

Newport Beach Hydrogen Station Key Performance Indicators

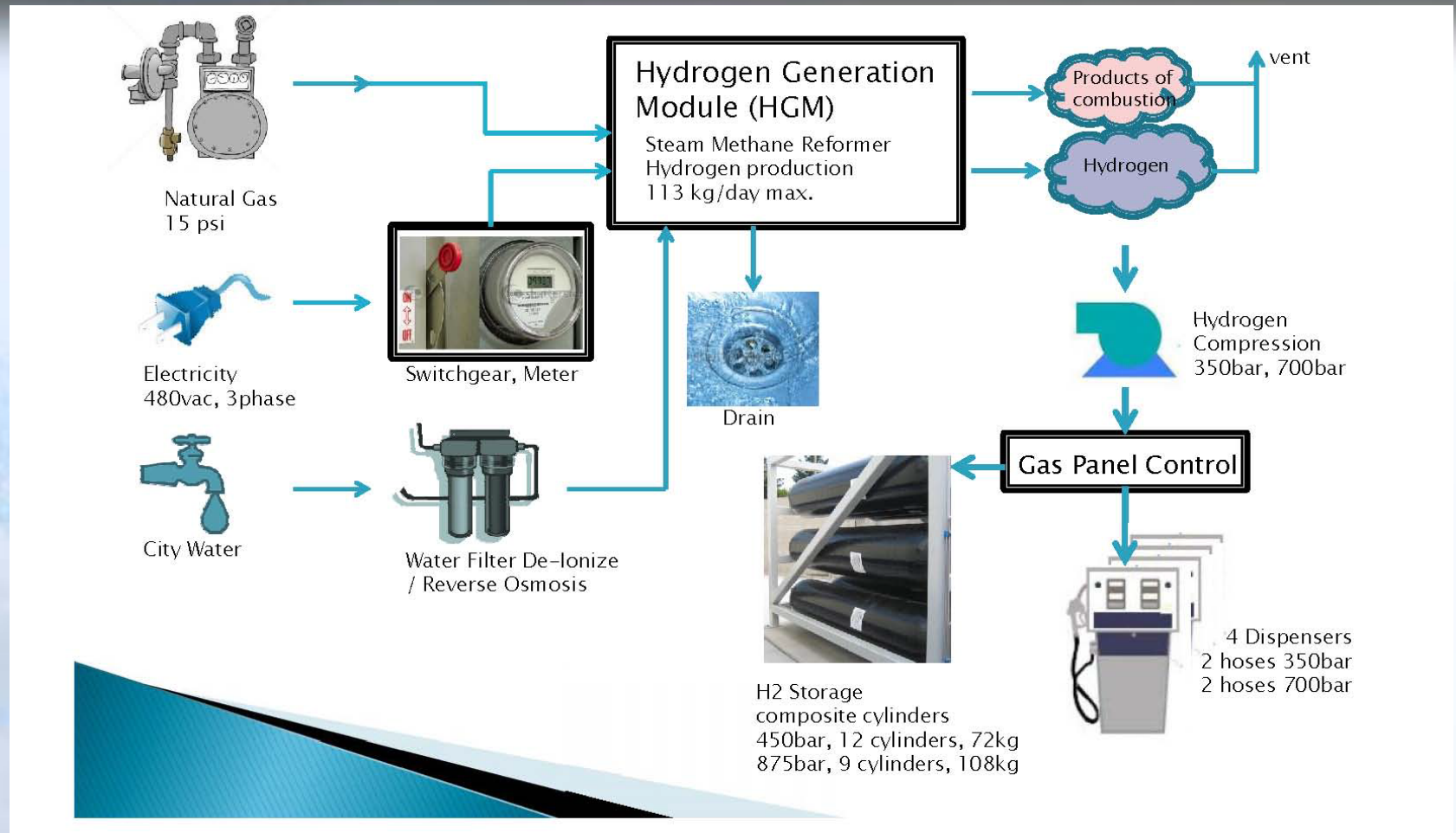
Michael J. Kashuba
California Air Resources Board
June 16-20, 2014

Project ID # TV023

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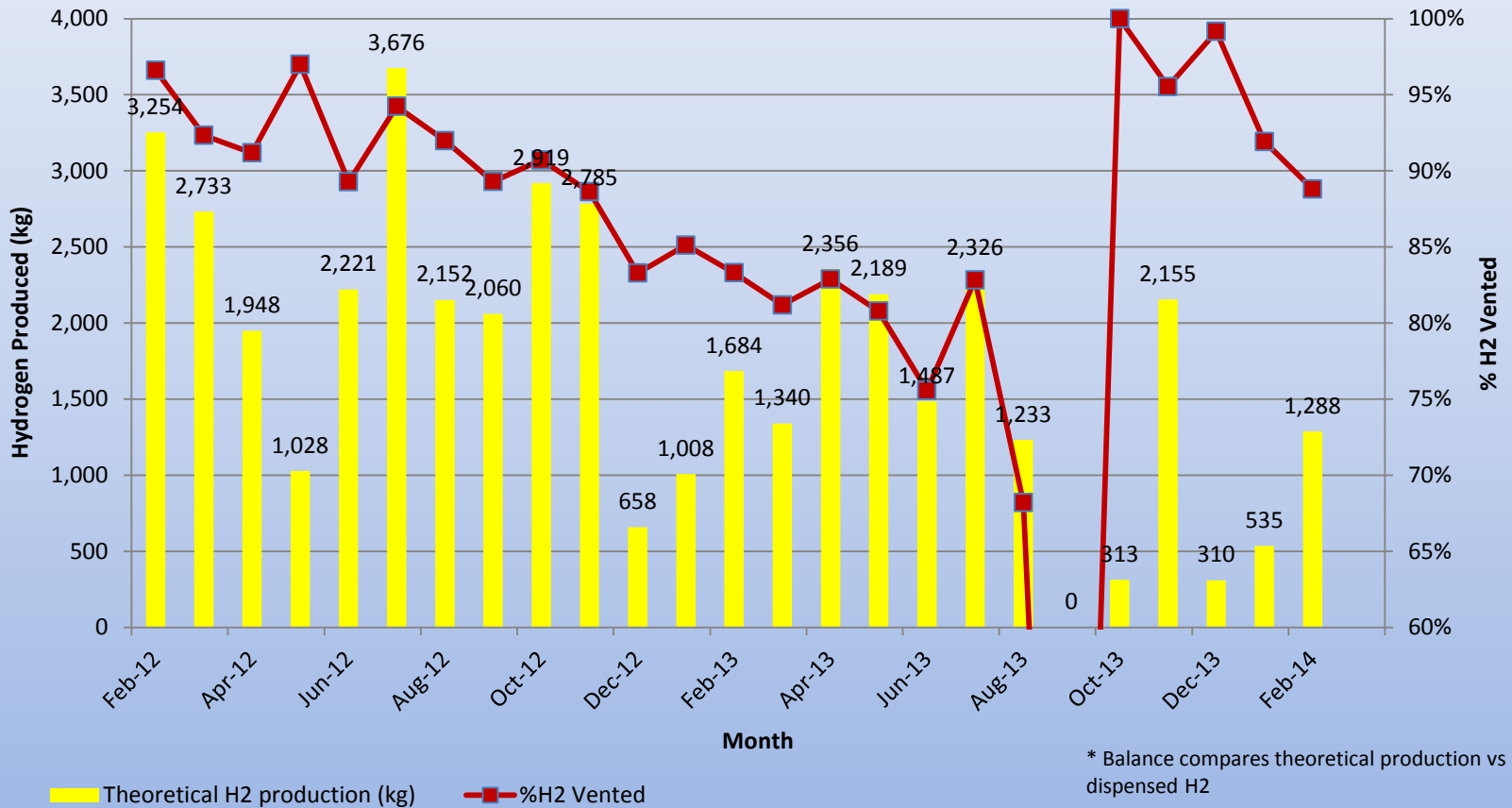
Simplified Process Flow Schematic

On-Site Steam Methane Reformation

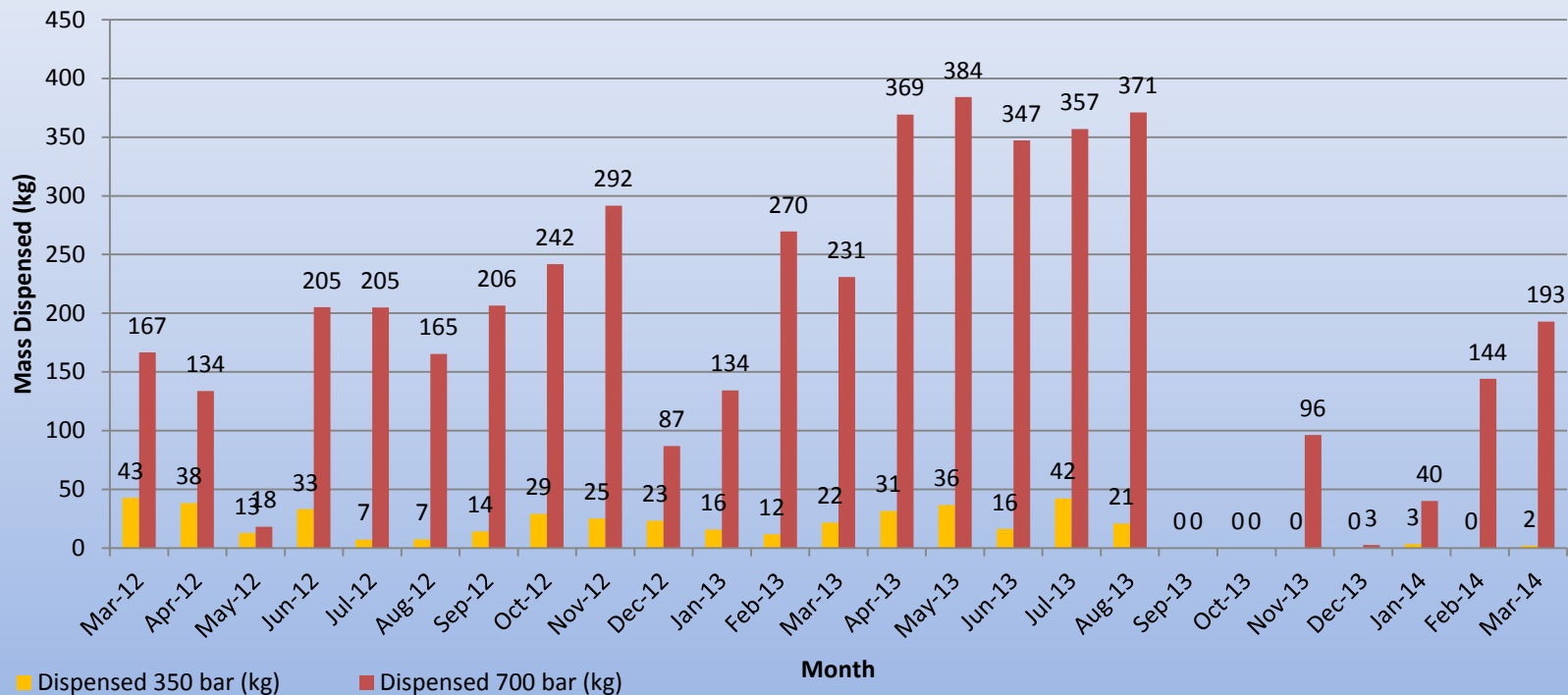


H2 Produced vs. H2 Vented

Mass Balance



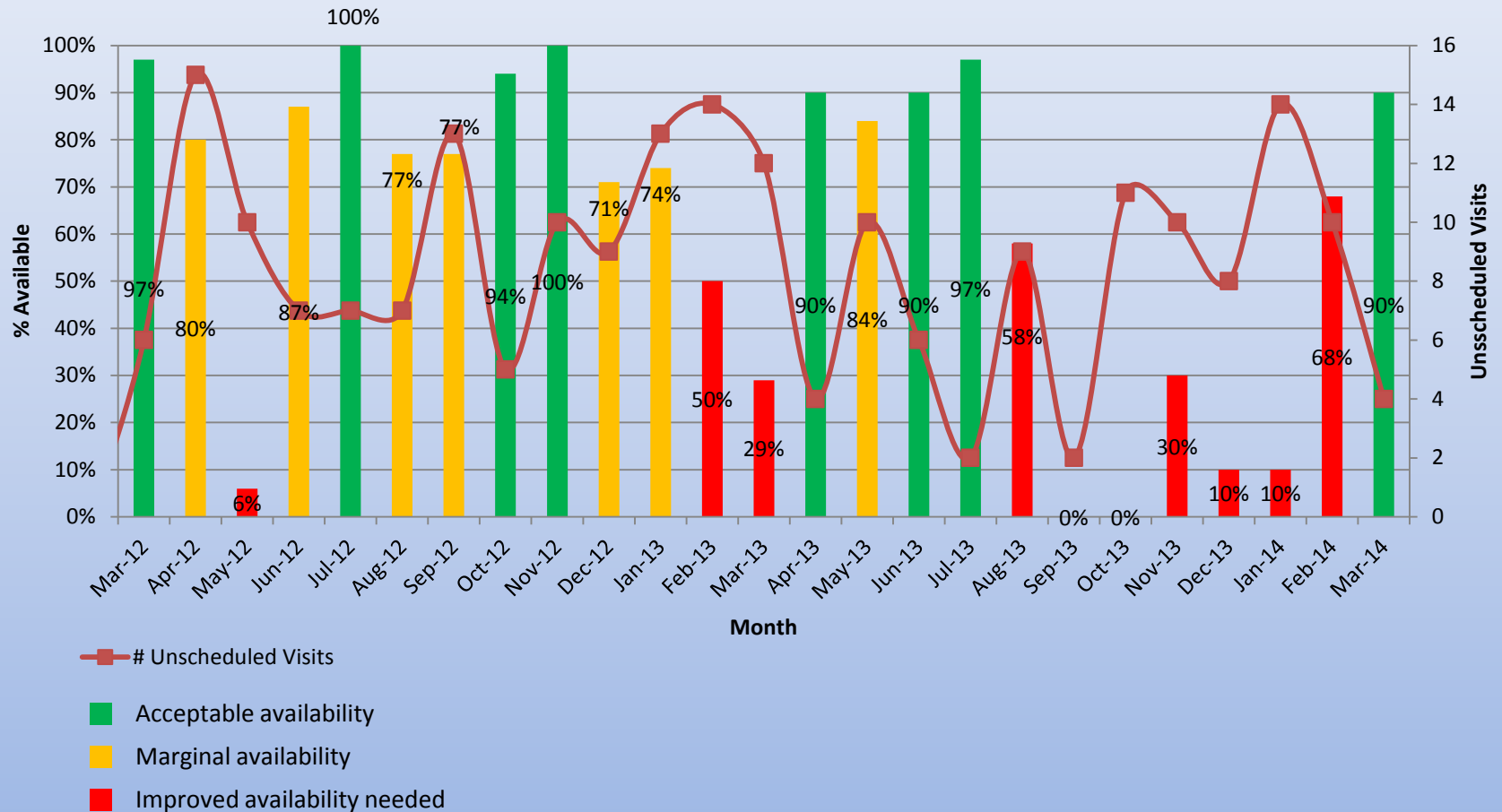
Monthly Hydrogen Dispensed Since Commissioning



Total Dispensed at 700 bar: 4,660 kg
 Total Dispensed at 350 bar: 433 kg

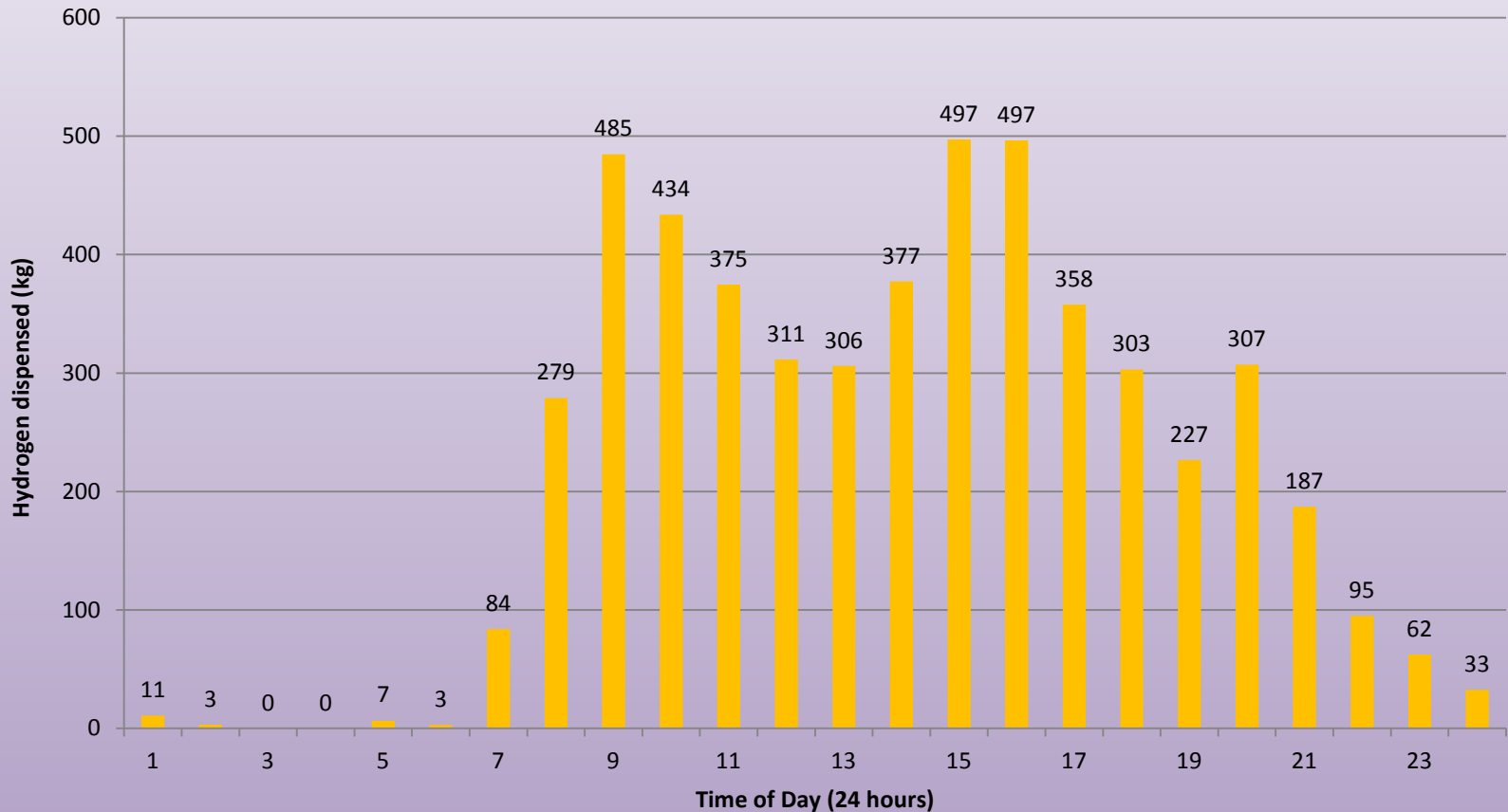
Unscheduled Visits & Station Availability

At least one 350/700bar dispenser available for a 24 hour period.



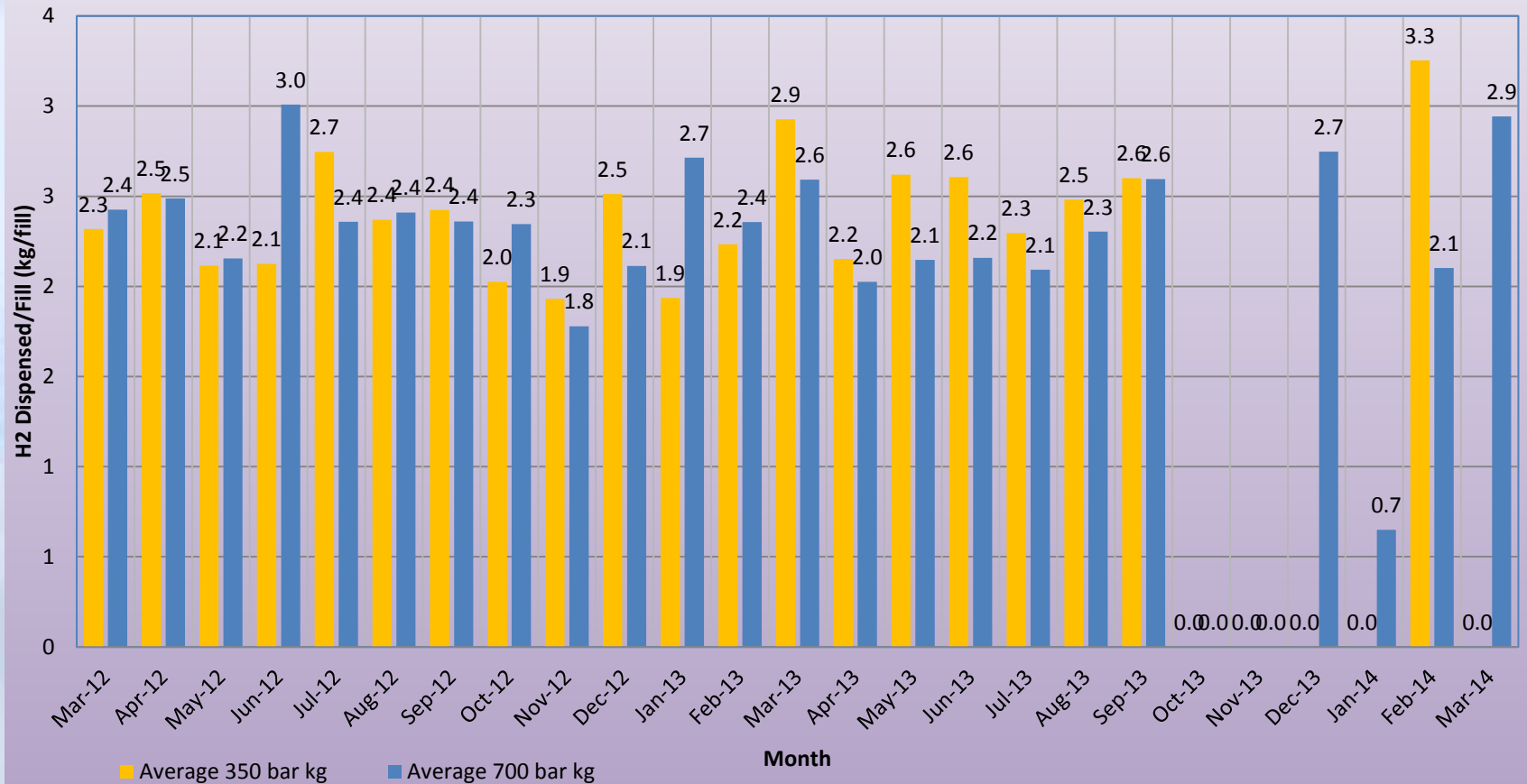
Customer Fueling Patterns (kg/hr of day)

February 2012 – March 2014



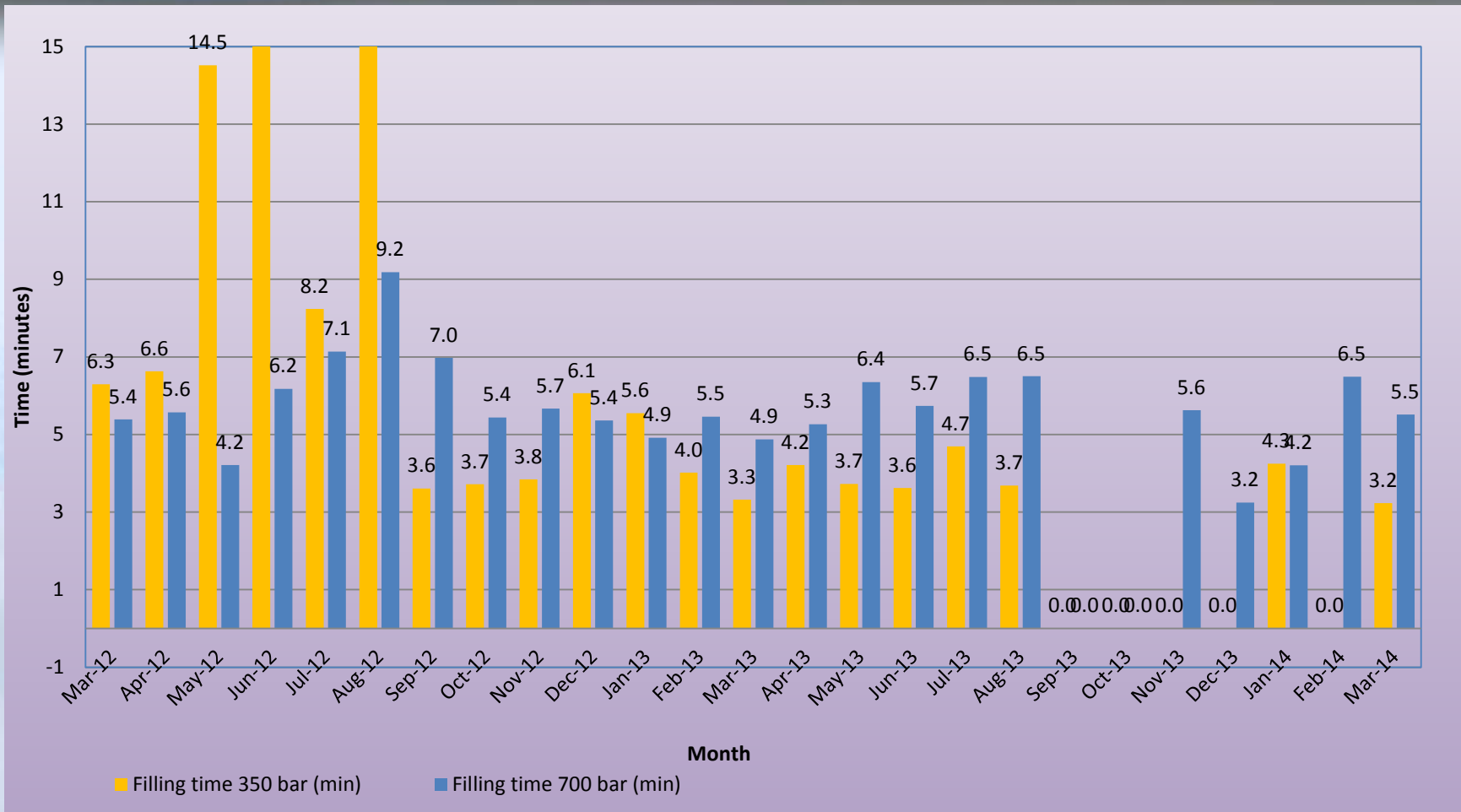
Average kg H2 Dispensed per Fill

350 & 700 bar



Average Fill Time (Minutes)

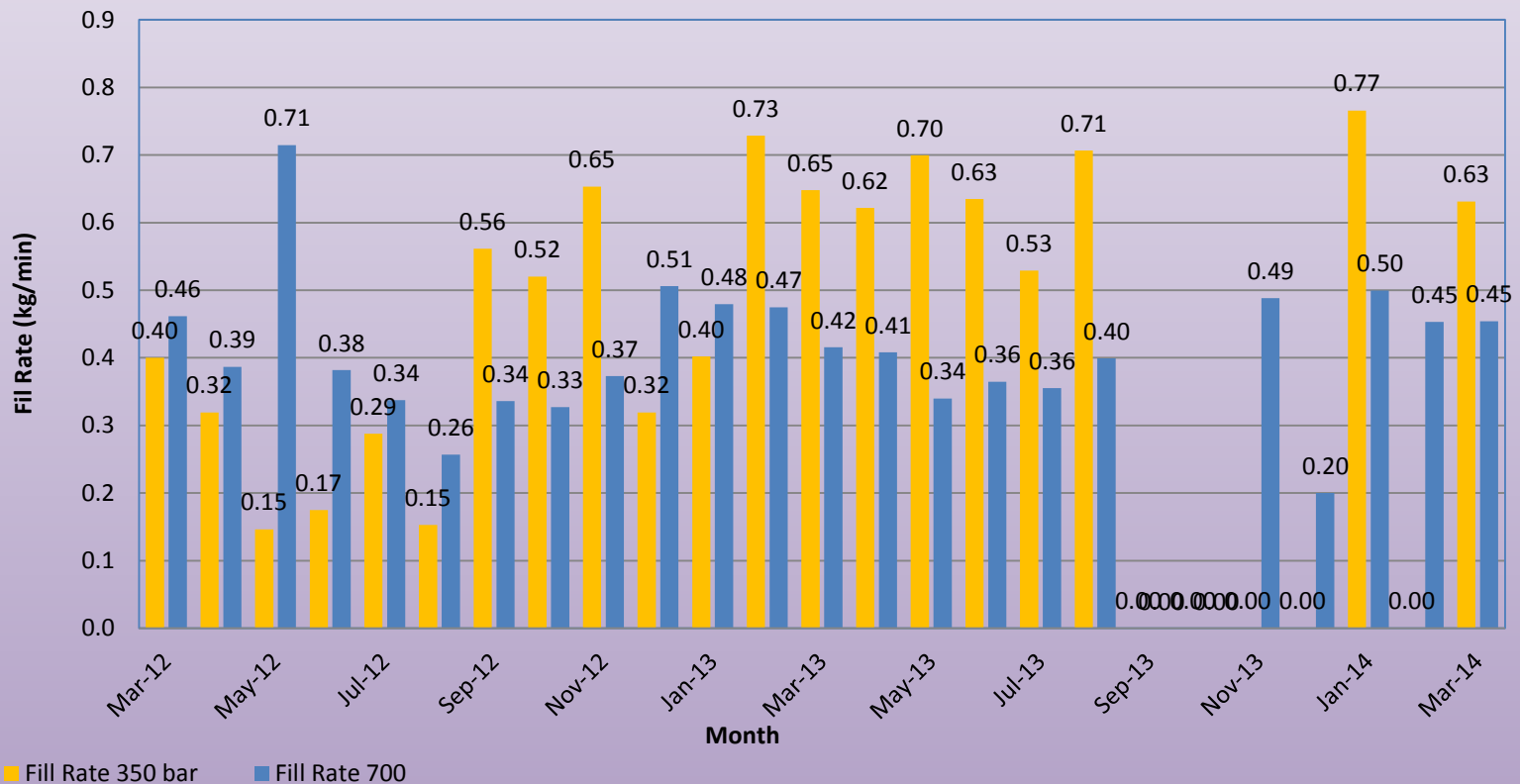
350 & 700 bar



Average Fill Rate (kg/min)

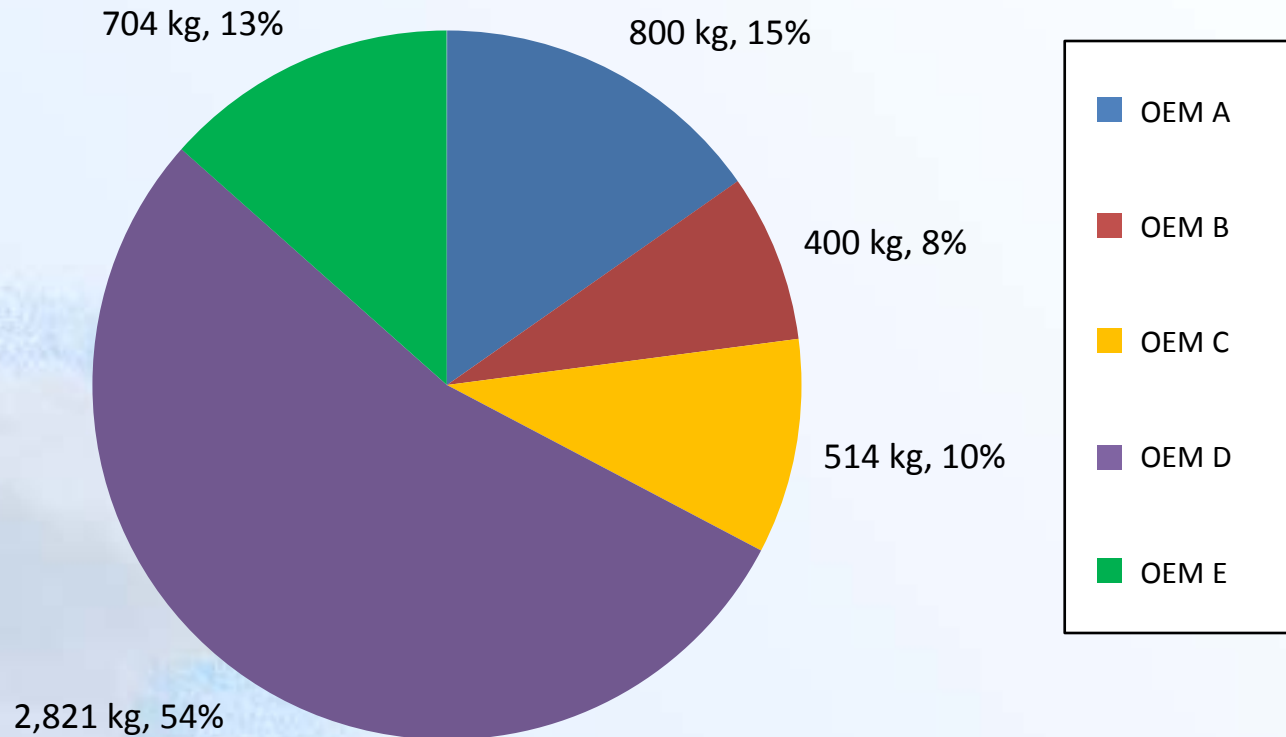
350 & 700 bar (-20°C fill)

Average Fill Rate



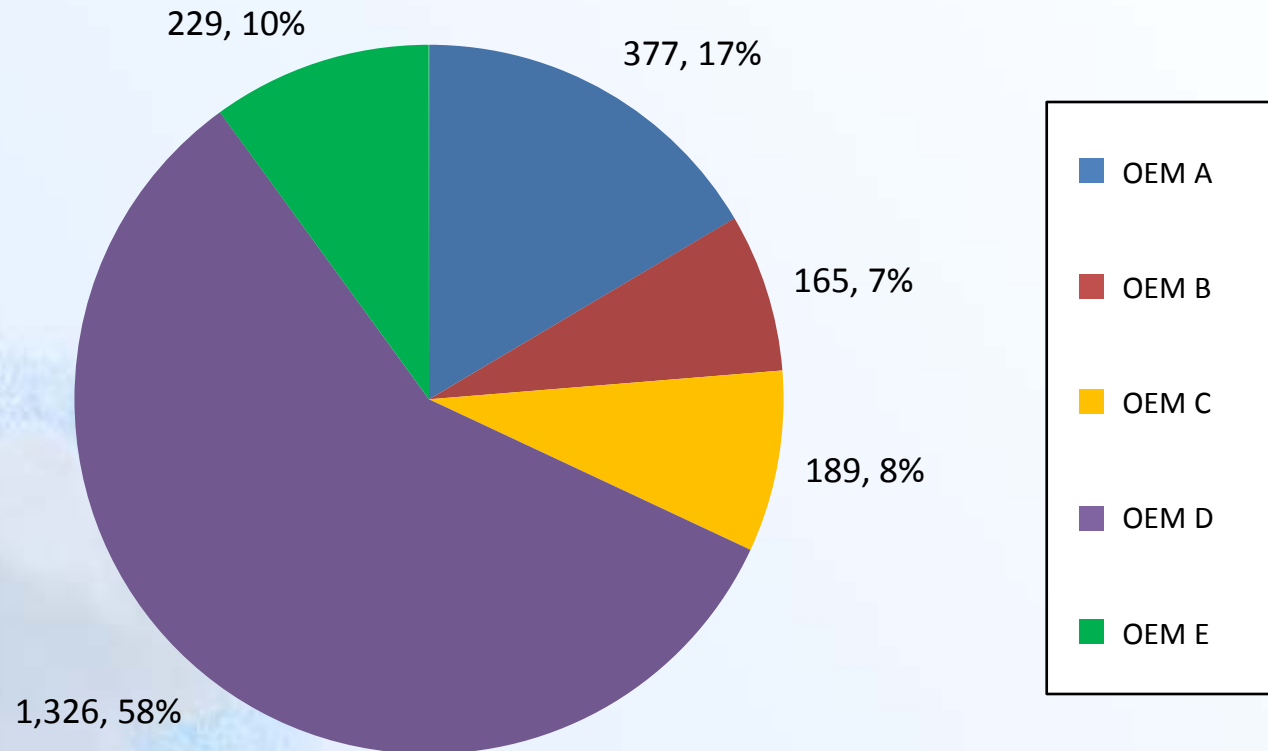
OEM Fill Pattern (kg)

02-2012 to 03-2014



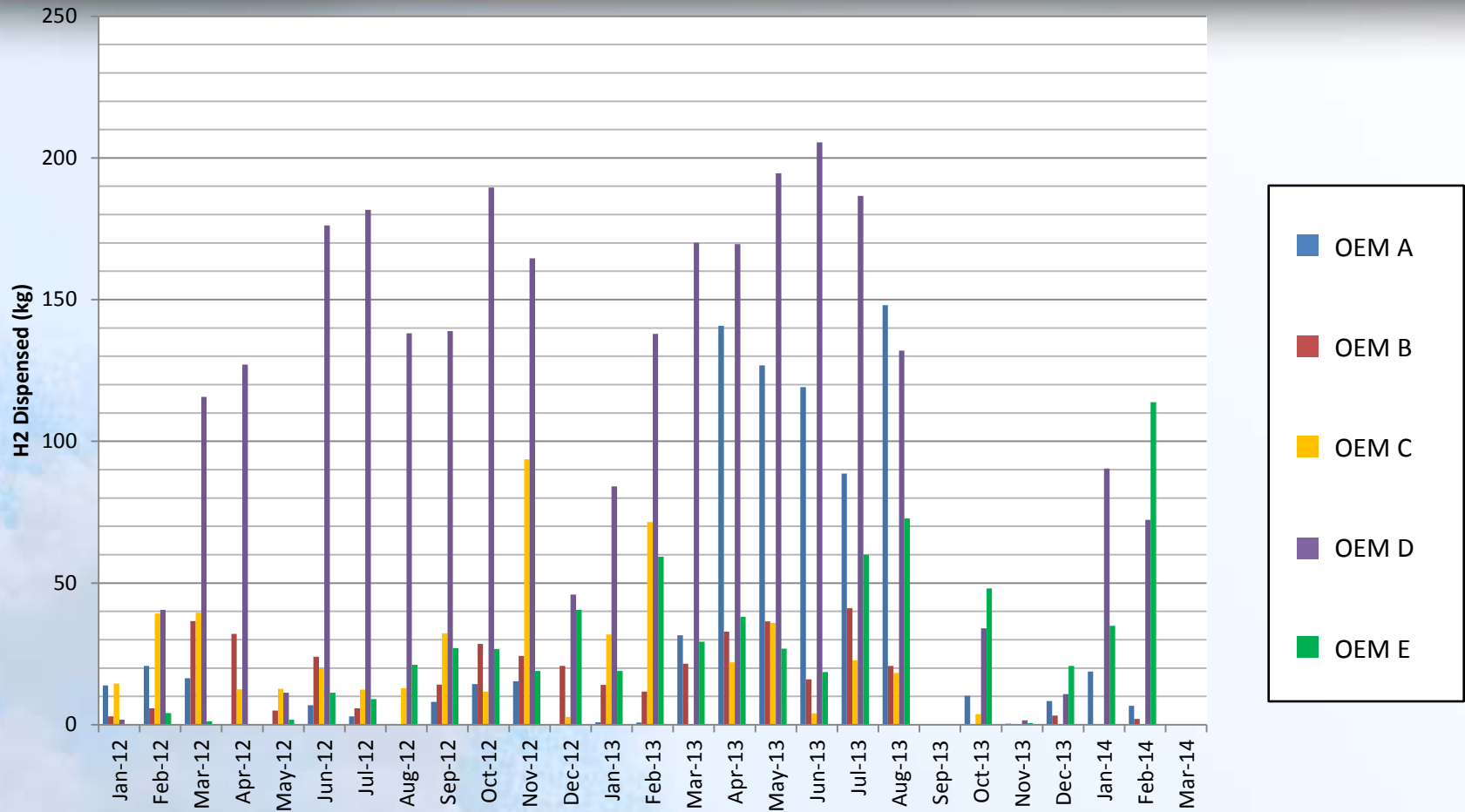
OEM Fill Pattern (# of Fills)

02-2012 to 03-2014

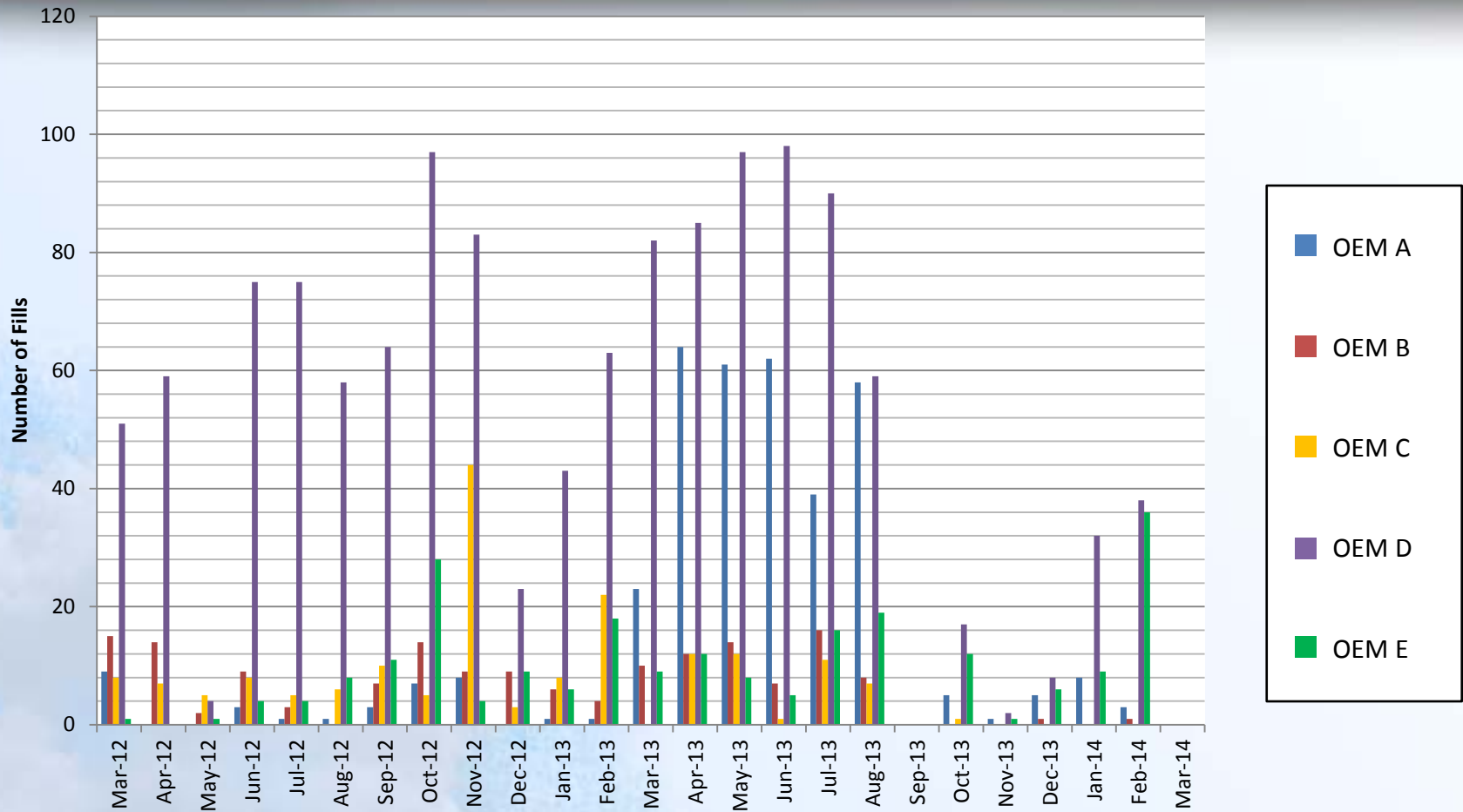


OEM Fill Pattern (kg)

Kilograms dispensed



OEM Fill Pattern (# of Fills)



Goals & Planned Improvements

- Increase overall station/equipment up time
- Reduce non-scheduled maintenance visits
- Make recommendations on how to optimize components
- Act on recommendations/continue to monitor and check/validate station optimization

Additional Information

- The following slides describe work conducted by the California Air Resources Board (CARB), California Department of Food and Agriculture's Division of Measurement Standards, and the National Renewable Energy Laboratory. The Hydrogen Field Standard was funded by the State of California. The station testing program is funded by CARB, California Energy Commission, South Coast Air Quality Management District, and the California Fuel Cell Partnership.

Hydrogen Dispenser Certification

Hydrogen Field Standard, Test Program and Results to Date

Michael J. Kashuba – California Air Resources Board

Kristin J. Macey - California Department of Food and
Agriculture, Division of Measurement Standards

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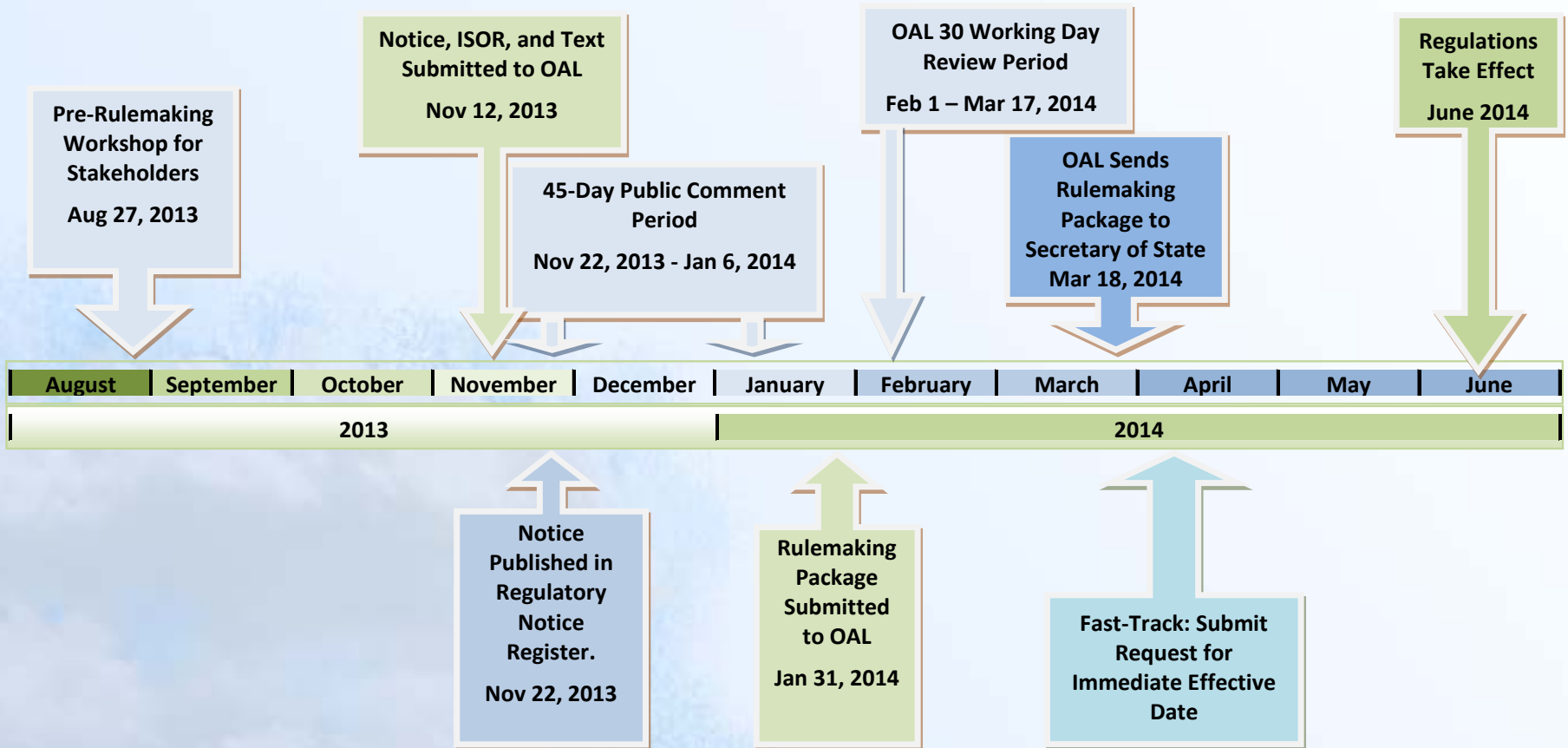
Purpose

- The California Air Resources Board's (CARB) Zero Emission Vehicle (ZEV) regulation requires that 15.4 % of all vehicles sales be ZEVs – either Fuel Cell Electric (FCEV), Battery Electric (BEV) or plug-in Hybrid Electric (PHEV) by 2025
- The California Department of Food and Agriculture (CDFA), Division of Measurement Standards (DMS) must certify hydrogen dispensers so hydrogen can be legally sold to fuel FCEVs
- To do this, this test program:
 - Developed specifications and tolerances for new regulations to address current dispenser technology accuracy
 - Fabricated and evaluated a reference standard
 - Built a portable hydrogen field standard for field testing
 - Conducted initial metrology testing of seven existing hydrogen stations
- The test program will continue testing newer dispenser designs in late 2014 and follow-up permanence testing of stations into 2015

Background

- **Regulatory Driver**
 - State Goal - GHG reductions 80% below 1990 levels by 2050
 - Zero Emission Vehicle Rule and Hydrogen Fuel Cell Vehicles
 - Motor fuel dispensers must receive a Certificate of Approval before they may be used in commerce in California
- **Setting**
 - National Institute of Standards and Technology Handbook 44 language with modifications adopted by CDFA
- **Next Steps:**
 - Fabrication and evaluation of reference standards
 - Statewide testing program
 - Results to date – testing approximately one third complete...

CDFA-DMS Rulemaking Timeline



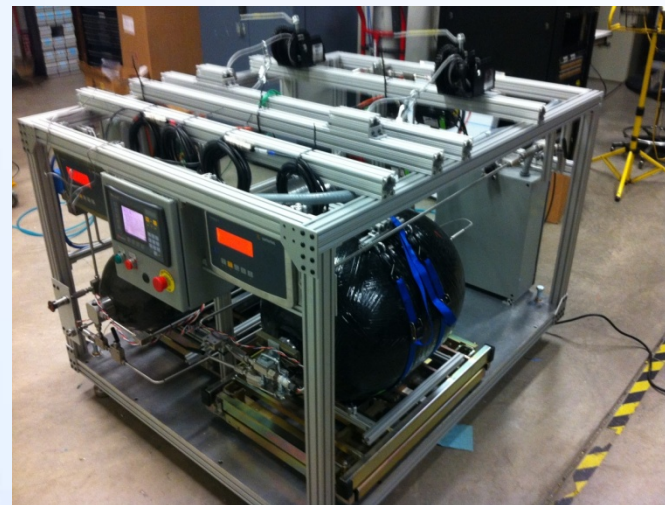
Fabrication of the Reference Standard

- California funded /subcontracted National Renewable Energy Laboratory (NREL) to build Hydrogen Field Standard (HFS)
 - Included three working standards
 - Gravimetric - Precision scale (150 kg x 0.001 kg)
 - Volumetric – Tanks, tubing, pressure/temperature sensors
 - Master Meter - Mass flow meter
 - Programmable Logic Controller, Data Acquisition & Display Electronics
 - Two hydrogen tanks – Approximately 60 and 70 liters
 - Valves, piping, structural support, and securing mechanism to allow transport for field use

Hydrogen Field Standard (HFS) Metrology Testing Device

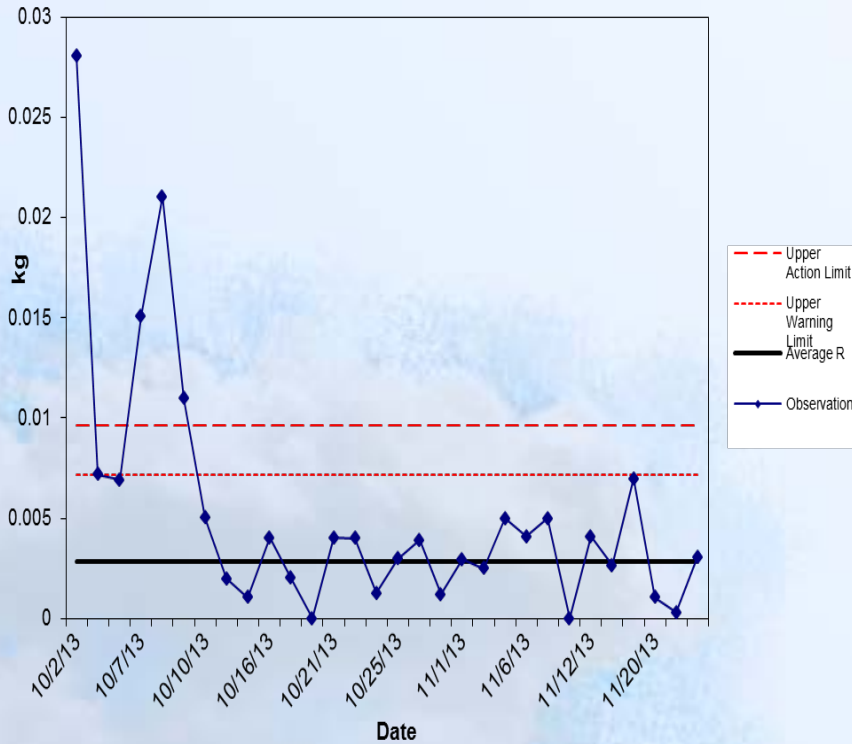
Timeline

- First version (top image) completed summer 2013
- Final field device (lower image) completed November 2013
- Required 30 test fills completed December 2013
- Raw data has been analyzed by DMS
- Preliminary determination that gravimetric method is most reliable, most suitable for verifying accuracy

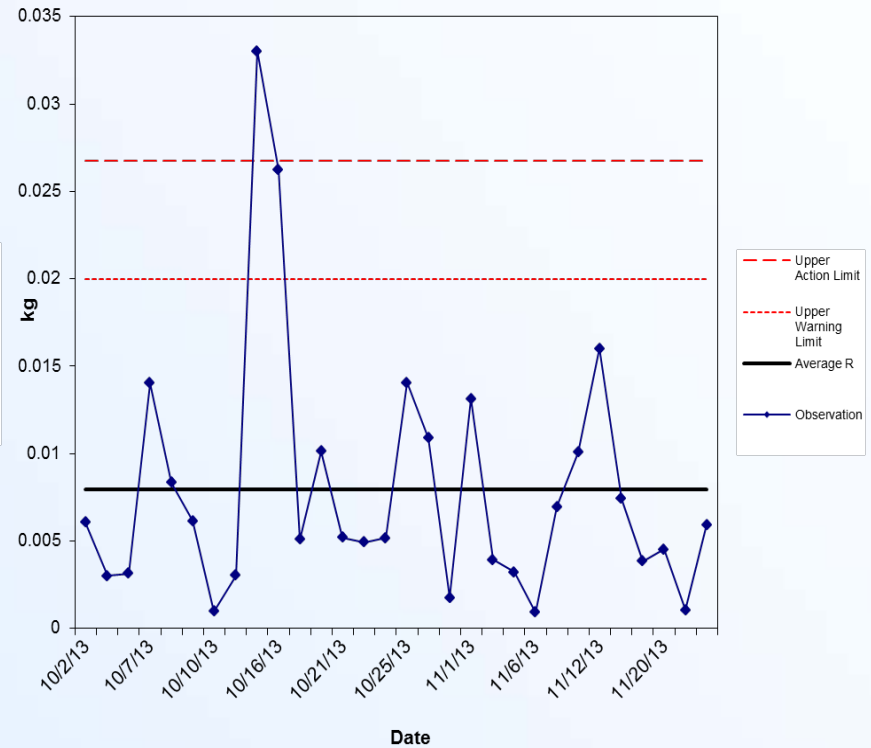


Validation of the Reference Standard Gravimetric Control Charts

State of California, Department of Food & Agriculture
Division of Measurement Standards Metrology Laboratory
35 MPa Gravimetric Graph



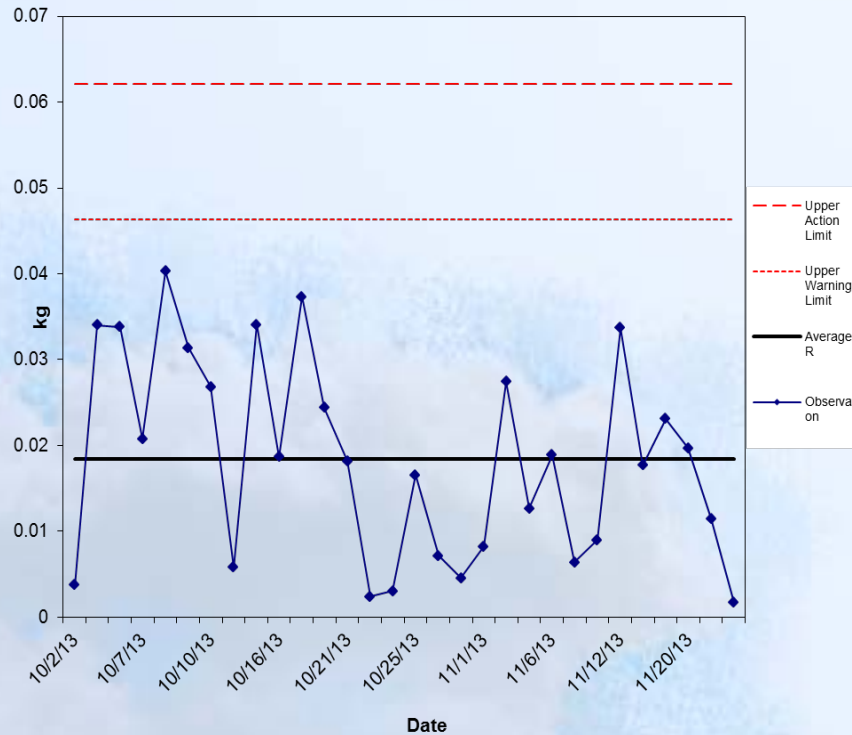
State of California, Department of Food & Agriculture
Division of Measurement Standards Metrology Laboratory
70 MPa Gravimetric Graph



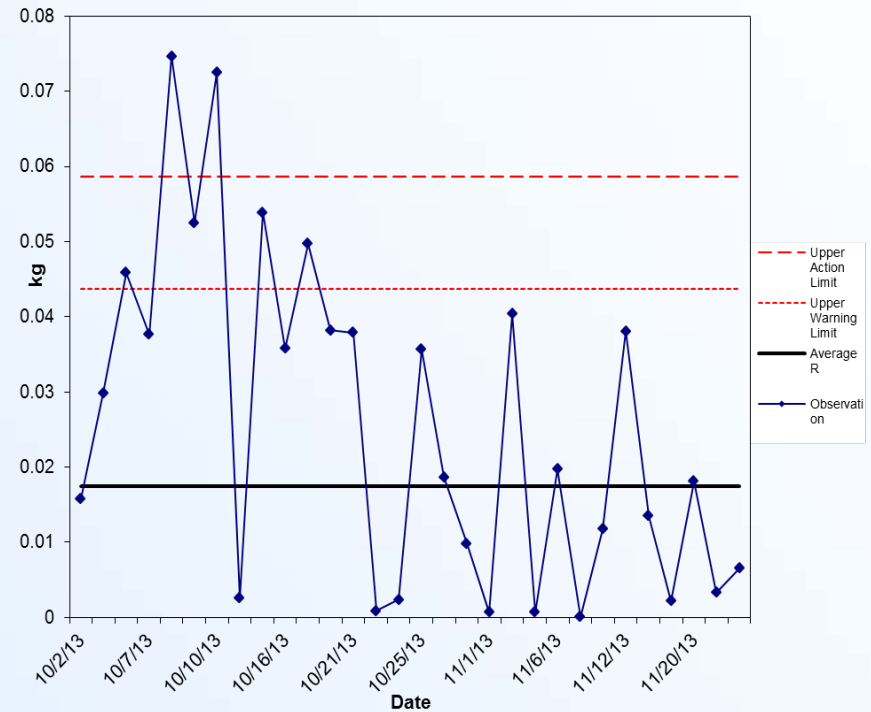
Validation of the Reference Standard

PVT Control Charts

State of California, Department of Food & Agriculture
 Division of Measurement Standards Metrology Laboratory
 35 MPa PVT Graph



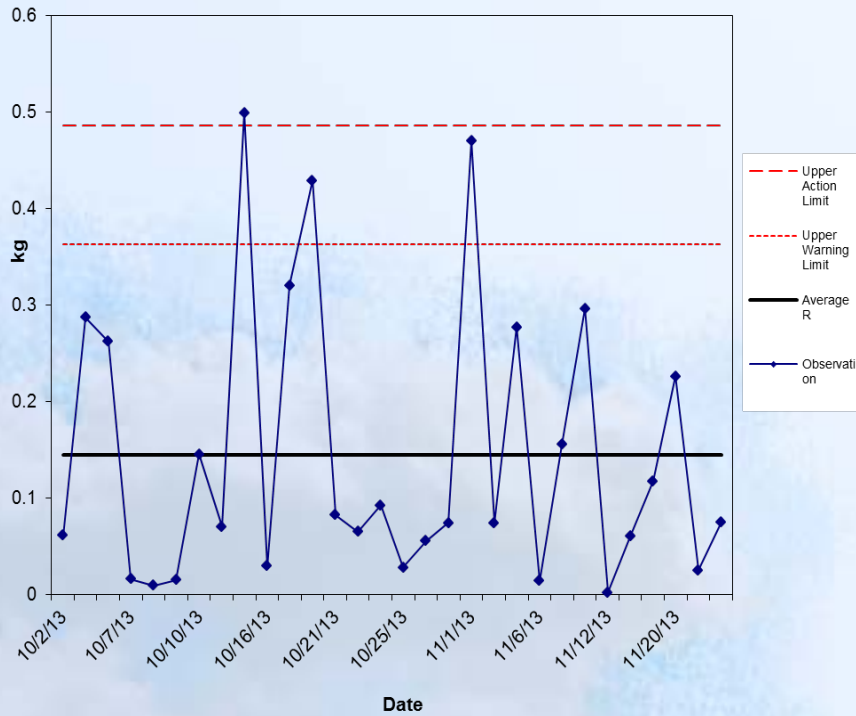
State of California, Department of Food & Agriculture
 Division of Measurement Standards Metrology Laboratory
 70 MPa PVT Graph



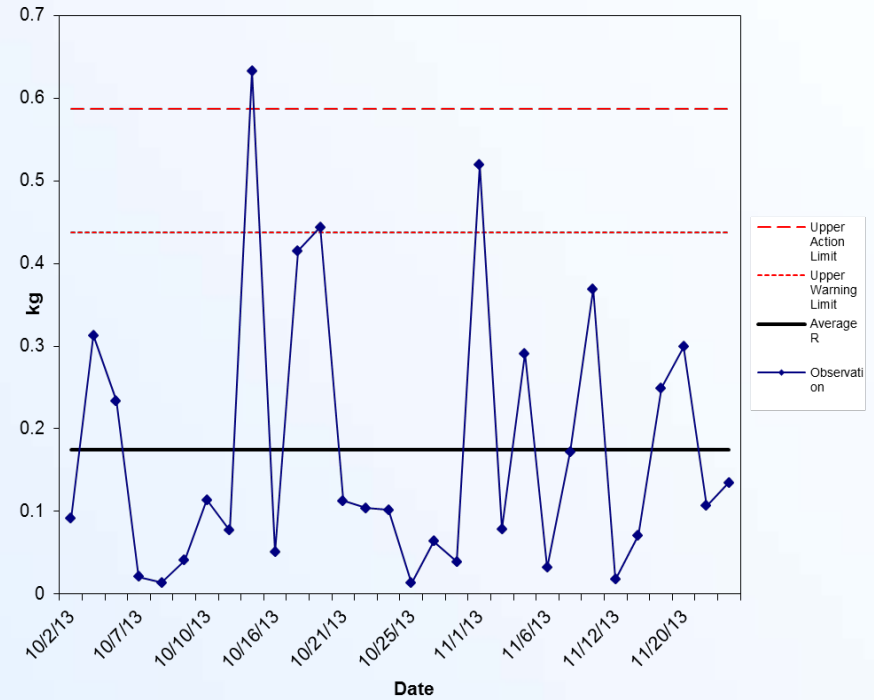
Validation of the Reference Standard

Master Meter Control Charts

State of California, Department of Food & Agriculture
Division of Measurement Standards Metrology Laboratory
35 MPa Master Meter Graph



State of California, Department of Food & Agriculture
Division of Measurement Standards Metrology Laboratory
70 MPa Master Meter Graph



Assessing Control Chart Data

To calculate the expanded uncertainty, the measurement uncertainty was multiplied by a coverage factor, k , based on the degrees of freedom (number of data points, $n - 1$) to provide a level of confidence of approximately 95%

2kg 35 MPa				
Procedure	Degrees of Freedom (n-1)	Measurement Uncertainty	Coverage Factor k	Expanded Uncertainty
Gravimetric	19	2.4 g	2	4.8 g
Volume	29	15.5 g	2	31 g
Master Meter	29	144.4 g	2	288.8 g

4kg 70 MPa				
Procedure	Degrees of Freedom (n-1)	Measurement Uncertainty	Coverage Factor k	Expanded Uncertainty
Gravimetric	29	7.6 g	2	15.2 g
Volume	19	16.8 g	2	33.6 g
Master Meter	29	170.0 g	2	340 g

California's Proposed Accuracy Classes* and Tolerances for Hydrogen Fuel

Accuracy Class	Acceptance Tolerance	Maintenance Tolerance
2.0	1.5%	2.0%
3.0 installed before 2020*	2.0%	3.0%
5.0 installed before 2020*	4.0%	5.0%
10.0 installed before 2018*	5.0%	10.0%

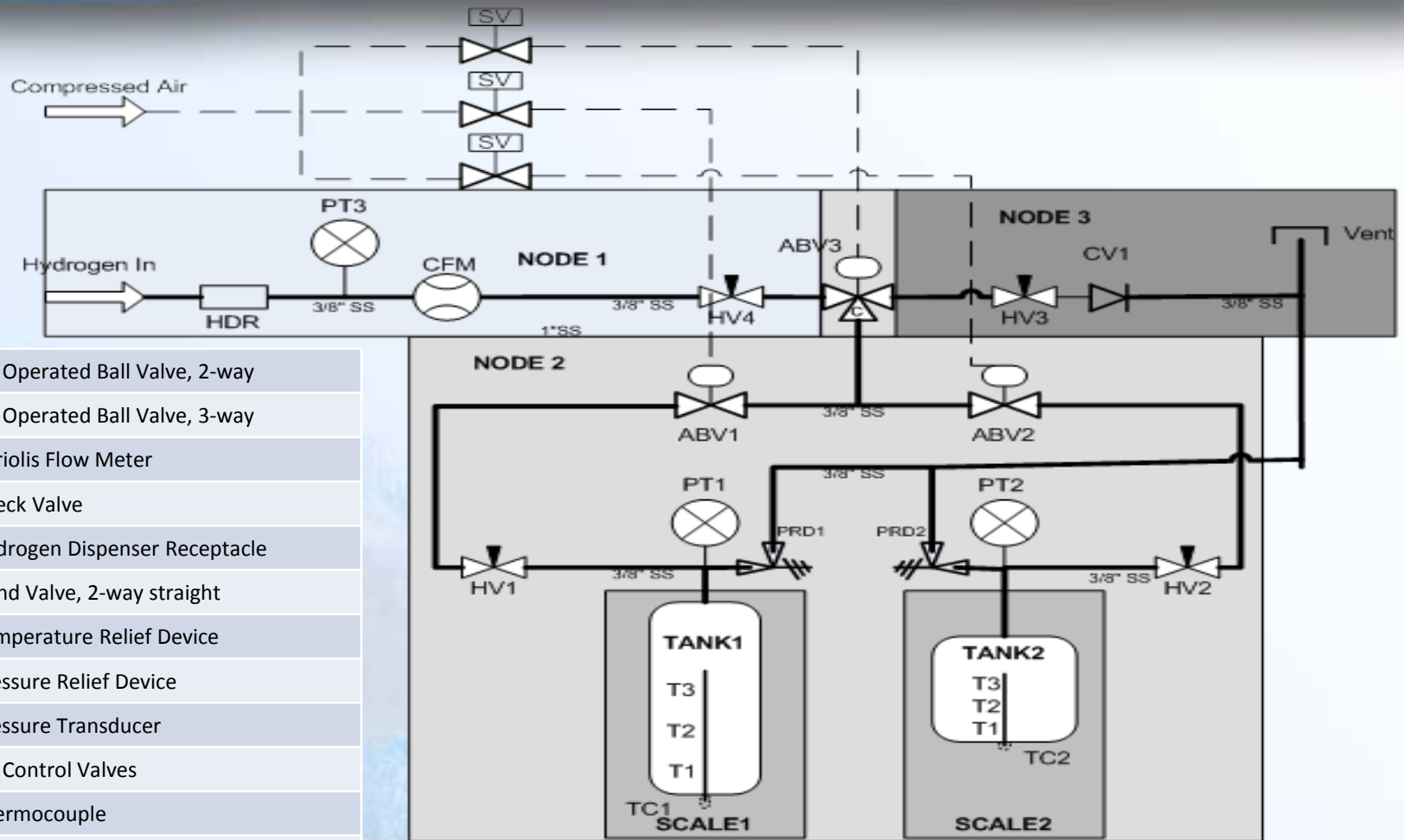
* No new installations after the end of the designated calendar year unless regulations are further amended. Existing installations allowed to operate until decommissioned.

Preparing the HFS for Transport

- Installed into Ford F250 pickup truck
 - 2,200lb cargo weight rating
- Custom fiberglass protective shell
 - Protection from elements
 - Security against theft and vandalism
 - Features a capped, passive vent at the high point of the roof to prevent accumulation of hydrogen
- HFS is mounted into the bed similar to the way a fifth wheel trailer is mounted



HFS P & ID



ABV 1-2	Air Operated Ball Valve, 2-way
ABV 3	Air Operated Ball Valve, 3-way
CFM	Coriolis Flow Meter
CV1	Check Valve
HDR	Hydrogen Dispenser Receptacle
HV 1-4	Hand Valve, 2-way straight
PRD 1	Temperature Relief Device
PRD 2	Pressure Relief Device
PT 1-3	Pressure Transducer
SV	Air Control Valves
TC 1--3	Thermocouple
UFM	Ultrasonic Flow Meter

HAZOPs Conducted

- Identify hazards and develop appropriate operational procedures to mitigate risks associated with those hazards
- The process used is based on NREL's experience with conducting HAZOP studies and DOE's recommendations outlined in "DOE Handbook – Chemical Process Hazard Analysis" Document # DOE-HDBK-1100-2004
- **Results of the hazard analysis show risk levels ranked in the low and routine categories.**
- These risk levels are determined to be acceptable by NREL and DOE process safety guidelines
- Process safeguards such as hydrogen detection, trained operators and overpressure protection will ensure that an acceptable level of safety is achieved when operating the metering apparatus at dispensing stations

H2 Station Testing Plan

- Surveyed station operators last summer
 - Station capacity, dispenser features, type of meter present, timing, etc.
- Created a list of ten stations to test with “high value” and one station for “shakedown” testing
- Presented/discussed in a November California Fuel Cell Partnership Working Group call:
 - List of stations and a weekly from monthly testing schedule
 - A proposed geographic sequence of testing
 - Adjustments made for DMS workload (2 weeks on 1 week off)
 - Sequence adjustments made for ensuring device and procedures thoroughly tested before testing at high value customer stations
- **Important:** ensuring effective communication procedures to inform customers when/how long station will be out of service

2014/15 California Test Schedule

(Subject to Change)

Testing Order	Station	Expected Evaluation Outcome	Initial Test Date	Permanence Test Date
1	Berkeley	Accuracy Assessment / shakedown	February 10-14, 2014	Unlikely
2	Emeryville	Temporary Use Permit	March 3 – 7, 2014	June 9 - 13, 2014
3	Thousand Palms	Accuracy Assessment / Temporary Use Permit	March 24 - 28, 2014	May 26 - 30, 2014
4	Torrance	Accuracy Assessment	April 1 – 4 , 2014	Unlikely
5	Burbank	Accuracy Assessment	April 14 - 18, 2014	Unlikely
6	CSULA	Temporary Use Permit	April 21 – 25, 2014	June 23 - 27, 2014
7	Newport Beach	Temporary Use Permit	May 5 - 9, 2014	June 30 – July 3, 2014
8	West Los Angeles	Temporary Use Permit	May 12 - 16, 2014	July 21-25, 2014
9	Diamond Bar	Full Type Evaluation	July 14 - 18, 2014	October 13-17, 2014
10	Anaheim	Full Type Evaluation	October 6 - 10, 2014	January 5 - 9, 2015
11	West Sacramento	Full Type Evaluation	October 27 – 31, 2014	January 12- 16, 2015

Typical Testing Regimes

Day 1

- Travel to site
 - Driving to So Cal sites will take an entire day
 - *If flying - may proceed with next steps of testing regime*
- Set up, site/dispenser inspections, applications
 - Approximately 120+ min
- Pressure /safety test, run first draft
 - Approximately 120+ min for dispensing & venting 4 kg
- Breakdown
 - Approximately 60 min

Day 2 through Day 5

- Setup and pressure test (if necessary)
 - Approximately 90-120 min dispensing & venting 4 kg
- Run drafts
 - 5 drafts expected
 - Dispense approximately 20 kg
 - Approximately 90+ min each for venting
- Make dispenser adjustments, if appropriate
 - Continue or restart drafts/testing
- Breakdown
 - Approximately 60 min
- *Day 5 only:* return travel

Initial Setup

- Position HFS
- Set up cones/safety zone
- Stabilize test vehicle
- Install vent stack
- Unstrap tanks/scales
- Level HFS skid
- Warm up scales
- Calibrate scales



Expected Outcomes

- Issuance of a Temporary Use Permit or Certificate of Approval would allow the legal commercial sale of hydrogen on a per kilogram basis

Type of Testing	Description
1. Certificate of Approval	In addition to the initial assessment, subsequent permanence testing is required. DMS Certificate of Approval issued are applicable to other stations using the same type of dispenser. Handbook 44 metered dispensers new APCI, Linde, Air Liquide dispensers.
2. Temporary Use Permit	Following successful initial assessment, a limited-time, temporary use permit is issued only for the station tested. Successful permanence testing is required for a DMS Certificate of Approval. Stations with older metering technology may be one-of-a-kind or limited-use dispensers.
3. Accuracy assessment	Data collected at the station to only determine the accuracy of dispenser. No follow-up permanence testing is required. No use permit is issued – reverse PVT stations.

Estimated Testing Costs

Item	Cost Per Station	Total Approximate Cost
1. DMS cost recovery	\$14,000 - \$26,000	\$200,000
2. Vented hydrogen	\$2,100 - \$4,200	\$29,400 - \$33,600
3. Support from station technician(s)	\$5,000 - \$11,000	\$24,000 - \$75,000
4. Contingency	-	\$38,000 - \$46,000
Total Estimated Cost/budget		\$291,000 - \$355,000

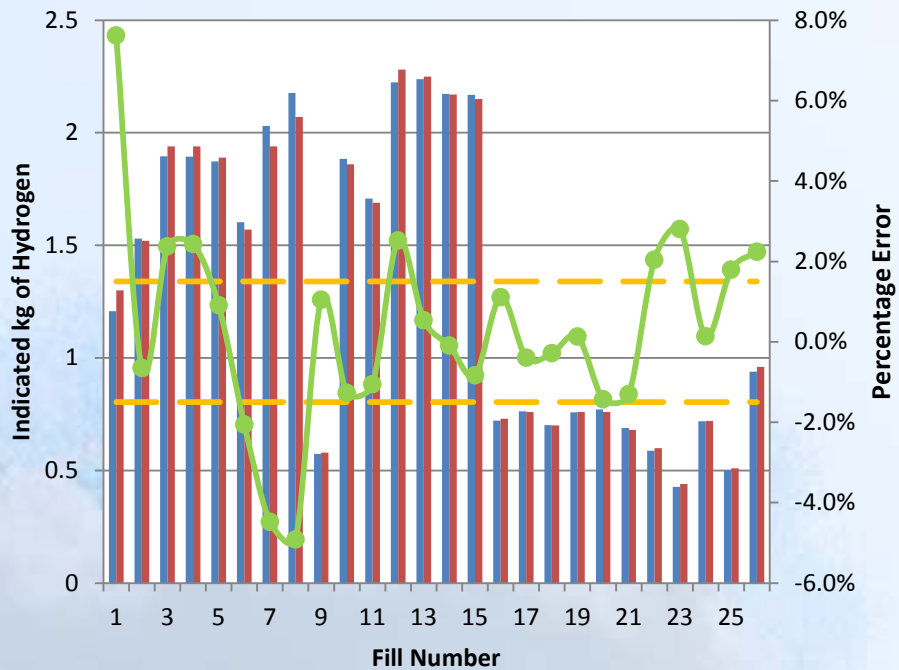
- DMS mandated to recover all costs including, tests, travel, data analysis, etc
- 150-300kg of H₂ will be vented - estimated \$14/kg
- 27-60 hours of technician support labor - \$175/hr
- Costs may be less depending on cost share and other potential efficiencies
- Contingency cost is 15% of the total of item 1,2,3 for unforeseen expenses
- Testing program funded collectively by CARB, California Energy Commission, South Coast Air Quality Management District, and the California Fuel Cell Partnership

Ownership and Sharing of Testing Data/Results

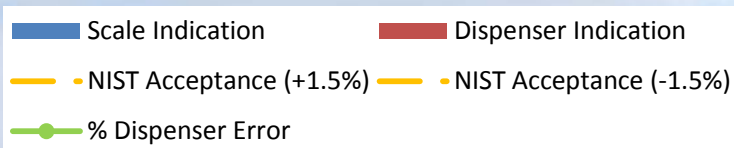
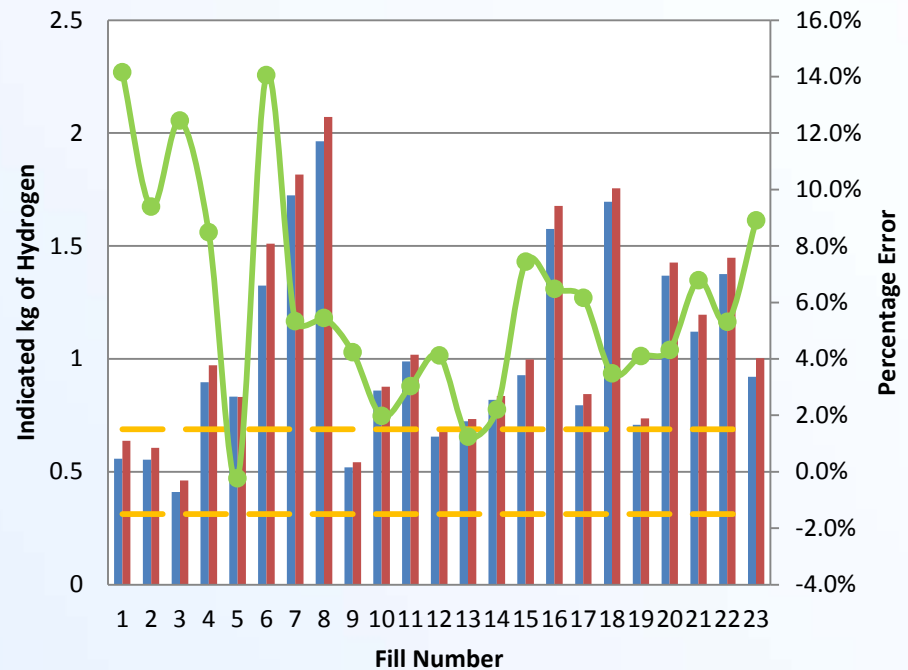
- Test data (e.g., checklist, data calculations for individual draft fills, etc.) are considered working notes
- Working notes are considered “exempt” from public disclosure
- DMS will sanitize results (Pass/Fail, % Accuracy) and release information after multiple stations have been tested so data cannot be traced to a particular station
- Final results will be very public – No sticker (Fail), Temporary Use Permit sticker (Pass initial tests), Approval Seal and Accuracy Class sticker with +/- 2%, 3%, 5% or 10% accuracy (Pass all tests and Certificate issued)

H35 Dispenser Delivery and Associated Errors

Station 1: H35

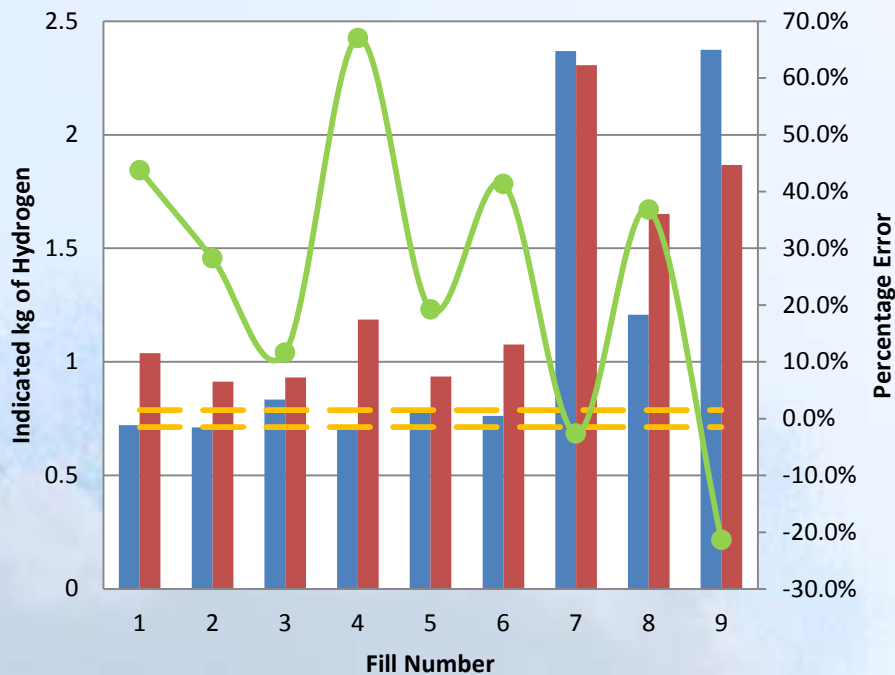


Station 2: H35

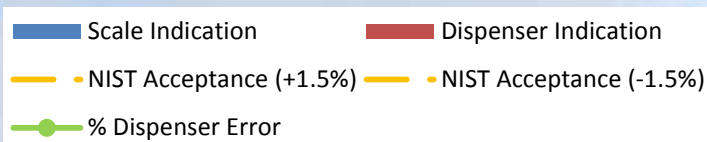
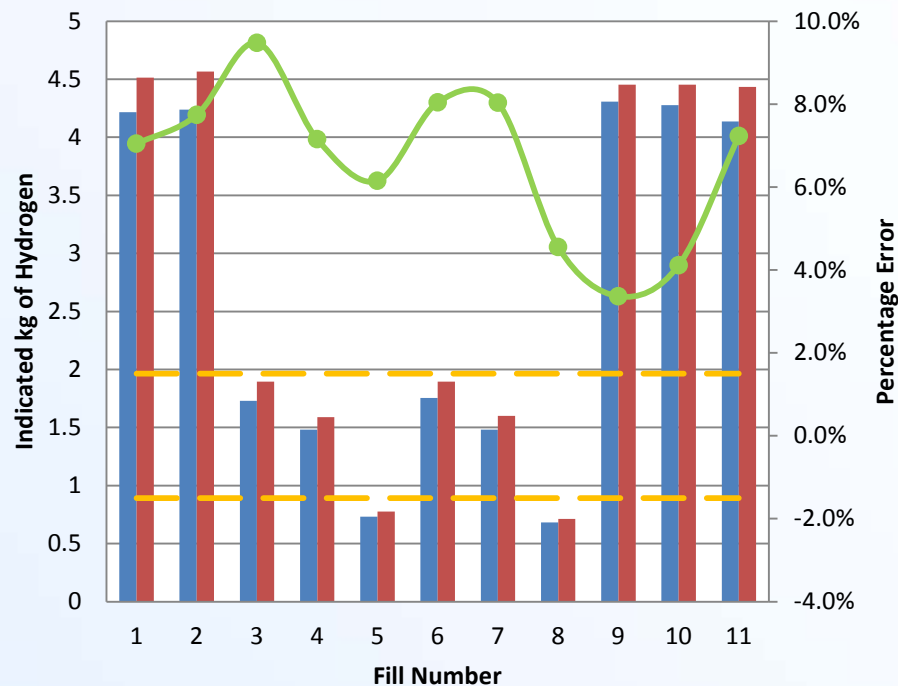


H70 Dispenser Delivery and Associated Errors

Station 3: H70

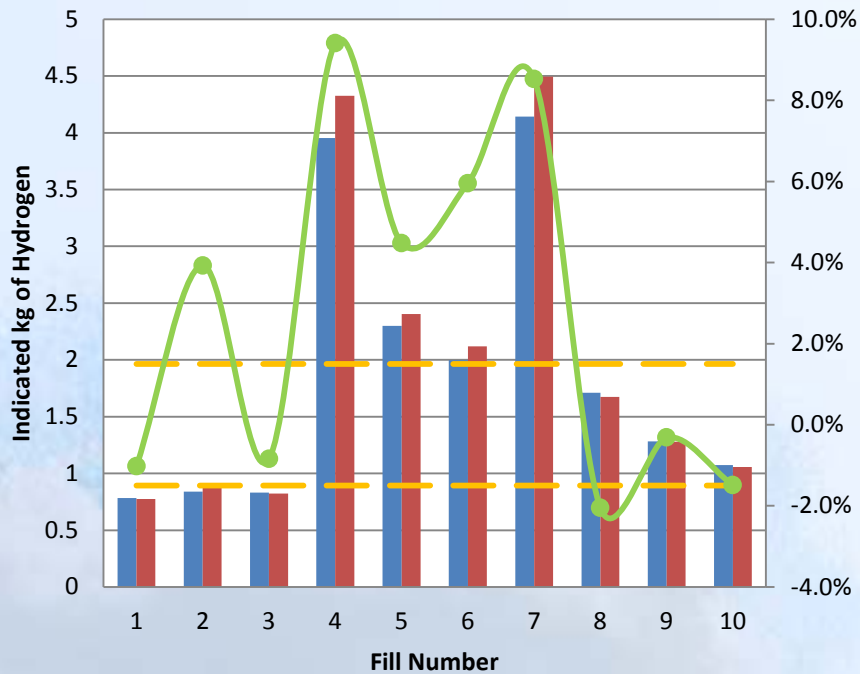


Station 4: H70

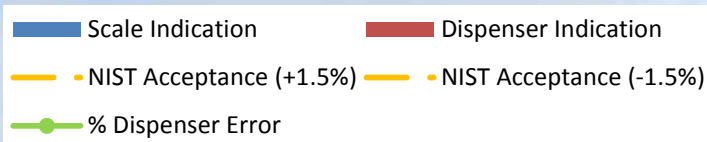
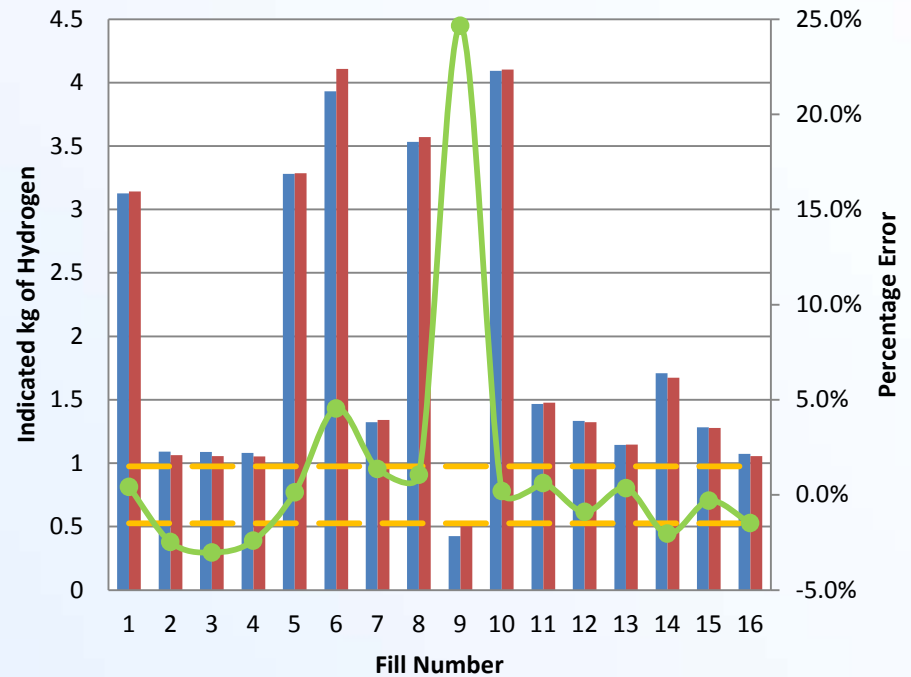


H70 Dispenser Delivery and Associated Errors

Station 5: H70



Station 6: H70



Expected/Observed Demonstration Dispenser Deficiencies

California Code of Regulations, Title 4, Division 9.

- **Provision for Power Loss** - Need to maintain transaction information on display during a power loss.
- **Display of Quantity and Total Price** - Transaction information needs to be displayed for 5 minutes after the completion of delivery.
- **Provision for Sealing** - The measuring device electronics is exposed allowing access to adjustment parameters.
- **Pressurizing the Discharge Hose** – The discharge hose is not pressurized until after the start of a delivery preventing the customer from receiving metered dispensed product due to venting of the discharge hose at the end of a delivery.
- **Identification Plate** – The identification plate does not have the designated markings for the model number, accuracy class listing, maximum/minimum flow rate in kilograms per unit time, maximum working pressure, minimum measured quantity, and the product for which the dispenser will dispense.
- **Display Resolution** – Resolution should be 1 gram.
- **No Receipt Available** – Recorded representations are not available to customer.

Challenges, Lessons Learned, Recommendations – To Be Continued

- Coriolis meter in master meter standard exhibited a limited capability to measure gas flows accurately at high pressures and low densities.
- Original plan had a validation process that required 35 and 70 MPa data collection daily for 30 consecutive days at a stations in California. This would interrupt normal station operations. Instead, validation was conducted at NREL's facility.
- Procurement of 70 MPa high volume stationary storage tank created a significant delay. The first tank ordered failed to meet specifications.
- A larger truck bed and enclosure to house the HFS would be preferable. Limited space makes setup, adjustments, and repairs difficult.
- Measurement compensation/corrections may need to be made for ambient conditions such as wind, relative humidity, and temperature.
- Device design requires careful attention be paid to hydrogen dispenser flow rates.
- Dispenser accuracy at minimum measured quantity remains challenging for today's dispensers.