

Fueling Specification for 70 MPa Compressed Hydrogen Vehicles

Release Version *(A)*

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Document Change Management

- This document has undergone 7 revision levels before this release Version "A".
- Subsequent document revision expected in 2007 to incorporate fueling communication and non-communication 70MPa Fueling Protocol recommendations based on experimental evaluation of assorted 70MPa fueling protocols also from the Powertech fueling program.
- The fueling portion of this document is to be superseded by SAE J2601 when it is published.

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List of Abbreviations

CAN	Controller Area Network
CHG	Compressed Hydrogen (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 (as Prefix/Suffix: Component belongs to fueling station)
FTA	Fault Tree Analysis
H ₂	Hydrogen gas
IR	Infrared light
IrDA	Infrared Data Association
LFL	Lower Flammability Limit (of hydrogen)
MAWP	Maximum Allowable Working Pressure (125% NWP)
NIST	National Institute of Standards and Technology
NWP	Nominal Working Pressure (e.g. 35MPa or 75MPa)
PRD	Pressure Relief Device (Thermal fuse in the vehicle's fuel system)
PRV	Pressure Relief Valve (Mechanical valve in fueling station; overpressure protection)
RDI	Fueling Data Interface
SAE	Society of Automotive Engineers
SNV	Signal not Valid
SoC	State of Charge (in %). Ratio of actual to target hydrogen density times 100. Target H ₂ density (100% SoC) equals 70MPa at 15°C, or 40.2 g/liter. SoC is computed based on the gas density as per formula below.

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Note: p and T are the pressure and temperature of the gas inside the vehicle tank.

$$\text{SoC} = \frac{\rho(p,T)}{\rho(70 \text{ MPa}, 15^\circ\text{C})}$$

Tbc	To be confirmed
Tbd	To be determined
TCU	Tank Control Unit (of vehicle)

Referenced Documents

- [1] IR-DI_CAN-communication_V3.2
- [2] SAE J2600, "Compressed Hydrogen Surface Vehicle Fueling Connection Devices", Issued October 2002
- [3] Draft SAE J2601, "Hydrogen Surface Vehicle Fueling System – Overview", in development at SAE, September 2006
- [4] SAE TIR J2799, "70MPa Compressed Hydrogen Surface Vehicle Fueling Connection Device & Optional Vehicle to station Communications",
- [5] Compressed Hydrogen 350-bar Fueling Station Specifications, Version 2.0, Rev. 0; Document Number CHGFSS350, November 2006
- [6] Draft SAE J2579, "Recommended Practice for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles", in development at SAE, January, 2007
- [7] SAE J2760, "Technical Information Report For Pressure Terminology Used In Fuel Cells and Other Hydrogen Vehicle Applications"
- [8] NFPA 52, "Vehicle Fuel Systems Code", 2006

Definition of Dedicated Terms

Definition of Dedicated Terms

Fueling Command Message from the vehicle to the fueling station containing fueling instruction to the station (Fuel, Halt, Abort) and vehicle status (e.g., sensor information) during a communication fueling. The Command is validated by means of a CRC.

Fueling Command: "Fuel" Instructs the fueling station to initiate or continue fueling.

Fueling Command: "Halt" Instructs the fueling station to stop the hydrogen flow. Fueling may resume when the Fueling Command "Fuel" is received again.

Fueling Command: "Abort" Instructs the fueling station to stop the hydrogen flow. To continue fueling, the operator is required to re-initiate the fueling from beginning.

Terminology

FS Fueling Algorithm Set of instructions given by a FS ECU to FS flow control devices to implement fueling according to the common industry-wide Fueling Protocol

Fueling Protocol Industry specification of minimum critical characteristics and performance requirements of the fueling process that is achieved by all fueling stations and is accounted for in the design of all vehicle storage systems.

FS Fueling Process Procedure to implement vehicle fueling according to parameters established under the industry-wide Fueling Protocol to which vehicles are designed for receiving fuel. The FS Fueling Process includes design, hardware, and procedures for the control and operation of hardware, at a fueling station to dispense fuel in accord with the common industry fueling protocol.

Electric Actuated Solenoid

Valve(s) Electronically-controlled shut-off valve(s) in the vehicle's fuel storage system capable of opening and completely shutting off the flow out of the storage cylinder(s).

Check-valve(s) Valves that limit the gas flow through them to one direction.
Check Valves are typically spring-loaded to open when the pressure difference between the input and the output of the valve creates enough force to overcome the spring force. Typically two check-valves are used on the storage system inlet.

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Stop valve(s)	Electronically-controlled shut-off valve(s) in the vehicle's fuel storage system capable of opening and completely shutting off the flow into the storage system. This functionality is optional; it may or may not be implemented.
FS Valve(s)	Main flow controlling valve(s) within the fueling station. Operated and electronically controlled by the ECU of the Fuelling Station. The valve enables and disables the hydrogen flow from the fueling station to the vehicle. The valve is intended to control the flow rate by automatic adjustment of the valve position to allow a continuous pressure increase rate independently of the volume of the vehicle's fuel system.
FS PRV	Pressure relief valve within the fueling station that opens and re-closes to prevent the outlet pressure of the dispenser from exceeding the MAWP of the vehicle storage system.
PRD	Pressure Relieve Device (safety device) on the vehicle storage system that is a non-reclosing, thermally-activated opening. It is sometimes referred to as a thermally activated relief device or TRD. A PRD is typically placed in the tank valve assembly of each container in the vehicle's fuel system. If the PRD of a hydrogen container activates, the hydrogen content in that container will vent to atmosphere. The activation temperature of the PRD is specified by the manufacturer in agreement with the OEMs (110±5 °C is a commonly used PRD activation temperature). The PRD is a safety device developed to prevent container rupture during fires but is not intended to open during fueling.
Fueling	Transfer of hydrogen fuel from the fueling station to the fuel storage system of a vehicle.
Operator	Person or Persons owning, maintaining and ensuring the proper functionality of the fueling station.
Ambient Temperature	The environmental temperature in the vicinity of the dispenser.
Tolerance	The allowable deviation from a standard; especially: the range of variation permitted in maintaining a specified measurement or performance accuracy
Demonstration Phase	The pre-commercial period during which vehicles and fueling stations demonstrate capability to meet performance requirements reliably and cost efficiently. During this time, Standards Develop Organizations are expected to finalize the first set of standards. This period is expected to be 2007-2009.

1. Introduction

1.1 The number of hydrogen fueling stations is steadily growing worldwide as the number of hydrogen-fueled vehicles increases. Most of these vehicles have a compressed hydrogen gas (CHG) storage system. This document defines common requirements between multiple Automakers (OEMs) for fueling of 70MPa vehicle storage systems as guidance during the Demonstration Phase.

The purpose of this document is to share the safety requirements and performance expectations of vehicle manufacturers to aid station providers in designing stations in the period before a complete set of standards are adopted (1) to ensure that vehicles can be designed to be fueled at common fueling stations, and (2) to indicate performance targets for fueling seen by drivers as competitive with conventional fueling, and (3) to guide future station performance. Most of the features identified herein are achievable today. Capacity and reliability targets are set forth to support expected growth in numbers of vehicles in cluster regions over the 2008-2010 period.

1.2 This document also describes generic elements of a 70 MPa Fueling Protocol. The specific elements of the protocol are targeted to be completed in 2007. Station designers will develop hardware, control and operating systems and procedures to effect fueling within the parameters of the Fueling Protocol under which vehicles will have been designed to accept fuel.

1.3 A communication interface between vehicle and fueling station will be introduced with the intent of improving the fueling process. Both communication and non-communication fueling methods are described in this document. Requirements for common vehicle communication features are in the draft SAE Technical Information Report (TIR) J2799. Some OEMs and energy providers have developed J2799-compliant interface hardware. Fueling stations that are designed to provide 70MPa fueling during the Development Phase should at a minimum have J2799 communications capability (additional communications per OEM request are optional).

1.4 Fueling station providers and other OEMs are invited to participate in the development of a common Fueling Protocol. The evaluation of fueling protocols (fuel temperature, flow rate, and criteria for termination of fueling) is underway in several projects: a multi-client 70 MPa fast fill study by Powertech under the sponsorship of multiple vehicle manufacturers and station providers, and studies by individual OEMs, and by individual station providers. The results of these evaluations are expected to be coalesced into a common set of requirements and captured in SAE J2601 and corresponding fueling station standards (e.g., CSA 4.3) to optimize and commonize fueling over a range of ambient conditions and hydrogen storage systems.

1.5 The contents of this document will be available to Standards Development Organizations such as

SAE and CSA for consideration, as appropriate, in the development of vehicle and dispenser standards, respectively.

2. Scope: This document will serve as interim guidance until it is superseded by SAE J2601

This document applies to the design, safety, operation and verification of compressed hydrogen fueling stations that fuel vehicles with compressed hydrogen storage with a nominal working pressure of 70 MPa. This document is focused on fueling stations for passenger cars with fuel storage up to 5 kg H₂, but these requirements can also be applied to fueling of commercial vehicles – such as buses – with higher fuel capacities. J2601 will cover passenger and commercial vehicle H₂ fueling.

The purpose of this document is to achieve common fueling conditions for 70 MPa CHG vehicles and fueling stations (not intended to be fully applicable to home-based or other small scale fueling devices) that optimize performance across assorted vehicle storage systems and fueling station designs. Therefore, interested parties have been invited to share in the development of these requirements.

The document is intended to provide minimal elements of expected commonality, not to restrict implementation of additional features in individual fueling stations.

This document is intended to be submitted to the SAE 2601 taskforce when the participants deem it is ready for release. The SAE FC Committee has expressed interest in the summary data report from Powertech as guidance prior to standardization. This document assumes the fueling interface hardware is specified in SAE J2799 (fueling receptacle and IrDA-based data interface) and that the fuel quality is being addressed through SAE TIR J2719.

3. Hydrogen Station Specification

The following is a summary guideline of the technical needs for a hydrogen fueling station, specifically at 70MPa. The details of the fueling process are described in Section 4 of the document.

3.1. 70 MPa H₂ Fueling Limits

- 3.1.1. Maximum fueling pressure in vehicle H₂ storage system87.5 MPa @ 85°C
- 3.1.2. H₂ gas temperature at dispensing nozzle (the point of delivery to a vehicle) is described in Section 4. Required H₂ gas temperature delivered to vehicle depends on ambient temperature. H₂ gas cooling is needed to offset the heat of compression during fast fueling. The lower temperature limit for this 70MPa fueling is -40C. During the

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Demonstration Phase, the nozzle H₂ gas temperature at the nozzle should be continuously monitored, recorded, and controlled to meet the fuel temperature limits of the Fueling Protocol..

- 3.1.3. Maximum gas temperature in vehicle tank 85°C
- 3.1.4. Maximum pressure rise and fueling rate are described in Section 4.
 - 3.1.4.1. Maximum fueling rate (equivalent to 10kg/180 s).....60g/s
- 3.1.5. Station-side PRV activation pressure (=1.38*70MPa)..... 96.3 MPa
- 3.1.6. Maximum allowable SoC: (40.2 g/L) = 100%

3.2. 70MPa H₂ Dispenser Fueling Capability (Demonstration phase)

- 3.2.1. Fueling time (passenger car*) with capacity up to 5 kg hydrogen ≤ 180 sec
- 3.2.2. Average Pressure Ramp Rate dispenser capability (for a 5kg tank)87.5MPa/180 sec
 - 3.2.2.1. Station should have data capability to confirm that from the station side the pressure rise and fueling rate requirement are met as described in Section 4.
- 3.2.3. Percentage (%) Fueling Target
 - 100% Full is defined as 40.2 g/L (70MPa @ 15C; 87.5MPa @ 85C)
 - 3.2.3.1. with communication..... 98-100%
 - 3.2.3.2. if communication fails see Section 4
 - 3.2.3.3. without communication see Section 4.
- 3.2.4. The station should at a minimum have the capability to fuel at least three 5kg vehicle storage systems within a time span of 45 minutes and 10 vehicles per day. Daily capacity may be larger based on regional fleet size projections.
- 3.2.5. Station owner / provider should incorporate the SAE J2799 communications hardware system for 70 MPa fueling stations to allow for vehicle to station communications

* Assuming a maximum total pressure drop from receptacle to onboard vehicle storage of less than 20MPa, under the following conditions: a vehicle tank pressure of 10MPa and a mass flow corresponding to a 1.5 factor of the mass flow given by the CPRR for a certain vehicle tank size (e.g. for a capacity of 5kg: mass flow = 5kg/180s * 1.5 = 41.67g/s). If the pressure drop value is exceeded, then the fueling time would be anticipated to be greater than target fueling time. Reference Section 1.4 regarding evaluation of these values for standardization.

3.3. Fueling Process

- 3.3.1. The station should be capable of fueling vehicles with and without active communication between the vehicle and dispenser. The station should calculate a new non-comm

procedure based on last recorded temperature and pressure in the event that the communication link is lost or the data integrity check fails and all safety checks of the fueling stations based on vehicle data. See table 1.

- 3.3.2. A detailed 70 MPa fueling process is described in Section 4.

3.4. *Hydrogen Gas Quality*

- 3.4.1. H2 gas quality guidance is given by the guideline SAE Technical Information Report (TIR) J2719. The goal is to revise SAE J2719 as research proceeds and standardize at the end of the Demonstration Phase.
- 3.4.2. Regarding particulates, at a minimum a 5- μ m filter should be installed upstream of the fueling nozzle to ensure that the maximum particle size requirement (10microns diameter) is met.
- 3.4.3. The fueling stations should include a means of preventing entry of oil, graphite or any other impurity into the gas stream. Synthetic oils shall be used in the compressed hydrogen handling equipment, due to a concern for sealing degradation with mineral oils.
- 3.4.4. Sampling of H2 gas to verify fuel quality should be done at the point of discharge to the vehicle using a sampler adapter according to ASTM D03.14 working group, which is expected to be finalized in 2007.
- 3.4.5. The fueling stations should provide an operation mode for taking H2 gas samples.
- 3.4.6. Fueling station owner / provider should have the delivered H2 gas analyzed at sufficient frequency to demonstrate the gas composition is reliably controlled to the requirements of J2719. Statistical capability should also be demonstrated.

3.5. *Dispenser / Fueling nozzle / Leakage*

- 3.5.1. Fueling nozzle geometry is to be in compliance with SAE J2799 for 70MPa (SAE J2600 for 25MPa & 35MPa.). The nozzle is to be certified according to SAE J2600.
- 3.5.2. Fueling nozzle-to-vehicle fueling receptacle connection should have a leak rate (< 20 Ncm³ / hour) in compliance with SAE J2600. (Ncm³/h = normal cubic centimeter per hour)
- 3.5.3. The fueling station owner / provider should document the leak check method that will be used at the beginning and during the fueling process (as per NFPA 52). Statistical capability of this leak check method should also be documented.
- 3.5.4. The fueling station operator should perform periodic leak checks of the nozzle.
- 3.5.5. A break away coupling should be installed in the connection from the dispenser to the vehicle.
- 3.5.6. The dispenser hoses and couplings should be designed for use that is free of obstructions; that is, designed for convenient handling that does not cause unusual awkwardness or use of force by the customer leading to excessive wear. The dispenser hoses should not touch the ground when the nozzle is stored in the dispenser unit.

3.6. *Electrostatic Discharge*

- 3.6.1. Maximum electrical resistance between fueling nozzle and ground of the filling station dispenser should be < 10 Ohm); i.e., the fueling stations nozzle should be grounded and bonded, and in good electrical contact with the dispenser ground.
- 3.6.2. Maximum electrical resistance between fueling station floor in the vehicle fueling area and ground of the fueling station dispenser should be less than or equal to 10^6 Ohm (per DIN EN 1081 Method B). Reference: American Petroleum Institute Recommended Practice 2003, Section 4.6.9.2.
- 3.6.3. The station owner / provider should certify that the fueling station is in compliance with 3.5.1 and 3.5.2.
- 3.6.4. Communication- and non-communication fuelings should require no additional connection for vehicle grounding.

3.7. *Material Compatibility*

- 3.7.1. All materials used in a hydrogen fueling station that are in direct contact with hydrogen should be hydrogen compatible according to applicable standards. For reference to hydrogen compatible materials, for example see website
3.7.1.1. <http://www.ca.sandia.gov/matlsTechRef/>

3.8. *Station Failure Protocol*

- 3.8.1. Fueling station should meet applicable codes, standards and regulations that govern hydrogen-fueling stations (reference NFPA 52).
- 3.8.2. Fueling station should change to a non-communications mode [1] in the event of break in communications/ or shut down if the threshold limits described in document are exceeded.
- 3.8.3. Backup safety devices should include pressure relief initiation at 110% maximum fuel pressure to be complete by 120% maximum fuel pressure, and secondary (backup) flow control to less than the maximum flow rate (Section 3.1.4.2). The service station shall discontinue service after the initiation of pressure relief and until corrective action by the station owner/provider.
- 3.8.4. Alarms should be incorporated in case of failure.
- 3.8.5. An Emergency switch should be easily accessible in the case of failure.
- 3.8.6. The station owner / provider should provide a 24-hour, 7-day per week toll-free number for servicing the station or have a contract person on-site to assist with station recovery.

- 3.8.7. Station recovery to normal operation should be completed as soon as possible. Fueling station provider / owner should have a plan for backup fueling of vehicles in the event the station is out of service for more than 24 continuous hours.
- 3.8.8. Target station availability is 95%.
- 3.8.9. The 35 MPa dispenser required at all 70MPa stations serves as the primary dispenser for 35MPa vehicles, and as a backup dispenser for 70MPa vehicles

3.9. *Remote Monitoring*

- 3.9.1. The station should incorporate remote monitoring to:
 - 3.9.1.1. Alert station operator/entity in charge of maintenance of system failures.
 - 3.9.1.2. Alert station operator/entity in charge of maintenance of need to schedule deliveries if hydrogen is not generated on-site.
 - 3.9.1.3. Alert station operator/entity in charge of maintenance of the need to service critical process equipment.
 - 3.9.1.4. Provide capability to remotely collect fueling and related data.

3.10. *Other Requirements*

- 3.10.1. No special clothing or other personal protective equipment should be required during fueling if conditions in 3.4 and 3.5 are met.
- 3.10.2. Station operator/entity in charge of maintenance should develop an Emergency Response Procedure for operators and users of the station.
- 3.10.3. Station operator/entity in charge of maintenance should be responsible for training operators and users of the station. This responsibility may be transferred to vehicle manufacturers with mutual written agreement; both should maintain a copy of such agreements.
- 3.10.4. Station operator/entity in charge of maintenance should provide a means to detect hydrogen fires in the fueling area and alert the station operator.
- 3.10.5. Fueling station should have a means of detecting and alerting operators of major station leaks.
- 3.10.6. Station operator/entity in charge of maintenance is responsible for compliance with all applicable ordinances, regulations and laws, and for acquiring and maintaining all required permits for construction and operation. This will include meeting requirements for periodic inspection and maintenance.

- 3.10.7. Station location and dispenser access should be convenient to the customer.
- 3.10.8. Station should be well lit, clean and clearly labeled.
- 3.10.9. Station hours of operation should include 6am through 10 pm (to be agreed upon between Station Provider/ Customer).
- 3.10.10. Station should provide fueling convenient to customer or by attendant.
- 3.10.11. Station should post or otherwise provide convenient reminder of fueling process steps.
- 3.10.12. Station should have a convenient procedure to identify a qualified fueler (including convenient payment if applicable)
- 3.10.13. Station will have capability for real-time reporting of station operation status to owner / provider.
- 3.10.14. Where possible, station should provide information services for vehicle to transfer data available through the internet.

4. Operating Conditions

4.1. Operating Conditions of the Vehicle's Fuel System

Fueling stations should employ fueling algorithms that ensure the station hardware is operated so that the fueling process falls within the guidelines of the industry-wide 70MPa Fueling Protocol that is described in this document. The 70MPa Fueling Protocol specifies common industry requirements for fueling within the defined range of ambient temperatures and the full range of initial internal pressures and states-of-charge in the vehicle compressed hydrogen storage system.

The gas in the vehicle's fuel storage system during fueling should stay below 85°C and 100% state-of-charge, and the pressure in the storage system should not exceed the MAWP. If communication is used, the fueling station should use the transmitted vehicle data to optimize the fueling according to the Fueling Protocol.

The following fuel system parameters should be taken into consideration during fueling 70-MPa compressed hydrogen fuel systems:

- 4.1.1 Fuel Storage System Pressure:
 - Minimum working pressure: 0.1 MPa (the typical minimum working pressure used currently is 0.3 – 2.0 MPa and is dependant on tank type/OEM)
 - Nominal working pressure (NWP): 70 MPa at 15°C
 - MAWP(Maximum allowable working pressure): 87.5 MPa

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- Maximum allowed gas density = 40.2 g/l (equivalent to 100% SOC). Tolerance to be determined by Powertech Multi-Client Fueling study.

4.1.2 Typical vehicle fuel system capacities:

- Light-duty vehicles: typically up to 5kg, but some up to 10 kg H₂.
- Commercial vehicles: greater than 10 kg H₂. A fueling station could also offer the possibility of fueling systems larger than those of light-duty vehicles, e.g. buses. This requirement should not compromise the fueling performance (SoC and fueling time) of the fueling station for light-duty vehicles. Therefore, a slower fueling time for larger vehicles may be experienced.

4.1.3 Fueling limits

Hydrogen gas density, temperature and pressure are directly related (see Figure 1). 100% SoC (40.2 g/L) at 87.5 MPa may only be reached in combination with a temperature of +85°C. The density of 40.2 g/liter is also achieved at a pressure of 70 MPa and 15°C. For a report on density calculations reference the following website: <http://www.boulder.nist.gov/div838/Hydrogen/PDFs/Hydrogen-2006-01-0434.pdf>

- See Section 3.1 for a complete list of fueling limits
- The purpose of the Fueling Protocol is to provide a fueling as close as possible to a 100% full in a short amount of time without exceeding fueling limits.

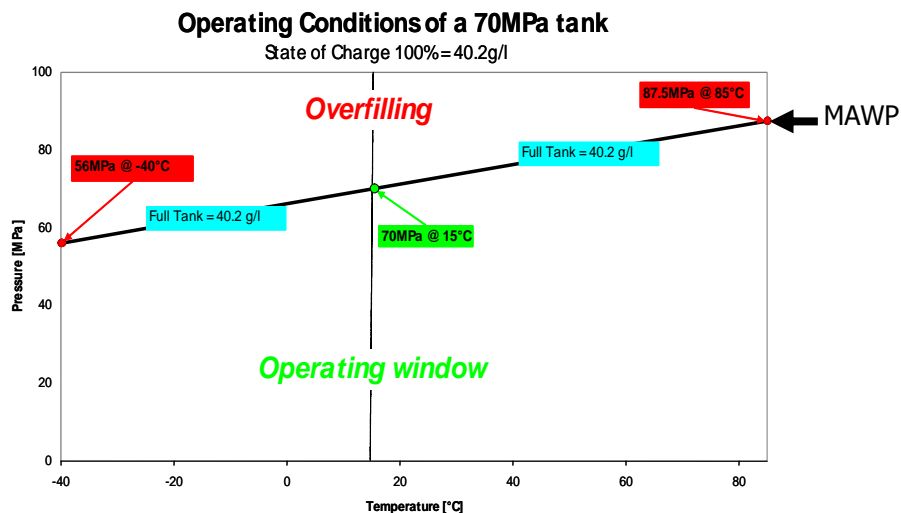


Figure 1: Operating conditions and definition of State of Charge of a 70MPa tank system

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4.1.4 Ambient Temperature range to which these requirements apply:

- Minimum ambient temperature: -40°C
- Maximum ambient temperature: +50°C

Fueling outside of the specified temperature range is dependent on OEM requirements and should be treated on a case-by-case basis.

4.1.5 Commercial Vehicle Fueling Rate:

- The expectations are identical between the commercial and light duty vehicles, with the exception of fueling time.

4.1.6 Light-duty Vehicle Fueling Rate:

- Targeted average fueling rate (Section 3.1.4.1) independent of fuel system's capacity and SoC.
- Maximum allowable fueling flow rate (Section 3.1.4.2).

4.1.7 Application of 70MPa Fueling Protocol to Fueling of Multiple Designs of 70MPa Vehicle Storage Systems

Several experimental programs are under way to evaluate the response (internal temperature & pressure) of currently representative vehicle storage tanks to variations in initial conditions, nozzle fuel temperature and rate of pressure increase (Section 1.4). It is expected that this information will be used to define a 70MPa Fueling Protocol that will specify common industry-wide characteristics and limits that all fueling processes implemented at 70MPa fueling stations (all variations of hardware, controls and control algorithms) will satisfy.

It would then be the responsibility of the station operators to periodically verify that fueling processes performed at the fueling stations provide fueling within the boundaries of the Fueling Protocol. It would be the responsibility of the vehicle manufacturers to ensure that vehicle storage systems are designed and verified to be capable of being fueled at fueling stations that provide fueling that satisfies the specifications of the 70MPa Fueling Protocol. This includes verification of the fueling of storage systems with multiple storage tanks that may differ in size and construction, and that may not fuel simultaneously, and that may not have the same initial temperature or pressure. Therefore, both vehicle manufacturers and fueling providers have an interest in developing a clear, well-validated 70MPa Fueling Protocol specification and ensuring it is

sufficiently robust.

Sections 4 and 5 of this document are expected to be revised in 2007 to include specification of a robust 70MPa Fueling Protocol based on experimental findings and modeling assessments (Section 1.4). Key elements of this Protocol will be the specification of parameters and limits on fueling processes, and also station verification tests to establish that appropriate performance occurs under extreme-case conditions.

4.2. Operating Conditions of the Fueling Station: the 70MPa Fueling Protocol

Fueling Stations that expect to fuel vehicles with up to 70-MPa compressed hydrogen gas storage systems should be capable of the performance described herein in order to fulfill the vehicle manufacturer's requirements for safe operation and also to fulfill customer expectations.

4.2.1 Ambient temperature range (Section 4.1.4):

- The station should fulfill performance requirements for the full ambient temperature range defined in this document. The fueling station may provide a reduced performance (e.g., slower fueling time and / or lower SoC) at ambient temperatures outside the temperature bounds. Note: This range is being confirmed by testing (see Section 1.4) and is expected to be incorporated into SAE J2601.

4.2.2 Pressure levels:

- 70-MPa dispenser: The fueling station should be capable of fueling 70-MPa fuel systems to 100% of targeted pressure in a reproducible manner without exceeding the limits in Section 3.1.
- The fueling station should also be capable of fueling 35 MPa fueling systems using a separate dispensing line with a 35 MPa nozzle. The 35 MPa fueling should be conducted in a reproducible manner without exceeding a fueling pressure of 43.8 MPa, a temperature of 85 C or 24.1 g/l SoC...

4.2.3 Fueling rates:

- The fueling station should ensure that the gas flow rate does not exceed the maximum allowable flow rate (Section 4.1).
- The fueling station should control the fueling rate to provide the targeted average fueling rate (Section 3.1.4.1).

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- A reduced fueling rate may be acceptable for fueling outside of the specified ambient temperature range.

4.2.4 Fueling time:

- Target fueling time (Section 3.1.5) applies when the ambient temperatures are within the specified range.
- Longer fueling times may be accepted for fuel systems with capacities > 10 kg or at ambient temperatures outside of the specified ambient temperature range.

4.2.5 Data Communication:

- A fueling station should allow for fueling with and without data communication.
- The data communication interface should be based on a minimum usage of IrDA as described in SAE J2799 (however some OEMs may have additional hardware requests)

4.2.6 Fueling Station flow restriction requirement:

The strongest restriction in the complete fueling path should be on the station side of the station-vehicle interface to ensure that the Joule-Thompson heating effect occurs on the station side. While station designs may vary, it is generally expected that this restriction would occur upstream of a fuel chiller and upstream of a station pressure sensor used to determine the pressure in the vehicle storage container.

4.2.6 Fueling Station Pressure Corridor:

The "pressure corridor" is an operating bandwidth governing the fueling process, defined by upper and lower limits placed on the pressure in the fuel system during a fueling. The vertical corridor width is intended to protect vehicle fuel lines from large potential fueling pressure pulses and Joule Thompson heating; the slope is intended to ensure sufficient fuel is delivered in an acceptable time. The corridor consists of several stages (see Figure 2).

4.2.7.1 Pressure Pulse

- Used for measuring the initial vehicle tank pressure P_0 . It may also be used to approximate the available volume in the tanks (and therefore determine a reasonable mass that is needed)
- This pulse should not exceed duration of (t_1-t_0) . During this time, the pressure at the nozzle should not exceed a value of P_p . At time t_1 the fueling station has measured the pressure inside the vehicle tank.

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- The fueling station computes the target final pressure P_{target} in the vehicle tank based on the initial tank pressure P_0 , the ambient temperature, and the pre-cooling temperature.

4.2.7.2 Fueling Stage 1

- After initial pressure in the vehicle storage system has been detected and P_{target} has been established by the fueling station, fueling begins
- The pressure at the nozzle should stay within a pressure corridor defined in Section 4.2.7.5 and within the flow limits listed in 4.2.3. The upper pressure limit in this stage is defined as "up1", and accordingly the lower pressure limit is defined as "lo1".
- Fueling rates should be consistent with the targeted average pressure rise (Section 3.1.4.1) and maximum flow rate (Section 3.1.4.2).

4.2.7.3 Fueling Stage 2

- The pressure at the nozzle should stay within a pressure corridor defined in Section 4.2.7.5 and within the flow limits listed in 4.2.3.
- Fueling rates should be consistent with the targeted average pressure rise (Section 3.1.4.1) and maximum flow rate (Section 3.1.4.2).

4.2.7.4 Fueling Stage 3

- The pressure at the nozzle should stay within a pressure corridor defined in Section 4.2.7.5 and within the flow limits listed in 4.2.3.
- Fueling rates should be consistent with the targeted average pressure rise (Section 3.1.4.1) and maximum flow rate (Section 3.1.4.2).
- Fueling is terminated when the target pressure, P_{target} , is reached. In communication fueling, the fueling process would also terminate if the hydrogen gas within the vehicle storage system reaches 85C.

4.2.7.5 Specification of Fueling Pressure Corridor

The fueling station should be capable of supplying the average fueling rate (Section 3.1.4.1) over the duration of the fueling process. The Fueling Protocol provides the target pressure P_{target} in the vehicle tank at the end of the fueling process based on the initial pressure in the vehicle tank P_0 , the ambient temperature and the fuel precooling temperature.

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The Fueling Protocol will be further developed to initially specify the pressure corridor parameters and fuel temperatures during 2007 once the experimental results of the Powertech multi-client study are available. That information is to be included in a revision to this document in late 2007.

Refer to Figure 2 and the following mathematical equations for a detailed description of the pressure corridor in which the fueling process must proceed.

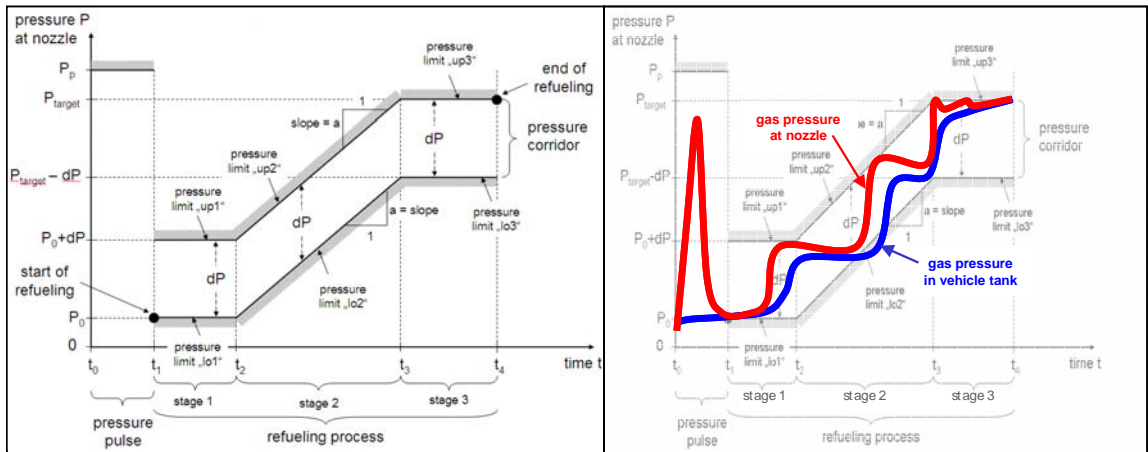


Figure 2: Fueling Protocol "Pressure corridor"

Figure 3. Example of a fueling process that satisfies the Fueling Protocol

Figure 3 shows an example of a fueling process that satisfies the Fueling Protocol shown in Figure 2. It includes an initial pressure pulse to determine the initial pressure in the vehicle storage system; the initial pressure pulse is limited by the mass flow limit (Section 3.1.4.2). If this pulse is also used for the initial leak test that confirms the nozzle/receptacle seal, then the pulse is expected to be at a low pressure and limited by the mass flow limit. The changing gas pressure is illustrated during the subsequent fueling stages, across which the average pressure rate defined by the corridor (Section 3.1.4.1) is achieved.

The Fueling Protocol defines a pressure corridor for the gas at the point of delivery to the vehicle; i.e., at the nozzle. The resulting pressure inside the vehicle tank may be outside this pressure corridor, as illustrated in Figure 3.

At any point during the fueling process, the momentary rate of pressure rise at the nozzle may be greater than the average rate specified in 3.1.4.1 if the nozzle pressure stays within the corridor and the mass flow is within limits (3.1.4.2).

Mathematical equations defining the pressure corridor:

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	upper pressure limit	lower pressure limit	intermediate switch times
stage 1	$P_{up1}(t) = P_0 + dP$	$P_{lo1}(t) = P_0$	
stage 2	$P_{up2}(t) = P_0 + dP + a * (t - t_2)$ $= P_0 + a * (t - t_1)$	$P_{lo2}(t) = P_0 + a * (t - t_2)$	$t_2 = t_1 + dP / a$
stage 3	$P_{up3}(t) = P_{target}$	$P_{lo3}(t) = P_{target} - dP$	$t_3 = t_1 + (P_{target} - P_0) / a$ $= t_2 + (P_{target} - P_0 - dP) / a$

Parameter definition:

- P_p = Maximum pressure (Section 3.1.1)
- dP = 10 MPa (*To be evaluated; Section 1.4*)
- a ≈ Stage 2 pressure corridor slope. Equivalent to the average fueling pressure rise (Section 3.1.4.1) if Stages 1 and 3 are very short.
- $t_1 - t_0$ = 2 s
- $t_4 - t_0$ ≤ targeted fueling time (Section 3.1.5) with exceptions as described in Section 4.1.2)
- $P_{target}, t_2, t_3,$ = determined by Fueling Station (parameters will be recommended based on fueling tests (Section 1.4). These parameters are expected to be different for Communication and Non-Communication fueling processes; e.g., $P_{target}(\text{Non-Communication}) < P_{target}(\text{Communication})$)

Transition points that define the fueling Stages and fueling pressure rates within each Stage are being evaluated (Section 1.4) and are expected to be incorporated in this document in the future and then made available for inclusion in SAE J2601 and corresponding dispenser standards (e.g., CSA 4.3).

4.2.8 Fueling Station Pre-cooling of Fuel (Gas Temperature at Nozzle, the Point of Delivery to Vehicle)

- The gas temperature in the vehicle's fuel storage system increases during fueling due to the heat of compression released and, to a lesser extent, the Joule-Thomson heating of the fuel as it is throttled through the system orifices. In order to prevent the containers from overheating while also allowing for more complete fuelings without sacrificing fueling speed. The Fueling Protocol specifies precooling of the hydrogen gas to be required as a function of

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- the ambient (non-communications) and initial (communications) tank temperature.
- The fueling station should have the capability to provide sufficiently pre-cooled hydrogen gas as to meet the minimum capacity (see 3.2.3).
 - The fueling station should be capable of setting the temperature of the pre-cooled hydrogen gas as a function of the ambient temperature consistent with the Fueling Protocol. (Figure 4 shows an example). The fueling station manufacturer should follow the Fueling Protocol to determine the necessary nozzle outlet temperatures as a function of ambient temperature and pre-cool the gas accordingly such that the nozzle outlet temperature does not exceed this temperature.
 - The temperature of the pre-cooled hydrogen at the nozzle outlet (vehicle inlet) may be lower than $-40\text{ }^{\circ}\text{C}$ only for ambient temperatures below $-40\text{ }^{\circ}\text{C}$. (Note: Some OEMs may not allow their vehicles to be fueled when the ambient temperature is below a value they specified.)
 - The station's pre-cooling equipment should be ideally installed 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.

Figure 4 shows a qualitative example of the dependence of the required hydrogen pre-cooling temperature on the ambient temperature (modeling results).

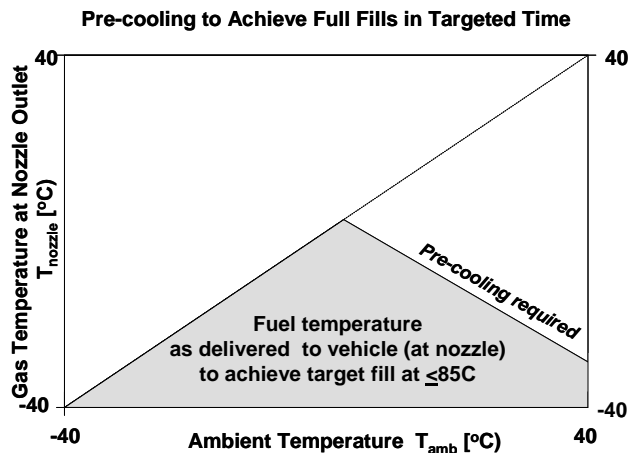


Figure 4: Example of Necessary Nozzle Outlet Temperatures as a Function of Ambient Temperature (goal: end temperature gas after 180 s: $< 85^{\circ}\text{C}$)

4.2.9 Termination of Fueling and Fault Management:

The fueling station should protect the vehicle's fuel system from pressurization over MAWP using at least three protection levels:

1st Level (normal control process):

Termination of the fueling process when the pressure in the fuel system reaches the calculated target pressure corresponding to the target capacity.

2nd Level (redundant electronic protection level):

Termination of the fueling process when the pressure in the fuel system reaches 87.5 MPa (43.8 MPa for 35-MPa dispenser). A dedicated, highly reliable, and calibrated station-side pressure sensor and processing of its signal should be used.

3rd Level (final, fully mechanical protection level):

Prevention of any further pressure increase in the fuel system by activation of a station-side (FS) PRV set at $1.25 \cdot \text{NWP} + 10\% = 1.375 \cdot \text{NWP}$ (96.25 MPa for a 70-MPa dispenser and 48.13 MPa for a 35-MPa dispenser). At this pressure, the fueling stations should release the fueling line pressure via a vent line. Note: NFPA 52 references a $1.4 \cdot \text{NWP}$ PRV set point.

5. IrDA for Communication Fuelings

5.1. General Philosophy / Definitions

The fueling station should enable a safe, reliable, complete, and fast fueling of the vehicle's fuel storage system with compressed hydrogen gas. All initial gas temperatures in the fuel systems as defined by the OEMs and all possible container types and sizes and initial SoC (partially fueled fuel systems) should be taken into account.

The station should provide a suitable pre-cooling temperature, pre-cooling capacity, and flow (pressure increase) rate such that the maximum gas temperature in the containers at the end of the fueling process does not exceed the maximum specified value and the targeted vehicle fuel system fueling density defined in section 4.1.

Two types of fueling should be provided at a 70MPa fueling station: fueling with and without active communication of information from the vehicle.

Currently, protocols employing both methods have room for optimization. Fueling process guidelines for

fueling stations (e.g., recommended pre-cooling, fueling rates and target final pressure) are under development (see Section 1. for both Communication and Non-Communication Fueling (see Section 1.4) and are expected to be standardized in SAE J2601 and associated dispenser standards.

5.1.1 Non-Communication Fueling.

During a Non-Communication Fueling, the station does not receive any data from the vehicle and relies on its sensor information for implementation of all control functions.

5.1.2 Communication Fueling. The objective of Communication Fueling is to use information transmitted from the vehicle to the fueling station to improve the final fuel density over the final fueling conditions that would be achieved in Non-Communication Fueling.

During Communication Fueling, the vehicle supports the fueling station by transmitting vehicle data to the station. The station should employ the IrDA-based data interface described in TIR J2799 to enable Communication Fueling.

The fueling station is to employ established validation protocols (See Section 5.4) to detect circumstances where the transmitted fuel system parameters are corrupted, or a wrong fueling command is transmitted by the vehicle or received by the station. The station is responsible not to exceed predefined thresholds for pressure, temperature and SoC in the vehicle's fuel system. This performance should be ensured by adequate test and verification procedures, based on the requirements derived from this document.

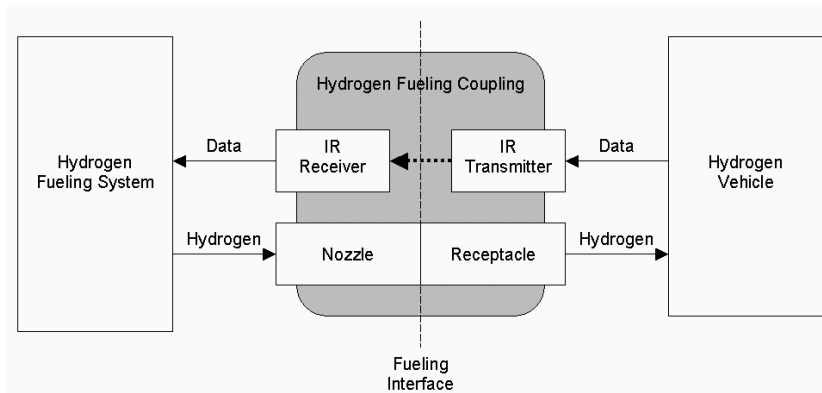


Figure 5: Schematic representation of the overall fueling system with communication (From SAE J2799)

For a communication fueling, the data defined in Section 5.4 (see also SAE J2799) should be transmitted by the vehicle and received by the station correctly. Successful

data verification is mandatory, including use of the station sensor information for plausibility checks and for the implementation of all safety-relevant control functions.

5.2. *Fueling Requirements*

The fuel level or state of charge (SoC) of the vehicle's hydrogen fuel storage system is not defined by pressure alone, but instead by combinations of pressure and temperature that correspond with specific hydrogen densities (defined in section 5.1).

5.3. *Fueling Data Interface Hardware*

The hardware of the fueling data interface is based on SAE J2799 (to be superseded in the future by SAE J2601). To enable reliable communication, at least one transmitting diode at the vehicle's fueling receptacle and at least three receiving diodes around the fueling station's fueling nozzle will allow for a stable signal transmission at every position of the connected nozzle.

The nozzle / receptacle interface for 35 MPa and 70 MPa systems are defined in SAE J2600 and J2799, respectively.

5.4. *Transmitted Data*

The vehicle's fuel storage system data defined in SAE J2799 (and later in J2601) are created by the vehicle's tank control unit and transferred to the IR transmitting diode(s) installed next to the fueling receptacle. In agreement with SAE J2799, the following data are transmitted continuously (with a frequency of 10 Hz):

- Protocol Identifier (ID)
- Software Version Number (VN)
- Tank Volume (TV)
- Receptacle Type / Pressure Level (RT)
- Fueling Command (FC) (Possible values: Dyna (dynamic), Stat (static), Halt, Abort)
- Measured Gas Pressure in Vehicle Fuel Containers (MP)
- Measured Gas Temperature in Vehicle Fuel Containers (MT)
- Optional Data (OD)

5.4.1. Data Integrity

The data transmission from the vehicle to the fueling station may be corrupted. To detect corruption of a data packet and to properly react to possible failures, different mechanisms are included in the transmission protocol and the receiving unit (see SAE J2799).

All data packets sent by the vehicle RDI system include a "frame check sequence" (FCS) field. This FCS field comprises a 16-bit cyclic redundancy check (CRC-CCITT) value computed on the application data field of the data packet. All data packets received by the fueling station RDI system should be checked analyzing the FCS field to detect potential errors in the received application data field. An implementation of the FCS field is specified in SAE J2799 (and in the future, J2601).

The fueling station RDI system should perform a data integrity check for all received application data. This includes a check of all received delimiters, tags, character data and numerical values as specified in SAE J2799.

A defined transparency character should be used to transform transmitted data bytes. This transparency is specified in SAE J2799.

Within the fueling station RDI system, different message counters are established:

- a counter for "good" messages (for each data integrity check passed successfully, the message counter is increased)
- a counter for "fail" messages (received data packet is out of specification (see SAE J2799))

The interpreting logic is based on the following conditions:

- If an incoming message is "good" and the "fail" message-counter is not increased, the message is valid and can be used.
- If an incoming message is "good" but the "fail" message-counter is increased also, the message is not valid. A failure was detected and the message should not be executed.
- If an incoming message increases only the fail message-counter, then the message is not valid. A failure was detected and the message should not be executed.
- If none of the counters is increased, no actual message was received. Either no message at all was received, or the identical message was sent again.

After the operator initiates the fueling process at the fueling station, the received data message should be confirmed to be valid via the CRC. A data field should have been updated by properly formatted message data within **10 times** the nominal transmission interval to be considered valid.

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If a problem is encountered, the fueling station may have the option to inform the vehicle operator by a fault message on the dispenser’s display.

If the last non-corrupted data package received by the station contained the Fueling Command "Dyna or Stat" then the fueling station should default to a non-communication method of fueling as defined in J2799.

If the last non-corrupted data package received by the station contained the Fueling Command "Halt" or "Abort" then the fueling station should stop the fueling operation.

Table 1: Corrupted data and corrupted data transmission management by the fueling station

Dispenser Pressure level	Last Fueling Type	Last Fueling Command	Fallback Strategy
35 MPa, 70 MPa	Communications Fueling	Dyna or Stat	Non-Communication Fueling *
		Halt	Terminate Fueling
		Abort	Terminate Fueling

* The dispenser should attempt to support the highest-level fueling process for which it has received all the required data that meets the required data integrity checks. If there is a break in communications and the last signal is halt, the controller shall abort the fueling process. The dispenser should default to an appropriate fallback fueling strategy, if one or more of the required data fields fails to pass its data integrity check.

5.4.2. Definition of Fueling Commands

Table 2 shows an example of fueling command thresholds. It shows how the vehicle TCU may set the fueling commands based on various relevant fuel system parameters. These thresholds may differ between OEMs. The "Halt" Command is not used in this example.

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Table 2: Example for Fueling Command Thresholds

Data Signal	Description	FUELING COMMAND (setting by TCU)		Comments
		Fuel	Abort	
Gas temperature	Usually one temperature per cylinder measured by TCU: Up to 85 °C: Volume-weighted average gas temperature over all sensors Above 85°C: Selection of max. sensor temperature	$T < 85^{\circ}\text{C} - T_{\text{Tolveh}}$	$T \geq 85^{\circ}\text{C} - T_{\text{Tolveh}}$	T_{Tolveh} is the tolerance of the gas temperature measurement in the vehicle storage system
Gas pressure	Min. one pressure measured by TCU	$P < 87.5\text{MPa} - P_{\text{Tolveh}}$	$P \geq 87.5\text{MPa} - P_{\text{Tolveh}}$	P_{Tolveh} is the tolerance of the pressure sensor in on-board storage system
State of Charge SoC	SoC calculated by TCU	$\text{SoC} < 100\% - \text{SoC}_{\text{Tolveh}}$	$\text{SoC} \geq 100\% - \text{SoC}_{\text{Tolveh}}$	$\text{SoC}_{\text{Tolveh}}$ is the tolerance of the SoC calculated by the TCU for the vehicle storage

T_{Tolveh} , P_{Tolveh} and $\text{SoC}_{\text{Tolveh}}$ are determined by the vehicle manufacturer based on its evaluation of measurement tolerance in the installed sensor instrumentation. These values are used onboard the vehicle in its determination of the appropriate fueling command to be issued by the vehicle.

5.4.3. Fueling Station Reaction to Fuel Command "Halt":

As soon as the station receives a valid fueling command "Halt", the hydrogen flow should be stopped. The fueling process itself remains active; if a valid fueling command "Dyna or Stat" is received again, the

hydrogen flow is reinitiated and the fueling is continued.

A fueling command "Halt" can be generated if one of the relevant parameters reaches or exceeds a defined threshold. After some time, for example, the gas temperature may drop below the threshold, the fueling can be continued. If the threshold is reached or exceeded for a certain period of time (to be determined), the vehicle TCU will generate the fueling command "Abort".

5.4.4. Fueling Station Reaction to Fueling Command "Abort"

When the station receives a valid fueling command "Abort", the hydrogen flow should be interrupted and the fueling process should be terminated. Terminating the fueling process includes depressurizing the hydrogen fueling hose and closing the relevant station-side valves.

If a fueling command "Dyna or Stat" is received after an "Abort" command has been received, the station should ignore the "Dyna or Stat" command. After a FC "Abort", the vehicle operator may reinitiate the fueling process manually. Possible criteria and corresponding thresholds for generating the Fueling Command "Abort" are indicated in Table 1 (may differ from OEM to OEM).

6. Hardware

6.1. Vehicle Fuel System Hardware

Figure 6 illustrates a generic example of an on-board compressed hydrogen fuel system. Specific OEM systems are likely to differ in several respects such as the number of tanks, number of internal components (i.e. valves and sensors), and placement/design of internal components. Some fuel systems may include a stop-fueling-valve in the fueling line that allows for an active mechanical interruption of the fueling process by the vehicle. Each fuel system will be equipped with a 70 MPa rated fueling receptacle as per SAE J2600 (initially specified in SAE J2799). A further description of these internal fuel system components are provided in the Terminology section within the Definition of Dedicated Terms. The operating condition of the vehicle's fuel system is described in section 4.1.

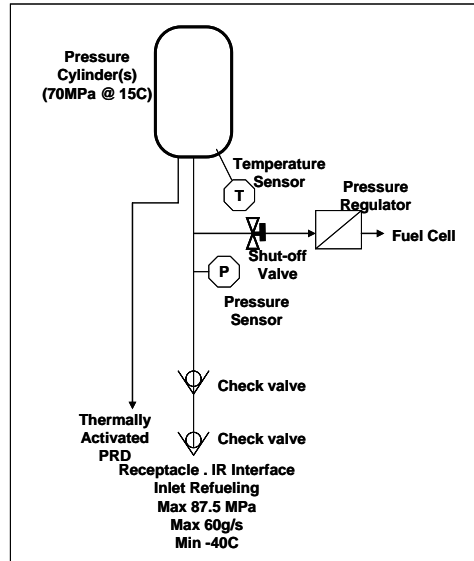


Figure 6: Schematic of a hypothetical vehicle's compressed hydrogen fuel storage system.

6.2. Fueling Station Hardware

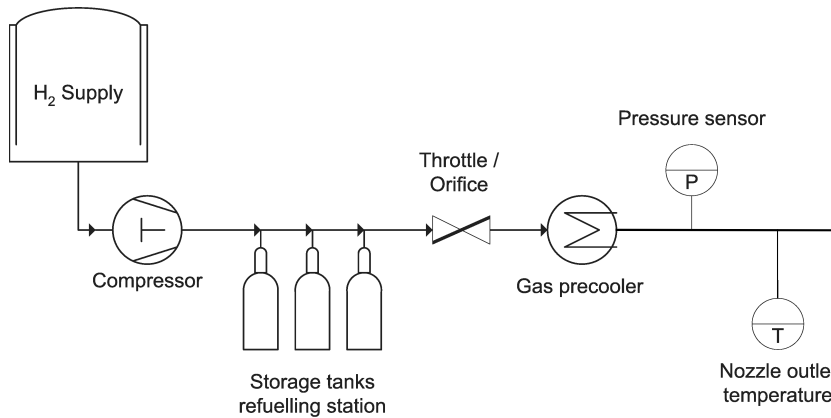


Figure 7: Schematic example of simplified 70 MPa compressed hydrogen fueling configuration

Figure 7 shows a simplified generic schematic of a 70 MPa compressed hydrogen fueling station that illustrates basic functional elements. As with OEM fuel systems, each hydrogen station will likely differ in its design and implementation. This equipment may be designed to provide fueling within the pressure corridor specified in 4.2.7.5 using a variety of methods. For example, fueling may proceed from station storage tanks that provide fuel at pressures up to the target fueling pressure (cascade fueling), or fueling may occur using compression during the fueling process (boost pressure fueling), or by a combination of these methods.

6.3. Fueling Process Control

6.3.1. Fueling Process Definitions

A “communication” fueling process requires the transmission from the vehicle to the fueling station of all signal data listed in section 5.4 (in some cases a sub-set of the data may be used).

A “Non-Communication” fueling process does not require any data transfer between vehicle and station.

Any corrupted data or data transmission should be handled as defined in Section 4.4.3

6.3.2. Non-Communication Fueling

The fueling station should determine a target fueling pressure. The fueling station should measure the fuel system initial pressure at the beginning of the fueling process. During the fueling process, a revised target pressure may be determined by the fueling station based on dedicated and proven algorithms.

The station should also estimate the current state of charge (SoC) of the vehicle’s fuel system during the fueling process based on the above data (iterated gas temperature). Due to inaccuracies in measurements such as the measurement of the vehicle storage pressure, uncertainty in the estimate of the initial internal temperature of the fuel storage system, the calculation of the SoC has a limited accuracy. Nevertheless, the fueling station should prevent an overfilling. Therefore, the station should end the fueling process during non-communication fueling as soon as the current calculated SoC for non-communication fueling reaches 100% minus the tolerance of the estimation. A threshold value for SoC (including allowance for tolerances of the SoC estimation and station sensors) for non-communication fueling should be defined by the manufacturer of the fueling station based on suitable tests that demonstrate that an overfilling for non-communication is not possible under extreme conditions (see Section 7). OEMs are working with station providers to define extreme conditions and corresponding station verification tests (Section 1.4) and will support fueling station suppliers to carry out station verification tests.

For non-communication fueling, the target density target is **not** specified in this document, as it is to be determined with data input from experiments (see Section 1.4). The result of these experiments will be a target SoC < 100% for non-communication fueling - called SoC_n -which could be optimized by station provider. The goal is to create enough data to establish thresholds for standardization in the draft document SAE J2601. The J2601 Fueling Protocol will be developed jointly between fueling station providers & OEMS but the station algorithms may differ because they need to take account of tolerances of station equipment. It is intended to finalize J2601 with data from the Multi-Client OEM/

Energy Company Study to be finalized in 2007.

If the threshold pressure (87.5 MPa) is reached prior to the SoC_n target, the station should stop the fueling process based on the achieved reached pressure level...

The fueling station should stop the non-communication fueling process as soon as one of the conditions listed in Section 4.1 is reached.

6.3.3. Communication Fueling

To control a communication fueling process, the fueling station should use the same information as in the non-communication fueling process plus the vehicle's fuel storage system data transmitted via the IR data interface. The station should use the received vehicle data to support the fueling station during communication fueling in order to allow for improvements to the fueling process. The station should rely on station measurements for primary safety assurance.

The vehicle transmits the signal data listed in Section 5.4. The station receives the fueling commands and should initiate or stop the fueling process. During normal operation, the vehicle controls all relevant parameters of its fuel system (see Table 2) and requires the station to end the fueling process by sending the corresponding fueling command ("Abort") to the station. The station should be responsible for the safety of the complete fueling process.

The station should stop the fueling process as soon as it receives an "Abort" command from the vehicle or one of the conditions listed in Section 4.1 is reached.

6.3.4. System Behavior during Corrupted Communication Fueling

If the communication is corrupted, fueling station behavior should be as follows:

If the **last non-corrupted** data package received by the station contained the Fueling Command "Dyna or Stat" then the fueling station should fall back into non-communication fueling.

If the **last non-corrupted** data package received by the station contained the Fueling Command "Halt" or "Abort" then the fueling station should terminate the fueling operation.

The station should stop fueling as soon as SoC_n or the pressure threshold of 87.5 MPa is reached.

The fueling station should be capable of detecting a corrupted communication (see Section 4.3.2 for error messages sent to the fueling station) and should also continuously perform the following plausibility checks:

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$$|\text{SoC}_{\text{FS}} - \text{SoC}_{\text{V}}| < \text{SoC}_{\text{D}}$$

$$|\text{P}_{\text{FS}} - \text{P}_{\text{V}}| < \text{P}_{\text{D}}$$

$$|\text{T}_{\text{FS}} - \text{T}_{\text{V}}| < \text{T}_{\text{D}}$$

With:

- SoC_{FS} : Current SoC value calculated by the fueling station based on its own data (using no data from the vehicle)
- SoC_{V} : Current SoC value calculated by the fueling station based on data received from the vehicle
- SoC_{D} : Maximum allowed absolute difference between SoC_{FS} and SoC_{V}
- P_{FS} : Current fueling pressure measured by the fueling station
- P_{V} : Current vehicle fuel pressure measured and transmitted by the vehicle
- P_{D} : Maximum allowed absolute pressure difference between P_{FS} and P_{V}
- T_{FS} : Current vehicle fuel temperature estimated by the fueling station
- T_{V} : Current vehicle fuel temperature measured and transmitted by the vehicle
- T_{D} : Maximum allowed absolute temperature difference between T_{FS} and T_{V}

If the limits SoC_{D} , P_{D} or T_{D} are exceeded, the fueling station should automatically switch to a non-communication fueling (with a SoC limit equal SoC_{n}). Once this has occurred, the fueling station should continue the non-communication fueling (and should not switch back to a communication fueling).

6.4. Defined Thresholds for Vehicle and Station

Table 3 summarizes the relevant fueling thresholds for gas temperature, pressure, and SoC. The thresholds valid for both fueling modes (non-communication fueling and communication fueling) are listed.

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Table 3: Overview of Thresholds

Thresholds for gas temperature, pressure, and state of charge valid for station and vehicle. (Measurement tolerances will vary between stations and vehicles depending on the selection of sensors and control equipment).

Threshold for:	Gas Temperature	Pressure	SoC (Gas Density)
<i>Non-Communication Fueling:</i>			
Station stop	85 °C* - T _{Tolstation}	P _{Target} - P _{Tolstation} **	SoC _n =100% - SoC _{Tolstation}
<i>Communication Fueling:</i>			
Vehicle Abort***	85 °C - T _{Tolveh}	P _{Target} - P _{Tolveh}	100% - SoC _{Tolveh}
Station Stop		P _{Target} - P _{Tolstation}	Or 100 %****
Station tolerance range 70 MPa	±3K within 5 s (ambient)	< ±0.88 MPa (1% FS)++	---
Vehicle tolerance range 70 MPa	±3K within 5 s (gas)	< ± 1.75 MPa (2% FS) within 1 s	---

* Vehicle storage gas temperature calculated by the fueling station using its own algorithm.

** P_{target} is chosen by the FS as the pressure which results in SOC_n.

*** Vehicle Abort strategy may be based on the SoC (typically) or on a vehicle calculated P_{target}.

**** May be revised in the future based on test results and field experience.

++ This tolerance may not be sufficient for controlling the fueling process especially at the beginning of the fueling

7. Tests to Verify Compliance of Fueling Process

The capability of a fueling station to fulfill the requirements of the 70MPa Fueling Protocol should be assured to perform reliable and efficient fueling. That capability is provided by the use of reliable equipment operated under the control of robust fueling algorithms that execute the fueling process according the required 70 MPa Fueling Protocol. This capability can be verified by performance tests described in this Section. These performance tests are designed to demonstrate required performance under extreme conditions. Specifically, they are designed to prove that neither overfilling nor overheating of the vehicle fuel system will occur during non-communication fueling, and that the fuel meets quality expectations at the point of delivery to the vehicle.

Station performance verification tests will be revised subject to their evaluation as extreme fueling conditions in fueling experiments that are underway (see Section 1.4) and are expected to be referenced in SAE J2601 and incorporated into CSA 4.3.

7.1. Test to Verify “No Overfilling of the Tanks”

The following test matrix is based on modelling and testing of CHG storage systems. Note: there is a tolerance given in order to utilize available storage tanks.

Test 1:

Container capacity	2.0±0.1 kg H2	<i>Minimal tank size passenger car (1 cylinder)</i>
Container type	metal lined composite	<i>Type tends more to be overfilled</i>
Volume-to-surface ratio [m]	0.05 m	<i>available test container can be used</i>
Ambient temperature range	5°C to 40°C	<i>Wide range ambient temperatures possible</i>
Initial temperature difference between the gas in the container and the ambient	Temperature after defueling procedure*	<i>Container temperature is lower than ambient temperature when fueling after fast driving</i>
Initial SoC in the container	30±1%	<i>Extreme case as shown by simulation</i>

* Defueling procedure: Fuel system with an initial SoC = 99±1% is defueled with a constant hydrogen mass flow of 1.8 g/s. When 30±1% SoC or -39 ±1 °C is reached, the fueling process is stopped. After 30 s, the fueling station fuels the storage system.

7.2. Test to Verify “No Overheating of the Tanks”

The following test matrix is based on modelling and testing of CHG storage systems. Note: there is a tolerance given in order to utilize available storage tanks.

Test 2:

Container capacity	10.0±0.1 kg H2 or max. size available at OEMs	<i>Maximum tank size passenger car (1 cylinder)</i>
Container type	Polymer lined composite	<i>Plastic liner heats up faster</i>
Volume-to-surface ratio [m]	0.1 m	<i>available test container can be used</i>
Ambient temperature range	0 - 20°C	<i>Wide range ambient temperature possible</i>
Initial temperature difference between the gas in the container and the ambient	$T_{amb}-T_{Tank}=-25\pm 2^{\circ}C$	<i>Tank temperature is 25°C higher than ambient**</i>
Initial SoC in the tanks	1±1%	<i>Extreme case, proved by simulation</i>

** Complete storage system should be homogeneously tempered for at least 4 hours.

7.3. Test to Verify Quality of Fuel Delivered to Vehicle (at nozzle)

Provide chemical analysis of H2 sampled at point of delivery to a vehicle (nozzle outlet) to confirm TIR J2719 threshold values. See section 3.4.4.