



# HyStEP: A device for testing hydrogen station fueling protocols

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# HyStEP design developed by H2FIRST team in collaboration with Powertech Labs



Team Member	Project Roles
Sandia National Laboratories	Project lead, management and coordination; device design; safety analysis
National Renewable Energy Laboratory	Device design; safety analysis; device validation testing
Air Liquide	Device design; safety analysis; facilitate pre-deployment testing
Boyd Hydrogen	Device design and safety analysis
CA Air Resources Board	Device design; safety analysis; facilitate pre-deployment testing; Deployment lead
Toyota	Device design; safety analysis; vehicle participation/comparison for pre-deployment testing
PNNL H <sub>2</sub> Safety Panel	HyStEP design and safety review

# What is HyStEP? The Hydrogen Station Equipment Performance Device



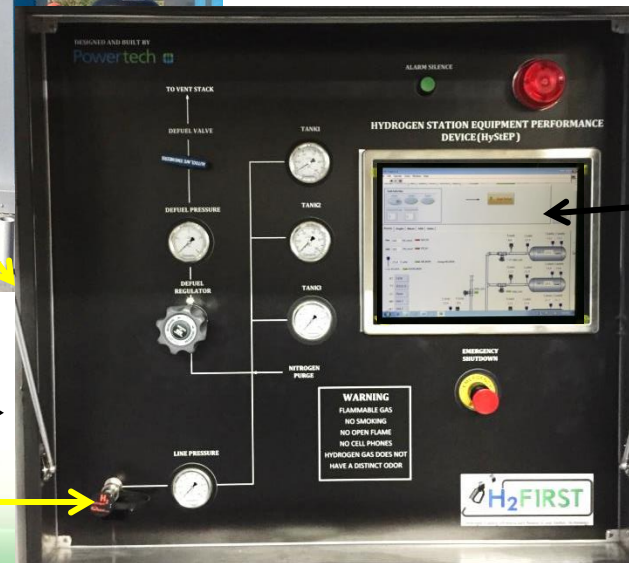
## Key Features:

Three 76L Type IV tanks (3.1 kg H<sub>2</sub> capacity each)

IrDA communications

70 MPa receptacle

Tanks and receptacle instrumented with P and T sensors



Operator panel →

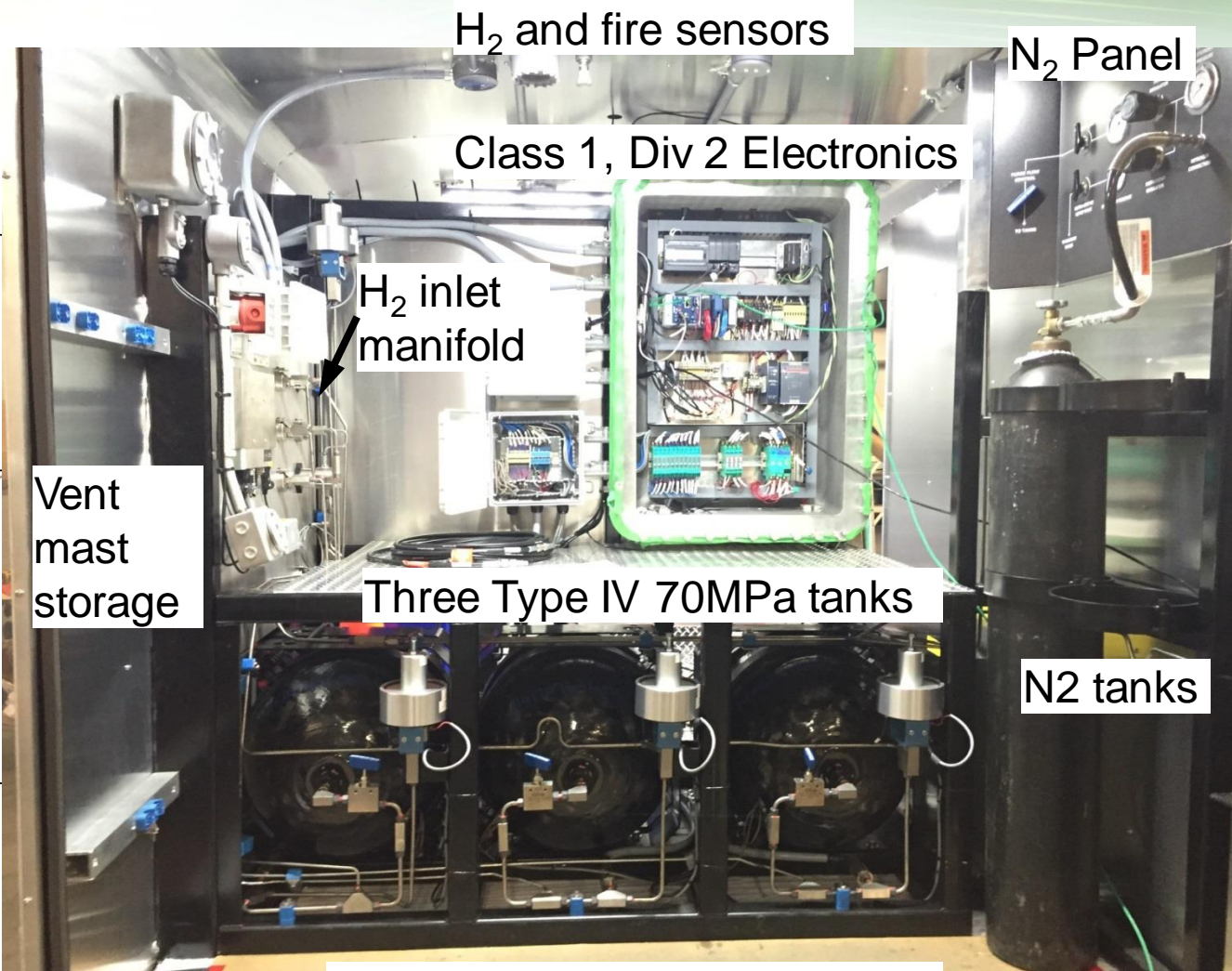
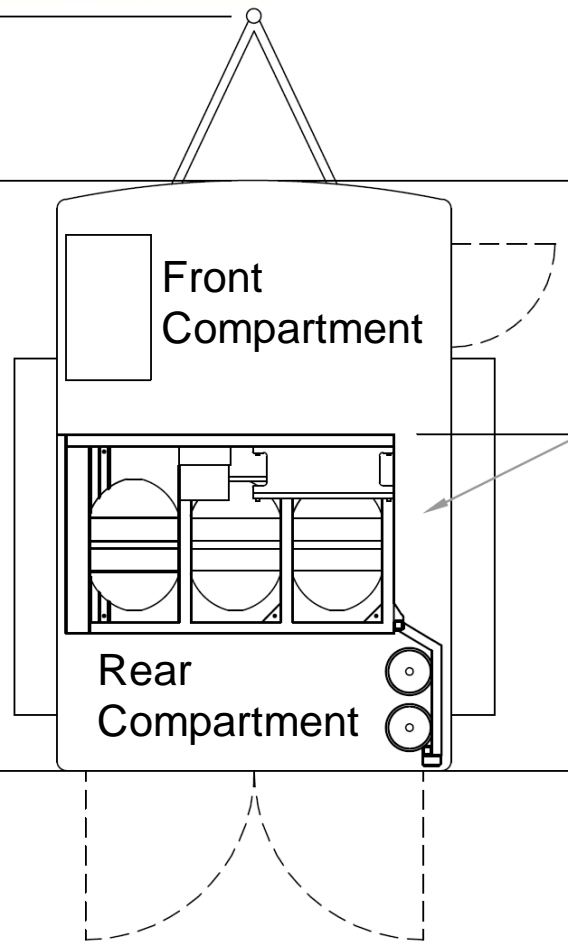
Receptacle →

Touchscreen  
User Interface

# Rear trailer compartment houses gas systems and electronics; front for tools and storage



Top view of trailer



View into Rear Compartment

# Primary goal of the HyStEP Device is to facilitate the commissioning of stations



**Fill safely:** Common goal of vehicle manufacturers, consumers, station operators, and state stakeholders

**Follow standards:**

- SAE J2601-2014 (fueling protocol), specifies how to fill hydrogen vehicles safely.
- CSA HGV 4.3 (test method), defines how to test dispensers for compliance with SAE J2601.

**Test stations:** HyStEP Device will be capable of testing to the CSA HGV 4.3 test methods.

Today's Problem: Each OEM performs vehicle test fills to validate station



Tomorrow's Solution: HyStEP acts as FCEV surrogate; operated by testing agency



# HyStEP designed to test dispenser compliance with SAE J2601-2014



SAE J2601-2014 published in July, 2014

- New tank sizes classes: 2-4kg, 4-7kg, and 7-10kg for H70; 2.4-4.2kg and 4.2-6kg for H35
- Three pre-cooling temperatures (T40, T30, T20)
- New protocols: Fallback, top-off, cold dispenser
- New definitions: Reference T and P for tables now near the hose break-away; pressure corridor with upper and lower tolerances
- Large number of tables: 30 standard tables; 24 optional cold dispenser tables;

H70-T40 4-7kg comm	Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure P <sub>target</sub> [MPa]	Target Pressure Top-Off [MPa]	Top-Off- APRR [MPa/min]	Target Pressure, P <sub>target</sub> [MPa]													
					Initial Tank Pressure, P <sub>0</sub> [MPa]													
					0,5 - 5 (no Interpolation allowed)					0,5	2	5	10	15	20	30	40	50
Ambient Temperature, T <sub>amb</sub> [°C]	> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	5,1	78,2	87,5	2,6	see Top-Off	see Top-Off	80,8	85,7	86,8	86,5	85,8	85,0	84,0	82,7	81,1	no fueling	no fueling
	45	8,1	76,3	87,5	4,0	see Top-Off	see Top-Off	81,1	86,9	86,6	86,2	85,3	84,3	83,0	81,6	79,7	no fueling	no fueling
	40	11,5	73,2	87,5	5,4	see Top-Off	see Top-Off	81,1	86,9	86,4	85,9	84,7	83,5	82,0	80,3	78,3	no fueling	no fueling
	35	12,4	72,9	87,5	5,6	see Top-Off	see Top-Off	81,2	86,9	86,4	85,9	84,7	83,4	81,9	80,2	78,2	no fueling	no fueling
	30	15,3	70,6	87,5	6,6	see Top-Off	see Top-Off	81,0	86,8	86,3	85,6	84,3	82,8	81,2	79,4	77,2	no fueling	no fueling
	25	18,5	69,0	87,4	7,2	see Top-Off	see Top-Off	81,0	86,8	86,1	85,4	83,8	82,2	80,4	78,5	76,1	no fueling	no fueling
	20	21,8	67,9	87,4	7,6	see Top-Off	see Top-Off	81,2	86,8	85,9	85,1	83,3	81,5	79,6	77,5	75,1	no fueling	no fueling
	10	28,0	66,3	87,4	9,0	see Top-Off	see Top-Off	81,2	86,8	85,7	84,7	82,6	80,5	78,3	76,1	73,4	no fueling	no fueling
	0	28,5	no Top-Off	no Top-Off	no Top-Off	78,4	84,6	86,8	85,6	84,4	83,1	80,6	78,1	75,6	73,1	no fueling	no fueling	no fueling
	-10	28,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,9	75,4	72,9	no fueling	no fueling	no fueling
	-20	28,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,6	75,1	72,7	no fueling	no fueling	no fueling
	-30	28,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,2	74,9	72,5	no fueling	no fueling	no fueling
	-40	28,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,0	74,6	72,3	no fueling	no fueling	no fueling
	< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

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# New version of CSA HGV 4.3 under development to harmonize with SAE J2601-2014



CSA HGV 4.3 defines three sets of tests to verify compliance with SAE J2601 <http://publicreview.csa.ca/>

## Fault Detection

- CHSS capacity range test
- Ambient temperature test
- Minimum fuel delivery temperature test
- Maximum CHSS gas temperature test
- Minimum CHSS initial pressure test
- Maximum CHSS pressure test
- Maximum state of charge test

## Communications

- Abort signal test
- Halt signal test
- Data loss test and then resumed fueling test
- Invalid CRC communication test
- Invalid defined data value test
  - Protocol Identifier (ID)
  - Software Version Number (VN)
  - Tank Volume (TV)
  - Receptacle Type (RT)
  - Fueling Command (FC)
  - Measured Pressure (MP)
  - Measured Temperature (MT)

## Fueling Protocol

- Non-comm Fueling tests
- Comm fueling tests
- Repeated table test
- No fueling test
- High pressure capacity test
- Pre-cooling capacity test
- Fallback test
- Top-off fueling test
- Cold dispenser test

# Fueling protocol test matrix is defined to include all station options in minimum number of tests



Tests should capture all of the following options available on the dispenser

Fueling protocol tests must validate that tables are selected properly

- Comm/Non-comm fueling
  - Pressure class (H35, H70)
  - Fuel delivery temperature (T40, T30, T20)
  - CHSS size category (2-4, 4-7, 7-10 kg (H70))
  - Fallback, Top-off, Cold Dispenser
- APRR, including interpolation
  - Fueling ends properly
    - Target Pressure, including interpolation
    - 95-100% SOC (Communication)
  - No Fueling

Station Example 2: All Functions Except T30 and T20 Fuel Delivery Temp. Category							
Test #	Comm.	Pressure Class	Fuel Delivery Temperature Category	CHSS Capacity Category	Ambient Temperature	Initial CHSS Pressure	Test Procedure
D1	Non-Comm	H35	T40	Small	$T_{A1}$	$P_{o1}$	8.5.1
D22	Comm	H70	T40	Medium	$T_{A2}$	$P_{o2}$	8.5.2
D25	Non-Comm	H70	T40	Large	$T_{A3}$	$P_{o3}$	8.5.1
D25 Rep	Non-Comm	H70	T40	Large	$T_{A3} - 5\text{ }^{\circ}\text{C}$	$P_{o3} + 5\text{ MPa}$	8.5.2
NF	Non-Comm	H35	T40	Medium	$T_{ANF}$	$P_{oNF}$	8.5.2
HP	Comm	H70	T40	Large	$T_{AHP}$	$P_{oHP}$	8.5.1
PC	Comm	H70	T40	Small	$T_{APC}$	$P_{oPC}$	8.5.1
Fall back	Comm	H70	T40	Medium	$T_{AFallback}$	$P_{oFallback}$	8.5.3
Top off	Comm	H70	T40	Medium	$T_{ATopoff}$	$P_{oTopoff}$	8.5.4
Cold Disp	Non-Comm	H70	T40	Medium	$T_{ACD}$	$P_{oCD}$	8.5.5

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# HyStEP Device harmonized with CSA HGV 4.3 for test selection



The screenshot displays the H2Fuel control software interface. At the top, there are tabs for H2Fuel, H2Defuel, and Purge, along with an ESD\_MON indicator and an Error status. Below these are controls for Tank1, Tank2, and Tank3, and a Tank Selection section with a 'Cancel Prep. Fuel Test' button and a 'Start Test' button. A log window shows a message: 'Tue 15 - 13:50:27 PrepFuel Aborted: Either: - Equalization did not succeed after 30 sec and Tanks are not within +/-0.5 MPa of each other, - Or Alarm(s) still present in system'. A central window titled 'PopTestTypesNames\_v1.vi' contains three columns of test types: 'Communication\_Tests' (ABORT\_Signal, HALT\_Signal, Data\_Loss, CRC, Faulty\_Data), 'Fueling\_Protocol\_Tests' (NonComm\_Fueling, Comm\_Fueling, Repeat\_Table, No\_Fueling, HP\_Capacity, PC\_Capacity, Fallback, TopOff, Cold\_Dispenser), and 'Faults\_Detection\_Tests' (CHSS\_Limits, Amb\_Temp\_Limits, Min\_Fuel\_Temp, CHSS\_Gas\_Temp, Min\_Init\_Press, Max\_CHSS\_Press, Max\_SOC, Misc\_Test). A 'SELECT TEST TYPE' button is located below these lists. At the bottom, a schematic diagram shows the fueling system with various sensors and valves. The diagram includes a red valve labeled 'RECEP\_AV5', a valve labeled 'TNK3\_AV5', and a tank labeled 'SOC\_3 Tank3' with a value of 84.8. Other numerical values shown are 10.3, 67.8, 59.0, 11.6, 33.6, and 33.6. On the left side of the interface, there are input fields for MP (067.8), MT (283.5), and MT\_°C (010.3).

# To carry out CSA HGV 4.3 tests, the operator will use the HyStEP touchscreen control panel



Fueling Tab    Defueling Tab    N2 Purge Tab    Tabs for viewing data and alarm status and sending IR signals manually

Tank selection  
 Comm mode; Halt and Abort Commands  
 H<sub>2</sub> Detectors  
 Ambient temp; Alarms  
 Transmitted IR signal

Alarm Status

Units: Pressure: MPa - Temperature: °C - SOC: %

Piping and instrumentation diagram:

- Receptacle P & T
- Valve status
- Tank inlet P & T
- Internal tank gas T
- SOC

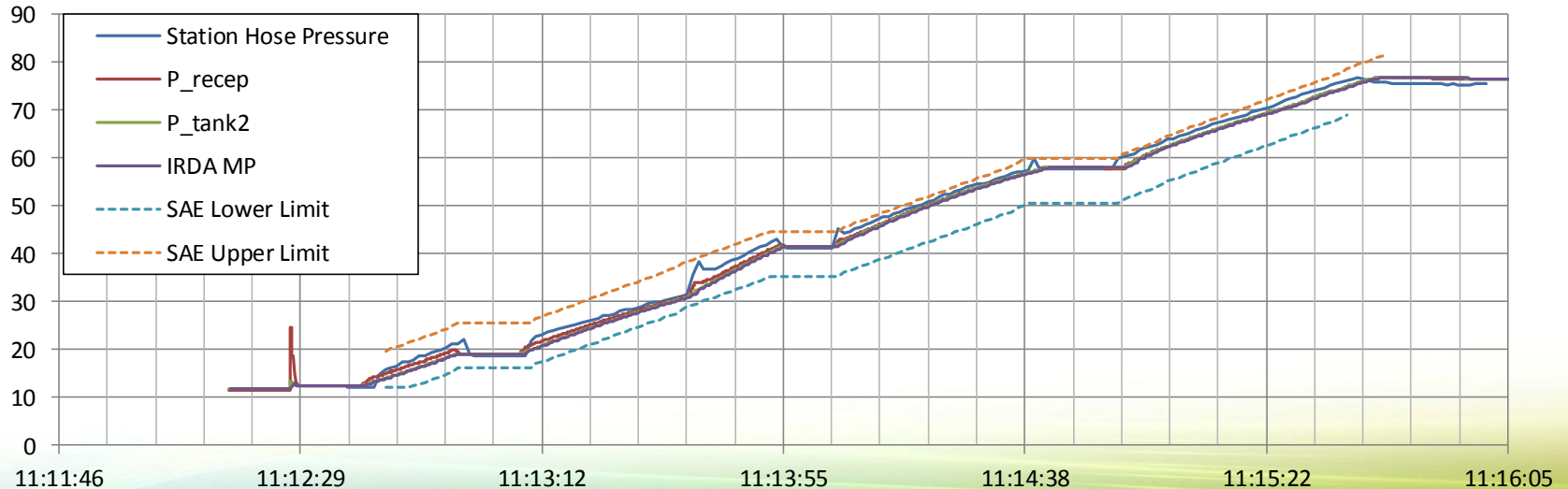
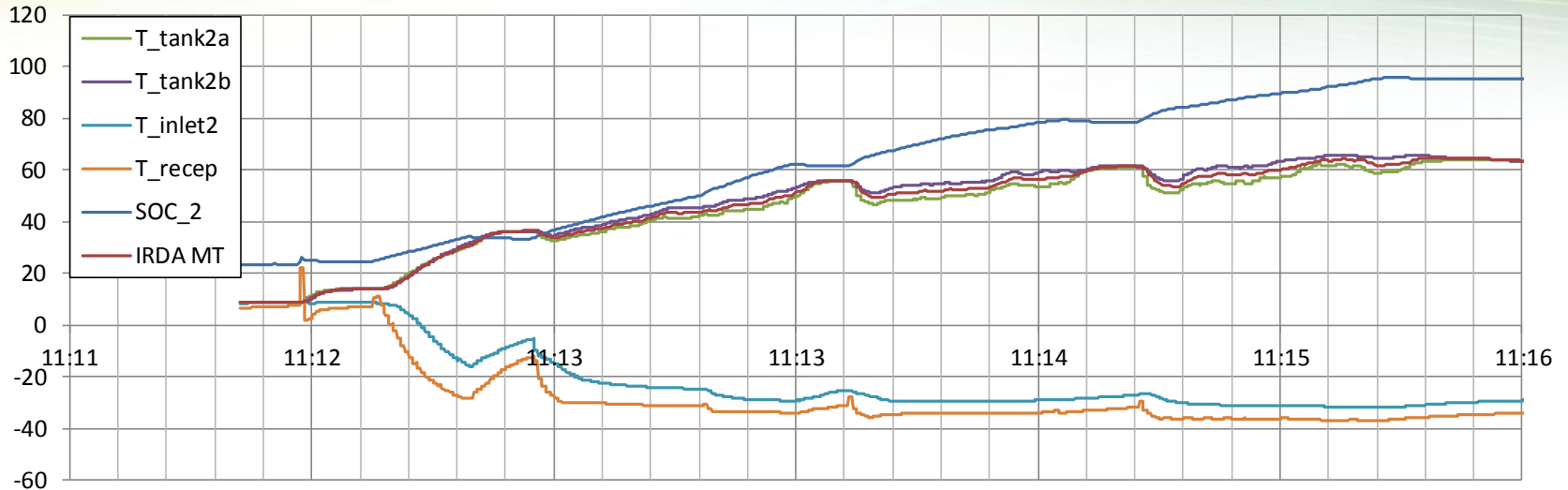
# For fault detection and communication tests, the IrDA tab is used to manually send field values



The screenshot displays the H2FIRST control interface. At the top, there are tabs for H2Fuel, H2Defuel, Purge, and ESD\_MON. Below these are controls for Tank Selection (Tank1, Tank2, Tank3), TestDuration, TestName, and Comm. Mode. A 'Prep. Fuel Test' button is highlighted with a '1.' and a 'Start Test' button with a '2.'. An 'Error' window on the right shows a log of events: 'Tue 15 - 13:50:27 PrepFuel Aborted: Either: - Equalization did not succeed after 30 sec and Tanks are not within +/-0.5 MPa of each other, - Or Alarm(s) still present in system', 'Tue 15 - 13:50:27 Equalize prep. completed', 'Tue 15 - 13:49:58 Equalize before fueling ...', and 'Tue 15 - 13:49:58 Start Equalization before'. Below the error window is a 'Keyboard' button and a red 'STOP' button.

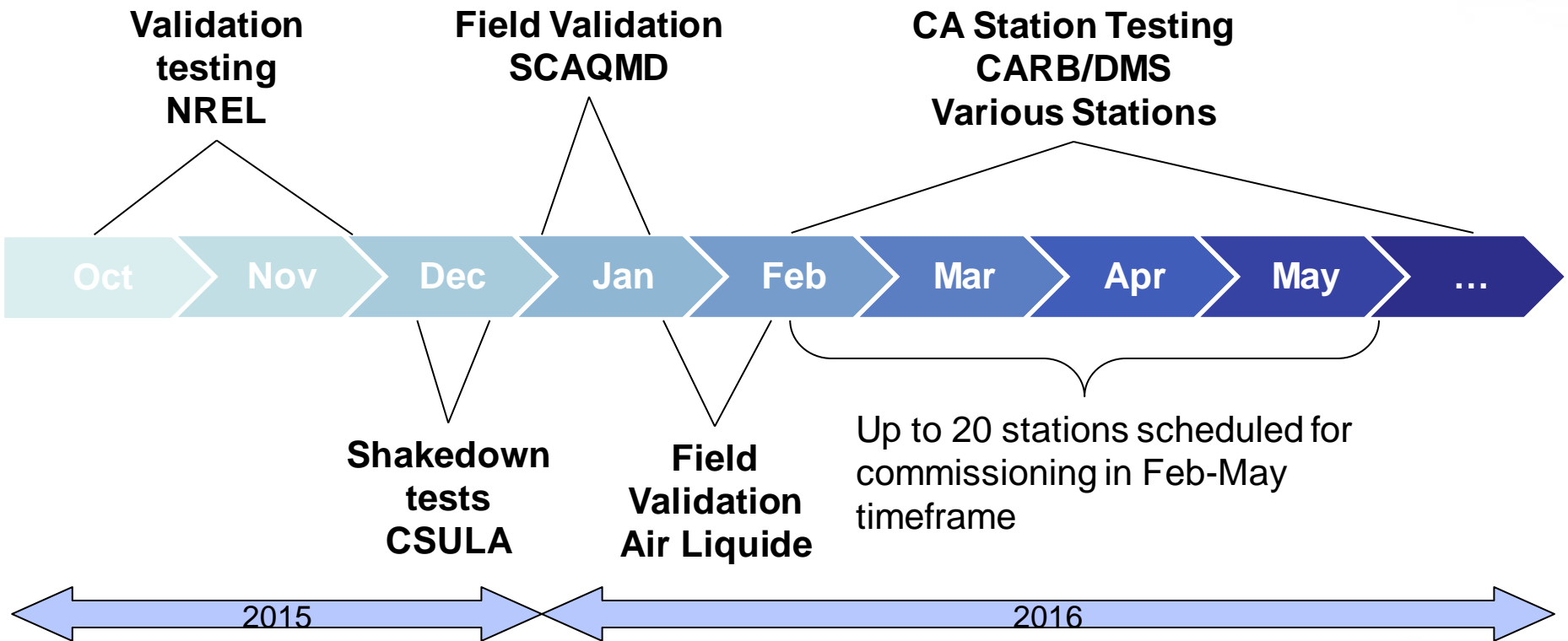
The main interface has tabs for Process, Graphs, Alarms, IrDA, Data, Health, and Engineering. The 'IrDA' tab is active, showing 'Alarm Status'. On the left, there are 'EnableSAEOverride' and 'CRC Corrupt' buttons. The central area is divided into 'Measured' and 'Prescribed' sections. The 'Measured' section has input fields for ID (SAE J2799), VN (01.10), RT (H70), TV (0001.0), FC (Dyna), MP (066.8), MT (273.0), and MT\_°C (032.0). The 'Prescribed' section has input fields for ID (SAE J2799), VN (01.10), RT (H70), TV (0180.0), FC (Dyna), MP (064.0), MT (032.0), and MT\_°C (-00.2). An arrow points from the 'Measured' section to the 'Prescribed' section. At the bottom, there is a 'Read' button and an 'IrDA String' field containing the text: 'yyyyyÀ|ID=SAE J2799|VN=01.10|TV=0001.0|RT=H70|FC=Dyna|MP=066.8|MT=273.0|ÔÁ'.

# H70-T40 fill completed at NREL on 10/23/2015



# HyStEP Schedule

## Validation and Station Testing



# Questions?



# BACKUP

# California Station Operational Schedule

## February – March 2016



Month	Week	City	Station Developer
February	1	Lake Forest	First Element Fuel
	1	Lawndale	APCI
	2	Foster City & San Ramon	Linde
	2	LA Hollywood	First Element Fuel
	3	LA Lincoln	First Element Fuel
	3	LA Woodland	APCI
	3	Orange	Hygen
	4	San Diego	First Element Fuel
	March	2	South Pasadena
4		Redwood City, Laguna Niguel	First Element Fuel
4		Palo Alto	Air Liquide
4		Redondo Beach	APCI

# HyStEP Testing Plan/Schedule



Month/week	Activity Schedule	Parallel Meetings
Oct 5 – 9	Ship Powertech to NREL	
Oct 12 - 15	Prepare install inspect HyStEP	
Oct 19 - 20	Powertech train NREL Operators	CaFCP ST & Exec Team meeting
Oct 21 – Nov 25	5+ weeks Validation at NREL	*FCS Nov 16 – 19, LA Auto show
Nov 23 – 27	Thanksgiving week	LA Auto Show
Nov 30 – Dec 4	CA Operator training at NREL	ISO 197 meeting 30 – 4 CaFCP WG 2 -3
Dec 7 – 11	Ship NREL to CSULA	HSP Meeting
Dec 14 - 18	CSULA Shakedown, Testing, Analysis	
Dec 21 – Jan 1	Christmas/New Years Holiday weeks	Optional Data Discussions
Jan 4 – 8	OEM/HyStEP Validation/Analysis APCI/SCAQMD	Field testing
Jan 11 – 15	OEM/HyStEP Validation/Analysis APCI/SCAQMD	Data Analysis
Jan 18 – 22	OEM/HyStEP validation Air Liquide/Anaheim	Field testing
Jan 25 – 29	OEM/HyStEP validation Air Liquide/Anaheim	Data Analysis

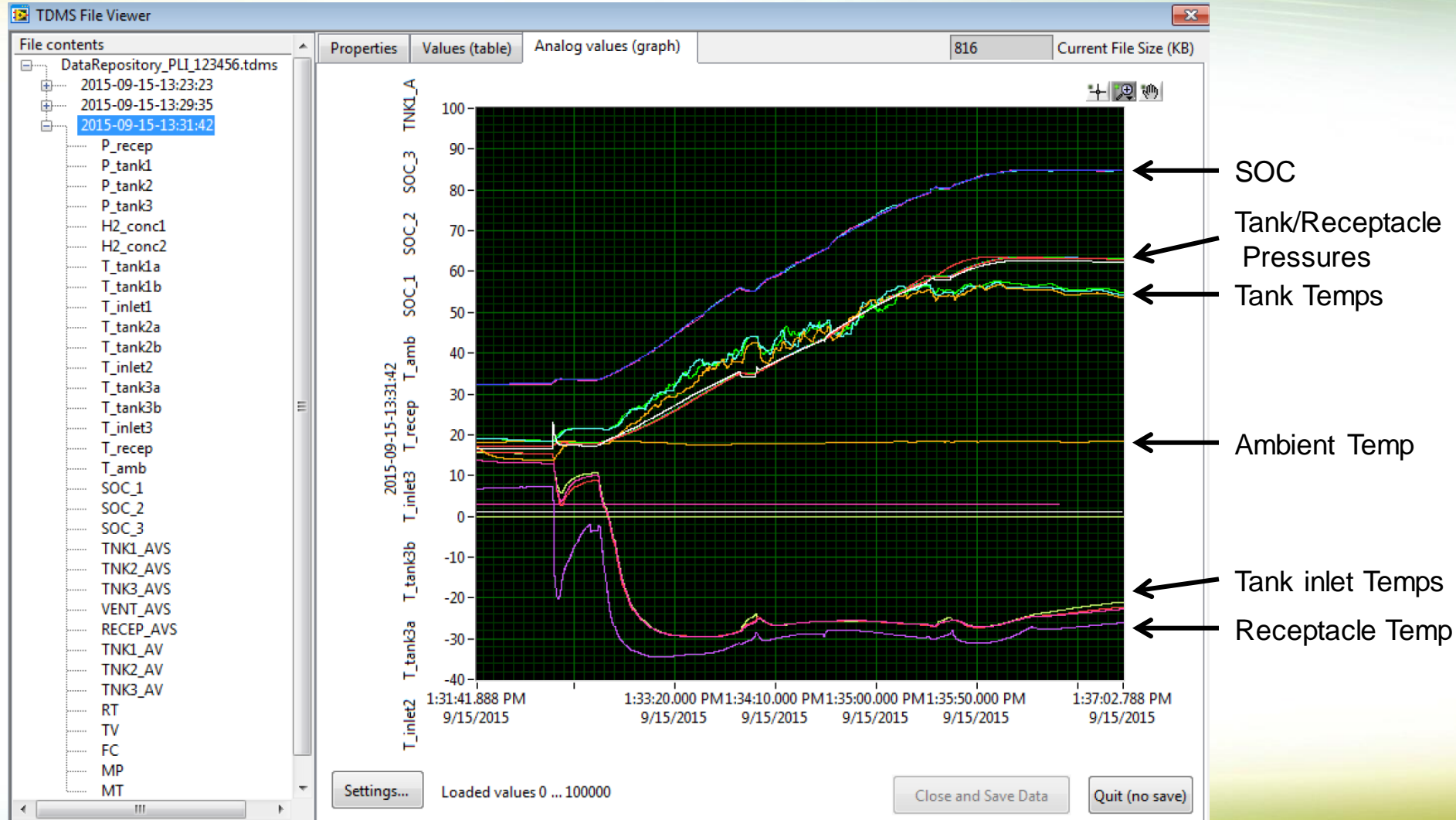
# HyStEP Draft Reports Summary Test Report



List of Potential Tests (ignore columns on right)

Test	Clause	# of Tests	Pass/Fail	Notes
<b>General Fault Detection Tests</b>				
CHSS Storage Limits	7.1.1			
Ambient Temperature Limits	7.1.2			
Minimum Fuel Delivery Temperature	7.1.3			
CHSS Gas Temperature	7.1.4			
Minimum Initial CHSS Pressure	7.1.5			
Maximum CHSS Pressure	7.1.6			
Maximum State of Charge	7.1.5.1			
<b>Table Based Communications Testing</b>				
ABORT Signal Test	8.7.1			
HALT Signal Test	8.7.2			
Data Loss Test and then ABORT Test	8.7.3			
Data Loss Test and then RESUMED Test	8.7.4			
Faulty Data Test	8.7.5			
CRC Test	XXX			
<b>Table Based Fueling Protocol Testing</b>				
Fueling Test without Communications	8.5.1			
Fueling Test with Communications	8.5.2			
Additional Tests – Repeated Table	8.2.5			
Additional Tests – No Fueling (NF) Test	8.3.6			
Additional Tests—High Pressure (HP) Capacity Test	8.2.7			
Additional Tests—Pre-Cooling (PC) Capacity Test	8.2.8			
Fuel Delivery Temperature Fallback Test	8.5.3			
Top Off Fueling	8.5.4			
Cold Dispenser Test	8.5.5			

# Data can be viewed real-time using the Graphs tab, or after testing with the data viewer



← SOC  
← Tank/Receptacle Pressures  
← Tank Temps  
← Ambient Temp  
← Tank inlet Temps  
← Receptacle Temp