HyApproval

WP4 - Safety

Establishment of Safety Matrix

Deliverable 4.1

- PUBLIC -

Review of best practices based on actual experiences with Hydrogen Refuelling Stations across Europe, US & Japan

Risk acceptance criteria

Safety Studies

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1 Introduction

This document is serving as introductory background information and input for the further development of WP4 work activities of the HyApproval Project.

Deliverable D4.1 is referred to the task of establishing an initial safety matrix related to the hydrogen refuelling stations considered within the HyApproval project DoW of the following:

- Available codes and standards and industry best practices.
- Safety studies
- Risk acceptance criteria

There are a number existing of codes and standards and industry best practices that are applicable and relevant to be considered for the HyApproval Project. Comprehensive and detailed safety studies have been performed in the CUTE and the CEP Berlin projects, but as a general conclusion, results from the studies as well as risk acceptance criteria are presently not publicly available for the HRS sizes considered in the DoW. The present hydrogen refuelling stations are often demonstration infrastructure projects provided to support the small numbers of demonstration hydrogen vehicle fleets trailed by OEMs to prove new H2 FCV and ICE technology. Hydrogen infrastructure facilities are not likely to be provided in big numbers and on a commercial scale until the mass introduction of hydrogen fuelled transportation vehicles.

2 Assumptions on HRS sizes

As stated in the HyApproval DoW, three different possible generic sizes for implementing a HRS will be considered and investigated in principle. Taking into account the timely applicability of the Handbook to be developed in HyApproval, typical assumed capacities of HRS of 300, 1,500 and 3,500 kg/day throughput respectively were chosen as being within the range of practical knowledge and adequate for the foreseeable range of uses for at least the next 10 years (up to 2015). The '3 sizes' are in existence at the moment and reflect the real likelihood of an H2 infrastructure build-up (e.g. HyNet) in the next 5 – 10 years:

- A 'small' <350 kg storage is the H2 quantity an existing CGH2 ‘trucked-in’ tube trailer will deliver to a site or could produced ‘on-site’. Current examples include all existing CUTE sites with CGH2 supply (e.g. CUTE Luxembourg & Porto); on-site H2 production at Barcelona, Amsterdam, Stuttgart, Reykjavik, Stockholm, Madrid.
- A 'medium' <1,500 kg storage is the quantity an existing ‘trucked-in’ LH2 tanker could deliver to a number of existing sites in EU & overseas at the moment (e.g. Total/Linde Berlin, CEP Berlin; Shell Washington)
- A 'large' <3,500 kg storage is the LH2 quantity supplied by a full delivery of an existing ‘trucked-in’ LH2 tanker (e.g. BP CUTE London).

The Handbook will consider the case of all 3 sizes and the HRS scenarios of stand alone and/or integrated with other gaseous or liquid fuels at existing vehicle refuelling stations, and include aspects related to on-site H2 generation.

It will be assumed that a maximum of one H2 tanker delivery per day is possible to any site:

- If buses are refuelled, assume refuellings of 35 kg CGH2 / bus / day (at 35 MPa).
- If cars are refuelled, assume refuellings in a **commercial market environment**:
  - CGH2 35 MPa: 4 kg H2 / car @ 3 –4 mins / fill
  - CGH2 70 MPa: 4 kg H2 / car @ 3 – 4 mins / fill
  - LH2: 5 – 10 kg /car @ 3 – 4 mins / fill

3 Review of available Codes & Standards & Industry Best Practice Experiences for hydrogen vehicle refuelling stations

For the purpose of satisfying public safety issues, existing HRS's have been built to a number of different codes & standards, primarily based on national and local specific requirements. Some codes and standards have been derived from experiences with the CNG industry. International codes and standards (e.g. ISO) are presently still under development.

A review of existing regulations, codes, standards and relevant technical references or guidelines that make use of recognised best practice industry experiences to set safety standards to design and construct HRS's have identified the following:

EU Regulations

- The PED (Pressure Equipment Directive): Directive 97/23/EC of the European Parliament and of the Council of 29 May 1997, on the approximation of the laws of the Member States concerning pressure equipment.

- The ATEX Directives:
  - The Directive 94/9/EC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres

  - Directive 1999/92/EC of the European Parliament and of the Council of 16 December 1999 on minimum requirements for improving EU: Protection of Workers in Explosive Atmospheres

- EMC (electromagnetic compatibility) Directive: Council Directive 89/336/EEC of 3 May 1989, on the approximation of the laws of the Member States, relating to electromagnetic compatibility.

- The Machinery Safety Directive: Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998, on the approximation of the laws of the Member States, relating to machinery.

- CE-marking: EU Directive 93/68/EEC

Hydrogen ISO standards/drafts related to hydrogen:

- ISO 17268: 2006 Compressed hydrogen surface vehicle refuelling connection devices (finalised standard)

- ISO 13984:|1999 Liquid hydrogen -- Land vehicle fuelling system interface (finalised standard)

- ISO/WD 22734-1 Hydrogen generators using water electrolysis process. Part 1: Industrial and commercial applications

- ISO/WD 22734-2 Hydrogen generators using water electrolysis process. Part 2: Residential applications

- ISO/DIS 16110-1 Hydrogen generators using fuel-processing technologies . Part 1 Safety

- ISO/DIS 16110-2 Hydrogen generators using fuel-processing technologies . Part 2 Procedures to determine efficiency

- IEC EN 60079-10, 14, 17, and 19:

    - IEC EN 60079-10 "Electrical apparatus for explosive gas atmospheres. Classification of hazardous areas"
    - IEC/EN 60079-14 "Electrical apparatus for explosive gas atmospheres. Classification of hazardous areas"
    - IEC/EN 60079-17 "Electrical apparatus for explosive gas atmospheres. Inspection and Maintenance "
    - IEC/EN 60079-19 "Electrical apparatus for explosive gas atmospheres. Repair"

Guidance documents

- NASA Safety Standard for Hydrogen and Hydrogen Systems

- Sourcebook for Hydrogen Applications

References (list of international / national / industry codes of practice) related to HRS safety

Name	**Status**	**Country**	**Applicability**	**Relevance to be considered & comments**
NFPA 52 (2005 Edition includes H2 vehicle refuelling)	Promulgated & recognized by US authorities	USA	H2 refuelling installations	Yes: • will not be completely applicable to H2 refuelling of FCVs if engine fuel systems > 25 MPa • does not include hazardous areas or zones • does not include risk assessments • covers CGH2 & LH2
NFPA 55 (will supersede NFPA 50A & 50B)	Final draft	USA	H2 industrial installations	Yes • will cover CGH2 & LH2
EIGA Document IGC 15/05 – Gaseous Hydrogen Stations	Code of (best industry) Practice	Recognised in Europe	CGH2 installations (compressors, drying, buffer storage)	Yes: • does not include CGH2 dispensing • does not include hazardous areas or zones • does not include risk assessments • includes safety distances
EIGA Document IGC 6/02 – Safety in storage, handling & distribution of liquid H2	Code of (best industry) Practice	Recognised in Europe	LH2 installations (layout, storage tanks, operations & transport)	Yes: • does not include LH2 dispensing • does not include hazardous areas or zones • does not include risk assessments • includes safety distances
EIGA Document IGC 75/01 – Determination of Safety Distances	Code of (best industry) Practice	Recognised in Europe	Relevant for CGH2 & LH2 stations. General document describing a risk based methodology for	Yes Included suggestions for quantitative risk acceptance criteria.

			determination of safety distances	
EIGA Document IGC 23/00 – Safety training of employees	Code of (best industry) Practice	Recognised in Europe	Guidelines for operator training & competency standards	Yes
EIGA Document IGC 40/02 – Work permit systems	Code of (best industry) Practice	Recognised in Europe	Guidelines for work permit systems	Yes
EIGA Document IGC 88/02 – Good environmental management practices for the industrial gas industry	Code of (best industry) Practice	Recognised in Europe	Guidelines for good environmental management practices for the industrial gas industry	Yes
EIGA Document IGC 90/03 – Incident/accident investigation & analysis	Code of (best industry) Practice	Recognised in Europe	Guidelines for incident/accident investigation & analysis	Yes
EIGA Document IGC 100/03 – Hydrogen Cylinders & Transport Vessels	Code of (best industry) Practice	Recognised in Europe	Design, material, manufacturing, testing & use of CGH2 individual cylinders, cylinder packs, and trailer tubes.	Cylinder packs can be used for transport and temporary storage
EIGA Document IGC 102/03 – Safety audit	Code of (best industry) Practice	Recognised in Europe	Guidelines for safety audits	Yes

guidelines				
EIGA Document IGC 122/04 – Environmental impacts of hydrogen plants	Code of (best industry) Practice	Recognised in Europe	Guidelines for environmental impacts of hydrogen facilities	Yes
Fire Prevention Technical Rule for Gaseous Hydrogen Refuelling Stations	Referenced Italian technical rule (Approved by Ministry of Interior's DM 31 August 2006)	Italy	35 MPa CGH2 refuelling installations	• part of a published Italian regulation (Ministerial Decree) • includes safety distances • does not include hazardous areas or zones • makes reference to the Italian Ministerial Decree on Fire Prevention of 4 May 1998, Annex 1, for risk assessment
German TRG 406 (Draft) regulations: Refuelling stations for Pressurised Gases (includes CGH2)	Promulgated German regulation	Germany	H2 refuelling installations	Yes: • does not include risk assessments • includes hazardous areas & zones
ISO/TR 15916 – Basic considerations for the safety of hydrogen systems	Technical Report	International	Basic considerations for the safety of hydrogen systems	Yes
EIHP2 Working Draft (Rev 3): Gaseous H2	Working Draft only	Ex EU EIHP2 Project	Gaseous H2 Vehicle	Yes: • Working Draft is being used to prepare ISO

Vehicle Refuelling Stations			Refuelling Stations	TC 197 WG11 (Gaseous H2 refuelling stations) • Isolation distances, hazardous areas & zones proposed • Does not include risk assessments
ENNA – Technical Guideline for Hydrogen refuelling Stations (Nov 2003)	Technical Guideline	Japan	Gaseous & Metal Hydride H2 Vehicle refuelling Stations	Yes: • does not include risk assessments • does not hazardous areas & zones

Appendix:
A comprehensive review and Report of Codes & Standards was undertaken by Hydro in the EIHP2 Project and in the CUTE Project. The Report is collection of existing codes and standards with references based on searching into web-sites of European and international standardisation organisations by using keywords. The key words applicable to hydrogen vehicle refuelling stations were:
Liquid fuel, gaseous fuel, gasoline, diesel, CNG, hydrogen fuel, liquid hydrogen, gaseous hydrogen fuel, vehicle + fuel, refuelling station, cryogenic.
EIHP2 Report WP 2.1 – Codes and Standards (dated 22/3/2003):

WP21_Codes_Standards_rev2.pdf

Reference is also given to the CUTE Report: ‘WP7 Quality & Safety Methodology, July 2003’.

4 Assessing the Hazards & Risks associated with hydrogen vehicle refuelling stations

Included in this report is a summary the industries current understanding of the specific hazards and risks posed by HRS's. The goal is to identify additional information or areas of work that would be helpful to further discuss within the WP4 activities of the HyApproval Project.

4.1 Background

Over the last few years a greater understanding has been gained of the hazard consequences from potential loss of containment of hydrogen on HRSs in projects such as CUTE, HyFLEET:CUTE, JHFC and the US DoE sponsored activities. Work by others was comprehensively reported at the International Conference on Hydrogen Safety, organised by HySafe at Pisa, Italy in September 2005.

The risks (combination of the probability and consequences of the hazard and hence a measure of the likelihood of harm to people) posed by HRSs have also begun to be considered. A risk based safety management methodology, see chapter 4.2 (below), of the CUTE stations were implemented. The safety methodology established in CUTE was recommended for future hydrogen stations.

Both qualitative and quantitative (QRA – Quantitative Risk Analysis) approaches have been used but it should be noted that for HRS's any QRA is currently limited by the dearth of relevant failure frequency data.

With several operational HRSs now in place in Europe, and more planned, it is timely to have a wider discussion on the hazards and risks of potential incidents, and in particular how these can be communicated with all stakeholders, including authorities or local communities in permitting processes.

In Europe these issues will be further addressed by other WP4 work activities in the HyApproval Project and in the HyFLEET:CUTE Project.

4.2 Risk based safety management

The Risk Based Safety Management (often called risk management) principle is that some risks, specified through risk acceptance criteria, should be removed or reduced to meet the safety requirements. Other accidents might have too low probability to be accounted for in terms of safety measures or design specifications. However, both prescriptive requirements (detailed standards) and goal-oriented requirements (risk based decisions) have a role to play in process design and operation.

The Risk Based Safety Management system is a systematic approach which measures risk through risk analysis methods and relates it to established risk acceptance criteria for the identification of design specifications or need for risk reduction measures. Cost benefit analysis should be used in order to evaluate different options. In addition to implementing risk-reducing measures in order to comply with acceptance criteria, such measures should also be implemented if the cost is low relative to the benefits or risk reduction. They can either be consequence reducing measures or accident probability reducing measures. Probability reducing measures should be preferred.

4.3 Potential Incident Scenarios

A list of potential incident scenarios can be arrived at in a number of ways but usually this comes from a HAZID (Hazard Identification) or PHA (Process Hazard Assessment). These may subsequently be analysed in a more systematic and detailed way in a HAZOP (Hazard and Operability study).

A description of risk management methodologies applied, specific risk acceptance criteria and rapid risk ranking methodology for HRSs with compressed gaseous and liquid storage, an electrolyser, and a natural gas reformer, are given in the EIHP2 Project WP5.2 Report on Risk Analysis of Refuelling Infrastructure (Sept 2003). Lists of accident scenarios will be evaluated in other HyApproval WP4 work activities.

Potential scenarios range from ones with low hazard consequence but high probability, for example a leak from a refuelling hose connector, to ones with a high consequence but very low probability, for example the catastrophic failure of the hydrogen storage. It is important to distinguish between 'credible' scenarios and 'improbable' ones. The former result in hazards that require to be assessed and managed. The latter are scenarios of such low probability that they in most cases not require further assessment. However, in some jurisdictions it may still be necessary to assess the consequence. Another term often used is "worst case scenario"; this can be taken to mean the worst outcome of a credible scenario <u>or</u> the worst outcome of an improbable scenario, and needs to be used with care. It is also important to note that improper maintenance might change the risk associated with certain scenarios.

The potential consequences of a hazard on HRS's depend on several factors, for example, the quantity and conditions of hydrogen delivered (gaseous or liquid), the quantity and conditions of hydrogen stored (gaseous or liquid in the bulk storage, and gaseous in the buffer storage), and the duration of a leak before the safeguarding system acts to mitigate the consequence. The latter is particularly important in determining the explosion consequences if the leak finds a source of ignition. Last, but not least the risk of accumulation of hydrogen in confined and congested areas should be considered at HRS, if hydrogen processing (production, cleaning, drying, compression etc.) is taking place inside an enclosure.

4.4 Additional information required

To demonstrate that we are managing the potential explosion hazard from small leaks (for example a dispenser hose failure) we need to know how fast the safeguarding system will act to mitigate the consequences. This information does not appear to be readily available and further investigation will need to be done within other HyApproval WP activities. At present, it is also important to note that as HRS are not standardised, this is also valid for the safeguarding measures. It can be advantageous to undertake a risk assessment while planning the HRS, to determine what safeguarding measured that are most effective in controlling the risks on the specific HRS. It is also important to know that safety systems like gas detectors and emergency shutdown valves all are associated with probabilities of successful operation/failure.

Arguably the largest credible release scenario on a HRS would be uncontrolled leakage from a liquid hydrogen tanker making a delivery. There is very little information available on cryogenic liquid hydrogen spills, necessary to reliably assess the hazard consequences.

As mentioned earlier, there is a dearth of component failure/ loss of containment frequency data for most components on a HRS and this severely limits our ability to quantify the risks. It will necessary to research if meaningful statistics are available for components in HRS service and in the meantime more effort is required to get data from broadly similar systems e.g. CNG systems, and industrial gaseous and cryogenic liquid installations.

5 Safety Studies

5.1 Guidance for Safety Aspects of Proposed Hydrogen Projects

Publicly available documents from the US DoE Hydrogen Safety Panel received from NREL, are considered as providing very useful supporting information as the basis of developing the process of Safety Studies for the HyApproval Handbook.
These comprehensive documents are listed for reference:

- DoE ‘Guidance for Safety Aspects of Proposed Hydrogen Projects’- provides basic safety planning requirements that all projects receiving DoE funding must meet.

  DOE_H2_safety_guidance.pdf

- ‘Safety Plan Checklist’- summaries what should be included in the required safety plan

  "US DoE Safety Plan Checklist.doc"

- US Code of Federal Regulations (CFR 29 1910.119) – governs the handling and use of hazardous materials (which is applicable to hydrogen) at the workplace.

  "US CFR 29 1910.119.doc"

Learning and recommendations from the CUTE project should be taken into account as well. Reference is given to “CUTE – Clean Urban Transport for Europe, Detailed summary of achievements”, May 2006.
(`http://ec.europa.eu/energy/res/fp6_projects/hydrogen_en.htm`)

6 Conclusions

WP4 work activities will continue to monitor the ongoing development of Codes and Standards, Industry Best Practices and safety studies and input to the Handbook development as applicable.
In WP4 Deliverables D4.3, recommendations for establishing risk assessment criteria will be developed and in Deliverable D4.5, a risk assessment workshop will be undertaken to establish agreed accident scenarios for CFD modelling.