



SURFACE VEHICLE TECHNICAL INFORMATION REPORT

J2601™-4

OCT2024

Issued

2024-10

Ambient Temperature Variable and Fixed-Orifice Fueling Protocols for Light-Duty
Gaseous Hydrogen Surface Vehicles

RATIONALE

The Technical Information Report, J2601, issued March 2010 (2010 TIR), provided guidance for fueling vehicles with and without precooling of the dispensed hydrogen. The 2010 TIR also highlighted a potential issue with higher-than-expected CHSS temperatures that could arise if a vehicle were to fuel at one station immediately followed by a higher pressure fueling at a second station, also known as a subsequent fill. Ongoing revisions of J2601 address subsequent fill issues for stations with precooling and eliminate the fueling protocol for stations that do not cool the hydrogen gas to the levels defined by the T20, T30, or T40 protocols.

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1. SCOPE

SAE J2601-4 establishes process limits for ambient temperature hydrogen fueling of light-duty automotive vehicles, passenger cars, and trucks that use a compressed hydrogen storage system (CHSS) that meets SAE J2579, where ambient temperature hydrogen fueling is defined as a fueling event where the fuel delivery temperature is greater (e.g., warmer) than the precooled requirements of SAE J2601.

Table 1 depicts the scope of SAE J2601-4 and potential work items for future revisions within this or other documents of the SAE J2601 series. SAE J2601 includes protocols that are applicable for two pressure classes (35 MPa and 70 MPa), three fuel delivery temperature categories (-40 °C, -30 °C, and -20 °C) and CHSS sizes from 49.7 to 248.6 L. Future versions of SAE J2601 may incorporate warmer fuel delivery temperatures (-10 °C and ambient) and smaller compressed hydrogen storage systems for motorcycles and other light-duty applications.

Fueling protocols should be developed based on a set of key assumptions described in Section 7 and Appendix A of J2601. These assumptions should be carefully considered in the development and implementation of an onboard CHSS. In particular, hydrogen storage systems with properties that do not fall within the parameters in Table A3 of SAE J2601 should be further evaluated with protocols developed based on the process limits described in this Technical Information Report (TIR).

For fueling with communications, this TIR is to be used in conjunction with SAE J2799.

This document focuses on the fueling protocol and the equipment necessary to implement the fueling protocol properly. Other requirements may be necessary to operate the station in a proper manner.

Table 1 - Content of SAE J2601

Storage Capacity Classification		Small Capacity (e.g. Motorcycle) (< 1.2 kg)	Light Duty (1.2 - 6.0 kg)	Small Capacity (e.g. Motorcycle) (< 2.0 kg)	Light Duty (2.0 - 10.0 kg)
SAE J2601 Fueling Protocols	T40	Not Included	Not Included	Not Included	Not Included
	T30				
	T20				
	T10				
	T_Ambient		Included		Included
Station Dispenser Type Category					

2. REFERENCES

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 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 +1 724-776-4970 (outside USA), www.sae.org.

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

SAE J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

SAE J2799 Hydrogen Surface Vehicle to Station Communications Hardware and Software

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

CSA HGV 4.3 Test methods for hydrogen fueling parameter evaluation

2.1.3 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61508 Functional safety of electrical/electronic/programmable electronic safety-related systems

IEC 61511 Functional safety - Safety instrumented systems for the process industry sector

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2574 Fuel Cell Vehicle Terminology

SAE J2578 Recommended Practice for General Fuel Cell Vehicle Safety

Schneider, J., Mathison, S., Ward, J., Taha, E. et al., "Gaseous Hydrogen Station Test Apparatus: Verification of Hydrogen Dispenser Performance Utilizing Vehicle Representative Test Cylinders," SAE Technical Paper 2005-01-0002, 2005, <https://doi.org/10.4271/2005-01-0002>.

3. DEFINITIONS

3.1 AMBIENT TEMPERATURE FUELING PROTOCOL

A fueling protocol where the fuel delivery temperature is greater (e.g., warmer) than the precooled requirements of SAE J2601.

3.2 ORIFICE

A fixed change in geometry used to preset or measure a flow rate. It can be as simple as a hole through a plate or as complicated as the torturous flow path through a valve or device.

3.3 PRECOOLED FUELING

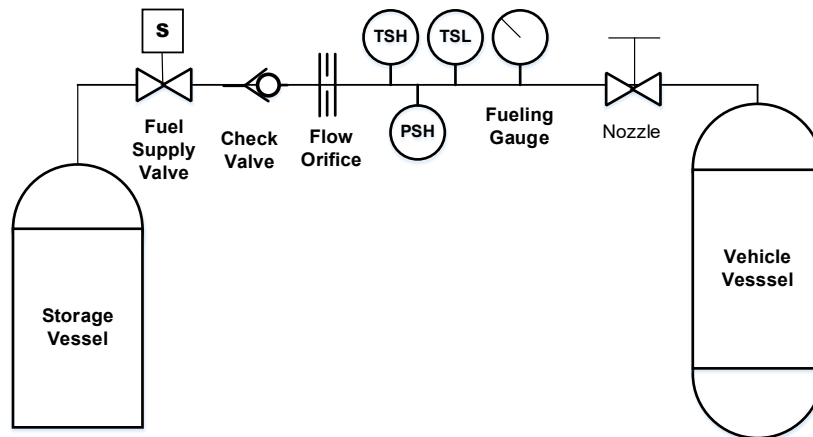
A fueling event that follows the requirements in SAE J2601 (2016) or later.

3.4 SUBSEQUENT FUELING

A fueling event, whether precooled or non-precooled, regardless of pressure class, which follows the current ambient temperature fueling event and may be affected by the thermodynamic characteristics of the gas in the CHSS at the end of the current ambient temperature fueling event. In simpler terms, it is the fueling event that follows the current ambient temperature fueling event. Refer to SAE J2601, Appendix A and 3.9 for further description.

3.5 FIXED-ORIFICE FUELING PROTOCOL

A fixed-orifice fueling protocol is a simple vessel-to-vessel gas transfer in which the flow rate is governed by a flow orifice of fixed size and geometry. A protocol may be defined by the orifice size and configuration, the upstream pressure and volume, various upper and lower temperature and pressure limits, and the downstream CHSS volume and target pressure. These conditions may be applied by a simple control system with appropriate temperature and pressure inputs and on-off valve outputs, which are configured to ensure that a specifically defined set of pressure and temperature boundaries are maintained, ensuring a safe fueling event that complies with the CHSS safe process limits. A conceptual schematic of a fixed-orifice Hydrogen Refueling System is shown the figure below. Safety elements and control elements are not depicted in the drawing.



4. ABBREVIATIONS AND SYMBOLS

4.1 CHSS - Compressed Hydrogen Storage System

4.2 TIR - Technical Information Report

5. FUELING PROTOCOL DESCRIPTION

SAE J2601-4 establishes the guidelines for ambient temperature fueling protocols for passenger cars and trucks with a total CHSS capacity of 10 kg or less when the fuel is provided above -17.5 °C. The TIR assumes that a station will perform fueling from its high pressure storage into the vehicle after successful vehicle connection and completion of initial safety checks. The fueling station shall be responsible for controlling the fueling process within the operating boundaries described in this document while considering compatibility with existing hydrogen fueling standard(s). Variables that affect the fueling process include, but are not limited to:

- Ambient temperature
- Supply gas temperature variation from ambient temperature
- CHSS size, shape, and material properties
- Dispenser to vehicle pressure drop and heat transfer
- Initial CHSS pressure

A representative fueling profile is shown in Figure 2. The profile consists of “start-up time,” which begins when the nozzle is connected to the vehicle and includes a connection pressure pulse. During the start-up time, the station measures the initial CHSS pressure and may determine CHSS capacity category and also check for leaks.

The main fueling begins when gas starts flowing into the vehicle. During this period, pressure and temperature of the gas within the CHSS may rise. The execution of a fueling protocol based on the process limits described in SAE J2601-4 (this document) should be implemented such that the CHSS does not exceed the maximum operating temperature or create conditions that would lead to exceeding the maximum operating temperature at any time during the fueling. The final stage is the shutdown, which occurs after hydrogen gas has stopped flowing from the dispenser to the vehicle and the nozzle is disconnected.

All references to SAE J2601 in Section 5 (this section) refer to the most recently published version of the standard.

5.1 Performance Goals

In general, the goal of this TIR is to allow fueling from a non-precooled fuel source in as little time as possible while staying within the safety limits defined in SAE J2579 for the vehicle CHSS. The fueling time may vary depending on ambient temperature, initial CHSS pressure, size of CHSS, final state of charge (SOC), and other conditions.

5.2 Normal Operating Boundaries

The fueling process limits in SAE J2601-4 are designed to ensure the hydrogen gas in the CHSS does not exceed the safety limits defined by the process requirements of SAE J2579. These requirements and the detailed description of the normal operating boundaries are provided in 5.2 of SAE J2601.

5.2.1 CHSS Temperature and Pressure Limits

For H35 or H70 fueling, the CHSS temperature and pressure limits are -40 to 85 °C and 5 to 70 MPa, respectively.

5.3 Standard Protocol

A standard protocol is defined as a protocol that complies with the general fueling protocol description of Section 5 of SAE J2601 and the general process requirements in Section 6; takes into account both the station and vehicle CHSS assumptions defined in Section 7 and Appendix A of J2601; has demonstrated the ability to keep the CHSS within its operation boundary limits under all conceivable operating conditions via computer modeling and bench testing; has been tested and validated in the field at representative real-world hydrogen stations; and has been reviewed and approved by the SAE Fuel Cell Standards Committee Interface Task Force.

5.4 Ambient Temperature Protocols

The ambient temperature protocols meeting the requirements of this document do not meet the definition of standard protocol (see 5.3). Therefore, the SAE J2601-4 TIR is not considered a standard protocol of SAE J2601.

6. GENERAL PROCESS REQUIREMENTS FOR AMBIENT TEMPERATURE HYDROGEN FUELING

This section is intended to cover the general hydrogen fueling process requirements. Appendix A provides guidance for fueling methods in accordance with Section 6 of this document.

NOTE: Section 6 does not define the dispenser or station equipment.

6.1 CHSS Storage Limits

This TIR applies to the fueling of light-duty vehicles with CHSS capacity from 2 to 10 kg for 70 MPa and 1.2 to 6.0 kg for 35 MPa. Refer to Table 4 of SAE J2601 for a more detailed description of storage capacities.

6.2 Process Requirements for Measurement and Sensors

6.2.1 Location

6.2.1.1 Station Pressure and Fuel Delivery Temperature

The sensors measuring the station pressure and fuel delivery temperature shall be located upstream of and as close as possible to the dispenser hose breakaway. The flow length between the sensor and hose breakaway shall be no greater than 1 m.

6.2.1.2 Ambient Temperature

The station storage shall contain an ambient temperature sensor and that ambient temperature sensor shall comply with the requirements of 6.2.1.2. The sensor used to measure the ambient temperature shall be protected from environmental conditions that may affect its accuracy.

6.2.2 Accuracy

The station pressure, fuel delivery temperature, and ambient temperature shall account for the sensor accuracy to ensure the general process requirements in Section 6 are not exceeded.

6.2.3 Reliability

As the station pressure, fuel delivery temperature, and ambient temperature measurements are safety-relevant, the station should implement means to ensure their reliability. This may include redundancy or other means. If redundancy is utilized, the most conservative value should be used. IEC 61508 and IEC 61511 may be referenced to provide guidance.

6.3 Temperature Process Requirements

6.3.1 Fuel Delivery Temperature Sensor

The fueling equipment shall monitor the fuel delivery temperature (T_{fuel}). If the fuel delivery temperature signal fails or is deemed unreliable, the station shall terminate the fueling as soon as possible but within 5 seconds. The fuel delivery temperature (T_{fuel}) shall be no less than $-17.5\text{ }^{\circ}\text{C}$. If the fuel delivery temperature (T_{fuel}) is below $-17.5\text{ }^{\circ}\text{C}$, the station shall terminate the fueling as soon as possible but within 5 seconds. The fuel delivery temperature shall be no more than $50\text{ }^{\circ}\text{C}$. If the fuel delivery temperature is greater than $50\text{ }^{\circ}\text{C}$, the station shall terminate the fueling as soon as possible but within 5 seconds.

6.3.2 Vehicle CHSS Gas Temperature

For communications fueling, the station should not fuel or should terminate vehicle fueling as soon as possible but within 5 seconds if the CHSS gas temperature signal is greater than $85\text{ }^{\circ}\text{C}$.

6.3.3 Ambient Temperature

Fueling shall only occur when the ambient temperature is greater than or equal to $-40\text{ }^{\circ}\text{C}$ and less than or equal to $50\text{ }^{\circ}\text{C}$.

6.4 Pressure Process Requirements

The station shall terminate fueling immediately after detecting a CHSS supply pressure greater than or equal to 125% NWP. For communication fueling, the station should not fuel or should terminate fueling as soon as possible but within 5 seconds if the CHSS pressure is greater than or equal to 100% NWP. For non-communication fueling, the station should not fuel or should terminate fueling as soon as possible but within 5 seconds if the station pressure sensor is greater than or equal to 100% NWP.

6.4.1 Station Pressure Sensor

The station shall measure the station pressure. The station pressure sensor shall comply with the requirements of 6.3.

6.4.2 The initial CHSS pressure is the settled pressure measured immediately after the connection pulse during the start-up time. If the measured initial CHSS pressure is less than 5 MPa or greater than 90% of the pressure class nominal working pressure (35 MPa or 70 MPa), then the station shall terminate the fueling procedure as soon as possible but within 5 seconds.

6.5 Other Process Requirements

The station should terminate fueling as soon as possible but within 5 seconds if the SOC is greater than or equal to 100%. The station may use SOC_vehicle or SOC_station (more conservative value) based on the station dispenser fueling methodology.

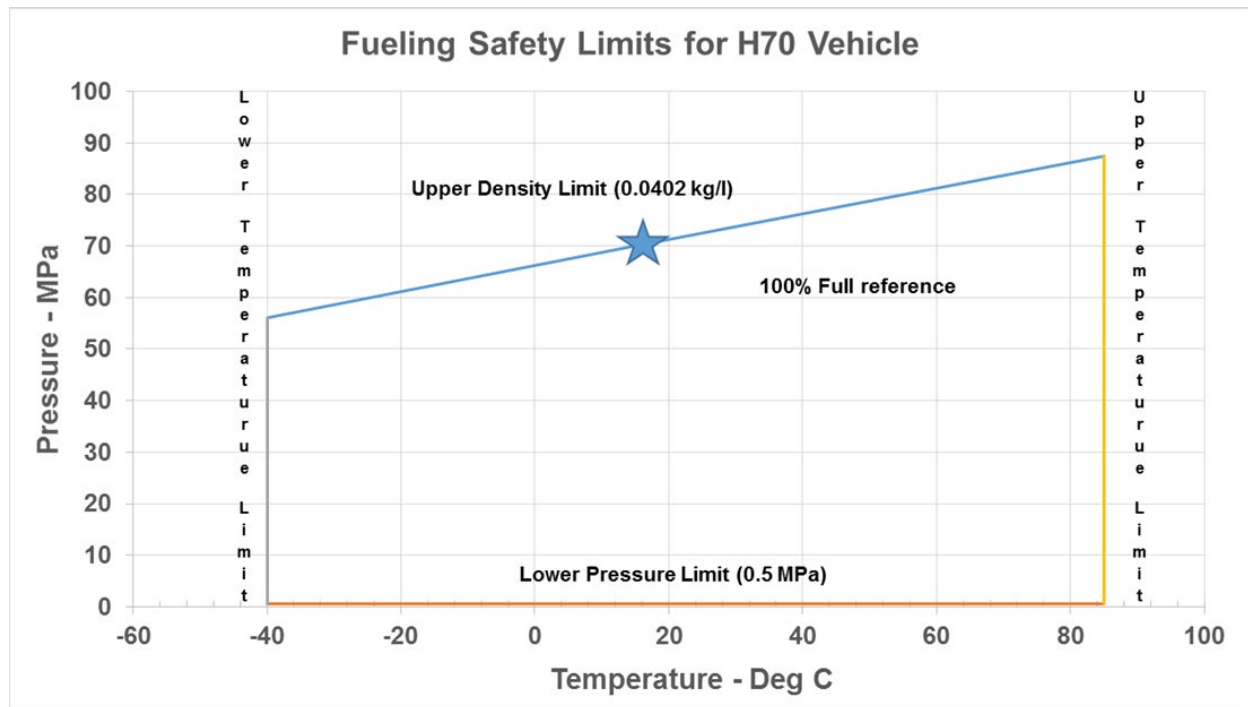


Figure 1 - Fueling limits for H70 vehicle

6.5.1 Flow Rate

Fueling protocols that adhere to the process requirements in this document shall be designed to not exceed a maximum flow of 60 g/s to the vehicle CHSS under any operating condition. After the initial connection sequence, the station shall terminate fueling as soon as possible but within 5 seconds if the measured maximum flow rate of the hydrogen gas exceeds 60 g/s. If the flow rate is less than 0.1 g/s for more than 10 seconds, the station shall terminate the fill within 5 seconds.

6.5.2 Start-Up Time

6.5.2.1 Maximum Hydrogen Mass During Start-Up

The total mass of hydrogen transferred to the vehicle during start-up shall be less than 200 g.

6.5.3 Tolerances

Stations shall consider appropriate tolerances in any protocol implementation methodology to ensure a fueling is performed safely and accurately.

7. FUELING REQUIREMENTS

The following section is intended to contain the description and requirements for individual ambient temperature fueling protocols. Because this document does not contain a specific fueling protocol, it contains minimum requirements and guidelines for developing a fueling protocol.

7.1 General Protocol Requirements

Any ambient temperature protocols shall meet all of the requirements in Section 6.

7.2 CHSS Capacity

Table 2 contains the allowable CHSS capacity categories for ambient temperature protocols. The CHSS capacity will be used to select proper refueling rates and determine appropriate end of fueling conditions that meet the requirements of Section 6.

The station shall determine the CHSS capacity using a method that is accurate within $\pm 15\%$. If the station is not able to determine CHSS capacity or cannot guarantee this degree of accuracy, it shall use the most conservative CHSS capacity to determine the fueling protocol.

Table 2 - CHSS capacity ranges

NWP	Total Amount of Hydrogen in Tank System at SOC = 100% Kilograms	Water Volume of Tank System at NWP Liters
35	1.19 to 2.39	49.7 to 99.4
35	2.39 to 4.18	99.4 to 174.0
35	4.18 to 5.97	174.0 to 248.6
70	2.00 to 4.00	49.7 to 99.4
70	4.00 to 7.00	99.4 to 174.0
70	7.00 to 10.00	174.0 to 248.6

7.3 CHSS Final Temperature

Fueling protocols shall be designed not to exceed a final CHSS temperature of 85 °C when fueled to 100% SOC at 70 MPa or create a condition that could result in an end of fueling CHSS temperature of above 85 °C in subsequent fueling events using precooled or non-precooled protocols per this TIR or SAE J2601.

7.4 Vehicle Vessel Soak State - Initial CHSS Temperature

The temperature of the vehicle storage system (gas and the vessel wall) at the onset of fueling is assumed not to be available to the dispenser and could potentially be warmer or colder than ambient temperature because of transport, storage, parking, and other conditions (refer to A.3.8 and A.3.9 of SAE J2601). The fueling protocol shall account for conditions described in A.3.8 and A.3.9 of SAE J2601 when determining fueling rate and end of fill pressure. Any protocol developed using this TIR shall consider the initial soak conditions in Appendix A and as developed for SAE J2601. These conditions will affect the CHSS temperature, pressure, and SOC.

7.5 End of Fueling

The station shall determine the end of fill based upon satisfying the requirements in Section 6 throughout the entire fueling event.

7.5.1 Use of Communication Data in End of Fueling Determination

The dispenser may use vehicle data, including the communicated CHSS temperature and pressure, to calculate the SOC. The dispenser shall use the most conservative SOC calculation between the vehicle data and station data to determine end of fueling conditions at a pressure corresponding to an SOC of 90 to 100%.