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European hydrogen train the trainer framework for responders: Outcomes of the HyResponder project

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ABSTRACT

HyResponder is a European Hydrogen Train the Trainer programme for responders. This paper describes the key outputs of the project and the steps taken to develop and implement a long-term sustainable train the trainer programme in hydrogen safety for responders across Europe and beyond. This FCH2 JU (now Clean Hydrogen Joint Undertaking) funded project has built on the successful outcomes of the previous HyResponse project. HyResponder has developed further and updated educational, operational, and virtual reality training for trainers of responders to reflect the state-of-the-art in hydrogen safety, including liquid hydrogen, and expand the programme across Europe and specifically within the 10 countries represented directly within the project consortium: Austria, Belgium, the Czech Republic, France, Germany, Italy, Norway, Spain, Switzerland, and the United Kingdom. For the first time, four levels of educational materials from fire fighter through to specialist have been developed. The digital training resources are available on the e-Platform (https://hyresponder.eu/e-platform/). The revised European Emergency Response Guide is now available to all stakeholders. The resources are intended to be used to support national training programs. They are available in 8 languages: Czech, Dutch, English, French, German, Italian, Norwegian and Spanish. Through the HyResponder activities, trainers from across Europe have undertaken joint actions which are in turn being used to inform the delivery of regional and national training both within and beyond the project. The established pan-European network of trainers is shaping the future in the important for inherently safer deployment of hydrogen systems and infrastructure across Europe and enhancing the reach and impact of the programme.

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1. Introduction

Hydrogen is playing an increasingly important role in the transition of Europe's energy system. Closing knowledge gaps and education are vital to ensure deployment of inherently safer hydrogen systems and infrastructure. Approaches to responder training vary across Europe, and training specific to hydrogen safety is extremely limited due to lack of experience and specialised knowledge. The HyResponder project "European Hydrogen Train the Trainer Programme for Responders" (January 2020–May 2023) was designed to implement a pan-European approach to build on complementarities of partners to achieve the synergy in beyond the-state-of-art response to hydrogen incidents. HyResponder builds on the successful HyResponse project (2014–2016) led by L'École nationale supérieure des officiers de sapeurs-pompiers (ENSOSP) [1,2]. A properly trained responder community is recognised as critical to their successful introduction [3]. Through HyResponse the World's first comprehensive training programme for first responders was established consisting of a European Hydrogen Safety Training Platform (EHSTP). A threefold training programme was developed in HyResponse comprising of educational training, including the state-of-the-art knowledge in hydrogen safety, operational training on mock-up real scale hydrogen and fuel cell installations at ENSOSP, and innovative virtual reality training reproducing in detail an entire incident scenario. Within HyResponse a series of pilot training sessions, delivered in English, was organised. The European Emergency Response Guide (EERG), which gives details of intervention strategy and tactics, was developed and included into the pilot training sessions. HyResponder sought to build upon the HyResponse activities and maximise the reach and impact of the training across Europe.

HyResponder was a collaborative project funded by the Fuel Cells and Hydrogen 2 Joint Undertaking (since 2021 Clean Hydrogen Joint Undertaking). The consortium comprised of fire service institutions, international fire and rescue associations, a partner experienced in application of virtual reality for training of fire and rescue services, academic partners with prior experience in the education/training of responders in hydrogen safety, and representatives of hydrogen industry. The HyResponder consortium was composed of 16 partners from 10 countries were coordinated by Ulster University and included.

- Ulster University (UU) (United Kingdom)
- Air Liquide (AL), France
- Ecole nationale supérieure des officiers de sapeurs-pompiers (ENSOSP), France
- Persee (Persee), France
- Crisis Simulation Engineering (CRISE), International
- Landes Feuerwehrverschule Tirol (LFT), Austria
- Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France
- Service Public Federal Interieur (SPFI), Belgium
  •Ayuntamiento De Zaragoza (AYTO-ZGZ)/Bomberos Zaragoza (BMBZGZ), Spain
- DLR Institut fur Vernetzte Energiesysteme (DLR), Germany
- International Association of Fire and Rescue Services (CTIF), France
- Fire Service College (FSC), United Kingdom
- Università degli Studi di Roma "La Sapienza" (URS), Italy
- International Fire Academy (IFA), Switzerland
- Ministry of the Interior of the Czech Republic (MICR), Czech Republic
- University of South-Eastern Norway (USN), Norway

The main aim of HyResponder was to develop and implement a sustainable train the trainer programme in hydrogen safety for responders throughout Europe, supporting the commercialisation of fuel cell and hydrogen (FCH) technologies by informing the participation of responders in the initial permitting process, improving resilience and preparedness through enhanced emergency planning, and ensuring appropriate incident management and recovery. To support this aim, the project included the following specific objectives which have been fully met.

- Identify intervention strategies and tactics for liquid hydrogen (LH2) applications and reflect these in teaching activities.
- Develop clear, updated, operational, virtual reality, and educational training for trainers of responders to reflect the state-of-the-art in hydrogen safety.
- Establish a Pan-European Network of Responder Trainers with members from at least 10 European countries.
- Train trainers from at least 10 European Countries in hydrogen safety pertinent to responders
- Make teaching materials for responders available in at least 8 languages: Czech, Dutch, English, French, German, Italian, Norwegian and Spanish
- Support newly trained trainers to deliver workshops for responders in at least 10 countries, maximising the reach and impact of the training programme,
- 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
- Ensure sustainability of the training programme through the availability of translated materials on an educational e-Platform.
- Update the European Emergency Response Guide, previously developed within the HyResponse project [1,2] to reflect advancements in the state-of the art, specifically intervention strategies and tactics for LH2 applications, and ensure this is available online for all responders.
- Establish an International Forum of Responders in Hydrogen Safety Training, incorporating members of the European Network and International Stakeholders.

1.1. HyResponder work plan

The project was structured into six work packages (WPs), each with a clear distinct purpose and measurable outputs.

- WP1. The state-of-the-art in hydrogen safety provisions and training of responders
- WP2. Training materials development
- WP3. Train the trainer programme
- WP4. National training programmes
- WP5. Dissemination and sustainability
- WP6. Management

The project methodology is schematically presented in Fig. 1. In WP1, partners analysed the state-of-the-art in hydrogen safety provisions and training of responders, laying the foundations to revise training materials. Professional training requirements were identified, and emergency scenarios were selected and prioritized in order to identify intervention tactics and strategies.

In WP2 "Training materials development", the focus was on the design and development of revised educational, virtual reality and operational training, including novel tools. The design and development stage specifically incorporated.

- Revision of the International Curriculum on hydrogen safety training for responders to reflect the state-of-the-art and recent advancements in the field.
- Development of scientifically informed educational training materials, to include written materials and consolidation of relevant engineering tools.
- Revision of the European Emergency Response Guide (EERG) for responders to reflect interventions and strategies for new scenarios.

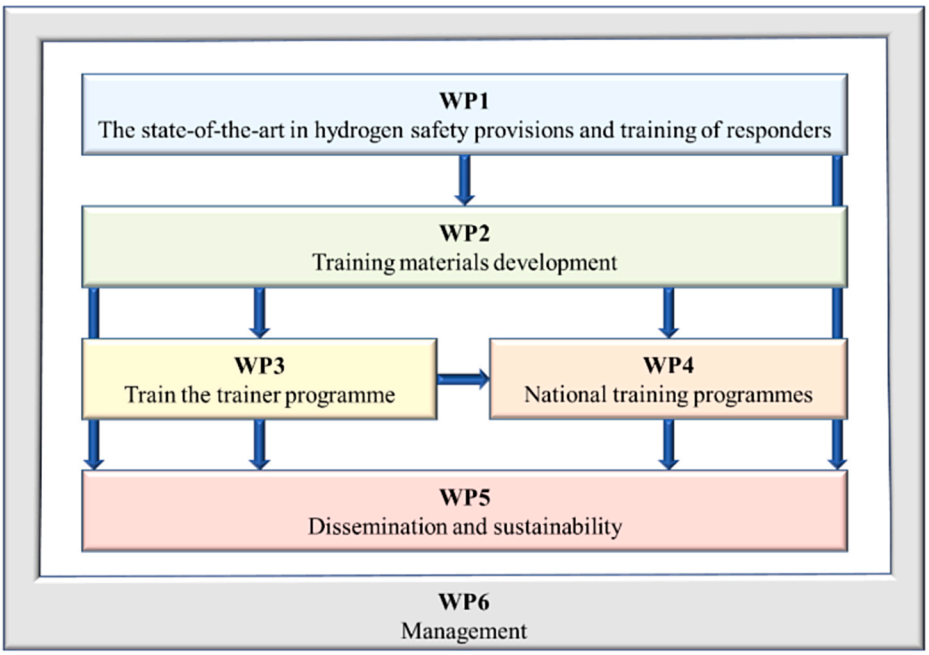

Fig. 1. Schematic of HyResponder workpackages.

- Design and development of advanced Virtual Reality training materials for responders to reflect new scenarios.
- Expansion of the operational training platform created in HyResponse to encompass an LH2 scenario.

WP3 and WP4 were dedicated on the implementation and delivery of the HyResponder training. In WP3, the train the trainer programme was implemented. This was achieved through the establishment of national training clusters in 10 European countries and the subsequent delivery of educational, virtual reality and operational training to trainers from each of the clusters. Feedback on the training was used to inform the delivery of training at a national level. National training was delivered through WP4, where the educational training materials developed in WP2 and trialled in WP3, were translated with the input of trainers so that materials are available in 8 European languages (Czech, Dutch, English, French, German, Italian, Norwegian, and Spanish). Tailored training was delivered through 10 National Training Clusters in Austria, Belgium, the Czech Republic, France, Germany, Italy, Norway, Spain, Switzerland and the United Kingdom.

WP5 was centred on evaluation and communication and dissemination of the HyResponder activities to ensure exploitation of the results beyond the project. Analysis of the training needs and training approaches has recommendations on a pathway to establish the HyResponder training as the recognised standard in Europe.

Project coordination and management activities were dealt with within WP6.

All deliverables and the teaching materials can be accessed through the project website (https://hyresponder.eu/). This paper gives an overview of some of the key project achievements.

2. Training materials

2.1. Revised curriculum

The International Curriculum in Hydrogen Safety Training for First Responders was developed for the first time within the HyResponse project [1,2], 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). The educational approach is described in the 2017 work by Tretsiakova-McNally et al. [1]. Whilst the majority of the original curriculum remains relevant there have been advancements in the field since its publication. The revised curriculum, presented in HyResponder, reflects the advancements that are most relevant to responders. Details can be found on the HyResponder website in Deliverable 2.1 "A revised curriculum on hydrogen safety for responders" [4]. Key changes and additions are in the introduction of specific modules/lectures on storage, liquefied hydrogen, confined spaces, hydrogen refuelling stations and infrastructure. A standalone glossary/terminology section has been incorporated including relevant terms from all modules and relevant regulations, codes and standards (RCS).

In recent years a number of novel engineering tools have been developed by Ulster University and other centres of excellence in hydrogen safety. Examples can be found within the "e-Laboratory for hydrogen safety" [5] currently supported by HyResponder and being the sub-set of the resources developed initially within the Net-Tools project [6]. Relevant existing, and new digital tools are incorporated into the revised curriculum and lectures where they are deemed appropriate for responders and can be used to directly support a specific module. An educational training programme developed within HyResponse, and the revised curriculum was used as a foundation to the teaching materials of educational training within HyResponder.

2.2. Enhanced operational training platform

The unique operational training facilities in hydrogen safety previously built at ENSOSP within HyResponse [1,2] were upgraded within HyResponder to enable new training practices due to the risks of LH2 and LIN (Liquid Nitrogen). The operating training platform of ENSOSP in France is built on an area of 6000 m^2 and divided into 10 operational exercises which can be combined in several scenarios. A scenario is primarily defined by reviewing the previous training offering and expanding the operational platform to incorporate LH2 activity based on the scenarios identified within HyResponder. The different scenarios identified are.

- Liquid spreading
- Cryogenic cloud

- Liquid storage in fire
- Road accident and overturning of a liquid hydrogen trailer
- Release on a connection between the liquid hydrogen trailer and the storage
- Ignited release

The educational objectives of the new practical exercise were to simulate a number of phenomena enabling the responder to prepare to safely tackle incidents with LH2. These included an awareness of.

- Liquid spreading: what kind of behaviour, from liquid to vapor, cold embrittlement of equipment, cold burn.
- Cryogenic cloud: limited visibility for intervention, anoxia risk, safety features frozen, containment of the cloud.
- Release: leak detection means.
- Deflagration due to flammable cloud ignition: feel overpressure/energy.
- Ignited high pressurized release: flame length, radiative heat fluxes, invisible flame.
- Difference between immediate and delayed ignition.
- More generally: what are the safety features on LH2 applications – for what – where.

It was determined that the new operational training exercise must reach 2 principal goals i.e., enable creation and dispersion of a cryogenic hydrogen cloud, and activate ignition just on the leak or remote ignition. A tool combining Gaseous H2 and Liquid Nitrogen (LIN) was favoured due to being safer, easier to handling, more flexible, and less expensive for training yet representing LH2 incidents. This new experimental facility developed within HyResponder is composed of.

- 2 cryogenic tanks (simulation of a liquid hydrogen leak with liquid nitrogen), shown in Fig. 2.
- 1 thermal camera (To see the level of liquid in the tank and also useful for observing hydrogen flames on other simulators).
- 4 infrared thermometers (To see the temperature of liquid and gas and also useful for observing hydrogen flames on others simulators).
- 2 oxygen detectors (Safety of the trainers and the trainees).
- 4 pairs of cryogenic gloves, 2 cryogenic aprons, 2 pairs of cryogenic over boots.

2.3. Virtual reality resources

Virtual reality (VR) simulators have been used as part of firefighter training for about twenty years, as described by Querrec et al. [7]. Thanks to this technology, it has been possible to simulate complex scenarios, such as road tunnel fires [8], big cities and forests [9], industrial environments [10], aerial firefighting helicopters [11], fuel leakages in maritime areas [12], etc. This technology can be considered an excellent complement to real world training, particularly when safety, cost and difficulties to reproduce events can make it very difficult or even not feasible at all. Furthermore, VR can be the essence for developing different kinds of serious games, as shown by Williams-Bell et al. [13], to train firefighters.

Partner CRISE was the lead of the VR provision in HyResponder, their role was to lead delivery of VR training to the trainers who are trained within HyResponder, those trainers in turn introduced the training in their regions, but as with the operational training it was not expected that this was exactly replicated across all countries, rather that key elements are selected and integrated within existing training provisions. Experience gained in the pedagogic strategies successfully trialled during the HyResponse project and described by Tretsiakova-McNally et al. [1] were the basis of the activities in HyResponder. In HyResponse, the use of andragogy and experience-based training is what governed the pedagogic choices and set ups [14].

In the context of HyResponder, this methodology has been favoured.

Fig. 2. The two LIN tanks simulating a liquid hydrogen leak and dispersion in atmosphere.

The goal was to train trainers ensuring they can in turn deliver correct hydrogen related knowledge and know-how, both at a theoretical, technical, doctrinal and operational level.

It was necessary to ensure the pedagogic concepts were well understood by the future trainers, so that they can get a good comprehension of the methodology, and provided tools. The VR scenarios already developed within HyResponse included.

- Liquefied hydrogen trailer.
- Hydrogen bus.
- Combined heat and power installation.
- Hydrogen delivery pipe.
- Hydrogen delivery trailer.
- Dismantled trailer.
- Containerized hydrogen installation.
- Hydrogen production and storage site.
- Multiple car crash on motorway.
- Remote power backup installation, and
- Hydrogen car in a tunnel.

As with the operational training platform, the new VR scenarios developed within HyResponder to complete the HyResponse scenarios were focused on LH2, either on storage leak, transportation and mobility. Within HyResponder new assets were developed to enhance these scenarios specifically: sources (jet, dispersion, thermal) and measurement tools. In addition, the scenarios were extended to include situations with liquid hydrogen jet and rainout forming a LH2 pool that causes vaporization and cryogenic cloud formation, an example is shown in Fig. 3. Full details on the VR scenarios developed are available from partner CRISE but are not elaborated on here in this overview

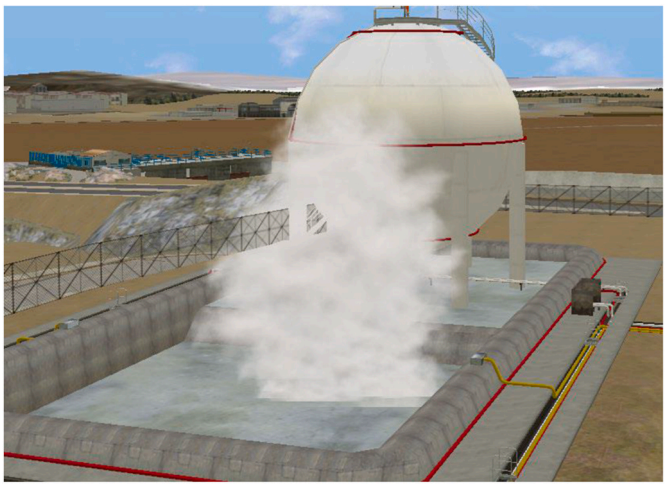

Fig. 3. LH2 leak, dispersion, and possible pool formation at a storage facility.

paper.

2.4. Stratification of teaching materials in the educational lectures

It became apparent through discussions with firefighters across Europe that training needs and educational backgrounds varied significantly. In some countries a significant number of responders are volunteers. Thus, it was deemed that the educational lectures initially developed where at a level which was not fit for purpose for all. Four different learning levels were defined, corresponding to identified roles and competence levels for.

- Firefighter.
- Crew Commander.
- Incident Commander, and
- Specialist Adviser.

The specialist adviser role is the most detailed being the equivalent to the level of training required by for example HAZMAT officers. The roles were selected on the basis that there are recognised equivalencies across the countries represented within the project. The learning levels were also aligned to the European Qualifications Framework (EQF) for future reference and possible incorporation within national competency certification frameworks. These were validated by responders from each region represented in the consortium and through CTIF ("Comité Technique International de prevention et d'extinction de Feu").

The stratified framework was used as the organisational basis to define and assemble the educational lectures into 4 levels, each being appropriate to the topic and role, to support adoption and integration by any particular training centre into its curriculum and training courses. It was agreed that the Level 1 "Firefighter" should be the initial focus when translating materials, and in the focus for a standard training framework beyond the project to help achieve greater benefit and absorption of the training by the end user community of responders, many of whom are volunteers or operate in remote locations.

2.5. European Emergency Response Guide

The European Emergency Response Guide (EERG) on hydrogen and fuel cell applications for first responders was produced within HyResponse [1,2]. It is intended to be used by emergency response personnel, both by front-liners and commanders, from the moment they have received an emergency call until the incident resolution. It is intended that the EERG will support the decision-making personnel, who already have knowledge of emergency response operations and procedures. The EERG, familiarity with its content, use, and application forms an important element of the training materials for responders. Within HyResponder the Guide has been essentially revised and updated to reflect progress in the field. Specifically, the revised EERG includes events related to LH2 (outcomes on pre-normative research project PRESLHY) and confined spaces (outcomes on pre-normative research project HyTunnel-CS). New vectors of mobility and transport such as buses, trucks and trains were added. Two new sets of operational tactical sheets were inserted, and the previous version was enriched with multiple contributions from stakeholders, responder trainers, the consortium and beyond. Indeed, the working version of the revised guide was made publicly available via the HyResponder e-Platform throughout the project to maximise feedback. The final version is now available on the HyResponder site (https://hyresponder.eu/e-platform/european-emergency-response-guide/). It is intended to be used as a guide only, whilst keeping national specificities in mind.

2.6. HyResponder e-platform

An e-Platform for responders (https://hyresponder.eu/e-platform/) has been implemented online by partner PERSEE. The platform is intended to be a "one stop shop" for all information and training resources to be utilized by responders. As shown in Fig. 4, the platform incorporates the EERG, the educational training materials at each level, details on the operational and virtual reality training and online tools for hydrogen safety (e-Laboratory of Hydrogen Safety).

Training materials in 8 European languages are accessible and searchable on the e-Platform. One of options at the project outset was to develop the educational lectures into interactive training modules. However, feedback received across the responder community indicated that the preferred approach would be to have documents validated by the consortium freely available instead. Effectively acting as a repository of information. It was agreed that it was not necessary to develop a "one size fits all" training programme as the needs varied so greatly across Europe, nor was this deemed the best way by the responders. Ultimately, by providing a wealth of information, training organisations can select the content to align to their existing training provision and adapt as required. The training package presented on the e-Platform incorporates the educational lectures, online tools, EERG and also "training sequences". It is expected that responders providing training in hydrogen safety have undertaken operational training in this area. Information is provided on the facilities available at ENSOSP and the VR capabilities that can be provided by CRISE. However, not all fire schools will be able to replicate this training locally. Whilst not a substitute, topical "training sequences" have been developed to support trainers. These materials are not intended to replace hands-on training and should be used by trainers who have undergone appropriate training as prompts. Each sequence incorporates one or more videos and refers directly to the relevant tactic sheets in the EERG. For each sequence three elements should be used, namely: a summary video sheet with embedded video links, the EERG and the related exercise sheet. Examples of sequences include vehicle fires and an LH2 incident. An e-Forum to facilitate discussions has been incorporated.

2.7. Guidelines for training: firefighter safety with hydrogen

A goal of HyResponder is that the training impacts well beyond the lifetime of the project and becomes the recognised standard of training for responders in Europe. The International Association of Fire and Rescue Services, CTIF, is an international non-governmental organisation of fire and rescue services present in 40 countries worldwide, with representation in national associations and groups who in turn represent millions of firefighters globally. Within this context, CTIF was well placed in the project to provide input to training and develop recommendations for a route to ensure the training developed in HyResponder is the recognised training standard. A key output of HyResponder has

Fig. 4. Landing page of the HyResponder e-Platform.

been a framework for recognition of firefighter level training. The aim is to seek recognition of first responder firefighter training in Europe to enable the wide diversity of emergency first responders that exist, primarily in Europe, to seek and secure localised arrangements to develop and promote acceptable practice standards using the HyResponder training outcomes. The objective is to try and ensure the training being developed is accepted and adopted by as many first responders as possible to help sustain the educational gains from HyResponder and to secure comparability of practice to aid interoperability at hydrogen related emergencies.

A programme has been designed to generally satisfy qualification requirements for the European Qualification Framework at Level 2 by providing basic factual knowledge in a field of work. This level will provide basic cognitive and practical skills so that relevant information can be used in order to carry out tasks and solve routine problems using simple rules and tools whilst working under supervision with some autonomy. The suggested programme covers the equivalent to 20 h of guided study and practice with each unit based on each 2 h period of learning time. Learning time is the time taken by trainees at the level of the unit, on average, to complete the learning outcomes to the standard determined by the assessment criteria. The Framework is intended to be flexible and to complement and support local training arrangements.

3. Train the trainer

HyResponder identified and trained the responder trainers from across 10 European countries, who would in-turn deliver training locally and develop a longer-term plan for impact on training in their region beyond the project. There is significant variation in knowledge and experience of FCH technologies across responder training organisations in Europe. The approach to training varies from country to country, in some cases there is a national training programme, in others training is specific to a province or region. Currently a disparate approach is taken to the delivery of hydrogen safety training for responders with responders, academics and industrial experts providing training, depending on the local circumstances. Thus, "National Training Clusters" were established in 10 countries in Europe (Austria, Brussels, Czech Republic, France, Germany, Italy, Norway, Spain, Switzerland, and the United Kingdom). These incorporated responder training organisations, experts in hydrogen safety, and additional stakeholders where appropriate. Each training cluster nominated trainers to take part in the HyResponder training.

Ideally the educational lectures, operational and VR training would be taken over the same period. However, due to the Covid pandemic, it was necessary to split the training rather than postpone it indefinitely. Initially a 5-day virtual training course was delivered in June 2021, followed by hands-on training at ENSOSP in June 2022. A consequence of this approach was the development of the digital training resources described in Section 2.6. Specifically, the training sequences, supported by video content. These resources were not foreseen at the project outset but have been a welcome output of the project, forming part of a wider "training package" to be used by trainers.

4. National training

The HyResponder training package has been introduced by trainers in 10 European countries: France, Austria, Belgium, Italy, Switzerland, Germany, Norway, Czech Republic, Spain and the UK. The format of the delivery varied across the regions, depending on local needs and capabilities. In each country a plan is in place to ensure the training is built upon beyond HyResponder, some examples are given in Section 5. A summary of the training leads and formats is given in Table 1, and

Table 1
Overview of initial training delivered at a national level.

	Region	Lead	Supporting organisations	Format of initial training	Language
1	Austria	Landes-Feuerwehrschule Tirol		Online, e-learning modules	German
2	Belgium	Service Public Federal Interieur	Center of Expertise, KCCE, Brussels	Online and F2F workshop	Dutch French
3	Czech Republic	Fire and Rescue Service of the Czech Republic		F2F workshop	Czech
4	France (I)	ENSOSP French National Fire Officers Academy	CRISE	F2F, hands-on	French
5	France (II)	Commissariat à l'énergie atomique et aux énergies alternatives	Local fire brigades and hydrogen energy stakeholders (companies, governmental organisations)	Hybrid workshop	French
6	Germany	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	Fire service of Oldenburg	F2F workshop	German
7	Italy	Sapienza University of Rome	Italian National Fire Corps	F2F workshop	Italian
8	Norway	University South Eastern Norway		F2F workshop	Norwegian
9	Spain	Zaragoza Ayuntamiento	University of Zaragoza, Foundation for the Development of New Hydrogen Technologies in Aragon	F2F workshop	Spanish
10	Switzerland	International Fire Academy		F2F workshop	German
11	United Kingdom	Fire Service College		F2F workshop	English

Note: F2F – face to face.

further details on national approaches can be found in a parallel publication.

In all cases the National training was delivered in the local language and supported by the HyResponder materials. However, to account for local preferences there was no "one-size fits all" with approaches ranging from fully online to in-person. Some partners have secured additional national funding to develop smaller scale operational facilities to complement the training delivery long term. Whilst in some countries the training package could be used almost in its entirety, in others, for example Switzerland a need continues to exist for training focused on confined spaces, and it is acknowledged that this is not covered by the operational facilities developed within HyResponder, i.e. at ENSOSP (France).

Three examples of training approaches within HyResponder are online (Austria), Hybrid (Norway) and in-person (Italy). The first regional training was delivered in Austria, where online training modules in German have been developed and successfully delivered by Landes Feuerwehrverschule Tirol. This has evolved to two courses, one in basic knowledge and one for specialists. To date, over 200 responders have enrolled in the basic course in Austria. It is expected to reach 800 participants in the basic hydrogen knowledge training and 350 in specialist training by the end of 2023. A hybrid approach has been taken by USN in Norway, where following in-person training in Norwegian, longer-term plans are underway for both online workshops, and physical workshops around Norway, with 5 additional face to face activities delivered to date. In Italy, where the Università degli Studi di Roma "La Sapienza" are the lead partner, an initial workshop was organized together with the National Fire Corps as part of a wider 3-day event "Days on energy transition, sustainability and fire safety". One day was dedicated to hydrogen, and the HyResponder training programme specifically. A small scale operational facility was used to present practical tests of jet fires generated by different fuels: LPG, methane and hydrogen, thus evidencing the differences among them.

5. Longer term plans for hydrogen incident responder training

The e-Platform established by HyResponder will be supported beyond the project and will remain as a resource for responders around the globe. However, a key outcome of the project is longer-term impact on responder training within each of the regions represented within the project. The intention from the outset of HyResponder was to ensure the training was embedded within national training wherever possible and developed. Plans are in place within each of the 10 countries as described elsewhere. Three examples are given below for illustration purposes.

In Italy a working group focused on hydrogen safety training has been formed. Planned activities beyond the project include, long term consideration of the training framework developed within HyResponder, and development and delivery of a course on hydrogen safety as one of the standard courses offered to the officers by the Italian National Fire Academy.

In Belgium recognition of the HyResponder training has commenced through the relevant official bodies, namely the Ministry of Home Affairs (Center of Expertise), the result will be official recognition of the course and a certificate (High Council for Education). Plans are in place for annual national training up to 2028.

In France, a 5-day training module has already been offered by ENSOSP to hydrogen risk ambassadors in the French fire services. The training will utilise the training package. Delivery of this training outside of HyResponder has commenced.

6. Conclusions

The *originality* of HyResponder is in its innovative and flexible training approach, indeed three of the outputs have been recognised and analysed by the European Commission's Innovation [15] and categorised as addressing the needs of existing markets, these are: (1) The e-Platform to support training of responders in hydrogen safety, (2) Novel training sequences to support online training of responders, and (3) Stratified training materials for responders spanning four learning levels.

The *significance* of HyResponder is in its impact across training for responders across 10 countries. Plans are in place to ensure the training is utilized beyond the project in Austria, Belgium, the Czech Republic, France, Germany, Italy, Norway, Spain, Switzerland, and the United Kingdom. Through HyResponder a train the trainer programme in hydrogen safety for responders has been developed and implemented across Europe. Over the course of the project the goal of a "one-size fits all" training has evolved into region specific training to ensure a more sustainable approach.

The *rigour* of the HyResponder outputs is in the robust approach to review and the development of the teaching materials and the standard training framework. Training organisations from across Europe have been actively involved in each step of the process. Operational, virtual reality and educational training materials have been updated and revised to incorporate liquid hydrogen applications and materials in

support of this are available on the HyResponder e-Platform. Four levels of educational materials have been developed, and a framework is in place to develop a European Standard in Training at Firefighter level. Training has been delivered across 10 countries, in the local language and plans are in place, and activities underway to ensure the training has impact beyond the project. A revised European Emergency Response guide is available on the e-Platform.

CRediT authorship contribution statement

Síle Brennan: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Christian Brauner:** Writing – review & editing, Investigation, Conceptualization. **Dennis Davis:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Natalie De Backer:** Writing – review & editing, Methodology, Conceptualization. **Alexander Dyck:** Writing – review & editing, Methodology, Conceptualization. **César García-Hernández:** Writing – review & editing, Methodology, Conceptualization. **André Vagner Gaathaug:** Writing – review & editing, Methodology, Conceptualization. **Petr Kupka:** Writing – review & editing, Methodology, Conceptualization. **Laurence Grand-Clement:** Writing – review & editing, Conceptualization. **Etienne Havret:** Writing – review & editing, Methodology, Conceptualization. **Deborah Houssin:** Writing – review & editing, Methodology, Conceptualization. **Laurent Lecomte:** Writing – review & editing, Methodology, Conceptualization. **Eric Maranne:** Writing – review & editing, Methodology, Conceptualization. **Pippa Steele:** Writing – review & editing, Methodology. **Paola Russo:** Writing – review & editing, Methodology, Conceptualization. **Adolfo Pinilla:** Writing – review & editing, Methodology. **Gerhard Schoepf:** Writing – review & editing, Methodology, Conceptualization. **Vladimir Molkov:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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