2016 DOE Hydrogen Program and Vehicle Technologies Program AMR

# CSULA Hydrogen Refueling Facility Performance Evaluation and Optimization


Dr. David Blekhman
California State University, Los Angeles

*prepared April, 2016*

Project ID: **tv024_blekhman**

*This presentation does not contain any proprietary, confidential, or otherwise restricted information*

# 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.
- Crystallogy, 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.

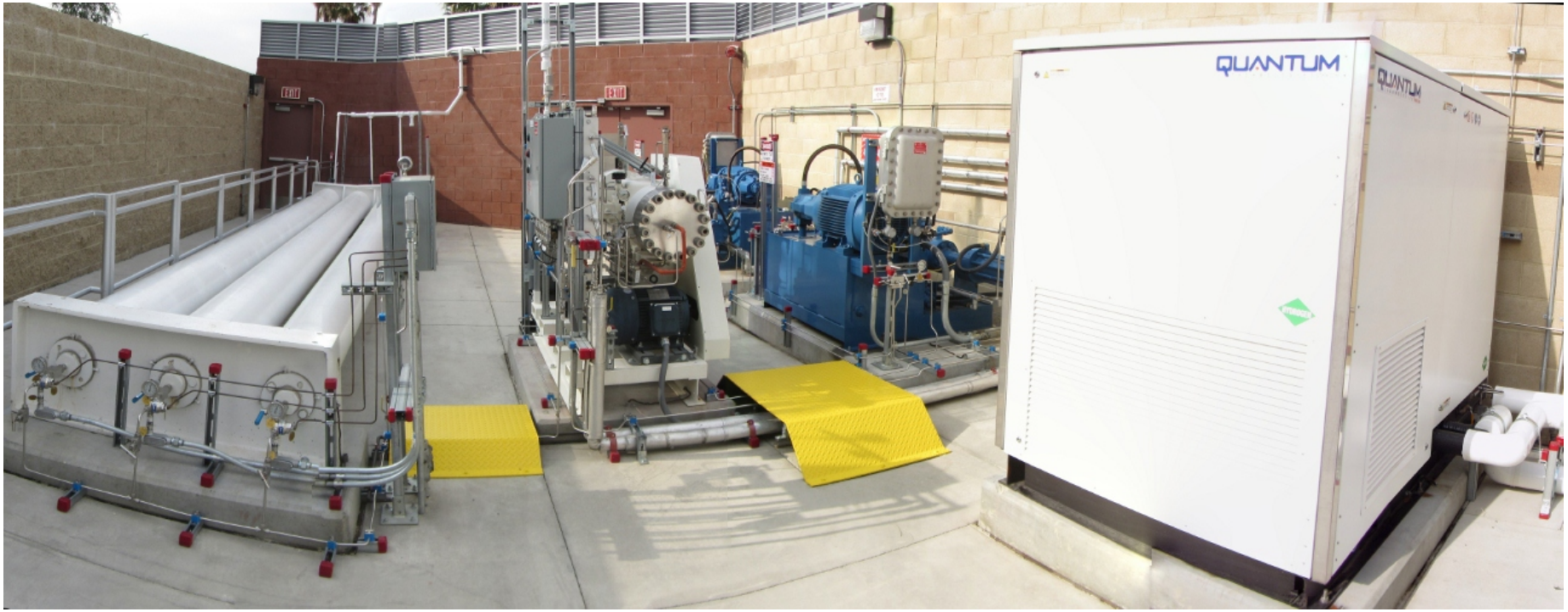
**COMPLETED**

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

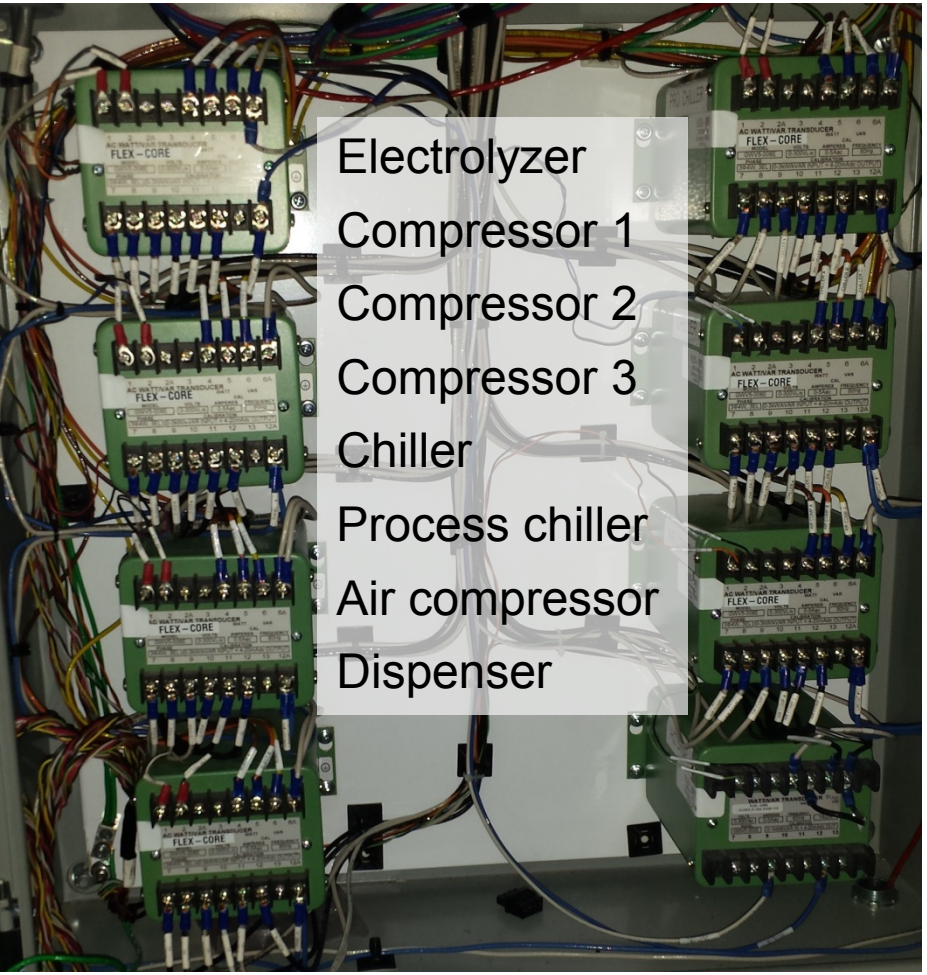
Task 7. Evaluate station utilization and assess the need for station upgrades and enhanced performance

# 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



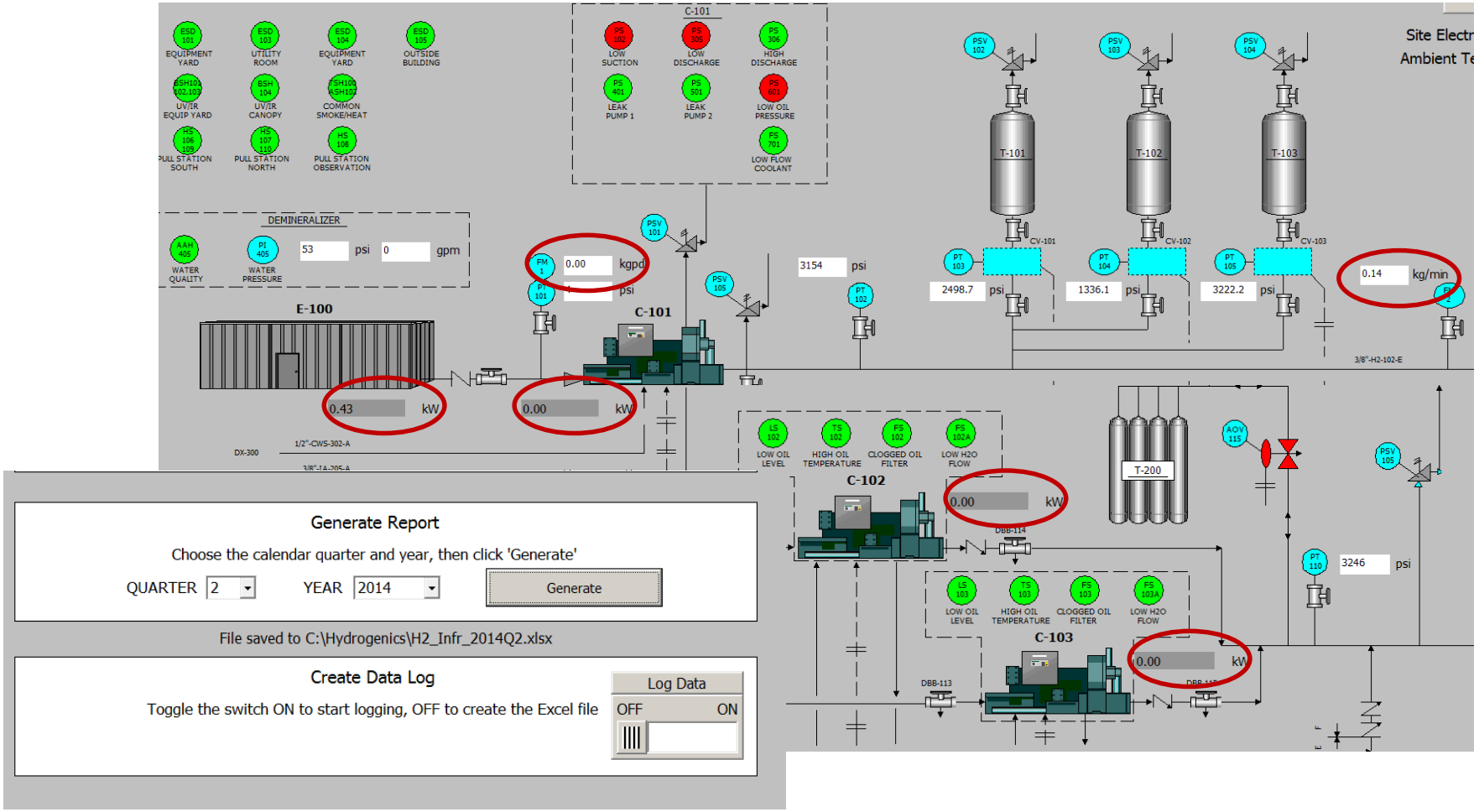
# Approach/Strategy: Facility Power Meters




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 | **Data should be from reporting quarter** | | | | | |
| 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**

Keep track of amount of hydrogen in storage and deliveries if applicable.
Should have storage amounts at least at beginning and end of quarter.

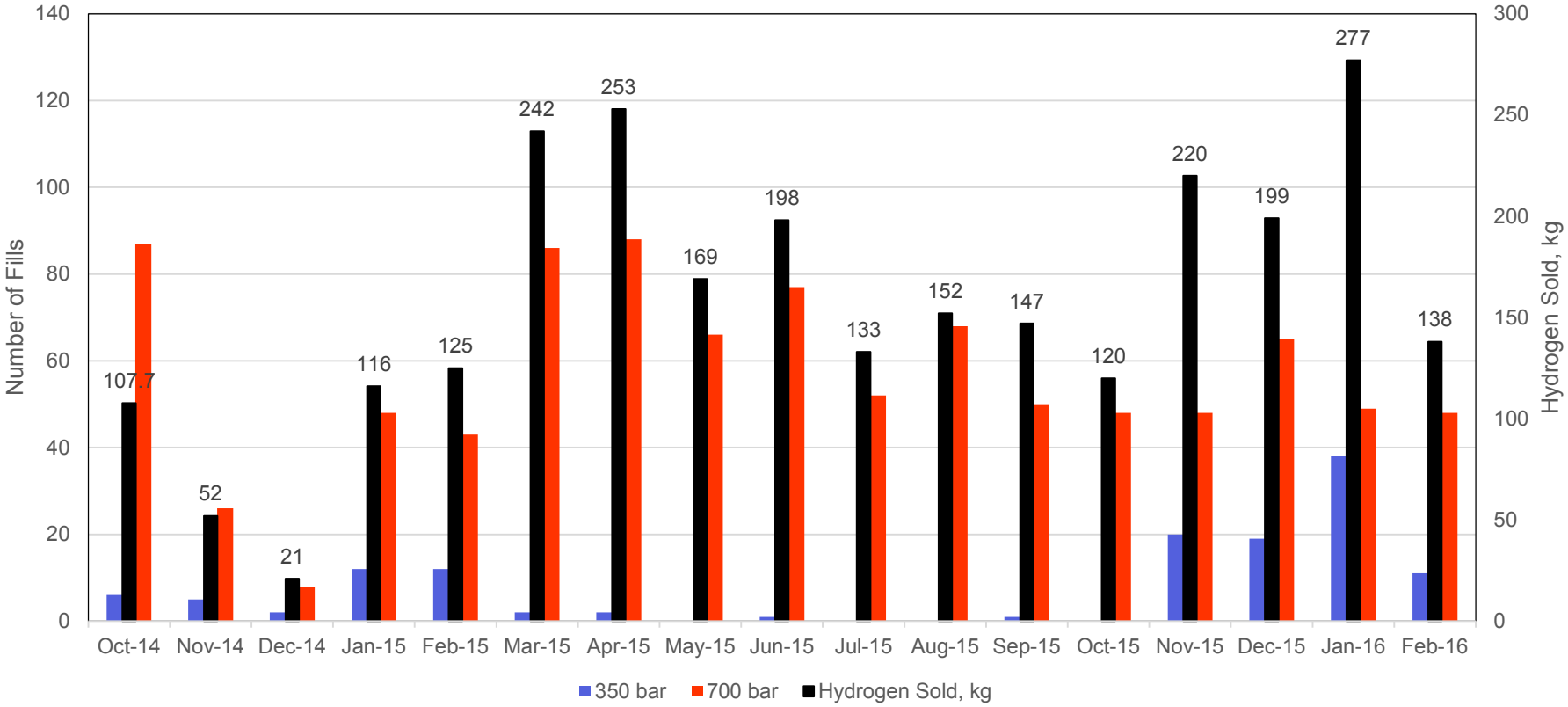
Hydrogen delivered can be total for a month or single events.

Record any hydrogen taken away as negative number (Example: Tube trailer leaves w/ H2 left)

| | | | Tank Volume (m^3): | 0.767 | Tank Volume (m^3): | 0.767 | Tank Volume (m^3): | 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 |

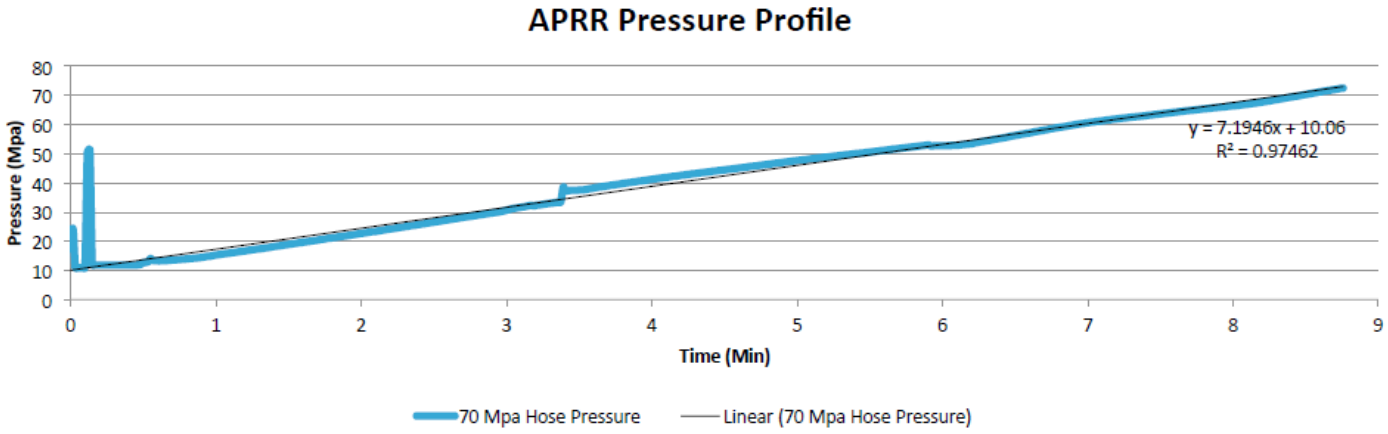
Per NREL request, daily storage data has been added to the NREL file. Data for three storage tanks is recorded.

# Fueling Events



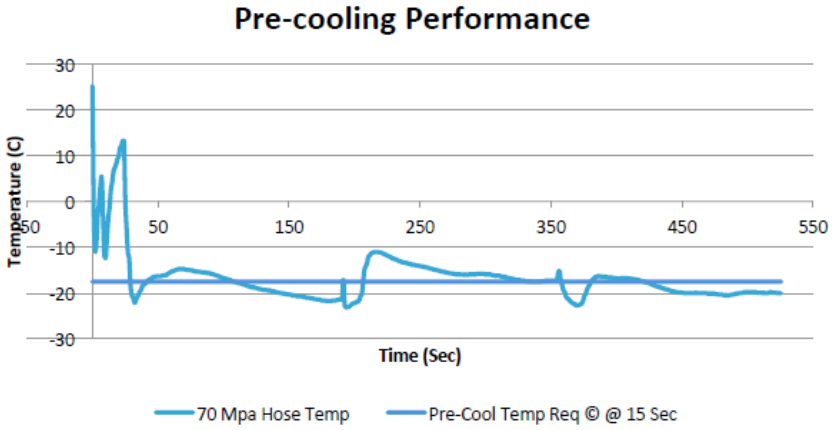

The chart demonstrates:
Fueling events, maximum in January 2016 at 277kg
700 bar fills are dominant

# Station Upgrades toward J2601 Compliance




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.




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)

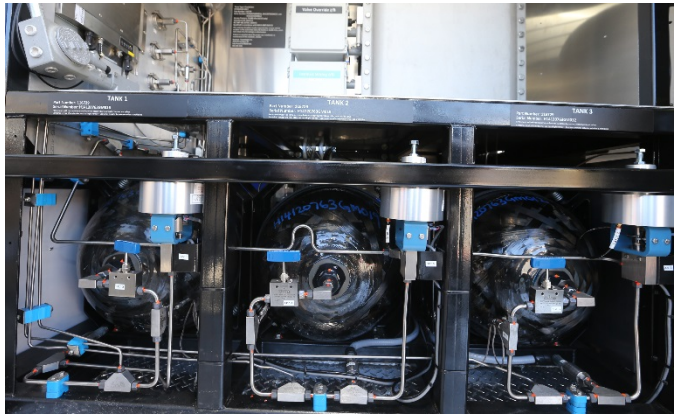
-Point of Sale (right), works in both secured chip and strip

# 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.

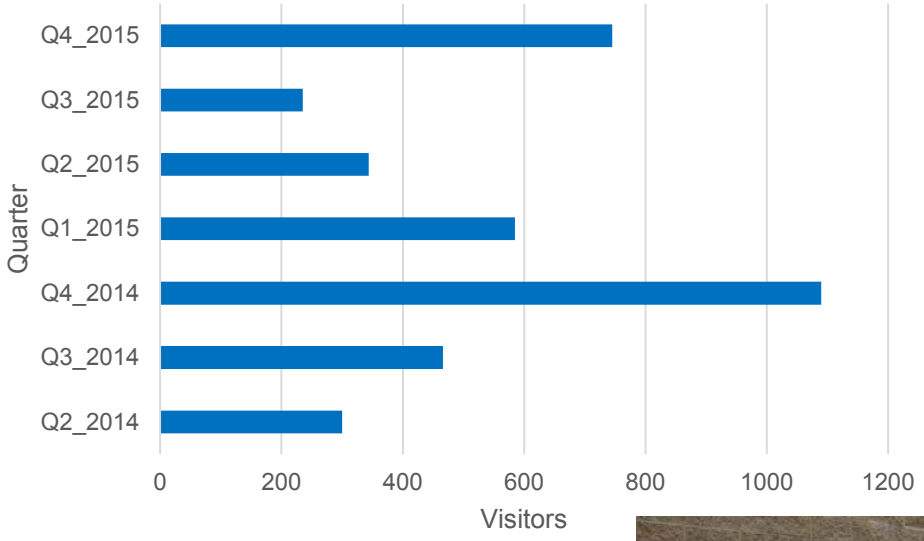

Testing equipment at CSULA Station
Right, yellow sticker- seal of approval

# 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


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

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

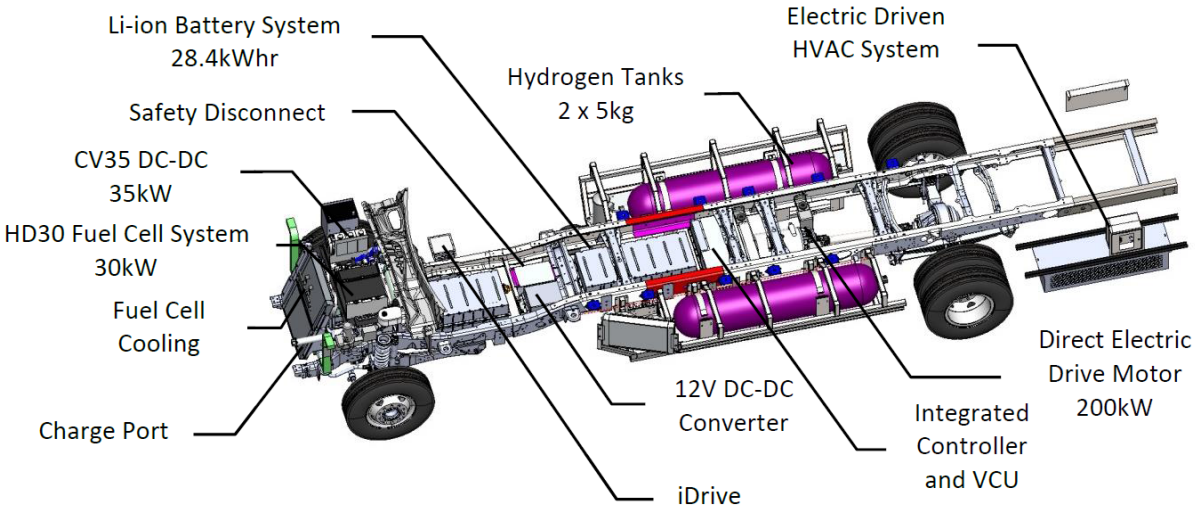
Evaluate station utilization and assess the need for station upgrades and enhanced performance

# Future Work and Collaborations: Fuel Cell Shuttle Bus Program

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

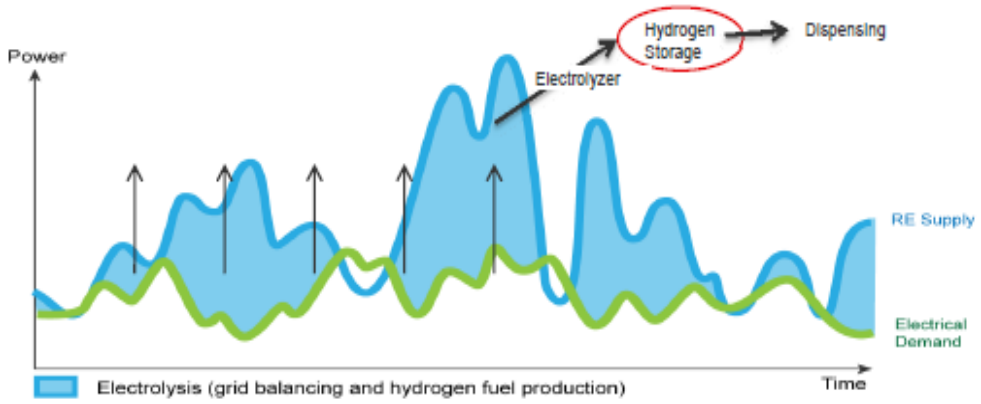
**California Energy Commission**
**Alternative and Renewable Fuel and Vehicle Technology Program**
**Solicitation PON-14-605**
**Medium- And Heavy-Duty Advanced Vehicle Technology Demonstration**
**Revised Notice of Proposed Awards**
**June 18, 2015**

| 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~~ $2,998,948 | $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