

Developing Safety Standards for FCVs and Hydrogen Vehicles

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ABSTRACT

The SAE Fuel Cell Vehicle (FCV) Safety Working Group has been addressing FCV safety for over 9 years. The initial document, SAE J2578, was published in 2002. SAE J2578 has been valuable as a Recommended Practice for FCV development with regard to the identification of hazards and the definition of countermeasures to mitigate these hazards such that FCVs can be operated in

the same manner as conventional gasoline internal combustion engine (ICE)-powered vehicles.

SAE J2578 is currently being revised so that it will continue to be relevant as FCV development moves forward. For example, test methods were refined to verify the acceptability of hydrogen discharges when parking in residential garages and commercial structures and after crash tests

prescribed by government regulation, and electrical requirements were updated to reflect the complexities of modern electrical circuits which interconnect both AC and DC circuits to improve efficiency and reduce cost.

An update to SAE J1766 for post-crash electrical safety was also published in 2008 to reflect unique aspects of FCVs and to harmonize electrical requirements with international standards.

In addition to revising the SAE J2578 and J1766, the Working Group also published a new Technical Information Report (TIR) for vehicular hydrogen systems (SAE J2579). The original focus of this document was to define systems-level, performance-based requirements for compressed hydrogen storage systems, as most FCVs currently use this form of storage. The TIR is being used as a basis of verification testing that is intended to demonstrate the effectiveness and practicality of the test methods that can be used to qualify compressed hydrogen storage systems. Revision to the TIR is also in progress based on test experience, and it is envisioned that additional revisions will be made periodically until the document can be upgraded and published as a Recommended Practice.

The objective of these documents is to address long-term real-world system safety while still facilitating rapid advances by the industry.

DESIGN FOR SAFETY

The automotive industry is applying design practices developed over the past 100 years to ensure that FCV development and commercialization is successful and safe. Under normal and anticipated driving and vehicle scenarios, the vehicle and associated subsystems are designed with the objective that foreseeable single-point hardware or software failures do not result in an unreasonable safety risk to any person or uncontrolled vehicle behavior. As a result, SAE J2578 and J2579 recommend use of risk analysis tools such as failure mode and effects analysis (FMEA) to investigate the impact of potential single-point failures and mitigate potentially hazardous situations with fail-safe designs, redundancy, and/or additional design margins.

MANAGING ELECTRICAL SYSTEM HAZARDS

Since the high voltage electrical system of a fuel cell vehicle is very similar to other electrical and hybrid vehicles, the document relies heavily on previously published work in these areas. SAE J2578 provides specific guidance with regard to preventing electrical fires and electric shock in the areas of high voltage withstand capability, fusing and over-current protection, and limiting access to live high voltage systems.

Requirements for electrical isolation are also addressed in both SAE J1766 and J2578 as the high voltage electrical systems in electric vehicles are not bonded (or grounded) to the chassis (as is typically done with low voltage automotive systems) but rather are isolated from the electrically-conductive chassis to provide a critical measure of safety against electric shock (even under first fault conditions where the basic electrical insulation has been breached). This protection is primarily provided by ensuring that the electrical isolation resistance between the high voltage circuits and the chassis is adequately high such that current flow through the body of a person that may contact the high voltage circuits does not represent a hazard.

The SAE Safety Working Group is harmonizing isolation requirements for DC and AC circuits with international requirements but is also extending coverage to address –

- 1) more complex situations where AC and DC circuits may be conductively connected through DC-to-AC inverters that are used for traction power control, and
- 2) more demanding situations such as post-crash.

In order to provide electric shock protection under these more challenging situations, the SAE Safety Working Group is defining additional countermeasures including use of ruggedized supplementary insulation, barriers, and enclosures or use of event or fault monitoring that can de-energize the circuits.

The SAE Safety Working Group expects to include the definition of new requirements in the revision to J2578 that is planned before the end of 2008.

MANAGING HYDROGEN DISCHARGES

Successful commercialization of fuel cell (and hydrogen) vehicles requires that these vehicles be used in a manner consistent with current gasoline-ICE vehicles. To achieve this objective, the SAE has defined recommended practices such that hydrogen vents, purges, leaks, and exhausts during operating and non-operating states are consistent with usage in residential garages and commercial structures.

To ensure that discharges are non-hazardous, the discharge is examined in two regions:

- 1) The local region where the discharge from the vehicle initially mixes with surrounding air.
- 2) The general space surrounding the vehicle after dispersal of the discharge.

As described in a previous paper at the 2008 SAE World Congress^[1], requirements and test methods were added to ensure that the vehicle exhausts are non-flammable at the point-of-discharge or, if potentially flammable during excursions, degradation, and faults, locally non-ignitable so that the exhaust cannot initiate a fire or cause excessively loud noise.

In order to complete the evaluation of hydrogen discharges from the vehicle, it is necessary to look beyond the local region of discharge and evaluate the condition of the general space surrounding the vehicle. To gain acceptance by Authorities Having Jurisdiction (AHJs), the space surrounding the vehicle must be "unclassified" and thereby considered non-hazardous by virtue of having a hydrogen concentration less than 25% of the Lower Flammability Limit (LFL). For hydrogen, 25% LFL is 1% hydrogen concentration by volume.^[2]

While the original issue of SAE J2578 addressed the general space surrounding the vehicle when parking in "very tight" residential garages as well as public buildings, the working group re-examined these situations to ensure that assumptions were appropriate for a global market and that the test methods were accurate and practical to conduct on vehicles of varying size and type.

SAE J2578 originally defined the hypothetical space around a vehicle as 6.0 x 3.0 x 2.6 meters based on SAE J1718 for typical American

garages. The minimum standard space in the draft revision of SAE J2578 was reduced to 4.5 x 2.6 x 2.6 meters to be more consistent with global requirements for smaller passenger vehicles. As with the original issue, there is a provision to enlarge the hypothetical space for larger vehicles, but the enclosures dimensions should not exceed vehicle dimensions by more than 1.0 meter in length or width and 0.5 meters in height.

The ventilation through the hypothetical space is fundamental in establishing the allowable discharge of hydrogen from the vehicle, as it is ultimately this ventilation flow that is expected to render any discharge non-hazardous. The SAE FCV Safety Working Group re-examined ventilation flows for both residential garages and commercial buildings, and determined the following:

- 1) Residential garages — The ventilation air flow should be reduced from 0.18 to 0.03 air changes per hour to provide adequate coverage for "extremely tight" garages that could exist under a combination of adverse climatic and physical conditions.^[3]
- 2) Commercial buildings — The ventilation flow rate should be set to the lowest value for spaces where vehicles are expected to park or operate in order to not restrict the use of FCVs indoors. This value is 0.3 cubic meters per minute per square meter (1.0 cubic feet per minute per square foot) of vehicle footprint according to the current model building codes^[4] and corresponds to an air exchange rate of approximately 7 air exchanges per hour for the minimum standard space surrounding a vehicle.

While the original issue of SAE J2578 allowed for verification of the space by test, analysis, or combination of both, the SAE FCV Working Group decided to develop a more specific test methodology that could be used to verify that the space surrounding the vehicle remains "unclassified" without necessitating testing of the vehicle in an actual enclosure.

For situations such as parking in residential garages where the hydrogen discharge rate from the hydrogen storage system is small and the diffusion rate of hydrogen within the space is very good, hydrogen concentration as a function of time ($C_{H_2}(t)$ in %) can be expressed as follows: