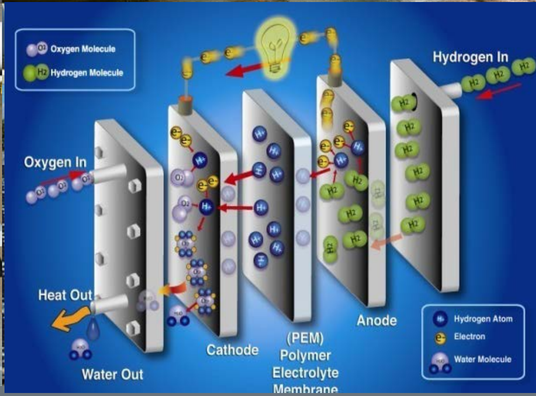
An Introduction to SAE Hydrogen Fueling Standardization

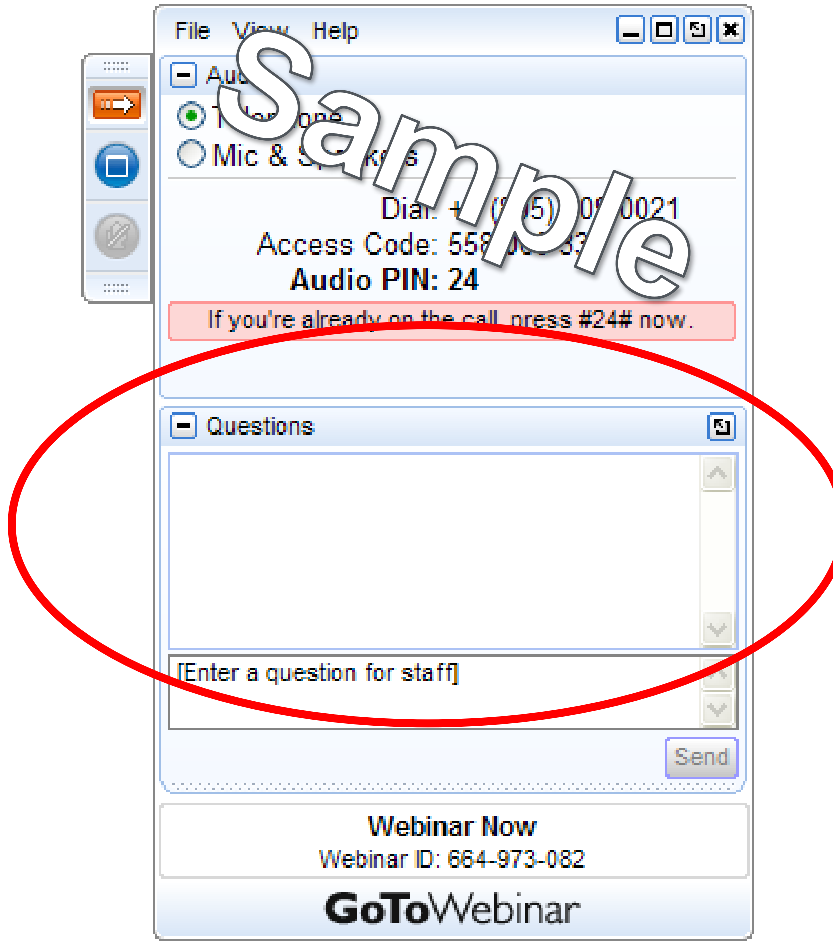
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Will James

U.S. Department of Energy
Fuel Cell Technologies Office

- Please type your question into the question box



hydrogenandfuelcells.energy.gov

SAE INTERNATIONAL

U.S. DOE WEBINAR:

An Introduction to SAE Hydrogen Fueling Standardization

PARTICIPANTS AND AGENDA

DOE WEBINAR:

An Introduction to SAE Hydrogen Fueling Standardization

•Will James	- Moderator
•Jesse Schneider	- SAE J2601 Standard L.D. Hydrogen Fueling Protocol - SAE J2799 Standard FCEV Communications
•Steve Mathison	- SAE J2601 Development Fueling- MC Method
•Webinar Q&A	

SAE HYDROGEN FUELING STANDARDIZATION

Jesse Schneider (BMW)
SAE J2601 & J2799 Sponsor

Outline

- Hydrogen Fueling Background
- SAE H2 Fueling Standardization
- SAE J2799 Standard
- SAE J2601 Standard
- Lab Testing and Field Verification of Hydrogen Fueling
- Implementing of SAE J2601

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Worldwide hydrogen Infrastructure Developments Status 2014

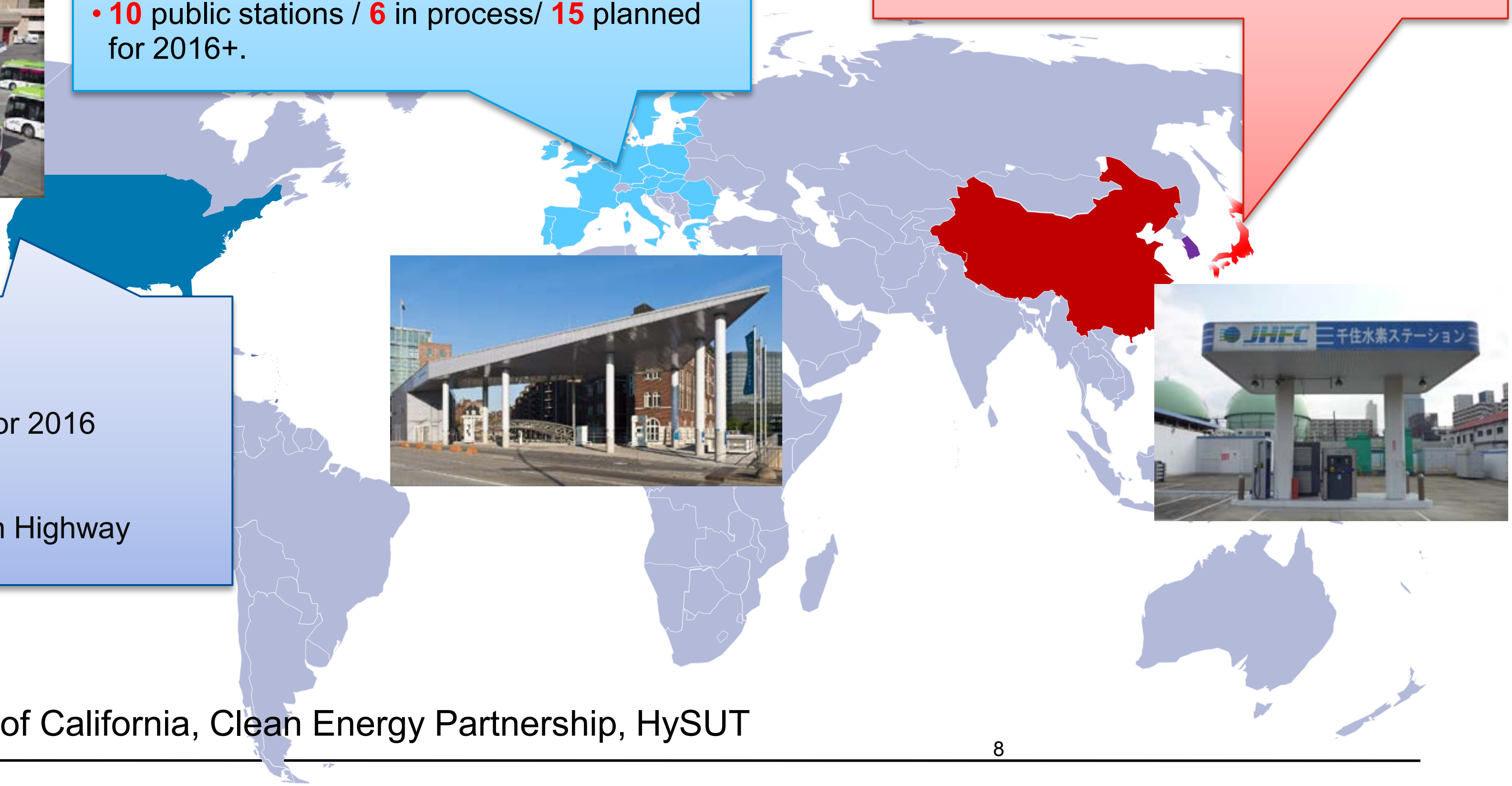
Europe:
Germany
- Demo-project Clean Energy Partnership
  15 public stations + 35 in process in 2016
- 400 Privately funded in planning until 2023

Scandinavian Countries
- Scandinavian Hydrogen Highway,
- 10 public stations / 6 in process/ 15 planned for 2016+.

Japan
- 100 stations planned until 2016+
- 1000 stations in discussion until 2025

California / US
- ZEV Mandate
  10 public station, /
- 45 more in process for 2016
(100 Total planned)

US/ East Coast
- East Coast Hydrogen Highway evaluation (TBD)



Source: State of California, Clean Energy Partnership, HySUT

8

US Status of Hydrogen for vehicles: Creating the First Generation of Infrastructure National and Local Organizations

•Major Automakers recently announced their plans in hydrogen fuel cell electric vehicles (BMW-Toyota / Daimler-Ford-Nissan / Honda-GM / Hyundai)

•The State of California announced plans funding for 100 H2 stations to support FCEVs

•The US DOE along with the industry and partnerships created a new hydrogen initiative called H_2USA to coordinate a national hydrogen infrastructure in the US (including assisting with C&S.)

•H_2USA is also working with the DOE project called H_2FIRST to accelerate the technology needed for the fueling infrastructure.

“This new project brings important federal know-how and resources to accelerate improvements in refueling infrastructure that support the commercial market launch of hydrogen fuel cell vehicles,” *said Air Resources Board Chairman Mary D. Nichols*. “California is committed to deploying at least 100 hydrogen refueling stations in the next decade, and the H2FIRST effort is a big step toward the development and deployment of a broader, consumer-friendly infrastructure for us and the rest of the United States…”

Hydrogen Fueling Infrastructure Research and Station Technology

Hydrogen Fueling Background
Why is it important ?

- Hydrogen fueling is critical to the success of Fuel Cell Electric Vehicles (or Hydrogen Surface Vehicles, HSV)

- Factors for success:
  - Fueling has to be within hydrogen storage system limits.
  - Fueling rate and driving range have to be acceptable to customer
  - Vehicles need to fuel at same as today's rate.

- Hydrogen Fueling is the <u>only</u> ZEV infrastructure technology proven to achieve „same as today's" fuel delivery rates and equivalent driving range for all vehicle segments.

Zero Emission L.D. Vehicles Reference Comparison: BEV Charging vs. FCEV Hydrogen Fueling

	LD Electric Vehicle Charging, SAE J1772 (Reference), BEV Reference	L.D. Fuel Cell Electric Vehicle Fueling SAE J2601 Energy Storage at 70MPa
Reference Storage Capacity in kWh (C Segment)	30 kWh	100 kWH el. (5 kg H2) (160kWH chem. x 60% FCEV eff.)
Current Maximum L.D. Storage Capacity + (E Segment vehicle)	85 kWh	200 kWH el. (10kg H2) (330 kWH chem. x 60% FCEV eff.)
Fueling Time, Empty-100% SOC (Reference Charging)	3-8 hours / 8-20 hours (depending on storage, SOC, voltage)	3-15 minutes within 4-7kg (T40/T30, Dispenser Types)
Fueling Time Empty-100% SOC (Fast Charging)	20-60 minutes (to 80%) (with „fast charge“ with 60-200 kW required)	3-5 minutes (T40 Dispenser)
Average Reference Range at 100% SOC (C-Segment)	160 km (100%) / 130km (80%) (Normal Charge / Fast Charge)	500 km+ (100%)

Source: Jesse Schneider

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Path to Hydrogen Fueling standardization
Guideline to SAE Standards

Hydrogen Coupling: SAE J2600

Hydrogen Gas Quality for FCEVs: SAE J2719

<u>Hydrogen Fueling:</u>

FCEV to Station Communications: SAE J2799

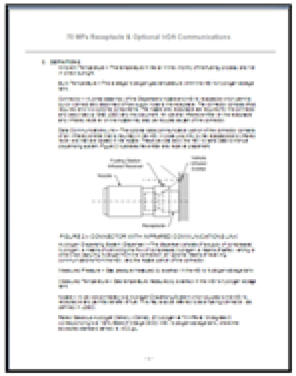
Light Duty Vehicles: SAE J2601

Heavy Duty Vehicles: SAE J2601-2

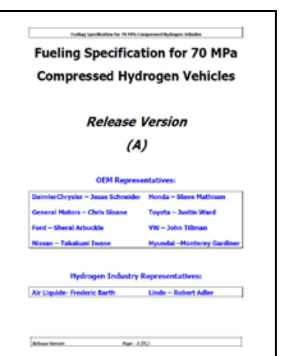
Fork Lift Vehicles: SAE J2601-3

Path to SAE Hydrogen Fueling standardization
Guideline to Standards

SAE TIR J2799
70MPa Coupling
& IrDA Comm.Guideline
2007



OEM H2 Fueling
„Rev A“ 2007

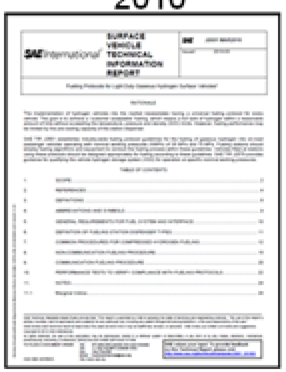

Fueling Specification for 70 MPa
Compressed Hydrogen Vehicles

Release Version
(A)

OEM Representatives:

Hydrogen Industry Representatives:

SAE TIR “L.D. H2
Fueling“ Guideline
2010



7 years of Field data +
Additional Optional Data
Field

3 years of
Field data. Lessons
Learned & Relaxed
Tolerences and easier
to implement.

2014 SAE STANDARDS RELEASE

Standard
J2600 (2012)

***Standard**
J2799 (IrDA)

**Standard*
J2601
(CGH_2 Fueling)

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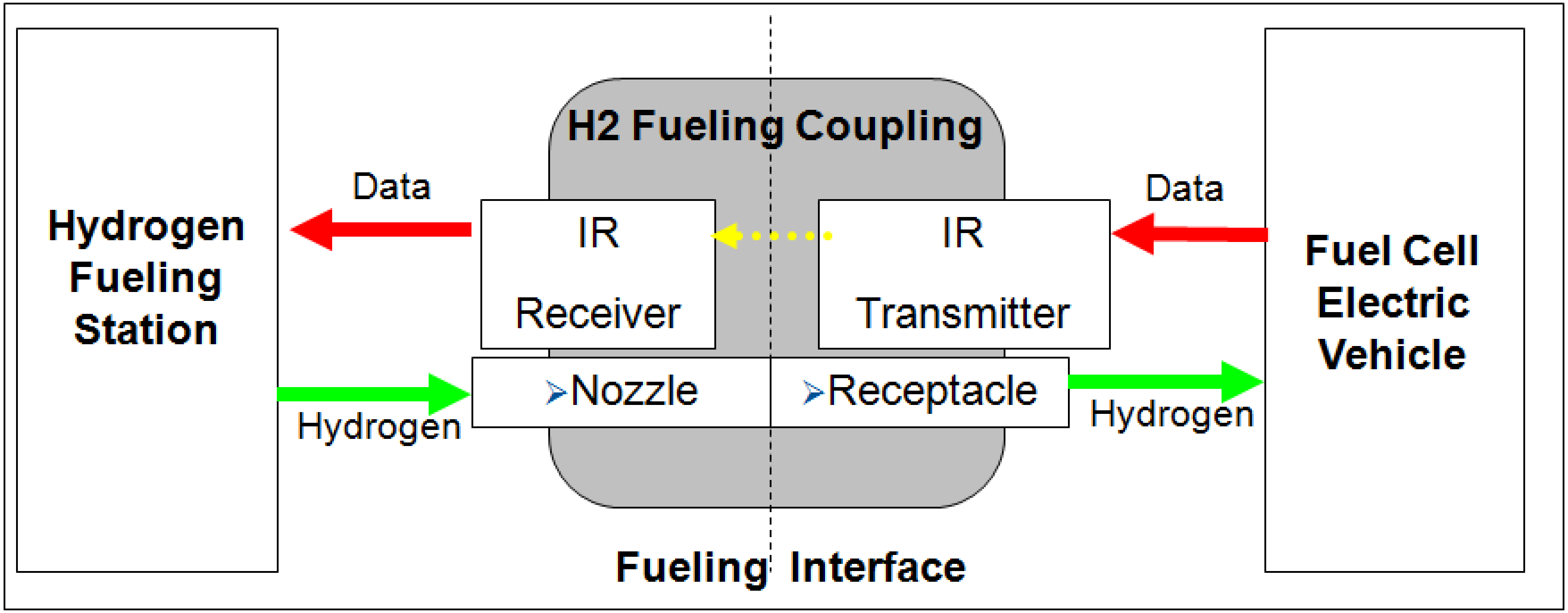
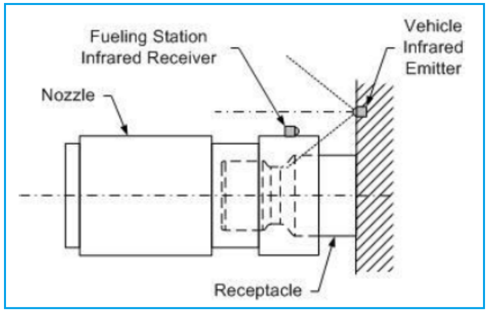
SAE J2799 Standard
Wireless FCEV to Hydrogen Station Standard

- Transparent to customer
- Wireless, IrDA is an Available Technology
- Vehicle / tank information used for improving fueling
- Enables consistent 95-100% SOC fueling
- Optional "Vehicle Abort Signal" to stop fueling



SAE J2799 Signals Transferred

Data format According to SAE J2799 / J2601		
Variable	Unit	Format
Protocol Identifier	N/A	|ID=SAE⎵J2799|
RDI Software Version Number	N/A	|VN=##.##|
Tank Volume	Liter	|TV=####.#|
Receptacle Type	N/A	|RT=H##|
Fill Command	N/A	|FC=Dyna|
Measured Pressure	MPa	|MP=###.#|
Measured Temperature	Kelvin	|MT=###.#|
Optional Data	0-74 characters not including "|"	|OD=ASDEFINEDINJ2601|



Note: For the SAE Table-based Fueling Protocol, the Optional Data Command is ignored. It is reserved for future revisions of J2601.

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SAE J2601
Enabling 3 minute fueling and 300+ miles range

- SAE J2601 (also with J2799) fuels all hydrogen storage systems quickly to a high state of charge (SOC) without violating the storage system operating limits of internal tank temperature or pressure.
- SAE J2601 meets the U.S. DOE FCEV Targets for 2017 by enabling a hydrogen fueling in 3 minutes* which enables a 300+ miles (500 km) range
- SAE J2601/J2799 is being used as a basis for FCEV fueling worldwide.

* H70-T40 dispenser, 4-7 kg H2 storage; Reference Ambient Temperature 20C

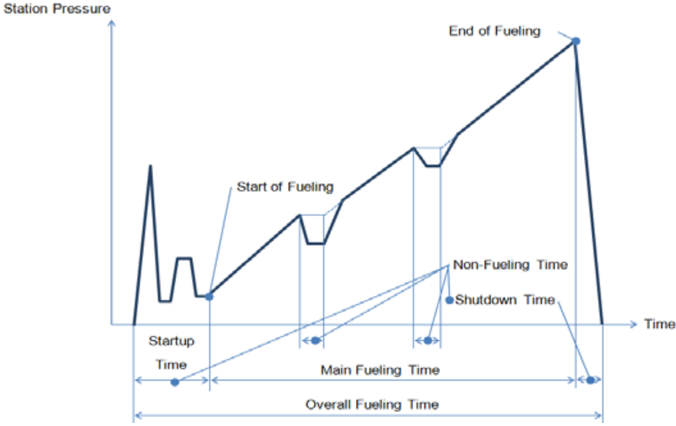
SAE J2601 LD Summary

After 12 years of work, the SAE J2601 was released in 2014 as a standard.

•What is SAE J2601?
First World-Wide Light Duty Hydrogen Vehicle Fueling Standard for 35 & 70MPa :
Created by Math Modeling, Confirmed by Real OEM System Testing in both the lab and field.

•What does the J2601 standard cover?
Light Duty Hydrogen Vehicle Fueling (2-10kg@70MPa / 2.4-6kg@35MPa)

•Fueling Protocol with & without communications
•Defines Safety Limits and Performance Targets.
•Table-Based Approach (relaxed from TIR Levels)
•New Fueling Temperature Categories
•New Fueling Concepts (update from TIR):
"Fall-Back", "Top-Off", "Cold Dispenser",
Development "MC Method"



Steps to Standardization

- FCEV Hydrogen Fueling Simulation Model was created to develop J2601 Look-up Table with industry input
  - Modeling of Real Tank Properties (from OEMs)
  - Modeling of Real Station Components (from H2 Suppliers)
  - Correlation of Models between OEMs
- Lab Validation with Extreme Temperatures and FCEV Tank Volume Sizes. Testing with
  - OEM Tanks
  - H2 Supplier Station Hardware
- J2601 Protocol Field Validation at H2 Stations in Field with real FCEVs
  - Field Testing of Stations at Public Locations in three continents
  - Numerous OEMs FCEV participated

SAE J2601 Hydrogen Fueling Protocol Approach

Technical Goals for Compressed Hydrogen Fueling

- <u>Maintain the safety limits of storage system.</u>
  - Minimum/ Maximum Gas Temperature: -40˚C / 85˚C
  - Maximum Dispenser Pressure: 87.5 MPa (70 MPa NWP) and 43.8 MPa (35 MPa NWP)
  - Maximum Flow Rate: 60 g/s
- <u>Achieve target desired customer attributes.</u>
  - Fueling Time: 3 minutes (T70-H70)
  - Typical State of Charge Range : 90% to 100% (density based on NWP at 15 C)

Options for Compressed Hydrogen Fueling Protocol

- Vehicle to station interface strategies
  - <u>Communication:</u> vehicle provides tank parameters through an electrical interface
  - <u>Non-communication:</u> vehicle provides tank pressure only
- Station key control factors
  - <u>Pre-cooling of hydrogen:</u> station conditions H2 temperature prior to dispensing
  - <u>Hydrogen delivery rate:</u> station provides average pressure rise rate as per the tables
  - <u>Fill termination:</u> station determines end pressure and/or density based on tables

SAE J2601-2014, Compressed Hydrogen Storage System Table Capacity Categories

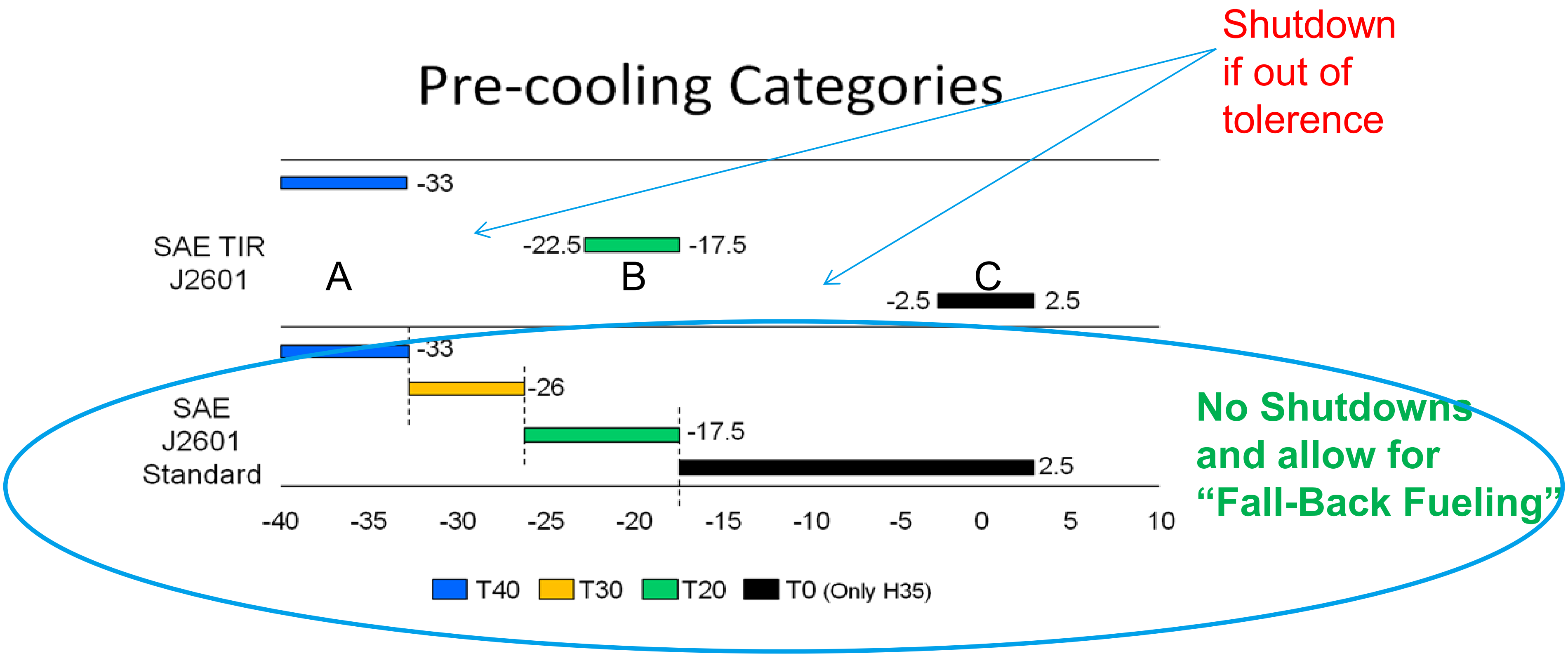
70MPa (3 Categories) : 2-4 kg / 4-7kg / 7-10kg

35MPa (2 Categories) : 2.4-4.2kg / 4.2-6kg

NWP [MPa]	Total amount of hydrogen in tank system at SOC=100% [kg]	Water Volume of Tank System at NWP [liters]
35	2.39 to 4.18	99.4 to 174.0
35	4.18 to 5.97	174.0 to 248.6
70	2.00 to 4.00	49.7 to 99.4
70	4.00 to 7.00	99.4 to 174.0
70	7.00 to 10.00	174.0 to 248.6

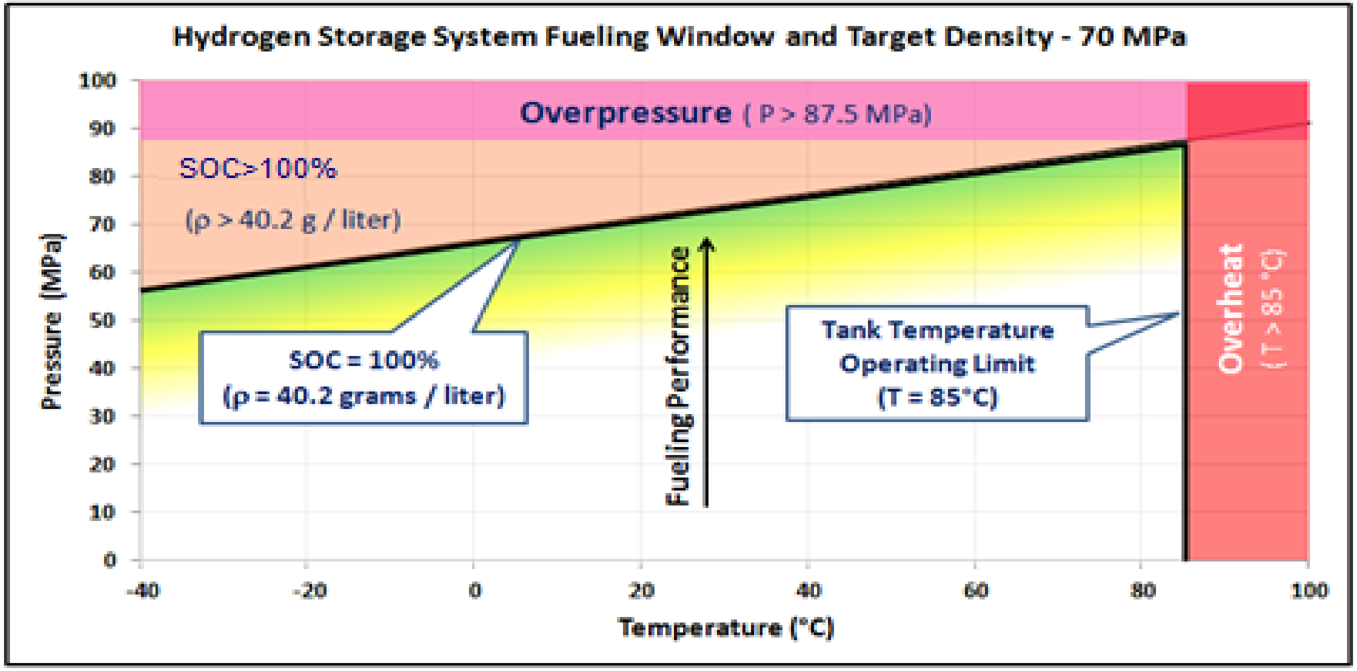
J2601-2014 Standard vs. TIR J2601-2010
Table Hydrogen Gas Temperature Ranges for Dispenser s

J2601 Standard defines fueling station dispenser type by capability to dispense hydrogen fuel at a specific "pre-cooled" or hydrogen gas temperature range. No Shutdowns in new standard.

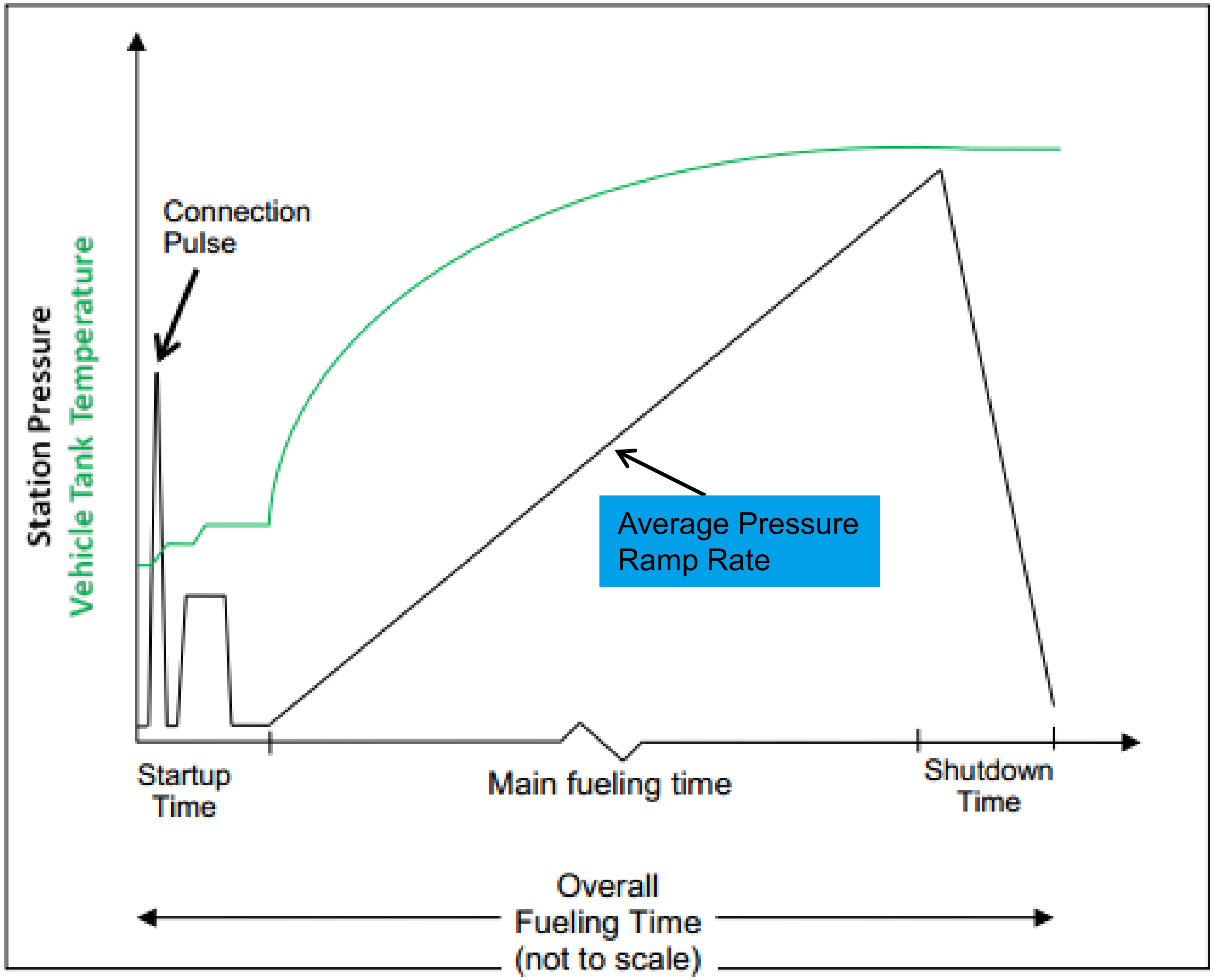


Fueling Limits and SAE J2601 Tables "Line of Constant Density"

- Fuel all hydrogen storage systems quickly to a high state of charge (SOC)
- Keep within the storage system operating limits of internal tank temperature (don't overheat) or upper limits of pressure (don't overpressure)



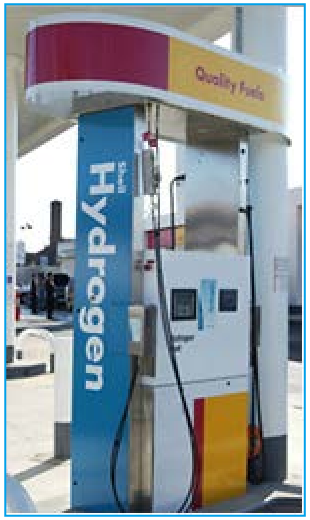
SAE J2601 Hydrogen Fueling Pressure vs. Temperature Development in Vehicle Tank



Fueling Fundamentals

Lookup Table Control Methodology

Inputs



Station Dispenser Type

- **T40 Station H2@ -40˚C**
- **T30 Station H2@ -30˚C**
- **T20- Station H2@ -20˚C**

Vehicle Parameters

Initial Gas Pressure

Station Parameters

Ambient Temp.

Delivered Gas Temp.

SAE J2601-2014 Fueling Standard

H70-T40 4-7kg comm		Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure Ptarget [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]											
			Initial Tank Pressure, P_0 [MPa]														
			0,5 - 5 (no interpolation allowed)			0,5	2	5	10	15	20	30	40	50	60	70	> 70
Ambient Temperature, T_{amb} [°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
	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
	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
	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
	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
	30	16,3	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
	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
	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
	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
	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
	-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
	-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
	-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	72,6	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
	< -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

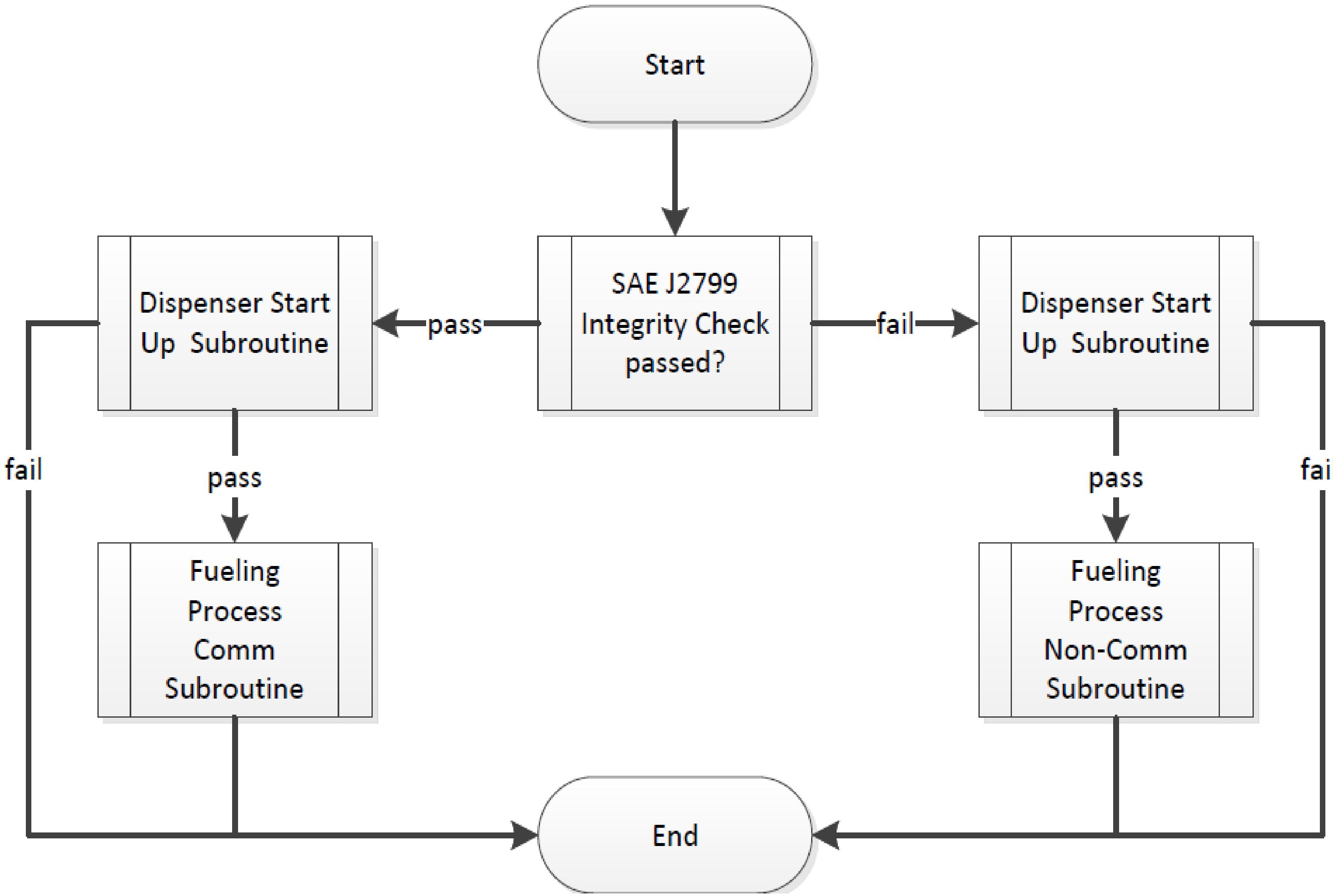
Target (End) Pressure

Average Pressure Ramp Rate

Outputs

Refueling Control

SAE J2601 Communications/ Non-Communications Flow Diagram for Look Up Tables



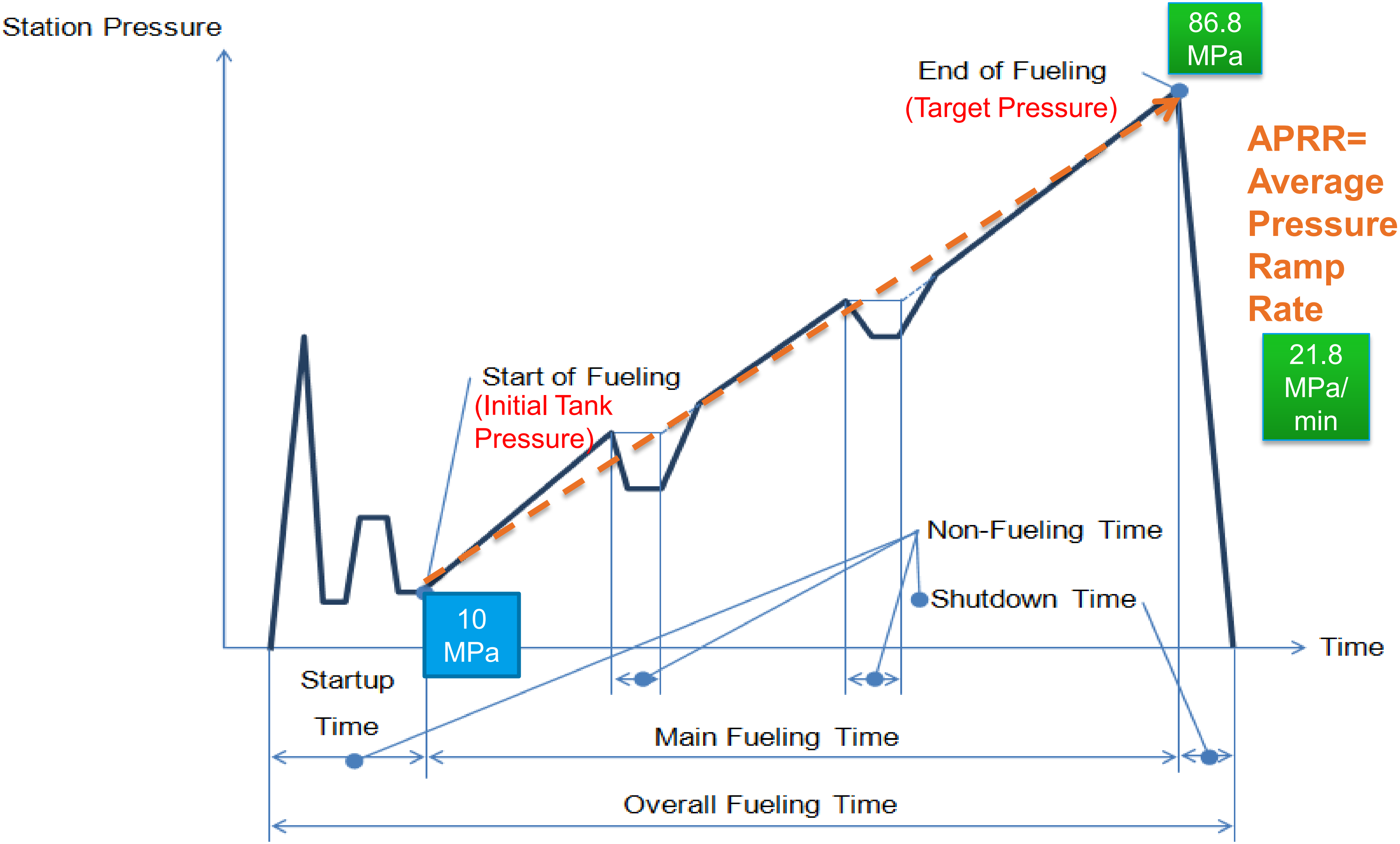
SAE J2601 „Standard“ Table Example

H70-T40 (4-7kg) Lookup Table with Communications

H70-T40 4-7kg comm		Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure Ptarget [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]							
			Initial Tank Pressure, P_0 [MPa]										
			0,5 - 5 (no interpolation allowed)			0,5	2	5	10	15	20	30	40
Ambient Temperature, T_{amb} [°C]	> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	[illegible]	no fueling	no fueling	no fueling	no fu
	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,
	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,
	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,
	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,
	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,
	[illegible]	[illegible]	69,0	87,4	7,2	see Top-Off	see Top-Off	81,0	[illegible]	86,1	85,4	83,8	82,
	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,
	[illegible]	[illegible]	66,3	87,4	9,0	see Top-Off	see Top-Off	81,2	[illegible]	85,7	84,7	82,6	80,
	0	23,5	no Top-Off	no Top-Off	no Top-Off	78,4	84,6	86,8	85,6	84,4	83,1	80,6	78,
	-10	23,5	no Top-Off	no Top-Off	no Top-Off	82,2	87,1	86,4	85,2	84,0	82,8	80,4	77,
	-20	23,5	no Top-Off	no Top-Off	no Top-Off	86,0	86,8	86,1	84,9	83,7	82,4	80,0	77,
	-30	23,5	no Top-Off	no Top-Off	no Top-Off	86,8	86,5	85,7	84,5	83,3	82,1	79,6	77,
	-40	23,5	no Top-Off	no Top-Off	no Top-Off	86,5	86,2	85,4	84,2	83,0	81,8	79,3	77,
	< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fu

4 Minute Fueling

SAE J2601 Representative Fueling Pressure vs. Time Average Pressure Ramp Rate Methodology (w/example)



SAE J2601 Optional „Cold Dispenser“ (CD)
Maximum Station Component and Fuel Temperature Table

- Colder station components can occur when multiple vehicles are fueled consecutively with minimal time in between.

- Stations may optionally use the Cold Dispenser Fueling Procedure allowing for increased APRR when all station components are at sufficiently low temperature.

- The CD fueling procedure can use a higher APRR because if the station components begin the fueling at a lower temperature, less heat is generated within the CHSS.

Maximum Station Component and Tfuel Temperature	Cold Dispenser Non-Communications		Cold Dispenser Communications	
°C	**H70-T30**	**H70-T40**	**H70-T30**	**H70-T40**
0	Non-Comm H70-T30 CD0	Non-Comm H70-T40 CD0	Comm H70-T30 CD0	Comm H70-T40 CD0
-10	Non-Comm H70-T30 CD-10	Non-Comm H70-T40 CD-10	Comm H70-T30 CD-10	Comm H70-T40 CD-10

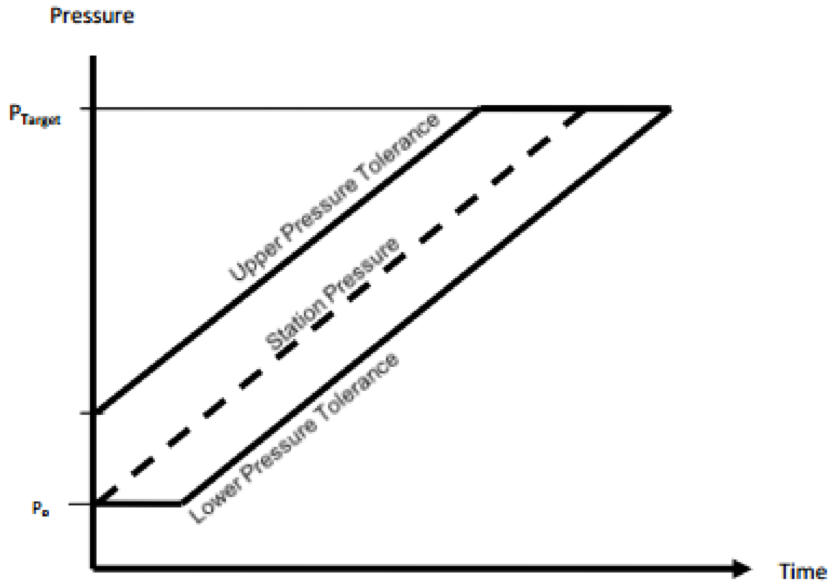
SAE J2601 „Cold Dispenser“ CD-10 Table Example

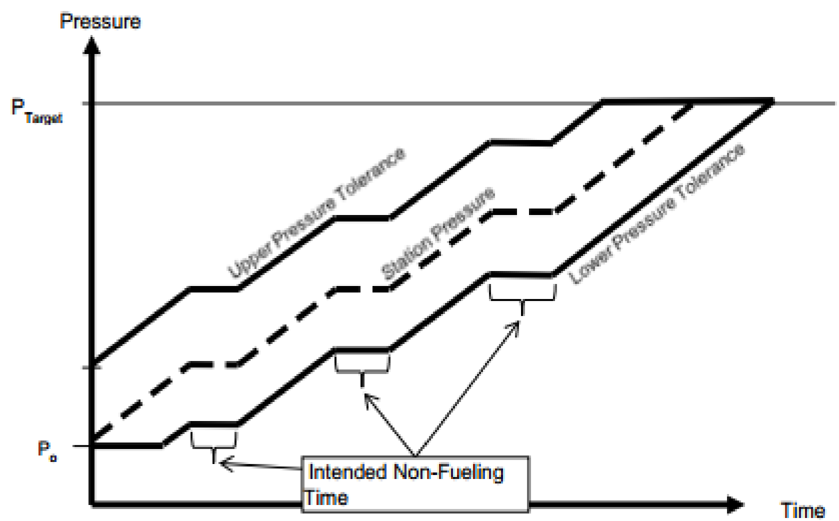
H70-T40 (4-7kg) Lookup Table, CD -10 (with Communications)

H70-T40 4-7kg comm CD-10	Average Pressure Ramp Rate, APRR [MPa/min]	Target Pressure Ptarget [MPa]	Target Pressure Top-Off [MPa]	Top-Off-APRR [MPa/min]	Target Pressure, P_{target} [MPa]							
		Initial Tank Pressure, P_0 [MPa]										
		0,5 - 5 (no interpolation allowed)			0,5	2	5	10	15	20	30	4
Ambient Temperature, T_{amb} [°C] > 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	[illegible]	no fueling	no fueling	no fueling	no fu
50	11,1	75,9	87,5	4,1	see Top-Off	see Top-Off	81,2	87,2	86,8	86,5	85,6	84
45	15,1	73,1	87,5	5,4	see Top-Off	see Top-Off	81,1	87,1	86,6	86,1	85,0	83
40	18,9	70,9	87,4	6,2	see Top-Off	see Top-Off	81,1	87,0	86,4	85,8	84,4	82
35	19,4	71,0	87,4	6,2	see Top-Off	see Top-Off	81,2	87,0	86,4	85,8	84,4	82
30	22,2	69,8	87,4	6,7	see Top-Off	see Top-Off	81,3	87,0	86,3	85,5	84,0	82
[illegible]	[illegible]	68,5	87,4	7,5	see Top-Off	see Top-Off	81,1	[illegible]	86,1	85,3	83,5	81
20	27,7	67,0	87,5	7,4	see Top-Off	see Top-Off	81,1	86,9	86,0	85,0	83,1	81
[illegible]	[illegible]	71,0	87,4	7,6	see Top-Off	see Top-Off	86,7	[illegible]	85,4	84,3	82,2	80
0	28,5	no Top-Off	no Top-Off	no Top-Off	81,0	87,2	86,5	85,3	84,1	82,9	80,4	77
-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
-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
-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
-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
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fu

3 Minute Fueling

J2601 Standard revised Fueling Corridor pressure tolerances (with and without intended non-fueling time)

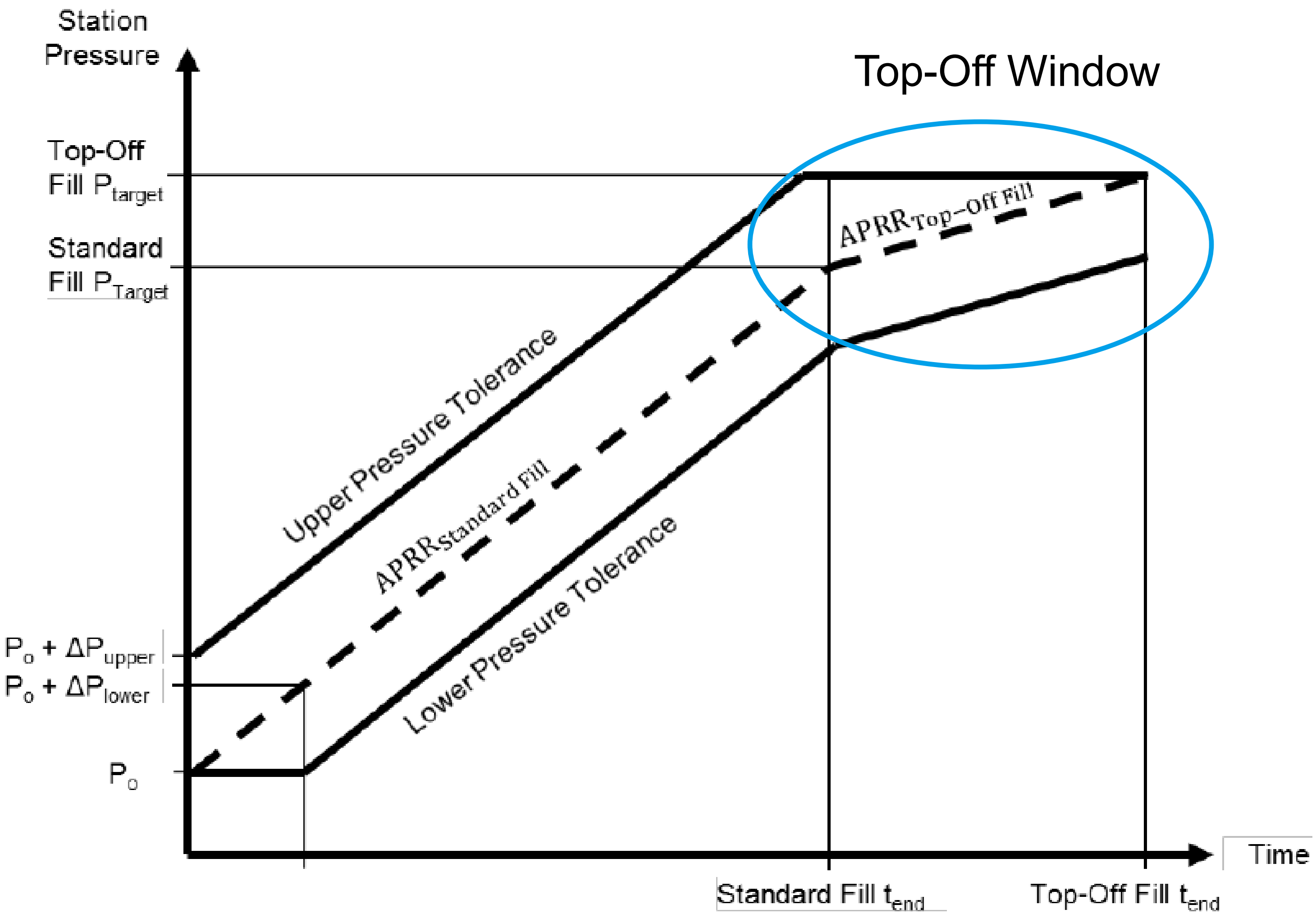




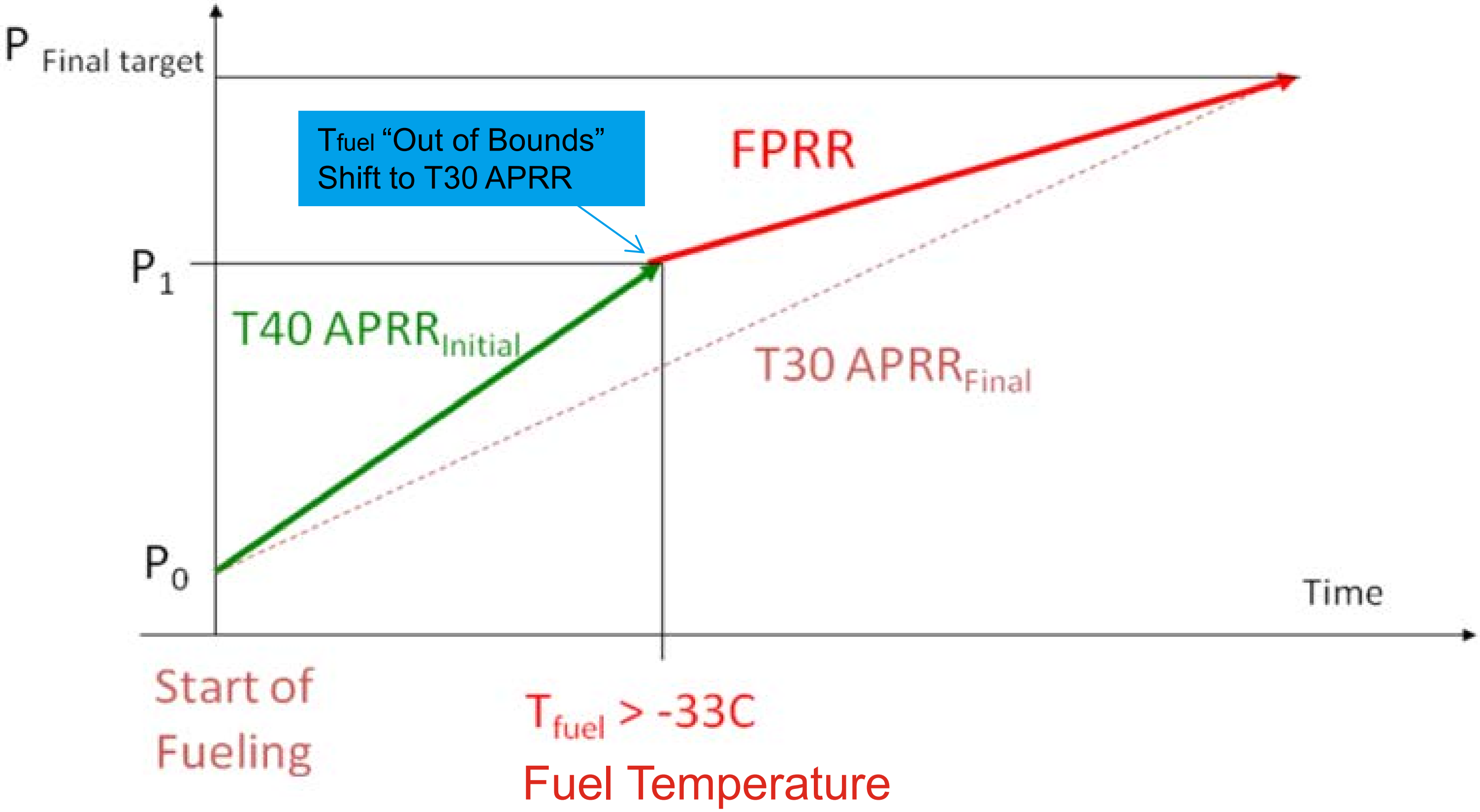
Tolerences

dP_{lower} = 2.5 Mpa
dP_{upper}= 7.0 Mpa

Station Pressure Bounds for Standard and Top-Off Fueling



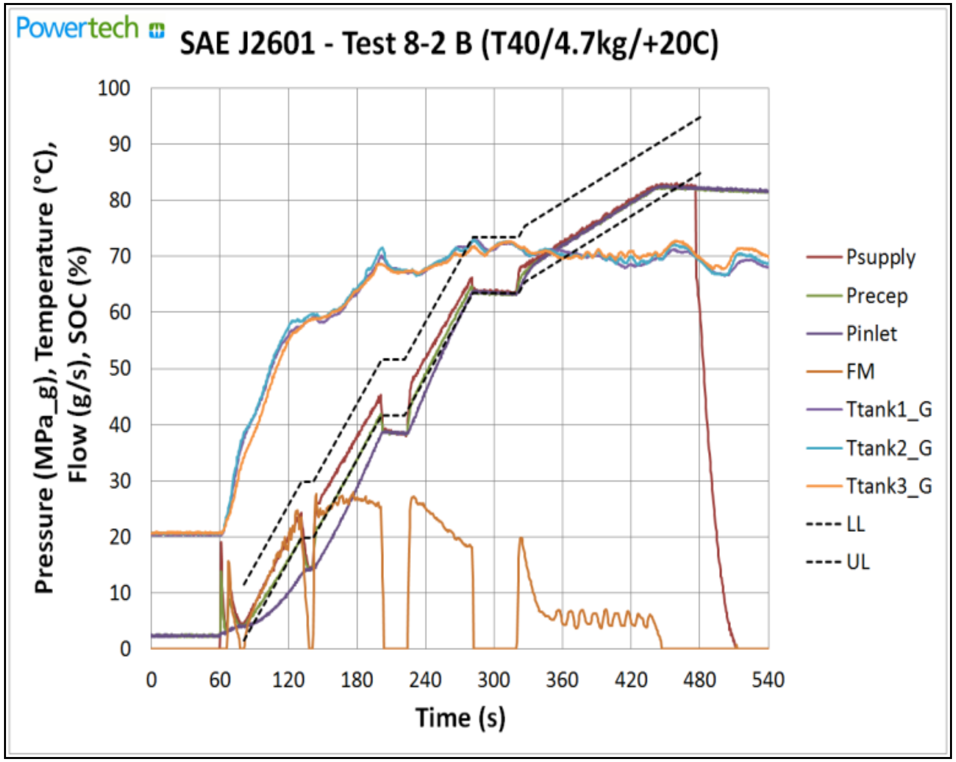
"Fall-Back" Pressure Ramp Rate (FPRR) and Average Pressure Ramp Rate Hydrogen Fueling Example- T40 to T30"



Outline

- Hydrogen Fueling Background
- SAE H2 Fueling Standardization
- SAE J2799 Standard
- SAE J2601 Standard
- Theory and Modeling/ Tables
- **Lab Testing and Field Verification of Hydrogen Fueling**
- Implementing of SAE J2601

SAE J2601 Lab validation Tests with H2 fueling with real vehicle storage systems (Type 3&4)



- 35MPa and 70MPa Fueling
- Extreme Temperature Tests: -40℃<u><</u>x<+50℃
- Real Station Hardware
- Real Vehicle Hardware

Source: Graham Meadows Powertech/ J. Schneider-BMW

Field Testing J2601 in 2013-2014 With Real Fuel Cell Vehicles (5 OEMs)

H2 Logic

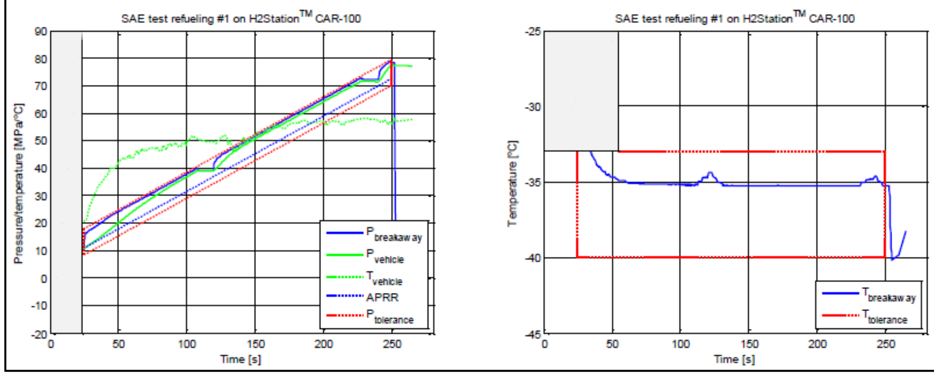
SAE J2601 field testing on H2Station® CAR-100

1. Tests planned and performed in close cooperation with Daimler and Hyundai
2. Some tests were witnessed by representative from Shell Global Hydrogen
3. A total of 18 refueling tests were performed, where 10 was com-refuelings
4. Test vehicles: 2 pcs. Daimler F-CELL B-class and 2 pcs. Hyundai ix35

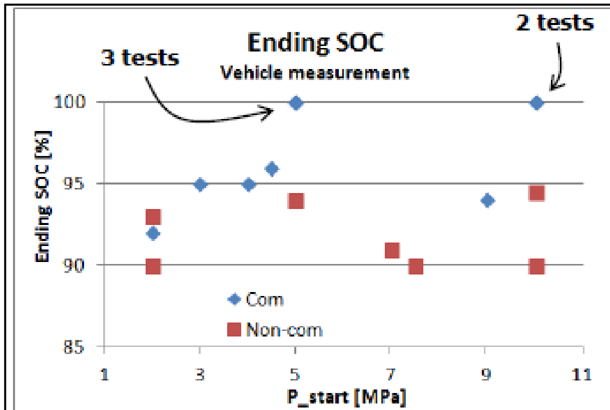
Example of Fueling Validation with Comm.

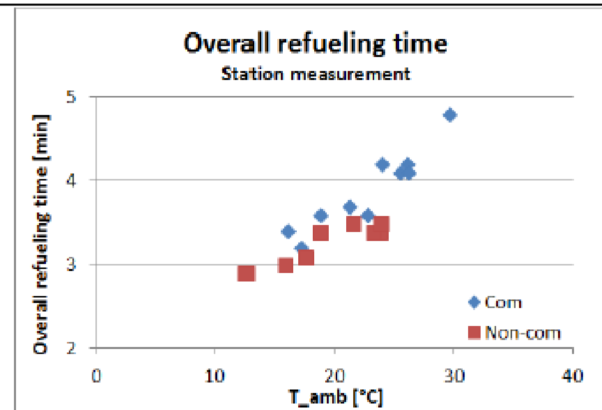
Station data

Date and time	Vehicle type	T_amb [°C]	Refueling time [min]	Non-refueling time [s]	P_start [MPa]	P_start (IrDa) [MPa]	T_start (IrDa) [°C]	SOC start [%]	P_end [MPa]	P_end (IrDa) [MPa]	T_end (IrDa) [°C]	SOC end [%]	P_target [MPa]	Peak mass flow [g/s]
13-05-2013, 09:45	Daimler F-CELL B-Class	23.9	4.2	29	10.6	9.8	15.4	19.3	78.9	77.3	56.5	97.3	86.7	26.3



All Tests:
SOC 90%<x<100%
Fueling Time: 3-5 mins.





Source: Jesper Boison, H2Logic

Outline

- Hydrogen Fueling Background
- SAE H2 Fueling Standardization
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- SAE J2601 Standard
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- **Implementing of SAE J2601**

SAE J2601 applications and supporting organizations worldwide

EU*

EHA/
NOW/ CEP/
H2 Mobility/
H2 Moves

* SAE J2601 is also being referenced in ISO 19880-1 in 2015

US

DOE,H_2USA, H_2First, State of CA (CEC, CARB,etc), FCHEA, CaFCP, CHBC

Japan

HySUT/FCCJ/
JARI/ NEDO

Conclusion

SAE J2601/J2799 enables standard fueling / verification needed

•The J2601 and J2799 Standards are enablers to fuel cell vehicle commercialization, worldwide, and enable consistent, safe refueling for Fuel Cell Vehicles and are be available on the SAE Website:
http://standards.sae.org/j2601_201407/
http://standards.sae.org/j2799_201404/

•J2601 has been validated with real automaker vehicles and tanks and hydrogen stations and documented in the SAE Technical Report (http://papers.sae.org/2014-01-1990/): "Validation and Sensitivity Studies for SAE J2601" available in June 2014.

•At station commissioning, dispensers need to be validated that they meet SAE J2601/ J2799 by a Hydrogen Dispenser Station Test Apparatus (http://papers.sae.org/2005-01-0002/). Note, organizations such H_2First for the US, HySut in Japan and CEP in Germany are in process of implementing HSTAs.

Conclusion Continued
Links to other SAE Documents

SAE J2600 - Compressed Hydrogen Surface Vehicle Fueling Connection Devices

http://standards.sae.org/j2600_201211/

SAE J2601/2 - Hydrogen Bus Fueling Technical Information Report

http://www.sae.org/technical/standards/J2601/2_201409

SAE J2601/3 - Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles

http://standards.sae.org/j2601/3_201306/

SAE J2578 - Recommended Practice for General Fuel Cell Vehicle Safety

http://standards.sae.org/j2578_201408/

SAE J2579 - Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles

http://standards.sae.org/j2579_201303/

SAE J2719 - Hydrogen Fuel Quality for Fuel Cell Vehicles.

http://standards.sae.org/j2719_201109/

SAE J2601 DEVELOPMENT FUELING- MC METHOD

(APPENDIX H)

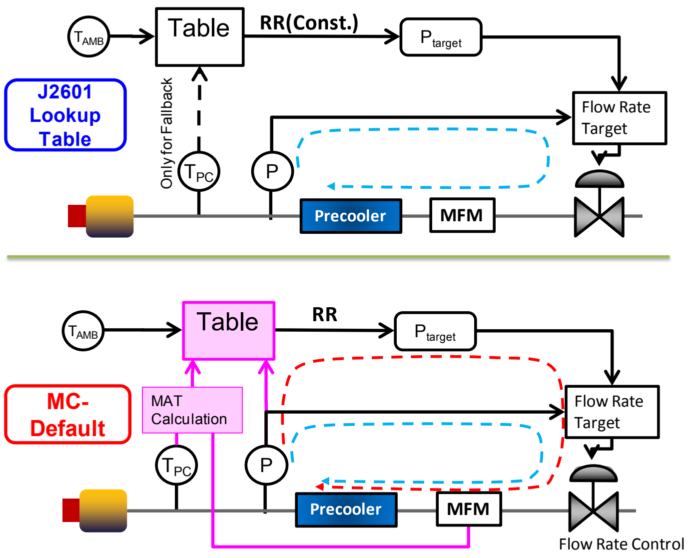
Steve Mathison
(Honda R&D Americas, Inc.)

SAE J2601 Development Fueling: MC Default Fill - Philosophy

Philosophy for both Lookup Tables (L/T) and MC Default Fill:

- H_2 Station is fully responsible for safe fueling of car
- No safety critical information from vehicle is used
- Worst case boundary conditions are assumed

- ❑ The **key difference** between the L/T and MC Default Fill is that the MC Default Fill uses the **actual** pre-cooling temperature of the dispenser as the control input, rather than the station type (e.g. T40) **boundary** temperature.
  - <u>All other boundary conditions remain the same</u>
- ❑ The other key difference is the ramp rate control methodology:
  - Lookup Table uses feed forward **static** control
  - MC Default Fill uses feedback **dynamic** control
- ❑ MC Default Fill Pressure targets are also calculated dynamically
- ❑ These attributes allow the MC Default Fill to dynamically adjust and optimize the fill to the dispenser capabilities are at the time



MC Default Fill - Boundary Conditions

Pressure Ramp Rate

Common Boundary Conditions

- **Vehicle Components** — *J2601 (Appendix A)*
- **Reference Pressure Drop** — *J2601 (Appendix A)*
- **Type IV (2, 4, 7, 10kg)** — *J2601 (Appendix A)*
- **Station Components** — *J2601 (Appendix A)*
- **Initial Pressure Assumptions** — *J2601 (Appendix A)*
- **Hot Soak Assumptions** — *J2601 (Appendix A)*

Hot Case

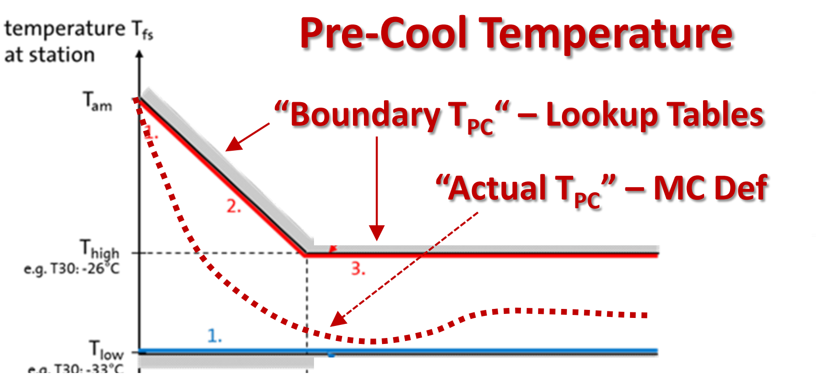
Appendix A of SAE J2601 Describes Boundary Conditions

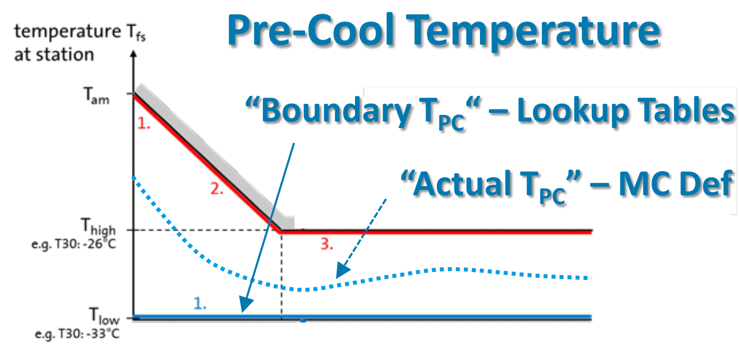
Pressure Targets

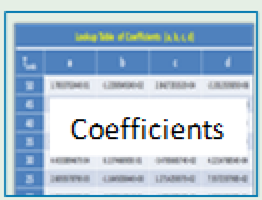
Common Boundary Conditions

- **Vehicle Components** — *J2601 (Appendix A)*
- **Reference Pressure Drop** — *J2601 (Appendix A)*
- **Type III (1 kg H35 / H70)** — *J2601 (Appendix A)*
- **Station Components** — *J2601 (Appendix A)*
- **SOC Limits (Comm & Non-Comm)** — *J2601 (Appendix A)*
- **Cold Soak / Defuel Assumptions** — *J2601 (Appendix A)*

Cold Case



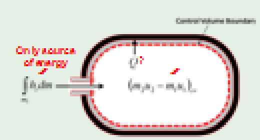




Press Ramp Rate = $f(T_{PC}, \dot{m}, T_{AMB})$

Continuous Equation

Dynamic Control



$$T_{final} = \frac{m_s C_v T_{adiabatic} + MCT_{initial}}{MC + m_s C_v}$$

$P_{TARGET} = f(T_{PC}, \dot{m}, P_{INIT}, time)$

Dynamically Calculated

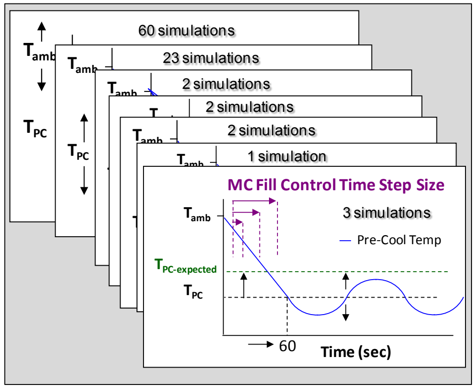
The only boundary condition which differs between the J2601 Lookup Tables & MC Default Fill is the T_{PC} used

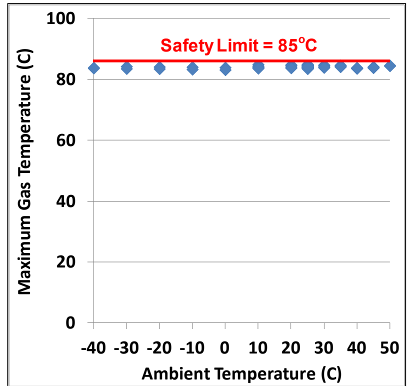
MC Default Fill - Safety

Documented in the **SAE Technical Report (2014-01-1833)**:
"Validation and Sensitivity Studies for SAE J2601"

MC Default Fill is designed such that T_{GAS} will not exceed 85 °C under worst case conditions

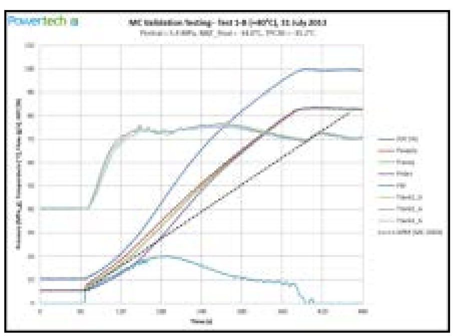
Simulations *(Wenger Engineering)*





93 Simulations conducted under worst case conditions

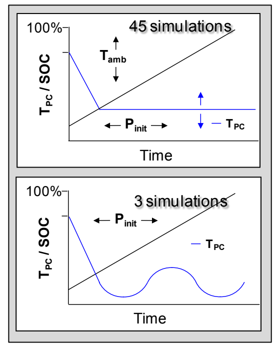
Bench Tests *(Powertech Labs)*

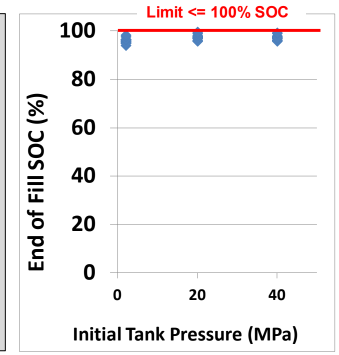


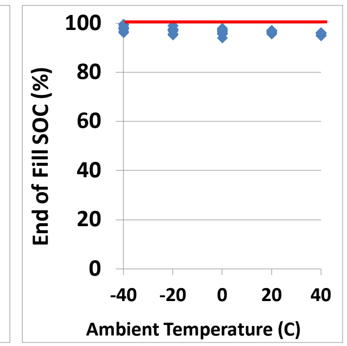
6 Bench Tests conducted under same conditions as J2601 L/T bench validation tests – no overheating

MC Default Fill calculates P_{TARGET} such that no overfilling occurs under worst case conditions

Simulations *(Wenger Engineering)*

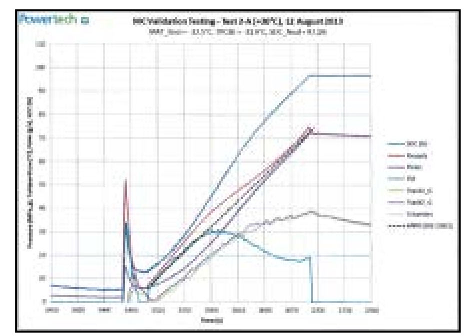






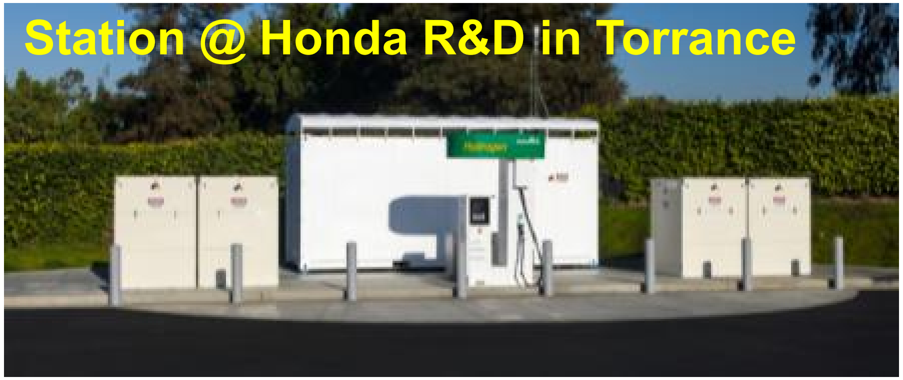
48 Simulations conducted under worst case conditions

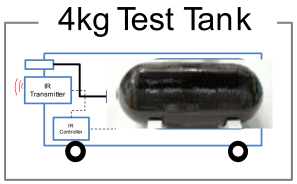
Bench Tests *(Powertech Labs)*



1 Bench Test conducted under same condition as J2601 L/T bench validation test – no overfilling

Real World Field Validation

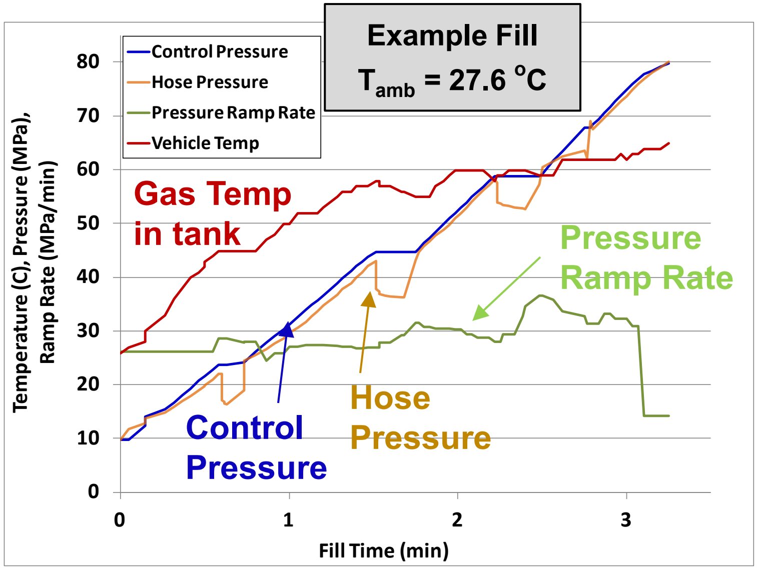


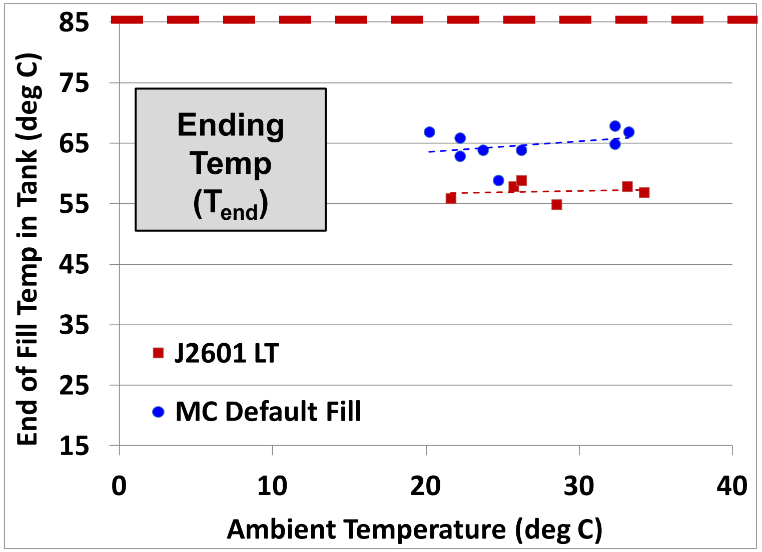


35 Fills
- 19 MC Def Fills
- 16 J2601 L/T Fills

34 Fills
- 22 MC Def Fills
- 12 J2601 L/T Fills

12 Fills
- 12 MC Def Fills





MC Default Fill - Conclusions

- **The MC Default Fill is currently a non-normative protocol defined in Appendix H of SAE J2601**
- **The MC Default Fill offers many benefits:**
  - **Customer Experience :**
    - Fast fueling times
    - More consistency in fueling time (i.e. less variability due to changes in ambient temperature)
  - **Station Design:**
    - More flexibility due to the MC Fill's adaptive qualities
  - **H_2 Infrastructure:**
    - Better station utilization (more vehicles per hour can fuel due to quicker fill times)
- **In-field use and validation of the MC Default Fill is ongoing:**
  - Two OEMs have conducted a combined 35 MC Default Fills to date
  - Other Dispenser Manufacturers are in the process of implementing the MC Default Fill
- **The SAE Interface Task Force is evaluating the data from this real world usage and is considering making the MC Default Fill a normative fueling protocol in a future revision to SAE J2601.**

DOE Webinar Q&A

- Will James — Contact: Charles.James@ee.doe.gov
- Jesse Schneider — Contact: Jesse.Schneider@bmw.com, Jesse.Schneider@web.de,
- Steve Mathison — Contact: SMathison@hra.com

Informational:
Face-to-Face Training for SAE Hydrogen Fueling Standards at the Fuel Cell Seminar in Los Angeles California on November 10th, 9-11 AM PT.

FUEL CELL SEMINAR & ENERGY EXPOSITION Featuring Hydrogen Fuel

Fuel Cell & Hydrogen Energy Association

Fuel Cells the Power to Drive Change TODAY

Participant Dedication

The presenters dedicated this webinar to Linda Gronlund, who was one of the pioneers in the hydrogen at BMW, NA. and was the first employee to work on this topic there.

As an avid car enthusiast and environmentalist, she was instrumental in promoting the use of hydrogen-fueled cars.

She passed away on Flight 93 on 9/11/2001.

http://www.flight93memorialsfb.com/Heros-Of-Flight-93/pages/Linda-Gronlund_jpg.htm
http://www.nps.gov/flni/historyculture/linda-gronlund.htm