European Train the Trainer Programme for Responders

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Deliverable D2.1
Revised International Curriculum on hydrogen safety training for responders

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Summary

This deliverable describes the Revised International Curriculum in Hydrogen Safety Training for Responders. The original curriculum was developed within the HyResponse project[1] and was the basis for the educational training package developed for first responders. Since the publication of the original International Curriculum, developments have been made in the state of the art in hydrogen safety, and in applicable regulations codes and standards. Progress has been made in many areas pertinent to responders, namely hazards and risks associated with liquefied hydrogen, progress in the understanding of hydrogen behaviour in confined spaces and refuelling stations and storage technologies. In addition online tools relevant to responders are now available and can be used to support the syllabus. This revised curriculum reflects advancements in the field and accounts for the recent state-of-the-art. Teaching materials on hydrogen safety for responders will be revised on the basis of this curriculum.

Keywords

Curriculum, State-of-the-art, liquefied hydrogen, education and training, teaching materials.

[1] http://www.hyresponse.eu/

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1. Introduction

The International Curriculum in Hydrogen Safety Training for First Responders was developed for the first time within the HyResponse project[2] which ran from 2013-2016, the curriculum formed the basis for a set of teaching materials specific to first responders and informed the development of educational training namely the European Hydrogen Safety Training Platform (EHSTP). This threefold training programme for first responders was implemented through: educational training, operational training on mock-up real-scale transport and hydrogen stationary installations, and innovative virtual training exercises reproducing the entire accidental scenarios. The educational approach is described in the 2017 work by Tretsiakova-McNally et al.[3]

Whilst the majority of the original curriculum remains relevant there have been advancements in the field since its publication. The revised curriculum, presented in this document reflects the advancements that are most relevant to Responders.

Key changes and additions are in the introduction of specific modules/lectures on storage, liquefied hydrogen, confined spaces and hydrogen refuelling stations and infrastructure. In addition, a standalone glossary/terminology section is incorporated including relevant terms from all modules.

In recent years a number of novel engineering tools have been developed based on digital applications related to Hydrogen and Fuel Cell Technology, including safety specific tools. Examples can be found within the "e-Laboratory" of the NET-Tools project.[4] Relevant existing, and proposed, digital tools are incorporated into the revised curriculum where they are deemed appropriate for Responders and can be used to directly support a specific module.

An educational training programme was developed within HyResponse, the revised curriculum will be used as a foundation to update the teaching materials within work package 2 of HyResponder. The curriculum presented in this document reflects the state-of-the-art in hydrogen safety science and engineering at the point of preparation. Educational materials in their intermediate and final forms will be prepared in month 12 (Milestone), 18 (D2.2), and 36(D2.3) of the project, respectively.

1.1 Referencing approach within this document

This document includes a list of references relevant to each learning module/lecture. However, it is also necessary to cite documents in support of the deliverable text. In order to differentiate, references in support of the deliverable text are given as a footnote on the page in which they are cited. References to the modules/lectures which

[2] http://www.hyresponse.eu/
[3] Mixed e-learning and virtual reality pedagogical approach for innovative hydrogen safety training of first responders, Tretsiakova-McNally, S., Maranne, E., Verbecke, F. & Molkov, V., 16 Mar 2017, In : International Journal of Hydrogen Energy. 42, p. 7504-7512
[4] Scientific Principles of e-Laboratory of Hydrogen Safety, Shentsov, V., Makarov, DV. & Molkov, V., 26 Apr 2019, International Seminar on Fire and Explosion Hazards, p. 1306-1314. 8 p.

are an element of the actual curriculum are listed within the modules and in the final reading list.

1.2 Acknowledgement of HyResponse

It should be stressed that this document is a revision of work performed by the HyResponse consortium and that this revised curriculum is an amendment of the document prepared and delivered previously. The original curriculum may be accessed on the HyResponse website[5].

2. Objectives of HyResponder and the educational training

In this section the main aim and objectives of HyResponder are first outlined to clearly demonstrate the how the revised curriculum underpins these.

The main aim of HyResponder is to develop and implement a sustainable trainer the trainer programme in hydrogen safety for responders throughout Europe, supporting the commercialisation of FCH technologies by informing the participation of responders in the initial permitting process, improving resilience and preparedness through enhanced emergency planning, and ensuring appropriate accident management and recovery.

To support this main aim, the project will follow the specific objectives, which are consistent with the implementation and impact of the project namely:

1. Identify intervention strategies and tactics for Liquefied Hydrogen (LH2) applications, and reflect these <u>in teaching activities</u>.
2. <u>Develop clear, updated, operational, virtual reality, and educational training for trainers of responders to reflect the state-of-the-art in hydrogen safety.</u>
3. Establish a Pan-European Network of Responder Trainers with members from at least 10 EU countries;
4. Train trainers from at least 10 European Countries in hydrogen safety pertinent to responders
5. Reflect national specificities in teaching materials for responders, translated and made available in 8 languages.
6. Support newly trained trainers to deliver workshops for responders in at least 10 countries, maximising the reach and impact of the training programme,
7. Underpin the safe deployment of FCH technologies and infrastructure through the provision of hydrogen safety specific training for responders, supporting them in the permitting and approval of FCH projects at a local level.
8. Enhance emergency planning and preparedness relating to hydrogen technologies and infrastructure, and reduce the risk of related incidents or accidents through the training of trainers and responders
9. Ensure sustainability of the training programme through the availability of translated materials on an educational e-Platform.
10. Update the European Emergency Response Guide, previously developed within the HyResponse project to reflect advancements in the state-of the art,

[5] http://www.hyresponse.eu/

specifically intervention strategies and tactics for LH2 applications, and ensure this is available online for all responders.

11. Establish, an International Forum of Responders in Hydrogen Safety Training, incorporating members of the European Network, and International Stakeholders.

Clearly in order to deliver a fit for purpose train the trainer programme the topics covered and the resultant educational training materials must reflect the state of the art. Indeed, the revised curriculum directly informs the teaching materials and activities (objectives 1, 2, 5, and 10), training (objectives 4 and 6), and indirectly the safe deployment of FCH technologies and the sustainability of the HyResponder programme.

The aim and objectives of the training package within HyResponder is the same as HyResponse with the added goal if increased **reach** and **sustainability**.

The aim of the educational segment will enable responder to acquire a professional knowledge and an understanding of hydrogen properties, phenomena and the main principles of hydrogen safety with the view to contribute to FCH permitting process as an approving authority and to implement safe fire-fighting functions at a scene of an incident/accident. There are two steps within the HyResponder training – a "train the trainer" approach, where trainers representing organisations across Europe will attend an initial training event, then they will in turn deliver training at a local leval.

The educational training will provide responders with the fundamental knowledge as well as deep understanding of principles of hydrogen safety prior to the operational and virtual reality exercises.

As in HyResponse, the objectives of the educational training are:

- to provide responder trainers with an awareness, knowledge and understanding of the specificities of hydrogen as a new vector of energy carrier during its production, transportation, delivery and uses;
- to familiarise responder trainers with the operational principles and safety aspects of a range of FCH applications including FC vehicles, refuelling stations, materials handling, back-up power generation and stationary fuel cell systems for combined production of heat and power, etc;
- to develop in responders a critical awareness of safety issues associated with hydrogen physical, chemical and combustion properties and to achieve a systematic understanding of why the safety of hydrogen differs from that of conventional fuels;
- to provide responders with a knowledge of potential hazards, relevant safety concepts and safety features for targeted FCH systems and infrastructure;
- to introduce responders to typical risk scenarios and to instruct them on the correct way of intervention and tactics on how to deal with potential consequences of incidents/accidents that may occur at FCH systems and infrastructure;
- to develop in responders an ability to recognise and professionally deal with hazardous phenomena involving unwanted hydrogen releases (e.g. leaks),

hydrogen fires and explosions by applying the principles of hydrogen safety engineering;
- to provide responders with an analysis of hydrogen safety approaches and requirements defined in Regulations, Codes and Standards (RCS) related to FCH systems and relevant to the appropriate actions to be taken by responders;
- to provide responders with a clear picture of the safety requirements prescribed in RCS with respect to mitigation measures; assessment of the incident/accident scenes; and safety strategies for the operation of responders at the scene of an accident.

3. Scope of the International Curriculum

The scope of the revised curriculum, remains as described in Hyresponse in that it is intended to be wide and be used by interested organisations to address their own training needs (e.g. to organise 1-2 day training, a week or even for one semester), depending on their training needs and requirements. The potential users of the curriculum can select, mix and match the sections/modules/sub-topics of the current document to tailor their own courses. For example, within the HyResponder project, the curriculum will be used as the basis for a one week training event for responder trainers, and also to inform a series of 10 shorter workshops, each of 1 – 2 days duration. It has also been noted through feedback both within HyResponse and HyResponder that elements of the curriculum are specific to specialised training e.g. at HAZMAT level.

4. Target audience and their prerequisites

The targets of the curriculum and the training within HyResponder are slightly different. The curriculum is intended to be comprehensive, and as described in the previous section, it is intended for a wide audience to be tailored as required dependent on the audience. Whilst it is directed at responders, other interested stakeholders (e.g. policy-/decision-makers, site operators, industry representatives, scholars, academics, and members of the public) will have access through the website initially, and the HyResponder ePlatform, to all the educational materials developed during the project. There are no special pre-requisites necessary to understand the curriculum.

It is intended that the audience of the **training** delivered within HyResponder is "incident commander" level, relevant trainers at that level will be identified to attend training at ENSOSP, and will then deliver workshops at a local level. However, the teaching materials which will be available on the ePlatform will be presented in a format suitable for an easy comprehension by a wide audience and by the different categories of responder. During the internal review of the materials it is intended that any elements which are highly specialist e.g. HAZMAT level are identified.

5. Further revisions to the curriculum within HyResponder

While significant revisions to the curriculum are not envisaged, it is intended that the curriculum is a "living document". It is the intention within HyResponder to ensure the training package is fit for purpose and sustainable beyond the project completion. With this in mind, feedback is being sought on the teaching materials from as wide an audience as possible. The Stakeholders advisory board, which includes responders from organisations beyond the consortium will review the teaching materials in advance of the training events. The responder trainers identified by the consortium will also review the materials. The curriculum will be revised to reflect feedback if appropriate.

6. Introduction of online tools

In recent years a number of digital tools have been developed which are relevant to supporting education and training for in hydrogen safety. A specific example is the e-Laboratory within the European project "Novel Education and Training Tools based on digital Applications related to Hydrogen and Fuel Cell Technology" (NET-Tools)[6].

The NET-Tools project is delivering a technology platform, influencing robust and effective open source and free access learning management system while offering a unique blend of novel digital tools encompassing generic information, education and research. The digital platform includes two main pillars i.e. e-Education and e-Laboratory. The principles behind the e-Laboratory of Hydrogen Safety allow e.g. assessing hazard distances for unignited releases (flammable envelope size); ignited releases (jet fires); blast wave decay from deflagrations, detonations and high-pressure hydrogen storage tank rupture in a fire, fireballs, etc. It is clear that a number of these tools are relevant to responders and thus can be used in support of the HyResponder teaching materials. The e-Laboratory toolbox provides determination of hazard distances for unignited releases and jet fires in interactive regime, e.g. by varying system parameters like pressure and pipe (leak) diameter. The state-of-the-art safety tools of the e-Laboratory of Hydrogen Safety is a free-access tool, which HyResponder will utilise either directly or through related tools in the HyResponder ePlatform.

7. Training delivery within HyResponder

Training in HyResponder will take place through a series of at least 11 events.

- There will be a 5 day workshop attended by at least 20 responder trainers from 10 different regions. This workshop will incorporate theoretical lectures, operational training and VR exercises. This event is planned for June 2021. A follow up event may be offered if demand necessitates.
- There will be a series of 10 shorter 1- 2 day training events, delivered across Europe. These will involve a subset of the material presented at the longer training event. These regional workshops will take place between July 2021 and December 2022. The regions are shown in Figure 1.

[6] Scientific Principles of e-Laboratory of Hydrogen Safety, Shentsov, V., Makarov, DV. & Molkov, V., 26 Apr 2019, International Seminar on Fire and Explosion Hazards, p. 1306-1314. 8 p.

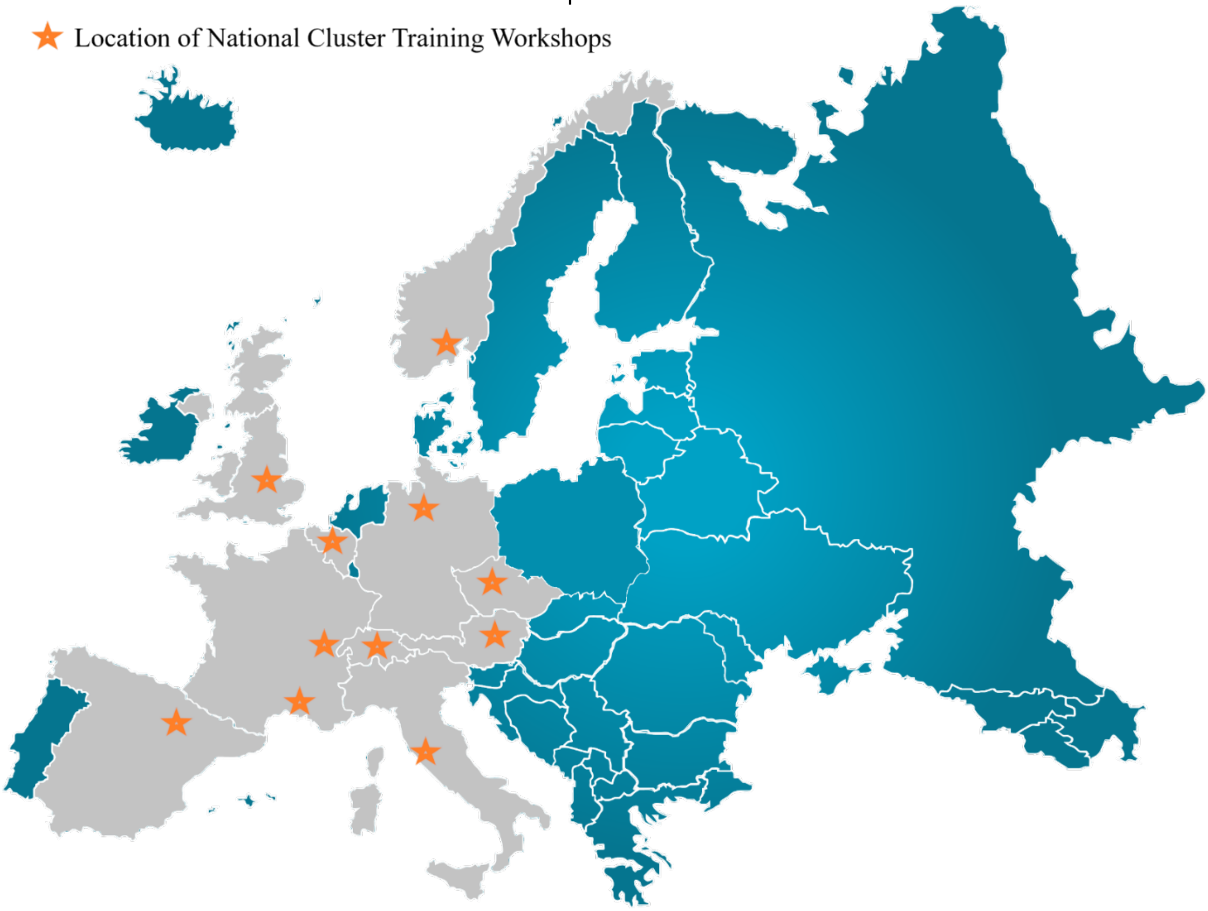

Figure 1. Location of the National Training Workshops

8. The table of contents of the International Curriculum

As with the original HyResponse materials, the teaching materials in HyResponder will consist of three core sections: Basics of Hydrogen Safety for responders; Regulations, Codes and Standards for Responders; and Intervention Strategies and Tactics for Responders. The first section on Basics of Hydrogen Safety will be supported by a series of lectures which will be available on the HyResponder ePlatform. The lectures will be supported by online digital tools where applicable and include the following themes: overview of FCH applications, infrastructure and uses; specific safety issues related to hydrogen storage; overview of incidents/accidents involving hydrogen; basic properties and behaviour of hydrogen (including combustion); comparison of hydrogen behaviour to that of other common fuels; compatibility and interactions of hydrogen with different substances; hazards and risks associated with hydrogen including liquefied hydrogen; hydrogen releases; ignition of hydrogen-oxidizer mixtures; hydrogen flames; hydrogen releases in confined spaces; explosions and blast waves; prevention, mitigation and fire-fighting techniques. The table of contents of the International Curriculum content is shown in Table 1.

Table 1: Table of contents for the Revised International Curriculum on hydrogen safety training for responders

SECTION "BASICS OF HYDROGEN SAFETY FOR RESPONDERS"	
Module	**Content**
1	**"Introduction to hydrogen safety for Responders"** • Introduction • Overview of hydrogen production, storage, industrial and hydrogen energy usage. • FCH vehicles. • Hydrogen transportation • Stationary FC applications. • Marine applications • Hydrogen-based energy storage systems. • Overview of incidents and accidents involving hydrogen. • Introduction to hydrogen safety engineering framework and standards • Pipelines – an introduction • Introduction to the e-Laboratory
2	**"Properties of hydrogen relevant to safety"** • Physical properties of hydrogen. • Combustion characteristics including flammability and detonability limits. • Comparison of hydrogen characteristics with those for other fuels.
3	**"Storage"** • Storage of gaseous hydrogen. • Consequences of catastrophic failure of on-board storage (blast waves, fireballs etc). • Liquefied hydrogen storage. • Fire resistance rating of hydrogen tanks. • Leak no burst technology • Novel storage techniques • Solid storage of hydrogen. • Safety features of storage setup *Supporting tools: blow down, time to tank rupture, fireball scale correlations*
4	**"Compatibility of hydrogen with different materials"** • Interaction of hydrogen with metals. • Interaction of hydrogen with non-metallic, polymeric materials and gases. • Mitigation measures for hydrogen embrittlement and good practices.

5	**"Liquefied Hydrogen"** • Liquid hydrogen properties • Liquid hydrogen hazards • Cryogenic releases • Combustion • Liquid hydrogen technologies • Liquid hydrogen production process and infrastructures • Liquid hydrogen storage & delivery • Liquid hydrogen systems for mobility • Liquid hydrogen hazards and associated risks, for responders • Recommendations and guidance *Supporting tools: thermal Radiation of a jet, videos of LH2 releases and pools*
6	**"Harm criteria for people and property"** • Health hazards of hydrogen. • Thermal effects of fires on humans, structures and environments. • Pressure effects from explosions. • Comparison of harm criteria for unprotected and protected people
7	**"Unignited hydrogen releases outdoors and their mitigation"** • Compressed hydrogen leaks. • How to decrease a separation distance from a hydrogen release? • Mitigation measures for unignited releases. • Utilisation of the e-laboratory • Detection of unignited hydrogen releases outdoors *Supporting tools: jet parameters model, Similarity law for concentration decay in hydrogen expanded and under-expanded jets and unignited jet hazard distances*
8	**"Ignition sources and prevention of ignition"** • Ignition sources. • Hydrogen ignition mechanisms. • Spontaneous ignition of sudden releases. • Ignitability: comparison between gaseous and liquid hydrogen. • Prevention of ignition
9	**"Separation from hydrogen flames and fire fighting"** • Microflames. • Jet fires and three separation distances. • Effect of buoyancy on separation distances. • Pipeline applications • Radiation heat fluxes from jet fires and fireballs. • Liquefied hydrogen fires. Detection, mitigation and fire-fighting of hydrogen flames. *Supporting tools: jet flame length calculation*

10	**"Dealing with hydrogen explosions"** • Deflagrations and blast waves. • Detonations and blast waves. • Physical explosions and blast waves. • BLEVE phenomenon • Super-high overpressures during rapid phase transition (RPT) phenomenon. • Possible mitigation measures for explosions. *Supporting tools: Blast wave decay*
11	**"Confined spaces"** • Hazards and associated risks for the use of hydrogen in enclosures. • Permeation leaks. • Indoor hydrogen releases and dispersion. • Natural and forced ventilation. • Pressure peaking phenomenon. • Carparks • Tunnels • Venting of hydrogen-air deflagrations. • Regimes of indoor jet fires including phenomena of self-extinction and external flame. • Hydrogen sensors and hydrogen fire detectors. *Supporting tools: pressure peaking phenomena for unignited constant mass flow rate and blowdown, pressure peaking phenomena for ignited releases*
12	**Hydrogen Refuelling Stations & Infrastructure** • Refuelling stations introduction o Comparison between Liquid and gaseous H2 storage based refuelling stations o Compressors o Liquid pump o Vaporizer o Precooling system o Dispensers • Production • Pipelines • Power to gas • Terminology • Safety features in HRS and other infrastructures
A1	**Glossary** establish good wording with associated definition, and meaning of usual abbreviations

SECTION "REGULATIONS, CODES AND STANDARDS (RCS) FOR RESPONDERS"	
• RCS for hydrogen production applications and relevance to Responders. • RCS for hydrogen distribution and transportation applications and relevance to Responders. • RCS for FC vehicles and relevance to Responders. • RCS for hydrogen refuelling stations and infrastructure relevance to Responders. • RCS for stationary FC applications and relevance to Responders. • RCS for hydrogen-based energy storage applications and relevance to Responders. • RCS specific to fire service intervention. • RCS on ignition prevention and electrical safety. Electrical safety of FCs • Prescriptive and performance-based approach to hydrogen safety	
SECTION "INTERVENTION STRATEGIES AND TACTIC FOR RESPONDERS"	
• Typical accident scenarios involving hydrogen production applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen storage applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen distribution and transportation applications and relevant emergency response strategies and tactics • Typical accidental scenarios related to FC vehicles and emergency response strategies and tactics • Typical accidental scenarios related to hydrogen refuelling stations and emergency response strategies and tactics • Typical accident scenarios involving stationary FC applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen-based energy storage • European Hydrogen Emergency Response training programme for Responders systems and relevant emergency response strategies and tactics • Rescue operations	
REFERENCES	
SECTION "BASICS OF HYDROGEN SAFETY FOR RESPONDERS"	

9. Basics of Hydrogen Safety for Responders: Suggested sources

9.1 References across all modules

The revised curriculum and learning modules build upon the modules developed within HyResponse. Thus all materials presented there are of relevance. In addition the following essential reading is advised:

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9.6 Liquefied hydrogen

It should be noted that this is a module where the content is very topical and as such is expected to be updated as HyResponder progresses. A number of research projects are ongoing, including the FCH JU project PRESLHy, as outputs from these projects become available they will be reflected in the teaching materials. This the sources listed below are the documents identified through HyResponder D1.1.

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9.11 Dealing with hydrogen explosions

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9.12 Confined spaces

As with the module on Liquefied hydrogen it should be noted that this is a module where the content is very topical and as such is expected to be updated as HyResponder progresses. A number of research projects are ongoing, including the FCH JU project HyTunnel-CS, as outputs from these projects become available they will be reflected in the teaching materials.

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9.13 Hydrogen Refuelling Stations & Infrastructure

This is a new module where the content is both topical and is expected to be driven by industry reports and outputs. As such is expected to be updated as HyResponder progresses. The references cited below are from work by Cassima et al in 2009, whilst clearly there have been advancement in the interim, this work was also highlighted by the European Hydrogen Safety Panel (2019), in recent planning documentation.

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10. Appendix 1 – Summary of revisions to the Curriculum

HyResponder: Revised curriculum: WP2

Points to note:

1. NO topics have been removed from the original curriculum, however, there has been some movement to balance distribution between learning modules.
2. There have been three new "chapters/modules" added to reflect advancements in the state of the art: LH2, Confined spaces and Hydrogen Refuelling Stations and Infrastructure
3. A glossary has been included within the introductory modules rather than as a part of the overall training package
4. Further subsections added e.g. pipelines and marine applications are based on ongoing projects and comments of the consortium
5. It is intended the modules will be supported by e-Laboratory tools where possible, all hydrogen safety tools will be introduced, with application of the most relevant ones only.
6. It is envisaged that the curriculum will be updated as the project progresses and new outputs become available from ongoing projects, e.g. those on liquefied hydrogen such as PRESLy

Topics highlighted green have been moved from the original module
Topics highlighted yellow are new

SECTION "BASICS OF HYDROGEN SAFETY FOR FIRST RESPONDERS"			
Module	**Original Curriculum**	**Revised Curriculum**	**Supporting tools**
1	**"Introduction to hydrogen safety for First Responders"** • Overview of hydrogen production, storage, industrial and hydrogen energy usage. • Storage of gaseous hydrogen. • Liquefied hydrogen storage. • Fire resistance rating of hydrogen tanks. • Consequences of catastrophic failure of on-board storage (blast waves, fireballs etc). • Solid storage of hydrogen. • FCH vehicles. • Hydrogen refuelling stations. • Hydrogen transportation. • Stationary FC applications. • Hydrogen-based energy storage systems. • Overview of incidents and accidents involving hydrogen.	**"Introduction to hydrogen safety for Responders"** • Introduction: Scope, target etc. • Overview of hydrogen production, storage, industrial and hydrogen energy usage. • FCH vehicles. • Hydrogen transportation (incl. HGV, trains & aviation) • Stationary FC applications. • Marine applications • Hydrogen-based energy storage systems. • Overview of incidents and accidents involving hydrogen. • Introduction to hydrogen safety engineering framework & standards • Pipelines – an introduction	

	• Introduction to hydrogen safety engineering framework	• Introduction to the e-Laboratory and HyRam • Glossary (establish good wording with associated definition, and meaning of usual abbreviations) (e.g. TPRD, BLEVE, DDT…)	
2	**"Properties of hydrogen relevant to safety"** • Physical properties of hydrogen. • Combustion characteristics including flammability and detonability limits. • Comparison of hydrogen characteristics with those for other fuels.	**"Properties of hydrogen relevant to safety"** • Physical properties of hydrogen. • Combustion characteristics including flammability and detonability limits. • Comparison of hydrogen characteristics with those for other fuels.	
3		**"Storage"** • Storage of gaseous hydrogen. • Consequences of catastrophic failure of on-board storage (blast waves, fireballs etc). • Liquefied hydrogen storage. • Fire resistance rating of hydrogen tanks. • Leak no burst technology • Novel storage techniques • Solid storage of hydrogen. • Safety features of storage setup	• Blow down tool • NEW tool potential: Non-adiabatic blowdown • Time of tank to rupture • Fireball scale correlations
4	**"Compatibility of hydrogen with different materials"** • Interaction of hydrogen with metals. • Interaction of hydrogen with non-metallic, polymeric materials and gases. • Mitigation measures for hydrogen embrittlement and good practices.	**"Compatibility of hydrogen with different materials"** • Interaction of hydrogen with metals. • Interaction of hydrogen with non-metallic, polymeric materials and gases. • Mitigation measures for hydrogen embrittlement and good practices.	
5		**"Liquefied Hydrogen"** • Liquid hydrogen properties • Liquid hydrogen hazards • Cryogenic releases • Combustion • Liquid hydrogen technologies	• Thermal Radiation of a jet • Videos of LH2 releases and pools coming from

		• Liquid hydrogen production process and infrastructures • Liquid hydrogen storage & delivery (storage in HyResponse to some extent) • Liquid hydrogen systems for mobility. • Liquid hydrogen hazards and associated risks, for first responders • Recommendations and guidance	PRESLHy experiments
6	**"Harm criteria for people and property"** • Health hazards of hydrogen. • Thermal effects of fires on humans, structures and environments. • Pressure effects from explosions. • Comparison of harm criteria for unprotected and protected people (firemen).	**"Harm criteria for people and property"** • Health hazards of hydrogen. • Thermal effects of fires on humans, structures and environments. • Pressure effects from explosions. • Comparison of harm criteria for unprotected and protected people (firemen).	
7	**"Unignited hydrogen releases outdoors and their mitigation"** • Compressed hydrogen leaks. • Cryogenic leaks. • How to decrease a separation distance from a hydrogen release? • Mitigation measures for unignited releases.	**"Unignited hydrogen releases outdoors and their mitigation"** • Compressed hydrogen leaks. • How to decrease a separation distance from a hydrogen release? • Mitigation measures for unignited releases. • Utilisation of e-laboratory • Detection of unignited hydrogen releases outdoors	• Jet parameters • Similarity law for concentration decay • Buoyancy calculation
8	**"Ignition sources and prevention of ignition"** • Ignition sources. • Hydrogen ignition mechanisms. • Spontaneous ignition of sudden releases. • Prevention of ignition.	**"Ignition sources and prevention of ignition"** • Ignition sources. • Hydrogen ignition mechanisms. • Spontaneous ignition of sudden releases. • Ignitability: comparison between gaseous and liquid hydrogen. • Prevention of ignition.	
9	**"Separation from hydrogen flames and fire fighting"** • Microflames. • Jet fires and three separation distances. • Effect of buoyancy on separation distances. • Radiation heat fluxes from jet fires and fireballs. • Liquefied hydrogen fires.	**"Separation from hydrogen flames and fire fighting"** • Microflames. • Jet fires and three separation distances. • Effect of buoyancy on separation distances. • Pipeline applications • Radiation heat fluxes from jet fires and fireballs. • Liquefied hydrogen fires.	• Jet flame calculation

	• Detection, mitigation and fire fighting of hydrogen flames.	Detection, mitigation and fire fighting of hydrogen flames.	
10	**"Dealing with hydrogen explosions"** • Deflagrations and blast waves. • Detonations and blast waves. • Physical explosions and blast waves. • Super-high overpressures during rapid phase transition (RPT) phenomenon. • Possible mitigation measures for explosions.	**"Dealing with hydrogen explosions"** • Deflagrations and blast waves. • Detonations and blast waves. • Physical explosions and blast waves. • BLEVE phenomenon • Super-high overpressures during rapid phase transition (RPT) phenomenon. • Possible mitigation measures for explosions.	• Blast wave from high pressure tank rupture • Fireball scale correlation with BLEVE
11	**"Hazards of hydrogen use indoors and relevant mitigation techniques"** • Hazards and associated risks for the use of hydrogen in enclosures. • Permeation leaks. • Indoor hydrogen releases and dispersion. • Natural and forced ventilation. • Pressure peaking phenomenon. • Venting of hydrogen-air deflagrations. • Regimes of indoor jet fires including phenomena of self-extinction and external flame. • Hydrogen sensors and hydrogen fire detectors.	**"Confined spaces"** • Hazards and associated risks for the use of hydrogen in enclosures. • Permeation leaks. • Indoor hydrogen releases and dispersion. • Natural and forced ventilation. • Pressure peaking phenomenon. • Carparks (specify if underground/open/covered) • Tunnels • Venting of hydrogen-air deflagrations. • Regimes of indoor jet fires including phenomena of self-extinction and external flame. • Hydrogen sensors and hydrogen fire detectors.	• Overpressure for a vent of known size • PPP unignited • PPP ignited: • Passive ventilation in an enclosure with one vent • Force ventilation system parameters

12		**Hydrogen Refuelling Stations & Infrastructure**
		• Refuelling stations introduction
		  ○ Comparison between Liquid and gaseous H2 storage based refuelling stations
		  ○ Compressors
		  ○ Liquid pump
		  ○ Vaporizer
		  ○ Precooling system
		  ○ Dispensers
		• Production (SMR, Electrolyser, Liquefier…)
		• Pipelines
			• Virtual visit to HRS

		• Power to gas • Terminology • Safety features in HRS and other infrastructures: What / Where / For what / Normal and abnormal (=emergency) operation / To do - to avoid during intervention	
A1		**Glossary** Establish good wording with associated definition, and meaning of usual abbreviations) (e.g. TPRD, BLEVE, DDT…)	
SECTION "REGULATIONS, CODES AND STANDARDS (RCS) FOR RESPONDERS"			
• RCS for hydrogen production applications and relevance to FRs. • RCS for hydrogen distribution and transportation applications and relevance to FRs. • RCS for FC vehicles and relevance to FRs • RCS for hydrogen refuelling stations and infrastructure relevance to FRs • RCS for stationary FC applications and relevance to FRs • RCS for hydrogen-based energy storage applications and relevance to FRs • RCS specific to fire service intervention. • RCS on ignition prevention and electrical safety. Electrical safety of FCs • Prescriptive and performance-based approach to hydrogen safety		• RCS for hydrogen production applications and relevance to FRs. • RCS for hydrogen distribution and transportation applications and relevance to FRs. • RCS for FC vehicles and relevance to FRs • RCS for hydrogen refuelling stations and infrastructure relevance to FRs • RCS for stationary FC applications and relevance to FRs • RCS for hydrogen-based energy storage applications and relevance to FRs • RCS specific to fire service intervention. • RCS on ignition prevention and electrical safety. Electrical safety of FCs • Prescriptive and performance-based approach to hydrogen safety	
SECTION "INTERVENTION STRATEGIES AND TACTIC FOR FIRST RESPONDERS"			
• Typical accident scenarios involving hydrogen production applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen storage applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen distribution and transportation applications and relevant emergency response strategies and tactics • Typical accidental scenarios related to FC vehicles and emergency response strategies and tactics		• Typical accident scenarios involving hydrogen production applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen storage applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen distribution and transportation applications and relevant emergency response strategies and tactics • Typical accidental scenarios related to FC vehicles and emergency response strategies and tactics • Typical accidental scenarios related to hydrogen refuelling stations and emergency response strategies and tactics	

• Typical accidental scenarios related to hydrogen refuelling stations and emergency response strategies and tactics • Typical accident scenarios involving stationary FC applications and relevant emergency response strategies and tactics	• Typical accident scenarios involving stationary FC applications and relevant emergency response strategies and tactics • Typical accident scenarios involving hydrogen-based energy storage • European Hydrogen Emergency Response training programme for First Responders systems and relevant emergency response strategies and tactics