



SURFACE VEHICLE INFORMATION REPORT

J2601™-2

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Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles

RATIONALE

When SAE J2601-2 was first published in 2014, there was not a published standard fueling protocol or adopted method for fueling hydrogen powered heavy duty transit buses and heavy duty vehicles. The original intent of this document was to establish the safety limits and performance requirements for 35 MPa hydrogen dispensing systems for refueling transit buses and heavy duty vehicles.

However, as the market developed, additional fueling protocols have been published in the SAE J2601 context (for example: CHSS Capacity Category D), and other protocols are being developed as part of SAE J2601-5 and other standards. The users of SAE J2601-2 should consider using protocols developed as the result of recent efforts, as they match current technology capabilities and reflect lessons learned in the field. SAE J2601-2 should only be utilized at non-public access hydrogen stations where the vehicles being fueled are known and appropriate administrative controls are enforced.

Users of SAE J2601-2 are also advised that SAE J2601 may contain requirements and considerations that should be applied to fueling protocols developed under SAE J2601-2. It is the responsibility of the fueling protocol developer to ensure that the resulting protocol can be used under all operating conditions for all vehicles and CHSS configurations.

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This document has been declared "STABILIZED" by SAE Fuel Cell Standards Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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FOREWORD

The intent of this document is to provide guidance for performance oriented dispenser standards for safe fueling of hydrogen powered transit buses and heavy duty vehicles.

1. SCOPE

The purpose of this document is to provide performance requirements for hydrogen dispensing systems used for fueling 35 MPa heavy duty hydrogen transit buses and vehicles (other pressures are optional).

This document establishes the boundary conditions for safe heavy duty hydrogen surface vehicle fueling, such as safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel hydrogen transit buses. For fueling light-duty vehicles SAE J2601 should be used.

SAE J2601-2 is a performance based protocol document that also provides guidance to fueling system builders, manufacturers of gaseous hydrogen powered heavy duty transit buses, and operators of the hydrogen powered vehicle fleet(s).

This fueling protocol is suitable for heavy duty vehicles with a combined vehicle CHSS capacity larger than 10 kilograms aiming to support all practical capacities of transit buses. It is non-prescriptive in how to achieve a full fill or 100% state of charge (SOC) in the vehicle tank storage system.

This document is an independent document from SAE J2601 "Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles" and should be used separately.

The fueling limits shown in this document are harmonized with the fueling assumptions used for on-board fuel systems, as provided by gaseous hydrogen transit bus manufacturers.

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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 J1939	Serial Control and Communications Heavy Duty Vehicle Network – Top Level Document
SAE J2574	Fuel Cell Vehicle Terminology
SAE J2578	Recommended Practice for General Fuel Cell Vehicle Safety
SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
SAE J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices
SAE J2601	Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles
SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles
SAE J2760	Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications
SAE J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, Tel: 212-642-4900, www.ansi.org.

ISO 14687-2	Hydrogen Fuel - Product Specifications
ISO 13849-1	Safety - Related Parts of Control Systems
ISO 17268:2012	Gaseous Hydrogen Land Vehicle Refuelling Connection Devices
ISO 19078	Gas Cylinders - Inspection of the Cylinder Installation, and Requalification of High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles
ISO/DIS 20100	Gaseous Hydrogen - Fuelling Stations

2.1.3 CSA Publications

Available from CSA International, 178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3, Tel: 416-747-4000, www.csa-international.org.

CSA B51-09 Boiler, Pressure Vessel, and Pressure Piping Code

ANSI/CSA CHMC 1-2014 Test Methods for Evaluating Material Compatibility in Compressed Hydrogen Applications - Metals

CSA HGV 2- 2014 Hydrogen Fuel System Containers (to be published March 2014)

CSA HGV 3.1 – 2013 Fuel system components for compressed hydrogen gas powered vehicles

ANSI/CSA HGV 4.1-2013 Standard for Hydrogen Dispensing Systems

ANSI/CSA HGV 4.2-2013 Standard for Hoses for Compressed Hydrogen fuel Stations, Dispensers and Vehicle fuel Systems

ANSI/CSA HGV 4.4-2013 Standard for Breakaway Devices for Compressed Hydrogen Dispensing Hoses and Systems

ANSI/CSA HGV 4.5-2013 Standard for Priority and Sequencing Equipment for Hydrogen Vehicle Fueling

ANSI/CSA HGV 4.6-2013 Manually Operated Valves for use in Gaseous Hydrogen Vehicle Fueling Stations

ANSI/CSA HGV 4.7-2013 Automatic Valves for use in Gaseous Hydrogen Vehicle Fueling Stations

ANSI/CSA HGV 4.8-2012 Hydrogen Gas Vehicle Fueling Station Compressor Guidelines

ANSI/CSA HGV 4.10-2012 Standard for Fittings for Compressed Hydrogen gas and Hydrogen Rich gas Mixtures

ANSI/HPRD 1-2013 Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers

2.1.4 ISA Publications

Available from the International Society of Automation, 67 T.W. Alexander Drive, PO Box 12277, Research Triangle Park, NC 27709, Tel: (919) 549-8411, www.isa.org.

ANSI/ISA-75.02.01-2008 Control Valve Capacity Test Procedures

2.1.5 European Commission Publications

EC79 Regulation (EC) No 79/2009 of the European Parliament and of the Council of 14 January 2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC – Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:035:0032:0046:EN:PDF> or <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009R0079:EN:NOT>

2.1.6 US DOT Publications

FMCSA-RRT-07-020 Guidelines for Use of Hydrogen Fuel in Commercial Vehicles – Available at: <http://www.fmcsa.dot.gov/facts-research/research-technology/report/guidelines-h2-fuel-in-cmvs-nov2007.pdf>

3. ABBREVIATIONS AND SYMBOLS

3.1 Abbreviations

ASOV	Automatic Shut Off Valve
CHSS	Compressed Hydrogen Storage System (on board vehicle)
ESDS	Emergency Shut Down System
FS	Fueling Station
FSP	Full Storage Pressure
H ₂	Hydrogen gas
HSV	Hydrogen Surface Vehicle
HDHSV	Heavy Duty Hydrogen Surface Vehicle
LDHSV	Light Duty Hydrogen Surface Vehicle
MAWP	Maximum Allowable Working Pressure (dispenser system)
NIST	National Institute of Standards and Technology
NWP	Nominal Working Pressure (same as SP)
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
SOC	State of Charge
SP	Service Pressure, (same as NWP)
VFA	Vehicle Fueling Appliance

3.2 Symbols

P	Pressure
T	Temperature
ρ	Density
t	Time

4. DEFINITIONS

4.1 CAPACITY

4.1.1 HDHSV Compressed Hydrogen Storage System Rated Capacity

Total rated onboard storage capacity of heavy duty gaseous hydrogen bus or vehicle in kilograms based on the nominal working pressure (NWP) and the water volume of the CHSS.

4.1.2 Fueling Rate

Fueling rate in g/s, measured at the nozzle, typically at variable speeds during the fueling process.

4.2 COMMUNICATION

4.2.1 Active Communication

Communication between vehicle and station about vehicle tank storage system bulk hydrogen gas temperature, CHSS pressure, CHSS internal volume, and detected hydrogen leaks.

4.3 DISPENSER COMPONENTS

4.3.1 Breakaway

Device in hose assembly that minimizes damage to the dispenser in the event when a vehicle drives off while the dispenser nozzle is connected.

4.3.2 Communication Connector

An optional connector specified by the HDHSV operator or HDHSV manufacturer to enable data transfer from the HDHSV to the dispenser. It may also be used to ground the vehicle prior to fueling.

4.3.3 Connection or Coupling

A coupling (receptacle with matching nozzle) as per SAE J2600 (or ISO 17268:2012), a joined assembly of Hydrogen Surface Vehicle (HSV) nozzle and receptacle which permits quick connect and disconnect of fuel supply to the vehicle.

4.3.4 Dispenser

The equipment that controls each fueling event; a transfer of hydrogen fuel from the station storage systems or compression system to HDHSV vehicle storage system for the purpose of fueling the vehicle.

4.3.5 Dispenser Hose

The flexible hose assembly which transfers gas between the dispenser and nozzle, as specified in e.g. ANSI/CSA HGV 4.2-2013.

4.3.6 Hydrogen Supply System

The equipment required to condition and transfer fuel from the station hydrogen source to vehicle dispensing systems for the purpose of fueling a fleet of HDHSVs.

4.3.7 Nozzle

Device connected to a fuel dispensing system which engages the vehicle receptacle and permits the transfer of fuel. SAE J2600 and/or ISO 17268:2012 define the mechanical nozzle geometry for fueling HDHSVs operating with a nominal pressure of 35 MPa.

4.4 HDHSV CHSS COMPONENTS

4.4.1 Connection or Coupling

A coupling (receptacle with matching nozzle) as per SAE J2600 (or ISO 17268:2012), a joined assembly of Hydrogen Surface Vehicle (HSV) nozzle and receptacle which permits quick connect and disconnect of fuel supply to the vehicle.

4.4.2 Automatic Fuel Tank Valves

Fuel tanks are typically outfitted with an automatic valve or automatic container valve (as defined in CSA HGV 3.1-2013) which is connected to the common fill line coming from the vehicle receptacle.

4.4.3 HDHSV Tank Storage System

The HDHSV gaseous hydrogen gas storage tank system (CHSS) of multiple tanks combined, including the piping and connectors to connect these tanks to each other and to the receptacle.

4.4.4 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. SAE J2600 and ISO 17268:2012 define the mechanical receptacle geometry for fueling HDHSVs operating with a nominal pressure of 35 MPa.

4.5 HEAVY DUTY HYDROGEN SURFACE VEHICLE

HDHSVs or hydrogen powered heavy duty vehicles are generally hydrogen powered heavy duty transit buses (transit buses) and LDHSVs are passenger vehicles fueled with gaseous hydrogen. However, heavy duty vehicles with similar storage capacity as those mentioned in 4.1.1 are assumed to fall within the same category.

4.6 HYDROGEN POWERED HEAVY DUTY TRANSIT BUS

A Hydrogen Powered Heavy Duty Transit Bus (bus) is a mobile, power-driven vehicle used to move a large number of passengers which makes frequent stops to facilitate entering and departing the vehicle in an urban environment, etc.

4.7 PRESSURE

4.7.1 Initial CHSS Pressure

The vehicle CHSS pressure as measured by the dispenser system after the dispenser provides the initial pressure pulse

4.7.2 Integrity Test

Verification of the leak-tightness of the fuel hose, breakaway, nozzle, receptacle prior to the start of fueling and/or during the fueling event.

4.7.3 Vehicle Storage Tank Valve Functional Check

A vehicle storage tank valve functional check or test performed during fueling, regular maintenance or vehicle diagnostics check to determine if there are any malfunctioning tank valves in the system.

4.7.4 Maximum Allowable Working Pressure (MAWP)

The MAWP is the maximum gauge pressure of the working fluid (gas or liquid) to which a piece of process equipment or system is rated with consideration for initiating fault management (see Figure A1 “Comparison of Pressure Vessel and Container Terminology” in Appendix A of J2579).

4.7.5 Nominal Working Pressure (NWP)

The NWP is the gauge pressure that characterizes typical operation of a vehicle pressure vessel, container, or system. For compressed hydrogen gas containers, the vessel pressure NWP is specified by the manufacturer, at a uniform gas temperature of 15 °C and 100% SOC. NWP is sometimes known as Service Pressure (SP) or Pressure Class.

4.7.6 Pressure Class

The pressure class will be defined by the protocol's nominal working pressure. The class is denoted by the letter H followed by the nominal working pressure in MPa. For example, H35 is the pressure class for a hydrogen fueling protocol with a NWP of 35 MPa.

4.7.7 Pressure Drop

The difference in pressure of gaseous hydrogen between two points in the fueling system used to fuel a vehicle. A high pressure drop leads to two effects that both yield a higher CHSS gas temperature at the end of fueling: First, the fueling is delayed. This consequently delays the temperature rise inside the CHSS and gives the gas less time to exchange heat with the internal liner surface. Secondly, more Joule-Thomson heating is introduced into the CHSS because a higher station pressure is required to generate a given mass flow rate, and the enthalpy of hydrogen fuel gas increases with pressure.

4.7.8 Tank Pressure

Pressure of hydrogen gas within each (single) vehicle storage tank

4.7.9 CHSS Pressure

Pressure of hydrogen gas within a vehicle storage tank system (CHSS). It is assumed that all tanks in the CHSS are at equal pressure.

4.7.10 Target Fill Pressure

The calculated pressure at which the dispenser will stop the fueling event in accordance to the boundaries outlined in this document

4.8 STATE OF CHARGE

The ratio of CHSS hydrogen density to the density at NWP rated at the standard temperature 15 °C. SOC is expressed as a percentage and is computed based on the gas density as per formula below.

$$SOC (\%) = \frac{\rho(P, T)}{\rho(NWP, 15^{\circ}C)} \times 100 \quad (\text{Eq. 1})$$

The density of H35, hydrogen at 35 MPa at 15 °C = 24.0 g/L. ¹

¹ For density calculations from the National Institute of Standards and Technology (NIST), see:
<http://www.boulder.nist.gov/div838/Hydrogen/PDFs/Lemmon.2008.pV113.N06.A05.pdf>.

4.9 TEMPERATURE

4.9.1 Ambient Temperature

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

4.9.2 Bulk Hydrogen Gas Temperature

The average temperature of the hydrogen gas in the vehicle CHSS (T_{vehicle})

4.9.3 Calculated Peak Temperature of Hydrogen Gas in CHSS

The peak temperature of the hydrogen gas in CHSS during fueling calculated by the dispenser system. This calculation may be used to determine the end of fill target pressure.

4.9.4 Fuel Delivery Temperature

The temperature of the hydrogen gas being supplied to the dispenser nozzle during fueling, measured as close to the dispenser hose breakaway as possible in the gas stream.

4.9.5 Vehicle Tank Gas Temperature

The average temperature of the hydrogen gas in each vehicle tank.

NOTE: If the vehicle contains a temperature measurement device for the purpose of sending a temperature signal to the dispenser during fueling, this temperature may be assumed to be the average temperature of the gas in the CHSS.

5. GENERAL REQUIREMENTS FOR FUEL SYSTEM AND INTERFACE

5.1 Operating Conditions of the Vehicle Fuel System

Stations dispensers shall consider appropriate tolerances in their protocol implementation methodology to ensure a fueling is performed safely and accurately. Vehicles that communicate to the station should consider appropriate tolerances for their signals.

This technical information report includes boundary parameters for 35 MPa service pressures. The target of each fueling event is to reach a full fill, corresponding with 100% SOC.. This Technical Information Report specifies the fueling boundaries based on the expectation that HDHSV fuel systems have constraints in their operation. For a H35 CHSS, these temperature and pressure limits are -40 to 85 °C and 0.5 MPa to 43.8 MPa, respectively. Figure 1 shows the boundary conditions for a H35 fueling. The maximum CHSS gas temperature and maximum operating pressure are fixed limits at the right (overheat) and top (over-pressure) portions of the graph. The maximum density (100% SOC) provides an additional boundary condition. An example of fueling system design components and procedures to perform within these boundaries can be found in the Appendix (section 8).

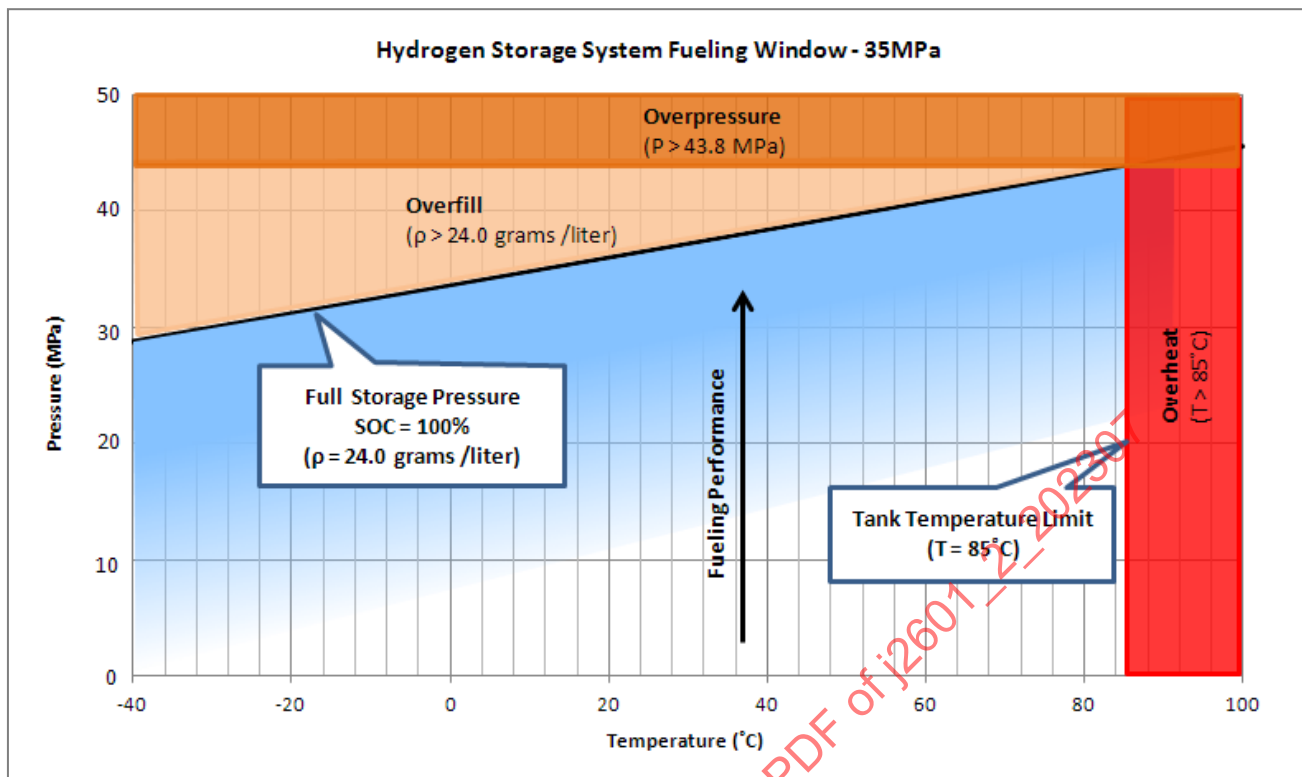


Figure 1 - TIR J2601/2 normal H35 boundary conditions

5.2 Hydrogen Storage Systems

- 5.2.1 This technical information report is based on the assumption that the fueling system of HDHSVs (between the receptacle and CHSS) and dispenser fuel path components (from the break-away to the nozzle exit) have been designed to minimize the pressure drop as low as practical.
- 5.2.2 Hydrogen Tanks and Storage System should be designed in accordance with CSA HGV-2, SAE J2579, Global Technical Regulation 13, or any other applicable local or national requirements.
- 5.2.3 Hydrogen Storage System PRDs should be designed in accordance with ANSI/CSA HPRD 1 or any other applicable local or national requirements.

5.3 Fueling Process Limits

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

- 5.3.1 Ambient temperature range at fueling station $\geq -40^{\circ}\text{C}$ and $\leq +50^{\circ}\text{C}$.
- 5.3.2 Pressure at the dispenser sensor $\leq 125\%$ NWP of the vehicle fuel system.

- 5.3.3 The fueling station is responsible for control of the fueling process, and is expected to provide over-pressurization protection, per applicable codes (e.g., NFPA, IFC, etc.) that will protect the CHSS from over-pressure in the event of any dispenser process malfunction.
- 5.3.4 Maximum pressure within the vehicle fuel system less than or equal to 125% NWP.
- 5.3.5 Bulk Hydrogen Gas Temperature within the vehicle fuel tanks less than or equal to 85 °C.
- 5.3.6 The SOC at the end of the fill should be ≤100%.
- 5.3.7 Stations shall limit the flow to one of following three options (Table 1).

Table 1 - Fueling options for HDHSV fueling

Category	Category description	Fueling rate
Fast Fueling-Option A	This option is for fast fueling of heavy duty buses or vehicles. Fueling covered by this option is typically at variable speeds and uses a “high flow” Heavy Duty Hydrogen Surface Vehicle (HDHSV) connection defined in ISO 17268:2012.	≤ 120 g/s (7.2 kg/min)
Normal Fueling-Option B	This option is for normal fueling of heavy duty buses or vehicles. Fueling covered by this option is typically at variable speeds and uses a connection defined in SAE J2600 or ISO 17268:2012.	≤ 60 g/s (3.6 kg/min)
Slow Fueling-Option C	This option is for slow fueling of heavy duty buses or vehicles, also known as “time fill”. Fueling covered by this option is typically at variable speeds.	≤ 30 g/s (1.8 kg/min)

- 5.3.7.1 A high flow dispenser nozzle for Heavy Duty Hydrogen Surface Vehicles (HDHSV) cannot connect to a vehicle with a standard H35 receptacle.

- 5.3.8 The Fuel Temperature at the Dispenser Nozzle Shall be ≥ -40 °C.

5.4 Special Requirements for HDHSV Operations

Varying ambient temperature conditions, such as fueling vehicles in hot or cold conditions, may result in over-temperature and over-density conditions. The station must consider these and the station shall adjust the fueling protocol accordingly.

5.5 Verification Process for Faulty Fill Valves

Transit bus station operators should not fuel above temperature compensated target pressure if there is no verification process in place to verify for the occurrence of faulty vehicle tank fill valves in an effort to avoid potential over-pressure within individual tanks (see section 6 & 7 for concerns about over-pressure, over-density, and over-temperature). One standard that can be used to verify fill valves is ANSI/ISA-75.02.01-2008.

5.6 Fueling Light Duty Road Vehicles with HDHSV Dispensers

Due to concerns about over-pressure, over-temperature, and over-density when fueling LDHSVs, HDHSV station operators should distinguish between HDHSVs and LDHSVs when providing fuel. All dispensers designed to fuel HDHSVs and light duty vehicles interchangeably shall meet all of the requirements of SAE J2601. Bus station dispensers which do not meet these requirements shall not be used to fuel light duty road vehicles. If the HDHSV dispenser is located in an area where there is a potential risk of LDHSVs fueling at the dispenser, then the operator of the dispenser must ensure that LDHSV fueling is prohibited. This can be done mechanically, or electronically.