



Hydrogen Fueling Infrastructure Research and Station Technology

# Initial Testing with the HyStEP Device

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# Presentation Outline



- HyStEP Status
- Typical schedule for HyStEP
- Overview of Station Validation Report Template
- Lessons learned and open items related to SAE J2601

# What is HyStEP? The Hydrogen Station Equipment Performance Device



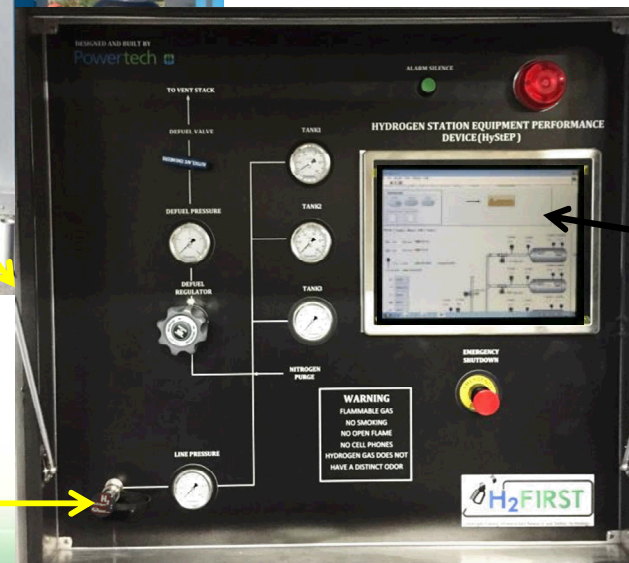
## Key Features:

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



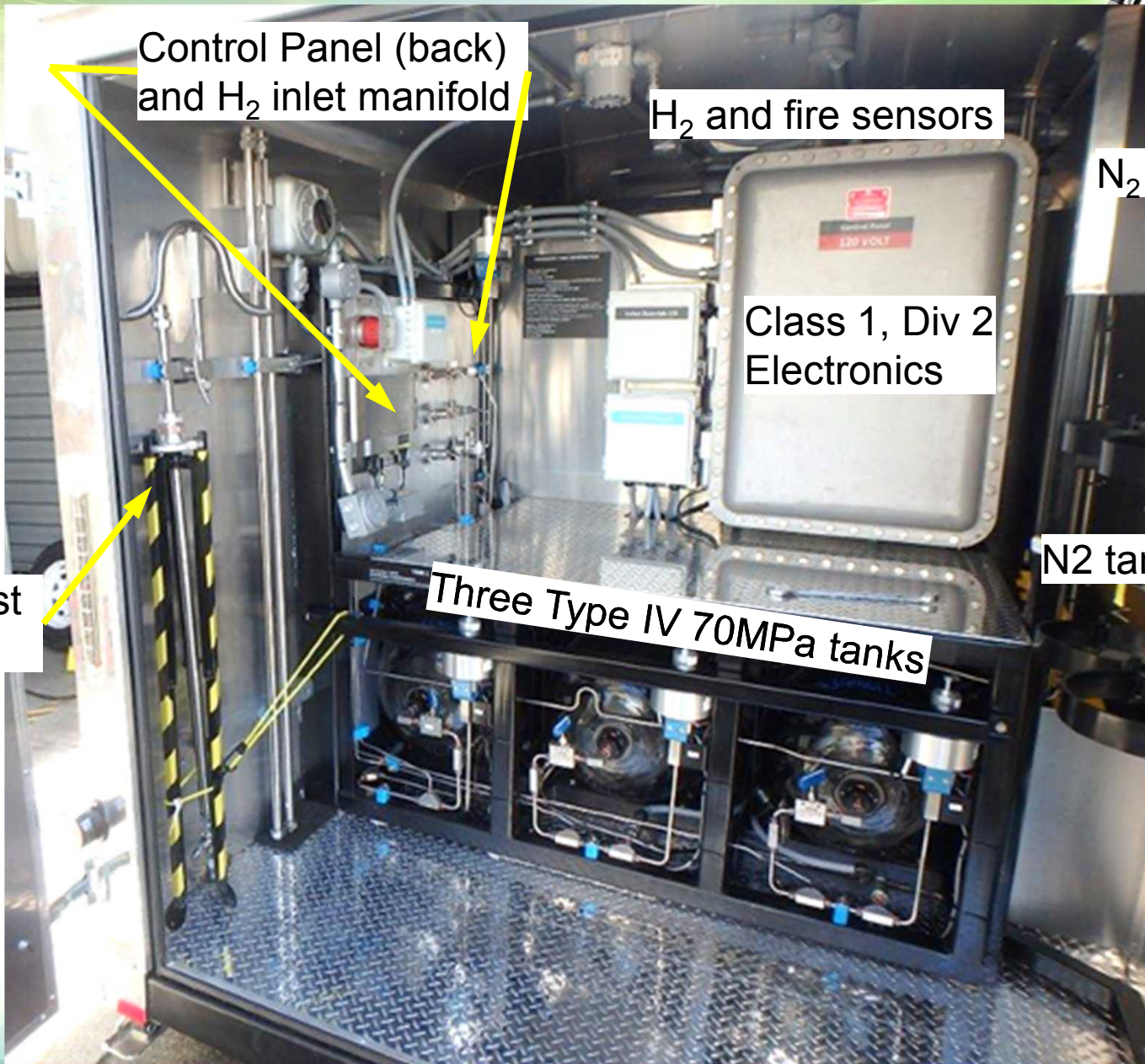
Touchscreen  
User  
Interface

Operator panel →

Receptacle →

# Tanks and electronics mounted in rear "Gas Room"

H<sub>2</sub>FIRST



Control Panel (back) and H<sub>2</sub> inlet manifold

H<sub>2</sub> and fire sensors

N<sub>2</sub> Panel

Class 1, Div 2 Electronics

N<sub>2</sub> tanks

Three Type IV 70MPa tanks

Vent mast storage

# HyStEP designed to test dispenser compliance with SAE J2601-2014 per CSA HGV 4.3



CSA HGV 4.3 defines three sets of tests to verify compliance with SAE J2601

## 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

# Typical test matrix can be carried out in three days



## Day One

Arrive on site and setup  
Safety inspection  
Instrument and sensor check  
Enter station info and review test matrix with operator  
Fault Detection tests

## Day Two

Communication tests  
Begin Fueling Protocol tests  
5-7 fills  
2-3 vent cycles

## Day Three

Review results from Day Two  
Complete Fueling Protocol tests  
5-7 fills  
2-3 vent cycles  
Prepare HyStEP for transport  
Vent and purge

# HyStEP Device performance was validated at three hydrogen stations



Diamond Bar station at SCAQMD headquarters



NREL's Hydrogen Infrastructure Testing and Research Facility



Hydrogen Fueling Infrastructure Research Station Technology

Hydrogen Research/Fueling Facility at California State University Los Angeles

# Validation tests included more than 30 fills



## NREL HITRF

- Instrument/sensor accuracy
- 5 Fault Detection tests
- 20 Communication tests (repeats)
- 3 H70-T40 non-comm fills (1, 2, and 3 tanks)
- 6 H70-T40 comm fills (1, 2, and 3 tanks)

## CSULA

- 6 Fault Detection tests
- 9 Communication tests
- 2 B-70 non-comm fills (1 tank)
- 3 B-70 comm fills (1, 2, and 3 tanks)
- 3 No Fueling tests

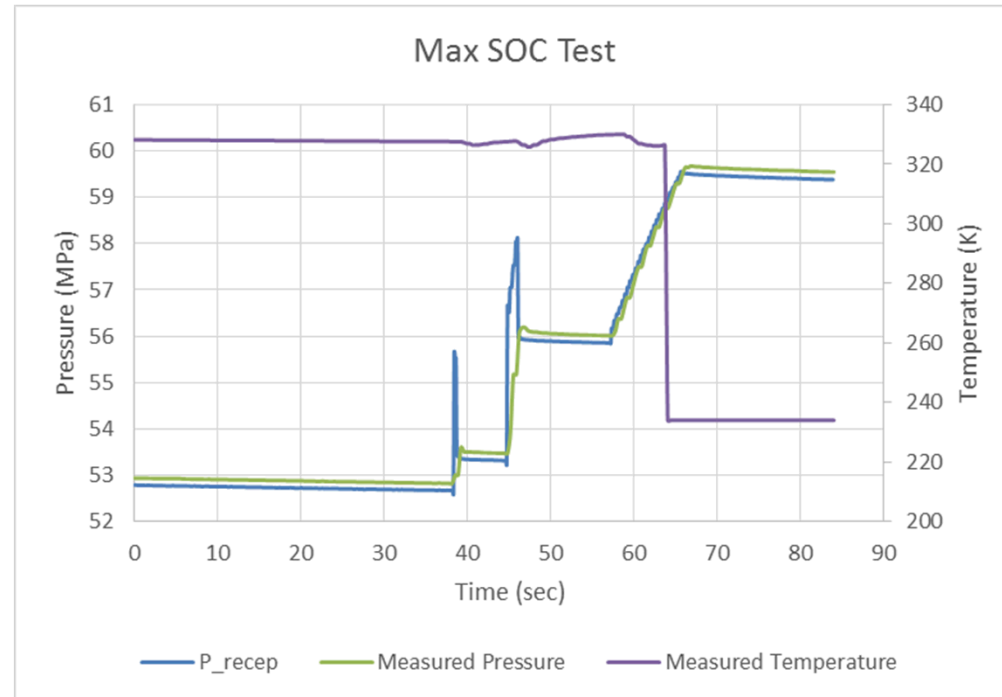
## SCAQMD

- 6 Fault Detection tests
- 9 Communications tests
- 6 non-comm fills
  - 3 H35-T20 (2 and 3 tanks)
  - 3 H70-T40 (1, 2, and 3 tanks)
- 11 H70-T40 comm fills (1, 2, and 3 tanks)
- 3 No Fueling tests
- 4 fill tests were side-by-side comparisons to FCEVs

# Example Fault Detection Test: Maximum SOC



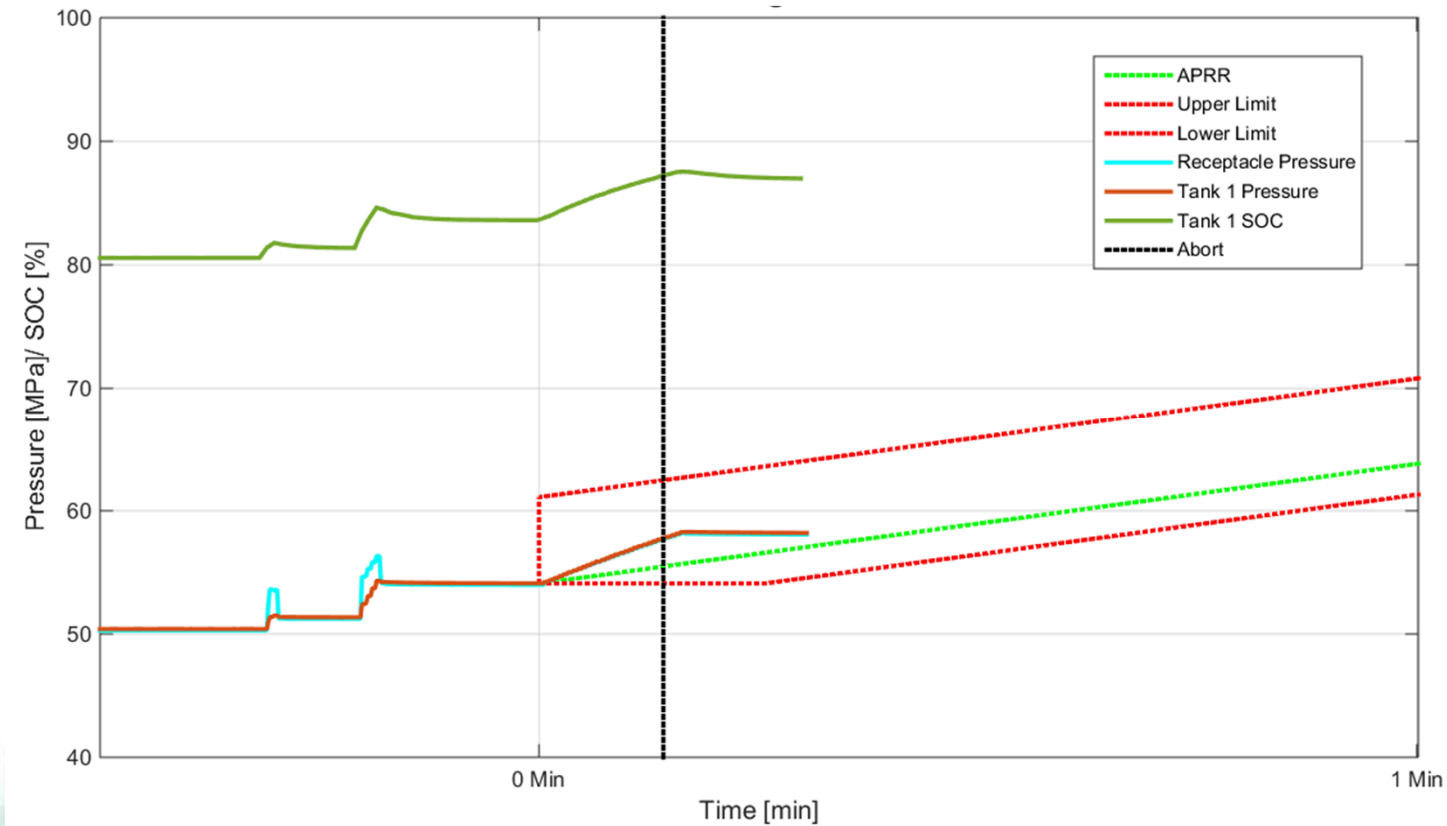
- H70 Comm fill
- IrDA temperature signal modified so that SOC > 100%
  - Set MT = 234 K when MP was 58 MPa
  - Resulting SOC = 102%
- Dispenser terminated fueling within a few seconds



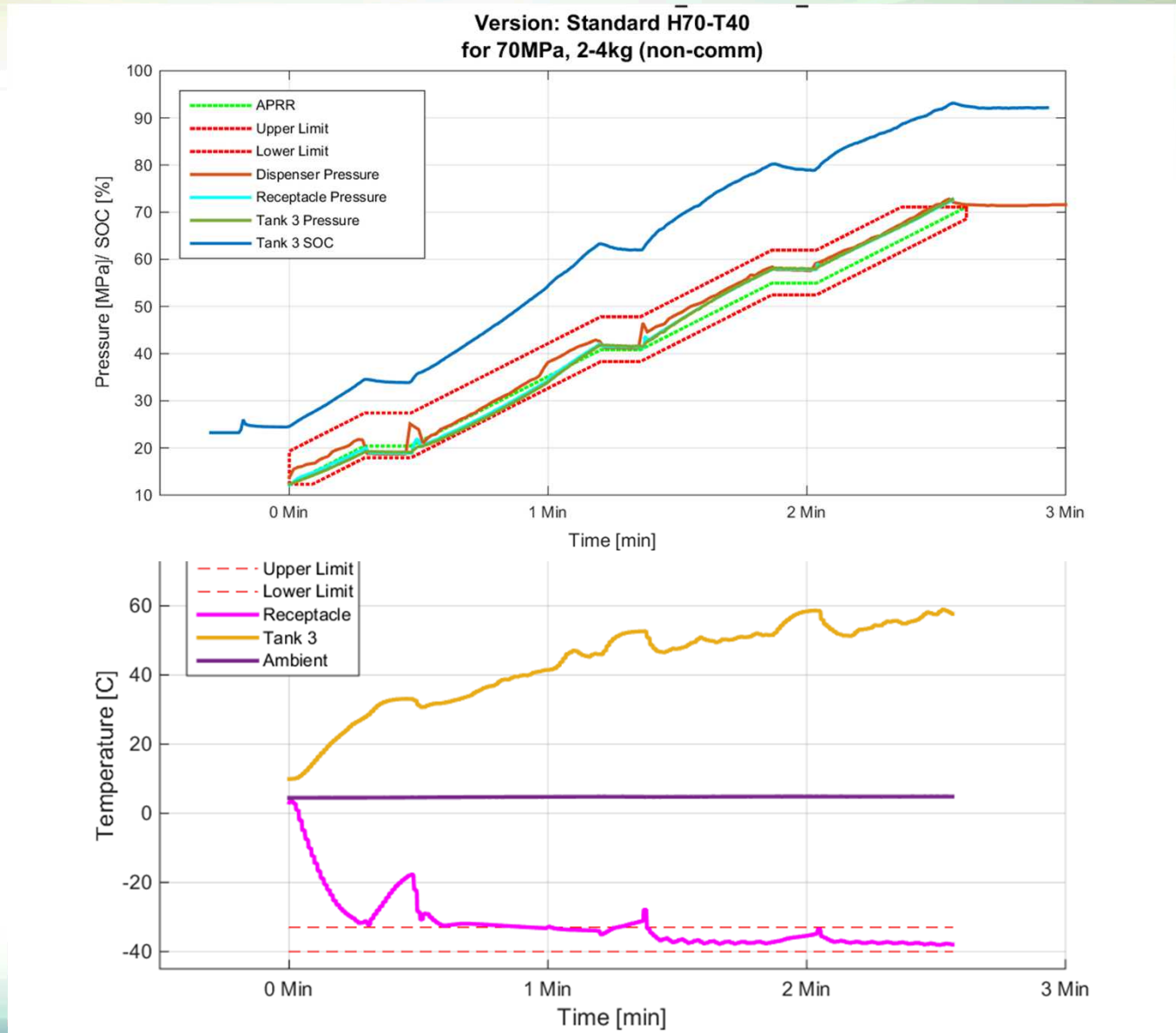
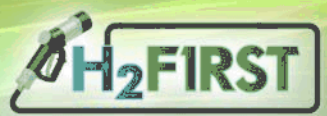
# Example Communications Test: ABORT



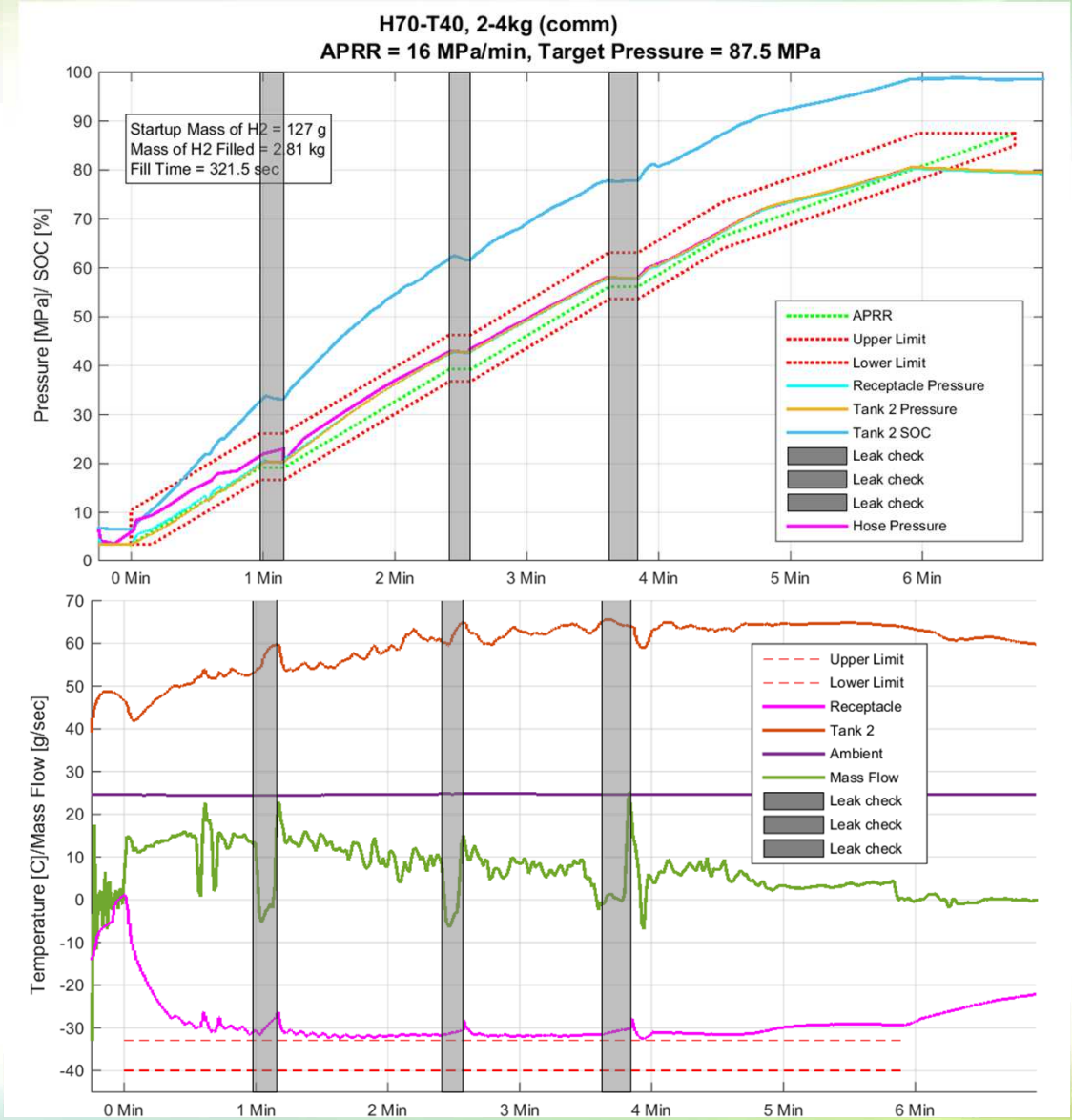
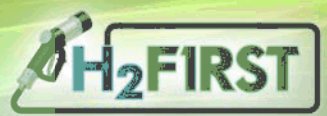
- H70 Comm fill
- IrDA Abort signal transmitted by HyStEP operator
- Dispenser terminated fueling within a few seconds



# Example Fueling Test: H70-T40 non-comm, 3kg



# Example Fueling Test: H70-T40 comm, 3kg, top off



# A station performance report will be used to record HyStEP test results



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Based primarily on CSA HGV 4.3  
Includes the following:

- Summary Report Card
- Station description
- Test Matrix
- Requirements
- Test Pass/Fail Checklists
  - General Fault Detection
  - Communication
  - Fueling Protocol

# Station Performance Test Report: Station Information



### 3. Operator(s)/Tester(s) Information

Operator Name(s): \_\_\_\_\_

#### Contractor / AHJ Information:

Name: \_\_\_\_\_ Phone #: \_\_\_\_\_

Address: \_\_\_\_\_

### 4. General Station Specifications

#### Station Developer Information:

Name: \_\_\_\_\_ Station Engineer/Technician : \_\_\_\_\_

Address: \_\_\_\_\_ Phone #: \_\_\_\_\_

Station Name: \_\_\_\_\_ Station Engineer/Technician : \_\_\_\_\_

Station Address: \_\_\_\_\_

Dispenser Name: \_\_\_\_\_ Dispenser Serial #: \_\_\_\_\_

### 5. Dispenser Functions: Select all possible functions available at the dispenser:

Dispenser Functions: H35			
Communication	Pressure Class	Fuel Delivery Temperature Category	CHSS Capacity Category
<input type="checkbox"/> Communication	<input type="checkbox"/> H35	<input type="checkbox"/> T40	<input type="checkbox"/> Small (H70: 2.0 - 4.0 kg, H35: N/A)
<input type="checkbox"/> Non-Communication	<input type="checkbox"/> H70	<input type="checkbox"/> T30	<input type="checkbox"/> Medium (H70: 4.0 - 7.0 kg, H35: 2.4 - 4.2 kg)
		<input type="checkbox"/> T20	

Dispenser Functions: H70			
Communication	Pressure Class	Fuel Delivery Temperature Category	CHSS Capacity Category
<input type="checkbox"/> Communication	<input type="checkbox"/> H35	<input type="checkbox"/> T40	<input type="checkbox"/> Small (H70: 2.0 - 4.0 kg, H35: N/A)
<input type="checkbox"/> Non-Communication	<input type="checkbox"/> H70	<input type="checkbox"/> T30	<input type="checkbox"/> Medium (H70: 4.0 - 7.0 kg, H35: 2.4 - 4.2 kg)
		<input type="checkbox"/> T20	

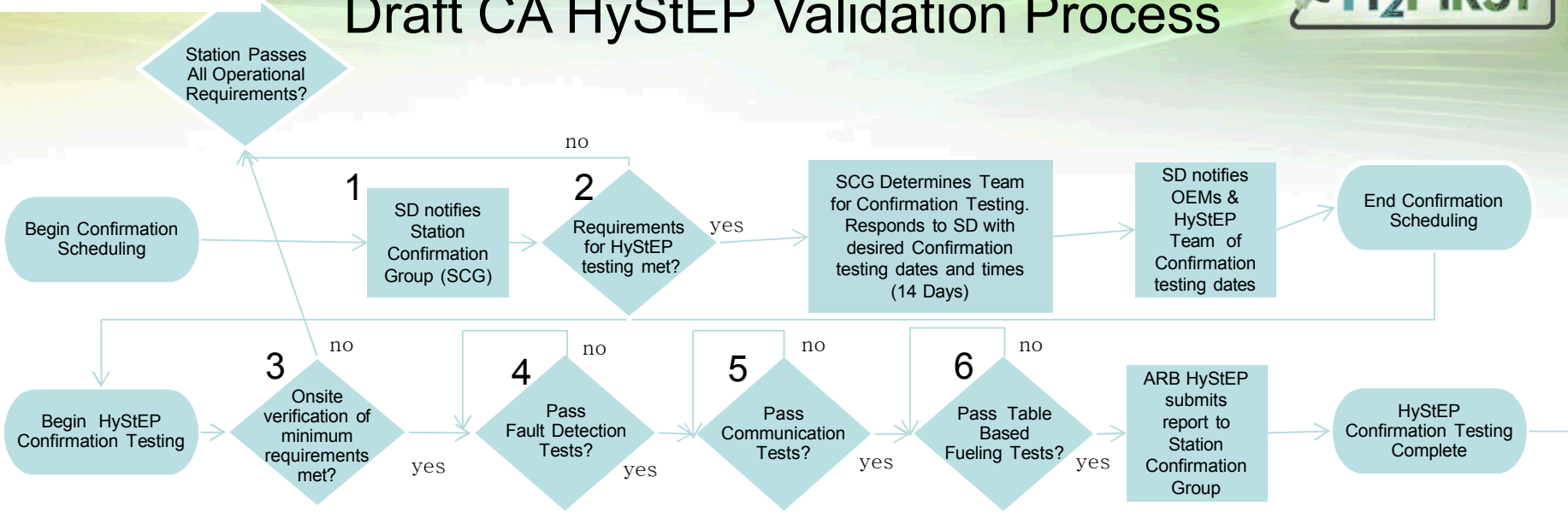
# Station Performance Test Report: Example Checklist for non-comm fueling test



Non-communications Test # 1	Result			Comment
Date and Time of Test				
Dispenser Type (e.g., H35, or H70)				
CHSS Category (e.g., small, medium, large)				
Initial CHSS Pressure (MPa)				
Initial CHSS SOC				
Initial CHSS Temperature				
Initial Ambient Temperature				
<b>Fuel Delivery Temperature at Startup.</b> T <sub>fuel</sub> < T <sub>fuel</sub> category max within 30 seconds after the start of fueling.				
For the above test, did the dispenser: 1) Meet this requirement? If No, 2) Terminate fueling within 5 sec? 3) End test result?	Yes <input type="checkbox"/> Yes <input type="checkbox"/> Pass <input type="checkbox"/>	No <input type="checkbox"/> No <input type="checkbox"/> Fail <input type="checkbox"/>	NA <input type="checkbox"/> NA <input type="checkbox"/> NA <input type="checkbox"/>	
<b>Fuel Delivery Temperature Tolerance.</b> T <sub>fuel</sub> category min < T <sub>fuel</sub> < T <sub>fuel</sub> category max for the remainder of the test.				
For the above test, did the dispenser: 1) Meet this requirement? If No, 2) Terminate fueling within 5 sec? 3) Used total mass average fuel delivery? 4) Rolling mass average fuel delivery? 5) End test result?	Yes <input type="checkbox"/> Yes <input type="checkbox"/> Yes <input type="checkbox"/> Yes <input type="checkbox"/> Pass <input type="checkbox"/>	No <input type="checkbox"/> No <input type="checkbox"/> No <input type="checkbox"/> No <input type="checkbox"/> Fail <input type="checkbox"/>	NA <input type="checkbox"/> NA <input type="checkbox"/> NA <input type="checkbox"/> NA <input type="checkbox"/> NA <input type="checkbox"/>	
<b>CHSS Capacity Accuracy.</b> 85% CHSS Cap Actual < CHSS Cap Measured < 115% CHSS Cap Actual.				
For the above test, did the dispenser: 1) Measure CHSS accuracy within ±15%? 2) Determine CHSS capacity is unknown? 3) Fuel at most conservative APRR, and end at most conservative pressure target? 4) End test result?	Yes <input type="checkbox"/> Yes <input type="checkbox"/> Yes <input type="checkbox"/> Pass <input type="checkbox"/>	No <input type="checkbox"/> No <input type="checkbox"/> No <input type="checkbox"/> Fail <input type="checkbox"/>	NA <input type="checkbox"/> NA <input type="checkbox"/> NA <input type="checkbox"/> NA <input type="checkbox"/>	
<b>Note: Only applicable to non-communications fueling.</b> <b>APRR Selection.</b> Dispenser shall select the				

<b>APRR Selection.</b> Dispenser shall select the proper APRR based upon the ambient temperature.	Pass <input type="checkbox"/>	Fail <input type="checkbox"/>	NA <input type="checkbox"/>	
<b>APRR Pressure Tolerance.</b> During the main fueling time, the dispenser shall maintain the APRR within upper and lower tolerance limits, or terminate fueling within 5 sec.	Pass <input type="checkbox"/>	Fail <input type="checkbox"/>	NA <input type="checkbox"/>	
<b>Cycle Control.</b> Dispenser shall not decrease the fuel flow below 1 % of the max flow more than ten times during main fueling period.	Pass <input type="checkbox"/>	Fail <input type="checkbox"/>	NA <input type="checkbox"/>	
<b>Maximum Flow Rate.</b> The station shall terminate fueling within 5 seconds if the flow rate of hydrogen is greater than or equal to 60 g/s.	Pass <input type="checkbox"/>	Fail <input type="checkbox"/>	NA <input type="checkbox"/>	
<b>Maximum Mass of Hydrogen Allowed During Startup.</b> If the mass of hydrogen transferred from the dispenser to the vehicle prior to the start of fueling exceeds 200 g, then the dispenser shall terminate fueling within 5 seconds.	Pass <input type="checkbox"/>	Fail <input type="checkbox"/>	NA <input type="checkbox"/>	
<b>Non-Communication End of Fueling.</b> Dispenser shall end fueling at the proper target pressure based upon the ambient temperature and initial CHSS pressure.	Pass <input type="checkbox"/>	Fail <input type="checkbox"/>	NA <input type="checkbox"/>	
Final CHSS Pressure (MPa)				
Final CHSS Temperature				
Final CHSS SOC				
Final Ambient Temperature				
Actual Fueling Time				
Cause for End Fueling (e.g., SOC 95-100%, Abort Signal, etc)				

# Draft CA HyStEP Validation Process



## 1 Station Confirmation Group

- Jackie Birdsall, Toyota
- Tim McGuire, Mercedes Benz
- Kevin Lee, Hyundai
- Steve Mathison, Honda
- Lance Atkins, Nissan
- Tyson Eckerle, GOBiz
- Mike Kashuba, CARB

## 2 Determination of Readiness for HyStEP Confirmation Testing

- Station Operational
- Has Permit to Operate
- IGC provides station Temperature and Pressure
- IGC provides technician and programmer
- Station has performed successful fills
  - Types of fills, PIG, Types of Vehicles
  - Fill Protocol: Temperature, Pressure, Type of fill
- Identify status of the following
  - DMS Fuel Meter Certification
  - Fuel Quality Confirmation
  - Retail POS Function
- Verify station information
  - Dispenser model
  - Manufacturer

## 3 Onsite Confirmation: HyStEP Checklist at Station Arrival

- Station site survey
- Safety Inspection
  - PRV, Pressure classes, ESD locations, etc.
  - Verify use of station or appropriate HyStEP vent stack location
  - Locate appropriate 110VAC source
- Verify Determination of Readiness for HyStEP Confirmation Testing

## 4 Fault Detection • Communication • Table Based Fueling

- CHHS Limits
- Amb. Temp. Limits
- Min. Fuel Temp.
- CHSS Gas Temp
- Min. Initial Pressure
- Max. SOC
- ABORT signal
- HALT signal
- Data Loss
- CRC
- Faulty Data
- Non Comm. Fueling
- Comm. Fueling
- Repeat Table
- No Fueling
- HP Capacity
- PC Capacity
- Fallback
- Topoff
- Cold Dispenser

# Lessons learned and open issues from HyStEP testing thus far



- What tolerance should be used for target pressure?
  - From SAE J2601: *“The station shall account for its tolerances in applying this fueling protocol. Tolerances shall be applied to ensure that the pressure ramp rate and ending pressure remain within their specified boundaries or limits.”*
- How to perform Maximum SOC fault test?
  - Transmitted tank temperature (MT) can be modified to simulate SOC > 100%
  - Should provide an equation or table for MT versus pressure.
- Storage bank switches may be difficult, if not impossible, to detect with a test device. Thus, perceived failures to stay within the pressure corridor may be incorrect.
- How should a failed test be handled? Can a re-test be approved?

# Lessons learned and open issues from HyStEP testing thus far



- Dispenser software may have a target APRR programmed that meets the corridor, but the actual hose pressure falls below the target, is that a fail?
- How to pick the exact point of the start of a fill should be clearly defined for the testing agency. Is this based on the dispenser target APRR, the hose pressure, the receptacle pressure, or the CHSS pressure?
- Should a dispenser be allowed to limit a fill to the 35 MPa non-comm tables without secondary confirmation of H70?
- Two Fault Detection tests, Ambient Temperature Limits and Minimum Fuel Delivery Temperature, were not tested because ambient temperature sensor and hose temperature sensor could not be modified. Should these be F.A.T. only?
- Should FC = Stat command be tested?



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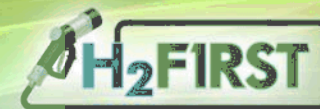
# Questions?

# Thanks!

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# BACKUP

# Sensor verification and large test matrix performed at NREL



Test	Complete (Y/N)	# of Tests	Pass/Fail	IrDA signal	Pressure Class	Tanks
<b>General Fault Detection Tests</b>						
CHSS Storage Limits – 22Oct	Y	1	Pass	TV=1, 250	H70	1
Ambient Temp. Limits						
Min. Fuel Delivery Temp.						
CHSS Gas Temp.	Y	1				
Min. Initial CHSS Pressure – 22Oct	Y	1	Pass	MP=0.1	H70	1
Max. CHSS Pressure – 21Oct	Y	1	Pass	Yes	H70	1
Max. State of Charge – 9Nov	Y	1	Pass	MT=233	H70	1
<b>Table Based Communications Testing</b>						
ABORT Signal Test – 22Oct	Y	3	Pass	ABORT	H70	1
HALT Signal Test – 22Oct	Y	3	Pass	HALT	H70	1
Data Loss Test, then ABORT Test – 22Oct	Y	3	Pass	Com>Non	H70	1
Data Loss Test and then RESUMED Test – 22Oct	Y	3	Pass	Com>Non	H70	1
Faulty Data Tests – 21Oct	Y	1 Ea	Pass	Yes	H70	1
Protocol Identifier (ID)	Y	1	Pass	Yes	H70	1
Software Version Number (VN)	Y	1	Pass	Yes	H70	1
Tank Volume (TV)	Y	1	Pass	Yes	H70	1
Receptacle Type (RT)	Y	1	Pass	Yes	H70	1
Fueling Command (FC)	Y	1	Pass	Yes	H70	1
Measured Pressure (MP)	Y	1	Pass	Yes	H70	1
Measured Temperature (MT)	Y	1	Pass	Yes	H70	1
CRC Test	Y	3	Pass	Yes	H70	1
<b>Table Based Fueling Protocol Testing</b>						
Fueling Test without Communications						
Test 1 – 11Nov	Y	1	Pass	No	H70	1
Test 2 – 12Nov	Y	1	Pass	No	H70	2
Test 3 – 12Nov	Y	1	Pass	No	H70	3
Fueling Test with Communications						
Test 1 – 23Oct, 4Nov, 5Nov	Y	3	Pass	Yes	H70	1
Test 2 – 6Nov	Y	1	Pass	Yes	H70	2
Test 3 – 9Nov	Y	1	Pass	Yes	H70	3
No Fueling (NF) Test – 21Oct	Y	1	Pass	Yes	H70	1

# 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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# 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

- 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

Fueling protocol tests must validate that tables are selected properly

- 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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