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**Gaseous hydrogen — Fuelling  
stations —**

**Part 8:  
Fuel quality control**

*Hydrogène gazeux — Stations de remplissage —  
Partie 8: Contrôle qualité du carburant*

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# Contents

	Page
Foreword .....	iv
Introduction .....	v
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Abbreviated terms</b> .....	<b>3</b>
<b>5 Hydrogen specifications</b> .....	<b>4</b>
<b>6 Quality control approaches</b> .....	<b>4</b>
6.1 General .....	4
6.2 Sampling .....	4
6.3 Monitoring .....	4
<b>7 Potential sources of impurities</b> .....	<b>4</b>
<b>8 Hydrogen quality assurance methodology</b> .....	<b>4</b>
8.1 General .....	4
8.2 Prescriptive methodology .....	5
8.3 Risk assessment methodology .....	5
8.4 Impact of impurities on fuel cell powertrain .....	7
<b>9 Routine quality control</b> .....	<b>8</b>
<b>10 Non-routine quality control</b> .....	<b>8</b>
<b>11 Remedial measures and reporting</b> .....	<b>9</b>
<b>Annex A (Informative) Impact of impurities on fuel cell powertrains</b> .....	<b>10</b>
<b>Annex B (informative) Example of risk assessment</b> .....	<b>14</b>
<b>Annex C (informative) Example of Japanese hydrogen quality guidelines</b> .....	<b>24</b>
<b>Annex D (informative) Typical hydrogen fuelling station supply chain</b> .....	<b>33</b>
<b>Annex E (informative) Routine hydrogen quality analysis</b> .....	<b>37</b>
<b>Bibliography</b> .....	<b>39</b>

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee TC 197, *Hydrogen technologies*.

A list of all parts in the ISO 19880 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

This document was developed to specify how the quality of gaseous hydrogen fuel for road vehicles which use PEM fuel cells can be assured. The document discusses hydrogen quality control approaches for routine and non-routine conditions, as well as quality assurance plans. It is based upon best practices and experience from the gaseous fuels and automotive industry. ISO 21087 describes the requirements for analytical methods to measure the level of contaminants found in the gaseous hydrogen fuel.

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# Gaseous hydrogen — Fuelling stations —

## Part 8: Fuel quality control

### 1 Scope

This document specifies the protocol for ensuring the quality of the gaseous hydrogen at hydrogen distribution facilities and hydrogen fuelling stations for proton exchange membrane (PEM) fuel cells for road vehicles.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19880-1, *Gaseous hydrogen — Fuelling stations — Part 1: General requirements*

### 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

#### 3.1

##### authority having jurisdiction

AHJ

organization, office or individual responsible for approving a facility along with an equipment, an installation, or a procedure

#### 3.2

##### indicator species

one or more *constituents* (3.3) in the gas stream which can signal the presence of other chemical constituents because it has the highest probability of presence in a fuel produced by a given process

#### 3.3

##### constituent

component (or compound) found within a hydrogen fuel mixture

#### 3.4

##### contaminant

*impurity* (3.9) that adversely affects the components within the *fuel cell system* (3.6) or the hydrogen storage system

Note 1 to entry: An adverse effect can be reversible or irreversible.

#### 3.5

##### filter

equipment to remove undesired *particulates* (3.15) from the hydrogen

**3.6  
fuel cell system**

power system used for the generation of electricity on a *fuel cell vehicle* (3.7), typically containing the following subsystems: fuel cell stack, air processing, fuel processing, thermal management, and water management

**3.7  
fuel cell vehicle  
FCV**

vehicle which stores hydrogen on-board and uses a *fuel cell system* (3.6) to generate electricity for propulsion

**3.8  
fuelling station**

facility for the dispensing of compressed hydrogen vehicle fuel, including the supply of hydrogen, and hydrogen compression, storage, and dispensing systems

Note 1 to entry: Fuelling station is often referred to as hydrogen fuelling station or hydrogen filling station.

**3.9  
impurity**

non-hydrogen component in the gas stream

**3.10  
irreversible damage  
irreversible effect**

effect, which results in a permanent degradation of the fuel cell power system performance that cannot be restored by practical changes of operational conditions and/or gas composition

**3.11  
monitoring**

act of measuring the *constituents* (3.3) of a hydrogen stream or process controls of a hydrogen production system on a continuous or semi-continuous basis by on-site equipment

**3.12  
non-routine**, adjective  
not in accordance with established procedures

**3.13  
on-site supply**  
hydrogen fuel supplying system with a hydrogen production system in the same site

**3.14  
off-site supply**  
hydrogen fuel supplying system without a hydrogen production system in the same site, receiving hydrogen fuel which is produced out of the site

**3.15  
particulate**  
solid or liquid such as oil mist that can be entrained somewhere in the delivery, storage, or transfer of the hydrogen fuel entering a *fuel cell system* (3.6)

**3.16  
purifier**  
equipment to remove undesired *constituents* (3.3) from the hydrogen

Note 1 to entry: Hydrogen purifiers may comprise purification vessels, dryers, *filters* (3.5), and separators.

**3.17  
quality assurance**  
part of quality management focused on providing confidence that quality requirements will be fulfilled

**3.18****quality control**

part of quality management focused on fulfilling quality requirements

**3.19****quality plan**

documentation of quality management

**3.20****reversible damage****reversible effect**

effect, which results in a non-permanent degradation of the fuel cell power system performance that can be restored by practical changes of operational conditions and/or gas composition

**3.21****risk**

combination of the probability of occurrence of harm and the *severity* (3.26) of that harm, encompassing both the uncertainty about and severity of the harm

**3.22****risk assessment**

determination of quantitative or qualitative value of *risk* (3.21) related to a specific situation and a recognized threat also called a hazard

**3.23****risk level**

assessed magnitude of the *risk* (3.21)

**3.24****routine**, adjective

in accordance with established procedures

**3.25****sampling**

act of capturing a measured amount of hydrogen for chemical analysis by external equipment

**3.26****severity**

measure of the possible consequences for fuel cell cars if filled with H<sub>2</sub> containing higher level of *impurities* (3.9) than the threshold value

**4 Abbreviated terms**

Abbreviated term	Definition
Halogens	total halogenated compounds
HDS	hydrodesulphurization
PEM	proton exchange membrane
PSA	pressure swing adsorption
SC	severity class
SMR	steam methane reforming
THC	total hydrocarbons
TS	total sulphur compounds
TSA	temperature swing adsorption

## 5 Hydrogen specifications

The quality requirements of hydrogen fuel dispensed to PEM fuel cells for road vehicles are listed in ISO 14687-2.

## 6 Quality control approaches

### 6.1 General

There are two common methods to control the quality of hydrogen at a fuelling station, by spot sampling and continuous monitoring. These methods can be used individually or together to ensure hydrogen quality levels.

### 6.2 Sampling

Spot sampling at a fuelling station involves capturing a measured amount for chemical analysis. Sampling is used to perform an accurate and comprehensive analysis of impurities which is done externally, typically at a laboratory. Since the sampling process involves drawing a sample of gas, it is typically done on a periodic basis and requires specialized sampling equipment and personnel to operate it. Sampling procedures shall conform to ISO 19880-1. The advantage of spot sampling is that a more detailed laboratory analysis can be conducted on the sample. The disadvantage of spot sampling is that it is not continuous and results in a detail analysis of a single point in time.

### 6.3 Monitoring

A fuelling station can have real time monitoring of the hydrogen gas stream for one or more impurities on a continuous or semi-continuous basis. A critical impurity can be monitored to ensure it does not exceed a critical level, or monitoring of indicator species are used to alert of potential issues with the hydrogen production or purification process. Monitoring equipment is installed in line with the hydrogen gas stream and shall meet the process requirements of the fuelling station, as well as be calibrated on a periodic basis. Continuous monitoring compliments spot sampling by offsetting the disadvantages.

## 7 Potential sources of impurities

For a given fuelling station, the contaminants listed in the hydrogen specification referred to in [Clause 5](#) may or may not be potentially present. There are several parts of the supply chain where impurities can be introduced. The potential impurities in each step of the supply chain are described in [Annex D](#).

When a contaminant is classified as potentially present, it shall be taken into account in the quality assurance methodology (risk assessment or prescriptive approach) described in [Clause 8](#).

## 8 Hydrogen quality assurance methodology

### 8.1 General

A quality assurance plan for the entire supply chain shall be created to ensure that the hydrogen quality will meet the requirements listed in [Clause 5](#). The methodology used to develop the quality assurance plan can vary but shall include one of the two approaches described in this document. The general description of these two approaches are described in [8.2](#) and [8.3](#). Examples of these approaches 1) prescriptive approach and 2) risk assessment for hydrogen quality, are presented in [Annexes A, B and C](#), respectively. The quality assurance plan for the fuelling station shall include the following to ensure hydrogen quality is properly maintained:

- identification of potential impurities;

- methods to control and remove these impurities;
- sampling impurities and frequency;
- monitoring of impurities or process controls;
- description of solid and liquid particulate filters;
- cleanliness and maintenance procedures.

It is important to understand that quality should be maintained throughout the complete supply chain of the product (from production source to fuelling station nozzle), such that the impurities that are given in the specification remain below the threshold values.

Each component of the supply chain shall be investigated taking into account the already existing barriers for a given contaminant.

NOTE An effective quality control approach can further ensure the quality of the hydrogen by providing a proactive means to identify and control potential quality issues which can include sampling and monitoring. Additionally, use of quality assurance can improve the decision making if a quality problem arises.

## 8.2 Prescriptive methodology

The prescriptive approach to hydrogen quality assurance considers potential sources of contaminants and establishes a fixed protocol for analysing and addressing potential contaminants. The prescriptive approach can be applied for the clearly identified supply chain.

The prescriptive quality assurance plan shall be determined taking into account all hydrogen production methods, hydrogen transportation methods and non-routine procedures which exists in the area where the assurance plan is applicable.

NOTE [Annex C](#) presents Japanese hydrogen quality guidelines which is an example of a prescriptive quality assurance plan.

## 8.3 Risk assessment methodology

The risk assessment approach determines the probability to have each impurity above the threshold values of specifications given in [Clause 5](#) and evaluates severity of each impurity for the fuel cell vehicle (see [Annex A](#)). As an aid to clearly defining the risk(s) for risk assessment purposes, three fundamental questions are often helpful:

- What can go wrong: which event can cause the impurities to be above the threshold value?
- What is the likelihood (probability of occurrence expressed relative to the number of fuelling events) that impurities can be above the threshold value?
- What are the consequences (severity) for the fuel cell vehicle?

In doing an effective risk assessment, the robustness of the data set is important because it determines the quality of the output. Revealing assumptions and reasonable sources of uncertainty will enhance confidence in this output and/or help identify its limitations. The output of the risk assessment is a qualitative description of a range of risk. To determine the probability of the occurrence that impurities in hydrogen exceed the threshold value, [Table 1](#) defines the occurrence classes.

**Table 1 — Occurrence classes for an impurity**

Occurrence class	Class name	Description	Occurrence or frequency
0	<b>Very unlikely (Practically impossible)</b>	Contaminant above threshold never been observed for this type of source in the industry	Never

**Table 1** (continued)

Occurrence class	Class name	Description	Occurrence or frequency
1	Very rare	Known to occur in the industry for the type of source/Supply chain considered	1 per 1 000 000 fuellings
2	Rare	Has occurred more than once/year in the Industry	1 per 100 000 fuellings
3	Possible	Has occurred repeatedly for this type of source at a specific location	1 out of 10 000 fuellings
4	Frequent	Occurs on a regular basis	Often

If the occurrence class is unknown, then the risk assessment shall assume the worst case. In addition, the experience of the hydrogen supplier, station manufacturer/installer should be taken into account when performing the risk analysis.

The range of severity classes (level of damage for vehicle) is defined in [Table 2](#).

**Table 2 — Severity classes for an impurity**

Severity class	FCV performance impact or damage	Impact categories		
		Performance impact	Hardware impact temporary	Hardware impact permanent
0	— No impact	No	No	No
1	— Minor impact	Yes	No	No
	— Temporary loss of power			
	— No impact on hardware			
	— Vehicle still operates			
2	— Reversible damage	Yes or No	Yes	No
	— Requires specific light maintenance procedure			
	— Vehicle still operates			
3	— Reversible damage	Yes	Yes	No
	— Requires specific immediate maintenance procedure			
4 <sup>a</sup>	— Gradual power loss that does not compromise safety			
	— Power loss or Vehicle Stop that compromises safety	Yes	Yes	No
	— Irreversible damage			
	— Requires major repair procedure (e.g. stack change)		No	Yes

<sup>a</sup> Any damage, whether permanent or temporary, which compromises safety will be categorized as SC 4, otherwise temporary damage will be categorized as SC 1, 2 or 3.

The final risk is defined by the acceptability table ([Table 3](#)) which combines results from [Tables 1](#) and [2](#):

Table 3 — Combined risk assessment

Probability per one fuelling	Occurrence	Severity							
		0	1	2	3	4			
Frequent: Often	4	+	*	*	*	*			
Possible: 10 <sup>-4</sup>	3	+	o	*	*	*			
Rare: 10 <sup>-5</sup>	2	+	+	o	*	*			
Very Rare: 10 <sup>-6</sup>	1	+	+	+	o	*			
Practically Impossible	0	+	+	+	+	+			
Key	+	Acceptable risk area: Existing controls sufficient		o	Further investigation is needed: existing barriers or control may not be enough		*	Unacceptable risk; additional control or barriers required	

NOTE 1 It is possible that contamination of a vehicle at severity class 1 or 2 is not noticeable immediately, thereby making it difficult to identify the source of the contamination.

If a vehicle is found to have hydrogen with contamination that exceeds the specification in [Clause 5](#) and the source is unknown, the procedures in [Clause 11](#) shall be followed.

For each impurity of the specification and for a given fuelling station (including the supply chain of hydrogen), a risk assessment shall be applied to define the global risk.

NOTE 2 Risk control includes decision making to reduce and/or accept risks. The purpose of risk control is to reduce the risk to an acceptable level.

The amount of effort used for risk control should be proportional to the significance of the risk. Decision makers might use different processes, including benefit-cost analysis, for understanding the optimal level of risk control. Risk control can focus on the following questions:

- Is the risk above an acceptable level?
- What can be done to reduce or eliminate risks?
- What is the appropriate balance among benefits, risks and resources?

For each level of risk, a decision shall be taken in order to either refuse the risk and find mitigation or barriers to reduce it, or accept the risk level as it is. Risk reduction focuses on processes for mitigation or avoidance of quality risk when it exceeds an acceptable level (“o” or “\*” zone in [Table 3](#)). Risk reduction typically includes actions taken to mitigate the severity and/or probability of occurrence. However, this document only deals with the mitigation of probability of occurrence.

#### 8.4 Impact of impurities on fuel cell powertrain

It is necessary to evaluate the possible consequences on a fuel cell car if each impurity exceeds the ISO 14687-2 threshold value. The impact for the car will depend on the concentration of the contaminant. [Table 4](#) shows a summary of the concentration-based impact of the impurities on the fuel cell. The contaminants and their chemical formulas are given in the first two columns of [Table 4](#).

An estimation of the exceeded concentration above the ISO 14687-2 threshold value for each impurity is named “Level 1” and is given in column 5. According to this concentration a severity class is given in column 4 for each impurity. This severity class covers the impact of this impurity above the threshold value up to this limit.

If higher concentrations that exceed Level 1 can be reached, the severity class is given in column 6.

Table 4 — Impact of impurities on fuel cell powertrain

Impurity		ISO 14687-2 threshold value <sup>a</sup> [μmol/mol]	Severity class (from ISO 14687-2 to Level 1)	Level 1 value [μmol/mol]	Severity class (greater than Level 1 threshold)
Total non-H <sub>2</sub> gases		300	1	UD	UD
Total nitrogen and argon	N <sub>2</sub> , Ar	100	1 <sup>b</sup>	300 <sup>a</sup>	4
Oxygen	O <sub>2</sub>	5	UD	UD	4 <sup>c</sup>
Carbon dioxide	CO <sub>2</sub>	2	1	3	4
Carbon monoxide	CO	0,2	2-3 <sup>d</sup>	1	4
Methane	CH <sub>4</sub>	100	1	300	4
Water	H <sub>2</sub> O	5	4	5	4
Total sulphur compounds	H <sub>2</sub> S basis	0,004	4	>0,004	4
Ammonia	NH <sub>3</sub>	0,1	4	>0,1	4
Total hydrocarbons	CH <sub>4</sub> basis	2	1-4 <sup>d</sup>	>2	4
Formaldehyde	CH <sub>2</sub> O	0,01	2-3 <sup>d</sup>	1	4
Formic acid	HCOOH	0,2	2-3 <sup>d</sup>	1	4
Halogens		0,05	4	>0,05	4
Helium	He	300	1	300	4
Maximum particulate concentration (liquid and solid) <sup>e</sup>		1 mg/kg	4	>1 mg/kg	4

**Key**  
 UD: Undertermined  
<sup>a</sup> The threshold value is according to hydrogen specification of ISO 14687-2.  
<sup>b</sup> At the time of publication, the revision of the threshold limit for inert gases (N<sub>2</sub>+Ar+He) is undergoing. When the threshold limit is changed from 100 μmol/mol to 300 μmol/mol, severity class for inert gases in a range of 100 μmol/mol to 300 μmol/mol will be 0.  
<sup>c</sup> Data is lacking to confirm the Level 1 concentration and severity class for oxygen,; therefore, the most conservative approach of severity class 4 should be taken unless demonstrated otherwise.  
<sup>d</sup> A higher value is to be considered for risk assessment approach until more specific data is available.  
<sup>e</sup> Particulates are based upon mass density mg/kg.

## 9 Routine quality control

Routine analysis is performed on a periodic basis once every specified time period or once for each lot or batch. The methodology selected in the hydrogen quality assurance plan determines the type and frequency of the routine analysis. A prescriptive methodology may be used as described in 8.1 or a risk assessment methodology may be used (8.2). Information on the routine analysis for each step of the supply chain is provided in Annex E.

## 10 Non-routine quality control

The hydrogen quality plan shall identify any non-routine conditions and subsequent required actions. Some common non-routine conditions include the following:

- a new production system is constructed at a production site or a new fuelling station is first commissioned;

- the production system at a production site or fuelling station is modified;
- a routine or non-routine open inspection, repair, catalyst exchange, or the like is performed on a production system at the production site or fuelling station;
- any severe malfunctions of a transportation system of compressed hydrogen, liquid hydrogen, and hydrogen pipeline occur;
- a question concerning quality is raised when, for example, there is a problem with a vehicle because of hydrogen supplied at the production site or fuelling station, and a claim is received from a user directly or indirectly;
- an issue concerning quality emerges when, for example, a voluntary audit raises the possibility that quality control is not administered properly; or
- analysis is deemed necessary for testing, research, or any other purposes.

## 11 Remedial measures and reporting

If a fuelling station dispenses hydrogen which does not meet the requirements in [Clause 5](#), the fuelling station operator shall immediately prevent any further dispensing until repaired, and notify the station owner/operator as soon as possible, as well as the authorities having jurisdiction. The fuelling station owner/operator shall also review and update quality assurance methodologies to prevent future contamination.

## Annex A (Informative)

### Impact of impurities on fuel cell powertrains

#### A.1 General

This annex gives a brief description of the impact of impurities on the stack, fuel cell components, and the complete fuel cell powertrain. Detailed information can be found in the relevant literature and journal publications. It shall be noted that this annex refers to known impurities and their effects on the fuel cell powertrain at the time of publication. It cannot be excluded that other impurities exist. Furthermore, in most cases only the impact of a single impurity has been investigated and there is still the need for fundamental research regarding the impact of a combination of the different impurities on the fuel cell powertrain.

#### A.2 Inert gases

The main effect due to the presence of inert gases such as Ar and  $N_2$  is to lower the cell potential due to the dilution effect of the inert species (dilution of the hydrogen gas) and inertial (diffusion) effects. Nevertheless, under consideration of the threshold value current stack designs, fuel cell components and fuel cell powertrains are not adversely affected by inert constituents. High inert gas concentrations will lead to power losses, increased fuel consumption, and loss of efficiency. Furthermore,  $H_2$  starvation caused by high inert gas concentrations may lead to permanent damage of the fuel cell stack or vehicle stop. Inert gases will accumulate in the anode loop and may affect venting and recycle blower control. Further sources report that the presence of  $N_2$  hinders desorption of adsorbed CO from the surface of the anode catalyst. It should also be noted that inert gases can affect the accuracy of mass metering instruments for hydrogen dispensing.

#### A.3 Oxygen

Oxygen may have a detrimental effect on the fuel cell anode, but the concentration where this effect occurs is not fully known. Higher levels of oxygen may have an impact on metal hydride storage materials.

#### A.4 Carbon dioxide

The contamination effects of  $CO_2$  depend on the concentration, fuel cell operation conditions, and anode catalyst composition. Firstly,  $CO_2$  dilutes the hydrogen gas and may affect venting and recycle blower control of the fuel cell powertrain. Furthermore, very high concentrations of  $CO_2$  can be catalytically converted via a reverse water gas shift reaction into CO which in consequence poisons the catalyst. In addition, co-occurrence of CO and  $CO_2$  in hydrogen has an accumulated influence on cell performance.  $CO_2$  may adversely affect on-board hydrogen storage systems using metal hydride alloys.

#### A.5 Carbon monoxide

Carbon monoxide causes severe catalyst poison that adversely affects the performance of the fuel cell powertrain. CO binds strongly to Pt sites, resulting in the reduction of the effective electrochemical surface area available for  $H_2$  adsorption and oxidation. The catalyst poison effect is strongly related to the concentration of CO, the exposure time, the cell operation temperature and anode catalyst types. Although the effects of CO on the fuel cell can be reversed through mitigating strategies, such as material selection of membrane electrode assembly, system design and operation, the life time effects

of CO on performance is a strong concern. The lower catalyst loadings needed for cost optimization and longer hydrogen protection times especially lead to more severe poisoning effects. Therefore, CO needs to be kept at very low levels in hydrogen fuel.

## A.6 Methane

Methane is one of the very few hydrocarbons that does not contaminate PEM fuel cells. It does not react with the catalyst, so dilution is the major effect that shall be considered with methane gas.

## A.7 Water

Water is an issue for hydrogen dispensing systems, in the on-board vehicle tank system or fuel cell components due to the formation of ice. Excess water can exist in a liquid state and can cause corrosion of metallic components. Low quantities could lead to severe impacts on the components. Furthermore, water affects the function of the stack. Water provides a transport mechanism for water-soluble impurities, especially as a solvent for cations like  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Cs}^+$  and  $\text{NH}_4^+$  when present as an aerosol. The cations adsorb to and block the functional groups of the ionomer thereby reducing the proton conductivity of the membrane. Water is only a concern for the stack in very large quantities. It can lead to water management issues that may limit the current and increase in over-potential. Water should remain gaseous throughout the operating conditions of system. It is believed that water affects the metal hydride life cycle due to exothermic reactions.

## A.8 Total sulphur compounds

Sulphur containing compounds are severe catalyst poisons that at even very low levels can cause irreversible degradation of fuel cell performance. The specific sulphur compounds that are addressed are in particular: hydrogen sulphide, sulphur dioxide, carbonyl sulphide, carbon disulphide, methyl mercaptan. Beside these specific compounds further sulphur compounds can exist. The adsorption of the sulphur-containing species to the active sites of the catalyst prevents the hydrogen from adsorbing at the catalyst surface resulting in a significant drop in performance. The reactions of the adsorbed sulphur compounds result in the formation of the very stable platinum sulphide which makes it impossible to recover the fuel cell catalyst from contamination. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

## A.9 Ammonia

Ammonia contamination causes some irreversible fuel cell performance degradation by reducing the proton conductivity of the ionomer.  $\text{NH}_3$  migrates into the membrane and reacts with protons to  $\text{NH}_4^+$  which then adsorb to and block the functional groups of the ionomer. The level of deterioration depends on both the  $\text{NH}_3$  concentration and exposure time. Performance decay is also attributed to the adsorption of ammonia on the catalyst surface blocking the active sites.

## A.10 Total hydrocarbons

Different hydrocarbons have different effects on fuel cell performance. The main effect is the adsorption on the catalyst layer, reducing the catalyst surface area and thereby decreasing the cell performance. Another effect is the decomposition into carbon monoxide, which then adsorbs on the catalyst layer. The severity of the effect depends on the type of hydrocarbon. Generally aromatic hydrocarbons adsorb more strongly on the catalyst surface than other hydrocarbons inhibiting access to hydrogen. Acids, aldehydes, etc. degrade performance. Phthalates, squalene, erucamide which could be found in seals and hoses will cause problems on the stack side.  $\text{CH}_4$  is considered an inert constituent since its effect on fuel cell performance is to dilute the hydrogen fuel stream (see [A.5](#)).

### A.11 Formaldehyde

Formaldehyde has a similar effect on fuel cell performance as carbon monoxide. The adsorption process of formaldehyde on the catalyst is the same as for CO followed by an immediate conversion of the  $\text{CH}_2\text{O}$  to  $\text{CO} + \text{H}_2$ . The adsorption of the produced CO on the catalyst layer leads to a reduction of the catalytic surface area which decreases the cell performance. Contamination due to formaldehyde can be recovered by changing the cell voltage and by purging with pure hydrogen. Therefore, formaldehyde can be considered as a reversible contaminant with the same impact on the fuel cell as for CO. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

### A.12 Formic acid

Formic acid has a similar effect on fuel cell performance as carbon monoxide. Under certain operating conditions CO is a possible intermediate during the adsorption process of formic acid and the subsequent reaction of  $\text{HCOOH}$  to  $\text{CO}_2 + \text{H}_2$ . The adsorption of the intermediate CO product on the catalyst layer leads to a reduction of the catalytic surface area which decreases the cell performance. Contamination due to formic acid can be recovered by changing the cell voltage and by purging with pure hydrogen. Therefore, formic acid can be considered as a reversible contaminant with the same impact on the fuel cell as for CO. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

### A.13 Halogenated compounds

Halogenated compounds adsorb on the catalyst layer, reduce the catalytic surface area, and decrease the cell performance. The performance degradation caused by halogenated compounds is an irreversible effect. The biggest concern is about chlorine in hydrogen from electrolysis of water. Chloride for example promotes the dissolution of Pt by the formation of soluble chloride complexes and subsequent deposition in the fuel cell membrane. Potential sources include chloralkali production processes, refrigerants used in processing, and cleaning agents.

### A.14 Helium

The main effect due to the presence of helium is to lower the cell potential due to the dilution effect of the inert species (dilution of the hydrogen gas) and inertial (diffusion) effects. It should be considered that hydrogen sensors show interference with helium. Higher inert gas concentrations may also affect the venting and recycle blower control. Current stack designs are not adversely affected by higher inert gas concentrations. Nevertheless, higher inert gas concentrations will lead to power losses, increased fuel consumption, and loss of fuel cell efficiency.

### A.15 Solid and liquid particulates (aerosols)

Aerosols are dispersed solid and/or liquid particles in a gas. These particulates may be introduced in the production, storage, or delivery of hydrogen fuel. A maximum solid and liquid particle concentration is specified to ensure that filters are not clogged and/or solid and liquid particles do not enter the fuel system and affect operation of fuel system components and fuel cell stacks. A maximum particulate size diameter is not specified yet but should be addressed in a fuelling station standard and/or future revision of ISO 14687-2. Particulate sizes should be kept as small as possible.

There are various effects of station operating fluids and solid particulates on the stack, fuel cell components, and the complete fuel cell powertrain. These particulates originate from the operation of hydrogen fuelling stations and show severe impacts. This group of substances comprises cleaning agents, oils, lubricant oils, siloxanes, ionic liquids, decomposition products of ionic liquids, additives, metals, metal oxides, and metal ions. One effect of these substances is the adsorption to the active site of the fuel cell catalyst which prevents the hydrogen from adsorbing at the catalyst surface resulting in significant performance drop. Other effects are the reduction of the proton conductivity of the membrane, impact on storage systems, and interference of  $\text{H}_2$  sensors. Generally, the use of operating fluids shall be minimized as far as possible. If the use of operating fluids is mandatory, means shall

be provided by the hydrogen fuelling station to hinder these operating fluids from contaminating the vehicle fuel cell powertrain.

The contamination due to aerosols is of extreme importance as illustrated by the following example using  $\text{SnO}_2$ , the oxide of the tetravalent tin as a model substance. This heavy metal oxide is present in the solid state of matter with a molar mass of  $M_{\text{SnO}_2} = 150,69 \text{ g} \cdot \text{mol}^{-1}$  and a density of  $\rho_{\text{SnO}_2} = 6,95 \text{ g} \cdot \text{cm}^{-3}$  at  $20 \text{ }^\circ\text{C}$ . Under the assumption of a spherical particle shape with a diameter of  $d_{\text{particle}} = 0,1 \text{ } \mu\text{m}$  and under consideration of the Avogadro Constant  $N_A = 6,022 \cdot 10^{23} \text{ mol}^{-1}$  the number of  $\text{SnO}_2$ -molecules  $n_{\text{SnO}_2}$  in the particle can be calculated as follows:

$$n_{\text{SnO}_2} = \frac{\pi \cdot d_{\text{particle}}^3 \cdot \rho_{\text{SnO}_2}}{6 \cdot 10^{15} \cdot M_{\text{SnO}_2}} \cdot N_A \quad (\text{A.1})$$

$$n_{\text{SnO}_2} = 1,45 \cdot 10^7 \quad (\text{A.2})$$

These 14,5 million  $\text{SnO}_2$  molecules can lead to irreversible impacts in microelectronic structures. Therefore it is necessary to filter out any solid and liquid particles close to the fuelling nozzle to prevent any impact on the fuel cell powertrain.

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## Annex B (informative)

### Example of risk assessment

#### B.1 Centralized production, pipeline transportation

The different steps for elaborating the quality assurance plan of one fuelling station are illustrated using the following case: one fuelling station delivered by pipeline from an off-site SMR.

The solutions selected in this example to decrease the risk when necessary are given as a possible solution for this specific case. Other solutions may be chosen depending on each fuelling station.

Following the procedure described in [Clause 8](#), the risk assessment is performed on the identification of the probability to have each impurity above the threshold values of specifications and the evaluation of severity for the fuel cell vehicle, assuming some values of impurities above the specification (see [Table B.1](#), [Table B.2](#) and [Table B.3](#)). This risk assessment is done for each part of the supply chain: SMR, pipeline distribution and fuelling station itself.

#### B.2 Steam methane reformation

##### B.2.1 General

In this process, methane from natural gas and steam react at a high temperature to produce synthesis gas (or syngas). Syngas is a mixture consisting mainly of hydrogen and carbon monoxide.

In order to achieve the reaction between natural gas and steam, catalysts and a high temperature are required. These catalysts are poisoned by any trace of sulphur or chlorinated compounds. It is then necessary to remove all sulphur components from natural gas before the SMR reaction. The purification system, named hydrodesulphurisation is a two steps process: first transformation of all sulphur species in  $H_2S$  and then adsorption of  $H_2S$  in specific adsorbents. At the outlet of this purification step, the natural gas contains less than 50 nmol/mol of  $H_2S$  by design and less than 10 nmol/mol in normal conditions.

After the reforming reaction, the carbon monoxide is further reacted with steam in a water gas shift reaction. It produces carbon dioxide and hydrogen and it increases the hydrogen yield. An additional separation step is mandatory to provide hydrogen with a purity suitable for FCV application.

##### B.2.2 Purification by pressure swing adsorption

Pressure swing adsorption is a non-cryogenic gas separation process which uses adsorbent technology to purify hydrogen from a gas mixture. PSA principle is based on preferential adsorption of some gaseous components to others on highly porous materials. The PSA ability to trap impurities depends on the affinity between the adsorbent and the gas molecule. Typically a PSA column is filled with multiple adsorbents with very high surface area to volume ratios. Typical adsorbents include silica, alumina, molecular sieves, and activated carbons, which have different relative strength of adsorption depending on the gaseous compounds.

Table B.1 — Probability of occurrence for off-site SMR

Impurity	Threshold μmol/mol	Possible causes For the source studied	Typical barriers employed in this process	Probabil- ity with barriers
<b>Inert gas</b> N <sub>2</sub>	100	Present in natural gas and syngas PSA malfunction	— PSA — Double analysis PSA outlet <100 μmol/mol	3
<b>Inert gas</b> Ar		Only ATR and POx present in O <sub>2</sub> typical 0,6 % in syngas from ATR	— PSA. Not sized to remove Ar. Ar content may be higher if H <sub>2</sub> comes from ATR, POX or feeds with high Ar content	
<b>O<sub>2</sub></b>	5	Not present in syngas. O <sub>2</sub> is unsta- ble in the condition of reforming and shift reactions. Combines with H <sub>2</sub> , CO CH <sub>4</sub>	— PSA cannot be used with significant O <sub>2</sub> content for safety reasons	0
<b>CO<sub>2</sub></b>	2	Present in syngas (%)	— PSA adsorption strength of MS, activated carbon, silicagel higher for CO <sub>2</sub> than CO. — A CO content lower than 10 μmol/mol insures a CO <sub>2</sub> content lower than 2 μmol/mol	0
<b>CO</b>	0,2	Normal operation below threshold. Occasional peaks at μmol/mol level	— Double analysis at the PSA outlet + trip if the CO > 1-10 μmol/mol at PSA outlet	4
<b>C H<sub>4</sub></b>	100	Present in syngas at % level	— In most cases CO is sizing the PSA, therefore CO < 10 μmol/ mol ==> C H <sub>4</sub> < 100 μmol/mol depending on users' specification (Europe pipeline 2 μmol/mol).	2
<b>H<sub>2</sub>O</b>	5	Syngas saturated in H <sub>2</sub> O	— PSA adsorbed in alumina and MS adsorption strength higher than CO <sub>2</sub> . — A CO content lower than 10 μmol/mol insures a H <sub>2</sub> O content lower than 5 μmol/mol.	0

Table B.1 (continued)

Impurity	Threshold µmol/mol	Possible causes For the source studied	Typical barriers employed in this process	Probability with barriers
<b>TS</b>	0,004	TS from natural gas	— Desulphuration upstream reformer (typical values: normal < 10 ppb, maximum < 20 ppb, guarantee < 50 ppb.)	0
			— Typical dilution factor 2,5 (1mole natural gas produces 2,5 mole H <sub>2</sub> )	
<b>NH<sub>3</sub></b>	0,1	Traces present in syngas	— Pre-reformer catalyst poisoning by sulphur is irreversible. Sulphur trapped at this stage. In case of breakthrough, process condition cannot be achieved	0
			— Reformer catalyst poisoning by sulphur is irreversible. Sulphur trapped at this stage. In case of breakthrough, process condition cannot be achieved	
<b>THC</b>	2	Traces of C2+ after reforming reaction	— Shift catalyst poisoning by sulphur is irreversible. Sulphur trapped at this stage. In case of breakthrough, process condition cannot be achieved	0
			— PSA adsorption of H <sub>2</sub> S before CO, CO <sub>2</sub> , species	
<b>HCHO</b>	0,01	May be present in syngas. essentially liquid	— H <sub>2</sub> S adsorption in pipe and vessels. Strong affinity with steel	1
			— PSA adsorption strength of alumina and molecular sieve higher than CO. A CO content lower than 10 µmol/mol insures a NH <sub>3</sub> content lower than 0,1 µmol/mol	
<b>HCOOH</b>	0,2	May be present in syngas essentially liquid	— PSA C2 C3, C4, C5+adsorbed by activated carbon layer. A CO content lower than 10 µmol/mol insures a THC (C <sub>2</sub> H <sub>4</sub> excluded) content lower than 2 µmol/mol	0
			— PSA. Formaldehyde adsorption strength of alumina and molecular sieve higher than CO. A CO content lower than 10 µmol/mol insures a HCHO content lower than 0,1 µmol/mol. To guarantee 0,01 µmol/mol would require more experience of measuring at those levels	
			— PSA. Formic adsorption strength of alumina and molecular sieve higher than CO. A CO content lower than 10 µmol/mol insures a HCOOH content lower than 0,2 µmol/mol	0

Table B.1 (continued)

Impurity	Threshold $\mu\text{mol/mol}$	Possible causes For the source studied	Typical barriers employed in this process	Probabil- ity with barriers
<b>Halogens</b>	0,05	Present in natural gas	<ul style="list-style-type: none"> <li>— Any Cl present in natural gas would be stopped by HDS</li> <li>— Pre-reformer catalyst poisoning by Cl irreversible. Cl trapped at this stage. If breakthrough, process condition cannot be achieved</li> <li>— Reformer catalyst poisoning by Cl irreversible. Cl trapped at this stage. I break through, process condition cannot be achieved</li> <li>— Shift catalyst poisoning by Cl irreversible. Cl trapped at this stage. I break through, process condition cannot be achieved</li> <li>— PSA adsorption of Cl before CO, CO<sub>2</sub>, species</li> </ul>	0
<b>He</b>	300	Not present in natural gas in N Europe (<10 $\mu\text{mol/mol}$ ). Passes through the whole process. Dilution factor 2,5		0

Table B.2 — Probability of occurrence for pipeline

Impurity	Threshold μmol/mol	Causes possible For the item studied	Typical barriers employed in this process	Probability with barriers
Inert gas N <sub>2</sub>	100	Air intake if some areas are at negative pressure From seal gas or purge gas Wrong purging after maintenance	Inlet pressure PSL trip on compressors	1
Inert gas Ar		No potential	1 % Ar in the air. 100 μmol/mol would mean 1 % air in the pipe Never been observed	0
O <sub>2</sub>	5	Air intake if some areas are at negative pressure	Inlet pressure PSL trip on compressors	1
CO <sub>2</sub>	2	From Air: C O <sub>2</sub> at 400 μmol/mol in the air	2 μmol/mol of C O <sub>2</sub> would mean 0,5 % air in the pipe Never been observed	0
CO	0,2	No potential		0
CH <sub>4</sub>	100	No potential		0
H <sub>2</sub> O	5	Wrong drying after pressure hydraulic test	H <sub>2</sub> > 40 bar ==> leak from H <sub>2</sub> O to H <sub>2</sub> unlikely during operation.	0
TS	0,004	No potential		0
NH <sub>3</sub>	0,1	No potential		0
THC	2	No potential		0
HCHO	0,01	No potential		0
HCOOH	0,2	No potential		0
Halogens	0,05	From cleaning material after maintenance		1
He	300	No potential		0

Table B.3 — Probability of occurrence for fuelling station to be source of impurities

Impurity	Threshold $\mu\text{mol/mol}$	Causes possible For the source studied	Existing barriers	Probability
Inert gas $\text{N}_2$	100	$\text{N}_2$ purging operation, air intake during normal operation or maintenance		3
Inert gas Ar		Air intake during normal operation or maintenance	1 % Ar in the air. 100 $\mu\text{mol/mol}$ would mean 1 % air in the fuelling station Never been observed	0
$\text{O}_2$	5	Air intake during normal operation or maintenance		2
$\text{CO}_2$	2	Air intake during normal operation or maintenance	2 $\mu\text{mol/mol}$ $\text{CO}_2$ would mean 0,5 % air in the fuelling station. Never been observed	0
CO	0,2	No potential at fuelling station level		0
$\text{CH}_4$	100	No potential at fuelling station level		0
$\text{H}_2\text{O}$	5	Maintenance, leaks from compressor exchangers, improper pressure vessel drying after periodic inspection, $\text{H}_2\text{O}$ coming from the vent in case of check valve malfunction, depending on fuelling station/compressor technology		2
TS	0,004	Materials gaskets, valve seats and tubing	Material specifications	1
$\text{NH}_3$	0,1	No potential		0
THC	2	Oil carryover from compressor (depending on compressor technology)		2
HCHO	0,01	No potential		0
HCOOH	0,2	No potential		0
Halogens	0,05	From degreasing material		1
He	300	No potential at fuelling station level	If pure He is not used for maintenance	0

When the study has been conducted for each step within the supply chain (i.e. production, distribution, and fuelling) the highest probability is selected as the compounded probability. [Table B.4](#) gives an example.

To define the severity class of each impurity as it is presented in [Table B.4](#), some assumptions are made concerning the impurity levels above the threshold value. These impurity levels are assumed to be reached for a short period of time.

Table B.4 — Combined risk assessment

ISO specification		Supply chain probability			Severity	Criticality	Additional risk reduction measures	Residual		
Impurity	Threshold µmol/mol	Production SMR	Pipeline distribution	Fuelling station				Compounded probability	Severity reduction measures	Prob-ability
Inert gas N <sub>2</sub>	100	3	1	3	1	0	Systematic N <sub>2</sub> analysis after shutdown before resuming operation or specific purging procedure	1	1	+
		2	0	0	1	+		2	1	+
Inert gas Ar	5	0	1	2	0	+		2	0	+
		0	0	0	1	+		0	1	+
CO	0,2	4	0	0	2	*	CO absorber at fuelling station design margin 100 % + operation procedure for replacement when H <sub>2</sub> quantity purified = 50 % of design capacity.	1	2	+
CH <sub>4</sub>	100	2	0	0	1	+		2	1	+
H <sub>2</sub> O	5	0	0	1	4	*	Check H <sub>2</sub> O at commissioning and after maintenance involving opening of vessels or piping. Measurement shall be done at appropriate location downstream of the considered vessel or piping	0	4	+
TS	0,004	0	0	1	4	*	Check TS at commissioning and after maintenance involving parts modification (piping, valves, seals, gaskets). Not required for part replaced by identical component	0	4	+
NH <sub>3</sub>	0,1	0	0	0	4	+		0	4	+
THC	2	0	0	2	4	+	Oil/grease cleaning at commissioning and after maintenance. Compressor surveillance depending on compressor technology (coalescing filter), THC analysis or commissioning and after maintenance	0	4	+

Table B.4 (continued)

ISO specification	Supply chain probability			Severity	Criticality	Additional risk reduction measures	Residual			
	Production SMR	Pipeline distribution	Fuelling station				Severity reduction measures	Prob-ability	Se-veri-ty	Criti-cality
HCHO μmol/mol	1	0	0	2	+		None	1	2	+
HCOOH	0	0	0	2	+		None	0	2	+
Halogens	0	0	1	4	*	Halogenated analysis at commissioning (species shall be defined) or after maintenance	None	0	4	+
He	0	0	0	1	+		None	0	1	+
Key		+ Acceptable risk area: existing controls sufficient			0 Further investigation is needed: existing barriers or control may not be enough		* Unacceptable risk; additional control or barriers required			

[Table B.4](#) is used to define the criticality for each impurity.

When the result is light grey or "+", the H<sub>2</sub> quality is under control and the risk of having an issue with the vehicle using this hydrogen is considered acceptable. No additional barrier is necessary and this impurity has no reason to be controlled at the fuelling station nozzle.

When the result is medium grey or "o", which is the case for N<sub>2</sub>, the conclusion is to further investigate the means to decrease the occurrence probability. For instance, in addition to the existing analysis at SMR plant, measure N<sub>2</sub> at the commissioning of the fuelling station and after each maintenance where some parts of the system are open to air or apply a specific purge procedure which guarantees reaching a value within the specification.

When the result is dark grey or "\*", it is necessary to reduce the probability of occurrence or to decrease the severity to bring back the risk at an acceptable limit. Additional barriers shall be added. These barriers are studied case by case.

For CO the conclusion in this example of risk assessment may be:

- to add a purifier with proper capacity of purification and to define a strict procedure for the purifier replacement, or
- to add a continuous analysis and shutoff valve at the inlet of the fuelling station (at pipeline connection).

For H<sub>2</sub>O the conclusion is to measure H<sub>2</sub>O at the commissioning of the fuelling station and after each maintenance open vessels or piping or replace one of them. This analysis could be done at low pressure to have more sensitivity.

For THC, depending of the compressor type, add a coalescing filter and proper maintenance procedure. Measure THC after commissioning or maintenance operation involving cleaning/degreasing.

For Halogens, make an analysis at commissioning on a list of predefined components.

In conclusion,

- for commissioning: measure N<sub>2</sub>, H<sub>2</sub>O, THC, TS, and Halogens;
- after maintenance: measure N<sub>2</sub>, H<sub>2</sub>O, THC.

The analysis of other impurities is not mandatory if there is an analysis of CO and N<sub>2</sub> at the production site.

### B.3 Alkaline electrolysis

[Table B.5](#) shows the probability of occurrence of different contaminants for hydrogen produced by alkaline electrolysis.

Table B.5 — Probability of occurrence for alkaline electrolysis

Impurity	Threshold μmol/mol	Possible causes For the source studied	Typical barriers employed in this process	Probability
Inert gas N <sub>2</sub>	100	Insufficient purging after shutdown	Electrolyser process control	3
Inert gas Ar		Insufficient purging after shutdown	If N <sub>2</sub> below 1 %, Ar < 100 μmol/mol	1
O <sub>2</sub>	5	Insufficient purging after shutdown (does not apply to all systems) O <sub>2</sub> permeation through the membrane	Process control Deoxo O <sub>2</sub> sensor	2
CO <sub>2</sub>	2			0
CO	0,2			0
C H <sub>4</sub>	100			0
H <sub>2</sub> O	5	H <sub>2</sub> from electrolyser is saturated.	Dryer plus water sensor downstream of electrolyser	2
TS	0,004			0
NH <sub>3</sub>	0,1			0
THC (excluding CH <sub>4</sub> )	2			0
HCHO	0,01			0
HCOOH	0,2			0
Halogens	0,05	Cl from water?	Any trace of halogenat- ed compounds would be trapped in the dryer which has a stronger adsorption capacity for Cl than for H <sub>2</sub> O	0
He	300			0

## Annex C (informative)

### Example of Japanese hydrogen quality guidelines

#### C.1 General

This annex is a condensed version of the Japanese quality control guidelines developed in Japan and is intended to be an example of a prescriptive approach to hydrogen quality assurance.

#### C.2 Approaches to administration of Japanese quality control guidelines

The approach to conducting a quality analysis of the contaminants listed in ISO 14687-2 is to first consider the potential sources of contaminants, and, second, establish a protocol for analysing potential contaminants.

- Potential sources of contaminants:
  - sampling procedures;
  - characteristics of hydrogen production method(s);
  - characteristics of hydrogen transport method(s);
  - non-routine procedure (for example maintenance, major production system change).
- Analysis of possible contaminants:
  - possible quantification.

#### C.3 Hydrogen production methods, hydrogen purification methods and hydrogen transportation methods

##### C.3.1 Hydrogen production methods

Potential sources of contaminants are evaluated for the following hydrogen production methods:

- steam reforming (off-site/on-site);
- partial oxidation (off-site);
- autothermal reforming (off-site);
- water gas shift reaction (WGSR);
- catalytic reforming (off-site);
- coke-oven gas (COG) (off-site);
- steam cracking for ethylene by-product (off-site);
- chloralkali process (off-site);
- electrolysis of H<sub>2</sub>O (on-site/off-site).

### C.3.2 Hydrogen purification methods

Potential sources of contaminants are evaluated for the following hydrogen purification methods:

- adsorption;
- membrane separation;
- solvent absorption;
- cryogenic separation;
- methanation;
- selective CO oxidation.

### C.3.3 Hydrogen transportation methods

Potential sources of contaminants are evaluated for the following hydrogen transportation methods:

- transportation of hydrogen in compressed state;
- transportation of hydrogen in liquid form;
- pipeline transportation;
- transportation by storage materials.

## C.4 Constituents requiring analysis (potential sources of contaminants)

### C.4.1 General

An analysis shall be conducted on constituents that may contaminate hydrogen regardless of which hydrogen production method is used, as well as those constituents that may contaminate hydrogen due to the unique nature of a given hydrogen production method (see [Table C.1](#) and [Table C.2](#)).

### C.4.2 All hydrogen production methods

**Table C.1 — Constituents requiring an analysis for all production methods**

Name of constituent	Hydrogen production method to be analysed	Approach
N <sub>2</sub>	All hydrogen production methods	Perform an analysis on all production methods since there is a risk of contamination through the equipment in case of hydrogen sampling
O <sub>2</sub>	All hydrogen production methods	Perform an analysis on all production methods since there is a risk of contamination through the equipment in case of hydrogen sampling
H <sub>2</sub> O	All hydrogen production methods	Perform an analysis on all production methods since there is a risk of contamination through the equipment in case of hydrogen sampling
Ar	All hydrogen production methods	Perform an analysis on all production methods since there is a risk of contamination through the equipment in case of hydrogen sampling. The ISO standard specifies the limit as a total combined value of N <sub>2</sub> and Ar.

## C.4.3 Specific hydrogen production methods

Table C.2 — Constituents requiring an analysis for specific production methods

Name of constituent	Hydrogen production method to be analysed	Approach
<b>He</b>	All hydrogen production methods using natural gas as feedstock	An analysis is necessary since natural gas contains up to 300 µmol/mol of He Exclude a hydrogen production method if He has been removed from the natural gas used for the method
<b>NH<sub>3</sub></b>	NH <sub>3</sub> production process generating excess hydrogen Biogas reforming Coal gasification generating hydrogen by-product NH <sub>3</sub> hydride method	
<b>Halogens</b>	Chloralkali process producing excess hydrogen* Biogas production from plastic waste generating hydrogen Coke oven gas Water electrolysis**	*Excludes ion exchange membrane method **Limited to cases where tap water is used as feedstock and the performance of H <sub>2</sub> O purification system cannot be warranted
<b>TS</b>	Steam reforming* Catalytic reforming Partial oxidation Autothermal reforming Coal gasification generating hydrogen by-product Production methods using TS as odorant	*Since TS are found in the form of H <sub>2</sub> S, analysis of H <sub>2</sub> S, not total sulphur content, is sufficient
<b>THC</b>	Production methods in which fossil fuels are present, such as steam reforming, catalytic reforming, partial oxidation, autothermal reforming, and coal gasification generating hydrogen by-product	
<b>CO</b>	Steam reforming* Catalytic reforming Partial oxidation Autothermal reforming Coal gasification generating hydrogen by-product	
<b>HCHO</b>	Hydrogen production methods using city gas or petroleum as fuel other than steam reforming	Rationale for excluding steam reforming methods using city gas or petroleum: it has been verified that the thermo-equilibrium concentration of HCHO in steam reforming is significantly lower than the ISO limit
<b>HCOOH</b>	Hydrogen production methods using city gas or petroleum as fuel other than steam reforming	Rationale for excluding steam reforming methods using city gas or petroleum: it has been verified that the thermo-equilibrium concentration of HCOOH in steam reforming is significantly lower than the ISO limit

## C.5 Constituents that do not require analysis

Listed below in [Table C.3](#) are constituents for which there is no scientific basis for conducting a routine analysis, and the rationale for this conclusion, such as when there is no risk of contamination in any

hydrogen production method (a framework shall be provided to conduct a non-routine analysis, however).

**Table C.3 — Constituents that do not require an analysis**

Substance	Rationale
Hydrogen	While it is clear that hydrogen is the main component, there is no method for directly determining its quantity to a required degree of accuracy. If the proportion of hydrogen is to be calculated by division, it would be necessary to determine the quantity of all contaminants.
All non-hydrogen gases	There is no method for directly determining their quantity. If the proportion of non-hydrogen gases is to be calculated by summation, a qualitative determination of all contaminants would be required.
Particulates	If a filter is installed in the flow path, contamination is highly unlikely. Generally speaking, particulates found at demonstration fuelling station have been lower than the standard upper limit by two digits. Particulates should be controlled as indicated in <a href="#">C.9</a>

## C.6 Administration of quality control

### C.6.1 Frequency of routine analysis

#### C.6.1.1 Routine analysis at a centralized production and distribution facility

As a general rule, the product quality of a plant is consistent regardless of the size of its production system, as long as the input and the operating conditions are consistent. If there are no changes in the input and the operating conditions over a long period of time, only one quality analysis shall be needed per operation period. On the other hand, if there are changes in the input and the operating conditions, a quality analysis shall be needed for each condition.

When the input and the operating conditions have not changed and if it can be assured that the possibility of contamination is eliminated by the good operation and control of the distribution facility by, for example, continuously monitoring the indicator species before shipping, the test frequency may be reduced to as low as once per year.

#### C.6.1.2 Routine analysis at fuelling station

##### C.6.1.2.1 Off-site fuelling station

Hydrogen received by an off-site fuelling station is subject to a routine analysis for the chemical constituents that have not been covered by the centralized hydrogen production and distribution facility and for those that may infiltrate the gas after it is accepted by the fuelling station. For individual contaminant species that may enter after fuelling station acceptance, the frequency of analysis may be reduced to as low as once per year, provided that the possibility of infiltration is deemed eliminated by having a good operation and control program at the fuelling station, such as a purge procedure.

While sampling is to be, as a rule, made at the end of a nozzle, it may be conducted upstream of the fuelling nozzle to the extent that no changes occur to the quality of hydrogen.

##### C.6.1.2.2 On-site fuelling station

When a hydrogen generator (such as reformer or H<sub>2</sub>O electrolysis apparatus) is operated in the daily start and shut mode, the quality of the hydrogen gas produced fluctuates on a daily basis. Such operation therefore calls for one analysis per day. However, the frequency of analysis may be reduced to as low as once per year, provided that the possibility of infiltration is deemed eliminated by the good operation and control of the fuelling station, such as when accumulators are filled after the indicator species is continuously monitored for quality control on a daily basis following the start-up of the generator.

While sampling is to be, as a rule, made at the end of a nozzle, it may be conducted upstream of the fuelling nozzle to the extent that no changes occur to the quality of hydrogen.

### C.6.2 Frequency of non-routine analysis

After the conditions described in [Clause 10](#), a quality analysis of all cases is needed.

## C.7 Administration of analysis and monitoring records

### C.7.1 Forms for analysis and monitoring records and reports

Each operator is to design and administer forms for records of analyses at its centralized production and distribution facilities, records of sampling and analyses at fuelling station, and records of monitoring.

### C.7.2 Safekeeping and recording

Centralized production or distribution facilities and fuelling station are to safekeep their own records of analyses at the facility, of samples collected at the fuelling station, and of monitoring in an appropriate manner.

The records shall be kept for a period of ten years. Such records may be kept at the department (or headquarters) that oversees the operation other than the applicable facilities or fuelling station.

## C.8 Routine analysis work

[Table C.4](#) provides the routine analysis work defined on the basis of the attitudes stated in [C.4](#), [C.5](#) and [C.6.1](#). The table gives the analytical species and the minimum analysis frequencies classified by hydrogen dispensing sites and hydrogen production, purification and transportation methods.

## C.9 Non-routine analysis work

[Table C.5](#) provides the non-routine analysis work defined on the basis of the attitudes stated in [C.4](#), [C.5](#) and [C.6.2](#). The table gives the analytical species classified by hydrogen dispensing sites and hydrogen production, purification, and transportation methods.

## C.10 Approaches to particulates requirements

According to ISO 14687-2, the requirements of particulates are no more than 1 mg/kg in concentration. The hydrogen shall be sampled from a dispenser nozzle of the fuelling station under conditions that are as close to the actual fuelling conditions as possible. The weight of the particulates collected in a filter is measured.

However, past analyses of particulates collected by filters at the fuelling station have demonstrated that particulates occur intermittently, and not always consistently, from such sources as pieces of sealing tapes for threaded parts, particles found in new equipment, and friction from movable parts. Therefore, it is questionable whether the concentration of the samples collected by the method described above can be considered representative of a given period of time. For this reason, filters shall be installed at fuelling station to remove particulates in lieu of conducting a routine analysis of particulate concentration levels.

It is appropriate to install filters with an aperture of no more than 5 µm (nominal) downstream of dispenser components. Filters should be as close as possible to the nozzle or hose breakaway device. Filters shall be mesh-type because of the filter robustness.

Table C.4 — Routine analysis work

Category: Distribution				
Facility type	Sampling/ Monitoring point	Contaminant	Threshold ( $\mu\text{mol/mol}$ )	Reduced frequency
Production of hydrogen from hydrocarbons utilizing steam reforming, catalytic reforming, partial oxidation, or ATR, purification using refining equipment, and distribution	Downstream of the purifier	TS <sup>a</sup>	0,004	Annual <sup>b</sup>
		THC as C1	2	Annual <sup>b</sup>
		CO	0,2	Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b,c</sup>
		H <sub>2</sub> O	5	Annual <sup>b</sup>
		O <sub>2</sub>	5	Annual <sup>b,c</sup>
Electrolysis of Na Cl for hydrogen, purification, and distribution	Downstream of the purifier	Halogens	0,05	Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b</sup>
		H <sub>2</sub> O	5	Annual <sup>b</sup>
		O <sub>2</sub>	5	Annual <sup>b</sup>
Purification of coke-oven gas, and distribution	Downstream of the purifier	TS	0,004	Annual <sup>b</sup>
		THC as C1	2	Annual <sup>b</sup>
		CO	0,2	Annual <sup>b</sup>
		Halogens	0,05	Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b</sup>
		H <sub>2</sub> O	5	Annual <sup>b</sup>
		O <sub>2</sub>	5	Annual <sup>b</sup>
		NH <sub>3</sub>	0,1	Annual <sup>b</sup>
		HCHO	0,01	Annual <sup>b</sup>
		HCOOH	0,2	Annual <sup>b</sup>
Purification of by-product hydrogen from ethylene plants, and distribution	Downstream of the purifier	TS	0,004	Annual <sup>b</sup>
		THC as C1	2	Annual <sup>b</sup>
		CO	0,2	Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b</sup>
		H <sub>2</sub> O	5	Annual <sup>b</sup>
		O <sub>2</sub>	5	Annual <sup>b</sup>

Table C.4 (continued)

Category: Fuelling station				
Facility type	Sampling/ Monitoring point	Contaminant	Threshold ( $\mu\text{mol/mol}$ )	Reduced frequency
With off-site supply of transported compressed or liquid hydrogen	End of nozzle	Those not analysed by the distributor		Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b,c</sup>
		H <sub>2</sub> O	5	Annual <sup>b,d</sup>
		O <sub>2</sub>	5	Annual <sup>b,c</sup>
With off-site supply from hydrogen pipelines	Downstream of the deodorant equipment	(Those listed for the odorant)		Annual <sup>b,e</sup>
	End of nozzle	Those not analysed by the distributor		Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b,c</sup>
		H <sub>2</sub> O	5	Annual <sup>b,d</sup>
		O <sub>2</sub>	5	Annual <sup>b,c</sup>
With on-site supply of hydrogen produced from hydrocarbons utilizing steam reforming, catalytic reforming, partial oxidation, or ATR and purification using refining equipment	Downstream of the purifier	CO	0,2	Continuous and Annual <sup>b,f</sup>
	End of nozzle	TS <sup>a</sup>	0,004	Annual <sup>b</sup>
		THC as C1	2	Annual <sup>b</sup>
		CO	0,2	Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b,c</sup>
		H <sub>2</sub> O	5	Annual <sup>b,d</sup>
		O <sub>2</sub>	5	Annual <sup>b,c</sup>
With on-site supply from hydroelectrolysis and purification using refining equipment	Downstream of the purifier	N <sub>2</sub> +Ar	100	Annual <sup>b</sup>
		H <sub>2</sub> O	5	Continuous and Annual <sup>b,f</sup>
		O <sub>2</sub>	5	Continuous and Annual <sup>b,f</sup>
	End of nozzle	Halogens	0,05	Annual <sup>b</sup>
		N <sub>2</sub> +Ar	100	Annual <sup>b</sup>
		H <sub>2</sub> O	5	Annual <sup>b</sup>
		O <sub>2</sub>	5	Annual <sup>b</sup>