The Fuel Cell Vehicle: Shaping The Future With Standardization

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Abstract

Fuel cells are considered a key element for the future development of electrically driven vehicles. The fuel cell-powered vehicle, which can be either a “pure fuel cell” vehicle or a “fuel cell hybrid” (e.g.. with a buffer battery) is often regarded as “the vehicle of the future”.

This emergence of a completely new technology presents a considerable challenge in the field of standardization development. Fuel cells are likely to be used in a variety of applications: stationary, on-board vehicles or portable power units. Specific standards covering the fuel cell system itself do not exist to this day, and existing standards on electrical safety only cover general aspects of these applications..

As for the fuel-cell powered vehicle, one should consider that, with respect to its traction system, it is basically an electric vehicle, on which relevant electric vehicle standards such as drafted by IEC and ISOare applicable.

The fuel cell technology is now in transition from a R&D to a commercial stage: this is a key phase to elaborate international standards to facilitate commercialization, international trade and approval procedures for fuel cell systems. Care should be taken however not to restrict further development of this young technology through too restrictive standards: initial standardization efforts should be aimed at safety and interface issues rather than at design aspects.

The “fuel cell” itself can be quite rightly considered an “electrical device” since it generates electricity; its standardization would thus be a task of the IEC. Automotive applications on the other hand are covered by ISO, who considered the fuel cell system as a “black box” delivering electricity, to be compared with the battery on a battery-electric vehicle, and it saw its job in the integration of the fuel cell into the vehicle. A formal liaison between both committees (IEC TC105 and ISO TC 22 SC21), as well as with the ISOcommittee specifically dealing with hydrogen (ISOTC 197) was thus established. Considerable work is also being performed on a regional (American or European) level, where particularly the SAE has been active in the field through its “Fuel Cell Initiative”, in collaboration with ISO.

This paper will give an overview of ongoing activities on automotive fuel cell standardization by the international and regional standardization organizations, focusing on the interaction and complementarity of the standards under preparation.

Keywords: fuel cell, standardization

1 Introduction

The “fuel cell” is an electrochemical device which converts the chemical energy of a fuel directly into electrical energy without making use of thermodynamical processes.
The basic theory of the fuel cell was published by Christian Friedrich Schonbein and Sir William Grove as early as 1839 - that is twenty years before Gaston Planté invented the lead-acid battery - but it is only in recent years that its large-scale commercial application is being envisaged.
Fuel cells are considered a key element for the future development of electrically driven vehicles. The fuel cell-powered vehicle, which can be either a “pure fuel cell” vehicle or a “fuel cell hybrid” (e.g.. with a buffer battery) is often regarded as “the vehicle of the future”. Prototype vehicles are being demonstrated to-day, whileas series production is expected to start in the 2010-2020 period. The fuel cell vehicle is the subject of several international research and demonstration programmes, such as the ELEDRIVE thematic network funded by the EU (www.eledrive.org).

This emergence of a completely new technology presents a considerable challenge on the field of standardization development. Fuel cells are likely to be used in a variety of applications: stationary, on-board vehicles or portable power units. Existing standards may include certain aspects of these applications; specific standards covering the fuel cell system itself do not exist however.
As for the fuel-cell powered vehicle, one should consider that, with respect to its traction system, it is basically an electric vehicle, on which relevant electric vehicle standards are applicable.
The fuel cell technology is now in transition from a R&D to a commercial stage: this is a key phase to elaborate international standards to facilitate commercialisation, international trade and approval procedures for fuel cell systems. Care should be taken however not to restrict further development of this young technology through too restrictive standards: initial standardization efforts should be aimed at safety and interface issues rather than at design aspects.

2 Fuel cell standardization at IEC

2.1 Inception of IEC TC105

The “fuel cell” can be quite rightly considered an “electrical device” since it generates electricity; its standardization would thus be a task of the IEC.
In 1996 the iec’s President Advisory Committee for future Technology (PACT) established an ad-hoc working group to study the potential of IEC work in the fuel cell field. This led to the founding of IEC Technical Committee 105 “Fuel Cell Technologies” in October 1998, in charge of preparing international standards regarding fuel cell technologies for all applications.
TC105 held its first meeting in Frankfurt am Main, Germany, in February 2000, where the initial work programme was discussed, and where delegates from ISO TC22 SC21 were present. The collaboration between TC105 and SC21 was deemed essential due to the application of fuel cells for automotive purposes.
The point of view of ISO was to consider the fuel cell system as a “black box” delivering electricity, to be compared with the battery on a battery-electric vehicle, and it saw its job in the integration of the fuel cell into the vehicle.

A formal liaison between the two committees was thus proposed, and undersigned by both parties in August 2000. IEC TC 105 and ISO TC22 SC21 agreed

> “to co-operate with each other to make a positive contribution to the standardization of the integration of fuel cell systems into road vehicles”

Furthermore, both committees agreed on the principle of creating the minimum number of standards.

The collaboration would be based on a so-called “Mode 4” liaison. In this system, one organization takes the lead in the activities, but work sessions and meetings receive delegates, with observer status (i.e. with the right to intervene in the debates but not to vote), from the other one, who observe the liaison. The work would be divided as follows:

- ISO TC22 SC21was to take the lead in the standardization activities with respect to the integration of fuel cell systems into road vehicles; the activities would be integrated in the existing SC21 structure.
- IEC TC105 was to take the lead in the standardization activities concerning fuel cell systems for propulsion in its WG6.
- A joint steering committee would co-ordinate the allocation of work to either of the committees.

It is clear that the realization of such collaboration agreement, before the actual start of the standardization work, has been a key step in making a fruitful collaboration possible, without any hitches that might have occurred otherwise.

A similar agreement was signed between ISO TC22 SC21 and ISO TC197, which deals with “Hydrogen”, and which in the framework of the fuel cell standardization would be responsible for all hydrogen infrastructure issues.

Furthermore, at the first TC105 meeting, the activities of other bodies involved with electric vehicle standardization, such as IEC TC69 and SAE, were presented. The co-operation of TC105 with SAE was assured both through ISO TC22 SC21 and through the participation of US delegates in TC105.At the 2002 meeting of TC105, a so-called “Category D” liaison between TC105 WG6 and SAE was announced. This type of liaison means that sae has indicated a wish to participate in the work of WG6, and that SAE experts will be informed and invited to meetings by the convenor.
IEC TC105 defined the following working groups:

- WG1: Definitions and terminology
- WG2: Fuel cell Modules
- WG3: Stationary fuel cell power plants - Safety
- WG4: Stationary fuel cell power plants - Performance
- WG5: Stationary fuel cell power plants - Installation
- WG6: Fuel cell systems for propulsion and auxiliary power units
- WG7: Portable fuel cell systems
- WG8: Regenerative fuel cell systems

TC105 started its work on these aspects; the new standards on fuel cells to be drafted will form the IEC 62282 family of international standards, which comprises several parts. Part 2 deals with “fuel cell modules”.

2.2 Fuel cell modules: IEC 62282-2

A New Work Item Proposal (NWIP) on the subject “Fuel cell modules: safety, quality assurance and environmental aspects of fuel cell modules in all applications” was circulated in December 2000 and accepted in May 2001. Committee Drafts (CDs) of this document, IEC 62282-2, were circulated in February and August 2002. The Committee Draft for Voting (CDV) was circulated in December 2002, due to be voted in parallel CEN/CENELEC enquiry by May 2003.
This document will be the general standard for fuel cell modules, providing the minimum requirements for safety and performance of different types of fuel cell modules:

- Alkaline
- Proton exchange membrane (including direct methanol)
- Phosphoric acid
- Molten carbonate

- Solid oxide

As such, the document is of course also relevant for automotive applications.

The term “fuel cell module” is understood as a sub-assembly including “slightly more” than the fuel cell stack proper, e.g. sensors, enclosure, but not its peripheral devices, electrical output beyond d.c., or fuel storage and delivery, as shown in Figure 1.

The main issue of this draft is “safety”: conditions that can yield hazards to personnel and damage outside the fuel cell module.

IEC 62282-2 is drafted out of a general safety strategy, referring to risk assessment procedures as defined in particular IEC standards like IEC 60812 “Analysis techniques for system reliability - Procedure for failure mode and effects analysis”, IEC 61025 “Fault tree analysis” and IEC 61508-1 “Functional safety of electrical / electronic / programmable electronic safety-related systems”.

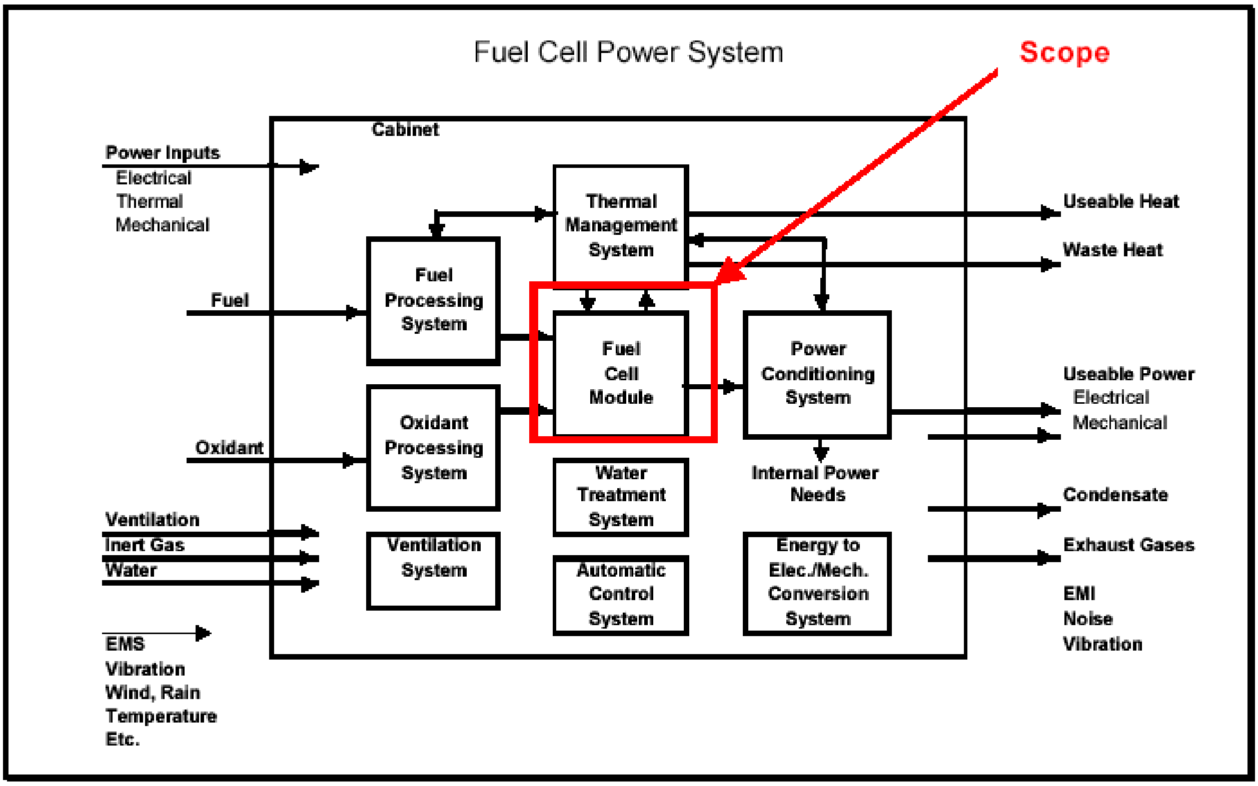

Figure 1: “Fuel cell module” (IEC TC 105)

This IEC 61508 standard is an “IEC basic safety publication” covering all safety-related systems that are electrotechnical in nature.

IEC 61508 uses a risk-based, approach to determine the required performance of safety-related systems, specifying safety integrity levels and covering all safety lifecycle activities. It is a generic document that can be used directly as a standalone standard, but which is also used frequently as a basis for developing other standards.

The general safety strategy for the fuel cell module is based on the quantity of stored energy in the module, and is established in the following sequence:

- Eliminate hazards outside the fuel cell module when such energy is released nearly instantaneously, or
- Passively control such forms of energy (e.g. burst disks, release valves, thermal cut-off devices) to ensure a release without endangering the ambient, or

- Actively control such forms of energy (e.g. by electronic control equipment). In this case, the remaining risk due to failures of this control equipment shall be investigated in detail. Alternatively, the hazard may be communicated to the fuel cell system integrator, or
- Provide appropriate safety markings, concerning the remaining risks or hazards.

Hazards to be considered include mechanical, electrical, EMC, thermal, fire and explosion, malfunction, dangerous substance, waste disposal and environmental hazards.

One can see that the hazard control measures are classified in a hierarchical way as key element of the safety strategy.
It is thus clear that the implementation of such safety strategy will have a profound influence on the whole of the system design process, and that the imposition of this policy in a standard will be a guidance to system manufacturers to come to a safe product.
This overall approach to safety, stressing on design strategy and design philosophy is typical for present-day system standards writing, more particularly for a general system standard like the future IEC 62282-2.

The draft for IEC 62282-2 also states design requirements addressing following issues:

- Behaviour at normal and abnormal operating conditions
- Leakage
- Pressurized operation
- Fire and ignition
- Safeguarding
- Piping and fittings
- Electrical components
- Terminals and electrical connections
- Live parts
- Insulating materials and dielectric strength
- Equipotential bonding
- Shock and vibration
- Monitoring.

It finally features a battery of type tests (covering both normal and abnormal operating conditions) and routine tests, the latter being limited to the gas tightness test and the dielectric strength withstand test, and states requirements for marking and documentation.

2.3 Towards a vehicle fuel cell standard: IEC 62282-4

In September 2001, a NWIP was circulated in TC105 on “Fuel cell system for propulsion and auxiliary power units (APU)”. It was aimed at performance, safety, EMC, quality assurance and environmental aspects of fuel cell systems for propulsion and auxiliary power units in automotive applications.
To consider as a starting point, the NWIP contained draft specifications:

- “Fuel cell systems for propulsion - General safety requirements”, prepared by US delegates and referring mainly to work performed by SAE .
- “Draft fuel cell vehicle safety specification part 1-3”, the draft documents of ISO TC22 SC21 presented here by JEVA

The NWIP was accepted in March 2002. This will become IEC 62282-4.
The definition of the work to be performed to draft a standard useful enough to provide worldwide coverage, particularly in view of avoiding double work with ISO, led to the necessity to extend the timing of the work; the new target date for the CD is October 2003, as decided on the third meeting, which took place in Montréal in June 2002.

The strategic policy statement of IEC TC105 foresees the following activities for WG6:

- Transportation fuel cell system - propulsion unit: safety and performance tests (timeline: 2004)
- Transportation fuel cell system - auxiliary power unit: safety and performance tests (work not yet started)
- Fuel cell system integration into vehicle: safety and performance tests (timeline: 2004, also dependent on ISO TC22)

2.4 Other work by IEC TC105

Other items included in the work programme of IEC TC105 include:

- Terminology (IEC 62282-1 TR), for which a CD has been circulated in March 2002. At a later stage, this will be included in the IEV. WG1 is responsible for this work.
- Safety of stationary fuel cell power plants (IEC 62282-3-1): this project, executed by WG3, is at ANW stage; a CD is expected for October 2003.
- Test methods for the performance of stationary fuel cell power plants (IEC 62282-3-2), the work of WG4, which circulated a CD in February 2002
- Installation of stationary fuel cell power plants (IEC 62282-3-3), the work of WG5. This is in ANW stage, target date for the first CD is June 2004.
- Safety and performance of portable fuel cell appliances (IEC 62282-5), a CD for this item is expected October 2003, prepared by WG7.

3 Fuel cell standardization at ISO

3.1 Generalities

The topic of fuel cell vehicles first appeared within ISO TC22 SC21 in 1998, with the idea to start working on safety requirements for fuel cell vehicles being forwarded by the chairman of SC21, Dr. Sahm. The production of water by the fuel cell stack was in fact perceived as a potential problem for the system electrical insulation, to be considered in standards like ISO 6469. Several national committees declared that their industry had started the development of fuel cell vehicles. One main point of the discussion was whether it would not be premature to start standardization work at this early level of development; Sahm stated however that:

> “Relevant standardization should not be retarded to avoid unnecessary debates at later work.”

The proposed work item (PWI) on safety requirements for fuel cell vehicles was distributed by the German committee in 1999. It states the baselines of a possible safety strategy for fuel cell vehicles, which should have both basic safety provisions and first failure safety provisions.

Furthermore, the number of standards developed should be the minimum necessary for new car developments. The proposed policy of SC21 was to create only one international standard for safety, only one standard for performance aspects and only one standard for exhaust gas emissions. If one of the last two topics were already covered by existing international standards(such as ISO 6469 for safety) for EV or HEV, no new standard should be worked out.

SC21 accepted this PWI, and charged WG1 to consider the document together with input from the SAE Fuel Cell Forum and to get feedback from automobile manufacturers, in order to prepare a NWIP.

At the same occasion, WG2 was asked to begin preparation of a draft for fuel cell terminology, as a PWI for material to be added to ISO 8713.

3.2 ISO TC22 SC21 WG1: System and safety standards

As stated in the co-operation agreement with IEC TC105, ISO TC22 SC21 will deal with vehicle-related aspects of fuel cell standardization within its existing working group structure.
WG1 deals with "Vehicle operating conditions, safety and energy storage installation", and is thus also responsible for fuel cell vehicle safety.
It considered a number of drafts (from Germany, Japan and the USA), and chose the four-part Japanese draft as basis for its further development on the standard "Fuel cell powered road vehicles - Safety specifications":

- Part 1: Vehicle functional safety
- Part 2: Fuel cell system integration
- Part 3: Protection against hydrogen hazards
- Part 4: Protection of persons against electrical hazards

Further work concerned the measurement of hydrogen emissions from vehicles at standstill.
These drafts were discussed at the WG1 meetings in Rome, Italy (May 2002) and Sacramento, California (November 2002).
On this last meeting, WG1 recognized unanimously the advantage to develop iso standards referring to "minimum safety requirements" for fuel cell powered road vehicles, in view of their adoption by the relevant national or international regulatory bodies.
The main content of these draft standards is as follows:

3.2.1 Vehicle functional safety

Part 1 of the draft standard specifies requirements of the functional safety of fuel cell powered road vehicles in respect to hazards caused by the operational characteristics of the fuel cell system and the electrical propulsion.
The proposed draft is largely based on the equivalent standard for battery-electric vehicles which is ISO 6469-2:2001.

3.2.2 Fuel cell system integration

Part 2 of the draft standard specifies requirements of the integration of fuel cell systems into fuel cell powered road vehicles for the protection of personnel and the environment of the vehicle.
The January 2002 draft presents some quite succinct requirements for leakage-current protection, electric shock protection, insulation resistance (100 Ω/V) and requirements in case of collision.
This part will be further developed together with IEC TC105, with the appropriate standard (IEC 62282-4) being considered as reference.

3.2.3 Protection against hydrogen hazards

Part 3 of the draft standard specifies the minimum safety requirements of fuel cell powered road vehicles in regard to hydrogen hazards, when pressurized hydrogen is used as raw fuel for propulsion.

It prescribes the following safety equipments to be used in the hydrogen system, which is shown schematically in Figure 2:

- A tank valve and pressure relief device, for each tank used.
- A main shut off valve that shall be closed when electric power is lost.
- An excess flow valve that shuts off the gas flow at an excessive flow rate (e.g. when a pipe is broken).

- A hydrogen concentration monitoring and shut-off system.

Furthermore, this document states requirements for the equipment to be installed and the way of installing them, for the lay-out of the installation as to separate potential hazards, for ventilation and hydrogen purging, and for fuelling.

For the complete drafting of this standard, the liaison with ISO TC197 will be essential, also because this standard refers to other standards (e.g. the ISO 15869 hydrogen tank standard) which are part of TC197's work programme.

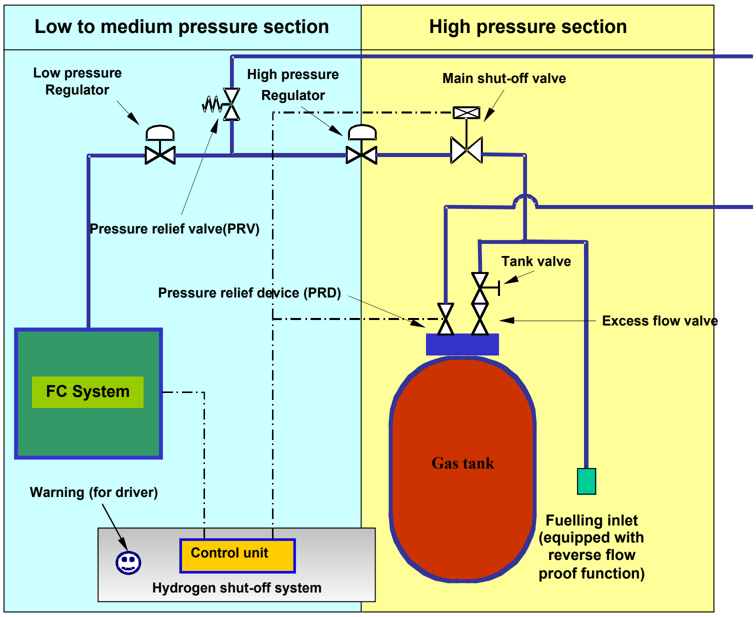

Figure 2: Example of hydrogen fuel supply system in fuel cell vehicle (ISO TC22 SC21)

3.2.4 Protection of personnel against electrical hazards

Part 4 of the draft standard specifies requirements of fuel-cell powered road vehicles for the protection of persons against electrical hazards, when the vehicles are not connected to an external power supply (in the latter case, IEC 61851-21 applies).
This document is largely based on the standard ISO 6469-3:2001.
The issue of galvanic connection between power circuits and the vehicle chassis was discussed at the WG1 meeting in Rome. Although all experts agreed that the chassis shall not be used as a conductor for the propulsion system, it is hard to avoid a galvanic connection between the fuel cell system and the vehicle chassis due to functional constraints, e.g. cooling and piping systems.

3.2.5 Hydrogen emission

WG1 is also working on a document on the "measurement of hydrogen emissions at standstill of the vehicles". This document, ISO/PWD 17374, is aimed both at battery-electric and fuel cell vehicles, and is an enlargement of scope of an earlier work item, which only covered battery-electric vehicles. It was proposed by the USA and is largely inspired on SAE J1718.
The presence of a world-wide standard for hydrogen emission measurement was also deemed useful because requirements for hydrogen concentrations were defined in other standards like ISO 6469-1.

It should be taken into account however that, with respect to potential hydrogen emissions, there is a significant difference between battery-electric vehicles, where hydrogen emissions are a side-effect of the charging process, and fuel cell vehicles, which have a much greater quantity of hydrogen stored on board.
The measurement procedure described in this document is applicable to the charging process of battery-electric vehicles on one hand, and on the release of hydrogen from fuel cell vehicles at power-off mode on the other hand. The purpose is to determine what concentrations of hydrogen gas the vehicle can generate in a sealed test chamber, under normal and abnormal (i.e. first failure) conditions.
Systems and components subject to specific legal requirements (e.g. hydrogen storage cylinders) or which are tested to any other regulation or standard concerning hydrogen emissions are not covered.
Two reference test volumes are provided: 50 m^3 for small vehicles, and 200 m^3 for large vehicles such as buses.
The volume of 50 m^3, which accommodates most passenger cars, can be considered as a typical garage; the aim of the test is thus to determine whether hazardous concentration of hydrogen do occur when the vehicle is located in a closed garage, either charging (battery-electric vehicle) or parked (fuel cell electric vehicle).
The test procedure described in this document can be compared with the hydrogen emission test in the regulation ECE 100. Both are performed in a sealed measurement chamber; the proposed ISO document has hydrogen concentrations as output, whileas the ECE regulation specifies hydrogen mass emission. As stated above, it is the hydrogen concentration which may pose a hazard, so the ISO approach seems to be a much more sensible one in this case.

3.3 ISO TC22 SC21 WG2: Performance standards and terminology

In 2001, the Italian NC submitted six NWIP to tc22, which were unanimously accepted, and allocated the following project numbers:

- ISO/AWI 22918: Electrically propelled road vehicles - Measurement of road operating ability - Fuel cell electric hybrid vehicles - Hydrogen based
- ISO/AWI 22919: Electrically propelled road vehicles - Measurement of road operating ability - Pure fuel cell electric vehicles - Hydrogen based
- ISO/AWI 22920: Road vehicles - Energy performance - Fuel cell electric hybrid vehicles
- ISO/AWI 22921: Road vehicles - Energy performance - Pure fuel cell vehicles
- ISO/AWI 22922: Road vehicles - Emission of hybrid vehicles - Fuel cell electric hybrid vehicles
- ISO/AWI 22923: Road vehicles - Emission of hybrid vehicles - Pure fuel cell vehicles

To perform this work, a new WG2 was formed in TC21, with a specific Task Force (TF1). TF1 met in October 2002 in Tokyo to define its work programme.

A second task force (TF2) would focus on terminology.

3.4 ISO TC197: Hydrogen standards

ISO TC197 “Hydrogen technologies” is responsible for standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen. The activities of this TC are of course of high relevance for the fuel cell vehicle. TC197 has established liaisons with several other TCs in ISO, such as TC58, which deals with “Gas cylinders”, but also with TC22 “Road vehicles”.
Although the hydrogen technology which is treated in the work of TC197 falls largely beyond the scope of this work, it is nevertheless interesting to give an overview of ongoing hydrogen standardization which may be relevant to the fuel cell vehicle application.

Up to now, TC197 has produced two international standards:

- ISO 13984:1999 “Liquid hydrogen - Land vehicle fuelling system interface”, which specifies the characteristics of liquid hydrogen refuelling and dispensing systems on land vehicles of all types It describes the system intended for the dispensing of liquid hydrogen to a vehicle, including that portion of the system that handles cold gaseous hydrogen coming from the vehicle tank, that is, the system located between the land vehicle and the storage tank. This standard states technical requirements for the interface, and even defines the necessary qualifications for the personnel, but does not define a dimensional standard for the interface.

- ISO 14687:1999 “Hydrogen fuel - Product specification” which defines quality requirements for hydrogen intended to be used as a fuel.

TC197 has various running projects at various stages of evolution.

- DIS stage (Draft International Standard)
  - ISO/DIS 13985-1 “Liquid hydrogen - Land vehicle fuel tanks - Part 1: Design, fabrication, inspection and testing”
  - ISO/DIS 13985-2 “Liquid hydrogen - Land vehicle fuel tanks - Part 2: Installation and maintenance”
- CD stage (Committee Draft)
  - ISO/CD 15869-1: “Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks - Part 1: General requirements”. (The 15869 series of standards is developed by a joint working group TC197/TC58.)
  - ISO/CD 15869-2: “Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks - Part 2: Particular requirements for metal tanks”
  - ISO/CD 15869-3: “Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks - Part 3: Particular requirements for hoop wrapped composite tanks with a metal liner”
  - ISO/CD 15869-4: “Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks - Part 4: Particular requirements for fully wrapped composite tanks with a metal liner”
  - ISO/CD 15869-5: “Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks - Part 5: Particular requirements for fully wrapped composite tanks with a non-metallic liner”
- WD stage (Working Draft):
  - ISO/WD TR 15916: “Basic considerations for the safety of hydrogen systems”
  - ISO/WD 17268: “Gaseous hydrogen - Land vehicle filling connectors”
  - ISO/WD 22734: “Hydrogen generators using water electrolysis process”
- AWI stage (Accepted Work Item):
  - ISO/AWI 16110: “Hydrogen generators using fuel processing technologies” - i.e. reformers
  - ISO/AWI 16111: “Transportable gas storage devices - Hydrogen absorbed in reversible metal hydride”

  A first draft of this document was distributed to ISO TC22 SC21. It shall apply to refillable transportable gas storage devices with a metal hydride hydrogen storage system, stating safety requirements and defining a series of type tests to be performed both on the storage tank itself and on the canister in which contains the complete hydrogen storage system.

4 Fuel cell standardization in Europe

CEN TC301 followed up the activities of ISO in the field, and resolved to complete the standards of the EN 1821, 1986 and 13444 series with parts covering fuel cell hybrid vehicles, pure fuel cell vehicles and other electrically propelled vehicles.
Work is being pursued on these items within CEN TC301 WG1, starting with the document EN 1821-3 on the road operating ability of fuel cell hybrid electric vehicles, with a distinction being made between

"hydrogen-based" and "carbon-based" (i.e. with methanol reformer) fuel cell. This will then become documents EN 1821-3-1 and EN 1821-3-2. No drafts of these documents have been circulated too national committees yet though.

5 Fuel cell standardization at SAE

5.1 Generalities

In the United States, large-scale actions on automotive fuel cell standardization have been launched by sae in the framework of the "SAE Fuel Cell Initiative", which was formed in 1999 to facilitate and accelerate the development of standards, codes and recommended practices for fuel cell powered vehicles, with the following mission:

"Establish standards and test procedures for fuel cell powered vehicles."

and scope:

The standards will cover the safety, performance, reliability and recyclability of fuel cell systems in vehicles with emphasis on efficiency and environmental impact. The standards will also establish test procedures for uniformity in test results for the vehicles/systems/components performances, and define interface requirements of the systems to the vehicle."

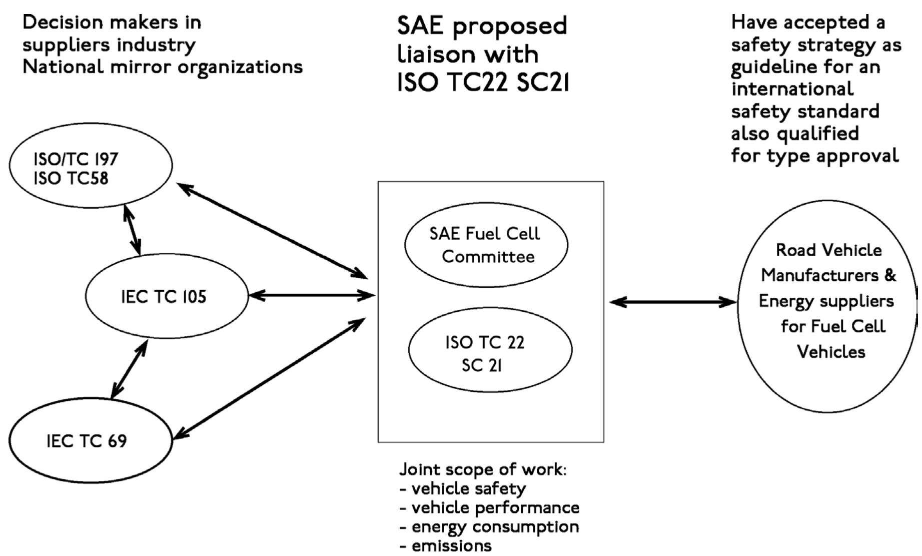

Figure 3: Fuel cell standardization landscape (ISO TC22 SC21 / SAE)

To this effect, a Fuel Cell Standards Committee has been set up, with members from vehicle manufacturers, fuel cell manufacturers, component suppliers, energy providers, government agencies and other organizations involved.

The committee liaised with ISO TC22 SC21 in order to build an effective standardization landscape for the fuel cell vehicle industry, as shown in Figure 3. An uncoordinated approach by the different standardization bodies would in fact create the risk of unharmonized drafts, dual standards, and the resulting confusion when it comes to type approval of the vehicles. This liaison, although it is officially "informal" (formal liaisons with ISO being only possible with other international standardization bodies such as IEC or CEN, and not with a national organization like SAE), is an essential element in the avoidance of double work being done by ISO and SAE.

The SAE Fuel Cell Standards Committee is constituted of six working groups, which will be discussed in the following paragraphs.

5.2 WG Emissions and fuel consumption

The mission of this WG is to establish standards and test procedures for measuring emissions and fuel consumption. Its goal is to define methodologies for uniformity in test results for all designs of fuel cell vehicles, and to allow a comparison with conventional vehicles.
The WG is working on a first draft document, and will in the future tackle vehicles fitted with a reformer.

- SAE J2572, "Fuel consumption and range" for fuel cell vehicles using compressed hydrogen from an off-board source and stored as a compressed gas onboard, including hybrid versions (i.e. with an on-board storage battery). This document is still under development and has not yet been published.

5.3 WG Interface

This WG aims to develop standards to coordinate between fuel suppliers and vehicle manufacturers to ensure safe, efficient and customer friendly delivery of fuel to fuel cell powered vehicles. Topics covered include fuel supply, infrastructure, fuel storage, fuel processor and vehicle interface.
The interface WG has the following standards on its work programme:

- SAE J2600: "Compressed Hydrogen Vehicle Fuelling Connection Devices". This standard was published in October 2002, and was presented to ISO TC22 SC21 for review in the framework of the liaison between the committees.

  SAE J2600 applies to design, safety, and operation verification of compressed hydrogen surface vehicle refuelling connection devices (nozzle and receptacle). Working pressures considered are 25, 35, 50 and 70 MPa (250, 350, 500 and 700 bar). The nozzles and receptacles considered shall:
    - prevent vehicles from being refuelled by dispenser stations with working pressures higher than the vehicle fuel system working pressure;
    - allow vehicles to be refuelled by dispenser stations with working pressures equal to or lower than the vehicle fuel system working pressure;
    - prevent vehicles from being refuelled by other compressed gases dispensing stations;
    - prevent other gaseous fuelled vehicles from being refuelled by hydrogen dispensing stations.

- SAE J2601: "Compressed Hydrogen Vehicle Fuelling Communication Devices", which will define different fuelling strategies and document their advantages and disadvantages. It will also develop the strategies and protocols for refuelling with and without communications, and focus on the most effective communication technology. This draft standard is targeted for publication mid-2003.

5.4 WG Performance

The mission of this WG is to develop procedures for testing PEM fuel cell system and its major subsystems for automotive applications. It has defined performance and measured parameters for three test subjects: PEM fuel cell system, fuel processor and PEM fuel cell stack.

5.5 WG Recyclability

This WG wants to identify recyclability issues associated with fuel cells in End of Life vehicles. It only deals with the PEM Fuel cell stack and its ancillary components, and is developing a guidance document incorporating and summarizing existing recyclability measurement techniques and recycling guidelines.

5.6 WG Safety

The Safety WG recommends design and construction, operation, emergency response, and maintenance practices for the safe use of fuel cell vehicles by the general public. Its work programme includes the following standards:

- SAE J2578: "General Fuel Cell Vehicle Safety", which provides criteria for integration for fuel systems into the vehicle. It contains the guidelines for design and construction, operations, emergency procedures and maintenance. Areas of concern include classifications, failures (enclosed areas), fail-safe actions when vehicle is moving and safety labelling.

- SAE J2579: "Fuel systems for Fuel Cell Vehicles", which provides criteria for systems containing or processing fuel or other hazardous materials. It contains information including design and construction, general mechanical requirements, operation, emergency procedures and maintenance. Areas of concern include fuel storage, processing, stacks, and other systems handling hazardous fluids. This document will consider all types of fuel cell systems.

The final versions of these standards are expected for the end of 2002.

5.7 WG Terminology

This WG defines the terminology for fuel cell powered vehicles. It has published an information report in March 2002:

- SAE J2574 Surface Vehicle Information Report "Fuel Cell Vehicle Terminology" which contains definitions for hydrogen fuel cell powered vehicle terminology, and which is intended to be a resource for the drafting of other fuel cell vehicle standards.

6 Other Relevant Standards

There are a number of other standards available which may be relevant to vehicle fuel cell applications.

6.1 NASA Hydrogen Safety Standard

Space applications have been a key area for fuel cell development and application. Furthermore, hydrogen is used as a fuel for rocket engines. To this effect, NASA has published a general standard on hydrogen applications: NASA NSS1740.16 "Safety standard for hydrogen and hydrogen systems"
The scope of this standard is to define guidelines for safely storing, handling and using hydrogen.
It defines specifications on the following topics:

- Basic hydrogen safety guidelines
- Properties and hazards of hydrogen
- Materials for hydrogen service
- Hydrogen facilities
- Hydrogen storage vessels
- Hydrogen and hydrogen fire detection

- Operating procedures
- Transportation
- Emergency procedures

The NASA document is very detailed and extensive, and takes into account a number of issues which are more relevant for space applications than for road vehicles. It contains however a number of general issues which can be applied to automotive applications, and which have actually been used as a base for sae standardization work in the field.

6.2 The European Pressure Equipment Directive

The European Directive 97/23/EC defines requirements for pressure vessels. The directive is reflected in the harmonized European standard EN 13445:2002, which consists of the following parts:

- EN 13445-1:2002 - Unfired pressure vessels - Part 1: General
- EN 13445-2:2002 - Unfired pressure vessels - Part 2: Materials
- EN 13445-3:2002 - Unfired pressure vessels - Part 3: Design
- EN 13445-4:2002 - Unfired pressure vessels - Part 4: Fabrication
- EN 13445-5:2002 - Unfired pressure vessels - Part 5: Inspection and testing
- EN 13445-6:2002 - Unfired pressure vessels - Part 6: Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron
- CR 13445-7:2002 - Unfired pressure vessels - Part 7: Guidance on the use of the conformity procedures.

Its scope however states that is not applicable on devices mounted on vehicles.
Its only usefulness for automotive applications would be stationary hydrogen storage devices, which can find the following uses:

- Hydrogen refuelling stations
- Stationary fuel cell generators for supplying battery-electric vehicles.

The detailed discussion of such stationary applications however falls out of the scope of this paper.

7 Conclusions

The development of the fuel cell technology has created new challenges for standardization. The construction of an appropriate standardization landscape for this new application has allowed the structuring of effective collaboration and interaction between different standardization committees involved, avoiding double work which might lead to conflicting standards.
Although most work on fuel cell standards is still on the working group level at the time of writing, an interesting outcome can be expected.
For what concerns the standardization of test procedures for fuel cell vehicles, which may or may not be equipped with an on-board rechargeable energy storage system, the same viewpoints expressed above for the hybrid vehicle apply.

8 References

Peter Van den Bossche, *The electric vehicle: raising the standards*, Ph.D. thesis, Vrije Universiteit Brussel, 2003

Published standards:

IEC 60050, International Electrotechnical Vocabulary
IEC 61851-21:2001, Electric vehicle conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an a.c./d.c. supply

ISO 6469-1:2001, Electric road vehicles - Safety specifications - Part 1: On-board electrical energy storage
ISO 6469-2:2001, Electric road vehicles - Safety specifications - Part 2: Functional safety and protection against failures
ISO 6469-3:2001, Electric road vehicles - Safety specifications - Part 3: Protection of persons against electric hazards
ISO 8713:2002, Electric road vehicles - Vocabulary
ISO 13984:1999, Liquid hydrogen - Land vehicle fuelling system interface
ISO 14687:1999, Hydrogen fuel - Product specification
EN 1050:1996, Safety of machinery - Principles for risk assessment
EN 1175-1:1998, Safety of industrial trucks - Electrical requirements - Part 1: General requirements for battery powered trucks
EN 1821-1:1996, Electrically propelled road vehicles - Measurement of road operating ability - Part 1: Pure electric vehicles
EN 1821-2:1999, Electrically propelled road vehicles - Measurement of road operating ability - Part 2: Thermal electric hybrid vehicles
EN 1986-1:1997, Electrically propelled road vehicles - Measurement of energy performances - Part 1: Pure electric vehicles
EN 1986-2:2001, Electrically propelled road vehicles - Measurement of energy performances - Part 2: Thermal electric hybrid vehicles
EN 13444-1:2001, Electrically propelled road vehicles - Measurement of emissions of hybrid vehicles - Part 1: Thermal electric hybrid vehicles
EN 13445:2002, Unfired pressure vessels
NASA NSS1740.16:1997, Safety standard for hydrogen and hydrogen systems
SAE J2574:2002, Fuel Cell Vehicle Terminology
SAE J2600:2002, Compressed Hydrogen Surface Vehicle Refuelling Connection Devices

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