



SURFACE VEHICLE RECOMMENDED PRACTICE

J2578™

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Superseding J2578 AUG2014

Recommended Practice for General Fuel Cell Vehicle Safety

RATIONALE

This revision to SAE J2578 represents an evolution to requirements for the integration of hydrogen and electrical systems for hydrogen and fuel cell vehicles (FCVs). Rationale for specific changes are summarized below:

- Sections 4.2.4.1 and 5.2 and Appendices C and D were updated to clarify and streamline verification test requirements for hydrogen discharges from the vehicle. See Appendices C and D for detailed discussion of issues and recommended verification procedures.
- Sections 4.2.4.2 and 4.2.5 and Appendix E were changed to clarify guidance with regard to locating hydrogen storage systems within passenger, luggage, and cargo compartments to ensure that discharges from vents and Pressure Relief Devices (PRDs) are properly managed and directed.
- Section 4.2.6 was modified and the new Appendix F was added to ensure that either the vehicle cannot be moved while the fueling nozzle is connected or the fueling receptacle is properly installed, protected, and secured.
- Sections 4.2.6, 4.7, and 5.1 were updated to clarify fuel system labeling requirements and harmonize with vehicle badging requirements in SAE J2990 for emergency responders.
- Sections 4.2.7, 4.4.3, 4.4.3.1, 6, and 7.2 were re-worded to clarify previously-defined issues and guidance.
- Section 4.4.3 and subordinate subsections were revised to account for Y-capacitors in high voltage circuits and their effect on body current if the high DC and AC voltage circuits are touched.
- Section 5.2.2 and Appendix C was changed to extend allowable discharge scaling to smaller (micro) vehicles and not just larger vehicles such as buses. Clarifications to the analytical bases of requirements were also made.
- Appendix A was modified to correct post-crash formulas, improve the explanations, and provide an alternative approach for calculating the mass leakage rate.
- Appendix E was also modified to clarify guidance with regard to using Pressure Relief Devices (PRDs) in series.

SAE J2578 has been reaffirmed to comply with the SAE Five-Year Review policy.

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Documents

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FOREWORD

Vehicles manufactured with liquid hydrocarbon as fuels have a long history of creating appropriate safety countermeasures. With the onset of new hydrogen fuel cell systems, new mechanical and electrical system safety design parameters will need to be provided to vehicle developers. This SAE report establishes safety criteria and methodologies for fuel cell vehicle and subsystem developers.

The purpose of this document is to identify the unique requirements and criteria for the integration of hydrogen fuel systems (as defined in SAE J2579) and fuel cell systems into vehicles.

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1. SCOPE

This SAE Recommended Practice identifies and defines requirements relating to the safe integration of the fuel cell system, the hydrogen fuel storage and handling systems (as defined and specified in SAE J2579) and high voltage electrical systems into the overall Fuel Cell Vehicle. The document may also be applied to hydrogen vehicles with internal combustion engines.

This document relates to the overall design, construction, operation and maintenance of fuel cell vehicles.

1.1 Purpose

The purpose of this document is to provide mechanical and electrical system safety guidelines, safety criteria and methodologies that should be considered when designing fuel cell vehicles for use on public roads.

1.2 Field of Application

This document is applicable to fuel cell vehicles designed for use on public roads.

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.

Applicable FMVSS standards and regulations should supersede any SAE recommended practices as described in this document.

SAE J1142	Towability Design Criteria and Equipment Use - Passenger Cars, Vans, and Light-Duty Trucks
SAE J1645	Fuel Systems and Components - Electrostatic Charge Mitigation
SAE J1718	Measurement of Hydrogen Gas Emission from Battery-Powered Passenger Cars and Light Trucks During Battery Charging
SAE J1739	Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA)
SAE J1742	Connections for High Voltage On-Board Road Vehicle Electrical Wiring Harnesses - Test Methods and General Performance Requirements
SAE J1766	Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing
SAE J1772	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
SAE J1773	SAE Electric Vehicle Inductively Coupling Charging
SAE J2344	Guidelines for Electric Vehicle Safety

SAE J2574 Fuel Cell Vehicle Terminology

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

2.1.2 ANSI Publication

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

ANSI Z535.4 Product Safety Sign and Label

2.1.3 Motor Vehicle Safety Standards

Motor vehicle standards for the U.S. and Canada are listed below. In other countries, other regulations may apply.

2.1.3.1 Federal Motor Vehicle Safety Standards (FMVSS)

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6396, <http://quicksearch.dla.mil/>.

The following Federal Motor Vehicle Safety Standards are specifically applicable to this document for use in the U.S. See the Code of Federal Regulations (49 CFR 571) for other applicable FMVSS.

FMVSS 301 Fuel System Integrity

FMVSS 303 Fuel System Integrity of Compressed Natural Gas Vehicles

FMVSS 305 Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection

2.1.3.2 Canadian Motor Vehicle Safety Standards (CMVSS)

Available from Transport Canada, Road Safety and Motor Vehicle Regulation Directorate, P.O. Box 8880, Ottawa Post Terminal, Ottawa, Ontario, K1G.3J2, www.tc.gc.ca.

The following Canadian Motor Vehicle Safety Standards are specifically applicable to this document for use in Canada. See the Canada Motor Vehicle Act for other applicable CMVSS.

CMVSS 301.2 Fuel System Integrity

CMVSS 305 Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection

2.1.4 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 60079 (Parts 0 through 20) Electrical Apparatus for Explosive Gas Atmospheres

IEC 60417 (Parts 1 and 2) Graphical Symbols for Use on Equipment

IEC 60950 Safety Testing

2.1.5 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 6469-1	Electrically propelled road vehicles—Safety specifications—Part 1: On-board rechargeable energy storage system RESS
ISO 6469-2	Electrically propelled road vehicles - Safety specifications - Part 2: Functional safety means and protection against failures
ISO 6469-3	Electrically propelled road vehicles - Safety specifications - Part 3: Protection of persons against electric shock
ISO 26262	Road Vehicle Functional Safety (Parts 1 through 10)
ISO 20653	Road vehicles - Degrees of protection (IP code) - Protection of electrical equipment against foreign objects, water and access

2.1.6 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 991	Standard for Tests for Safety-Related Controls Employing Solid-State Devices
UL 1998	Standard for Safety-Related Software
UL 2202	Standard for Electric Vehicle (EV) Charging System Equipment
UL 2231	Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits
UL 2251	Plugs, Receptacles, and Couplers for Electric Vehicles
UL 2279	Standard for Electrical Equipment for Use in Class I, Zone 0, 1, and 2 Hazardous (Classified) Locations

2.1.7 Other Publications

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

DGMK Research Report 508, 1996	Avoiding the Ignition of Otto-type Fuel/Air Mixtures when Refueling Automobiles at Gas Stations
EPRI TR-105939	Final Report Prepared Underwriters Laboratories, December 1995, "Personnel Protection Systems for Electric Vehicle Charging Circuits"
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment 1998 Edition

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

- SAE J551-1 Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles, Boats (up to 15 m), and Machines (16.6 Hz to 18 GHz)
- SAE J551-2 Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices
- SAE J551-4 Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles and Devices, Broadband and Narrowband, 150 kHz to 1000 MHz
- SAE J551-5 Test Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz to 30 MHz
- SAE J551-11 Vehicle Electromagnetic Immunity - Off-Vehicle Source
- SAE J551-12 Vehicle Electromagnetic Immunity- On-Board Transmitter Simulation
- SAE J551-13 Vehicle Electromagnetic Immunity- Bulk Current Injection
- SAE J1113-2 Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft) - Conducted Immunity, 15 Hz to 250 kHz- All Leads
- SAE J1113-3 Conducted Immunity, 250 kHz to 400 MHz, Direct Injection of Radio Frequency (RF) Power
- SAE J1113-4 Immunity to Radiated Electromagnetic Fields- Bulk Current Injection (BCI) Method
- SAE J1113-11 Immunity to Conducted Transients on Power Leads
- SAE J1113-12 Electrical Interference by Conduction and Coupling- Capacitive and Inductive Coupling via Lines Other than Supply Lines
- SAE J1113-13 Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Part 13: Immunity to Electrostatic Discharge
- SAE J1113-21 Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Part 21: Immunity to Electromagnetic Fields, 30 MHz to 18 GHz, Absorber-Lined Chamber
- SAE J1113-24 Immunity to Radiated Electromagnetic Fields; 10 kHz to 200 MHz- Crawford TEM Cell and 10 kHz to 5 GHz - Wideband TEM Cell
- SAE J1113-25 Electromagnetic Compatibility Measurement Procedure for Vehicle Components- Immunity to Radiated Electromagnetic Fields, 10 kHz to 1000 MHz- Tri-Plate Line Method
- SAE J1113-26 Electromagnetic Compatibility Measurement Procedure for Vehicle Components- Immunity to AC Power Line Electric Fields
- SAE J1113-41 Limits and Methods of Measurement of Radio Disturbance Characteristics of Components and Modules for the Protection of Receivers Used on Board Vehicles
- SAE J1113-42 Electromagnetic Compatibility - Component Test Procedure- Part 42- Conducted Transient Emissions

SAE J1115	Guidelines for Developing and Revision SAE Nomenclature and Definitions
SAE J1654	High Voltage Primary Cable
SAE J1673	High Voltage Automotive Wiring Assembly Design
SAE J1715	Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
SAE J1752-1	Electromagnetic Compatibility Measurement Procedures for Integrated Circuits - Integrated Circuit EMC Measurement Procedures- General and Definitions
SAE J1752-2	Measurement of Radiated Emissions from Integrated Circuits - Surface Scan Method (Loop Probe Method) 10 MHz to 3 GHz
SAE J1812	Function Performance Status Classification for EMC Immunity Testing
SAE J2464	Electric Vehicle Battery Abuse Testing
SAE J2799	70 MPa Compressed Hydrogen Surface Vehicle Fuelling Connection Device and Optional Vehicle to Station Communications
SAE J2990	Hybrid and EV First and Second Responder Recommended Practice
SAE Paper 2007-01-0428	Diffusion and Ignition Behavior on the Assumption of Hydrogen Leakage from a Hydrogen-Fueled Vehicle, presented at 2007 SAE World Congress
SAE Paper 2007-01-0437	Development of Safety Criteria for Potentially Flammable Discharges from Hydrogen Fuel Cell Vehicles, presented at 2007 SAE World Congress

2.2.2 ANSI Publications

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

ANSI/IEEE C62.41	Surge Voltages in Low-Voltage AC Power Circuits
ANSI/IEEE C62.45	Equipment Connected to Low-Voltage AC Power Circuits, Guide on Surge Testing for
ANSI FC1	Standard for Stationary Fuel Cell Power Plants
ANSI IMC	International Mechanical Code

2.2.3 CISPR Publications

Available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +41-22-919-02-11, www.iec.ch.

CISPR 12	Vehicles, Motorboats and Spark-Ignited Engine-Driven Devices - Radio Disturbance Characteristics - Limits and Methods of Measurement
CISPR 22	Information Technology Equipment - Radio Disturbance Characteristics - Limits and Methods of Measurement
CISPR 25	Limits and Methods of Measurement of Radio Disturbance Characteristics for the Protection of Receivers Used on Board Vehicles

2.2.4 EU Directives

The following Directive is available for download from the European Union at <http://www.euro.alexandria.eu/eur-lex/en/index.html>



Documents

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Commission Directive 95/54/EC Automotive Directive (amends 72/245/EEC)

2.2.5 IEC Publications

No IEC publications are provided for guidance.

2.2.6 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 11451-1 Road Vehicles - Vehicle Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 1: General and Definitions
- ISO 11451-2 Road Vehicles - Vehicle Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 2: Off-Vehicle Radiation Sources
- ISO 11451-3 Road Vehicles - Electrical Disturbances by Narrowband Radiated Electromagnetic Energy - Vehicle Test Methods - Part 3: On-Board Transmitter Simulation
- ISO 11451-4 Road Vehicles - Electrical Disturbances By Narrowband Radiated Electromagnetic Energy - Vehicle Test Methods - Part 4: Bulk Current Injection (BCI)
- ISO 11452-1 Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 1: General and Definitions
- ISO 11452-2 Road Vehicles - Electrical Disturbances by Narrowband Radiated Electromagnetic Energy - Component Test Methods - Part 2: Absorber-Lined Chamber
- ISO 11452-3 Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 3: Transverse Electromagnetic (TEM) Cell
- ISO 11452-4 Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 4: Bulk Current Injection (BCI)
- ISO 11452-5 Road Vehicles - Electrical Disturbances by Narrowband Radiated Electromagnetic Energy - Component Test Methods - Part 5: Stripline
- ISO 11452-6 Road Vehicles - Electrical Disturbances by Narrowband Radiated Electromagnetic Energy - Component Test Methods - Part 6: Parallel Plate Antenna
- ISO 11452-7 Road Vehicles - Electrical Disturbances by Narrowband Radiated Electromagnetic Energy - Component Test Methods - Part 7: Direct Radio Frequency (RF) Power Injection
- ISO 23273 Fuel Cell Road Vehicles - Safety Specifications: Protection Against Hydrogen Hazards for Vehicles Fuelled With Compressed Hydrogen
- ISO/26262-1 Road Vehicles - Functional Safety - Part 1: Vocabulary
- ISO/26262-2 Road Vehicles - Functional Safety - Part 2: Management of Functional Safety
- ISO/26262-3 Road Vehicles - Functional Safety - Part 3: Concept Phase

ISO/26262-4	Road Vehicles - Functional Safety - Part 4: Product Development: System Level
ISO/26262-5	Road Vehicles - Functional Safety - Part 5: Product Development: Hardware Level
ISO/26262-6	Road Vehicles - Functional Safety - Part 6: Product Development: Software Level
ISO/26262-7	Road Vehicles - Functional Safety - Part 7: Production and Operation
ISO/26262-8	Road Vehicles - Functional Safety - Part 8: Supporting Processes
ISO/26262-9	Road Vehicles - Functional Safety - Part 9: ASIL-Oriented and Safety-Oriented Analyses
ISO/26262-10	Road Vehicles - Functional Safety - Part 10: Guideline

2.2.7 Other Publications

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

FCC Rules and Regulations Parts 15 and 18

CAN/CSA-C108.4M-1992	Limits and Methods of Measurement of Radio Interference Characteristics of Vehicles, Motor Boats, and Spark-Ignited Engine - Driven Devices
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CSA Component Acceptance Service No. 33

ICES-002	Spark Ignition Systems of Vehicles and Other Devices Equipped with Internal Combustion Engines
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MIL-SPEC-1472 B for Thermal Hazards

Available from the the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>

NFPA 52	Vehicular Fuel Systems Code, 2006 edition
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“Vehicle Hydrogen Storage Using Lightweight Tanks”, Lawrence Livermore Nat. Laboratory, Proceedings of the 2000 DOE Hydrogen Program Review

NFPA 497	Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, 2004 Edition
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NFPA 704	Identification of Materials by Hazard Rating System
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ASTM E 681-04	Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)
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Ballard Power Systems Report RPT5104988H2	Accumulation in Closed Structure Hazard: Validation of Models and Air Exchange Rate Measurement Technique, 2005 September
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US Department of Interior, Bureau of Mines Report 503, Limits of Flammability of Gases and Vapors, 1952

3. DEFINITIONS

Standard Fuel Cell Vehicle (FCV) terminology is provided in SAE J2574. Terminology specific to this document is contained in this section.

3.1 AUXILIARY CIRCUIT

Electrical circuit supplying low voltage vehicle functions other than for propulsion, such as lamps, windscreen (windshield) wiper motors, and radios.

3.2 BARRIER

A device or panel that prevents the passage of a person (or part of a person) or material from one side to another.

NOTE: In the context of this document, barriers are discussed in two areas:

- a. A flow barrier provides passive or active means for controlling flow of potentially hazardous fluids from one space in the vehicle to another.
- b. An electrical barrier is a physical device or panel that prevents people from touching high voltage electrical parts.

3.3 BASIC INSULATION

The electrical insulation required for protection against electrical shock hazard under fault-free conditions.

3.4 CLASS I SYSTEM

An electrical system having basic insulation throughout, whose conductive accessible parts are connected to the protective earthing conductor and provided with an earthing terminal or connection to the vehicle.

3.5 CLASS II SYSTEM

An electrical system having double insulation and/or reinforced insulation throughout.

3.6 COMPARTMENT

A space that is enclosed (by barriers) except for openings necessary for interconnection, control, and ventilation.

3.7 (LIQUID OR GASEOUS) DISCHARGES

Liquids or gases leaving a system.

3.8 DOUBLE INSULATION

A system of two independent insulations, each of which is capable of acting as the sole insulation between live and accessible parts in the event of failure of the other insulation. The insulation system resulting from a combination of basic and supplementary insulation.

3.9 ELECTRICALLY-CONDUCTIVE CHASSIS

Conductive parts of the vehicle whose electrical potential is taken as reference and which are: (1) conductively linked together, and (2) not energized by high voltage sources during normal vehicle operation.

3.10 ELECTRICAL PROTECTION BARRIER

The part(s) providing against contact with live parts from any direction of access.

3.11 EXPOSED CONDUCTIVE PART

The conductive part that can be touched under the provisions of the IPXXB protection degree and becomes electrically energized under isolation failure conditions. This includes parts under a cover that can be removed without using tools.

3.12 ENCAPSULATION

The process of applying a thermoplastic or thermosetting protective or insulating coating to enclose an article by suitable means, such as brushing, dipping, spraying, thermoforming, or molding.

3.13 EXHAUST

Discharges of spent or processed fluids.

3.14 FLAMMABILITY LIMITS

The limits of sufficient concentrations of fuel and oxidant to propagate combustion from an ignition source.

NOTES:

- a. Gas mixtures involving hydrogen and oxygen require 4% hydrogen and 5% oxygen to be flammable at room temperature when no other reactants are present.
- b. Propagation includes unsustained events such as flashes moving away from the ignition source as well as sustained flames.

3.14.1 Upper Flammability Limit (UFL)

Highest concentration of fuel at which there is sufficient oxidant in the gas mixture for the mixture to be flammable.

NOTE: The UFL of hydrogen is 74% in air and 95% in pure oxygen as in both cases 5% oxygen is required in the mixture.

3.14.2 Lower Flammability Limit (LFL)

Lowest concentration of fuel in which a gas mixture is flammable.

NOTES:

- a. National and international standard bodies (such as NFPA and IEC) recognize 4% hydrogen in air as the LFL. See the US Department of Interior, Bureau of Mines Report 503 for further information. Flammability limits (LFL, UFL) depend on mixture temperature, pressure and the presence of dilution gases, and are assessed using specific test methods (e.g., ASTM E 681-04).
- b. While the LFL value in Note a is appropriate for evaluating flammability in general surroundings of vehicles or inside passenger compartments, this criteria may be overly restrictive for flowing gas situations where ignition requires more than 4% hydrogen in many cases. Whether an ignition source at a given location can ignite the leaking gas plume depends on the flow conditions and the type of ignition. At 4% hydrogen in a stagnant, room temperature mixture, combustion can only propagate in the upward direction. At approximately 8 to 10% hydrogen in the mixture, combustion can also be propagated in the downward and horizontal directions and the mixture is readily combustible regardless of location of ignition source.
- c. Given the potential confusion that often exists between notes a and b above, this report only uses LFL when referring to levels established in note a.

3.14.3 Non-flammable

A non-flammable discharge is one that cannot propagate or sustain combustion at its point of release or as it disperses in the surrounding atmosphere (or fluid).

NOTES: Figure 1 illustrates the flammability of gas mixtures containing hydrogen, oxygen, and nitrogen (as an inert). The potential flammability of a discharge can be determined by plotting the initial composition of the discharge and its concentration trajectory as it disperses into the surrounding air and then seeing which regions the discharge passes through. See notes a and b for descriptions of “non-flammable” and “potentially ignitable” discharges, respectively, and note c for examples.

- a. The “non-flammable” region is defined by mixtures that are either below 4% hydrogen (LFL) or below 5% oxygen (or both) based on 3.11 and 3.11.2. If the concentration of the discharge remains in the “non-flammable” region from the point of discharge through dispersal in the surrounding atmosphere, the discharge is non-flammable.
- b. The “potentially ignitable” region represents where the concentration exceeds 4% hydrogen and 5% oxygen as described in 3.14. The region is triangular (rather than rectangular) as the nitrogen (and other inert gases normally occurring in air) “clip” the top of the “potentially ignitable” region. As discussed in 3.14.2, where ignition below approximately 8% hydrogen is only possible in relatively quiescent conditions whereas concentrations above approximately 8 to 10% hydrogen can support ignition in flowing conditions (such as discharges from vehicles).
- d. If the concentration of the discharge passes through the “potentially ignitable” region at any point, the discharge should be considered ignitable unless verified to be non-ignitable per 4.2.4.1 and Appendix D, for example. The following discharges are discussed to illustrate the evaluation of “potential ignitability” and are shown as dotted lines (and identified by number) on Figure 1:
 1. A release of 100% hydrogen is not locally flammable at its point of release due to insufficient oxygen, but, as the release disperses in air, the resultant mixture becomes potentially ignitable in some regions before fully dispersing into the surrounding atmosphere.
 2. A mixture of hydrogen and nitrogen gas with less than 5% hydrogen is non-flammable because, when mixed with air, the hydrogen falls below the LFL (of 4% hydrogen) before there is sufficient oxygen (5%) in the mixture to support combustion.
 3. A typical discharge from a fuel cell vehicle shows that there can be both hydrogen and oxygen at the point of discharge from the vehicle, but that the discharge is usually non-flammable by virtue of using cathode and ventilation air to dilute the hydrogen content of the anode exhaust.

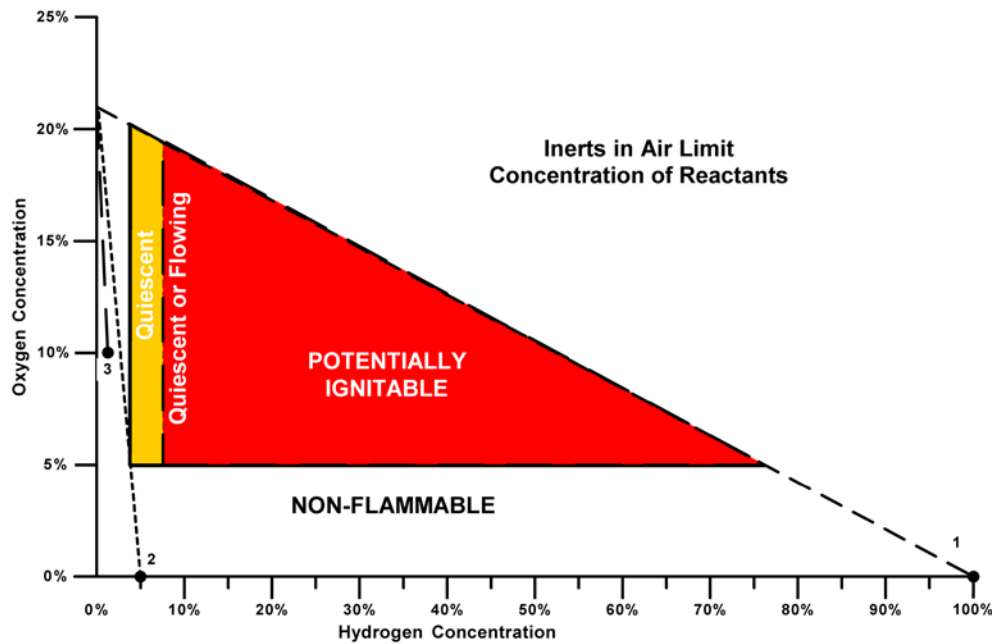


FIGURE 1 - POTENTIAL FLAMMABILITY OF HYDROGEN DISCHARGES IN AIR

3.15 FUEL CELL MODULE

Fuel cell modules are comprised of one or more fuel cell stacks; connections for conducting fuels, oxidants, and exhausts; electrical connections for the power delivered by the stacks; and means for monitoring and/or control. Additionally, fuel cell modules may incorporate means for conducting additional fluids (e.g., cooling media, inert gas), means for detecting normal and/or abnormal operating conditions, enclosures or pressure vessels, and ventilation systems.

3.16 HAZARDOUS AREA

An area or space in which an explosive gas atmosphere or other hazardous condition is or may be expected to be present in such quantities as to require special precautions for the construction, installation and use apparatus.

3.17 HAZARDOUS CONDITION

A condition that is potentially dangerous. Among these are hazardous fluids and high electrical voltages.

3.18 HAZARDOUS FLUIDS

Gases or liquids that pose potential dangers. Hazards present with fluids in fuel systems are as follows:

- Flammability - Sufficient quantities of fuel/air mixtures at or above the lower flammability limit (LFL) are by definition dangerous. See 3.11, including 3.11.1 through 3.11.3, for further information.
- Toxicity - Point sources greater than the IDLH (Immediately Dangerous to Life and Health) and occupiable areas greater than OSHA TWA (Time Weighted Average) or other equivalent standard should be considered hazardous.
- High Pressure - High-pressure fluids in fuel supply subsystems, fuel processors, fuel cells, and/or thermal management subsystems that can transfer kinetic energy causing personal injury.
- Extreme Temperature - Very high or low temperature fluids or materials that are capable of causing personal injury such as burns or frostbite.
- Reactive - Materials that can react with other common materials and can directly or indirectly pose hazards to humans. Fluids with extreme pH are examples.

3.19 HAZARDOUS VOLTAGE INTERLOCK LOOP (HVIL)

The HVIL is a system intended to protect people from exposure to high voltage or other hazardous conditions. It typically detects unwanted access or faults by passing a small (non-hazardous) signal through a loop connecting a set of normally-closed conductors, connectors, sensors, and switches to check for electrical continuity.

3.20 HIGH VOLTAGE

Voltage levels greater than 30 VAC or 60 VDC.

3.21 IGNITION SOURCES

Thermal or electric energy sources capable of igniting flammable gas mixtures. See 4.2.3.3 for discussion of avoiding thermal, electrical, and static discharges, respectively.

3.22 IMMEDIATELY DANGEROUS TO LIFE OR HEALTH (IDLH)

An IDLH exposure condition is defined as one that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment.

3.23 INTERNAL TRANSFER (OR CROSS LEAKAGE)

Leakage of fluids and/or gases through seams, joints, cracks, holes, or defects between circuits within components containing multiple fluids (or gases) such as heat exchangers or the fuel cell stack, driven by operating and/or non-operating pressure differences and/or concentration gradients. Possible internal transfer types include, fuel-to-air, air-to-fuel, fuel-to-coolant, coolant-to-fuel, air-to-coolant, and coolant-to-air.

3.24 NORMAL DISCHARGES

Discharges expected during normal operation and not associated exclusively with failures.

3.25 NORMAL OPERATION

All transient and steady state operating conditions of the vehicle occurring during start, intended operation and shut down which do not involve a component or system failure.

3.26 POINT OF RELEASE

Interface where ventilation exhaust or other discharge potentially containing hazardous fluids leaves the vehicle and is expelled to the surroundings, the passenger compartment, or other area that is assumed to be non-hazardous.

3.27 PURGES

Discharges associated with the removal of fluids or types of fluids from systems.

3.28 REINFORCED INSULATION

A single insulation system with such mechanical and electrical qualities that it, in itself, provides the same degree of protection against the risk of electric shock as does double insulation. The term "single insulation system" does not necessitate that the insulation must be in one homogeneous piece. The insulation system may comprise two or more layers that cannot be tested as supplementary or basic insulation.

3.29 RELEASES

Discharges, which in the context of this recommended practice, that are undesired or unwanted.

3.30 SUPPLEMENTARY INSULATION

An independent insulation provided in addition to the basic insulation to protect against electric shock hazard in the event that the basic insulation fails.

3.31 TUBING

A metallic or non-metallic enclosed conduit for transferring gaseous or liquid fluids.

3.32 VEHICLE ELECTRICAL CONNECTOR

A portable receptacle that by insertion into a vehicle inlet, establishes an electrical connection to the electric vehicle for the purpose of providing power and information exchange, with means for attachment of flexible cord or cable. This device is a part of the coupler.

3.33 VEHICLE ELECTRICAL COUPLER

A means of enabling the connection, at will, of a flexible supply cord to the equipment. It consists of a connector and a vehicle inlet.

3.34 VENTS

Discharges of unspent, unprocessed, or partially processed gases or liquids.

4. TECHNICAL SYSTEMS SAFETY GUIDELINES

4.1 General Vehicle Safety

It is important to protect persons from hazardous conditions, where the fundamental hierarchy of vehicle system safety design is:

- a. To protect vehicle occupants and the public from injuries that could result from the failures of components within the vehicle systems that support operation and/or as a result of damage caused by external events (e.g., collisions).
- b. To protect vehicle occupants, general public, and service personnel from hazards associated with operation or servicing of the fuel cell vehicle (e.g., high voltage, extreme temperatures, high pressure, and flammable or toxic fluids).
- c. To minimize vehicle system damage caused by subsystem or component failures.

4.1.1 Design for Safety

The vehicle and associated subsystems should be designed with the objective that a single-point hardware or software failure should not result in an unreasonable safety risk to any person or uncontrolled vehicle behavior.

4.1.1.1 Risk Assessment

Risk assessments such as Failure Modes and Effects Analysis (FMEA) are necessary to identify potential faults and define appropriate countermeasures. See SAE J1739 Reference Manual for guidance.

4.1.1.2 Isolation and Separation of Hazards

Isolation and separation of hazards are approaches used to prevent cascading of failures and preclude unwanted or unexpected interactions. Ignition sources should be isolated from hazardous fluid systems.

4.1.1.3 Critical Control Function

Safety-critical control systems should be designed such that a single hardware or software failure will not cascade into a hazardous condition. This may include isolation, separation, redundancy, supervision, and/or other means. Guidance for hardware and software design can be found in ISO 26262, UL 991, and UL 1998.

4.1.1.4 Fail-Safe Design

The vehicle design should consider fail-safe design of electrical and hazardous fluid system controls. Automatic electrical disconnects should open and fuel shutoffs should close when deactivated. By so doing, any interruption of this control signal will cause isolation of electrical or fuel sources.

Vehicle operational safety should consider loss of vehicle power due to an automatic shutdown that may in itself lead to a hazardous operating condition. A staged warning and shutdown process or some other alternative means should be provided to mitigate the posed hazard, particularly, if the vehicle is moving. When faults that pose potential hazards are detected, specific actions to be taken are defined in 4.6.

Guidance can be found in ISO 6469-2 - Electric road vehicles - Safety specifications. Part 2: Functional safety means and protection against failures.

4.1.2 Electromagnetic Compatibility (EMC) and Electrical Transients

All electrical assemblies on an FCV, which could affect safe operation of the vehicle, should be functionally tolerant of the electromagnetic environment to which the vehicle will be exposed. This includes fluctuating voltage and load conditions, which may occur during normal operation of the vehicle during driving and fueling. Also, electrical transients resulting from normal operation of the vehicle should not cause false shutdowns of the vehicle.

The vehicle should meet the applicable government regulatory requirements for EMC. See industry standards and guidelines in 2.2.1, 2.2.3, 2.2.5, 2.2.6, and 2.2.7.

4.1.3 Fuel Cell Vehicle Crashworthiness

Crashworthiness guidelines for FCVs should meet applicable government regulatory requirements. In the U.S., use the applicable FMVSS (see 2.1.3). See 4.6.2 for crash response. Fuel system and electrical integrity may be tested simultaneously or separately. If performed separately, electrical integrity testing can be performed with a partial or no fuel inventory.

4.1.3.1 Fuel System Integrity

In the U.S., FMVSS 301 and FMVSS 303 provide fuel system integrity requirements of motor vehicles using liquid fuels with boiling points above 0 °C (32 °F) and compressed natural gas, respectively. In the absence of such regulations, the following criteria are proposed for post-crash fuel releases from Fuel Cell Vehicles (FCVs), as well as other hydrogen vehicles, likely subject to such regulation in the future:

- a. The same equivalent energy of fuel as currently in FMVSS 301. See Appendix A for specific guidance for compressed hydrogen systems.
- b. No expulsion of other hazardous fluids from the fuel system (such as hydrogen as a liquid, metal hydride or chemical hydride materials).

4.1.3.2 Electrical Integrity

Post-crash electrical requirements for fuel cell vehicles are addressed in SAE J1766. See also 4.6.2.

4.1.4 Vehicle Immersion

Immersion of a FCV in water as specified by the vehicle manufacturer should not result in electric potential or current flow, gas or liquid emissions, flame or explosion that is hazardous to any person inside or outside the vehicle.

4.1.5 Towability Design Criteria

Specific procedures for sling, wheel-lift, or car-carrier towing should be considered normal service information and included in the owner's manual/guide. Included in the procedures should be photographs or line drawings describing recommended attachment points. For further information on towing, refer to SAE J1142.

4.2 Fuel System Safety

Fuel systems that store, contain, process, and/or deliver fuel should be designed to SAE J2579. Integration of fuel systems into the vehicle should address the following items.

4.2.1 Installation

All components and interconnecting piping and wiring should be securely mounted or supported in the vehicle to minimize damage and prevent leakage and/or malfunction. Protection from gravel and road debris as well as chafing or damage should be considered. Thermally-activated PRDs should be located in the same area or compartment as the components or systems that are being protected. See SAE J2579 for guidance.

4.2.2 Fail-Safe Shutoff

A means should be provided to prevent the unwanted discharge of fuel arising from single-point failures to the shutoff function. The HVIL could also possibly be used to isolate the fuel supply. See 4.1.1.

4.2.3 Management of Potentially Hazardous Conditions within Vehicle Compartments

All components containing or generating hazardous fluids as defined in 3.15 should be located in spaces or compartments of the vehicle where potentially hazardous conditions can be managed. When appropriate, the spaces or compartments may be formed using barriers as defined in 4.2.3.1. Equipment installed within these spaces or compartments should be suitable for their environments based on control of the potentially flammable atmosphere per 4.2.3.2 and/or elimination of ignition sources per 4.2.3.3.

Discharges of hazardous fluids from these spaces or compartments should address the following:

- a. External release of hazardous fluids from the vehicle per 4.2.4.1.
- b. The entry of hazardous fluids into the passenger compartment per 4.2.4.2.
- c. The passage of flammable fluids into compartments or spaces containing equipment not suitable for hazardous areas per 4.2.4.3.

Credible failures of equipment and systems in 4.2.3.1 through 4.2.3.3 should be considered and, if warranted, addressed in 4.2.8.

4.2.3.1 Flow Barriers

Flow barriers may be used to form spaces or compartments with hazardous materials and separate them from non-hazardous areas inside or surrounding the vehicle. Flow barriers should control the passage of hazardous fluids by either passive or active means. All seams, gaps, and penetrations of passive barriers should be sealed sufficiently to meet 4.2.3. Active barriers should meet the criteria for pressurization in 4.2.3.2(c).

Flow barriers for containing fuel-bearing equipment as well as ventilation exhaust ducts and channels should be constructed of metallic or other materials that will not propagate flame and be designed to prevent static electrical discharges. The potential for transient flame transmission between compartments, pressure rise and other effects should be addressed. See 4.2.4.1 and the evaluations in Appendix D. Inlets and exhaust outlets should be protected such that functionality is not compromised due to flow restrictions. See Appendix E for additional guidance in designing barriers in conjunction with PRDs and other shields for hydrogen systems.

4.2.3.2 Potentially Flammable Atmospheres

The following approaches may be used to manage potentially flammable atmospheres in compartments containing fuel bearing equipment:

- a. Ventilation - Natural or forced ventilation is an effective method for reducing the potential for the existence of a flammable gas mixture by diluting the flammable gas to a level below its lower flammability limit. When establishing a ventilation inlet location and flow requirement, possible contamination of the diluent air stream should be considered. Ventilation equipment and sensors within ducts and channels carrying potentially flammable fluids should be suitable for their application per 4.2.3.3. The size and location of other shields (if any) that thermally or physically protect the hydrogen system shall be such that they do not interfere with the functionality of the ventilation system or the flow barriers. If the ventilation flow is incapable of diluting all releases (including abnormal releases) of flammable gas mixtures or if loss of ventilation flow causes a potential hazard, then countermeasures should be provided per 4.2.8. See IEC 60079-10 for guidance.
- b. Encapsulation - Encapsulation may be used to isolate flammable atmospheres from potential ignition sources within equipment. See IEC 60079-18 for guidance.
- c. Pressurization - Pressurization is a type of protection of electrical apparatus in which safety is achieved by means of a protective gas maintained at a pressure above an adjoining space containing potentially flammable gas. An opposing pressure differential or velocity may be used to prevent the leakage of hazardous fluids through openings in a compartment (or space) to other compartments (or spaces) in the vehicle. If loss of pressure or velocity causes a potential hazard, then countermeasures should be provided per 4.2.8. See NFPA 496 for guidance.
- d. Consumption - Catalytic reactors or other means to reduce flammable gas concentration may be used to reduce combustible mixtures. A means of unacceptable flame suppression should be provided if catalytic reactors or other potential ignition sources are used.
- e. Suppressants - Inert gases or other materials may be used to reduce the effective flammability of an atmosphere or prevent combustion. The asphyxiation risk or toxicity associated with suppressants should be considered.

4.2.3.3 Potential Ignition Sources

If a local area contains flammables on a frequent or continuous basis, then equipment installed in this area should not be an ignition source during either normal operation or a single failure of said equipment. If the discharge is flammable only on an abnormal or infrequent basis, then equipment should not be an ignition source during normal operation. The following ignition sources should be treated as follows:

- a. External Surfaces - During normal operation, external surface temperatures of components within the spaces or compartments containing fuel-bearing equipment should be less than the autoignition temperature of the flammable fluid. See IEC 60079-20 for guidance regarding auto ignition temperatures of flammable fluids.
- b. Electrical Equipment - Electrical equipment installed within spaces or compartments containing fuel-bearing equipment should be suitable for use within that area. Guidance for the determining the protection techniques can be found in IEC 60079-14 and UL 2279.
- c. Static Discharge - The potential for static discharge in spaces or compartments containing fuel-bearing equipment should be eliminated by proper bonding and grounding. See 4.4.8 for installation of equipment within areas containing fuel-bearing components.
- d. Catalytic Materials - Equipment containing materials that are capable of catalyzing the reaction of flammable fluids with air should suppress the propagation of the reaction from the equipment to the surrounding flammable atmosphere.

If the ignition sources cannot be adequately suppressed or if there is a potential for auto-ignition, see 4.2.3.1, 4.2.3.2, and/or 4.2.8.

4.2.4 Normal Gaseous Discharge Systems

The vehicle design for all fuel system exhausts, purges, vents, and other normal gaseous discharges should meet the physical and functional requirements set forth in 4.2.4.1 through 4.2.4.4. Credible failure of gaseous discharge systems should be addressed as part of fault monitoring in 4.2.8.

4.2.4.1 Normal Gaseous Discharges Outside the Vehicle

Fuel constituents in purges, vents, and exhausts, which occur during normal operation shall not cause a hazardous condition. The hazards posed include the possibility of local flammability or toxicity at point of discharge or as the discharge disperses into the surrounding atmosphere, and the subsequent possibility of build-up of emissions to a flammable or toxic level when the vehicle is operated or parked in enclosed environments.

Discharges may be managed through a combination of process and component design, natural or forced convection, catalytic reactors (recombiners) or other means. See 4.2.3 for guidance.

Local regions at point of discharge or as the discharge disperses into the surrounding atmosphere shall meet the following criteria throughout normal operation including start-up and shutdown:

- a. Below the IDLH of constituent compounds.
- b. Below the lower flammability limit (LFL) per 3.14.2 or, if potentially flammable at point of discharge or as the discharge disperses into the surrounding atmosphere, limited in both volume and concentration of hydrogen and verified to meet Appendix D.

If degradations or faults as discussed in 4.1.1 could result in the above criteria being exceeded, then these items should be addressed per 4.2.8 or verified to not pose a hazard using Appendix D (including Appendices D.1, D.2, and D.3 as appropriate) for guidance.

See also 5.2 and Appendix C for specific criteria and evaluations for ensuring that the general atmosphere surrounding the vehicle remains non-hazardous during normal operation.

4.2.4.2 Normal Gaseous Discharges to Passenger, Luggage, and Cargo Compartments

Discharges of hazardous gases to passenger, luggage, and cargo compartments shall be prevented. This can be accomplished using barriers, natural or forced convection, catalytic reactors (recombiners) or other means as defined in 4.2.3. Flammable gas and toxic gas levels inside passenger, luggage, and cargo compartments should be less than 25% LFL (based on Note a in 3.14.2) and OSHA TWA (Time Weighted Average) or other equivalent method as evaluated using 4.1.1.

4.2.4.3 Normal Gaseous Discharges to Other Compartments

Flammable fluids shall not be discharged into compartments or spaces within the vehicle that contain equipment not suitable for flammable locations. This can be accomplished using barriers, natural or forced convection, catalytic reactors (recombiners) or other means as defined in 4.2.3.

4.2.4.4 Potential Hydrogen Evolution from Traction Batteries

The vehicle design should preclude the release of hazardous gases beyond the limits defined in 4.2.4.1 through 4.2.4.3 and follow safety measures defined in 4.2.3.

4.2.5 Discharges from Hydrogen Storage Systems and Pressure Relief Devices (PRDs)

Hydrogen storage systems may discharge hydrogen following an accident or fault. Since it is often not practical to dilute these discharges to non-hazardous levels as done with normal discharges in 4.2.4 or 5.2.1, the discharge from pressure relief devices (PRDs) should be vented to the outside of the vehicle passenger, luggage, and cargo compartments. Additionally, if the hydrogen storage system is located within the passenger, luggage, or cargo compartment, all other discharges or potential discharges from the hydrogen storage system should be directed outside of these compartments. The placement and direction of vent flows should minimize exposure to humans (both inside and outside the vehicle) or the progression of hazards within the vehicle or surroundings.

See Appendix E for guidance with regard to packaging hydrogen storage systems, PRDs, and vent systems.

4.2.6 Fueling

The fueling receptacle should be located on the vehicle such that potential leaks during filling are vented directly over-board without flammable gases passing through the passenger compartment, luggage compartment, or other interior spaces of the vehicle. Consideration should also be given to not locating the receptacle in areas very likely to be damaged in accidents such as the energy absorbing elements of the vehicle .

The receptacle should be protected from the ingress of dirt and water as far as is reasonably practicable, and receptacle sealing surfaces shall be protected by a door, cover, or cap.

The receptacle, when connected, shall be bonded to the electrically-conductive chassis of the vehicle. The measured electrical resistance shall be less than 1,000 Ω .

The fuelling receptacle should also be protected against maladjustment and rotation (e.g., accomplished by means of positive locking in all directions) and should be secured to the vehicle in such a manner that it provides against foreseeable handling errors. See SAE J2579 for guidance in the design of fueling systems and SAE J2600 for nozzle and receptacle requirements for compressed hydrogen.

The vehicle should also have provisions such that one (or both) of the following are met:

- a. the vehicle cannot be moved while the fueling nozzle is connected
- b. the fueling receptacle is properly installed and secured to prevent rupture of the fill line or connections within the vehicle if a drive-away occurs and the break-away functions to separate the fueling hose on the fill station. See Appendix F.

See also 4.7 and 5.1 for safety labeling requirements and fueling safety guidance, respectively.

4.2.7 Defueling

A means should be developed for removing fuel from the FCV for maintenance or other special purposes such as post-crash and post-fire. See 6 and 7.2.

4.2.8 Fuel System Monitoring

Potential faults such as the items listed below should be evaluated per 4.1.1. Faults leading to potential hazards should be addressed using 4.1.1.4 for guidance and 4.6 for appropriate actions.

- a. Fuel Discharge Fault - A fuel discharge fault is a discharge of fuel that results in potentially flammable atmospheres in excess of the limits specified in 4.2.3. Fault detection methods may include odorants, direct measurements such as hydrogen concentration or combustibility, or indirect measurements such as flow or pressure measurements within the system.
- b. Fuel Shutoff Fault - Detection of a fault in the fuel shutoff function as defined in 4.2.2.

- c. Process Fault - A process fault is a pressure, temperature, or other process parameter exceeding its normal operating condition of the component or system.
- d. Ventilation Fault - A ventilation fault is a loss or reduction of airflow intended to manage a potentially hazardous environment per 4.2.3.2.

4.3 Fuel Cell System Safety

Fuel cell systems typically contain a gaseous-fueled electrochemical reactor (the fuel cell stack) and support subsystems, which if not monitored and controlled appropriately, can expose the vehicle occupants and/or the public to specific hazards (e.g., electrical shock, fuel leak).

4.3.1 Fuel Cell System Design

SAE J2579 should be used for the design of subsystems containing hydrogen, and 4.2 should be used for integrating these subsystems into the vehicle. Correspondingly, subsystems using electrical components should be designed to 4.4 and comply with SAE J2344.

4.3.2 Fuel Cell Stack Design

Fuel cell stacks should be designed to prevent hazardous faults including hazardous fluid leakage, overpressure, fire, and electric shock hazards.

If hazardous fluid leakage can develop over time due to stack or other component faults or wear, the potential effects of these external leakages or internal transfers should be assessed and addressed as per 4.1.1, 4.2.8, 4.6, 5.1 and 5.2. Examples include fuel-to-coolant transfer, which may result in the presence of hydrogen within (and possibly emitted from) the cooling system, and fuel-to-air transfer, which may result in potentially flammable mixtures being emitted during operation. (See 4.2.4.1 for methods for assessing normal gaseous discharges outside the vehicle.)

4.3.3 High Voltage Electric Shock Protection

The fuel cell system should meet electrical requirements defined in 4.4.3.

4.3.4 High Voltage Withstand Capability

For design verification, each high voltage system should demonstrate adequate dielectric strength such that there is no indication of a dielectric breakdown or flashover after the application of a voltage per 4.4.4. The fuel cell stack(s) and other equipment/circuits that could be damaged by this test may be disconnected.

4.3.5 Fuel Cell System and Stack Monitoring

Potential faults such as the items listed below should be evaluated per 4.1.1. Items exceeding limits for safe operation should be addressed using 4.1.1.4 for guidance and 4.6 for appropriate actions.

- a. Cell Stack or Process Fault - Out-of-limit thermal, pressure, flow, or composition conditions within cell stacks or other reactors in the fuel cell system could lead to internal or external component failures and subsequently expose personnel to hazards.
- b. Isolation Fault - See 4.4.9a.
- c. Low Voltage Fault - The fuel cell stack or individual cells may experience low voltage that could lead to internal or external component failures and subsequently expose personnel to hazards.
- d. Overcurrent Fault - Currents greater than the rated values could lead to internal or external component failures and subsequently expose personnel to hazards.