SURFACE VEHICLE TECHNICAL INFORMATION REPORT

SAE International

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Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*

RATIONALE

The implementation of hydrogen vehicles into the market necessitates having a universal fueling protocol for every vehicle. The goal is to achieve a 'customer acceptable' fueling, which means a full tank of hydrogen within a reasonable amount of time without exceeding the temperature, pressure and density (SOC) limits. However, fueling performance may be limited by the pre-cooling capacity of the station dispenser.

SAE TIR J2601 establishes industry-wide fueling protocol guidelines for the fueling of gaseous hydrogen into on-road passenger vehicles operating with nominal working pressures (NWPs) of 35 MPa and 70 MPa. Fueling stations should employ fueling algorithms and equipment to conduct the fueling process within these guidelines. Vehicles filled at stations using these protocols should be designed appropriately for fueling according to these guidelines. SAE TIR J2579 provides guidance for qualifying the vehicle hydrogen storage system (HSS) for operation at specific nominal working pressures.

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1. SCOPE

SAE TIR J2601 establishes safety limits and performance requirements for gaseous hydrogen fuel dispensers. The criteria include maximum fuel temperature at the dispenser nozzle, the maximum fuel flow rate, the maximum rate of pressure increase and other performance criteria based on the cooling capability of the station's dispenser.

This document establishes fueling guidelines for "non-communication fueling" in the absence of vehicle communication and guidelines for "communication fueling" when specified information is transmitted from the vehicle and verified at the dispenser. The process by which fueling is optimized using vehicle-transmitted information is specified. This document provides details of the communication data transmission protocol.

The mechanical connector geometry is not covered in this document. SAE J2600 defines the connector requirements for fueling vehicles operating with a nominal working pressure of 35 MPa. SAE TIR J2799 defines the mechanical connector geometry for fueling vehicles to 70 MPa and also provides specifications for the hardware for vehicle-to-station dispenser communication. It is expected that SAE J2600 will be revised to include the receptacle content of SAE TIR J2799, in which case the resulting SAE J2600 will provide connector hardware requirements for gaseous hydrogen fueling at all working pressures. The vehicle-to-station communication portion of SAE TIR J2799 is to be integrated into SAE TIR J2601 in the next revision, and it is planned that the 70 MPa nozzle in SAE TIR J2799 will be replaced by SAE J2600. Figure 1 illustrates the scopes and relationships of SAE J2600, SAE TIR J2799, and SAE TIR J2601.

This document applies to light duty vehicle fueling for vehicles with storage capacity from 1 to 10 kg for 70 MPa and 1 to 7.5 kg for 35 MPa. It is intended to be revised in the next two years to include separate requirements for fueling heavy duty vehicles and motorcycles, forklifts and also for residential hydrogen fueling appliances. Since there is a significant difference between the onboard storage capacity of heavy-duty and light-duty vehicles, the performance specifications could be different.

Standard Designation		H35			H70		
Storage Capacity Classification		Small (motorcycle)	Light Duty (light duty ≤ 10kg)	Heavy Duty (bus, commercial truck)	Small (motorcycle)	Light Duty (light duty ≤ 10kg)	Heavy Duty (bus, commercial truck)
Fueling Connection Device		J2600			J2799 (to J2600 in future)		
Vehicle-to-Station Communication		J2799 (to J2601 in future)			J2799 (to J2601 in future)		
Fueling Type Type ➔ Cooling	A ➔ -40C	2601 in future	J2601 TIR in 2009	2601 in future	2601 in future	J2601 TIR in 2009	2601 in future
	B ➔ -20C	2601 in future	J2601 TIR in 2009	2601 in future	2601 in future	J2601 TIR in 2009	2601 in future
	C ➔ 0C	2601 in future	J2601 TIR in 2009	2601 in future	2601 in future	2601 in future	2601 in future
	D ➔ None	2601 in future	J2601 TIR in 2009	2601 in future	2601 in future	2601 in future	2601 in future
	Residential	2601 in future	2601 in future	2601 in future	2601 in future	2601 in future	2601 in future

FIGURE 1 - SUMMARY OF FUELING INTERFACE STANDARDS AND SCOPE OF CURRENT SAE TIR J2601

This document applies to fueling using an average pressure ramp rate methodology which is to be verified with a hydrogen dispenser test apparatus as defined CSA HGV 4.3. This document includes provisions for optional alternative communications fueling protocols and is planned to be revised in the future to include specifications for additional fueling processes to allow more freedom than the present document. New dispenser protocol proposals would need to be verified with data and experience demonstrating the fueling algorithm's capability to operate within the constraints of Section 5.

It is expected that this document will be used in conjunction with the CSA HGV 4.3 Hydrogen Dispenser Temperature Compensation Confirmation Report, which will to provide a test method and equipment specification for confirming that the performance of a fuel dispenser is consistent with the requirements of SAE TIR J2601.

This document establishes a formal industry-wide fueling guideline that supersedes all temporary guidelines informally established by non-ANSI-certified organizations, such as the vehicle manufacturer (OEM) document Fueling Specification for 70 MPa Compressed Hydrogen Vehicles, Version A posted on the NextEnergy website and all CaFCP Fueling Protocols. It is understood, however, that other fueling protocols that differ from the look-up table-based protocol specified in this document may be used when the station provider has (a) an agreement from a vehicle manufacturer that the protocol is appropriate for a particular vehicle system, and (b) a method of identifying the particular vehicle and limiting the protocol to that vehicle is utilized in the station design and operation. The intent is that developments be brought to the SAE TIR J2601 team to enable modification of the document to allow for a more performance based approach for future revisions. The current document is table-based, providing concise performance targets and dispenser performance specifications for both communicated and non communicated fills as shown in Figure 2 and detailed in Sections 5 through 9.

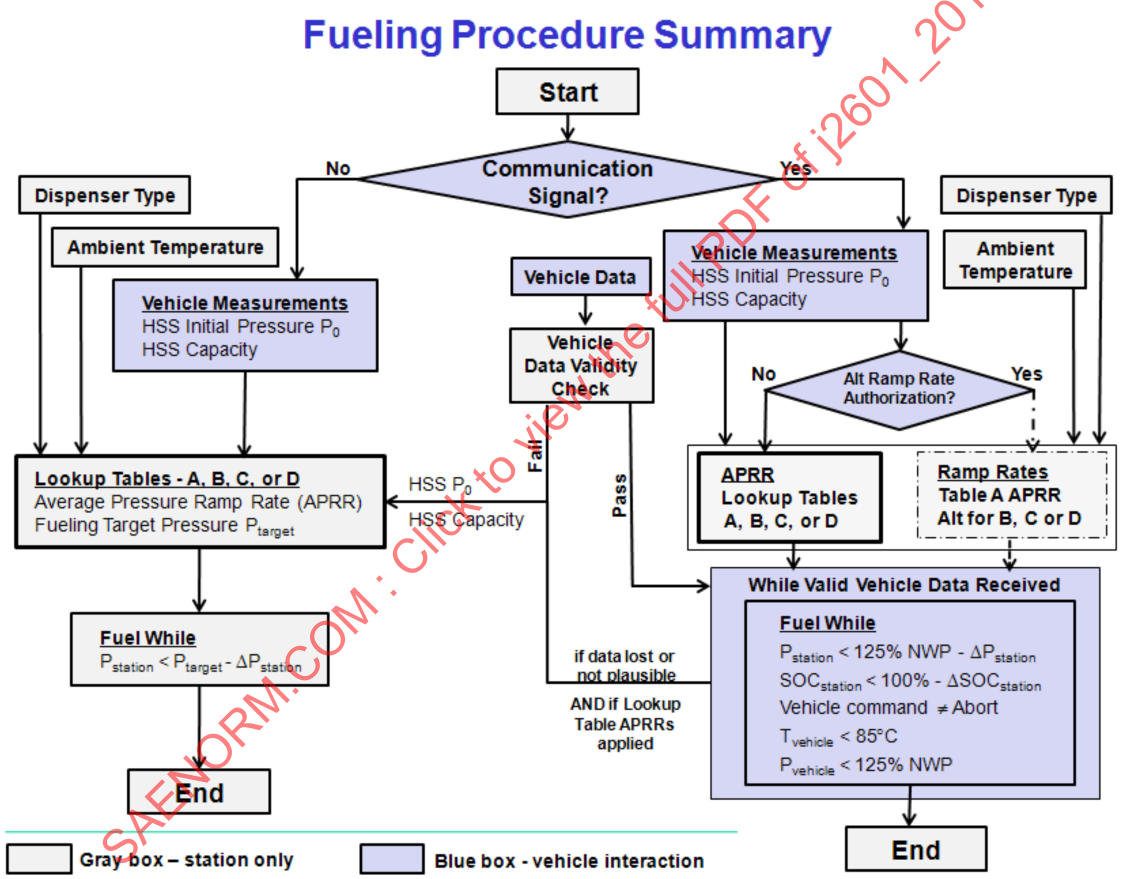


FIGURE 2 - FLOW SHEET OF DECISION TREE FOR EACH FUELING PROCEDURE

This TIR is intended to evolve over time before it is standardized. The goal is to establish a protocol guideline in the initial publication and request industry to give feedback and improvement suggestions before standardizing within a two-year timeframe.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J2574 Fuel Cell Vehicle Terminology

SAE J2578 Recommended Practice for General Fuel Cell Vehicle Safety

SAE TIR J2579 Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Fueled Vehicles

SAE TIR J2719 Information Report on the Development of a Hydrogen Quality Guideline for Fuel Cell Vehicles

SAE TIR J2760 Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications

SAE TIR J2799 70 MPa Compressed Hydrogen Surface Vehicle Fueling Connection Device and Optional Vehicle to Station Communications

SAE Paper 2005-01-0002 “Gaseous Hydrogen Station Test Apparatus: Verification of Hydrogen Dispenser Performance Utilizing Vehicle Representative Test Cylinders”

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 14687-2 Hydrogen Fuel - Product Specifications

ISO 13849-1 Safety of machinery - Safety-related parts of control systems

2.1.3 EN Publications

Available from http://www.din.de/cmd?level=tpl-home&languageid=en

EN50014:1997, EN50015:1998, EN50016:1995, EN50017:1998, EN50018:2002, EN50019:2000, EN50020:1994, EN50021:1998, Electrical apparatus for potentially explosive atmospheres

EN60079-14: 1998, Electrical apparatus for explosive gas atmospheres – part 14: electrical installations in hazardous areas (other than mines)

2.1.4 IEC Publications

Available from International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, 1211 Geneva 20,Switzerland, Tel: +44-22-919-02-11, www.iec.ch.

IEC 61508 Application of Safety Instrumented Systems for the Process Industries

IEC 62061 Safety of machinery - Functional safety of safety related electrical, electronic and programmable electronic control systems

2.1.5 IETF Publications

Available from http://www.faqs.org/rfcs/rfc1171.html

RFC1171 The Point-to-Point Protocol for the Transmission of Multi-Protocol Datagram Over Point-to-Point Links

2.1.6 API Publications

Available from American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005-4070, Tel: 202-682-8000, http://api-ec.api.org.

API RP 2003 Protection against Ignitions Arising Out of Static, Lightning, and Stray Currents

2.1.7 Military Publications

Available from http://www.everyspec.com/MIL-STD/MIL-STD+%280900+-+1099%29/

MIL-HDBK-310 Global Climatic Data for Developing Military Products

MIL-STD-810G Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests

2.1.8 CSA America Documents

Available from http://www.csa-america.org/

CSA America HGV 4.1 Technical Interim Report Hydrogen Gas Vehicle (HGV) Dispensing Systems

CSA America HGV 4.2 Technical Interim Report Hoses and Hose Assemblies for Hydrogen Gas Vehicle (HGV) Dispensing Systems

CSA America HGV 4.3 Technical Interim Report Hydrogen Fueling Parameter Verification

CSA America HGV 4.4 Technical Interim Report Breakaway Devices for Hydrogen Gas Dispensing Hoses and Systems

CSA America HGV 4.5 Technical Interim Report Priority and Sequencing for Hydrogen Gas Dispensing Systems

CSA America HGV 4.6 Technical Interim Report Manually Operated Valves for Hydrogen Gas Dispensing Systems

CSA America HGV 4.7 Technical Interim Report Automatic High Pressure Operated Valves for Hydrogen Gas Dispensing Systems

CSA America HGV 4.8 Technical Interim Report Hydrogen Gas Vehicle Fueling Station Compressor Guidelines

CSA America HGV 4.10 Hydrogen Fittings

2.1.9 NHA Papers

Available from http://www.hydrogenassociation.org/general/publications.asp

Optimizing Hydrogen Vehicle Fueling, 2005, Schneider, J. Ward, et al.

70 MPa Hydrogen Storage and Fueling Testing and Future Prospects, 2009, J. Schneider, I. Sutherland, et al

2.1.10 IrDA Publications

Available from http://www.irda.org/displaycommon.cfm?an=1&subarticlenbr=8

IrDA IrPHY 1.4 IrDA Serial Infrared Physical Layer Specification

IrDA IrLAP 1.1 Serial Infrared Link Access Protocol

3. DEFINITIONS

3.1 CAPACITY

3.1.1 Light Duty Vehicle Hydrogen Storage Capacity

Onboard storage capacity of light duty gaseous hydrogen will to be 10 kg or less when fully filled. This fueling protocol is designed for timely fueling of onboard storage with a capacity from 1 kg up to 10 kg. Capacity Categories for 70 MPa and 35 MPa: In order to fuel the range of available OEM storage containers, a data study was carried out to determine how to best fuel all vehicles to an acceptable fill level within a short amount of time. It was determined that in order to fuel the vehicles in a reasonable amount of time, capacity categories had to be established to separate the tables-based fueling approach. These are as follows:

3.1.1.1 70 MPa

Less than or equal to 7 kg hydrogen for total capacity and single cylinder; Greater than 7 kg up to 10 kg hydrogen.

3.1.1.2 35 MPa

Less than or equal to 7.5 kg hydrogen total capacity.

3.1.2 The peak fueling capacity shall be expressed in kg/h and is defined by the total quantity of hydrogen that can be delivered to 7 kg-capacity vehicles according to the Fueling Protocol in a 1 h period.

The daily station capacity shall be expressed in kg/day and is defined by the total quantity of hydrogen that can be delivered to 7 kg-capacity vehicles according to the Fueling Protocol over a 12 h period.

3.1.2.1 Assumption for capacity calculation is that each fueling takes place at 0 °C ambient, starts at initial HSS pressure of 2 MPa, adds 7 kg to achieve 100%SOC at 80 MPa, and is followed by a 2-min interval before the next vehicle can fuel at the same dispenser.

3.1.2.2 Ambient temperatures greater than 0 °C may reduce actual station output. Potential ambient temperature effects on fueling time can be understood from the non-communication pressure ramp rates in Tables 8-1 to 8-8. Output loss due to ambient temperature effects can be mitigated by Type A dispensing and/or by multiple dispensers operating in parallel.

3.2 DISPENSER COMPONENTS

3.2.1 Hydrogen Dispensing System (Dispenser)

The equipment required to condition and transfer fuel from the station to vehicle storage for the purpose of fueling the vehicle.

3.2.2 Connector

A joined assembly of Hydrogen Surface Vehicle (HSV) nozzle and receptacle which permits quick connect and disconnect of fuel supply to the vehicle.

3.2.3 Nozzle

Device connected to a fuel dispensing system which engages the HSV receptacle and permits transfer of fuel.

3.2.4 Receptacle

Device connected to a vehicle or storage system that receives the dispenser nozzle and permits transfer of fuel. This may also be referred to as a fueling inlet.

3.3 TEMPERATURE

3.3.1 Ambient Temperature

The ground-level temperature of the air measured at the fueling station, and not in direct sunlight.

3.3.2 Fuel Delivery Temperature

The temperature of the hydrogen gas at the dispenser nozzle during fueling; this is identical to the pre-cooling temperature. Station dispensers are classified based on their fuel delivery temperature capability, which may be different than the pre-cooling hardware set temperature.

3.3.3 Vehicle Tank Gas Temperature

The average temperature of the gas in the vehicle tank. If the vehicle tank contains a temperature measurement device for the purpose of sending a temperature signal to the dispenser during fueling, this temperature is also assumed to be the (nominal) average temperature of the gas in the vehicle tank. Due to accuracy and sensor reliability concerns, the vehicle manufacturer should consider the tolerances of the temperature measurement by the vehicle and include as criteria for the abort signal.

3.3.4 Soak Temperature of Vehicle Storage Tank

Temperature of vehicle storage tank after parking, which may differ from the ground-level ambient temperature at a fueling station. Figure A1 shows the range of soak temperature relative to ambient temperature due to hot soak or cold soak conditions. Soak temperature is independent of the thermal effects of fueling or defueling.

3.4 PRESSURE

3.4.1 HSS Pressure ($P_{vehicle}$)

Pressure of hydrogen gas within the vehicle Hydrogen Storage System (NOTE: For vehicles with multiple tanks, this document assumes all tanks are at equal pressure and are filled in parallel).

3.4.2 Station Pressure ($P_{station}$)

Pressure measured at the pressure transducer in dispenser at the nearest point to the nozzle.

3.4.3 Settled Pressure

Pressure of hydrogen gas within a vehicle storage tank with gas temperature equilibrated at ambient temperature.

3.4.4 Target Fueling Pressure (P_{target})

Pressure associated with maximum fill according to this Protocol. This is the pressure at which fueling should cease.

3.4.5 Nominal Working Pressure

$P_{vehicle}$ corresponding to a full fill equilibrated at 15 °C.

3.5 STATE OF CHARGE (SOC)

Ratio of hydrogen density within the vehicle storage system to the full-fill density. SOC is expressed as a percentage and is computed based on the gas density as per formula below. NOTE: P and T are the pressure and temperature of the gas inside the vehicle tank, and ρ is the calculated density

$$SOC\ (\%) = \frac{\rho\,(P,\ T)}{\rho\,(NWP,\ 15°C)}\ x\ 100 \qquad \text{(Eq. 1)}$$

The ρ(P,T) function for hydrogen is available from the National Institute of Standards and Technology (NIST) at http://www.boulder.nist.gov/div838/Hydrogen/PDFs/Hydrogen-2006-01-0434.pdf NOTE: The accuracy of the NIST equation has only been quantified up to 45 MPa at the publishing of this document.

3.5.1 100% SOC=Density Reference Values at 15 °C and the NWP of the hydrogen storage system

3.5.1.1 Density of H_2 at 15 °C and 35 MPa = 24.0 g/L

3.5.1.2 Density of H_2 at 15 °C and 70 MPa = 40.2 g/L

3.6 COMMUNICATION / NON-COMMUNICATION

3.6.1 "Non-Communication" when used in combination with a fueling procedure or fueling type means that no data connection from vehicle to fueling station dispenser as described in SAE J2799 has been established, or that the received data has not been recognized as valid by the dispenser. However, if the station receives an "abort" signal from the vehicle, then the station should stop fueling, regardless of whether the fueling mode was non-communication or communication.

3.6.2 "Communication" when used in combination with a fueling procedure or fueling type means that a data connection from vehicle to fueling station dispenser as described in SAE J2799 has been established and the received data has been recognized as valid by the dispenser. In this document there are two types of communications ramp rate: Default, utilizing non-communications APRR and Alternative (ALT) communications using same APRR for Type 'A' Dispensers, with different rates possible with types 'B, C and D' dispensers.

4. ABBREVIATIONS AND SYMBOLS

4.1 Abbreviations

- APRR Average Pressure Ramp Rate (MPa/min)
- ALT Alternative, non-specified, Hydrogen Fueling Methodology within limits describe in Section 9
- CAN Controller Area Network
- CHG Compressed Hydrogen Gas (H_2)
- CRC Cyclic Redundancy Check
- ECU Electronic Control Unit
- FC Fueling Command (Fuel, Halt, Abort)
- FMEA Failure Modes and Effects Analysis
- FS Fueling Station
- FTA Fault Tree Analysis
- H_2 Hydrogen gas
- HDTA Hydrogen Dispenser Test Apparatus
- HSS Hydrogen Storage System (on board vehicle)
- HSV Hydrogen Surface Vehicle
- IR Infrared light
- IrDA Infrared Data Association
- LFL Lower Flammability Limit (of hydrogen)
- MAWP Maximum Allowable Working Pressure (fueling station)
- NIST National Institute of Standards and Technology
- NWP Nominal Working Pressure (vehicle fuel system), based on 15 °C settled pressure.
- PRD Pressure Relief Device (thermally activated gas release device in vehicle fuel system)
- PRV Pressure Relief Valve (Mechanical valve in fueling station; over-pressure protection)
- SAE Society of Automotive Engineers
- SNV Signal not Valid
- SOC State of Charge (in %)
- TCU Tank Control Unit (of vehicle)

4.2 Symbols

- ρ(P,T) Gas density, a function of pressure, P, and temperature, T
- P0 Initial HSS pressure level prior to fueling
- Ptarget Target Fueling Pressure (see 3.4.4)
- Pstation Fueling pressure as measured by station (see 3.4.2)
- Pend Pstation at the end of fill
- Pvehicle HSS Pressure (see 3.4.1)
- dP Pressure drop between Pstation and Pvehicle
- ΔPstation Uncertainty in Pstation measurement, as defined in CSA HGV 4.9
- tfueling Fueling time
- tend tfueling at the end of fill
- tleak check Time allotted for leak checks during the fill (10 seconds per check – up to 10 seconds total for 35 MPa dispenser, up to 30 s total for 70 MPa dispenser)
- Tvehicle HSS temperature data received by station from vehicle during communication fueling
- Tfuel Fuel Delivery Temperature (see 3.3.2)
- Tamb Ambient temperature as measured by fueling station, not in direct sunlight
- SOCstation SOC calculated by station dispenser using Pstation + ΔPstation and Tvehicle

5. GENERAL REQUIREMENTS FOR FUEL SYSTEM AND INTERFACE

5.1 Operating Conditions of the Vehicle Fuel System

The fueling station is responsible for control of the fueling process. The Fueling Protocol specifies the fueling process based on the expectation that vehicle fuel systems have the following constraints in their operation. The following is also described in SAE J2579.

5.1.1 Maximum pressure within the vehicle fuel system 125% NWP

5.1.2 Gas temperature within the vehicle fuel system less than or equal to 85 °C

5.1.3 Gas density within the vehicle fuel system ≤ 100% SOC (see 3.5)

5.1.4 Operating window for pressure, temperature, and SOC

5.1.5 The Fueling Protocol is defined such that designers of vehicle fuel systems can confirm that the gas in their vehicle fuel system during fueling will remain within the operating window shown in Figure 3 where it does not exceed 125% NWP or 85 °C or 100% SOC.

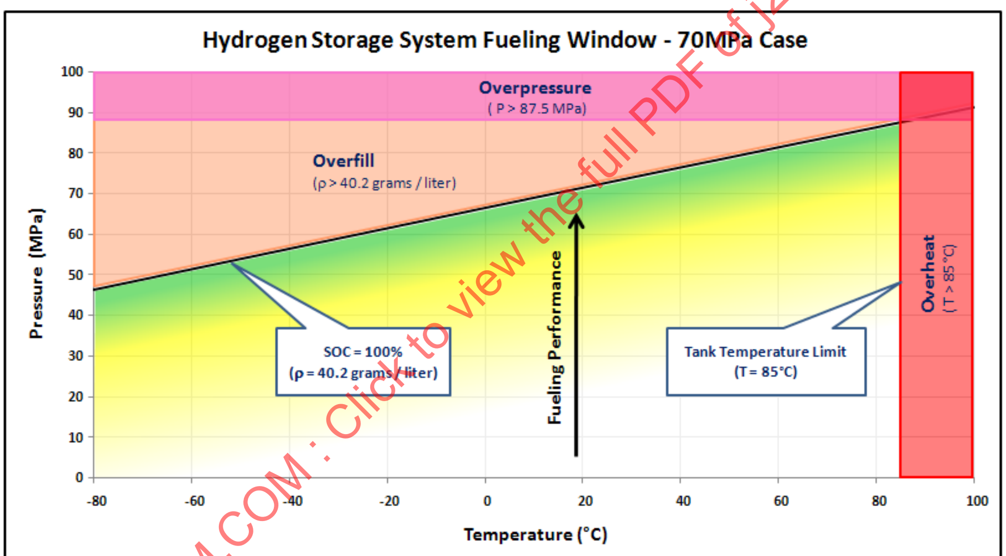


FIGURE 3 - OPERATING WINDOW OF FUELING PROCESS (70 MPA NWP FUEL SYSTEMS)

5.1.6 In developing this protocol, the maximum total pressure drop from receptacle to HSS was assumed to be less than 20 MPa under the following conditions: a vehicle tank pressure of 10 MPa, a fuel temperature of -15 °C at the nozzle and a mass flow 1.5 times the average mass flow required to fill the entire storage capacity in 3 min (e.g., for a capacity of 5 kg : mass flow = 5000 g/180 s * 1.5 = 41.67 g/s).

5.1.7 Vehicle fuel system in accordance with SAE TIR J2579.

5.1.8 Data communicated from the vehicle to the station dispenser shall follow all protocols specified in SAE J2799.

5.1.9 NOTE: Vehicles and station component selection should consider the applicable ambient conditions in 5.2.1 and the fuel temperature tolerances in Section 6.

5.2 Fueling Process Limits

Fueling dispenser algorithms shall ensure that the fueling process falls within the guidelines of the Fueling Protocol as described in this document. The Fueling Protocol specifies common industry requirements for fueling within the following defined limits.

5.2.1 Ambient temperature range at fueling station ≥ -40 °C and ≤ +50 °C.

5.2.2 No lower bound on the starting pressure or SOC in the vehicle fuel system at the onset of fueling.

5.2.3 $P_{station}$ ≤ 125% NWP of the vehicle fuel system

5.2.4 Station PRV set point = 1.1 x 1.25 x NWP = 1.375 x NWP (SAE J2760)

5.2.5 Station max developed pressure = 1.2 x 1.25 x NWP = 1.5 x NWP (SAE J2760)

5.2.6 Fuel flow rate at dispenser nozzle ≤ 60 g H_2/s (3.6 kg/min)

5.2.7 Hydrogen flow should not be controlled in an on/off manner. No more than 10 complete stops in flow during a fill cycle are allowed (defined as the number of times flow drops to below 1% of the max flow rate). This allowance includes leak checks where required (e.g., NFPA)

5.2.8 The fuel temperature at the dispenser nozzle shall be ≥ -40 °C.

6. DEFINITION OF FUELING STATION DISPENSER TYPES

Fueling dispenser types determine which tables are used for fueling a vehicle fuel system. A fueling station that implements a certain fueling type shall be capable of delivering the fuel at the nozzle within the parameter limits specified in the Fueling Type definition.

If a Fueling dispenser Type is specified for more than one NWP level, then the nomenclature for the Fueling Type shall consist of the letter defining the Fueling Type and the NWP level in MPa (e.g., fueling type “A-70” means the fueling protocol according to Fueling Type “A” at a NWP of 70 MPa).

The Fueling dispenser Type lettering system relates to the pre-cooling capability of the dispenser. “A” represents the coldest fuel delivery and the fastest fueling rates, while “D” represents the absence of cooling capability and slower fueling rates. The following are the fueling type categories for 70 MPa and 35 MPa NWPs.

NOTE: This document assumes components comply with the performance limits specified in the individual component requirements listed in Section 2.

Fueling dispenser types per pressure level as defined below. No other dispenser types are defined or accepted per this document.

70 MPa:
“A” = -40C T_{fuel} Capable Dispenser (-40C ≤ T_{fuel} ≤ -33C)
“B” = -20C T_{fuel}Capable Dispenser (colder of -22.5C or T_{amb} ≤ T_{fuel} ≤ -17.5C)
“C”= 0 C T_{fuel}- Protocol not specified or recommended in this document
“D” = No-Pre-cooling or ambient T_{fuel} - Protocol not specified or recommended in this document

35MPa:
“A” = -40C T_{fuel}Capable Dispenser (-40C ≤ T_{fuel} ≤ -33C)
“B” = -20C T_{fuel}Capable Dispenser (colder of -22.5C or T_{amb} ≤ T_{fuel} ≤ -17.5C)
“C” = 0 C T_{fuel}Capable Dispenser (colder of -2.5C or T_{amb} ≤ T_{fuel} ≤ 2.5C)
“D” = No-Pre-cooling or ambient T_{fuel} Capable Dispenser (protocol development based on T_{fuel} = T_{amb} ±5C)

The pre-cooling temperature (T_{fuel}) is the temperature at the nozzle outlet within the tolerances specified above. This temperature should be reached within 15 s after the start of the fueling ramp, and maintained on a mass-averaged-basis over any 30 s period. For type “B” and “C” stations, if the ambient temperature, T_{amb}, is less than the pre-cooler set temperature, it is assumed that $T_{fuel} = T_{amb}$. Each fueling type will have a corresponding “look-up table” for fueling parameters based on key inputs such as ambient temperature, measured initial pressure of HSS, and measured capacity category of HSS (see 3.1).

Adherence of the dispenser to this protocol must be confirmed with the CSA 4.3 HDTA prior to general customer fueling.

7. COMMON PROCEDURES FOR COMPRESSED HYDROGEN FUELING

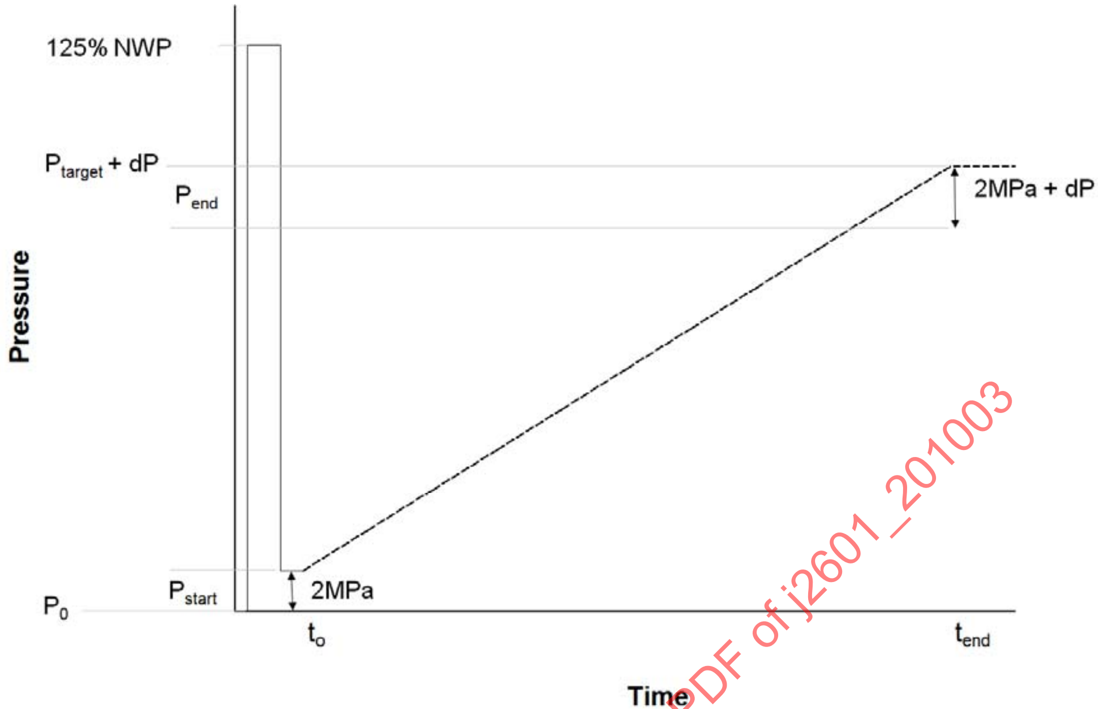
7.1 Fueling Diagram: Tolerance of Ramp Rate

7.1.1 Fueling is to be conducted according to the illustration in Figure 4. The reference pressures are measured from $P_{station}$. The fueling diagram and tolerances specify the operating bandwidth for the fueling process. The ramp rate is shown with no tolerance as the allowable deviation has two separate requirements. The first ramp rate tolerance is a tolerance on ramp rate measured over any 10 s interval of the fueling process. This is to allow for larger deviation during station storage bank cascade switches or compressor start-ups. The second ramp rate tolerance is the overall tolerance on the average ramp rate when measured from t_0 to any time t during fueling. This tolerance is to ensure the fueling time and ramp rate meet the requirements of the fueling tables (Sections 8 and 9).

7.1.1.1 In the stated hourly capacity of the station is exceeded, slower than normal fueling speeds may produce a lower ending tank temperature and consequently a higher ending tank SOC than the models predict for a given station type. If, in this case, the flow speed drops below the allowed 90% of $APRR_{target}$ (7.1.2.4), the control system must compensate for lower ending fill temperature by setting P_{target} of 80% NWP instead of that listed in Tables 8-1 to 8-8. This ensures that the dispenser will conform to Section 5 limits. Further, the non-standard filling conditions may result in longer fueling times and lower SOCs (from those in Appendix B).

7.1.2 It should be noted that there is a difference between pressure ramp rate as controlled by the dispenser and the actual vehicle pressure ramp rate. (Note that the pressure difference is subject to vehicle design and condition.)

The fueling corridor has 3 stages, each with parameters specified below.



7.1.2.1	P_0 = Initial Pressure
7.1.2.2	$P_0 \leq P_{start} \leq P_0$ + 2MPa
7.1.2.3	P_{target} - 2MPa $\leq P_{end} \leq P_{target}$ +dP
7.1.2.4	$APRR_{actual} = APRR_{target}$ +/- 10%, when measured from t_0 to any intermediate time t when t $\geq$ 15 sec
7.1.2.5	$APRR_{actual} = APRR_{target}$ +0/- 10%, when measured over entire fueling
7.1.2.6	$t_{end} = t_0 + (P_{end}-P_{start})/APRR_{actual}$
7.1.2.7	If leak checks performed during fueling, total leak check time shall not

FIGURE 4 - FUELING DIAGRAM WITH TOLERANCES

7.2 Stage 1: Initial Integrity / Volume Pressure Pulse

The fueling station dispenser can receive tank volume through the SAE J2799 communication from the vehicle. The station uses a pressure pulse with maximum pressure of 125% NWP and maximum flow rate of 60 g/s to measure initial vehicle tank pressure, P_0, and verify that it is below the Fueling Pressure Target, P_{target} specified in Section 8. The amount of fuel transferred during the pressure pulse must be such that the vehicle pressure at the start of fill, P_{start}, is no more than 2 MPa greater than the pressure before the pulse, P_0 (7.1.2.1). During this time, there is a leak tightness integrity check as per NFPA 52 (US) or other applicable code. A combination of pressure pulses and/or flow rate measurements may also be used to measure and calculate tank volume and capacity to reference in fueling table look-up. The time to perform these measurements and calculations should be minimized.

For the vehicle volume calculation test (with tanks in parallel), the dispenser expects that the total 'cracking pressure' (i.e., pressure required to open check valves, etc.) of the fuel system is less than approximately 0.3 MPa. It is understood that there is no way to differentiate between the volumes of onboard multiple tanks versus a single tank.

Percent Accuracy in Tank Volume Measurement (Capacity) must be within ±10% total. This is to be confirmed with CSA HGV 4.3. As the document evolves, it is intended to have a lower tolerance band for those utilizing this methodology.

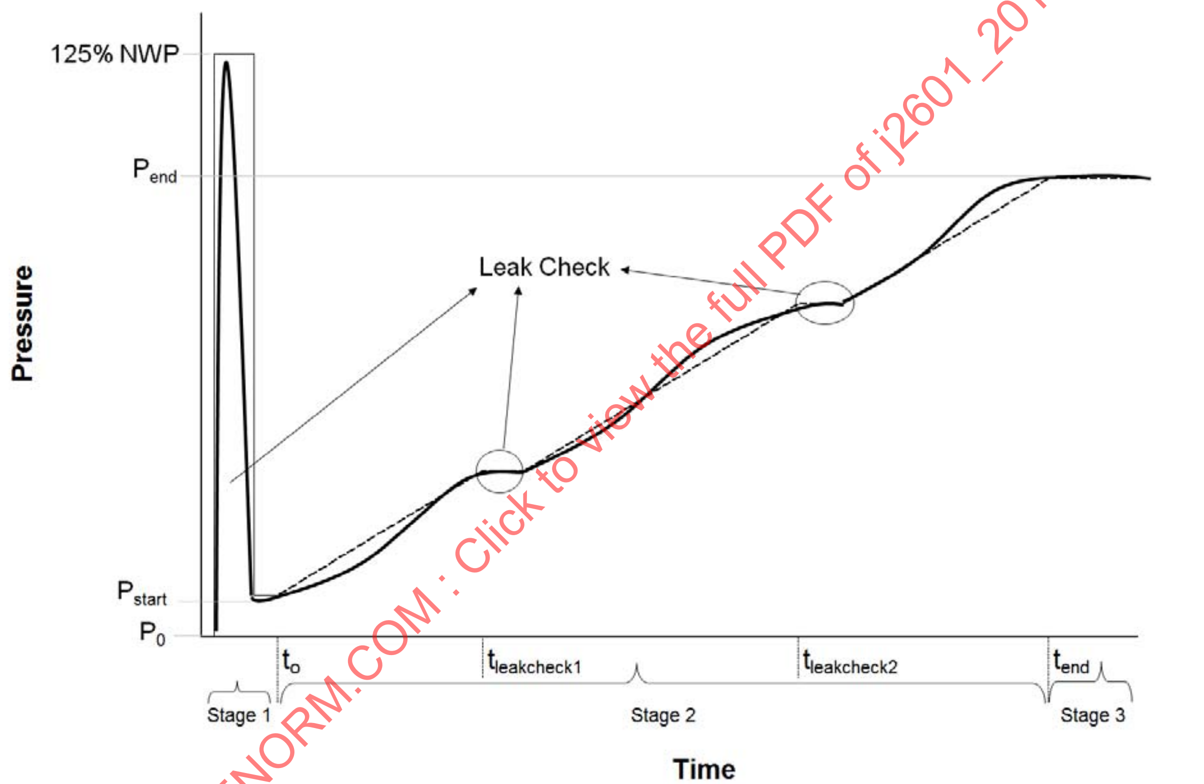
The acceptable accuracy for dispenser pressure sensors is specified in HGV CSA 4.1.

7.3 Stage 2: Average Pressure Ramp Rate Within Tolerances

Fueling is to proceed at the average pressure ramp rate defined by the look-up table per dispenser type:

7.3.1 Due to concerns with over-heating and over-density, the actual average pressure ramp rate between start of fueling and any intermediate time cannot vary from the average pressure ramp rate specified in Section 8 and 9 by more than 10% (7.1.2.4).

7.3.2 Figure 5 shows an example of a fueling process that satisfies the Fueling Protocol Diagram (the reference pressures are measured from $P_{station}$). It includes an initial pressure pulse to determine the initial pressure in the vehicle fuel system; the initial pressure pulse is limited by the mass flow limit (5.2.5). This pulse can also used for the initial leak test that confirms the nozzle/receptacle seal. Also included are two leak tightness checks, during which the flow is stopped to allow pressure equalization and leak measurement of the fueling system. The changing gas pressure is illustrated during the subsequent fueling stages, across which the average pressure ramp rate, $APRR_{actual}$, that defines the diagram specified in 7.1, is achieved.



1 $P_0 \leq P_{start} \leq P_0 + 2MPa$

2 $P_{target} - 2MPa \leq P_{end} \leq P_{target} + dP$

3 $APRR_{actual} = APRR_{target}$ +/- 10%, when measured from t_0 to any intermediate time t when t ≥ 15 sec and not including $t_{leakcheck}$

4 $t_{end} = t_0 + (P_{end} - P_{start})/APRR_{actual} + t_{leakcheck1} + t_{leakcheck2}$

5 $t_{leakcheck1} + t_{leakcheck2} \leq 30$ sec

FIGURE 5 - EXAMPLE OF A FUELING PROCESS THAT SATISFIES THE FUELING PROTOCOL

7.4 Stage 3: Completion of Fueling

Completion of fueling is at $P_{end} = P_{target} - \Delta P_{station}$ +0 MPa/ -2 MPa + dP. NOTE: P_{end} can be adjusted to compensate for the pressure drop (dP) between pressure measurement and actual tank pressure, so long as this compensation occurs within the allowed tolerance for APRR plus allotted time for leak checks ($t_{leak\ check}$), i.e., $t_{end} = t_0 + (P_{end}-P_{start})/APPR_{actual} + t_{leak\ check}$. (NOTE: dP, as utilized above, is the pressure drop at the end of fueling, not the 20 MPa as specified in 5.1.5. Only the momentary pressure drop, dP, at the end of fueling should be compensated. The pressure overshoot to account for dP should be no greater than 2 MPa.

7.5 General Fueling Guidance

7.5.1 T_{Fuel}, as defined in Section 6 and utilized in the tables in Section 8, is the value of the gas temperature at the dispenser nozzle. The allowed tolerances can be found in Section 6. NOTE: There will be an initial time delay before the T_{Fuel} meets the specified values. This time delay is dependent on dispenser design and fueling frequency, but must be kept within 15 s under all conditions.

7.5.2 The Fueling Procedure for communication fueling is specified to provide a fueling as close as possible to 100% SOC within the limits of chapter 5 and specified Fueling Time ($t_{fueling}$).

7.5.3 The Fueling Procedure for non-communication fueling is specified to provide fueling within the limits of chapter 5 under all potential ambient and vehicle conditions that may occur at a dispenser

7.5.4 The Fueling Pressure Target, P_{target}, is specified to prevent over-pressurization (> 125% NWP) and over-filling (>100% SOC) of the vehicle fuel system. The maximum fueling pressure varies with the temperature of the hydrogen as shown in Figure 3.

8. NON-COMMUNICATION FUELING PROCEDURE

SAE TIR J2601 defines a “tables-based” approach for non-communications fueling. The purpose is to optimize performance for each fueling type (or hydrogen dispenser cooling capability). See Section 6 for fueling types for both 35 and 70MPa.

This approach utilizes the ambient temperature measured at the station (T_{amb}, as defined in 3.3.1), the initial measured pressure in the HSS (P_0), and the and the capacity of the HSS (calculated based on station measurement) to ‘look-up’ the associated average pressure ramp rate and target fill pressure to be utilized in control algorithms.

There are also “Extreme case” state of charge tables for each fueling type in Appendix B. These tables, which are to be used in the station dispenser confirmation process (CSA HGV 4.3), provide the lower bound on the expected SOCs when the protocol is applied.

These tables were developed from a multiple OEM/ Hydrogen Fueling Provider joint subteam of SAE TIR J2601 and CSA HGV 4.3. This was an open cross-industry effort put forth from this team to understand the fueling extremes and to encompass the full range of “real world” OEM onboard hydrogen storage systems. An exhaustive modeling table was created based on the hydrogen capacity categories (reference 3.1) and validated with testing of representative containers.

The following are the steps to be taken in utilizing the look-up tables.

8.1 If communication signal is present, then defer to communication fueling procedure (Section 9).

8.2 If the station receives an “abort” signal from the vehicle, then the station should stop fueling, regardless of whether the fueling mode was non-communication or communication

8.3 Fuel Delivery Temperature (T_{fuel}) should be in accordance to Fueling Type (as per Section 6)

8.4 Measure Ambient Temperature (T_{amb}) with temperature sensor on station within tolerance of ±0.5 °C.

8.5 Measure Initial HSS Pressure, P_0, with a Pressure Pulse from the Dispenser (Section 7)

Estimate HSS Capacity with a pressure pulse(s) and/or mass flow measurements from the dispenser. The dispenser is to convert the measured tank volume into mass capacity to determine the appropriate look-up table for APRR and target pressure

8.6 Use look-up tables to determine the Average Pressure Ramp Rate ($APRR_{target}$) and the Fueling Target Pressure, P_{target}, according to non-communication fueling table numbers (8-1 to 8-8). Table choice is based on Fueling Type and HSS Capacity. Parameter look-up within the table is based on ambient temperature and Initial tank pressure. Linear interpolation should be used to derive actual parameters from table values. This will be one-dimensional interpolation for the $APRR_{target}$ (based on ambient temperature) and two-dimensional interpolation for the target pressure (based on ambient temperature and initial HSS pressure) or extrapolation if P_0 is below 2 MPa. This is explained in more detail in Appendix D.

If the initial tank pressure exceeds the fueling target pressure corrected for measurement uncertainty (e.g., if $P_0 > P_{target} - \Delta P_{station}$), no fuel should be dispensed.

8.6.1.1 Initiate fueling within tolerances as described in Section 7 with Fuel Delivery Temperature T_{fuel} as specified in Section 6.

8.6.1.2 Continuously monitor $P_{station}$.

8.6.1.3 Terminate fueling as per 7.4.

8.6.2 See Appendix D for example of table interpolation. Note: If one of the interpolation values is in the "no fueling" zone of the table, then the dispenser should not fuel the vehicle.

8.7 Non-communication Look-Up Tables

Non-Communication Fueling Table 8-1

Type A-70 Fueling Ramp Rates and Pressure Targets for HSS with capacity 1-7 kg

A-70 1-7kg	**Average Pressure Ramp Rate, APRR (MPa/min)**	**Fueling Target Pressure, P_{target} (MPa)**										
		Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)		**2**	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**70**	**> 70**
> 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
50	11.4	73.5	73.2	73.0	72.8	72.6	72.4	72.2	72.0	71.9	72.2	no fueling
45	15.7	73.9	73.6	73.3	73.0	72.8	72.5	72.3	72.0	71.8	72.1	no fueling
40	19.8	74.2	73.9	73.6	73.2	73.0	72.6	72.2	72.0	71.8	72.0	no fueling
35	23.7	74.5	74.1	73.6	73.3	73.1	72.7	72.3	72.0	71.8	72.0	no fueling
30	27.4	74.1	73.8	73.2	72.7	72.5	71.9	71.4	71.0	70.6	71.0	no fueling
25	28.2	73.6	73.3	72.6	72.3	71.7	70.9	70.4	69.9	69.3	no fueling	no fueling
20	28.2	73.2	72.8	72.0	71.4	71.0	70.0	69.3	68.7	68.2	no fueling	no fueling
10	28.2	72.0	71.5	70.6	70.0	69.4	68.2	67.2	66.5	65.8	no fueling	no fueling
0	28.2	70.9	70.3	69.3	68.5	67.9	66.4	65.2	64.0	63.5	no fueling	no fueling
-10	28.2	69.8	69.2	67.9	67.1	66.1	64.4	63.0	61.6	no fueling	no fueling	no fueling
-20	28.2	68.9	67.9	66.6	65.5	64.3	62.4	60.7	59.1	no fueling	no fueling	no fueling
-30	28.2	67.8	66.7	65.2	63.7	62.5	60.4	58.3	56.4	no fueling	no fueling	no fueling
-40	28.2	67.3	66.5	65.0	63.7	62.5	60.1	58.3	56.4	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

Non-Communication Fueling Table 8-2

Type B-70 Fueling Ramp Rates and Pressure Targets for HSS with capacity 1-7 kg

B-70 1-7kg	Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)										
		Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)		2	5	10	15	20	30	40	50	60	70	> 70
> 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
50	1.8	75.8	75.4	74.8	74.4	74.0	73.4	73.0	72.7	72.6	72.4	no fueling
45	2.5	75.0	74.6	74.1	73.7	73.4	72.9	72.7	72.6	72.5	72.3	no fueling
40	3.4	74.5	74.1	73.7	73.3	73.1	72.7	72.6	72.6	72.4	72.3	no fueling
35	4.4	74.2	73.8	73.4	73.1	72.9	72.7	72.6	72.5	72.4	72.3	no fueling
30	5.5	73.6	73.3	72.8	72.5	72.2	71.9	71.7	71.5	71.2	no fueling	no fueling
25	6.7	73.2	72.8	72.2	71.8	71.5	71.1	70.8	70.4	70.0	no fueling	no fueling
20	7.9	72.7	72.3	71.7	71.3	70.9	70.3	69.8	69.3	68.8	no fueling	no fueling
10	10.7	72.0	71.5	70.8	70.2	69.6	68.7	67.8	67.0	66.3	no fueling	no fueling
0	13.6	71.4	70.8	69.8	69.0	68.3	67.0	65.8	64.6	63.6	no fueling	no fueling
-10	13.6	70.1	69.4	68.4	67.4	66.5	65.0	63.6	62.2	61.1	no fueling	no fueling
-20	13.6	68.9	68.1	66.8	65.8	64.7	62.9	61.2	59.5	no fueling	no fueling	no fueling
-30	13.6	67.7	66.7	65.3	64.1	62.8	60.7	58.6	56.8	no fueling	no fueling	no fueling
-40	13.6	67.3	66.4	65.0	63.8	62.6	60.6	58.7	56.8	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

Non-Communication Fueling Table 8-3

Type A-70 Fueling Ramp Rates and Pressure Targets for HSS with capacity 7-10 kg

A-70 7-10kg	Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)										
		Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)		2	5	10	15	20	30	40	50	60	70	> 70
> 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
50	9.2	74.3	74.0	73.7	73.4	73.1	72.7	72.3	72.0	71.9	72.1	no fueling
45	12.3	74.7	74.3	73.9	73.6	73.3	72.8	72.3	72.0	71.8	72.1	no fueling
40	15.3	74.9	74.6	74.1	73.8	73.4	72.8	72.3	71.9	71.9	72.1	no fueling
35	18.0	75.0	74.7	74.3	73.9	73.5	72.9	72.3	72.0	71.8	72.1	no fueling
30	19.4	74.7	74.3	73.7	73.1	72.8	71.9	71.3	71.0	70.6	70.9	no fueling
25	19.4	74.2	73.8	73.1	72.5	72.0	71.2	70.4	69.9	69.5	no fueling	no fueling
20	19.4	73.6	73.2	72.5	71.8	71.2	70.2	69.4	68.8	68.3	no fueling	no fueling
10	19.4	72.5	72.0	71.1	70.4	69.7	68.4	67.3	66.5	65.8	no fueling	no fueling
0	19.4	71.4	70.7	69.7	68.8	68.0	66.4	65.1	64.2	63.4	no fueling	no fueling
-10	19.4	70.3	69.6	68.4	67.3	66.3	64.5	63.0	61.7	60.9	no fueling	no fueling
-20	19.4	69.3	68.4	67.1	65.7	64.6	62.4	60.6	59.1	no fueling	no fueling	no fueling
-30	19.4	68.2	67.1	65.5	64.0	62.7	60.4	58.2	56.4	no fueling	no fueling	no fueling
-40	19.4	67.8	66.8	65.4	63.9	62.6	60.2	58.2	56.4	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

Non-Communication Fueling Table 8-4

Type B-70 Fueling Ramp Rates and Pressure Targets for HSS with capacity 7-10 kg

B-70 7-10kg	Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)										
		Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)		2	5	10	15	20	30	40	50	60	70	> 70
> 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
50	1.6	75.6	75.3	74.8	74.3	74.0	73.4	73.0	72.8	72.5	72.4	no fueling
45	2.3	75.0	74.7	74.2	73.9	73.6	73.1	72.9	72.7	72.4	72.3	no fueling
40	3.1	74.7	74.4	74.0	73.7	73.4	73.1	72.8	72.6	72.4	72.3	no fueling
35	4.0	74.7	74.4	74.0	73.7	73.4	73.1	72.9	72.6	72.3	72.3	no fueling
30	4.9	74.3	73.9	73.5	73.1	72.8	72.3	71.9	71.5	71.2	no fueling	no fueling
25	5.9	73.9	73.5	73.1	72.6	72.2	71.6	71.0	70.4	70.0	no fueling	no fueling
20	7.0	73.6	73.2	72.6	72.1	71.6	70.8	70.0	69.3	68.8	no fueling	no fueling
10	9.3	73.1	72.6	71.8	71.1	70.4	69.1	68.0	67.0	66.3	no fueling	no fueling
0	11.7	72.6	71.9	70.9	69.9	69.1	67.4	65.9	64.6	63.7	no fueling	no fueling
-10	11.7	71.4	70.6	69.4	68.3	67.3	65.4	63.6	62.1	61.0	no fueling	no fueling
-20	11.7	70.2	69.3	68.0	66.7	65.4	63.2	61.2	59.5	no fueling	no fueling	no fueling
-30	11.7	69.0	67.9	66.5	65.0	63.5	61.0	58.7	56.8	no fueling	no fueling	no fueling
-40	11.7	68.6	67.6	66.1	64.7	63.4	60.9	58.7	56.8	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

Non-Communication Fueling Table 8-5

Type A-35 Fueling Ramp Rates and Pressure Targets

A-35	Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)							
		Initial Tank Pressure, P_0 (MPa)							
Ambient Temperature, T_{amb} (°C)		2	5	10	15	20	30	35	> 35
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	15.1	36.8	36.7	36.5	36.4	36.2	35.9	36.0	no fueling
45	15.1	36.8	36.7	36.5	36.4	36.2	35.9	36.0	no fueling
40	15.1	36.7	36.5	36.4	36.2	36.2	35.9	36.0	no fueling
35	15.1	36.5	36.4	36.4	36.2	36.1	35.8	36.0	no fueling
30	15.1	36.3	36.2	36.0	35.9	35.7	35.3	35.4	no fueling
25	15.1	35.9	35.8	35.5	35.4	35.2	34.7	no fueling	no fueling
20	15.1	35.7	35.4	35.2	35.0	34.8	34.1	no fueling	no fueling
10	15.1	35.1	34.8	34.4	34.1	33.8	32.9	no fueling	no fueling
0	15.1	34.5	34.1	33.6	33.2	32.7	31.7	no fueling	no fueling
-10	15.1	33.8	33.4	32.9	32.2	31.6	30.4	no fueling	no fueling
-20	15.1	33.2	32.7	32.0	31.2	30.5	no fueling	no fueling	no fueling
-30	15.1	32.6	32.0	31.1	30.3	29.3	no fueling	no fueling	no fueling
-40	15.1	32.4	31.9	31.0	30.3	29.3	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

Non-Communication Fueling Table 8-6

Type B-35 Fueling Ramp Rates and Pressure Targets

B-35		Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)							
			Initial Tank Pressure, P_0 (MPa)							
			2	5	10	15	20	30	35	> 35
Ambient Temperature, T_{amb} (°C)	> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	4.4	37.1	37.0	36.7	36.6	36.5	36.3	36.1	no fueling
	45	6.1	37.2	37.0	36.8	36.7	36.6	36.2	36.1	no fueling
	40	7.8	37.3	37.1	36.9	36.7	36.6	36.2	36.1	no fueling
	35	9.6	37.4	37.2	37.0	36.8	36.7	36.2	36.1	no fueling
	30	11.3	37.2	37.0	36.7	36.5	36.3	35.6	35.5	no fueling
	25	12.9	37.1	36.8	36.4	36.2	35.9	35.0	no fueling	no fueling
	20	14.6	36.9	36.6	36.2	35.9	35.4	34.3	no fueling	no fueling
	10	15.1	36.3	35.9	35.4	34.9	34.4	33.0	no fueling	no fueling
	0	15.1	35.7	35.3	34.7	34.0	33.3	31.7	no fueling	no fueling
	-10	15.1	35.1	34.6	33.8	33.1	32.2	30.4	no fueling	no fueling
	-20	15.1	34.4	33.8	33.0	32.1	31.0	no fueling	no fueling	no fueling
	-30	15.1	33.3	32.6	31.7	30.8	29.5	no fueling	no fueling	no fueling
	-40	15.1	32.4	31.9	31.0	30.3	29.3	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

Non-Communication Fueling Table 8-7

Type C-35 Fueling Ramp Rates and Pressure Targets

C-35		Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)							
			Initial Tank Pressure, P_0 (MPa)							
			2	5	10	15	20	30	35	> 35
Ambient Temperature, T_{amb} (°C)	> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
	50	1.0	38.4	38.1	37.6	37.2	36.9	36.5	36.2	no fueling
	45	1.4	38.0	37.7	37.3	37.0	36.8	36.5	36.2	no fueling
	40	1.9	37.8	37.5	37.2	36.9	36.7	36.5	36.2	no fueling
	35	2.4	37.7	37.4	37.1	36.9	36.7	36.5	36.2	no fueling
	30	3.0	37.4	37.1	36.7	36.5	36.3	35.9	35.6	no fueling
	25	3.7	37.1	36.7	36.3	36.1	35.9	35.3	no fueling	no fueling
	20	4.3	36.8	36.5	36.0	35.7	35.4	34.6	no fueling	no fueling
	10	5.7	36.3	35.9	35.4	34.9	34.5	33.3	no fueling	no fueling
	0	7.2	35.9	35.4	34.7	34.2	33.6	31.9	no fueling	no fueling
	-10	7.2	34.7	34.2	33.5	32.9	32.2	30.5	no fueling	no fueling
	-20	7.2	33.4	32.9	32.2	31.5	30.8	no fueling	no fueling	no fueling
	-30	7.2	32.0	31.5	30.8	30.1	29.4	no fueling	no fueling	no fueling
	-40	7.2	31.2	30.8	30.2	29.7	29.1	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

Non-Communication Fueling Table 8-8

Type D-35 Fueling Ramp Rates and Pressure Targets

D-35	Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)							
		Initial Tank Pressure, P_0 (MPa)							
Ambient Temperature, T_{amb} (°C)		2	5	10	15	20	30	35	> 35
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	0.3	41.2	40.9	40.2	39.4	38.7	37.2	36.4	no fueling
45	0.3	40.6	40.1	39.4	38.7	38.1	36.9	36.4	no fueling
40	0.5	39.9	39.5	38.8	38.2	37.6	36.7	36.4	no fueling
35	0.7	39.3	38.9	38.3	37.7	37.3	36.7	36.3	no fueling
30	0.9	38.6	38.2	37.5	37.0	36.6	36.0	35.6	no fueling
25	1.3	38.0	37.5	36.9	36.4	36.0	35.4	no fueling	no fueling
20	1.8	37.3	36.9	36.3	35.8	35.4	34.8	no fueling	no fueling
10	3.4	36.3	35.8	35.2	34.8	34.4	33.4	no fueling	no fueling
0	6.4	35.6	35.1	34.5	34.0	33.4	31.9	no fueling	no fueling
-10	10.4	35.0	34.5	33.7	33.1	32.3	30.5	no fueling	no fueling
-20	15.1	34.3	33.7	32.8	32.0	31.0	no fueling	no fueling	no fueling
-30	15.1	33.0	32.4	31.4	30.5	29.4	no fueling	no fueling	no fueling
-40	15.1	32.4	31.9	31.0	30.3	29.3	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

NOTE: There is a known issue for non-communications fueling: Though fueling history is taken into account for individual pressure levels, using a 70 MPa dispenser directly after fueling with a 35 MPa dispenser could cause overheating of tank and should be prohibited. It is recommended that both the OEM and fueling station provide customer guidance to avoid this condition.

(Fueling a 70 MPa system at a 35 MPa dispenser has been comprehended in the protocol development; only the interaction between 35 MPa and 70 MPa protocols is a concern)

9. COMMUNICATION FUELING PROCEDURE

For the communication procedure, all Fueling Commands, Communications Hardware, etc. are to be according to SAE J2799.

If a station has communication fueling capability, the Fueling Dispenser shall be capable of fueling vehicles with and without communication between the vehicle and dispenser.

NOTE: Static communication protocols have not been defined yet in this document. Until protocols are defined, only dynamic communication and non-communication modes are to be applied by the dispenser.

Communication fueling is intended to give a higher SOC and potentially faster fueling times with the method below. Communications target SOC range is to be 95% < $SOC_{station} \leq$ 100%. Communication fueling is also used to give assurance to the OEM related to fueling procedure, and allows the vehicle to "abort fueling."

As per Figure 2, there are two possibilities given in this document for fueling rates for communications:

9.1 It is intended for communication fueling to utilize the same non-communication ramp rates as per Section 8 as a 'Default' or develop an alternative (ALT) strategy that provides an acceptable SOC (by Appendix B) with the same or shorter fueling duration. If the non-communication APRR values are utilized for communications fueling, linear interpolation should be used to extract ramp rates from the look-up tables. See Appendix D for illustrations of table interpolation. NOTE: If one of the interpolation values is in the "no fueling" zone of the table, then the dispenser should not fuel the vehicle

9.2 General Communication Fueling Procedure: Fuel Delivery Temperature (T_{fuel}) according to Fueling Type (as per Section 6)

9.2.1 Receive and validate data communicated from the vehicle as described in SAE J2799.

9.2.2 Respond to Fueling Commands transmitted from the vehicle as specified in SAE J2799

9.2.3 If communication fails, defer to non-communication procedure in Section 8, except for the ALT communication cases for dispenser types B, C and D. Note: it is advised to cease fueling if there is a break in communications for ALT fueling. .

9.2.4 Measure the initial HSS pressure, P_0, and compare to communicated value as confirmation of vehicle data.

9.2.5 If the initial tank parameters or the calculated initial SOC exceed the fueling limits then no fuel should be dispensed. There is no need for the station to add safety margins in utilizing vehicle data. The vehicle OEM should consider the tolerances of the temperature measurement by the vehicle and include as criteria for the abort signal.

9.2.6 Initiate Fueling as described in Section 7 with Fuel Delivery Temperature T_{fuel} as specified in Section 6.

9.2.7 Continuously monitor $P_{station}$, the pressure at the dispenser nozzle, as well as vehicle data parameters. Terminate fueling when one of the following conditions occurs: $P_{station} + \Delta P_{station} = 125\%$ NWP, calculated SOC = 100%, tank temperature limit is reached.

9.2.8 If the station receives an "abort" signal from the vehicle, then the station should stop fueling, regardless of whether the fueling mode was non-communication or communication

9.3 The two communication methodologies are described further in detail as follows:

9.3.1 The 'Communications Default Rate': utilizes identical APRR values as in the non-communications tables in 8.5 for all dispenser types (A-D), but the end pressure is based on density calculations using the transmitted vehicle temperature data.

9.3.2 The 'Communications ALT Rate' is a second option that can be authorized by the vehicle as an alternative to utilizing the default non-communications ramp rate for communication fueling. However, the alternative (ALT) rate, for 'A' type dispensers is identical to 9.3.1. This alternative (ALT) communications fueling methodology has the potential to offer improved communications fueling rates for type B (35 and 70MPa) and types C and D (only 35 MPa) stations.

9.3.3 The adherence of Dispensers to this protocol must be confirmed with the CSA HGV 4.3 Hydrogen Dispenser Test Apparatus (HDTA) prior to general customer fueling unless prior approval is obtained from the automaker utilizing the station.

9.3.4 Criteria for ALT Communication Ramp Rates for type B, C, or D dispensers

9.3.4.1 Positive confirmation of ALT-approved vehicle by dispenser

9.3.4.2 CSA HGV 4.3 Hydrogen Dispenser Test Apparatus (HDTA) confirmation data – Section 10

9.3.4.3 Fueling duration less than or equal to non-communication case under all conditions for the corresponding station type (B, C or D)

9.3.4.4 Dispenser appropriately responds to all vehicle signals per SAE J2799

9.3.4.5 If communications were to fail for types B, C or D, it is recommended the fueling shall cease and not restart, This is due to the concern that there may be no fallback to non-communications mode due to over temperature concerns.

9.3.4.6 Appendix F tables are an example of ALT initial ramp rates.

10. PERFORMANCE TESTS TO VERIFY COMPLIANCE WITH FUELING PROTOCOLS

The adherence of a fueling dispenser to the fueling protocol specified in this document should be verified by CSA HGV 4.3. The performance tests are designed to demonstrate that the protocol is followed under all conditions. Specifically, they are designed to demonstrate that fuel is delivered within the specified temperature range, at the specified ramp rate and up to the specified pressure target. Under the test conditions the test tanks will be successfully fueled within the temperature and pressure limits.

At this time, each dispenser installed wishing to comply with SAE J2601 must be tested according to CSA 4.3. In the future, type certification may be available.

Compliance to SAE J2601 is defined as verification by using CSA HGV 4.3 test procedure, which could include a "J2601 Compliant A70, B70, A35, etc" stamp, sticker, plate, etc. to display on the station.

10.1 Acceptance Criteria of Performance Tests for the Hydrogen Dispenser Test Apparatus

10.1.1 For non-communications fueling, the protocol in Section 8 is to be utilized. The dispenser should demonstrate capability to meet the specified average pressure ramp rates and stop at the specified pressure targets. SOC should be at least as good as the lower bound in the Appendix B tables

10.1.2 For communications protocol, Section 9 is to be used as reference.

10.1.3 Dispenser performance verification tests and testing equipment specification are contained within the CSA HGV 4.3 TIR guideline.

10.1.4 HSS Upper Temperature, Pressure and SOC Limits (as per chapter 5) shall not be exceeded during a fueling. Such a condition will result in a non-conformance to SAE TIR J2601.

10.1.5 For the 'Default APRR' Pressure vs. Fueling Time should fall within the tolerances described in Section 7, as per example in Figure 5.

10.1.6 Performance results are defined as "In Range" when:

10.1.6.1 For communications: $95\% < SOC_{station} \leq 100\%$ and non-communications: Appendix B $SOC < SOC \leq 100\%$

10.1.6.2 $APRR_{actual}$ to stay within the tolerances described in Section 7

10.1.6.3 NFPA 52 states that there must be a leak check every 3600 psi (25 MPa). It was decided by the SAE J2601 taskforce that an additional tolerance (above the APRR table tolerances) shall be given regarding fueling time of +30 s to account for the potential three leak checks (in the case of 70 MPa) at 10 s each. Although the fueling duration includes leak checks, $APRR_{actual}$ is calculated with time taken for leak checks, t_{leak_check}, excluded.

10.1.6.4 The fueling station capacity measurement is to be within ±10% of total tank system actual volume. The intent is to ensure that the dispenser has the capability to accurately measure the 70 MPa and 35 MPa capacity categories and limits.

10.1.7 If there are other fueling methodologies developed in the field that meet the Section 5 requirements in TIR J2601 and are demonstrated by CSA HGV 4.3, it is requested that the CSA HGV 4.3 confirmation data be brought to the SAE Interface team for subsequent team review and potential inclusion in future documents.

10.1.8 The following table in Figure 6 shows a 'check-list' for applicable requirements per fueling type: Non-communication; Default Communications; and Alternative (ALT) Communications methodologies. It is meant to be an overview to applicable sections in the document.

	Non-Communication	Default Communication	ALT Communication
X.X No fueling when T_{amb} < -40 °C or T_{amb} > 50 °C	•	•	•
5.1.1 Max Pressure ≤ 125% NWP	•	•	•
5.1.2 Gas temperature in HSS ≤ 85 °C	•	•	•
5.1.3 Gas density in vehicle ≤ 100%	•	•	•
5.1.7 Respond to signals in J2799: • Temperature ≥ 85 °C • Pressure ≥ 125% NWP • SOC(T, P) ≥ 100% • "Pause" • "Abort"	 • 	 • • • • •	 • • • • •
5.2.5 Fuel flow rate ≤ 60 g/s	•	•	•
5.2.6 ≤ 10 complete fueling pauses	•	•	•
7.X Leak check at the beginning of fueling (if required by NFPA 52)	•	•	•
7.1 $P_{start} = P_0$ +2 / -0 MPa	•	•	•
7.1 $P_{end} = P_{target} - \triangle P_{station}$ +0MPa/-2MPa + dP	•		
7.1.1 If $APRR_{actual}$ < 90% $APRR_{target}$, P_{target} = 80% NWP			
7.1.2.4 $APRR_{actual} = APRR_{target}$ +/-10% measured from t_0 to any intermediate time t as long as t ≥ 15 sec and excluding time taken for leak checks, t_{leak_check}	•	•	
7.1.2.5 / 7.3.1 $APRR_{actual} = APRR_{target}$ +0/-10% when measured over entire fueling excluding time taken for leak checks, t_{leak_check}	•	•	
7.2 Tank capacity calculation +/- 10% actual	•	•	•
7.2 Dispenser pressure sensor accuracy follows CSA 4.1	•	•	•
8.4 Linear interpolation is used to determine $APRR_{target}$ when t_{amb} and/or P_0 are not listed in the look-up tables; no fueling when one point in the interpolation is in the "no refueling" zone	•	•	
8.4 Linear interpolation interpolation/extrapolation to determine P_{target} when t_{amb} and/or P_0 are not listed in the look-up tables; no fueling when one point in the interpolation is in the "no refueling" zone	•		
8.4 Terminate fueling if $P_0 > P_{target} - \triangle P_{station}$	•		
9.1 P_{end} = P calculated from station hose pressure and vehicle transmitted temperature corresponding to SOC = 100%		•	•
9.X If communication signal lost or implausible, default to non-comm P_{target} using t_{amb} and P_0 and listen for "Abort" signal		•	
9.2.3X If communication signal lost or implausible AND if "ALT OK" signal received, terminate fueling (type B, C, D only)			•
10.X Calculated SOC_{end} ≤ 100% and ≥ SOC_{min} from App B	•	•	•
10.X Fueling duration ≤ Table Section 8.X7: *[(P_{target} - P_0)/P_{target}]*1.1[(P_{target}-P_0)/($APRR_{target}$*0.9)] + 30 sec	•	•	•

FIGURE 6 - SUMMARY OF REQUIREMENTS PER REFERENCE SECTIONS

11. NOTES

11.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications nor in documents that contain editorial changes only.

PREPARED BY THE SAE FUEL CELL COMMITTEE

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APPENDIX A - FUELING PROTOCOL RATIONALE AND DEVELOPMENT PROCESS

OVER-HEATING PROTECTION (HOT SOAK CASE): FUEL DELIVERY TEMPERATURE AND AVERAGE PRESSURE RAMP RATE FOR NON-COMMUNICATION FUELING

Fuel delivery pre-cooling temperature and pressure ramp rates have been specified to prevent existing and near-term vehicle storage systems from exceeding 85 °C when filled to 100% SOC.

NOTE: Look-up tables were developed with following: Diameter of smallest constriction in the Fueling Connector of 3 mm. SAE J2600 will be updated to define acceptable pressure drop for nozzle/receptacle connection.

Provision for Compressive and Joule-Thomson Heating within Vehicle Storage

The gas temperature in the vehicle storage system increases during fueling due to the heat of compression and the Joule-Thompson heating of the fuel as it is throttled through the system orifices. Different materials/constructions of vehicle storage systems will lead to different degrees of compressive heating during fueling due to differences in heat transfer characteristics, the heat capacity, and storage volume of on-board storage systems.

The fueling protocol in this document is based on an industry-wide determination of extreme-case heating in a vehicle storage system that reflects current storage technology. The extreme-case systems modeled for pressure ramp rate development were carbon composite wrap/polymer liner systems (type IV) with a large-capacity single vessel tank system and a small tank surface-to-volume ratio (see below for details on storage system capacities considered). A high pressure drop in the vehicle's fueling line was assumed to account for a high Joule-Thomson heating effect. For each fuel pre-cooling temperature considered, models were run to determine the fastest possible fueling ramp rate that could fill the storage system from 2 MPa to 100% SOC without exceeding the 85 °C temperature limit and without exceeding the 60 g/s mass flow rate limit. In some cases the resulting ramp rates corresponded to a fill time of less than 3 min; these ramp rates were capped at the 3-min rate to avoid driving excessive requirements into the fueling process. As expected based on real-world fueling experience and fueling tests conducted at laboratories under contract to SAE and the U.S. Department of Energy, the protocols show that 3-min fueling of 70 MPa can be achieved in most cases with -40 °C pre-cooling, and that 3-min fueling cannot be achieved in many cases when the pre-cooling temperature is -20 °C or warmer. Due to the flow rate constraint, 70 MPa systems with a capacity of >7 kg were reduced to a 4.5 min target fueling time.

This protocol was developed for the fueling of type III/IV tanks on road today. If other storage systems on vehicles are utilized, it is recommended that they be evaluated before implementing this protocol.

Initial Tank (Soak) Temperature Assumptions – Non-Communication Fueling

The temperature of the vehicle storage system at the onset of fueling is not available to the dispenser in non-communication fueling. The HSS could potentially be warmer or colder than ambient temperatures because of transport, storage, parking, and other conditions (i.e., on-board package location). The industry-wide consensus on the temperature difference (relative to ambient) or so-called “soak” temperature is shown in Figure A1. The "hot soak" case could result in over-heating the storage system if the dispenser assumes the HSS is at ambient temperatures. The "cold soak" case could result in over-filling the storage system if the dispenser assumes the HSS is at ambient temperatures. In addition, the initial HSS temperature may be even lower than the "cold soak" temperature due to depressurization while driving before fueling. This defueling effect was considered in determining the P_{target} values in Section 8.

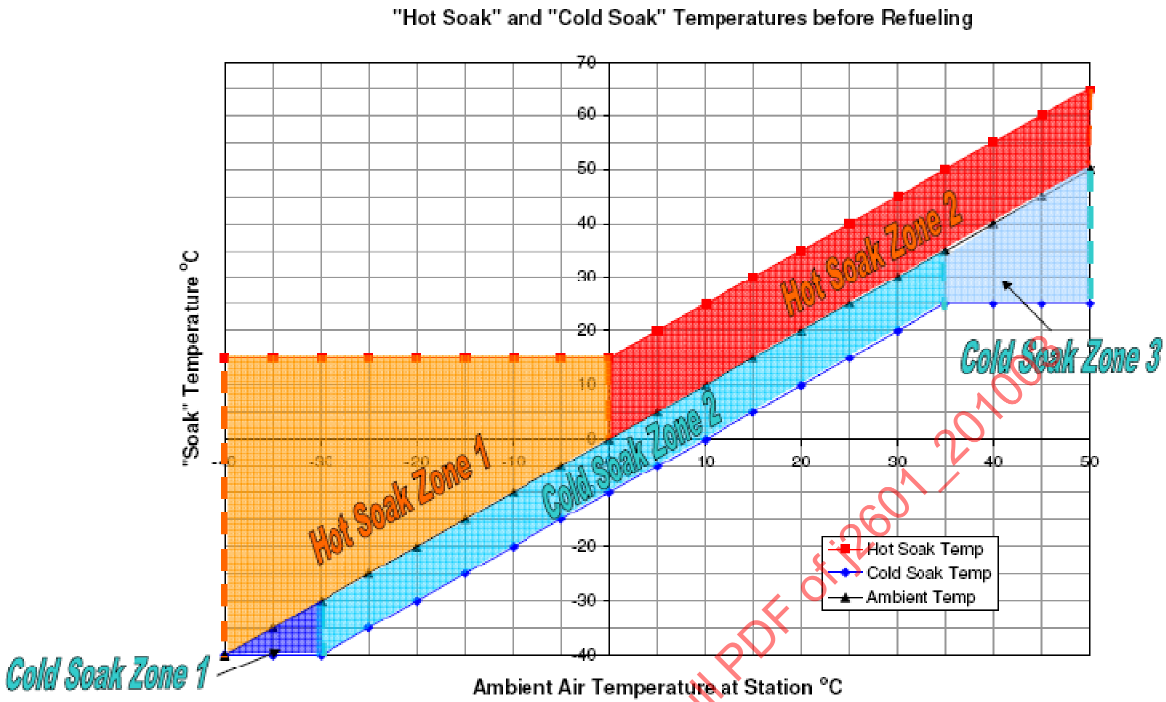

FIGURE A1 - "COLD SOAK" AND "HOT SOAK" ONBOARD STORAGE TEMPERATURES COMPARED TO AMBIENT TEMPERATURE

For non-communication fueling, the protocol was developed based on the soak zone conditions for the specified ambient temperature, as shown in Figure A1. The pressure ramp rates (fill times) were based on the hot soak condition such that vehicle tank temperature will not exceed 85 °C, even where the tank soak temperature at the onset of fueling is at the hot soak temperature. The assumptions for the specified "Hot Soak" and "Cold Soak" Zones are listed in Table A1.

TABLE A1 - ASSUMPTIONS FOR "HOT SOAK" AND "COLD SOAK" ZONES

Temperatures			Assumptions	
Ambient Temp (°C)	Cold Soak Temp (°C)	Hot Soak Temp (°C)	Cold Soak	Hot Soak
-40	-40	15	Cold Soak Zone 1: Vehicle minimum ambient operating temperature of -40 °C.	Hot Soak Zone 1: Vehicle stored in a climate controlled garage at 15 °C.
-30	-40	15	Cold Soak Zone 2: Vehicle is 10 °C colder than ambient due to local climate and storage variations.	
0	-10	15		Hot Soak Zone 2: Vehicle is 15 °C warmer than ambient due to diurnal effects, local climate, and storage variations.
35	25	50		
50	25	65	Cold Soak Zone 3: Vehicle stored in a climate controlled garage or underground parking at 25 °C.	

The temperature effects of fueling history are also unknown to the station dispenser(s). For example, a vehicle that has just been partially fueled may be hotter than even the hot soak line of Figure A1. For this reason, all fuelings were assumed to start from 2 MPa in the protocol development modeling. Heating due to fueling history from station dispenser(s) applying the SAE J2601 protocols may exceed the hot soak temperature, but the SAE J2601 fueling ramp rate applied to this tank will still finish within the temperature limits of ≤85 °C. The entire process in this case can be thought of as a SAE J2601 Non-Communication fueling that started from 2 MPa and was interrupted and then continued to completion.

Pressure Ramp Rate Determination – Non-Communication Fueling

The look-up tables provide the pressure ramp rates for a range of ambient temperatures, including the hot soak condition of the HSS. In developing the table, the following assumptions were made concerning station operation

1. A dispenser will always cool the hydrogen fuel to the greatest extent possible. For example, a dispenser capable of -40 ºC will deliver fuel in the -40 to -33 ºC pre-cooling range, regardless of ambient conditions.

2. A dispenser will hold the temperature at the nozzle within a tolerance as per Section 6. This means that a dispenser capable of -40 ºC will deliver fuel no warmer than -33 ºC. For determining the pressure ramp rates, as shown in Figure A3, the modeling assumed the station delivered the warmest possible gas allowed for a given dispenser type throughout the fill.

3. It is assumed that the first slug of gas is at ambient temperature if ambient is warmer than pre-cooling. This warm slug gradually cools down to the actual pre-cooling temperature at a linear ramp of 6 °C/s.

4. The fastest pressure ramp rate applied by the dispenser was constrained by limiting the peak mass flow rate to 60 g/s. With this constraint, the fastest pressure ramp rates applied are 28.2 MPa/min (87 MPa in 3.1 min) for 70 MPa ≤7 kg, 19.4 MPa/min for 70 MPa 7 to 10 kg (87 MPA in 4.5 min), and 15.1 MPa/min (43.75 MPa in 2.9 min) for 35 MPa. At this rate, a 2 MPa tank will be filled in 3 to 5 min, and a partially full tank will be filled in less than 3 to 5 min.

   The pressure ramp rate in the lookup tables depends only on tank capacity and ambient temperature. Dispensers will not increase the pressure ramp rate based on initial tank pressure because fueling history effects are unknown to the dispenser.

Figure A2 is an example of the look-up table of fueling values that define this protocol. Figure A3 illustrates the general approach used to model non-communication filling. The first step was to model the hot soak case to determine the ramp rate as shown with the red box in Figure A2 and red line in Figure A3. The second step was to determine the ending target pressure based on the cold soak case plus defueling (described in A.2) as shown with the blue box in Figure A2 and blue line in Figure A3. The final step was to determine the lower-bound SOC values based on the hot soak case using the target pressure result from step 2.

Example Lookup Table for Non-Communication Case

A-70 1-7kg		Average Pressure Ramp Rate, APRR (MPa/min)	Fueling Target Pressure, P_{target} (MPa)										
			Initial Tank Pressure, P_0 (MPa)										
			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
	50	11.4	73.5	73.2	73.0	72.8	72.6	72.4	72.2	72.0	71.9	72.2	no fueling
	45	15.7	73.9	73.6	73.3	73.0	72.8	72.5	72.3	72.0	71.8	72.1	no fueling
	40	19.8	74.2	73.9	73.6	73.2	73.0	72.6	72.2	72.0	71.8	72.0	no fueling
	35	23.7	74.5	74.1	73.6	73.3	73.1	72.7	72.3	72.0	71.8	72.0	no fueling
	30	27.4	74.1	73.8	73.2	72.7	72.5	71.9	71.4	71.0	70.6	71.0	no fueling
	25	28.2	73.6	73.3	72.6	72.3	71.7	70.9	70.4	69.9	69.3	no fueling	no fueling
	20	28.2	73.2	72.8	72.0	71.4	71.0	70.0	69.3	68.7	68.2	no fueling	no fueling
	10	28.2	72.0	71.5	70.6	70.0	69.4	68.2	67.2	66.5	65.8	no fueling	no fueling
	0	28.2	70.9	70.3	69.3	68.5	67.9	66.4	65.2	64.0	63.5	no fueling	no fueling
	-10	28.2	69.8	69.2	67.9	67.1	66.1	64.4	63.0	61.6	no fueling	no fueling	no fueling
	-20	28.2	68.9	67.9	66.6	65.5	64.3	62.4	60.7	59.1	no fueling	no fueling	no fueling
	-30	28.2	67.8	66.7	65.2	63.7	62.5	60.4	58.3	56.4	no fueling	no fueling	no fueling
	-40	28.2	67.3	66.5	65.0	63.7	62.5	60.1	58.3	56.4	no fueling	no fueling	no fueling

FIGURE A2 - EXAMPLE OF A LOOK-UP TABLE FOR NON-COMMUNICATION FUELING

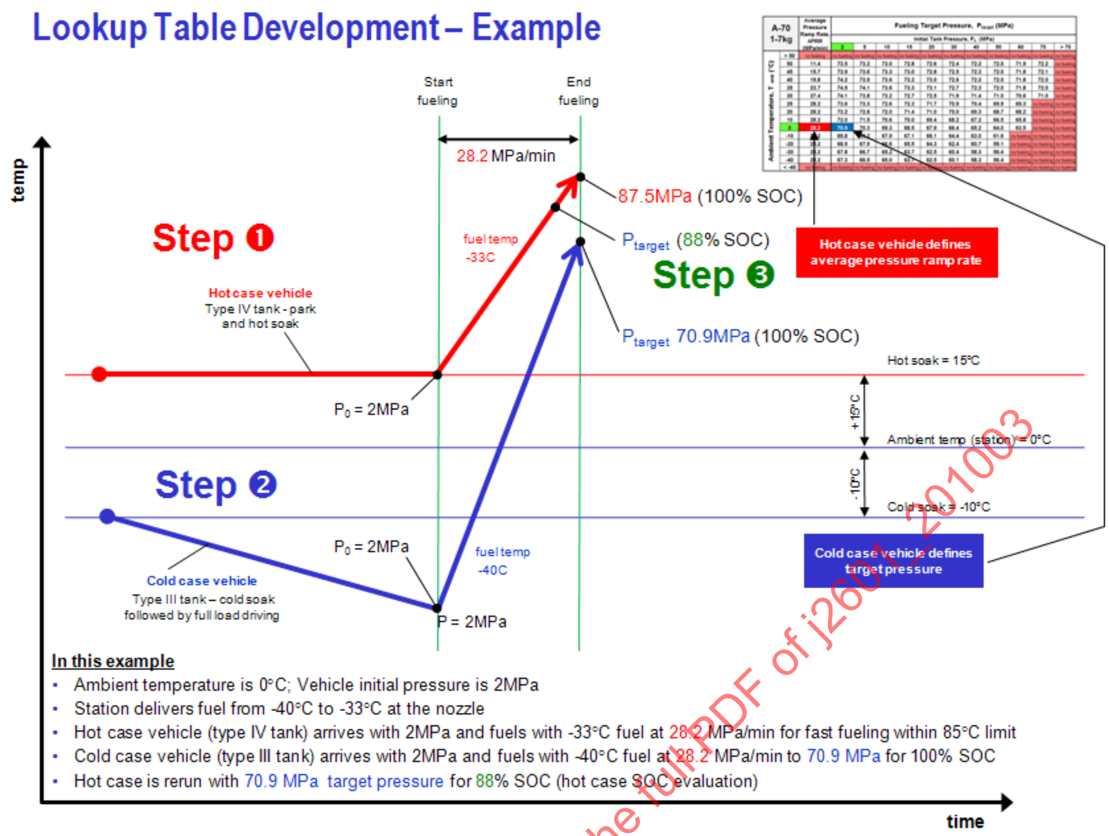

FIGURE A3 - EXAMPLE OF APPROACH USED TO GENERATE LOOK-UP TABLE VALUES

Pressure Ramp Rate Determination – Communication Fueling

The same fuel delivery temperature is specified for Non-Communication and Communication fueling, since it is assumed that the dispenser will not adjust fuel delivery temperatures dynamically.

The fueling look-up tables for communication fueling default are identical to the non-communication look-up tables in defining the pressure ramp rate; unless an alternative (ALT communication) methodology is used. The dispenser has the benefit of receiving the tank temperature measurement from the vehicle. Ambient temperature still plays a role in heat development during fueling, but initial tank temperature is the dominant parameter. In the alternative communication mode it is expected that the dispenser will adjust the ramp rate dynamically based on feedback from the vehicle. In many cases a potential faster fill can occur with ALT-communication.

Variations in Storage System Capacity, Dispenser Pre-cooling Capability, and Fill Pressure

Separate look-up tables have been developed to be applied by stations to cover a range of cases; These cases include 35 MPa vs. 70 MPa, defined dispenser pre-cooling capabilities of -40 °C, -20 °C, 0 °C and no pre-cooling; and defined ranges of 70 MPa storage system capacity of 1 to 7 kg and 7 to 10 kg. There are no capacity categories for 35 MPa, but 7.5 kg was the maximum HSS capacity considered in the modeling. Applying the tables to 35 MPa storage systems with capacities larger than 7.5 kg may result in peak flow rates exceeding 60 g/s.

OVER-FILLING PROTECTION (COLD SOAK CASE): FUELING PRESSURE TARGET

The specification of the Fueling Pressure Target at the dispenser nozzle is based on the pressure associated with 100% SOC, which is shown in Figure 3 as a function of the gas temperature within the storage system.

It is expected that the maximum fuel pressure achieved will differ from the fueling pressure target by the appropriate correction for uncertainty in the pressure measurement at the fueling dispenser and the expected pressure drop from dispenser to vehicle.

Provision for Cooling within Vehicle Storage

The gas temperature in the vehicle storage system decreases during vehicle operation due to depressurization. Different materials/constructions of vehicle storage systems will lead to different degrees of cooling during vehicle operation due to differences in heat transfer characteristics, the heat capacity, and storage volume of on-board storage systems. The cooling effects of vehicle operation are specific to each vehicle. The modeling and testing of these effects were done according to each OEM's specification. The cold soak modeling did not constrain the gas temperatures to existing certification temperature limits (i.e., -40 °C) of the system during defueling but allowed the gas temperature to proceed to an extreme cold condition. As an example, the gas temperature was allowed to proceed to -85 °C in the defueling model simulation to 2 MPa at an ambient of -20 °C. When the final defueling pressure is raised to 20 MPa, the final gas temperature increases to -61 °C. The practical allowance of these extreme temperatures is still under consideration since OEMs may establish temperature limitations or other countermeasures to manage these gas temperature extremes. Future revisions of the cold soak modeling will consider the realistic temperature limitations and countermeasures. However, the current modeling includes the extreme coldest condition at which a vehicle could ever arrive at a station for fueling.

The extreme-case systems modeled for pressure target development were carbon composite wrap/aluminum liner systems (type III) with a small-capacity multiple tank system (see below for details on storage system capacities considered). For each fuel pre-cooling temperature and initial pressure considered, this protocol specifies fueling pressure targets such that vehicle storage system state of charge (SOC) will not exceed 100% of the target value, even where the vehicle tank has been cold soaked and then been further cooled during operation, as specified in A.1.2. In most cases, the resulting pressure target corresponds to a SOC of greater than 90%, as shown in Appendix B.

Target Fueling Pressures Determination - Non-Communication Fueling

The look-up tables provide the pressure ramp rates for a range of ambient temperatures, including the hot soak condition of the HSS. The look-up tables provide the target pressures for a range of ambient temperatures (including the cold soak condition and driving cooling effects) and initial tank pressures. In developing the table, the following assumptions were made concerning dispenser operation.

1. A dispenser will always cool the hydrogen fuel to the greatest extent possible. For example, a dispenser capable of -40 ºC will deliver fuel in the -40 to -33 ºC pre-cooling range, regardless of ambient conditions

2. A dispenser will hold the temperature at the nozzle to the tolerance stipulated in Section 6. This means that a dispenser capable of -40 ºC will deliver fuel at -40 ºC in the coldest case. For determining the pressure targets, as shown in Figure A3, the modeling assumed the station delivered the coldest possible gas allowed for a given dispenser type throughout the fill

3. A dispenser will not necessarily deliver fuel at a temperature warmer than ambient. For example, if a dispenser has a pre-cooling capability of -20 ºC and the ambient temperature is -30 ºC, then it must be assumed for cold case modeling that the dispenser could deliver fuel as cold as -30 ºC

4. The dispenser will use interpolation or extrapolation if P0 is below 2 MPa to determine the specific Target Pressure to use for a measured ambient temperature and initial tank pressure, based on the look-up table values. If one of the interpolation values is in the “no fueling” zone of the table, then the dispenser should not fuel the vehicle

Figure A2 is an example of the look-up table of fueling values that defines this Protocol. Figure A3 illustrates the general approach used to model non-communication filling. The blue line in Figure A3 indicates the extreme cold case that is used to determine target pressures.

Figure A4 presents a full overview of the non-communication fueling process

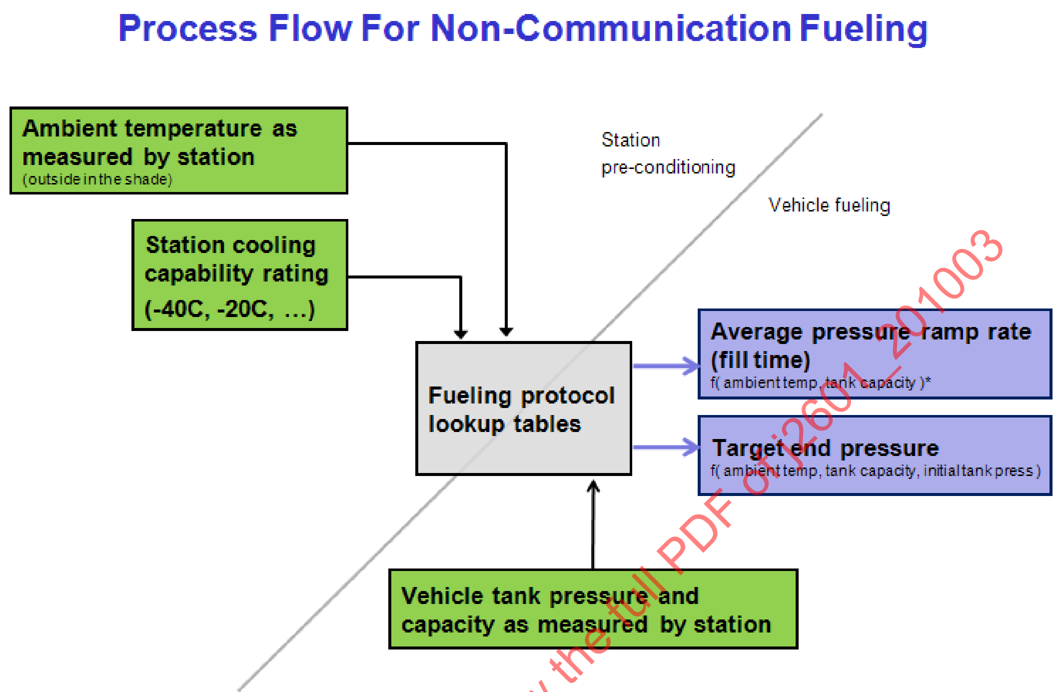

FIGURE A4 - PROCESS FLOW FOR NON-COMMUNICATION FUELING

Target Fueling Pressures - Communication Fueling

In the case of communication fueling, it is not necessary to specify target end pressures in advance. The dispenser should use information from the vehicle and the fueling process to determine its stop point for 100% SOC. The station should take into account allowances on its sensors. The vehicle OEM should consider the tolerances of the temperature measurement by the vehicle and include as criteria for the abort signal.

Dispenser Cooling Temperature Tolerances with Time Frame

Type A: -40C; -0C absolute tolerance; +7.0C mass average tolerance over any 30 s period

Type B: -20C; -2.5C mass ave. tolerance; +2.5C mass average tolerance over any 30 s period

Type C: 0C; -2.5C mass ave. tolerance; +2.5C mass average tolerance over any 30 s period

Type D: Ambient T; -5.0C mass ave. tolerance; +5.0C mass average tolerance over any 30 s period

The dispenser cooling temperature T_{Fuel} should be in the tolerance window within 15 s after start of fueling.

	General		Values for Simulation 70 MPa, 1-7 kg		Values for Simulation 70 MPa, 7-10 kg		Values for Simulation 35 MPa	
Parameter	**Cold Case**	**Hot Case**	**Cold Case**	**Hot Case**	**Cold Case**	**Hot Case**	**Cold Case**	**Hot Case**
vessel	type III tank with Aluminum liner thin wall large ratio surface to volume (long & slim) small pressure drop in fueling line	type IV tank with plastic liner thick wall small ratio surface to volume (short & fat) large pressure drop in fueling line	Vessel: smallest considered size is 1kg System: smallest considered has 2 vessels; use smallest system to give coldest temperatures in driving history	Vessel: largest considered single vessel for simulation is 6.3kg System: largest system has 7kg	Vessel: smallest considered size is 1.5kg System: must have 7kg or more: assume 4 vessels (4*1.5=6kg); this is somewhat within the tolerance for the station's volume estimation (7kg-10%)	Vessel: largest considered single vessel for simulation is 10kg System: largest system has 10kg	Vessel: smallest considered size is 1kg (at 35 MPa) System: smallest considered has 2 vessels; use smallest system to give coldest temperatures in driving history	Vessel: largest considered vessel is 10kg (at 70MPa) from 70MPa simulation; this will store 6kg at 35MPa System: largest system has 7.5kg at 35MPa
tank system	assume smallest capacity with multiple identical vessels	assume largest capacity with single vessel	2 vessels 1kg Type III 70 MPa	1 vessel 6.3kg Type IV 70 MPa	4 vessels 1.5kg Type III 70 MPa	1 vessel 10kg Type IV 70 MPa	2 vessels 1kg Type III 35 MPa	1 vessel 10kg Type IV 70 MPa
nozzle temp ramp	use instantaneous cold fill temperature at nozzle; there is no ramp down	if ambient is warmer than cold fill: use ambient temperature as initial nozzle temperature and ramp down nozzle temperature if ambient is colder than cold fill: use cold fill temperature at nozzle from beginning, there is no ramp	1kg Type III	nozzle temp ramp = 6°C/s	nozzle temp ramp = 0	nozzle temp ramp = 6°C/s	nozzle temp ramp = 0	nozzle temp ramp = 6°C/s
pressure drop in fueling line	smallest pressure drop conceivable	largest pressure drop allowed	70 MPa	pressure drop = 20 MPa	pressure drop = 2 MPa	pressure drop = 20 MPa	pressure drop = 2 MPa	pressure drop = 20 MPa
nozzle diameter	use the largest specified diameter	use the smallest specified diameter	nozzle diameter = Infinite	nozzle diameter = 3 mm	nozzle diameter = Infinite	nozzle diameter = 3 mm	nozzle diameter = Infinite	nozzle diameter = 3 mm
empty density			2.48 g/l	2.48 g/l	2.48 g/l	2.48 g/l	2.48 g/l	2.48 g/l
full density			40.2 g/l	40.2 g/l	40.2 g/l	40.2 g/l	24.0 g/l	24.0 g/l

FIGURE A3 - MODELING ASSUMPTIONS AND DEVELOPMENT APPROACH

The final look-up tables are not derived from a single hydrogen storage system, but rather reflect the full scope of storage system characteristics across all OEM applications that were considered during table development. Those systems most prone to heat development (i.e., hot at end of fill) have driven the need for pre-cooling and placed limitations on fill time. Those systems most prone to overfilling (i.e., cold at end of fill) have determined the target pressure limits. Table A2 lists the tanks used in the protocol development, along with some of their key parameters. It should be noted that not all of these are existing tank systems, but rather collections of parameters that represent boundary conditions for hot and cold fueling conditions. Table A3 summarizes the modeling assumptions and the protocol development, and it identifies which tanks were used in each step of the process.

TABLE A2 - TANKS USED IN PROTOCOL DEVELOPMENT

Tank parameters for simulation of fueling process

		Cold Case Tanks			Hot Case Tanks	
Parameters / Tanks		**Step 2: 35MPa**	**Step 2: 70MPa 1-7kg**	**Step 2: 70MPa 7-10kg**	**Step 1 & 2: 70MPa 1-7kg**	**Step 1 & 3: 70MPa 7-10kg Step 1 & 3: 35MPa**
General	**Units**					
Tank system acronym		*1kg 35MPa TypeIII*	*1kg 70MPa TypeIII*	*1.5kg 70MPa TypeIII*	*6.3kg 70MPa TypeIV*	*10kg 70MPa TypeIV*
Storage capacity total	kg	1	1	1.5	6.3	10
Nominal working pressure	MPa	35	70	70	70	70
Number of vessels		2	2	4	1	1
Defueling rate system (max)	g/s	1.4	1.4	1.4	1.4	1.4
Defueling rate per vessel (max)	g/s	0.7	0.7	0.35	1.4	1.4
Geometry	**Units**					
Internal volume	liters	39	25	37	157	249
Total external length, without necks	mm	902 (w/ necks)	900 (w/ necks)	900 (w/ necks)	1000	1517
External diameter	mm	300	240	306	557	557
Internal diameter	mm	270	200	251	476	476
Wall thickness carbon overwrap (cylindrical section)	mm	12	17	24		
Wall thickness liner (cylindrical section)	mm	3.25	3.25	3.25		
Mass of carbon overwrap	kg	14.50	15.53	28.30		
Mass of liner (without bosses)	kg	6.58	4.84	5.94		
Internal liner surface	m²	0.738	0.54	0.665	1.57	2.342
Material Data						
Composite overwrap						
Density	kg/m³	1500	1500	1500		
Heat conductivity	W/m-K	0,799 (const)	0,799 (const)	0,799 (const)		
Spec. heat capacity	J/kg-K	862,5 (const)	862,5 (const)	862,5 (const)		
Liner (aluminum, steel, plastic, etc.)		aluminum	aluminum	aluminum	plastic	plastic
Density	kg/m³	2700	2700	2700		
Heat conductivity	W/m-K	164 (@ 0°C)	164 (@ 0°C)	164 (@ 0°C)		
Spec. heat capacity	J/kg-K	1106 (const)	1106 (const)	1106 (const)		

With the lookup tables developed and accepted for use at all stations, the interface for fuel transfer from the dispenser to the vehicle is defined, and the history of the table development is no longer directly relevant. Station operators are expected to operate their stations in accordance with the protocols, and OEMs are responsible for ensuring that any newly developed storage tank or storage system is capable of safely receiving fuel according to the protocol.

The modeling approach for generating the tables was based on a thermodynamic representation of the filling process within the storage vessel. The analysis was performed by treating the interior of the vessel as a fixed control volume. The enthalpy of hydrogen entering the vessel from a single inlet results in a temperature rise. The models assume a well-mixed gas within the vessel such that the pressure, temperature, and density at any particular time are uniform. The conservation of mass and energy, along with an equation of state for hydrogen gas, provide the model with ability to calculate the pressure, temperature and density throughout the fill. The heat from the compressed gas is partly stored (i.e. heat capacity) in the liner material and partly transferred (i.e. heat conductivity) to the composite overwrap. In the same manner, the heat is stored and progresses through the composite overwrap to the ambient temperature environment within the model. The heat transfer is assumed only to take place through the body of the vehicle storage vessel, which implies no significant heat transfer through the station lines or components. The condition of the dispensed hydrogen gas from the station is defined by pressure and temperature at the nozzle. The pressure at the nozzle interface is given by the pressure ramp rate. The fuel gas mass flow rate at any given time is calculated from the time dependant pressure at the nozzle and the pressure in the vehicle tank. The pressure drop coefficient of the fueling line downstream the nozzle is calculated from the pressure drop at the reference condition. The gas temperature entering the tank is based on the nozzle delivery temperature at the appropriate tolerance along with the increase due to the Joule-Thomson effect and the gas dynamic influence of the nozzle diameter, which increases the dynamic enthalpy for a given temperature and pressure due to the increased flow velocity. The soak condition defines the initial homogeneous temperature of both the internal gas and wall of the vehicle storage system. As indicated in the previous sections, the soak condition deviates from the ambient temperature for various reasons, which are specified in the model as separate initial conditions of the fill.

APPENDIX B - MINIMUM STATE OF CHARGE RANGE PER FUELING TYPE

Appendix B defines the expected SOC range by defining the lower limit (the upper limit is 100%). An SOC greater than these lower limits and less than 100% should be achieved. The expected SOC should be at least the values shown in the tables below.

TABLE B1 - TYPE A-70 SOC LOWER BOUNDS FOR VEHICLE FUEL SYSTEMS WITH CAPACITY 1-7 KG

A-70 1-7kg		Hot Case Final State of Charge, SOC (Hot Soak - No History)										
		Initial Tank Pressure, P_0 (MPa)										
		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
	50	89%	89%	89%	89%	88%	89%	89%	89%	90%	91%	no fueling
	45	89%	89%	89%	89%	89%	89%	89%	90%	90%	92%	no fueling
	40	89%	89%	89%	89%	89%	90%	90%	90%	91%	92%	no fueling
	35	90%	89%	89%	89%	90%	90%	91%	91%	92%	93%	no fueling
	30	89%	89%	89%	89%	89%	90%	90%	91%	92%	94%	no fueling
	25	89%	89%	89%	89%	89%	89%	90%	91%	92%	no fueling	no fueling
	20	89%	89%	89%	89%	89%	89%	90%	91%	92%	no fueling	no fueling
	10	88%	88%	88%	88%	89%	89%	90%	91%	92%	no fueling	no fueling
	0	88%	88%	88%	88%	88%	89%	90%	91%	92%	no fueling	no fueling
	-10	87%	87%	86%	87%	87%	87%	88%	89%	no fueling	no fueling	no fueling
	-20	86%	85%	85%	85%	85%	85%	86%	86%	no fueling	no fueling	no fueling
	-30	85%	84%	84%	84%	84%	84%	84%	84%	no fueling	no fueling	no fueling
	-40	84%	84%	84%	84%	84%	83%	84%	84%	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

TABLE B2 - TYPE B-70 SOC LOWER BOUNDS FOR VEHICLE FUEL SYSTEMS WITH CAPACITY 1-7 KG

B-70 1-7kg		Hot Case Final State of Charge, SOC (Hot Soak - No History)										
		Initial Tank Pressure, P_0 (MPa)										
		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
	50	91%	91%	90%	90%	90%	90%	90%	90%	90%	91%	no fueling
	45	90%	90%	90%	89%	89%	89%	90%	90%	91%	92%	no fueling
	40	90%	90%	89%	89%	89%	90%	90%	91%	92%	93%	no fueling
	35	90%	89%	89%	89%	90%	90%	91%	92%	93%	94%	no fueling
	30	89%	89%	89%	89%	89%	90%	91%	92%	93%	no fueling	no fueling
	25	89%	89%	89%	89%	89%	90%	91%	92%	93%	no fueling	no fueling
	20	88%	88%	88%	89%	89%	90%	90%	92%	93%	no fueling	no fueling
	10	88%	88%	88%	88%	88%	89%	90%	91%	93%	no fueling	no fueling
	0	87%	87%	87%	88%	88%	89%	90%	91%	93%	no fueling	no fueling
	-10	86%	86%	86%	86%	87%	87%	88%	89%	91%	no fueling	no fueling
	-20	85%	85%	85%	85%	85%	85%	86%	87%	no fueling	no fueling	no fueling
	-30	84%	84%	83%	83%	83%	84%	84%	85%	no fueling	no fueling	no fueling
	-40	84%	83%	83%	83%	83%	83%	84%	85%	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

TABLE B3 - TYPE A-70 SOC LOWER BOUNDS FOR VEHICLE FUEL SYSTEMS WITH CAPACITY 7-10 KG

A-70 7-10kg	Hot Case Final State of Charge, SOC (Hot Soak - No History)										
	Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	40	50	60	70	> 70
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	90%	89%	89%	89%	89%	89%	89%	89%	90%	91%	no fueling
45	90%	90%	90%	90%	89%	89%	90%	90%	91%	92%	no fueling
40	90%	90%	90%	90%	90%	90%	90%	91%	91%	93%	no fueling
35	90%	90%	90%	90%	90%	90%	91%	91%	92%	94%	no fueling
30	90%	90%	90%	90%	90%	90%	91%	91%	92%	94%	no fueling
25	90%	90%	90%	90%	90%	90%	91%	91%	92%	no fueling	no fueling
20	89%	90%	90%	90%	90%	90%	90%	91%	92%	no fueling	no fueling
10	89%	89%	89%	89%	89%	90%	90%	91%	92%	no fueling	no fueling
0	88%	89%	89%	89%	89%	89%	90%	91%	92%	no fueling	no fueling
-10	88%	88%	87%	87%	87%	88%	88%	89%	90%	no fueling	no fueling
-20	87%	87%	86%	86%	86%	86%	86%	87%	no fueling	no fueling	no fueling
-30	86%	85%	85%	85%	84%	84%	84%	84%	no fueling	no fueling	no fueling
-40	85%	85%	85%	84%	84%	84%	84%	84%	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

TABLE B4 - TYPE B-70 SOC LOWER BOUNDS FOR VEHICLE FUEL SYSTEMS WITH CAPACITY 7-10 KG

B-70 7-10kg	Hot Case Final State of Charge, SOC (Hot Soak - No History)										
	Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	40	50	60	70	> 70
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	91%	90%	90%	90%	90%	90%	90%	90%	90%	91%	no fueling
45	90%	90%	90%	90%	90%	90%	90%	91%	91%	92%	no fueling
40	90%	90%	90%	90%	90%	90%	90%	91%	92%	93%	no fueling
35	90%	90%	90%	90%	90%	90%	91%	92%	93%	94%	no fueling
30	90%	90%	90%	90%	90%	90%	91%	92%	93%	no fueling	no fueling
25	89%	89%	89%	89%	90%	90%	91%	92%	93%	no fueling	no fueling
20	89%	89%	89%	89%	89%	90%	91%	92%	93%	no fueling	no fueling
10	89%	89%	89%	89%	89%	90%	90%	91%	93%	no fueling	no fueling
0	88%	88%	88%	88%	89%	89%	90%	91%	93%	no fueling	no fueling
-10	87%	87%	87%	87%	87%	88%	88%	89%	91%	no fueling	no fueling
-20	86%	86%	86%	86%	86%	86%	86%	87%	no fueling	no fueling	no fueling
-30	85%	85%	85%	84%	84%	84%	84%	85%	no fueling	no fueling	no fueling
-40	85%	85%	84%	84%	84%	84%	84%	85%	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

TABLE B5 - TYPE A-35 SOC LOWER BOUNDS

A-35	Hot Case Final State of Charge, SOC (Hot Soak - No History)							
	Initial Tank Pressure, P_0 (MPa)							
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	35	> 35
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	87%	87%	87%	87%	87%	87%	88%	no fueling
45	87%	87%	87%	87%	87%	88%	89%	no fueling
40	87%	87%	87%	88%	88%	89%	91%	no fueling
35	87%	87%	88%	88%	89%	90%	92%	no fueling
30	87%	87%	88%	88%	89%	90%	92%	no fueling
25	86%	87%	87%	88%	89%	90%	no fueling	no fueling
20	86%	86%	87%	88%	89%	90%	no fueling	no fueling
10	86%	86%	87%	87%	88%	90%	no fueling	no fueling
0	85%	85%	86%	87%	88%	90%	no fueling	no fueling
-10	83%	84%	85%	85%	86%	88%	no fueling	no fueling
-20	82%	82%	83%	83%	83%	no fueling	no fueling	no fueling
-30	81%	81%	81%	81%	81%	no fueling	no fueling	no fueling
-40	80%	80%	80%	81%	81%	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

TABLE B6 - TYPE B-35 SOC LOWER BOUNDS

B-35	Hot Case Final State of Charge, SOC (Hot Soak - No History)							
	Initial Tank Pressure, P_0 (MPa)							
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	35	> 35
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	87%	87%	87%	87%	88%	89%	89%	no fueling
45	88%	87%	88%	88%	88%	89%	90%	no fueling
40	88%	88%	88%	88%	89%	90%	91%	no fueling
35	88%	88%	88%	89%	90%	91%	92%	no fueling
30	87%	87%	88%	89%	89%	91%	92%	no fueling
25	87%	87%	87%	88%	89%	91%	no fueling	no fueling
20	86%	86%	87%	88%	89%	90%	no fueling	no fueling
10	85%	86%	86%	87%	88%	90%	no fueling	no fueling
0	84%	85%	86%	87%	88%	90%	no fueling	no fueling
-10	83%	84%	84%	85%	86%	88%	no fueling	no fueling
-20	82%	82%	83%	83%	83%	no fueling	no fueling	no fueling
-30	79%	79%	80%	80%	80%	no fueling	no fueling	no fueling
-40	78%	78%	78%	79%	80%	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

TABLE B7 - TYPE C-35 SOC LOWER BOUNDS

C-35	Hot Case Final State of Charge, SOC (Hot Soak - No History)							
	Initial Tank Pressure, P_0 (MPa)							
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	35	> 35
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	90%	90%	89%	89%	88%	89%	89%	no fueling
45	89%	89%	89%	88%	89%	90%	91%	no fueling
40	89%	89%	89%	89%	89%	91%	92%	no fueling
35	89%	88%	89%	89%	90%	92%	93%	no fueling
30	88%	88%	88%	89%	90%	92%	93%	no fueling
25	88%	87%	88%	88%	89%	92%	no fueling	no fueling
20	87%	87%	87%	88%	89%	91%	no fueling	no fueling
10	86%	86%	87%	88%	89%	91%	no fueling	no fueling
0	85%	85%	86%	87%	89%	91%	no fueling	no fueling
-10	83%	83%	84%	85%	86%	89%	no fueling	no fueling
-20	80%	80%	81%	82%	83%	no fueling	no fueling	no fueling
-30	77%	78%	78%	79%	81%	no fueling	no fueling	no fueling
-40	76%	76%	77%	79%	80%	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

TABLE B8 - TYPE D-35 SOC LOWER BOUNDS

D-35	Hot Case Final State of Charge, SOC (Hot Soak - No History)							
	Initial Tank Pressure, P_0 (MPa)							
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	35	> 35
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	95%	95%	94%	93%	92%	90%	90%	no fueling
45	94%	93%	93%	92%	91%	90%	91%	no fueling
40	93%	92%	92%	91%	91%	91%	92%	no fueling
35	92%	91%	91%	90%	91%	92%	93%	no fueling
30	90%	90%	90%	90%	90%	92%	93%	no fueling
25	89%	89%	89%	89%	89%	92%	no fueling	no fueling
20	88%	88%	88%	88%	89%	92%	no fueling	no fueling
10	86%	86%	86%	87%	89%	92%	no fueling	no fueling
0	85%	85%	86%	87%	88%	91%	no fueling	no fueling
-10	83%	83%	84%	85%	86%	89%	no fueling	no fueling
-20	81%	81%	82%	83%	83%	no fueling	no fueling	no fueling
-30	80%	80%	80%	80%	80%	no fueling	no fueling	no fueling
-40	81%	81%	81%	81%	81%	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

APPENDIX C - HYDROGEN REFUELING STATION RECOMMENDATIONS
FOR PRE-COOLING AND PRESSURE CONTROL

Fueling dispenser flow restriction shall be upstream of vehicle interface.

Fueling dispenser should be capable of setting the nozzle outlet temperature of the pre-cooled hydrogen gas consistent with the fueling protocol.

Installation of pre-cooling equipment shall be downstream of the smallest flow restriction in the complete fueling path. Otherwise, the Joule-Thomson effect will lead to a significant temperature increase of the hydrogen gas delivered to the vehicle, thereby making the pre-cooling less effective.

If a station has communication fueling capability, the fueling dispenser shall be capable of fueling vehicles with and without communication between the vehicle and dispenser.

The fueling station shall execute three levels of pressure control:

1st Level (normal control process): terminate fueling when target pressure is reached, when SOC limit is reached, or when the “abort” signal is received

2nd Level (initial fault management: redundant electronic protection level): terminate fueling when 125% NWP (87.5 MPa for a 70 MPa dispenser; 43.8 MPa for a 35 MPa dispenser) is reached

3rd Level (secondary fault management: fully mechanical protection level): when fueling station PRV set point is reached. The PRV set point should be 1.25*NWP +10% = 1.375*NWP (96.25 MPa for a 70 MPa dispenser and 48.13 MPa for a 35-MPa dispenser).

For all of the above cases, the fueling hose pressure should be released.

APPENDIX D - USING THE FUELING TABLES – NON-COMMUNICATION EXAMPLE

Linear interpolation should be used to derive actual parameters from table values. This will be one-dimensional interpolation for the $APRR_{actual}$ (based on ambient temperature) and two-dimensional interpolation for the target pressure (based on ambient temperature and initial HSS pressure), or extrapolation if P_0 is below 2 MPa. Note: If one of the interpolation values is in the "no fueling" zone of the table, then the dispenser should not fuel the vehicle.

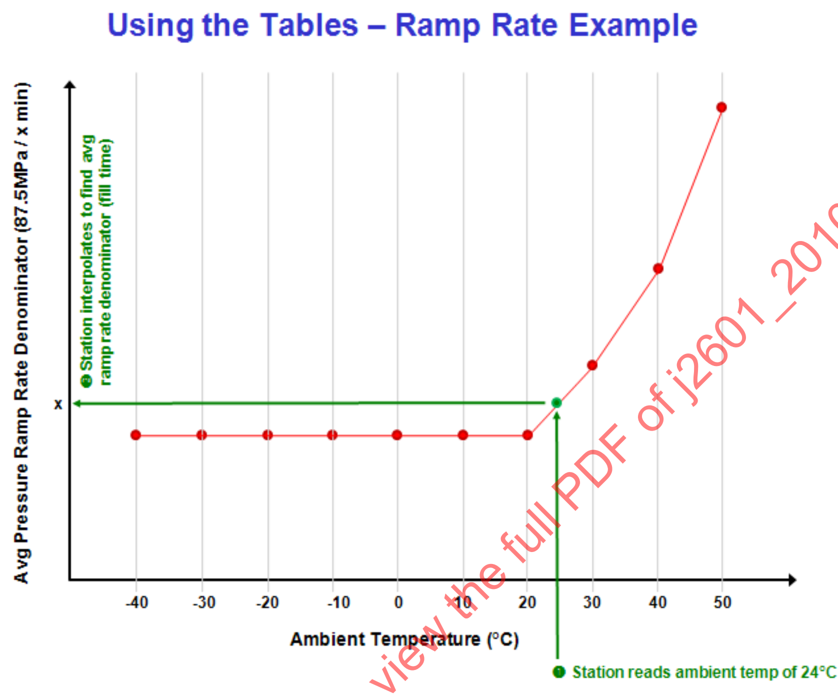

FIGURE D1

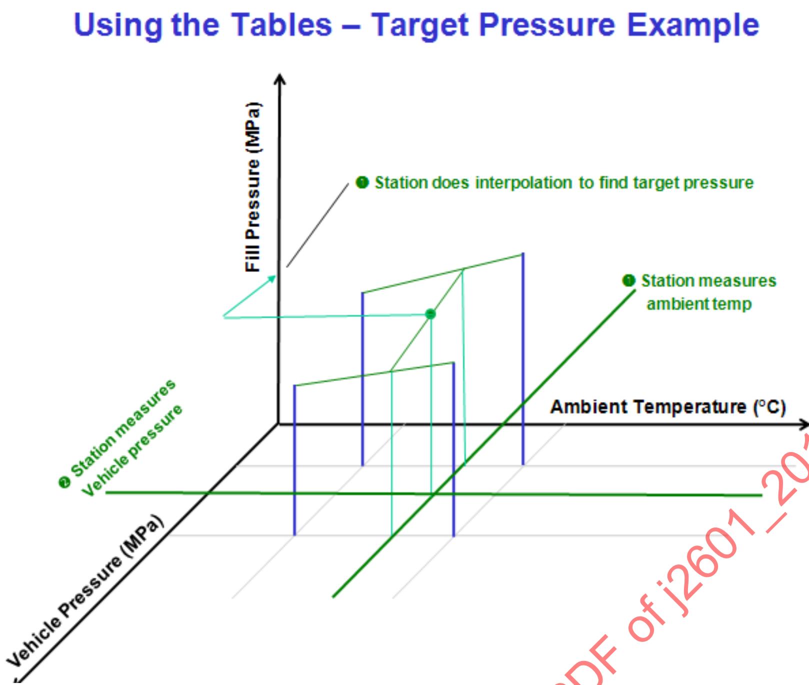
Using the Tables – Target Pressure Example
Fill Pressure (MPa)
❸ Station does interpolation to find target pressure
❶ Station measures ambient temp
Ambient Temperature (°C)
❷ Station measures Vehicle pressure
Vehicle Pressure (MPa)

FIGURE D2

APPENDIX E - PLANS FOR FUTURE REVISIONS OF SAE J2601 AND PATHWAY TO FURTHER PERFORMANCE BASED STANDARD

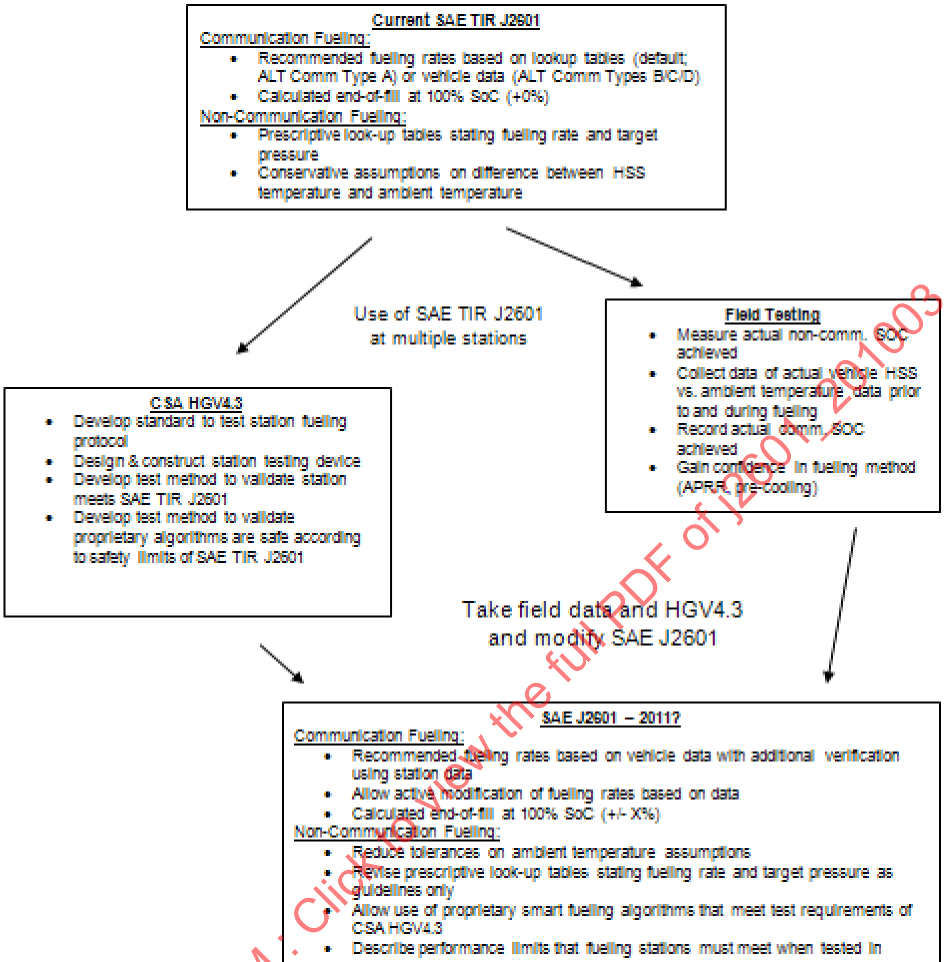

FIGURE E1

APPENDIX F - EXAMPLE OF ALT- COMMUNICATION FUELING INITIAL RAMP RATES

This appendix is strictly for reference only relating to Alt-Communications look-up tables as per Section 9. The tables give the initial ramp rates per initial tank pressure and initial internal tank temperature signal reading.

The vehicle (OEM) must give authorization to utilize this methodology at a given station.

<u>Communication Fueling Table F-1</u>

Type A-70 Example of ALT- Communication Initial Ramp Rates for HSS with capacity 1-7kg

A-70 1-7kg	Example ALT Ramp Rates (MPa/min) for Communication Fueling											
	Initial Tank Pressure, P_0 (MPa)											
Initial Tank Temperature, $T_{vehicle}$ (°C)	2	5	10	15	20	30	40	50	60	70	80	> 80
≥ 85	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
80	3.6	3.4	3.0	2.7	2.6	2.2	2.1	2.0	2.5	12.5	28.2	no fueling
75	6.7	6.3	5.5	5.1	4.9	5.1	6.7	14.6	28.2	28.2	28.2	no fueling
70	10.9	10.9	10.9	12.5	12.5	17.5	28.2	28.2	28.2	28.2	28.2	no fueling
65	17.5	17.5	17.5	21.9	21.9	28.2	28.2	28.2	28.2	28.2	28.2	no fueling
60	21.9	21.9	21.9	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling
55	21.9	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling
50	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
45	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
40	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
35	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
30	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
25	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
20	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
15	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
10	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
0	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
-10	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
-20	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
-30	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-40	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-50	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-60	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-70	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling	no fueling
-80	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling	no fueling
-90	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling	no fueling

Communication Fueling Table F-2

Type B-70 Example of ALT- Communication Initial Ramp Rates for HSS with capacity 1-7kg

B-70 1-7kg	Example ALT Ramp Rates (MPa/min) for Communication Fueling — Initial Tank Pressure, P_0 (MPa)											
Initial Tank Temperature, $T_{vehicle}$ (°C)	2	5	10	15	20	30	40	50	60	70	80	> 80
≥ 85	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
80	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	1.1	28.2	no fueling
75	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.6	2.5	28.2	28.2	no fueling
70	1.6	1.6	1.6	1.6	1.6	1.8	2.2	4.2	28.2	28.2	28.2	no fueling
65	1.9	1.9	1.9	2.2	2.2	2.9	4.9	21.9	28.2	28.2	28.2	no fueling
60	2.2	2.5	2.5	2.9	3.4	5.1	14.6	28.2	28.2	28.2	28.2	no fueling
55	3.0	3.1	3.5	4.0	4.9	9.7	28.2	28.2	28.2	28.2	28.2	no fueling
50	3.6	4.0	4.6	5.5	7.3	17.5	28.2	28.2	28.2	28.2	no fueling	no fueling
45	4.4	4.9	5.8	7.3	10.9	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
40	5.5	5.8	7.3	9.7	14.6	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
35	6.3	7.3	9.7	14.6	21.9	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
30	7.3	8.8	10.9	17.5	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
25	8.8	9.7	14.6	21.9	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
20	9.7	10.9	17.5	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
15	10.9	12.5	21.9	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling
10	12.5	14.6	21.9	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
0	14.6	17.5	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
-10	17.5	21.9	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
-20	17.5	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling
-30	21.9	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-40	21.9	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-50	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-60	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling
-70	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling	no fueling
-80	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling	no fueling
-90	28.2	28.2	28.2	28.2	28.2	28.2	28.2	no fueling	no fueling	no fueling	no fueling	no fueling