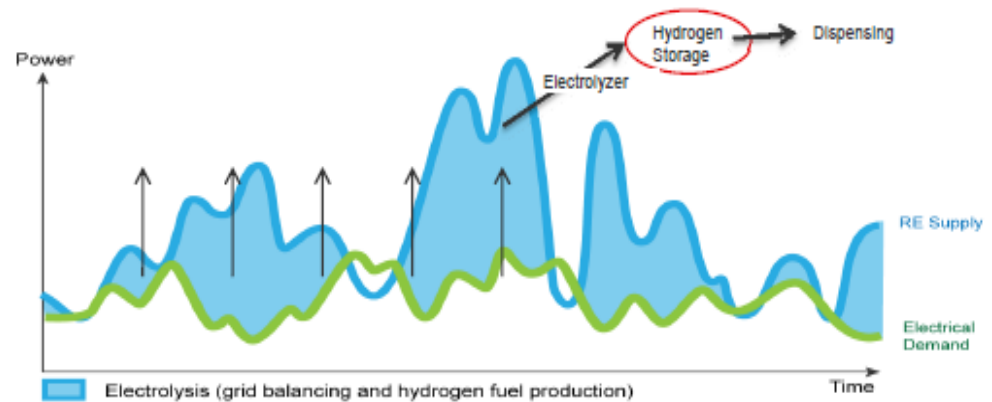
California Energy Commission Alternative and Renewable Fuel and Vehicle Technology Program Solicitation PON-14-605 Medium- And Heavy-Duty Advanced Vehicle Technology Demonstration Revised Notice of Proposed Awards June 18, 2015							
Proposal Number	Applicant	Project Title	Funds Requested	Proposed Award	Match Amount	Score	Recommendation
12	CALSTART, Inc.	H2Ride Hydrogen Shuttle Bus Demonstration Project	\$2,998,948	\$0 <del>\$2,998,948</del>	\$1,767,796	82.88%	Finalist Awardee



# Other Future Projects: Research Opportunities



- Performance Optimization, Hydrogen Fleet and Infrastructure Analysis
  - Weekly patterns/storage
  - Availability via mobile app
  - Metering
- Smart Grid: Load Following with Renewable Power Generation
  - Off-peak load
  - Load shedding
- Workforce, Public and Professional Education



Intermittent wind exceeds load

# Summary



- **RELEVANCE.** Program demonstrates high relevance to the DOE Hydrogen and Fuel Cell program especially in light of rapid development of hydrogen infrastructure in CA and thousands of FCV expected in 2016-2017.
- **APPROACH.** Reviewed NREL reporting requirements and identified instrumentation needed. Received NREL feedback. Developed pathways to improve station performance.
- **ACCOMPLISHMENTS.** Phases I and II are completed. Transitioned into Phase III. Data is continuously collected and analysis has been enabled. Reprogrammed station to meet safety standards: leak tests and aborts, pressure ramp rates and cooling temperatures to meet J2601, Class B. Point of Sale capability is introduced, sale by kg is approved. Students are trained in hydrogen station operation and secure related jobs.
- **COLLABORATIONS and OUTREACH.** Rapid development of collaborations: CA DMS, CAFCP, H2FIRST, HyStEP, Argonne, Lawrence Livermore Labs. Funded member of the Southern CA Alternative Fuel Center. Conducted robust outreach activities: 3765 visitors since July 2014, 85% students.
- **FUTURE WORK.** Short term: collecting data, analyzing station and individual equipment performance. Formed Calstart, US Hybrid, Cal State LA and SunLine partnership to have hydrogen shuttle buses (\$3M CEC award). Long term: smart grid, infrastructure and expanded education opportunities.



# Publications and Presentations

- “Living Labs for Advanced Transportation and Renewable Energy at CSULA,” D. Blekhman and M. Dray. CA Higher Education Sustainability Conference, San Francisco, CA, July 2015
- “An Emerging Culture: Hydrogen Fuel Cell Use in East Los Angeles,” C. Ney, D. Blekhman, and M. Dray. CA Higher Education Sustainability Conference, San Francisco, CA, July 2015
- Awards: UC and CSU the Eleventh Annual Higher Education Energy Efficiency and Sustainability Best Practice Awards: Cal State LA, Hydrogen Research and Fueling Facility, 2015