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Introduction

This document reports on the recommendations for the research topics on hydrogen safety education, research and engineering in the area of Fuel Cell and Hydrogen (FCH) technologies. The topics outlined in the current deliverable should be addressed in the future through research and development activities and could serve as themes for research proposals. This document collates the research topics identified by the HyResponse consortium throughout the duration of the project. The selection of the appropriate research themes commenced during the development of educational materials, operational and virtual reality training exercises. The topics also originated from the questions and enquiries raised during conferences, workshops, presentations etc. Other sources of information were through communication with Advisory and Consultative Panel (ACP) members, and from the feedback received from the trainees of three face-to-face training sessions. The list of the proposed recommendations presented in this document is not exhaustive.

Topics for hydrogen safety education and training

- European training programme for First Responders Trainers and Hazmat officers, who will be in charge of disseminating, in their country and their language, the European Hydrogen Safety Training Program developed in the frame of HyResponse. Provision of technically accurate and up-to-date hydrogen safety and emergency response information to the First and Second Responders is an essential activity to underpin the successful and publicly accepted implementation of the fuel cell and hydrogen systems and infrastructure.
- Development of educational programmes tailored for two different groups: operational firemen and firemen involved in the approval of new FCH systems and infrastructure
- First Responders training in dealing with accidents/incidents involving liquefied/cryo-compressed hydrogen.
- New virtual reality tools: further development of exercises for complex situations.
- Operational training on vehicles utilising alternative energies.
- Establishment of an international forum to facilitate discussion on the First Responders training with a focus on lessons learnt, experiences, needs, etc.
- Training engineers/operators/technical personnel in FCH technologies and hydrogen safety engineering.
- Digitization and open access to teaching/educational materials, increased use of virtual learning environments.
- Digital format of and open access to engineering nomograms.
- Introduction of ‘crash’ courses for novices/non-experts to improve the perception and to dispel the myths about the dangers of hydrogen and FCH technologies.
- Improved knowledge and understanding of the fundamental principles related to the FCH technologies processes (i.e. materials properties, design and testing, thermodynamics and chemistry of hydrogen production/storage, physics of combustions and explosions, etc.).
- Harmonization of hydrogen safety terminology for First Responders.
- Standardised European system of labelling and warning signs for FCH systems and infrastructure.

Research topics on hydrogen safety engineering, FCH systems and infrastructure

Unintended hydrogen releases indoors and outdoors

- Impinging jets from dismantled hydrogen storage tanks and time to tank rupture.
- Dispersion of hydrogen indoors depending on a point of the release, and its direction. Knowledge gap [2].
- A combined effect of wind and vent(s) location, mixture uniformity criterion. An effect of wind in real conditions is not studied yet due to difficulties of measuring wind parameters in large 3D space [2].
- An updated analytical model for two vents (passive instead of natural ventilation approach) to account for large hydrogen releases [2].
- Pressure effects of delayed ignition of jets and localized mixtures. Knowledge gap [2].
- Validation of pressure peaking phenomenon for releases in real enclosures such as garages. Knowledge gap [2].
- Pressure peaking phenomenon for ignited releases (jet fires) indoors. Knowledge gap [2].
- Further numerical investigation of fire regimes indoors by taking into account water condensation. Knowledge gap [2].
- An effect of transition from momentum- to buoyancy-generated jet on hazard distances. A jet trajectory should be easily predictable to reduce the hazard distances [2].
- Radiation hazards from hydrogen jets. Data available is not fully utilized and integrated into guidance [2].
- Prediction of a cryogenic hydrogen release behaviour. Industry stakeholders have expressed interest in such capabilities, which would advance the completeness in predictive capabilities for hydrogen releases [2].
- Laboratory testing of LH_2 releases: pools, spreading, "ice" formation, evaporation and fires. Releases of liquid can form a pool and flow along the ground. Flow behaviour along the ground is often required when modelling these systems. Walls can also be used as barriers, and these interactions need to be appropriately modelled. This behaviour, the plumes and flames from these sources needs further study. Better representation of the turbulence in the two phase cloud and its interaction with the atmospheric turbulence is necessary. This data can inform both models and codes and standards [2].

Mitigation, prevention and fire-fighting measures

- Development of thermal imaging devices adapted to hydrogen combustion.
- Systems for the communications between faults on a FC vehicle with First Responders.
- Harmful pressure and thermal effects on First Responders equipped with protective clothing.
- Optimization of a Temperature Activated Pressure Release Device (TPRD) release parameters to decrease hazard distances.
- Development of cheap and reliable materials for hydrogen sensors suitable to monitor gas purity, to measure temperatures, flow rates, and concentrations for a variety of applications [2].
- Reducing the number of sensors needed to monitor FC operations. Sensors are still expensive, often because of low unit sales for a specific application. Economy of scale manufacturing should lower cost, but is only feasible if there are common performance metrics for cross-cutting

applications (e.g. sensors for vehicles and for residential markets: neither are currently required but may be of relevance as the FC electric vehicles market expands) [2].

Stationary and mobile FC applications

- FC system coupled with gas turbine (pressurized systems). Safety issues related to the use of hydrogen and/or hydrogen-enriched waste streams in gas turbines [2].

FC passenger vehicles, speciality vehicles and refuelling stations

- Safety strategies for hydrogen-powered vehicles: storage tank fire protection. Protecting tanks to allow safely optimized blow-down times. The long flames from TPRDs and pressure peaking phenomenon must be avoided [1].
- Safety strategies and engineering solutions to prevent/exclude a significant car dislocation during an on-board storage tank rupture in a fire.
- Extinction of a fire with water vapours produced during combustion of a moderate TPRD hydrogen release from a car parked in a garage. A new safety strategy is to use storage tank as a storage of extinguishing agent, i.e. water (Ulster hypothesis).
- Development of detection mechanism(s) indicating a proximity to the end-of-life for on-board hydrogen storage [2].
- Development of a European standard for TPRDs position and orientation in FCH vehicles.
- Development of a European standard for emergency shutdown devices in refueling stations.

Gaseous hydrogen storage

- Evaluation of a size of fireball produced following a high-pressure storage tank rupture in a fire. Calculation of a radiation from the fireball. Fireball radiation effects on humans, environment, structures and equipment. Knowledge gap.
- Effect of the heat release rate used in a bonfire test on fire resistance rating (FRR) of on-board hydrogen storage. Knowledge gap.
- Development of novel coatings (including intumescent) suitable for the protection of hydrogen storage tanks in case of fires.
- Thermal degradation behaviour of a tank wrapping material in fires. Effect of a resin glass transition temperature on FRR of on-board hydrogen storage [2].
- Position of an innovative TPRD providing jet with reduced flame length. Design of real systems using Computational Fluid Dynamics (CFD) [2].
- Safety strategies and engineering solutions for thermal protection of hydrogen storage tanks. There is a need to decrease a TPRD diameter (to exclude the pressure peaking phenomenon indoors, and to decrease deterministic separation distances); this can only be done if fire resistance is increased (to allow longer blow-down times) [2].
- Development of reliable mitigation techniques in case of TPRD failures.

Liquefied hydrogen storage

- Novel materials for LH_2 storage. Lack of competitive cheap materials.
- Possibility of Boiling Liquid Expansion Vapour Explosion (BLEVE) for liquefied storage tanks in a fire.
- Safety of cryo-compressed storage tanks.

Hydrogen storage in solids

- Study of the loss-of-containment modes and the consequences for solid-state hydrogen storage containers. Knowledge gap [2].

Materials compatibility with hydrogen

- Development of new functional materials (e.g. corrosion-resistant, oxidant resistant, with long-term chemical stability, with high strength); good insulators for the components FC stacks [1].
- Modelling of materials degradation in a fire and/or under different chemical attack/or under pressure cycles. Prediction of reliability and estimation of time intervals for risk-based inspections and maintenance are critical to maintaining a high standard of safety in hydrogen and fuel cell applications [2].

Hydrogen production, distribution and transportation

- New corrosion-proof materials suitable for bipolar plates and interconnects for FC and electrolysers [1].
- Development of novel sealing materials suitable for FC and electrolysers [1].

Modelling tools and validation

- Development of an open source code for hydrogen safety engineering [2].
- Development and validation of new analytical models and engineering tools related to knowledge gaps to provide stakeholders, primarily hydrogen safety engineering, with tools for inherently safer design [2].
- Collection of tools published in peer-reviewed journals, development and support of an online tool for hydrogen safety research and engineering. To provide an easy access by all stakeholders.
- Simulation of complex scenarios of accident dynamics.
- Modelling the barrier wall effects on flame and overpressure behaviours.

Summary

Deliverable D7.3 prepared within WP7, task 7.3 provides recommendations on future educational and research topics. The topics were collected through discussions with HyResponse trainees, ACP members, industrial representatives, firemen, hazmat officers and other interested stakeholders. They also derived from numerous discussions at conferences, workshops, meetings attended by the members of the HyResponse consortium. Some topics presented in D7.3 can be used for the research proposals in the near future.

References

1. EERA, Joint Research Programme on Fuel Cells and Hydrogen technologies, IMPLEMENTATION PLAN 2014 – 2020, 2015.
2. 2014 HySafe Research priorities workshop. Washington, 2014.