# UL 2267

## STANDARD FOR SAFETY

Fuel Cell Power Systems for Installation in Industrial Electric Trucks

UL Standard for Safety for Fuel Cell Power Systems for Installation in Industrial Electric Trucks, UL 2267

Third Edition, Dated March 26, 2020

***Summary of Topics***

***This is the Third Edition of UL 2267 dated March 26, 2020 which includes several substantive changes to update the requirements to address current technology and safety issues.***

The new requirements are substantially in accordance with Proposal(s) on this subject dated July 12, 2019 and November 29, 2019.

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# UL 2267

## Fuel Cell Power Systems for Installation in Industrial Electric Trucks

First Edition – April, 2006
Second Edition – March, 2013

**Third Edition**

**March 26, 2020**

This ANSI/UL Standard for Safety consists of the Third Edition.

The most recent designation of UL 2267 as an American National Standard (ANSI) occurred on February 25, 2020. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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# INTRODUCTION

## 1 Scope

1.1 These requirements cover fuel cell power systems intended to be installed in Type E, Type CGH, Type CGH-EE, Type CHG-ES, or Type CGH-EX industrial trucks used in locations as defined in the Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations, NFPA 505, the National Electrical Code, NFPA 70, and the Standard for Electric-Battery-Powered Industrial Trucks, UL 583.

1.2 The fuel cell power systems covered by this Standard are anticipated for use as described in the following standards as applicable to the intended truck:

a) Safety Standard for Low Lift and High Lift Trucks, ITSDF B56.1;

b) Safety Standard for Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles, ITSDF B56.5;

c) Safety Standard for Rough Terrain Forklift Trucks, ITSDF B56.6;

d) Safety Standard for Industrial Crane Trucks, ITSDF B56.7;

e) Safety Standard for Personnel and Burden Carriers, ITSDF B56.8;

f) Safety Standard for Operator Controlled Industrial Tow Tractors, ITSDF B56.9; and the

g) Safety Standard for Manually Propelled High Lift Industrial Trucks, ITSDF B56.10.

1.3 These requirements cover fuel cell power systems that incorporate a permanently mounted pressure vessel containing compressed hydrogen gas.

1.4 These requirements cover the use of designs that are fueled by hydrogen gas without the pressure vessel being removed from the industrial truck (onboard fueling).

1.5 These requirements cover only the fuel cell and fuel cell balance of plant components including the power and/or power conditioning electronics, regardless of packaging, as defined in 5.11 and Figure 5.1, as well as any components in classified zones.



## 2 Components

2.1 A component of a product covered by this Standard shall:

a) Comply with the requirements for that component;

b) Be used in accordance with its rating established for the intended conditions of use;

c) Be used within its established use limitations or conditions of acceptability; and

d) Comply with the applicable requirements of this end product Standard.

2.2 A component of a product covered by this Standard is not required to comply with a specific component requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product;

b) Is superseded by a requirement in this Standard; or

c) Is separately investigated when forming part of another component, provided the component is used within its established ratings and limitations.

2.3 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

2.4 A component that is also intended to perform other functions such as overcurrent protection, ground-fault circuit-interruption, surge suppression, any other similar functions, or any combination thereof, shall additionally comply with the requirements of the applicable UL Standard that covers devices that provide those functions.

## 3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

## 4 Referenced Publications

4.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

4.2 The following publications are referenced in this Standard:

**ANSI:**

ANSI HGV 2, *Compressed Hydrogen Gas Powered Vehicle Fuel Containers*

ANSI/IAS NGV 4.2, *Hoses for Natural Gas Vehicles and Dispensing Systems*

ANSI Z21.24/CSA/CGA 6.10, *Connectors for Gas Appliances*

ANSI Z535.1, *American National Standard for Safety Colors*

ANSI Z535.3, *American National Standard for Criteria for Safety Symbols*

ANSI Z535.4, *American National Standard for Product Safety Signs and Labels*

**ASME:**

ASME B31, *Code for Pressure Piping*

ASME B31.3, *Process Piping*

**ASTM:**

ASTM D3580, *Standard Test Methods for Vibration (Vertical Linear Motion) Test of Products*

ASTM D5112, *Standard Test Method for Vibration (Horizontal Linear Motion) Test of Products*

ASTM E230/E230M, *Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples*

ASTM F1459, *Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (HGE)*

ASTM G142, *Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both*

**CFR:**

CFR 1910.145, (OSHA) Specifications for Accident Prevention Signs and Tags

**CGA:**

CGA G-5.5, *Hydrogen Vent Systems*

**CSA:**

CSA HGV 3.1, *Fuel System Components for Compressed Hydrogen Gas Powered Vehicles*

CSA HPIT 1, *Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage and Handling Components*

CSA HPIT 2, *Dispensing Systems and Components for Fueling Hydrogen Powered Industrial Trucks*

CSA HPRD1, *Thermally Activated Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers*

**IEC:**

IEC 60079-10-1, *Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres*

IEC 60529, *Degrees of Protection Provided by Enclosures (IP Code)*

IEC 60812, *Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis (FMEA)*

IEC 61025, *Fault Tree Analysis (FTA)*

IEC 61508 (all parts), *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems*

**IEC/ISO:**

IEC/ISO 31010, Risk Management - Risk Assessment Techniques

**ISO:**

ISO 4080, *Rubber and Plastics Hoses and Hose Assemblies – Determination of Permeability to Gas*

ISO 12100, *Safety of Machinery – General Principles for Design – Risk Assessment and Risk Reduction*

ISO 13849-1, *Safety of machinery – Safety-Related Parts of Control Systems – Part 1: General Principles for Design*

ISO 13849-2, *Safety of Machinery – Safety-Related Parts of Control Systems – Part 2: Validation*

ISO 15916, *Basic Considerations for the Safety of Hydrogen Systems*

ISO 19881, *Gaseous Hydrogen – Land Vehicle Fuel Containers*

ISO 26262, *Road Vehicles – Functional Safety* (all parts)

**MIL (DoD):**

MIL-STD-882E, *System Safety*

**NFPA:**

NFPA 54, *National Fuel Gas Code*

NFPA 70, *National Electrical Code*

NFPA 70E, *Standard for Electrical Safety in the Workplace*

NFPA 79, *Electrical Standard for Industrial Machinery*

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*

NFPA 505, *Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations*

**SAE:**

SAE J517, *Hydraulic Hose*

SAE J1127, *Low Voltage Battery Cable*

SAE J1128, *Low Voltage Primary Cable*

SAE J1654, *Unshielded High Voltage Primary Cable*

SAE J1678, *Low Voltage Ultra Thin Wall Primary Cable*

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 J2601, *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*

SAE J2601-3, *Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks*

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

SAE J2600, *Compressed Hydrogen Surface Vehicle Refueling Connection Devices*

SAE J2719, *Hydrogen Fuel Quality for Fuel Cell Vehicles*

**UL:**

UL 50E, *Enclosures for Electrical Equipment, Environmental Considerations*

UL 79, *Power-Operated Pumps for Petroleum Dispensing Products*

UL 157, *Gaskets and Seals*

UL 429, *Electrically Operated Valves*

UL 458, *Power Converters/Inverters and Power Converter/Inverter Systems for Land Vehicles and Marine Crafts*

UL 507, *Electric Fans*

UL 536, *Flexible Metallic Hose*

UL 583, *Electric-Battery-Powered Industrial Trucks*

UL 705, *Power Ventilators*

UL 746A, *Polymeric Materials – Short Term Property Evaluations*

UL 746C, *Polymeric Materials – Use in Electrical Equipment Evaluations*

UL 778, *Motor-Operated Water Pumps*

UL 810A, *Electrochemical Capacitors*

UL 840, *Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment*

UL 842, *Valves for Flammable Fluids*

UL 969, *Markings and Labeling Systems*

UL 991, *Tests for Safety-Related Controls Employing Solid-State Devices*

UL 1004-1, *Rotating Electrical Machines – General Requirements*

UL 1004-2, *Impedance Protected Motors*

UL 1004-3, *Thermally Protected Motors*

UL 1012, *Power Units Other Than Class 2*

UL 1310, *Class 2 Power Units*

UL 1450, *Motor-Operated Air Compressors, Vacuum Pumps, and Painting Equipment*

UL 1581, *Reference Standard for Electrical Wires, Cables, and Flexible Cords*

UL 1642, *Lithium Batteries*

UL 1741, *Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources*

UL 1836, *Electric Motors and Generators for Use in Class I, Division 2, Class I, Zone 2, Class II, Division 2 and Zone 22 Hazardous (Classified) Locations*

UL 1989, *Standby Batteries*

UL 1998, *Software in Programmable Components*

UL 2075, *Gas and Vapor Detectors and Sensors*

UL 2580, *Batteries for Use In Electric Vehicles*

UL 2271, *Batteries for Use in Light Electric Vehicle Applications*

UL 5085-1, *Low Voltage Transformers – Part 1: General Requirements*

UL 5085-3, *Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers*

UL 60730-1, *Automatic Electrical Controls for Household and Similar Use, Part 1: General Requirements*

UL 60950-1, *Information Technology Equipment – Safety – Part 1: General Requirements*



## 5 Glossary

5.1 For the purpose of this Standard, the following definitions apply.

5.2 BONDING – The permanent joining of metallic parts to form a positive electrically conductive path that provides electrical continuity between non-current carrying metal parts and is capable of conducting any fault current that may occur. This applies to bonding within the fuel cell system and between the fuel cell system and truck and does not refer to the means to ground the truck itself, such as with a grounding strap or with tires.

5.3 CHECK-VALVE – Fluid control device that allows fluids to flow in only one direction.

5.4 DILUTION BOUNDARY – The extent of a flammable area or zone created by a limited release of flammable gas or vapor, internal to the fuel cell power system or truck in which it is mounted, and controlled by mechanical ventilation or other effective means as outlined by Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres, IEC 60079-10-1.

5.5 ELECTROSTATIC DISCHARGE (ESD) – Discharge created by static electricity.

5.6 EQUIPOTENTIAL BONDING – For the purpose of controlling static electric hazards, the process of connecting two or more conductive objects together by means of a conductor so that they are at the same electrical potential, but not necessarily at the same potential as the earth.

5.7 FUEL CELL POWER SYSTEM - An assembly of components and parts that together electrochemically converts fuel and oxidant to electrical current. See Figure 5.1 for a block diagram of a fuel cell power system. A fuel cell power system may contain all or some of the components shown in Figure 5.1. The fuel cell power system for use with industrial trucks will be in one of the following forms:

a) SELF-CONTAINED SYSTEM – A complete system incorporated into its own housing that is intended to replace or combine with a battery system to power an industrial truck. Additional counterweighting may be located outside of the system's housing. Display and control functions may be located outside the system's housing in proximity to the operator's compartment.

b) INTEGRATED SYSTEM – A complete system of fuel cell components and parts that are incorporated into the industrial truck with the various parts of the system potentially distributed throughout the truck.

c) TYPE CGH-E FUEL CELL POWER SYSTEM – A fuel cell power system intended for use in Type E industrial trucks only.

d) TYPE CGH-EE FUEL CELL POWER SYSTEM – A fuel cell power system intended for use in Type EE industrial trucks that, in addition to meeting all requirements for a Type CGH-E and Type CGH-ES units, has its electric motors and all other electric equipment completely enclosed.

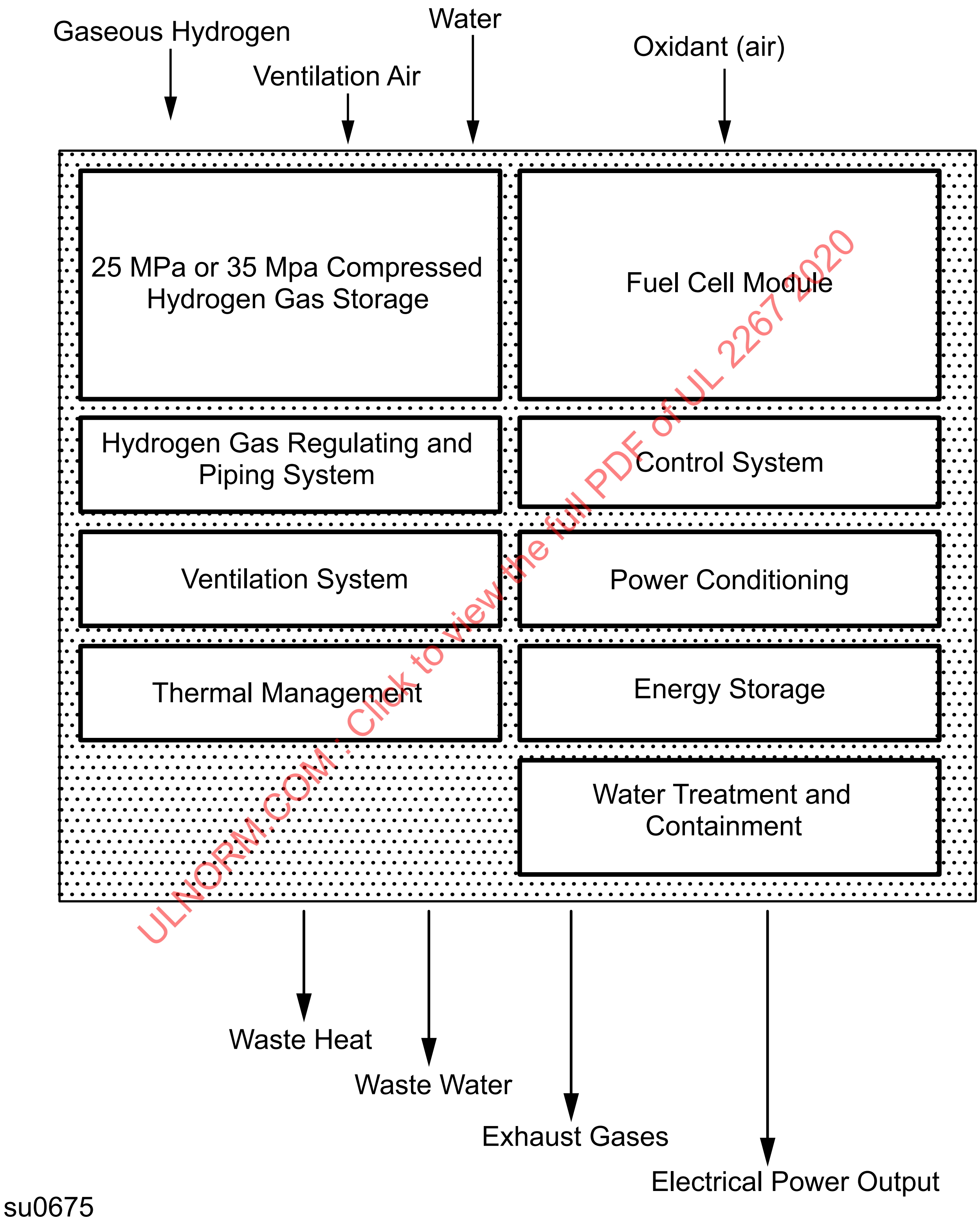
e) TYPE CGH-ES FUEL CELL POWER SYSTEM – A fuel cell power system intended for use in Type ES industrial trucks that, in addition to meeting all requirements for Type CGH-E units, is provided with additional safeguards to the electric system to prevent the emission of hazardous sparks and to limit surface temperatures.

f) TYPE CGH-EX FUEL CELL POWER SYSTEM – A fuel cell power system intended for use in Type EX industrial trucks that, in addition to meeting all requirements for Type CGH-E units, has electric fittings and equipment so designed, constructed, and assembled that the unit can be used in atmospheres containing specifically named flammable vapors, dusts, and, under certain conditions, fibers.

NOTE: Dilution by ventilation is a not viable protection measure against flammable gas leaks in fuel cell power systems used in hazardous (classified) areas.

**Figure 5.1**

**Fuel Cell Power System**






Note: A fuel cell power system may contain all or some of the above components

5.8 HAZARDOUS (CLASSIFIED) AREAS – Any work area or space where combustible dust, ignitable fibers, or flammable, volatile liquids gases, vapors or mixtures are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures as defined by the National Electrical Code, NFPA 70, or by Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres, IEC 60079-10-1.

5.9 HAZARDOUS VOLTAGE CIRCUIT - A circuit involving a potential greater than 42.4 V peak (30 Vrms) or 60 Vdc.

5.10 HPIT – Hydrogen Powered Industrial Truck

5.11 INTEGRAL – For the purposes of this standard, something that is either contained within the fuel cell power system or is external, but is a part of the fuel cell power system.

5.12 LIMITED POWER CIRCUIT – A circuit supplied from a source whose open circuit voltage is less than or equal to 60 Vdc and whose maximum current and power after 60 seconds of operation comply with the values in Table 30.1 and Table 30.2. Limited power circuits are considered equivalent to NEC Class 2 circuits as outlined in the National Electrical Code, NFPA 70 and to low-voltage limited energy circuits as defined in Section 16 of the Standard for Electric-Battery-Powered Industrial Trucks, UL 583.

5.13 LOW-VOLTAGE CIRCUIT – A circuit involving a peak open-circuit potential of not more than 42.4 V (30 Vrms) or 60 Vdc under both normal and single fault conditions.

5.14 LOWER FLAMMABILITY LIMIT (LFL) – The lowest volume percentage of a gas in air that will ignite.

NOTE: The LFL for hydrogen is 4% by volume.

5.15 MAXIMUM ALLOWABLE WORKING PRESSURE – The maximum gauge pressure of the contained fluid for which each portion of the system is rated with consideration of an abnormal condition that initiates the operating of the safety pressure relief devices. See Annex A for a comparison table of pressure terms. (MAWP)

5.16 MAXIMUM CONTINUOUS LOAD RATING – Maximum continuous power that can be sustained by the fuel cell system independent of any electrical energy storage device or storage component at 25°C (77°F) and 1 atm.

5.17 MAXIMUM CONTINOUS VA – The maximum Volt-Amps (VA) that can be delivered for at least 3 hours under the conditions of maximum continuous load rating (see 5.16).

5.18 MAXIMUM OPERATING PRESSURE (MOP) – The highest gauge pressure of a component or the system that is expected during normal operation. See Annex A for a comparison table of pressure terms.

NOTE: It is typically no more than 1.25 times the service pressure and a 10%-margin below the pressure relief device setting.

5.19 NORMAL RELEASE – Limited internal localized volumes of flammable vapor concentrations released during normal operation that may include fuel cell purge.

5.20 NORMAL OPERATION – All operating and non-operating modes encountered during product use that are not the result of a failure.

5.21 PRESSURE RELIEF DEVICE (PRD) – A pressure and/or temperature activated device used to prevent the pressure from rising above a predetermined maximum and thereby prevent failure of a pressurized part or system.

5.22 RISK ANALYSIS – Systemic use of available information to identify hazards and to estimate the risk.

5.23 RISK ASSESSMENT – Overall process comprising a risk analysis and a risk evaluation.

5.24 RISK EVALUATION – Procedure based on the risk analysis to determine whether a tolerable risk has been achieved.

5.25 SAFETY CONTROL – Automatic controls and interlocks including relays, switches, sensors and other auxiliary equipment used in conjunction therewith to form a safety control system, which is intended to prevent unsafe operation of the controlled equipment.

5.26 SAFETY CRITICAL COMPONENT – A component, device, circuit, software, or similar part whose failure would affect the safety of the fuel cell power system as determined by the requirements of Section 7, Risk Assessment and Risk Reduction.

5.27 SERVICE PRESSURE – This term only relates to the hydrogen pressure vessel, and is the pressure, as specified by the manufacturer, at a uniform gas temperature of 15° C (59° F) and full gas content. Service pressure is equivalent to the term "nominal working pressure". See Annex A for a comparison table of pressure terms.

5.28 STACK PURGE – A controlled hydrogen release from the stack fuel circuit.

5.29 TOUCH CURRENT – Electric current through a human body or an animal body when it touches one or more accessible parts.

5.30 TYPE CGH INDUSTRIAL TRUCK – An electrically operated industrial truck that utilizes a compressed hydrogen powered unit utilizing a fuel cell for conversion of the hydrogen fuel gas to electricity that has minimum acceptable safeguards against inherent fire hazards.

5.31 TYPE CGH-EE INDUSTRIAL TRUCK – A type EE industrial truck that utilizes a Type CGH-EE fuel cell power system.

5.32 TYPE CGH-ES INDUSTRIAL TRUCK – A type ES industrial truck that utilizes a Type CGH-ES fuel cell power system.

5.33 TYPE CGH-EX INDUSTRIAL TRUCK – A type EX industrial truck that utilizes a Type CGH-EX fuel cell power system.



5.34 TYPE E INDUSTRIAL TRUCK – An electrically powered truck that has minimum acceptable safeguards against inherent fire and electrical shock hazards. Type E Industrial Trucks can be operated in locations as outlined in the Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations, NFPA 505.

5.35 ZONE SYSTEM OF CLASSIFICATION – The means for classifying areas within the fuel cell power system in accordance with Article 505 of the National Electrical Code, NFPA 70, and the methods outlined in Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres, IEC 60079-10-1. The potential zones of this system are:

a) Class I, Zone 0 – A location in which ignitable concentrations of flammable gases or vapors are present for long periods of time (e. g. inside the fuel cell stack or other hydrogen carrying components).

b) Class I, Zone 1 – A location:

1) In which ignitable concentrations of flammable gases or vapors are likely to exist under normal operating conditions; or

2) In which ignitable concentrations of flammable gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or

3) In which equipment is operated or processes are carried on of such a nature that equipment breakdown or fault operations could result in the release of ignitable concentrations of flammable gases or vapors and also cause simultaneous failure of electrical equipment in a mode to cause the electrical equipment to become a source of ignition; or

4) That is adjacent to a Class I, Zone 0 location from which ignitable concentrations of vapors could be communicated, unless communication is prevented by adequate positive pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided (e.g. space in which purge gases are immediately released to be diluted or areas immediately adjacent to the fuel cell stack and hydrogen recirculation system).

c) Class I, Zone 2 – A location:

1) In which ignitable concentrations of flammable gases or vapors are not likely to occur in normal operation and if they do occur, will exist only for a short period; or

2) In which volatile flammable liquids, flammable gases or flammable vapors are handled, processed, or used, but in which the liquids, gases or vapors normally are confined within closed containers of closed systems from which then can escape only as a result of accidental rupture or breakdown of the containers or system or as a result of abnormal operation of the equipment with which the liquids or gases are handled, processed, or used; or

3) In which ignitable concentrations of flammable gases or vapors normally are prevented by positive ventilation, but which may become hazardous as result of failure or abnormal operation of the ventilation system; or

4) That is adjacent to a Class I, Zone 1 location from which ignitable concentrations of flammable gases or vapors could be communicated, unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided (e.g. an area with a hydrogen fuel line and fittings at bulkhead locations but without components – a pass through).

d) Unclassified Zone – A location:

1) In an area where there is no risk of ignitable concentrations of flammable gases; or

2) Where flammable gases are not present as part of the standard processes; or

3) Where there are no fittings that may leak; or

4) That is adjacent only to other unclassified zones or Zone 2 locations (e.g. a compartment with a fuel line passing through without bulkhead connections or other fittings adjacent only to zone 2 locations and areas outside of the systems).

## CONSTRUCTION

### 6 General

6.1 A Type CHG-EE fuel cell power system shall also comply with the construction requirements of a Type EE truck in accordance with UL 583.

6.2 A Type CHG-EX fuel cell power system shall also comply with the construction requirements of a Type EX truck in accordance with UL 583.

6.3 A Type CHG-ES fuel cell power system shall also comply with the construction requirements of a Type ES truck in accordance with UL 583.

### 7 Risk Assessment and Risk Reduction

7.1 The manufacturer of the fuel cell power system shall conduct a Risk Assessment and perform risk reduction using the principles and methodology of ISO 12100, Safety of Machinery – General Principles for Design – Risk Assessment and Risk Reduction.

7.2 IEC/ISO 31010 documents many different risk assessment techniques including Primary Hazard Analysis, Structured What If Technique (SWIFT), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and provides guidance on their applicability and use. Specific standards for some of these techniques include the following:

a) IEC 60812, Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis (FMEA);

b) IEC 61025, Fault Tree Analysis (FTA);

c) 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); and

d) MIL-STD-882E, System Safety.

7.3 Hazards to be addressed in the risk assessment and risk reduction include but are not limited to:

a) Mechanical hazards, such as sharp edges or corners, protruding parts, moving parts, rotating or sliding parts, mass, and center of gravity;

b) Liquids;

c) Flammable or pressurized gases;

d) Risk of fire and electric shock;

e) Temperature, such as hot surfaces;

f) Loss of output (loss of power to the industrial truck) and loss of control.

### 8 Hydrogen and Other Fluid Containing Parts

#### 8.1 General

8.1.1 Pressure or fluid containing parts shall be resistant to the action of the fluid.

8.1.2 Metallic parts containing hydrogen gas shall be resistant to hydrogen embrittlement as outlined in Basic Considerations for the Safety of Hydrogen Systems, ISO 15916. If employing a material other than as outlined in ISO 15916, an evaluation for susceptibility to hydrogen embrittlement will need to be conducted in accordance with the following:

a) Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both, ASTM G142; or

b) Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (HGE), ASTM F1459.

1) Results of testing done in accordance with ASTM G142 shall be at least one. Ratios below one indicate a susceptibility to hydrogen embrittlement with the test method outlined in ASTM G142.

2) Ratios above two indicate a susceptibility to hydrogen embrittlement with the test method outlined in ASTM F1459.

8.1.3 When atmospheric corrosion of a part containing fluid interferes with its intended function or permits external leakage of a fluid creating a hazardous condition, the part shall be made of corrosion-resistant material or is to be provided with a corrosion-resistant protective coating.

8.1.4 An elastomeric part, relied upon for safety such as a seal for fluids other than hydrogen, which could create a hazard when leaked (for example, a gasket between electrical and wetted parts), shall be suitable for the application as determined by the Standard for Gaskets and Seals, UL 157.

8.1.5 An elastomeric part employed as a seal for hydrogen shall be suitable for use with hydrogen. The elastomeric materials outlined in Basic Considerations for the Safety of Hydrogen Systems, ISO 15916, shall be considered for reference and guidance. The material shall be evaluated for tensile strength and elongation as-received and after oven-aging (based on service temperatures) in accordance with Elastomeric Seals, Gaskets and Tubing, Section 37.

### 8.2 Piping, hoses, tubing and fittings

8.2.1 Piping and associated component parts shall be fabricated and tested to comply with all applicable specifications of the Code for Pressure Piping, ASME B31.

8.2.2 Piping utilized at levels below the pressures and/or temperatures noted in 8.2.1 and nonmetallic piping shall be evaluated to the requirements of this standard with consideration given to materials and fluids contained and service conditions, including pressures and temperatures. Nonmetallic piping containing gaseous hydrogen fuel shall be evaluated to the additional requirements of 8.2.6.

8.2.3 Nonmetallic hoses used for gaseous hydrogen located external to the fuel cell power system and subject to physical stress shall meet the applicable requirements of Hoses for Natural Gas Vehicles and Dispensing Systems, ANSI/IAS NGV 4.2. Materials shall be suitable for service with hydrogen fuel, or the fluid contained, in accordance with 8.1. Flexible hose longer than 60 inches (1.5 m) shall have a stainless steel wire braid reinforcement.

8.2.4 Flexible metal connectors and associated fittings, when used for conveying gaseous hydrogen, shall comply with Connectors for Gas Appliances, ANSI Z21.24/CSA/CGA 6.10, or the Standard for Flexible Metallic Hose, UL 536, as applicable.

NOTE: ANSI Z21.24/CSA/CGA 6.10 is limited to pressures less than 1/2 psi (3.4 kPa). UL 536 is limited to pressures less than 500 psig (3.45 MPa).

8.2.5 A hydrogen fuel line shall be supported to minimize chafing and to maintain at least a 2-inch (50.8-mm) clearance from exhaust- and electrical-system parts.

*Exception No. 1: Electrical equipment and sensors in limited power circuits that do not have enough electrical energy to damage a fuel line are not required to comply with this requirement.*

*Exception No. 2: If it can be demonstrated that the fuel lines and wiring are sufficiently supported to prevent the clearance from being reduced to less than 1/2 in (12.7 mm), the clearance between fuel lines and electrical-system parts may be reduced.*

8.2.6 Nonmetallic hydrogen fuel lines shall:

a) Be protected within ventilated enclosures where they will be subject to a minimum of mechanical or physical stresses;

b) Be either conductive to avoid static discharge with a maximum resistance of 1 MΩ per meter as outlined in Hoses for Natural Gas Vehicles and Dispensing Systems, ANSI/IAS NGV 4.2, the Continuity Test, Section 28, or comply with the Test for Accumulation of Static Electricity as outlined in the Exception to 28.3;

c) Employ materials that have been evaluated and found suitable for fluids they contain with consideration given to temperatures they are exposed to during service. Compliance shall be determined by Elastomeric Seals, Gaskets and Tubing, Section 37, and Permeation of Nonmetallic Tubing and Piping, Section 38, as applicable; and

d) Comply with the ESD requirements for 100R14 Type B hose as defined in Hydraulic Hose, SAE J517, when connected between the fuel system and the stack.

8.2.7 Pipe, tubing, fittings, and other piping components shall be capable of withstanding a minimum hydrostatic test of 1.5 times the rated service pressure without structural failure.

*Exception: High-pressure pipe, tubing, fittings, and other piping components shall have a safety margin equivalent to the storage cylinder in use. See 8.3.*

## 8.3 Hydrogen pressure vessels (containers / tanks)

8.3.1 Pressure vessels shall be specifically designed for the service conditions of the industrial truck application that includes the maximum number of fill cycles expected, the ranges of pressures and temperatures expected during operation and filling, the effect of hydrogen on fatigue life and the frequency of inspection.

8.3.2 Pressure vessels shall be designed, manufactured, and tested in accordance with one of the following:

a) ISO 19881, Gaseous Hydrogen – Land Vehicle Fuel Containers;

b) ANSI HGV 2, Compressed Hydrogen Gas Powered Vehicle Fuel Containers;

c) CSA HPIT 1, Compressed Hydrogen Powered Industrial Truck On-Board Fuel Storage and Handling Components;

d) DOT 3AA or the Transport Canada (TC) equivalent; or

e) SAE J2579, Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles.

8.3.3 The following conditions and limitations shall apply if ISO 19881, Gaseous Hydrogen – Land Vehicle Fuel Container, or ANSI HGV 2, Compressed Hydrogen Gas Powered Vehicle Fuel Containers, is used:

a) Container Category C shall apply.

b) The term “working pressure” of the container as defined in ISO 19881 is identical to “service pressure” in this standard and shall be either 25 MPa or 35 MPa gauge (H25 or H35) only.

c) The container shall be designed for the expected life of the fuel cell power system. (For example, a fuel cell power system that is filled once per shift, 3 shifts per day, 365 days per year for 15 years will experience 16,425 filling cycles during its life.)

d) The hydrogen gas cycling test of ISO 19881 shall be done using hydrogen quality as specified in SAE J2719. The sample vessel shall be pressure cycled until failure or to a minimum of 3 times the full fill cycles specified in (c).

8.3.4 If DOT 3AA is used, materials shall be compatible with hydrogen in accordance with 8.1.2.

8.3.5 A pressure vessel and fill fitting shall be placed within the truck envelope or placed in an enclosure as defined in Section 17, Enclosures, and located to minimize the possibility of damage to the vessel or hydrogen-related fittings.

8.3.6 An excess-flow and check-valve, if required, shall be directly connected to the pressure vessel or mounted in-line with the pressure vessel, where there is no shut-off device in between the pressure vessel and the check valve, so as to minimize the negative effects of shock, vibration and accidental damage

8.3.7 The refueling line shall be fitted with a check valve redundant to the check valve in the SAE J2600 (Compressed Hydrogen Surface Vehicle Refueling Connection Devices) receptacle.

8.3.8 Pressure vessels shall have a provision for being de-fueled (de-pressurized) and purged of hydrogen using an inert gas as outlined in the operating instructions or the maintenance manual, as applicable, provided with the fuel cell system.

8.3.9 A manual valve to isolate the fuel supply, shall be located near the pressure vessel so that the fuel supply to the fuel power system can be shut off for maintenance or long term storage.

8.3.10 The hydrogen pressure vessel shall be permanently mounted to the fuel cell power system module or to the industrial truck to ensure the pressure vessel does not become dislodged while in use and is not removable for refueling.



## 8.4 Refueling

8.4.1 The refueling interface shall be either H25 or H35 to correspond with the container pressure rating [see 8.3.3 (b)] and shall be in accordance with the Compressed Hydrogen Surface Vehicle Refueling Connection Devices standard, SAE J2600.

8.4.2 Hydrogen fuel cell power systems shall be provided with a means for equipotential bonding with the fuel dispenser and shall comply with the following:

a) The impedance shall be less than or equal to 10 Ω; and

b) The bonding means shall be identified in the operating instructions in accordance with Section 46, Operating Instructions.

NOTE: This bonding may be accomplished via the refueling receptacle.

8.4.3 Hydrogen fuel cell power systems shall be designed to be refueled in accordance with one of the following:

a) SAE J2601-3, Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks; or

b) “Design by rule” requirements of CSA HPIT 2, Dispensing Systems and Components for Fueling Hydrogen Powered Industrial Trucks.

8.4.4 Hydrogen fuel cell power systems shall provide a warning to the truck operator and shutdown the fuel cell power system when the pressure in any fuel container drops below the minimum pressure required for refueling.

NOTE: SAE J2601 requires a minimum pressure of 0.5 MPa and CSA HPIT 2 requires a minimum pressure of 2.0 MPa.



## 9 Over Pressure and Thermal Protection

9.1 The hydrogen pressure vessel shall be protected from the effects of fire by a non-reclosing thermally activated pressure relief device (TPRD) that is designed, manufactured and tested in accordance with CSA HPRD1, Thermally Activated Pressure Relief Devices for Compressed Hydrogen Vehicle Fuel Containers.

9.2 Components and piping shall be protected from over-pressure in accordance with the Code for Pressure Piping, ASME B31.

9.3 Pressure relief devices shall be suitable for their application including materials in contact with hydrogen and pressure and flow ratings.

9.4 Pressure relief devices operating at over 150 psi (1034 kPa) shall be sized and designed to limit the pressure during a fault to less than 110% of the maximum allowable working pressure. Re-closure shall occur at no less than 90% of the set point. Pressure relief devices operating at or below 150 psi shall be sized and designed to limit the pressure during a fault to less than 125% of the maximum allowable working pressure. Re-closure shall occur at no less than 90% of the set point.

9.5 When provided, pressure relief discharge piping shall be sized to ensure compliance with 9.4.

NOTE: CGA G-5.5, Hydrogen Vent Systems, provides detailed information on sizing of discharge piping.

9.6 A pressure relief device shall have its discharge located so that operation of the device does not result in a hazardous situation such as:

a) Hydrogen gas in excess of 25% of the lower flammability limit (LFL) escaping to an unclassified or pressure-confined area within the fuel cell power system;

b) Deposition of moisture on live parts that could create a risk of electric shock;

c) Allowing foreign objects, moisture or debris to enter the venting system not protected by caps, covers or other means;

d) Allowing the venting system to become unsecured or removed such that it would affect the intended flow path; or

e) The pressure release is directed towards or impinged towards the normal operator position.

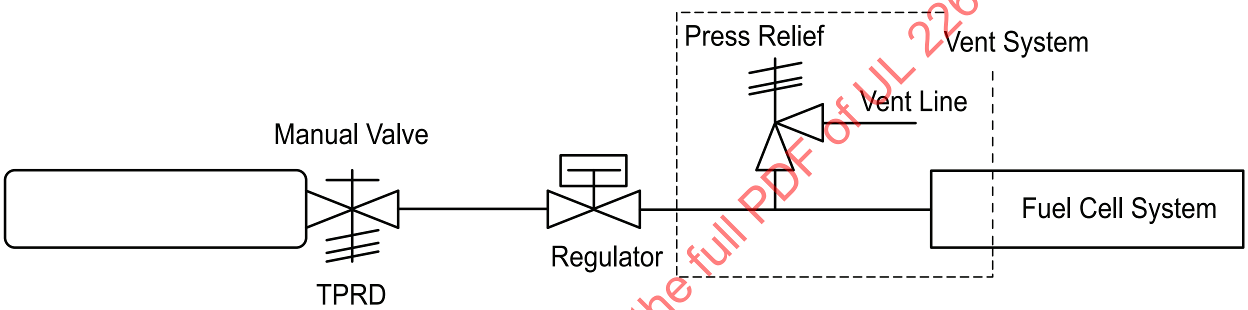
9.7 A pressure relief device vent shall be secured at intervals in such a manner as to minimize the possibility of damage, corrosion, or breakage of either the vent line or the pressure relief device due to expansion, contraction, vibration, strains, or wear and to preclude any loosening while in operation.

9.8 The vent system including the outlet connection of the relief device and associated vent lines shall be designed to withstand the maximum pressure developed during full flow operation of the relief device without becoming detached from its securement and without the vent cap, if provided, from being expelled.

9.9 Pressure relief devices, as shown in the example in Figure 9.1, shall be in accordance with ASME B31, Code for Pressure Piping.

**Figure 9.1**

**Diagram example of pressure components before (high pressure side) and after (lower pressure side) of the pressure regulator**

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## 10 Operating and Shut-Off Valves

10.1 Valves shall be rated for the application, including pressure, temperature, fluids contacted, and electrical ratings, if applicable.

10.2 Electrically operated valves shall comply with the Standard for Electrically Operated Valves, UL 429.

10.3 Valves for high pressure piping shall be tested in accordance with Part 10, Inspection, Examination, and Testing, of ASME B31.3, Process Piping, instead of the External Leakage Test and the Hydrostatic Strength Test of the Standard for Electrically Operated Valves, UL 429.

10.4 Valves for hydrogen shall also comply with CSA HGV 3.1, Fuel System Components for Compressed Hydrogen Gas Powered Vehicles.

10.5 Valves for other flammable fluids shall also comply with the Standard for Valves for Flammable Fluid, UL 842.

10.6 Flammable gas supplied to the fuel cell power system shall be supplied through fuel lines provided with at least one automatic safety shut-off valve. The safety shut-off valve may also be an operating valve. The closing time for a safety shut-off valve shall be no greater than 5 seconds.

10.7 If an emergency manual shut-off valve is deemed necessary by the Risk Assessment and Risk Reduction of Section 7, it shall be in a readily accessible location and shall not have more than 90 degrees rotation from the open to the closed positions. Access to the manual shutoff valve shall not require the use of any key or tool. The valve shall be securely mounted and shielded or installed in a protected location to minimize damage from vibration or collision.

10.8 Where a manual valve is used, the valve shall be indicated with a marking in accordance with 43.9.

10.9 Electrical and other automatically operated safety shut-off valves shall fail in a safe position.

10.10 Electrical valves located in classified areas shall be rated for the area of classification.

## 11 Filters

11.1 Air and fluid filters shall be suitable for the application and readily accessible if required to be inspected, cleaned, or replaced.

## 12 Pumps and Compressors

12.1 Air compressors and air vacuum pumps employed in the system shall comply with the Standard for Motor-Operated Air Compressors, Vacuum Pumps, and Painting Equipment, UL 1450, or shall be evaluated to the requirements of Section 41, Motor Evaluation – Locked Rotor, and Section 42, Motor Evaluation – Overload.

12.2 Water pumps shall comply with the Standard for Motor-Operated Water Pumps, UL 778, or shall be evaluated to the requirements of Section 41, Motor Evaluation – Locked Rotor, and Section 42, Motor Evaluation – Overload.

12.3 Chemical and gaseous hydrogen pumps and compressors shall be evaluated to the applicable material compatibility requirements and mechanical and electrical requirements as specified in the Standard for Power-Operated Pumps for Petroleum Dispensing Products, UL 79.

12.4 As an alternative to the requirement of 12.3, the electrical parts of chemical and gaseous hydrogen pumps and compressors may be evaluated to the requirements of Section 41, Motor Evaluation – Locked Rotor, and Section 42, Motor Evaluation – Overload. The wetted parts may be evaluated for chemical resistance in accordance with the Test for Resistance of Polymeric Materials to Chemical Reagents in UL 746A, Polymeric Materials – Short Term Property Evaluations, and the tests for Tensile Strength, Elongation, Volume Change and Extraction after Immersion in UL 157, Gaskets and Seals, as applicable to the chemical substance.



12.5 If evaluating elastomeric materials for chemical resistance after immersion per UL 157, the following are acceptable levels for the parameters measured:

a) Tensile Strength – 60% change from unconditioned value;

b) Elongation – 60% change from unconditioned value;

c) Volume Change – minus 1 to 25% change from unconditioned volume;

d) Extraction – 10% change in weight from unconditioned value.

12.6 A flammable fluid compressor or pump with rotating or other type dynamic seals, shall be provided with adequate ventilation so that small releases of hydrogen or other flammable vapor under normal operating conditions shall not allow the concentration of flammable vapors to be above 25% of the lower flammability limit (LFL) in the unclassified areas of the fuel cell power system during normal release.

## 13 Electrically Operated Pressure Sensing and Controlling Devices

13.1 Pressure activated switches and transducers shall be rated for the application. A pressure regulating control for a flammable or combustible fluid shall be suitable for its classification and the fluid it contains.

13.2 The maximum operating pressure of a pressure limiting or regulating control shall not exceed 90% of the operating pressure of a pressure relief device. An accessible and adjustable pressure regulating control that can exceed the limits of the system shall be reliably sealed at the maximum operating pressure at which it is intended to operate.

## 14 Ventilation to Prevent the Build Up of Flammable Gases and Vapors

14.1 A fuel cell power system shall be provided with adequate ventilation so that normal releases under normal operating conditions shall not collect in the unclassified zones of the fuel cell power system. This normal release shall include nominal stack fuel leakage rates or fuel purges that may occur during operation.

14.2 The diluted concentrations of flammable vapors exiting the fuel cell power system during normal operation shall not exceed 50% of the lower flammability limit (LFL).

14.3 The extent of a flammable region at a source of limited release (dilution boundary) shall be determined through appropriate analysis as outlined in IEC 60079-10-1, Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres.

14.4 Equipment located within the dilution boundary shall be suitable for the classification. Reference may be made to Recommended Practice for the Classification of Flammable Liquids, Gases or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, NFPA 497, or to IEC 60079-10-1, Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres.

14.5 Abnormal releases of hydrogen shall not create a safety hazard in accordance with the Risk Assessment and Risk Reduction of Section 7, and shall result in the appropriate action, including the prompt shutdown of the equipment, if necessary, that will mitigate the hazard or prevent the creation of additional hazards.

14.6 Failure of ventilation shall cause the fuel cell power system to mitigate any hazard or prevent the creation of additional hazards in accordance with the Risk Assessment and Risk Reduction of Section 7. This may include shutting off; either through the detection of high gas/vapor concentration or with ventilation interlock provisions.

*Exception No. 1: Limited, localized volumes of flammable vapor concentration within the fuel cell power system may momentarily exceed the 25% LFL of the flammable vapor, but it shall be determined in accordance with the Risk Assessment and Risk Reduction of Section 7 that this transient condition does not create a safety hazard.*

*Exception No. 2: Mechanical ventilation is not required if it can be determined that the flammable gas/vapor concentration level falls below 25% LFL under any conditions of normal release.*

14.7 If gas detection is employed as a critical safety component in the fuel cell power system, the gas detection system shall comply with the Standard for Gas and Vapor Detectors and Sensors, UL 2075. Gas detection systems shall be located where they can most effectively measure the accumulation of vapor within the fuel cell power system and monitor the ventilation output as determined necessary.

14.8 If gas detection is employed as a critical safety component in the fuel cell power system, it shall be located in a control circuit that complies with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, or alternative standards for functional safety, in accordance with Safety Controls, 19.1.

14.9 Ventilation openings and ducts shall not become obstructed or compromised when the fuel cell power system is installed in the truck during normal operation.

14.10 Fans, blowers, and other devices employed for the ventilation system shall be suitable for the application. If fans and ventilators are used as the primary safety mechanism to prevent the build-up of flammable gas/vapor, the failure of the ventilation system shall not create a safety hazard in accordance with the Risk Assessment and Risk Reduction of Section 7. Fans shall comply with the Standard for Electric Fans, UL 507, or be evaluated to the requirements of Section 41, Motor Evaluation – Locked Rotor, and Section 42, Motor Evaluation – Overload. Ventilators shall comply with the Standard for Power Ventilators, UL 705, or be evaluated to the requirements of Section 41, Motor Evaluation – Locked Rotor, and Section 42, Motor Evaluation – Overload.

14.11 For a Type CHG-ES fuel cell power system, the ventilation required by 14.1 – 14.6 shall be replaced with ventilation to prevent the accumulation of hydrogen inside the fuel cell power system. This may be either natural or mechanical ventilation. (Dilution by ventilation is a not viable protection measure against flammable gas leaks in fuel cell power systems used in hazardous (classified) areas.)

## 15 Electrostatic Discharge (ESD)

15.1 Hydrogen fuel containing parts and parts within classified zones of the equipment shall be constructed of materials that do not promote static discharges.

15.2 The exposed portion of moving metal parts such as fan blades and wheels, located in classified areas of the system shall be made of, or covered with, medium brass, bronze, copper or aluminum with a hardness not more than Rockwell B66. Energy storage components such as stack module and batteries and major power electronics components shall have their external conductive cases equipotentially bonded.

15.3 Components with non-current carrying metal parts and cases located in classified zones within the equipment shall be equipotentially bonded.

15.4 Any fuel receptacle on the fuel cell system provided for refueling shall be equipotentially bonded to the fuel cell power system chassis.

15.5 Nonmetallic fluid containing parts such as hoses and nonmetallic moving parts such as fan blades and belts located within the dilution boundary (see 5.5 and 15.3), shall comply with the Continuity Test in 28.3 or the Test for Accumulation of Static Electricity in accordance with the Exception to 28.3.

## 16 Discharges and Waste Materials

16.1 The fuel cell power system shall be constructed so that waste materials, including water, are not exhausted, discharged, or leaked in a manner that could create unsafe conditions.

## 17 Enclosures

17.1 A fuel cell power system shall be enclosed for protection from access by persons to electrical parts, safety circuits, hazardous moving parts, hot surfaces, and other parts that may be a risk of injury.

17.2 Openings in a fuel cell power system enclosure of hazardous parts shall be located and sized to provide adequate protection from access to hazardous parts with a minimum IPXXB or IP2X minimum rating in accordance with Degrees of Protection Provided by Enclosures (IP Code), IEC 60529.

17.3 An external enclosure for a fuel cell power system provided with an IP rating in accordance with 43.2(j) shall comply with 33.1.1.

17.4 An external enclosure shall comply with the Enclosure Loading Test of 34.1, unless the required protection is provided by the truck for an integrated fuel cell power system.

17.5 An external enclosure for a fuel cell power system shall be metal and be no less than 0.053 inch (1.35 mm) thick unless otherwise protected by the truck.

*Exception: A nonmetallic external enclosure may be employed, but it shall comply with the requirements for stationary equipment in the Standard for Polymeric Materials - Use in Electrical Equipment Evaluations, UL 746C, except that:*

*a) It is to be subjected to the test program in accordance with 34.2; and*

*b) It shall be flame rated V-1 minimum in accordance with UL 746C or shall comply with the Three-Quarter Inch Flame Test for Thermoplastic Materials, Section 35.*

## 18 Electrical System

### 18.1 General

18.1.1 Electrical components shall be rated for the application and conform to the appropriate standard for those components. They shall be located and secured so that they are not adversely affected by vibration, temperature, environment and other affects during normal operation of the fuel cell power system.

18.1.2 Electrical equipment internal to the fuel cell system located in hazardous (Classified) zones shall be suitable for the Classification as determined by IEC 60079-10-1, Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres.

### 18.2 Internal wiring

18.2.1 Internal wiring shall consist of any of the following:

a) General-use wire specified in the National Electrical Code, NFPA 70;

b) Appliance-wiring material of one or more of the types specified in Table 18.1; or

c) One or more of the types specified in the following automotive standards:

1) SAE J1127, Low Voltage Battery Cable;

2) SAE J1128, Low Voltage Primary Cable;

3) SAE J1654, Unshielded High Voltage Primary Cable;

4) SAE J1678, Low Voltage Ultra Thin Wall Primary Cable.

The wiring shall be considered with respect to the temperature and conditions of service to which the wiring is to be subjected in the end truck installation.

*Exception: At the connection to a component, wiring is permitted to extend beyond the braid for a length of no more than 10 inches (254 mm).*

18.2.2 Appliance-wiring material having a thickness of insulation less than the minimum acceptable value specified in Table 18.1 is permitted for a particular application, provided the insulation is considered with respect to temperature and conditions of service and is equivalent to one of the materials specified in the table.

18.2.3 A bare conductor is permitted to be insulated with insulating tubing.

18.2.4 A conductor connected to a moving or movable part that cannot be protected, shall be designed for the intended use and shall comply with the test requirements in this standard. Consideration shall be given to the resistance of the conductor to damage resulting from flexing, abrasion, or impact. Flexible metallic conduit is to be used only for flexible connections subject to small and infrequent movements.

18.2.5 Wiring connections to a continuously moving part, or a part for which the degree of movement is appreciable shall be Type S, SJ, SJO, SJT, SJTO, SO, ST or STO flexible cord.

*Exception: Individual conductors having flexible stranding such as Type FFH-2, TFF, or SFF-2, enclosed in flexible tubing may be used in place of flexible cord. The tubing may be omitted from exposed moving conductors that are readily visible to the operator and are therefore, subject to replacement when damaged. The maintenance manual shall include instructions regarding inspection of these conductors for replacement when damage occurs in accordance with 45.1(d).*

18.2.6 All connections shall be mechanically secure and shall provide electrical contact without stress on connections and terminals. A connection shall be provided with insulation equivalent to that on the wires involved.

18.2.7 A hole, by means of which insulated conductors pass through, shall be provided with a smooth, rounded bushing, or shall have smooth, rounded surfaces upon which the insulated conductors may bear.

18.2.8 Wireways shall be smooth and free from sharp edges, burrs, fins, or moving parts that may damage wiring.

18.2.9 An internal-wiring connection shall be made with a solder lug or pressure terminal connector.

*Exception: Control wiring and other small conductors, that are connected by, crimped or soldered special-type lugs or eyelets including barrel terminals or by ultrasonic welding and that are insulated in accordance with 18.2.6 comply with the intent of this requirement.*

18.2.10 A terminal lug shall be arranged so that in any position it cannot contact either the metal enclosure and non-energized accessible metal parts or other electrical circuits, or the shank of the lug shall be provided with insulation equivalent to that on the conductor.

**Table 18.1**
**Appliance Wiring Material**

| Wire insulation | Minimum acceptable average insulation thickness, in (mm) |
|---|---|
| Rubber, Neoprene or Thermoplastic (PVC) | 0.015 (0.38) plus an impregnated braid, or 0.030 (0.75) without a braid |

## 18.3 External wiring

18.3.1 An external electrical output lead shall be of a size and ampacity such that for a continuous maximum output, the insulation temperature does not exceed its rating at maximum ambient temperature. It shall be provided with insulation able to withstand flexing, handling, and impact at temperatures between 50°C (122°F) and minus 20°C (minus 4°F). If intended for exposure to extreme temperatures above 50°C (122°F) and at or below minus 20°C (minus 4°F), the lead shall comply with Electrical Output Leads, Section 39. The average insulation thickness shall not be less than 0.060 in (1.52 mm) for 8 – 2 AWG wire and shall not be less than 0.080 in (2.03 mm) for a 1 - 4/0 AWG wire. The length of the lead and connector assembly shall be as short as practicable without interfering with the disconnecting operation and without placing stress on terminals when installed in the truck.

18.3.2 An external electrical output connector shall be rated for the output of the fuel cell power system. Live parts shall be recessed from the face of the connector to reduce the possibility of shorting. A removable portion of the connector shall be provided with means for being grasped during removal. The connector shall be located to provide mechanical protection when the fuel cell power system is installed in the end use.

18.3.3 External wiring shall be protected against mechanical damage by:

a) Enclosing it in the body of the truck;

b) Enclosing it in metal raceway such as armored cable, rigid metal conduit or electrical metallic tubing; or

c) Protecting it with metal, phenolic composition, or other thermosetting material having equivalent mechanical strength and resistance to impact and having no greater combustibility than phenolic.

This enclosure or protection shall be such that any flame or molten material, which may be caused by an electrical disturbance in the wiring, cannot reach surrounding combustible material.

*Exception No. 1: This requirement does not apply to flexible external leads that require flexibility for disconnection, output leads of the fuel cell power system for example, that comply with 18.3.1.*

*Exception No. 2: This requirement does not apply to leads that, if damaged, do not result in a hazard.*

## 18.4 Motors

18.4.1 Motors shall comply with the Standard for Rotating Electrical Machines – General Requirements, UL 1004-1, unless they are located in NEC Class 2 circuits or limited power circuits.

*Exception: A motor need not comply with this requirement if located in a low voltage circuit and evaluated in accordance with Exception No. 3 of 18.4.2.*

18.4.2 A motor shall be provided with integral motor protection that complies with the Standard for Impedance Protected Motors, UL 1004-2, and the Standard for Thermally Protected Motors, UL 1004-3.

*Exception No. 1: A motor located in an NEC Class 2 circuit or a limited power circuit is not required to be provided with motor protection.*

*Exception No. 2: A motor with other means of motor protection, including external devices, that complies with the requirements in Article 430 of the National Electrical Code, NFPA 70, complies with the intent of this requirement.*

*Exception No. 3: A motor located in a low voltage circuit that is not NEC Class 2 or a limited power circuit need not be provided with motor protection if it can be determined through Locked Rotor and Running Overload Testing that it does not present a fire hazard in accordance with Section 41, Motor Evaluation – Locked Rotor, and Section 42, Motor Evaluation – Overload.*

### 18.5 Switches and motor controllers

18.5.1 A motor controller or switch shall be rated for the load that it controls. A motor controller shall have the current interrupting capacity not less than the locked rotor load of the motor controlled in accordance with Article 430 of the National Electrical Code, NFPA 70, and shall comply with the additional requirements for motor controls as specified in the Standard for Electric-Battery-Powered Industrial Trucks, UL 583.

18.5.2 A switch that controls an inductive load other than a motor, such as transformer, shall not be less than twice the rated full-load current of the transformer, or similar device, unless the switch has been investigated and found acceptable for the application.

### 18.6 Transformers and power supplies

18.6.1 Transformers located in hazardous voltage circuits shall be provided with overcurrent protection.

18.6.2 NEC Class 2 and 3 transformers shall comply with the Standard for Low Voltage Transformers – Part 1: General Requirements, UL 5085-1, and the Standard for Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers, UL 5085-3.

18.6.3 Power supplies shall comply with the Standard for Power Units Other Than Class 2, UL 1012, or the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1, or the Standard for Class 2 Power Units, UL 1310, as applicable.

### 18.7 Inverters, converters and controllers

18.7.1 Inverters and converters shall comply with one of the following:

a) The requirements for Potential Failure Modes and Abnormal Operation – Electric Equipment Failures in the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741;

b) Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1; or

c) The Standard for Power Converters/Inverters and Power Converter/Inverter Systems for Land Vehicles and Marine Crafts, UL 458.

### 18.8 Lamps and lampholders

18.8.1 Lamps and lampholders shall be totally enclosed. A lamp lens shall be protected against mechanical damage by bars, grids, recessing or equivalent means.

18.8.2 A light emitting diode (LED), vacuum fluorescent display (VFD), backlit liquid crystal display (LCD), and any other display that may be a source of ignition when mechanically damaged shall be protected against mechanical damage.

## 18.9 Energy storage components

### 18.9.1 Batteries

18.9.1.1 Primary or non-rechargeable lithium batteries shall comply with the Standard for Lithium Batteries, UL 1642. Lithium cells shall be provided with the appropriate reverse charging protection in the battery circuitry.

18.9.1.2 Lead acid type batteries and monobloc nickel cadmium or nickel metal hydride batteries employing relief valves and/or safety vents shall comply with the construction requirements of the Standard for Standby batteries, UL 1989. In addition, lead acid-type batteries shall comply with the Pressure Release Test or the Flame Arrester Vent Cap Tests of UL 1989, whichever applies.

18.9.1.3 Secondary/rechargeable batteries other than lead acid or monobloc nickel cadmium or nickel metal hydride types shall comply with the Standard for Batteries for Use In Electric Vehicles, UL 2580, or the Standard for Batteries for Use in Light Electric Vehicle Applications, UL 2271.

18.9.1.4 For lead acid or nickel monobloc batteries employed as a fuel cell power system/power battery combination:

a) Cells employing metal containers, such as alkaline batteries, shall be insulated from one another and from a metal tray or metal battery compartment. Insulation of wood or other material shall be:

1) Treated or painted to reduce deterioration by the battery electrolyte; and

2) Constructed to reduce the risk of damage to the insulation during the normal operation and maintenance of the truck.

b) Battery terminals that are threaded shall be provided with lock washers or equivalent means to reduce the risk of a loose wiring nut-terminal connection causing an arc ignition of gases from the battery that may be present. A flat washer shall be used between a lock washer and any surface that is made of lead.

c) Battery terminals shall be protected by insulating boots or covers, if applicable.

*Exception No. 1: A terminal that is intended to be connected to ground on the truck frame need not be provided with a boot or cover.*

*Exception No. 2: This requirement does not apply to a built-in battery charger equipped with a ground-fault circuit interrupter or having an isolated secondary output.*

### 18.9.2 Double layer capacitors (ultracapacitors)

18.9.2.1 For ultracapacitors employed as a fuel cell power system/ultracapacitor combination:

a) They shall comply with the requirements specified in the Standard for Electrochemical Capacitors, UL 810A.

b) Integral charging circuits for ultracapacitors shall be provided with reliable means of protection from overvoltage charging conditions and if necessary, overcurrent charging and discharging conditions.

c) Ultracapacitors employing metal containers shall be insulated from one another and from a metal tray or metal capacitor compartment. Insulation shall be constructed to reduce the risk of damage to the insulation during the normal operation and maintenance of the truck.

d) The metal container of an ultracapacitor that is connected to the negative electrode of the capacitor (negative electrode and the metal container or not insulated internally from each other) shall be considered part of the negative electrode and shall be enclosed or provided with an insulating cover.

e) Ultracapacitor terminals that are threaded shall be provided with lock washers or equivalent means to reduce the risk of a loose wiring nut-terminal connection causing an external short between terminals.

f) Ultracapacitor terminals shall be protected by insulating boots or covers, if applicable.

*Exception No. 1: A terminal that is intended to be intentionally connected to ground on the truck frame need not be provided with a boot or cover.*

*Exception No. 2: This requirement does not apply to a built-in ultracapacitor charger equipped with a ground-fault circuit interrupter or an isolated secondary.*

18.9.2.2 When ultracapacitors are used, an arc flash risk assessment shall be performed in accordance with NFPA 70E, Standard for Electrical Safety in the Workplace.

NOTE: Arc flash hazards can exist at voltages below the 50 V threshold mentioned in section 130.2(A)(3) of NFPA 70E. The allowance in that section does not apply when there is the possibility of electric arcs. The option of using the tables in lieu of the incident energy analysis allowed in section 130.7(C)(15)(B) of NFPA 70E is not valid for many systems as Table 130.7(C)(15)(B) does not extend below 100 volts. The incident energy analysis should always be performed for systems with ultracapacitors.

18.9.2.3 Systems with an arc flash hazard shall be labeled in accordance with Article 110.16 of NFPA 70, National Electrical Code

### 18.10 Electrical insulation

18.10.1 Materials employed as electrical insulation shall comply with Material Property Considerations, Section 6, of the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

18.10.2 The thickness of an insulating barrier employed as the sole insulation between uninsulated live parts and non-current carrying metal parts or between parts of opposite polarity shall be 0.028-in (0.71-mm) thick minimum.

*Exception: For a system with output rated 24 V or less, the thickness shall be 0.013-in (0.33-mm) minimum.*

18.10.3 For a system rated more than 24 V, where there is a minimum of half of the required acceptable spacing through air, a barrier or liner may be employed that has a minimum thickness of 0.013-in (0.33-mm).

*Exception: For a system rated 24 V or less, the thickness shall be 0.006-in (0.15-mm) minimum*

### 18.11 Limited power circuit

18.11.1 A limited power circuit shall comply with the test of Limited Power Circuits, Section 30. See also 5.12.

### 18.12 Electrical spacings

18.12.1 The spacings in a fuel cell power system for industrial trucks shall not be less than as specified in Table 18.2.

*Exception No. 1: Minimum acceptable spacings are not specified in a limited power circuit as defined in 5.12.*

*Exception No. 2: Minimum acceptable spacings within a component shall be determined by the component standard.*

*Exception No. 3: Minimum acceptable spacings may be reduced from that outlined in Table 18.2 if the circuits are evaluated in accordance with the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, and the following:*

*a) The reduced spacing requirements shall not be used at electrical connections to the truck or for spacings to a non-current carrying metal enclosure.*

*b) The fuel cell is to be rated for overvoltage category I and pollution degree 3 as defined in UL 840. Circuits provided with protective enclosures without ventilation openings to allow for the entrance of dust, humidity and other conductive debris may be considered pollution degree 2 and circuits that are in hermetically sealed or encapsulated enclosures may be considered pollution degree 1.*

*c) In order to apply clearance B (controlled overvoltage) clearances, control of overvoltage shall be achieved by providing an overvoltage device or system as an integral part of the fuel cell.*

*d) All printed-wiring boards are considered to have a minimum comparative tracking index (CTI) of 100 (material group IIIb) unless constructed of materials with higher CTI ratings.*



**Table 18.2**
**Spacings**

| Location | Nominal voltage 24 V or less | | | | Nominal voltage greater than 24 V[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | Through air | | Over surface | | Through air | | Over surface | |
| | inch | (mm) | inch | (mm) | inch | (mm) | inch | (mm) |
| In a power circuit – between a bare live part and (1) a bare live part of opposite polarity, or (2) a bare grounded part other than the enclosure | 1/16 | (1.6)[b] | 1/8 | (3.2)[b] | 1/8 | (3.2)[c] | 1/4 | (6.4)[c] |
| In a power circuit at a location where conductive dust cannot accumulate, such as a small totally enclosed cavity[d] | 1/32 | (0.8) | 1/16 | (1.6) | 1/16 | (1.6) | 1/8 | (3.2) |
| In other than a power circuit - between a bare live part and (1) a bare live part of opposite polarity, or (2) a bare grounded part other than the enclosure | 1/16 | (1.6) | 1/16 | (1.6) | 1/16 | (1.6) | 1/16 | (1.6) |
| In other than a power circuit at a location where conductive dust cannot accumulate, such as a small totally enclosed cavity[d] | 1/32 | (0.8) | 1/32 | (0.8) | 1/32 | (0.8) | 1/32 | (0.8) |
| Between any uninsulated live part and the ultimate enclosure[e] | 1/2 | (12.7) | 1/2 | (12.7) | 1/2 | (12.7) | 1/2 | (12.7) |

**Table 18.2 Continued on Next Page**

**Table 18.2 Continued**

| Location | Nominal voltage 24 V or less | | | | Nominal voltage greater than 24 V[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | Through air | | Over surface | | Through air | | Over surface | |
| | inch | (mm) | inch | (mm) | inch | (mm) | inch | (mm) |
| Between any uninsulated live part and the ultimate enclosure where the enclosure is formed of 1/8 in (3.2 mm) thick cast metal or 1/4 in (6.4 mm) thick steel plate[e] | 1/4 | (6.4) | 1/4 | (6.4) | 1/4 | (6.4) | 1/4 | (6.4) |

NOTE – A circuit is considered a power circuit if it supplies a motor-control circuit that is not provided with overcurrent protection. A circuit is not considered a power circuit if it supplies a circuit with overcurrent protection.

[a] Maximum of 150 V, see 1.3.

[b] These spacings apply to a system not electrically connected to the frame.

[c] These spacings also apply to a nominal 24-V or lower-voltage system electrically connected to the frame.

[d] Such as a point where a motor terminal passes through the motor frame.

[e] If deformation of the enclosure at the point of measurement of spacings is likely, the spacings after deformation shall be as specified.



### 18.13 Separation of circuits

18.13.1 A limited power circuit shall be separated from all other circuits either by:

a) Locating the circuit in a separate enclosure;

b) Proving through-air and over-surface spacings as noted in Table 18.2; or

c) The use of barriers.

18.13.2 An internal wiring insulated conductor of a limited power circuit shall be either separated by barriers or segregated from live parts connected to different circuits or provided with insulation acceptable for the highest voltage involved.

18.13.3 The barriers noted in 18.13.1(c) are permitted to be bonded metal not less than 0.020 in (0.51 mm) thick or insulating material not less than 0.028 in (0.71 mm) thick.

18.13.4 Conductors of circuits operating at different potential shall be reliably separated from each other unless they are each provided with insulation acceptable for the highest potential involved.

18.13.5 Separation of circuits between hazardous voltage and Class 2 circuits and between intrinsic and non-intrinsic circuits, and similar separations, shall be in accordance with the appropriate articles in the National Electrical Code, NFPA 70.

## 19 Control Circuits

### 19.1 Safety controls

19.1.1 Electronic circuits relied upon for safety (a safety critical component, for example) shall be evaluated in accordance with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991.

19.1.2 Software relied upon for safety as a safety critical component shall be evaluated in accordance with the Standard for Software in Programmable Components, UL 1998. The electronic hardware of the software safety system shall be evaluated in accordance with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991.

19.1.3 As an alternative, electronic circuits and programmable software controls relied upon for safety may be evaluated to one of the following:

a) Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems, IEC 61508, (all parts);

b) Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design, ISO 13849-1, and Safety of machinery – Safety-related parts of control systems – Part 2: Validation, ISO 13849-2; or

c) Road vehicles – Functional safety, ISO 26262 (all parts).

## 19.2 Start

19.2.1 The start of an operation shall only be possible when all of the safeguards are in place and are functioning in accordance with the Risk Assessment and Risk Reduction of Section 7. The fuel cell power system shall be started only by an intentional operation of the start sequence unless it is determined that there is minimal risk with automatic restarting as determined by the Risk Assessment and Risk Reduction of Section 7.

19.2.2 Restart of the fuel cell power system from a stop shall not result in a hazardous condition as determined by the Risk Assessment and Risk Reduction of Section 7.

## 19.3 Drive off

19.3.1 The fuel cell power system shall include means to minimize the likelihood of moving the industrial truck with the fueling hose attached. The drive off protection means may include an interlock switch in the fueling receptacle, an interlock circuit connected to the dispenser, or other means.

19.3.2 Switches, circuits, and the like used for drive off protection shall be suitable for the local area classification in which they are used. See 14.4.

## 19.4 Emergency stop

19.4.1 Fuel cell power systems shall be provided with an emergency stop in accordance with NFPA 79, Electrical Standard for Industrial Machinery.

19.4.2 The emergency stop shall close the fuel safety shut-off valves. See 10.6.

19.4.3 The fuel cell power system emergency stop shall have provisions for connecting to the industrial truck's emergency stop.

19.4.4 The fuel cell power system shall include an emergency stop actuator or device for industrial trucks that do not have an emergency stop. The actuator or device shall comply with the following:

a) The emergency stop actuator or device shall comply with NFPA 79, Electrical Standard for Industrial Machinery; and

b) The emergency stop actuator or device shall be marked to indicate that it affects only the fuel cell power system.

### 19.5 Early warning system

19.5.1 Fuel cell power system shall provide an early warning indication to the truck operator and an early warning signal to the truck at least 10 seconds before ceasing to provide power to the truck when that loss of power can create a hazardous situation. Loss of power from the fuel cell power system to the truck shall be considered in the Risk Assessment and Risk Reduction of Section 7. (An example of potential hazardous situation due to loss of power from the fuel cell power system to the truck is an emergency brake that engages on loss of power.)

19.5.2 Self-contained fuel cell power systems that can be moved from truck to truck and that do not have this early warning system shall be marked to warn against use with trucks that can become hazardous on loss of power in accordance with 43.12.

## 20 Field Installation

20.1 Units intended for field installation by qualified personnel shall be provided with all necessary wiring and hardware such that the installation can be made without major disturbance of factory-installed wiring in the fuel cell power system or the truck. Major disturbance of wiring and equipment includes, but is not limited to, rearrangement of wiring or components, cutting or splicing of existing wiring, and soldering of connections.

*Exception: This requirement does not apply when:*

*a) The fuel cell power system has been approved by the truck manufacturer for use in the truck with major modifications to wiring and equipment; and*

*b) The truck with the fuel cell power system installed with the necessary modifications has been evaluated in accordance with the applicable truck standard.*

20.2 The fuel cell power system shall be marked in accordance with 43.5, and provided with additional instructions in accordance with 47.3. A conversion kit in accordance with 20.3 shall be provided.

20.3 A conversion kit shall be provided for field installation of a fuel cell power system into an industrial electric truck. The conversion kit shall include the following items:

a) Step-by-step installation instructions with illustrations for clarification to the text, as necessary, along with contact information of the manufacturer's qualified personnel for performing the conversion.

b) All parts necessary to complete the installation, which may include the following:

1) Functional components;

2) Mounting brackets and hardware;

3) Connecting wires, hoses and fittings;

4) Sealants, if required; and

5) Any required sensors or safety devices.

c) A durable, corrosion-resistant plate indicating the converted type designation of the truck for permanent mounting adjacent to the manufacturers nameplate on the truck.

d) A metal nameplate attached to the hydrogen container (tank) mounting that identified the fuel container assembly to be used where a removable hydrogen fuel tank is to be used.

e) A hydrogen fuel container (tank) with necessary mounting and connection hardware and installation instructions.

f) Instructions for removal or deactivation of the existing components including any tanks, batteries, or similar parts that will not be utilized after the conversion.

g) Instructions covering checks and tests to be performed after the conversion and prior to putting the truck into service.

## PERFORMANCE

## 21 General

21.1 For the tests in Sections 22 – 39, the fuel cell power system shall operate at maximum continuous loading with controls set to maximum normal limits, unless otherwise noted in the test methods.

21.2 As a result of the tests in Sections 22 – 39, there shall be no leakage from parts containing liquid that would result in a hazardous condition, unless otherwise noted.

21.3 A Type CHG-EE fuel cell power system shall comply with the performance requirements of a Type CHG-E fuel cell power system in accordance with 21.1 and 21.2.

21.4 A Type CHG-ES fuel cell power system shall also comply with the additional performance requirements of a Type ES truck in accordance with the following requirements of UL 583:

a) The requirements in TYPE ES TRUCKS – PERFORMANCE – General, regarding cotton to be placed around components likely to cause sparks or emit molten metal; and

b) The requirements in TYPE ES TRUCKS – PERFORMANCE – General, for solid-state speed controls.

21.5 A Type CHG-EX fuel cell power system for Class I locations shall also comply with the additional performance requirements of a Type EX truck in accordance with the following requirements of UL 583:

a) Requirements for explosion-proof electrical components;

b) Requirements for intrinsically safe electrical components; and

c) Requirements for maximum operating temperatures on electrical components.

21.6 A Type CHG-EX fuel cell power system for Class II, Group G locations shall also comply with the performance requirements of a Type EX truck in accordance with the following requirements of UL 583:

a) Requirements for dust-ignition-proof electrical components;

b) Requirements for intrinsically safe electrical components; and

c) Requirements for maximum operating temperatures on electrical components.

## 22 Vibration

### 22.1 General

22.1.1 A fuel cell power system shall be subjected to a system vibration test in both the vertical and longitudinal/lateral axes in accordance with 22.2 and 22.3 using the methods of ASTM D3580, Standard Test Methods for Vibration (Vertical Linear Motion) Test of Products, and ASTM D5112, Standard Test

Method for Vibration (Horizontal Linear Motion) Test of Products. The fuel cell system shall not be operating for these tests. As a result of the tests, the fuel cell system shall comply with External Leakage, Section 24.

*Exception: If the fuel cell system is intended for use in an industrial truck with a known vibration profile, that profile may be used instead of the profile outlined in 22.2 and 22.3.*

22.1.2 A self-contained fuel cell system is to be tested outside of the truck for the Vibration Tests in 22.2 and 22.3. The fuel cell system is to be mounted using its own securement means, or a representative of the securement means, and secured to the test fixture of the vibration test apparatus in the same position which it occupies when in use.

22.1.3 An integrated fuel cell system is not required to be tested in accordance with the Vibration Tests in 22.2 and 22.3.

22.1.4 With reference to 22.1.2, individual components or sub-systems may be tested by themselves so long as they are mounted and supported as they would be in the complete system. Components normally mounted near the test subject must be included or simulated if there is any chance of interference or contact between the parts.

### 22.2 Vertical axis test

22.2.1 The following tests are to be performed in the vertical axis with respect to vehicle orientation:

a) 2000 sinusoidal cycles at 5 G peak acceleration applied at the vehicle manufacturer's recommended resonant frequency. If the manufacturer's resonant frequency is not available, the test is to be repeated between 10 Hz and 30 Hz in increments of 1 Hz with a dwell time of at least 1 second at each frequency; and

b) 60 sine sweeps from 10 Hz up to 190 Hz and back to 10 Hz to be conducted at a sweep rate of 1 Hz/s for a total duration of 6 hours using the load profile in Table 22.1, or as specified by the vehicle manufacturer.

**Table 22.1**
**Vertical Axis Vibration Conditions**

| Frequency Range (Hz) | Peak Acceleration (G) |
|---|---|
| 10 – 20 | 3.0 |
| 20 – 40 | 2.0 |
| 40 – 90 | 1.5 |
| 90 – 140 | 1.0 |
| 140 – 190 | 0.75 |



### 22.3 Longitudinal and lateral axes tests

22.3.1 The following tests are to be performed in both the longitudinal and lateral axes with respect to vehicle orientation:

a) 2000 sinusoidal cycles at 3.5 G peak acceleration applied at the vehicle manufacturer's recommended resonant frequency. If the manufacturer's resonant frequency is not available, the test is to be repeated between 10 Hz and 30 Hz in increments of 1 Hz with a dwell time of at least 1 second at each frequency; and

b) 60 sine sweeps from 10 Hz up to 190 Hz and back to 10 Hz, to be conducted at a sweep rate of 1 Hz/s for a total duration of 6 hours using the load profile in Table 22.1, or as specified by the vehicle manufacturer.

**Table 22.2**
**Longitudinal and Lateral Axes Vibration Conditions**

| Frequency Range (Hz) | Peak Acceleration (G) |
|---|---|
| 10 – 15 | 2.5 |
| 15 – 30 | 1.7 |
| 30 – 60 | 1.25 |
| 60 – 110 | 1.0 |
| 110 – 190 | 0.75 |

## 23 Endurance – System

23.1 A fuel cell power system employing nonmetallic flammable fuel handling parts and/or flammable fuel pumps with dynamic seals shall be subjected to a 720-hour endurance test in accordance with 23.2. The fuel cell power system shall comply with External Leakage, Section 24, before and after the test. There shall be no damage to the fuel cell power system that would result in a hazard. The fuel cell power system shall be operational.

23.2 The fuel cell system is to be connected to a source of fuel and operated at a minimum of 50% of the maximum continuous operating load conditions. This is to be done continuously for 720 hours under normal operating pressures and temperatures.

## 24 External Leakage

24.1 All piping shall be leak tested in accordance with ASME B31, Code for Pressure Piping.

## 25 Dilution Test

### 25.1 Releases

25.1.1 The leak rate for each potential release point in the fuel cell power system including any purge outlets shall be determined. See Section 14, Ventilation to Prevent the Build Up of Flammable Gases and Vapors, and IEC 60079-10-1, Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres, regarding releases.

### 25.2 Setup and operation

25.2.1 The testing shall be carried out in a draft free area, with the system located at least 10 feet (3.05 m) from room vents or forced ventilation.

25.2.2 If the fuel cell power system uses mechanical ventilation, it shall be operated at the minimum flow rate that satisfies all interlocks. See Section 14, Ventilation to Prevent the Build Up of Flammable Gases and Vapors.

### 25.3 Exhaust dilution

25.3.1 Hydrogen shall be released at the determined leak rate and at the location of the largest potential release point in the fuel cell power system.

25.3.2 The diluted concentrations of flammable vapors exiting the fuel cell power system shall not exceed the limits of 14.2.

### 25.4 Dilution boundaries

25.4.1 Hydrogen shall be released at the determined leak rate at each potential release point in the fuel cell power system.

25.4.2 The size and shape of each dilution zone shall be measured using a calibrated hydrogen detector.

25.4.3 The analysis of 14.3 shall be confirmed or updated with the measured sizes and shapes of the dilution zones.

25.4.4 The requirements of 14.4 and 14.6 shall be confirmed with the measured sizes and shapes of the dilution zones.

NOTE: In some cases, it may be sufficient to place the hydrogen detector at the locations of the nearest ignition source or unclassified equipment above and in the ventilation flow path, i.e. "downwind", of the release.



## 26 Potential Failure Modes

26.1 A review of the manufacturer's Risk Assessment and Risk Reduction of Section 7 is to determine the scope of this test procedure, including whether or not the system is to be operating during the test. Compliance with this section may also be determined through supporting evidence provided by the manufacturer.

26.2 Critical failure modes, as identified in the manufacturer's Risk Assessment and Risk Reduction of Section 7 are to be simulated to determine if the safety system is functional.

26.3 Compliance with this Section shall be determined by the performance of the correct actions by the safety system in accordance with the manufacturer's Risk Assessment and Risk Reduction of Section 7 upon initiation of a critical failure mode.

## 27 Temperature Tests

27.1 With the fuel cell system operating under maximum continuous load rating conditions, temperatures shall not reach a level high enough to cause a risk of a fire or damage to materials used in accordance with Table 27.2, and temperatures measured on accessible surfaces and temperature-sensitive components and materials shall comply with Table 27.1.

27.2 A thermal or overload protective device is not to operate during this test.

27.3 All temperature rise values in Table 27.2 are based on an assumed ambient temperature of 25°C (77°F). Tests may be conducted at any ambient temperature within the range of 10 – 40°C (50 – 104°F) when it is corrected by addition [if the ambient temperature is lower than 25°C (77°F)] or subtraction (if the ambient temperature is higher than 25°C) of the difference between 25°C and the ambient temperature.

27.4 Testing is to be continued until steady state temperatures are attained. Steady state temperatures are achieved when three successive readings taken at intervals of not less than 5 minutes indicate no further increase in temperatures.

27.5 Temperatures are to be measured by means of thermocouples. Temperatures on coil windings may be measured by either thermocouples or change of resistance method.

27.6 Thermocouples are to consist of wires not larger than 24 AWG (0.21 mm$^2$) and not smaller than 30 AWG (0.05 mm$^2$). Whenever referee temperature measurements by thermocouples are necessary, thermocouples consisting of 30 AWG iron and constantan wire and a potentiometer-type instrument are to be used. The thermocouple wire is to conform to the requirements specified in the Tolerances on Initial Values of EMF versus Temperature tables in the Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples, ASTM E230/E230M.

27.7 When using the resistance method, the windings are to be at room temperature at the start of the test, and the temperature rise of a winding is to be calculated using the formula:

$$\Delta t = \frac{R}{r}(k + t_1) - (k + t_2)$$

in which:

$\Delta t$ = the temperature rise in °C

$R$ = the resistance of the coil in ohms at the end of the test

$r$ = the resistance of the coil in ohms at the beginning of the test

$t_1$ = the initial room temperature in °C at the time resistance ($r$) is being measured (which is also the initial coil temperature)

$t_2$ = the room temperature in °C at the end of the test

$k$ = 234.5 for copper and 225.0 for electrical conductor grade (EC) aluminum, where values of the constant for other conductors are to be determined



**Table 27.1**
**Surface Temperature Limits**

| Surface temperature locations | Maximum temperature limits | |
|---|---|---|
| | °C | (°F) |
| A surface subject to continuous contact while the fuel cell power system is in use (for example, a momentary contact switch): | | |
| Metallic | 50 | (122) |
| Nonmetallic | 60 | (140) |
| A surface subject to deliberate contact while the fuel cell power system is in use, but not subject to continuous contact (for example, a switch): | | |
| Metallic | 60 | (140) |
| Nonmetallic | 85 | (185) |
| A surface subject to casual contact: | | |
| Metallic | 70 | (158) |
| Nonmetallic | 95 | (203) |

## Table 27.2
## Temperature limits

| Material and components | Temperature rise limits | |
|---|---|---|
| | °C | (°F) |
| Motors: | | |
| Class 105 (A) insulation systems | | |
| Thermocouple method | 65 | (117) |
| Resistance method | 75 | (135) |
| Class 130 (B) insulation systems | | |
| Thermocouple method | 85 | (153) |
| Resistance method | 95 | (171) |
| Class 155 (F) insulation systems | | |
| Thermocouple method | 110 | (198) |
| Resistance method | 120 | (216) |
| Class 180 (H) insulation systems | | |
| Thermocouple method | 125 | (225) |
| Resistance method | 135 | (243) |
| Coils other than motors: | | |
| Class 105 (A) insulation systems | | |
| Thermocouple method | 65 | (117) |
| Resistance method | 75 | (135) |
| Class 130 (B) insulation systems | | |
| Thermocouple method | 85 | (153) |
| Resistance method | 95 | (171) |
| Class 155 (F) insulation systems | | |
| Thermocouple method | 110 | (198) |
| Resistance method | 120 | (216) |
| Class 180 (H) insulation systems | | |
| Thermocouple method | 125 | (225) |
| Resistance method | 135 | (243) |
| Conductors: | | |
| Rubber or thermoplastic insulated wires and cords (unless rated for higher temperatures) | 35 | (63) |
| Surface temperatures of components (unless rated for higher temperatures): | | |
| Electrolytic capacitors | 40 | (72) |
| Other capacitors | 65 | (117) |
| Fuses<br>Electrical insulation (where deterioration would result in a safety hazard): | 65 | (117) |
| Electrical insulation (where deterioration would result in a safety hazard): | | |
| Fiber | 65 | (117) |
| Laminated phenolic | 100 | (180) |
| Molded phenolic | 125 | (225) |
| Other insulation materials [a] | – | – |
| Nonmetallic enclosure, structural and functional materials [a] | – | – |
| Safety critical gaskets and seals [a] | – | – |
| Supporting and adjacent surfaces | 65 | (117) |

[a] Temperature limits are dependent on the temperature rating of the material.

## 28 Continuity Test

28.1 Portions of the fuel cell power system intended to be bonded to the truck for electrostatic discharge protection shall be subjected to a bonding test.

28.2 Metallic parts required to be bonded to avoid electrostatic discharge shall have the impedance measured with a suitable ohmmeter between all points of connection of the metallic parts to determine that the resistance does not exceed 10 Ω.

28.3 Nonmetallic fluid lines shall have a maximum resistivity of 1 MΩ per meter when evaluated in accordance with the Conductivity Test in the Outline of Investigation for Electric Motors and Generators for Use in Class I, Division 2 and Class II, Division 2 Hazardous (Classified) Locations, UL 1836.

*Exception: Nonmetallic fluid lines may alternatively be evaluated according to the Test for Accumulation of Static Electricity in accordance with the Outline of Investigation for Electric Motors and Generators for Use in Class I, Division 2 and Class II, Division 2 Hazardous (Classified) Locations, UL 1836.*



## 29 Dielectric Voltage-Withstand Test

29.1 Each hazardous voltage circuit of the fuel cell power system shall withstand, without breakdown, the application of a test voltage of 1000 V plus twice rated voltage of the circuit.

29.2 The test voltage for AC circuits shall be an essentially sinusoidal potential at the frequency of the circuit.

*Exception: A DC potential equal to 1.414 times the value for the AC potential may be applied instead.*

29.3 Semiconductors or similar electronic components likely to be damaged by application of the test voltage may be bypassed or disconnected.

29.4 The test voltages shall be applied for a minimum of 1 minute.

## 30 Limited Power Circuits

30.1 A limited power source shall comply with one of the following:

a) The output is inherently limited in compliance with Table 30.1;

b) An impedance limited output in compliance with Table 30.1. If a positive temperature coefficient device is used, it shall comply with Manufacturing Deviation and Drift, Section 15, Endurance, Section 17, and Requirements for Controls Using Thermistors, Annex J, in the Standard for Automatic Electrical Controls for Household and Similar Use, Part 1: General Requirements, UL 60730-1;

c) A non-arcing over-current protective device is used and the output is limited in compliance with Table 30.2;

d) A regulating network limits the output in compliance with Table 30.1 both under normal operating conditions and after any single fault conditions in the regulating network (open circuit or short circuit); or

e) A regulating network limits the output in compliance with Table 30.1 under normal operating conditions and a non-arcing over-current protective device limits the output in compliance with Table 30.2 after any single fault condition in the regulating network (open circuit or short circuit).