Pre-normative REsearch for Safe use of Liquid Hydrogen (PRESLHY)

Project Deliverable

Report on the Communication Activities carried out to the General Public

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Key words

PRESLHY project summary; outcome; knowledge gaps; recommendations; publications list; communication; dissemination; workshops, events, conferences, website.

Publishable Short Summary

The present deliverable reports the communication activities carried out by the PRESLHY consortium to promote and disseminate the project outputs during the project duration. Particular attention is given to the main dissemination event organised by the consortium itself, i.e. the PRESLHY dissemination conference held on the 5-6 May 2021, by reporting the presentations, discussions, minutes and main outcomes of the international event.

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1 Introduction

The present deliverable reports the communication activities carried out by the PRESLHY consortium partners to advertise and disseminate the project outputs during the project duration. These include participation to international conferences and meetings, organisation of workshops, publications in peer-reviewed journals, etc. Focus is posed on the culmination event of the project, the PRESLHY dissemination conference, which was held on the 5-6 May 2021. The event proved to be a crucial activity for communicating the project outputs to the relevant stakeholders. This report provides an overview of the conference organisation, promotion and performance indicators. Furthermore, it summarises the minutes and main outcomes of the international event.

The listed dissemination activities follow the plan for the dissemination, communication and exploitation (PRESLHY D6.8 delivered December 2020), which reports a detailed description of each dissemination activity.

The communication activities addressed multiple audiences including relevant stakeholders, European institutions, academia and research organisations, education and training institutions, etc. Therefore, the present report presents all the performed communication activities widening the meaning of "general public" to all the target groups who can freely access PRESLHY outputs via public deliverables, dissemination conference, project website, open data repository, etc. Details on the target groups addressed by PRESLHY project are given in (PRESLHY D6.8).

2 PRESLHY dissemination conference

2.1 Organisation and performance

The Dissemination Conference was held as an online event on the 5-6 May 2021 and was organized by Ulster University. The conference date has been moved from M36 to M41 according to the project extension and amendment of the Grant Agreement. The developments in Covid-19 pandemic undermined the feasibility of the initially planned physical meeting in Athens, Greece. Therefore, the conference was turned into an online meeting, hosted and supported by NCSR "Demokritos".

The brochure and preliminary programme of the dissemination conference was prepared by UU in June 2020 (milestone MS28) and finalised in November 2020. A first announcement and invitation to the conference was electronically distributed in December 2020, once the project extension was officially announced. This was distributed through UU network to over 1000 people, and through HySafe and partners' networks. The conference was advertised through several announcements. A second and third announcement containing conference updates and info for registration were distributed in March and April 2021, respectively. A dedicated page on the project website had been set-up and regularly updated. The dissemination conference was further advertised during events where PRESLHY project outputs had been presented, e.g. the online HyResponder project meeting on 19th January 2021 and the online webinar "How to meet the safety challenges of hydrogen" on 22nd April 2021.

The conference had a duration of two days. The intense tentative programme included 37 presentations. The Project Officer presented the FCH JU activities and scope. Speakers from PRESLHY consortium presented the results of the outstanding research performed on the major phenomena associated to the release and dispersion of liquid and cryo-compressed hydrogen, the ignition of cryogenic hydrogen-air mixtures and their combustion. The conference addressed the potential impact of the project outputs on the international community working on hydrogen and fuel cell technologies. Presentations by invited international speakers enriched the conference program, providing a throughout overview of the state of the art and worldwide research on safety of liquid hydrogen. These include representatives from SH2IFT project, Kawasaki Heavy Industries, Daimler, Demaco, Sandia National Laboratories, DNV GL, Gexcon, Institute of Transport Economics and AVT. The two days of the conference were concluded by round table discussions on the presented project outcomes. The detailed programme is available in Appendix A. The conference programme has been subdivided in 7 sessions as follows:

1. Opening session
2. Liquid hydrogen applications
3. Liquid hydrogen releases
4. Cryo-compressed hydrogen releases
5. Ignition of cryogenic hydrogen-air mixtures
6. Combustion of cryogenic hydrogen-air mixtures
7. Implementation and impact of the research outcomes.

Registration and attendance

In total, 345 registrations were recorded from 25 different countries. Figure 1 shows an overview of the distribution of registrations by country. The registered audience included several members of industrial companies and academic institutions. Among the industrial companies, a high number of registrations came from Shell, DNV GL, Airbus, Toyota Motor Europe, Hyundai Motor Company, Gexcon, Equinor ASA, Engie, etc. This showed to be a great indicator of the wide types of industry engagement in PRESLHY conference. Among academic institutions, a large number of registrations was recorded from University of Bologna, University of Bergen, Hoseo University, etc. Overall, it is considered that the conference reached a well widen international and diversified audience.

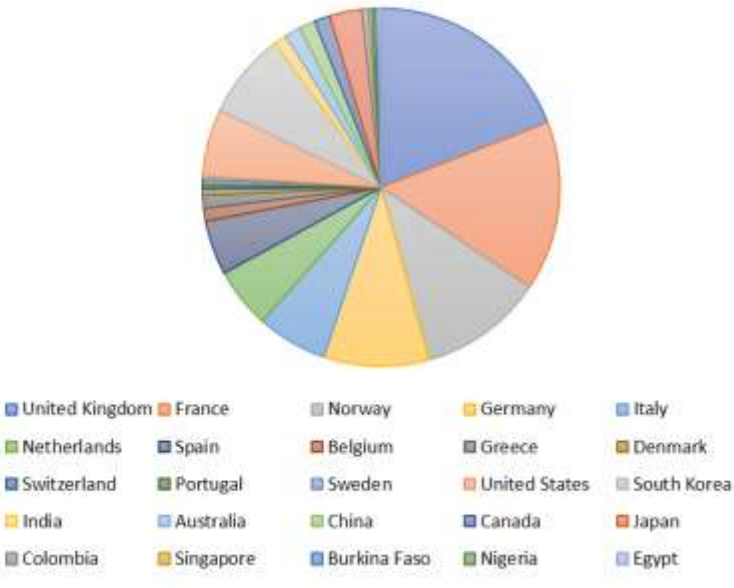

Figure 1. Registration to PRESLHY dissemination conference by country.

Throughout the intense two days conference a total number of 260 attendees joined the event, and a peak of 167 simultaneous connections was achieved. The conference presentations and video recordings, where consented, are available on PRESLHY website. It is considered that this is an optimal way to further disseminate the conference outputs and knowledge among stakeholders and people who could not attend entirely the two days programme.

2.2 Minutes of the dissemination event

The present section summarises the minutes of the conference. The detailed programme for the dissemination event on May 5th and 6th, 2021, the downloadable presentations as well as video recordings may be found under: http://www.preslhy.eu/meetings/dissemination-conference/

2.2.1 Opening session

T. Jordan, KIT and PRESLHY coordinator opened the meeting. He presented the two-days programme. Each day will be concluded by round table discussions to summarize the important findings of the dissemination event.

The following speaker Alberto J. Garcia Hombrados, project officer, Fuel Cells and Hydrogen – Joint undertaking presented the "Safety-related activities – Overview" (presentation available here). He gave an overview on the related FCH 2 JU activities provided by the EU Institutional Public-Private Partnership (PPP). It is the cooperation of Hydrogen Europe an industry grouping with 185 members, the European Commission and Hydrogen Europe Research with more than 80 research members. The goal is to implement an optimal research and innovation programme bringing FCH technologies to the point of market readiness by 2020. The programme is concerned on hydrogen technologies in the fields of Energy, Cross-cutting and Transport. The cross-cutting activities are concerned with regulations, codes and standards, education and training, Safety, social awareness & public acceptance, sustainability and databases & monitoring. The complementary actions for safety related activities are found in the Regulations, Codes and Standards Strategy Coordination Group (RCS SCG), the collaboration with the Joint Research Center (JRC) and the European Hydrogen Safety Panel (EHSP). Hereunder is the Pre-Normative Research (PNR) an essential step to advance RCS activities with the PRESLHY project being one of the important projects with PNR. Another on-going example is the HYTUNNEL-CS project on PNR for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces (https://hytunnel.net).

Further mentioned projects in the field are:

- HIGGS: A systematic validation approach at various admixture levels into high-pressure grids https://www.higgsproject.eu;
- THYGA: Testing Hydrogen admixture for Gas Applications https://thyga-project.eu;
- MULTHYFUEL: multi-fuel hydrogen refuelling stations (HRS): a co-creation study and experimentation to overcome technical and administrative barriers https://multhyfuel.eu;
- e-SHyIPS: Ecosystemic knowledge in Standards for Hydrogen Implementation on Passenger Ship https://e-shyips.com;

- TEACHY: Teaching Fuel Cell and Hydrogen Science and Engineering Across Europe within Horizon 2020 http://teachy.eu;
- HYREPONDER: European Hydrogen Train the Trainer Programme for Responders https://hyresponder.eu.

In summary the FCH 2 JU safety activities are important, because:

1) A high degree of safety is essential for the commercialization of FCH technologies;
2) FCH 2 JU commitment towards safety is sound, proactively promoting safety culture in Europe;
3) Cross-cutting projects and other supporting activities are contributing to a safe and frictionless deployment of FCH technologies.

The third presentation was given by T. Jordan presenting an overview of the PRESLHY project. This presentation is also found in appendix B.

The motivation of the project is to close the main knowledge gaps with regard to accidental behaviour of LH2 and inconsistent and potentially over-conservative RCS as e.g. stated in NFPA 2 and EIGA. There are 9 PRESLHY partners:

1. Karlsruhe Institute for Technology, Germany (coordinator)
2. Pro-Science, Germany
3. AirLiquide, France
4. Ineris, France
5. NSCR “Demokritos”, Greece
6. Ulster University, UK
7. Health and Safety Executive, UK
8. Warwick University, UK
9. International Association HySafe, Belgium

The objectives are anchored with the PNR (see Figure 2) and the prioritised research programme is driven by the initial report of the state-of-the art and identified knowledge gaps. The different work packages are shown in Figure 3.

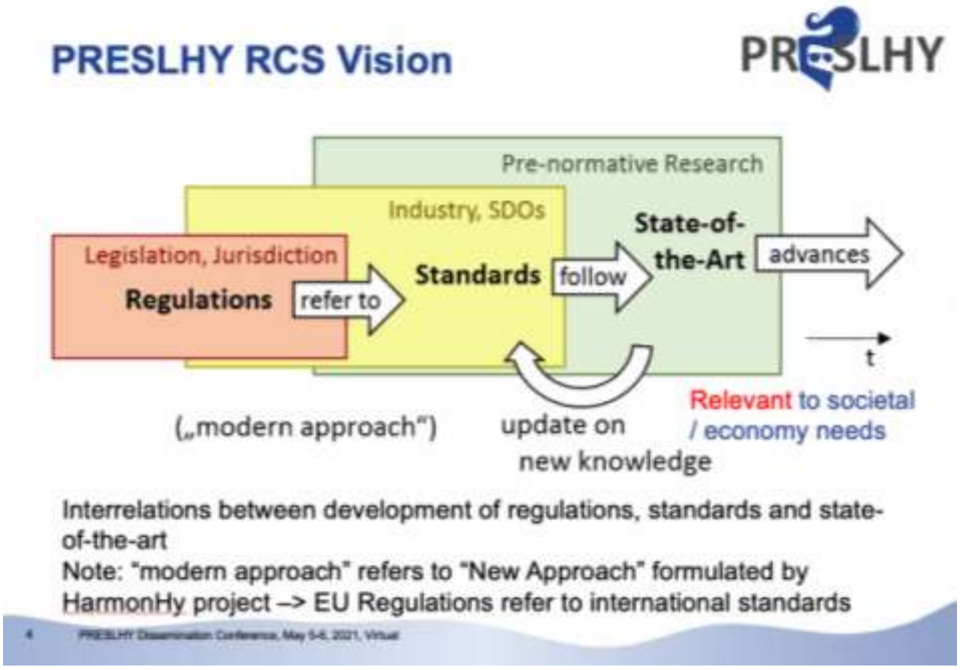

Figure 2. Pre-Normative Research (PNR) scope.

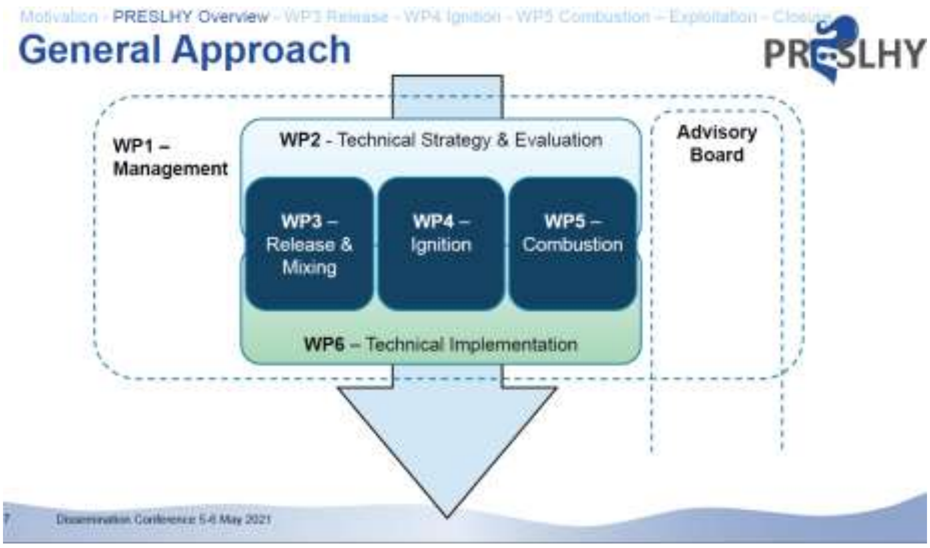

Figure 3. Structure of PRESLHY.

WP3 is designed to close knowledge gaps on LH2 releases. It developed a 1D model for multi-phase release including non-equilibrium processes. It measured discharge coefficients for circular nozzles with diameters between 0.5 and 4mm, pressures between 5 and 200 bar and temperatures between 20 and 300 K. Rain out tests provided no rainout for above ground horizontal release large scale tests by HSE. Temperature concentration correlation of cryogenic H2 air mixtures are obtained. Last and not least the effect of heat transfer through a pipe wall during a cryogenic hydrogen release is assessed.

Figure 4. Application areas of liquid hydrogen.

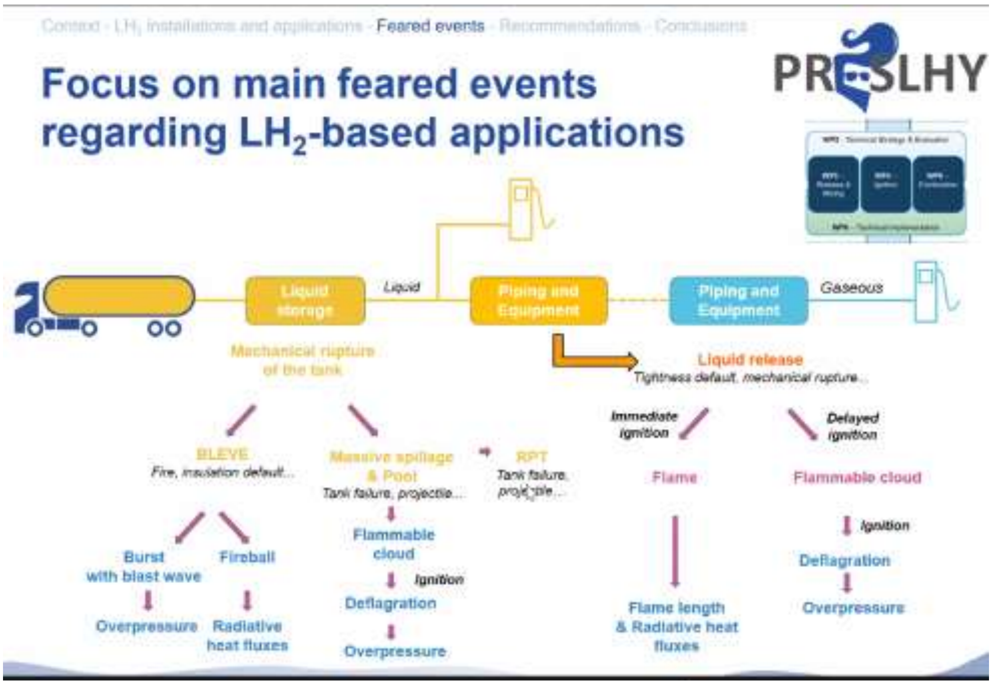

Figure 5. Knowledeg gaps for liquid hydrogen applications.

WP4 investigated the hot surface ignition temperature of LH2, which was found to be independent on mixture temperature, but with a marginal influence on the concentration and flow velocity. The minimum ignition energy (MIE) using a spark ignition device reproduced the findings from the reference tests at ambient temperature. Test at 173 K revealed a slight increase of the MIE. This was used to develop analytical and numerical models to predict MIE. Furthermore, electrostatic field measurements measured strong electrostatic fields at 80 K, which increased with increasing release pressure, but no spontaneous ignition was observed in these experiments. Multi-phase accumulations showed an explosion potential, as repeated spills on gravel beds might generate highly reactive condensed phase mixtures. This was not observed on other substrates. No critical effects were observed for water sprays on LH2 and LH2 spills on small water pools.

WP5 is concerned with combustion phenomena. The thermal hazards of cryogenic hydrogen jet fires are investigated. A CFD model is validated capable to assess the radiative heat flux for vertical and horizontal orientations. The buoyancy of combustion products has a positive effect on the reduction of the “no harm” distance for horizontal jet fires. Thermal radiation leads to longer “no harm” distances in the jet direction compared to hazard distances defined by temperature. The thermal dose provides to be a useful parameter for defining hazard distances for emergency personnel. Flame length dimensionless correlations can be expanded to cryogenic releases. The understanding of transient combustion effects is improved by conducting more than 100 discharge and ignited jet tests. In confined / congested domains, stronger pressure loads for cold tests are observed compared to “warm” tests provided the same volume, hydrogen concentration and blockage ratio. An increase in critical and defective expansion ratios determine the flame acceleration in cryogenic mixtures. The run-up distance for detonation transition DDT is reduced in cryogenic mixtures, while the influence of blockage ratio on DDT is less pronounced.

The results from PRESLHY are exploited. A number of knowledge gaps are closed and the state-of-the art knowledge on LH2 behaviour is improved. Models for use in risk assessment are developed. Recommendations for users and SDOs are established and a review or development of standards is initiated.

The overall impact of the PRESLHY programme will enable the safe and economic introduction of LH2/cryogenic hydrogen technologies with a flexible, but robust framework consisting of:

- Improved knowledge basis
- Consistent recommendations
- Performance based, harmonized specific standards to be referred by regulations.

An important part of the achievements is the white paper on LH2 solution for large scale storage of hydrogen presented by T. Jordan (presentation available here).

The next presenter in the opening session was S. Jallais presenting a critical analysis of the state of the art and research priorities (presentation available here).

The presentation resumes the process to identify the knowledge gaps at the beginning of the PRESLHY project. These were identified and ranked using a PIRT process. The findings were:

I. Release and mixing phenomena:
   1) Characteristics of flashing, multiphase releases and spillages in well defined conditions (subcooled, saturated) including rainout, pool evaporation, droplet granulometry & concentration
   2) Mass and heat transfer including phase transition (evaporation, condensing and freezing of contaminants) in LH2 releases and spillages
   3) Free cryo jet structure, morphology and behaviour in realistic conditions (impingement and surface effects)

4) Heavy gases and transition to buoyant dispersion
5) Possible interaction with active barriers: water spray, mist, curtains ...water foam

II. <u>Ignition phenomena:</u>
1) Influence of low T° on horizontal and downward flammability limits and MIE – Important to consider a credible flammable cloud
2) Electrostatic charging and ignition
3) Ignition of LH2 / condensed (solid) air

III. <u>Combustion phenomena:</u>
1) Unconfined obstructed explosion of cold mixtures
2) Laminar flame speed at low initial T°
3) Turbulent flame speed at low initial T°
4) Flame acceleration in tubes for cold mixtures
5) Critical expansion ratio of cold mixtures
6) Detonation cell size for cold mixtures
7) Rapid phase transition / BLEVE

2.2.2 Liquid hydrogen applications

The session provided four presentations. S. Kamiya from Kawaski Heavy Indutries talked about the world's first ocean going liquid hydrogen carrier (presentation available here). This is part of a demonstration project on-going between Japan and Australia. The certification process of a LH2 carrier is done based on Guidelines for LH2 carriers from March 2017. This includes the establishment of loading/ unloading terminals (e.g. in Kobe) and storage capacity.

The next speaker was L. Bernard from AirLiquide to report on the state of the art of LH2 installations and facilities (presentation available here). She explained the status of the LH2 infrastructure to provide LH2. For this development the main challenge is the risk and safety of the infrastructure. The goal of the PRESLHY project is therefore an excellent mean to answer such important questions to improving the future LH2 infrastructures.

This was followed by a contribution of J. Franzen from Daimler on LH2 application in heavy duty transport (presentation available here). Heavy duty transport is regarding 40 t trucks with a payload of 25 t. Long haul transport in a 10 years perspective is 120000 km/year. The powerful fuel cell electro motors will need 80 kg LH2 on board. The motors will provide 2 x 230 kW with a capability to reach peak power of 2 x 330 kW, which will make them equal to the performance of diesel motors. The state of the art of the standards using LH2 for trucks is presently still incomplete. The goal is to be on the road with such trucks by 2030.

The last speaker was R. Dekker from Demaco presenting LH2 application in cryogenic infrastructure (presentation available here). The presentation's focus is on solutions for the cryogenic infrastructures as well as LH2 in transport, distribution and consumer based applications. One example of technology is the closed loop infrastructure that will retransfer tank H2 emissions into the liquid state.

2.2.3 Liquid hydrogen releases

The session provided five contributions.

Bunkering scale LH2 releases on behalf of Norwegian Roads Administration: data and analyses by D. Allason, DNV GL (presentation available here). This is the report on a project initiated by the Norwegian road administration. Real scale experiments are performed with and without ignition, different tank pressures, different wind speeds and directions.

Atmospheric dispersion of large scale liquid hydrogen releases by J. Wen, University of Warwick (presentation available here). The work to model unignited LH2 release and the consecutive dispersion is described. The model is validated using former NASA tests. The influence of a pit around the place of the release is investigated using the HyFOAM code. The weather conditions, wind speed and ambient temperatures were variated.

Experimental study on formation and evaporation of LH2 pools by A. Friedrich, Pro-Science (presentation available here). The LH2 pool formation was investigated experimentally. The pool facility was 50 x 50 x 20 cm. Pool formation on concrete, sand, gravel and water was investigated. On gravel a 50% larger amount of LH2 could be absorbed due to the porosity.

Rain out in large scale LH2 releases by S. Coldrick, Health and Safety Executive (presentation available here). The programme included 25 tests to investigate the vaporisation and to characterize the flow to investigate the formation of solid deposits around the release point and the solidification of air. No rain out was observed, but the temperature of the concrete surface was not measured during these tests. Transient ignitable pockets above LFL were measured in a distance 14 m away from the release point. No unexpected ignitions were observed.

CFD validation against large scale liquefied helium/hydrogen releases by S. Giannissi, NCSR “Demokritos” (presentation available here). Modelling of LH2 releases are provided and validation is done on tests for Helium made by INERIS and HSE (110 kg He released in 52 sat a rate of 2.12 kg/s. The 3D steady state flow is modelled in dry air and different moister levels. Also a 3D transient dispersion model is employed.

2.2.4 Cryo-compressed hydrogen releases

The session included five presentations. The first presenter was E. Hecht, Sandia National Laboratory, Lab-scale dispersion of cryogenic hydrogen jets (presentation available here). Releases are characterised using Raman imaging techniques for H2 and Helium. The experiments were done at different temperatures, pressures and nozzle sizes. The finding is that the Gaussian shape of cold LH2 is slightly broader than the “warm” release. The LH2 release provide still self-similar behaviour. HyRAM is based on these results updated to enable calculations with LH2, but need to have more validation presently.

D. Cirrone, Ulster University, Effect of heat transfer through discharge line on parameters of cryogenic hydrogen release (presentation available here). Experiments with cryogenic hydrogen releases at the ICESAFE facility at KIT are used for validation of a CFD model accounting for heat transfer. Results are compared to those obtained with assumption of an adiabatic pipe wall.

E. Vyazmina, Airliquide, CFD benchmark on cryogenic hydrogen jets (presentation available here). Results of a modelling benchmark among three PRESLHY partners. A temperature difference of 20 K between the simulations and the experiment is observed. For a nozzle size of 1.25 mm all the three simulations underestimated the centreline concentrations.

A. Friedrich, Pro-Science, High-pressure cryogenic hydrogen releases (presentation available here). The blow down behaviour is investigated using KIT's DISCHA facility for releases at 80 K and 200 bar. The preliminary results indicate no ignition due to electrical discharges. An electrostatic field is observed due to ice crystal formation. The findings are based on 200 experiments with 4 nozzle diameters, 7 initial pressures and 2 initial temperatures.

A. Venetsanos, NCSR "Demokritos", An engineering tool for discharge calculations (presentation available here). The development of the model is presented that uses the Helmholtz free energy theory to enable prediction of the physical properties of normal and para hydrogen, methane, water vapour, carbon dioxide and nitrogen. The model includes a storage tank release, discharge time variations and virtual nozzles taking the 7 different models from the literature. The early version is implemented in the Net-tools environment.

LH2 coupling with superconductors by W. Fietz, Karlsruhe Institute of Technology (first presentation of day 2 - available here). The different storing concepts for LH2 are shown to be combined with superconductors enabling future pipeline transport of LH2 combined with super conductor transport of electrical power within these pipelines using LH2 as a coolant. This is investigated in the AppLHy project.

ROUND TABLE discussion day 1 (chair: T. Jordan)

The round table discussion was concerned with the further important phenomena to know more about.

Among these, it was highlighted the need for a better understanding on the influence of ice formation in the release and distribution phase. Appropriate tools are developed to predict such releases and distribution. It was found that PRESLHY contributed to better understand the near field phenomena. The release modelling is improved, which is important for risk assessment. This should be elaborated further. Knowledge on the performance of experiments and how to measure concentrations in case of transient releases should be further addressed in future projects. Good data are now available from Sandia and DNV experiments. The data are shared.

In Japan, many activities related to LH2 are on-going. This is an excellent basis for new or iterated standardization developments. Hereunder is the establishment of separation distances important to be revised in future standards. The releases should also in the future consider non adiabatic / non isotropic releases as they are needed to be considered for heat transfer in pipes and bulk storage. The understanding is still kind of black box in the experiments and combined with CFD this should be understood better. Another knowledge gap is seen in the balance between vapour and liquid at the release point and the two phase release modelling still has some issues to be resolved.

2.2.5 Ignition of cryogenic hydrogen air mixtures

The session was opened by C. Proust, Ineris, with a presentation on the ignition parameters of cryogenic hydrogen-air mixtures (presentation available here). Experiments on hot surface ignition as well as on spark ignition of cold hydrogen air mixture are reported. The experiments are done at various temperatures and a wide range of flow speeds. The MIE seem to increase slightly with temperature drop.

This is followed by a presentation of D. Cirrone, Ulster University, reporting on analytical and numerical determination of MIE by spark ignition (presentation available here). Chemical kinetics model is established by help of the CHEMKIN software package and has been implemented in form of a 13 species / 37 reaction steps model into a CFD code. The code reproduced experimental findings well, e.g. MIE.

P. Hooker, Health and Safety Executive, contributed with an experimental presentation on electrostatic charge in multiphase hydrogen releases (presentation available here). A great number of experiments investigated the potential multi-phase deposits (solids/liquids) from LH2 leaks. The clouds may create electrostatic ignition hazards. Therefore, the degree of charging that occurs inside the cloud is measured, including wall current measurements.

The session was closed by A. Friedrich, Pro-Science to report on ignition and flame propagation over a LH2 pool (presentation available here). The KIT pool facility setup is used. The ignited test using gravel as ground material caused an explosion. The gravel absorbed a much larger amount of hydrogen compared to concrete and sand. The explosion maybe be due to solid oxygen in the gravel experiment.

2.2.6 Combustion of cryogenic hydrogen-air mixtures

The first contribution was by F. Ustolin, Norwegian University of Science and Technology, on results from modelling of BLEVE: model validation and preliminary calculations for SH2IFT experiments (presentation available here). This was shared with a presentation by K. van Wingerden, Gexcon, on planned experimental work on BLEVE and how tests will answer the questions arising from modelling (presentation available here). The first part provided results from BLEVE modelling predicting LH2 tank fragments and fireball sizes. The second presentation presented the plans to perform BLEVE experiments in September 2021 at BAM site in Horstwalde, Germany. The tests comprise 3 vessel of 1 m^3 volume. The BLEVE will be triggered by an external propane fire.

A. Friedrich, Pro-Science, presented a characterisation of high pressure cryogenic hydrogen jet fires (presentation available here). The ignited DISCHA experiments are presented. Tests were made with 3 different nozzle sizes and a number of cameras and measurement equipment is used to detect the experimental parameters. It is found that there is a possibility of burn back in a few cases.

D. Cirrone, Ulster University, followed talking about thermal hazards from cryogenic hydrogen jet fires (presentation available here). Sandia experiments reported larger flame length and higher thermal radiation from cold jet fires. This leads to larger no harm distances. Presentation discussed results of CFD simulations on cryogenic hydrogen jet fires.

J. Wen, University of Warwick, presented the dynamics and flame characteristics of cryogenic hydrogen jets – a numerical study (presentation available here).

M. Kuznetsov, Karlsruhe Institute of Technology, talked about flame propagation regimes at cryogenic temperature (presentation available here). Presentation included results from the outstanding experimental work performed within PRESLHY to investigate flame acceleration in cryogenic hydrogen-air mixtures and the potential for Deflagration to Detonation Transition (DDT).

S. Coldrick, Health and Safety Executive, talked about the effect of congestion/ confinement on a cold plume combustion (presentation available here). Conclusions were based on the experiments performed for different congestion levels and hydrogen leakages.

2.2.7 Implementation and impact of the research outcomes

C. George, Institute of Transport Economics, on Societal perception and barriers to hydrogen fuel applications. The societal perception and barriers in connection with hydrogen fuel applications have been analysed in Norway. The hydrogen is considered sustainable in the society.

T. Jordan presented results of the cooperation with K. Verfondern, Research Center Juelich, on a chapter on LH2 safety for the Handbook of Hydrogen Safety (presentation available here). The book chapter is based on a former NoE HySafe activity the Biannual Report on Hydrogen Safety (BRHS) and the present PRESLHY results.

D. Cirrone, Ulster University, Engineering correlations and tools for cryogenic hydrogen hazards assessment (presentation available here). The detailed correlation and tools are reported in PRESLHY D6.5. Non-adiabatic blow down model and steady state single / two-phase choked / expanded flow approaches are presented. The dispersion and mixing of the cold H2 cloud can be assessed as well to estimate the final state of the mixture. This is compared to experiments from HSE. Extents of liquid hydrogen pools can be characterised by a model provided by INERIS. Analytical models are provided to estimate ignition parameters as the minimum ignition energies and the electrostatic field built-up. The laminar burning velocity and expansion rates for H2-air mixtures are established by INERIS, as well as the thermal hazards from jet fires by University of Ulster. Pressure hazards may be predicted as well.

L. Bernard, Airliquide, presented guidelines for safety and operation of LH2 (presentation available here). The guidelines include the formation of solid deposits (ice particles), the pool formation and the established flows of horizontal releases.

A. Tchouvelev, AVT, focused on the analysis of current standards and regulations. (presentation available here). An overview on the ISO /TC 197 committee work is provided. An area of concern are the public hydrogen fuelling infrastructures for cars, busses, trains and boats as well as residential applications. The LH2 is from the industry side a mature technology with very good safety records. It is in operation for more than 60 years. RCS priority topics are questions on degree of congestion around facilities, safety / separation hazard distances for cold gas venting, pool fires, solid air and rain out, the mitigation applying fire barriers to reduce safety distances, etc. For LH2 the hazardous area concerning transport and transfer operations are connected to spill control and prevention, spill mitigation concepts as well as the vent stack design. The NFPA 2/55 :2016 code as released in the present 2020 version has not updated many safety distances.

D. Houssin, Airliquide, reported on the PRESLHY recommendations for RCS (presentation available here). The recommendations compiled in D6.3 Recommendations for RCS are reported. In total 19 recommendations are formulated and have been listed in the presentation. Related publications are D6.2, D6.5 and D3.1 as well as the White paper and the Handbook of Hydrogen Safety.

The session and the last presentation of the two days workshop was made by T. Jordan, Karlsruhe Institute of Technology, on PWI “ Safe use of LH2 in non-industrial settings” for ISO/TC 197 (presentation available here). The objectives and scope for this Preliminary Working Item (PWI) is explained. Out of several options, it is decided to start a new working group WG24 task 2. The kick-off meeting is scheduled for June 21st 2021.

ROUND TABLE discussion day 2 (chair: T. Jordan)

The last presentation presented a number of potential knowledge gaps (see Figure 6) to be addressed by the Preliminary Working Item group. These were more widely discussed during the round table session.

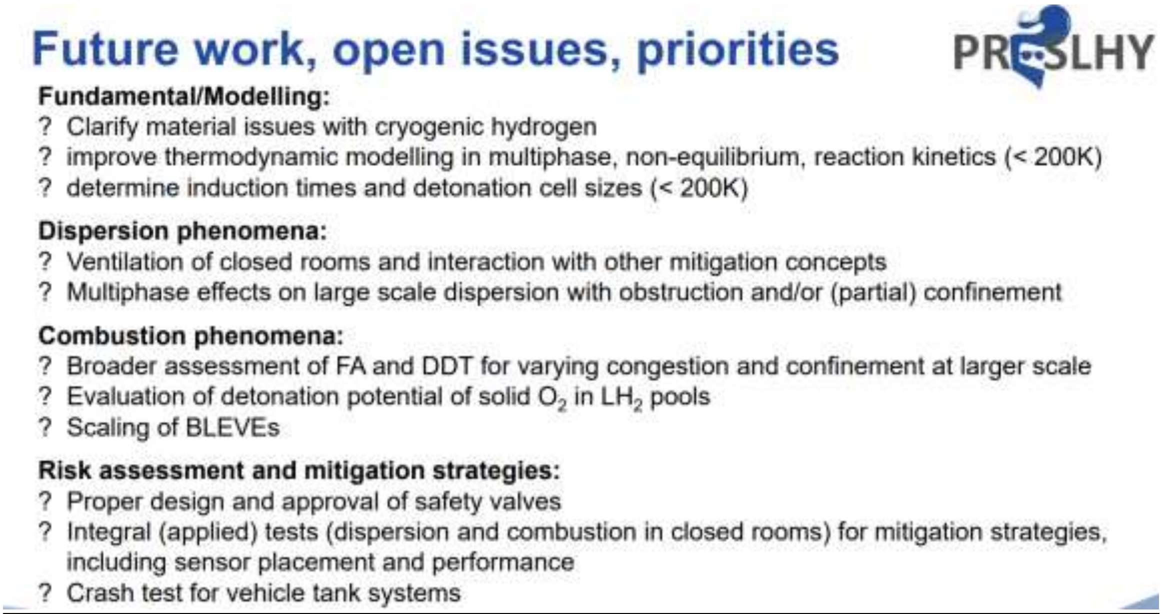

Figure 6. Future work, opening issues and priorities: points for round table discussion – day 2.

3 Dissemination and communication activities

This chapter reports all the dissemination and communication activities carried out by the PRESLHY consortium partners beyond the project dissemination conference, described in detail in Chapter 2.

All the communication activities addressing the audiences that can freely access PRESLHY outputs are listed and summarised. Among the open access channels can be mentioned the project website, conferences, publications, etc. The number of attendees to the organised events or number of contributions to international conferences and meetings are reported as performance key indicators. Detailed description of each activity and addressed target groups can be found in the plans for the dissemination, communication and exploitation. An initial plan was prepared in M6 of the project (PRESLHY D6.6), and was further updated and refined in two following updates in M18 (PRESLHY D6.7) and M36 (PRESLHY D6.8).

The project website is one of the main platforms for communicating the project progress and generated knowledge (www.preslhy.eu) by ensuring a free and open access to the produced outputs. All public deliverables were made available in a dedicated page, including the project key outputs implementing and exploiting the pre-normative research outcomes and conclusions:

- Chapter on LH2 safety for the Handbook on Hydrogen Safety
- White paper
- Novel engineering correlations and tools for LH2 safety
- Guidelines for safe design and operation of LH2 infrastructure
- Recommendations for RCS

A project poster and flyer were developed and used as promotional material at several dissemination events, including ICHS 2019, FCH JU review days 2019, etc.

3.1.1 Newsletter

A periodic newsletter has been prepared by UU and released by PRESLHY consortium to raise awareness of the project progress and outcomes among relevant target groups and stakeholders. The newsletter provided insights into the technical implementation and research activities of the project, including the experimental campaign, numerical and analytical studies and at highlighting the achieved results. The contents are concise to facilitate an easy and smooth reading of the edition, and the reader is provided with the proper links for more details. Finally, the newsletter advertises the events related to the projects, both past and upcoming.

Totally 5 issues were released during the project in M18, M20, M25, M36 and M41. They are available on the project website. The newsletter was circulated in electronic format through the partners' networks and uploaded on the project website.

3.1.2 Workshops

A series of workshops were organised to exchange knowledge and disseminate the project results. Four "technical" workshops were organised within the consortium and HySafe networks to exchange knowledge and expertise on special measurement technologies, experimental or numerical procedures and tools. The workshops were organized in conjunction with the project meetings to assure partners and advisory board members presence, reaching up to 25 attendees. The workshops were organised by the hosts of each project meeting, with support of work package leaders and coordinator. Table 1 reports the list of the organised workshops. Although indicated in previous plans (see PRESLHY D6.8), the two final workshops that should have taken place during the 5th and 6th project meeting were not performed, as the consortium meetings took place online due to Covid-19 restrictions. On the other hand, three additional online workshops dedicated to the outcomes of the experimental campaigns were introduced as deemed important for a better sharing of experimental details and results within and outside the consortium:

- 26 June 2020: review of the experiments performed by HSE on rainout, electrostatics, ignition and rapid phase transition. The event had 30 attendees.
- 23 July 2020: review of the experiments performed by PS on discharge, electrostatics and ignited jets. The event had 26 attendees.
- 30 July 2020: review of the experiments performed by PS and KIT on unignited and ignited liquid hydrogen pools. The event had 24 attendees.

In addition, three further events were organised to exchange knowledge in a broader sense and disseminate the project results:

- 18th September 2018, Research Priorities Workshop: the meeting aimed at summarising the state-of-the-art to derive the research priorities for the safer use of liquid hydrogen in non-industrial settings. PRESLHY research work plan was described in six presentations by the consortium, focusing on the project strategies to tackle such priorities. About 40 hydrogen safety experts attended the workshop.
- 6th March 2019, workshop on "LH_2 Safety - production, transport and handling" was a joint initiative by PRESLHY and SH2IFT (Safe Hydrogen Fuel Handling and Use for Efficient Implementation) projects. The workshop aimed at presenting the results and plans of the two LH_2 related projects, the current state-of-the-art of research and industrial applications through the invited talks of experts from organisations external to the project consortiums: Kawasaki HI, MAN Cryo, Sandia National Laboratories, Norled, Moss Maritime. Approximately 70 participants attended the workshop.
- 5-6th May 2021, Dissemination conference concluding the project. This dissemination event is described in detail in Chapter 2.

These three communication activities are reported as well in Table 1.

Details of all the listed workshops, including programmes, presenters, topics, etc., are given in PRESLHY D6.8 and not repeated here.

Table 1. List of meetings and workshops for internal and external information exchange.

Date	Meeting and Venue	Organiser/ Host	Workshop Topic
19 April 2018	**Kick-off Meeting** (1st Project Meeting) Karlsruhe, Germany	KIT	*Optical Measurement and Electrostatics*
18 September 2018	**Initial Workshop** Buxton, United Kingdom	HySafe / HSL	*Research Priorities Workshop on LH_2*
17 October 2018	**2nd Project Meeting** Saclay, France	Air Liquide	*Cryo-Techniques*
6 March 2019	**LH_2 Safety Workshop** Bergen, Norway	HySafe, PRESLHY, SH2IFT / Gexcon AS	*LH_2 Safety – production, transport and handling*
7 March 2019	**3rd Project Meeting** Bergen, Norway	HySafe / Gexcon AS	*P,T, flow measurement*
8 November 2020	**4th Project Meeting** Buxton, UK	HSL	*Tools for experiments*
5-6 May 2021	**Dissemination conference** Online	UU / NCSRD	*Dissemination conference on the project outputs*

3.1.3 Conferences

Participation to international conferences has been used to communicate the project results either in the form of papers in the conference proceedings and/or presentations. Unfortunately, Covid-19 pandemic caused the cancellation or postponement of many international conferences, thus affecting the number of events where results of the project could be presented. A list of the conducted communication at international conferences is given below (chronological order). In total 27 presentations and submitted papers were provided by the partners of PRESLHY consortium. Among these are 12 papers submitted to the International Conference on Hydrogen Safety taking place in September 2021. A list of the attended conferences is given in Table 2.

Presentations and posters

- Cirrone D., Makarov D., Molkov V., Numerical evaluation of MIE of hydrogen-air mixture, Hypothesis XIII, 24-27 July 2018, Singapore (presentation).
- Vendra C. Rao M., Wen J., Numerical simulation of flashing liquid hydrogen jet fires, International Seminar on Fire and Explosion Hazards, 21-26 April 2019, Saint-Petersburg, Russia (poster).
- Jordan T., Cirrone D., PRESLHY project, Hydrogen liquefaction & storage symposium, 26-27 September 2019, Perth, Australia (presentation).
- Ren Z. and Wen J., Numerical study of under-expanded cryogenic hydrogen jet flow, H2FC Supergen Conference 2020, 17-18 February 2020, Nottingham, UK (presentation).
- Fietz W., Jordan T., Liquid Hydrogen and High Temperature Superconductors, EURAG KIT Hydrogen Conference, 24 June 2020, Karlsruhe, Germany (presentation).
- Ren Z.X. and Wen J.X., Cryogenic hydrogen jets and jet flames, Joint Meeting on Low Carbon Combustion, organised by the French and British Sections of the Combustion Institute, online, November 2020 (presentation).

Papers in conference proceedings, including presentations

- Cirrone D., Makarov D., Molkov V., Thermal dose from cryogenic hydrogen jet fires, International Seminar on Fire and Explosion Hazards, 21-26 April 2019, Saint-Petersburg, Russia.
- Proust C., Fire and explosion safety in hydrogen containing processes: State of the Art and outstanding questions, International Seminar on Fire and Explosion Hazards, 21-26 April 2019, Saint-Petersburg, Russia (including plenary talk).
- Cirrone D., Makarov D., Molkov V., Cryogenic hydrogen jets: calculation of hazard distances, 8th International Conference on Hydrogen Safety, 24-26 September 2019, Adelaide, Australia.
- Giannissi S.G., Venetsanos A.G. and Hecht E.S., Numerical predictions of cryogenic hydrogen vertical jets, 8th International Conference on Hydrogen Safety, Adelaide, Australia, 24-26 Sept. 2019.
- Jordan T., Bernard L., Jallais S., Venetsanos A., Coldrick S., Cirrone D., Status of the pre-normative research project PRESLHY for the safe use of LH2, 8th International Conference on Hydrogen Safety, Adelaide, Australia, 24-26 September 2019.
- Venetsanos A.G., Giannissi S., Proust C., CFD Validation against large scale liquefied helium release, 8th International Conference on Hydrogen Safety, Adelaide, Australia, 24-26 Sept. 2019.
- Venetsanos A.G., Choked two-phase flow with account of discharge line effects, 8th International Conference on Hydrogen Safety, Adelaide, Australia, 24-26 Sept. 2019.

- Proust C., A new technique to produce well controlled electrical sparks. Application to MIE measurements, 13th International Symposium on Hazards, Prevention and Mitigation of Industrial Explosions, 27-31 July 2020, Germany.
- Wen, J. X., Numerical modelling of hydrogen combustion in the context of fire and explosion safety – overview of previous works and analysis of ignited releases of under-expanded cryogenic hydrogen jets, special invited presentation at German Combustion Meeting, 3 March 2021.

Papers submitted to ICHS 2021 conference

The International Conference on Hydrogen Safety (ICHS) 2021 will be used as well as a main platform for dissemination of the research outcomes beyond the project end. The conference will take place on the 21-24 September 2021 in Edinburgh, UK. However, most likely the event will be hosted online due to Covid-19 pandemic. Twelve papers have been submitted to the conference and they present results of the experimental, analytical and numerical works performed within the project. A list is given below in alphabetical order:

- Buttner W., Wischmeyer T., Hall J., Coldrick S., Hooker P. and Thorson J., Hydrogen wide area monitoring of LH2 releases at HSE for the PRESHLY project, submitted to ICHS 2021.
- Cirrone D., Makarov D., Kuznetsov M., Friedrich A., Molkov V., Effect of heat transfer through the release pipe on simulations of cryogenic hydrogen jet fires and hazard distances, submitted to ICHS 2021.
- Friedrich A., Necker G., Grune J., Kuznetsov M., Jordan T., Experimental investigation on the burning behavior of homogeneous H2-CO-air mixtures in an obstructed, semi-confined channel, submitted to ICHS 2021.
- Friedrich A., Veser A., Kuznetsov M., Jordan T., Kotchourko N., Hydrogen blowdown release experiments at different temperatures in the discha-facility, submitted to ICHS 2021.
- Giannissi S.G., Venetsanos A.G., Cirrone D., Molkov V., Ren Z., Wen J.X., Friedrich A., Veser A., Cold hydrogen blowdown release: an inter-comparison study, submitted to ICHS 2021.
- Giannissi S.G., Venetsanos A.G., Vyazmina E., Jallais S., Coldrick S., Lyons K., CFD simulations of large scale LH2 dispersion in open environment, submitted to ICHS 2021.
- Jordan T., Bernard L., Cirrone D., Coldrick S., Friedrich A., Hawksworth S., Jallais S., Kuznetsov M., Markert F., Proust C., Venetsanos A., Veser A., Wen J., Results of the Pre-Normative Research Project PRESLHY for the Safe Use of Liquid Hydrogen, submitted to ICHS 2021.
- Kuznetsov M., Denkevits A., Friedrich A., Necker G., Jordan T., Shock tube experiments on flame propagation regimes and critical conditions for flame acceleration and detonation transition for hydrogen-air mixtures at cryogenic temperatures, submitted to ICHS 2021.
- Ren Z., Wen J., Flame characteristics of ignited under-expanded cryogenic hydrogen jets, submitted to ICHS 2021.

- Venetsanos A.G., Ustolin F., Tolias I., Giannissi S., Momferatos G., Coldrick S., Atkinson G., Lyons K., Jallais S., Discharge modelling of large scale LH2 experiments with an engineering tool, submitted to ICHS 2021.
- Venetsanos A.G., Giannissi S., Tolias I., Friedrich A., Kuznetsov M., Cryogenic and ambient gaseous hydrogen blowdown with discharge line effects, submitted to ICHS 2021.
- Ustolin F., Tolias I.C., Giannissi S.G., Venetsanos A.G., Paltrinieri N., A CFD analysis of liquid hydrogen vessel explosions using the ADREA-HF code, submitted to ICHS 2021.

3.1.4 International meetings

The extensive list of activities communicating the project outputs includes also participation to international meetings, as those organised by relevant SDOs to present and motivate the recommendations for RCS developed during the project, IEA meetings to present the main developments and achievements of the project, etc. During the project course, PRESLHY project has been presented to about 20 international events. A non-exhaustive list is given below in chronological order:

- Jordan T., PRESLHY Project, IEA HIA Task 37 Hydrogen Safety, 19 October 2018, Saclay, France.
- Cirrone D., Progress on hydrogen safety at Ulster University, IEA HIA Task 37 Hydrogen Safety, 19 October 2018, Saclay, France.
- Jordan T., PRESLHY, poster presentation, FCH JU Program Review Days 16-17 November 2018, Brussels, Belgium (PRESLHY was listed as a key pre-normative research project).
- Jordan T., ISO/TC 197 Hydrogen Technologies, 6-7 December 2018, Vancouver.
- Jordan T., Overview of hydrogen safety research in Germany, International School Progress in Hydrogen Safety, 11-15 March 2019, Belfast, United Kingdom.
- Cirrone D., Thermal effects of hydrogen jet fires, International School Progress in Hydrogen Safety, 11-15 March 2019, Belfast, United Kingdom.
- Makarov D., Safety of liquefied hydrogen systems and infrastructure, Course in Hydrogen Safety, 17 May 2019, Belfast, United Kingdom.
- Makarov D., Thermal effects of hydrogen jet fires, Course in Hydrogen Safety, 17 May 2019, Belfast, United Kingdom.
- Jordan T., PRESLHY Project progress, IEA HIA Task 37 Hydrogen Safety, 25 June 2019, Oxford, United Kingdom.
- Makarov D., Progress on hydrogen safety at Ulster University, IEA HIA Task 37 Hydrogen Safety, 25 June 2019, Oxford, United Kingdom.
- Jordan T., PRESLHY project presentation, European Panel of Hydrogen Safety, 25 June 2019, in Brussels, Belgium.
- Jordan T., PRESLHY project presentation, European RCS Strategy Coordination Group (SCG), 26 June 2019, in Brussels, Belgium.
- Jordan T., PRESLHY project presentation, FCH JU Program Review Days, 19-20 November 2019, Brussels, Belgium.

- Jordan T., Update on ISO PWI24077- Safe Use of LH2 in Non-industrial Settings Contributions of the FCH JU project PRESLHY, ISO TC 197 Plenary Meeting, 12-13 December 2019, Grenoble France (presentation available here).
- Jordan T., Safe Use of LH2 in Non-industrial Settings, Contributions of the FCH JU project PRESLHY 13th plenary SFEM Working Group HYDROGEN, 28 January 2020, Brussels, Belgium (presentation available here).
- Molkov V., PRESLHY project presentation, NFPA 2 Hydrogen Storage Task Group meeting, 14 April 2020, Online meeting.
- Jordan T. et al., PRESLHY Pre-normative Research for the Safe Use of Liquid Hydrogen, FCH JU Program Review Days 24 November 2020, online meeting (available on project website).
- Jordan T., Hecht E., Odegard A., Low T LH2/cryogenic related progress in Safety Research HySafe Research Priorities Workshop, 30 October 2020, online presentation (available here).
- Jordan T., Update on PWI24077, ISO TC 197 Plenary Meeting, 9 December 2020, online.

Table 2. List of international conferences, meetings and events where PRESLHY outputs were presented.

Event	Location	Date
Hypothesis XIII	Singapore	24-27 July 18
IA HySafe Research Priorities Workshop	Buxton, UK	17-20 September 18
IEA HIA Task 37 Hydrogen Safety	Saclay, France	19 October 18
FCH JU Review Days	Brussels, Belgium	16-17 November 18
ISO/TC 197 Hydrogen Technologies	Vancouver, Canada	6-7 December 18
LH2 safety workshop	Bergen, Norway	6 March 2019
International School Progress in Hydrogen Safety	Belfast, UK	11-15 March 19
International Seminar on Fire and Explosion Hazards	Saint-Petersburg, Russia	21-26 April 19
Course in Hydrogen Safety	Belfast, UK	17 May 19
European Hydrogen Safety Panel	Brussels, Belgium	25 June 19
European RCS Strategy Coordination Group (SCG) meeting	Brussels, Belgium	26 June 19
FCH Review days 2019	Brussels, Belgium	2-6 September 19
International Conference on Hydrogen Safety 2019	Adelaide, Australia	24-26 September 19
Hydrogen liquefaction & storage symposium	Perth, Australia	27 September 19
FCH JU Review Days	Brussels, Belgium	19-20 November 19
ISO/TC 197 Hydrogen technologies	Grenoble, France	12 December 19
CEN/CENELEC SFEM WG Hydrogen	Brussels, Belgium	28 January 20

H2FC Supergen Conference 2020	Nottingham, UK	17-18 February 20
NFPA 2 Hydrogen Storage Task Group	Online meeting	14 April 20
IA HySafe Research Priorities Workshop	Online meeting	30 October 20
Program Review & Stakeholder meeting	Online meeting	24 November 20
ISO/TC 197 Hydrogen technologies	Online meeting	10-11 December 20
PRESLHY Dissemination Conference	Online meeting	5-6 May 21
International Conference on Hydrogen Safety 2021	Edinburgh, UK/ Online meeting	21-24 September 21

3.1.5 Scientific publications in peer-reviewed journals

Scientific publications in peer-reviewed journals, such as the International Journal of Hydrogen Energy, are the main channel for communicating and disseminating the knowledge generated by the project to the scientific community, along with presentations at the conferences mentioned above. Below is reported a list in chronological order of the papers published or submitted to peer-reviewed journals.

- Venetsanos, A. G. Homogeneous non-equilibrium two-phase choked flow modeling. International Journal of Hydrogen Energy 43.50 (2018): 22715-22726.
- Cirrone, D., Makarov, D., Molkov, V. Thermal radiation from cryogenic hydrogen jet fires. International Journal of Hydrogen Energy 44.17 (2019): 8874-8885.
- Giannissi, S.G., Venetsanos, A.G., and Hecht, E.S., Numerical predictions of cryogenic hydrogen vertical jets. International Journal of Hydrogen Energy 46 (2020): 12566-12576.
- Ren, Z. and Wen, J.X., Numerical characterization of under-expanded cryogenic hydrogen gas jets. AIP Advances, 10.9 (2020) 095303.
- Buttner, W., Hall, J., Coldrick, S., Hooker, P. and Wischmeyer, T., Hydrogen wide area monitoring of LH2 releases. International Journal of Hydrogen Energy 46. 23 (2021), 12497-12510.
- Ustolin F., Tolias, I.C., Giannissi, S.G., Venetsanos, A.G., Paltrinieri, N., A CFD analysis of liquid hydrogen vessel explosions using the ADREA-HF code. Submitted to the International Journal of Hydrogen Energy (2021).

3.1.6 Synergies and collaborations with other international projects

PRESLHY project has established collaborations with several international on-going projects:

- SH2IFT project on safe hydrogen fuel handling and use for efficient implementation. Collaboration with the project resulted in the joint workshop on “LH2 Safety - production, transport and handling” on the 6th March 2019 in Bergen, Norway, and the joint work on modelling of BLEVE by NCSRD and NTNU.

- HyTunnel-CS, FCH JU funded project. Few computational models and engineering correlations were developed through complementarities and synergies with HyTunnel-CS, e.g. a CFD model for PPP by UU and a reduced model to estimate maximum overpressure from delayed ignition of turbulent hydrogen jets by UU (see PRESLHY D6.5).
- HyResponder, FCH JU funded project. The Chapter on LH2 safety (PRESLHY D6.1) was used by HyResponder consortium to produce lectures informing responders on the relevant aspects of LH2 safety. Furthermore, PRESLHY project has been presented at the project meeting held on 19th January 2021 to inform responders regarding the research activities performed within PRESLHY project.

4 Conclusions

The present deliverable reported the communication activities carried out by PRESLHY project partners to the general public, which included all the audiences having free and open access to PRESLHY project outputs. Particular focus was posed to the project dissemination conference held in May 2021, reporting the organisation process and minutes of the event. Approximately 40 presentations by the project partners and invited international speakers provided the current status and research performed on all aspects related to liquid/cryogenic hydrogen safety. Approximately 260 participants attended the event. A second part of the report focused on all the dissemination activities that were performed by the consortium. Ten workshops were organised to exchange knowledge and disseminate the project results. PRESLHY partners communicated the pre-normative research outputs at numerous events, counting for about 30 contributions to international conferences and about 20 presentations at international meetings and events.

Appendix A - Dissemination conference programme

PRESLHY

PRENORMATIVE RESEARCH FOR
SAFE USE OF LIQUID HYDROGEN

Research and Innovation Action supported by the FCH JU,
Grant Agreement No 779613, 2018-2020, **www.preslhy.eu**

Conference programme

Dissemination conference of PRESLHY project
5-6 May 2021, Virtual event

Date and connection details

The conference will be held on Zoom platform.
5th May 2021, 9:00 AM – 5:30 PM (CEST time)
6th May 2021, 9:00 AM – 5:00 PM (CEST time)

Please use the following link to join the event on the days of the conference:
https://us02web.zoom.us/j/89260723322
Meeting ID: 892 6072 3322
The meeting room will be opened 30 minutes before the official start of the conference.

Instructions for participants

⇒ Microphone and video camera options will be deactivated by the hosts at the start of the conference, given exception for questions (see following point). However, please ensure at any time that your microphone and video are off.

⇒ Presentations will allow 5 minutes for questions. Please ask your questions to presenters using the chat option. If this is not possible (e.g. short available time to write up a question) please use the option "raise hand" in the webinar controls.

The hosts and chairs will be notified and you will be prompted to unmute yourself and verbally ask your question.

⇒ The conference will be video recorded for convenience of stakeholders and those who could not attend all conference sessions.

Organiser's contacts - please contact for any assistance:

- Prof Thomas Jordan, E: thomas.jordan@kit.edu, P: +4972160826105
- Dr Donatella Cirrone, E: d.cirrone@ulster.ac.uk, P: +442890368283

KIT HySafe HSE INERIS Air Liquide Pro-Science WARWICK Ulster University

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FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

PRE-NORMATIVE RESEARCH FOR
SAFE USE OF LIQUID HYDROGEN

Conference programme (CEST time)	
5 May 2021	
Opening session. Chair: Thomas Jordan, KIT	
09:00-09:10	Welcome by the project coordinator (Thomas Jordan, KIT)
09:10-09:40	FCH JU presentation (Alberto Garcia Hombrados, FCH JU)
09:40-10:10	PRESLHY project overview (Thomas Jordan, KIT)
10:10-10:30	LH_2 solution for large-scale storage of hydrogen: a white paper (Thomas Jordan, KIT)
10:30-10:50	Critical analysis of the state of the art and research priorities (Simon Jallais, AL)
10:50-11:10	Coffee break
Session on LH_2 applications, part 1. Chair: Simon Jallais, AL	
11:10-11:30	World's first ocean going liquid hydrogen carrier (Shoji Kamiya, Kawasaki Heavy Industries)
11:30-11:50	State of the art of LH_2 installations and facilities (Laurence Bernard, AL)
11:50-12:10	LH_2 application in heavy duty transport (Jens Franzen, Daimler)
12:10-12:30	LH_2 application in cryogenic infrastructure (Ronald Dekker, Demaco)
12:30-13:30	Lunch break
Session on liquid hydrogen releases. Chair: Alexandros Venetsanos, NCSRD	
13:30-13:50	Bunkering scale LH_2 releases on behalf of Norwegian Roads Administration: data and analyses (Daniel Allason, DNV GL)
13:50-14:10	Atmospheric dispersion of large scale liquid hydrogen releases (Jennifer Wen, UWAR)
14:10-14:30	Experimental study on formation and evaporation of LH_2 pools (Andreas Friedrich, PS)
14:30-14:50	Rain out in large scale LH_2 releases (Simon Coldrick, HSE)
14:50-15:10	CFD validation against large scale liquefied helium/hydrogen releases (Stella Giannissi, NCSRD)
15:10-15:30	Coffee break
Session on cryo-compressed hydrogen releases. Chair: Alexandros Venetsanos, NCSRD	
15:30-15:50	Lab-scale dispersion of cryogenic hydrogen jets (Ethan Hecht, Sandia National Laboratories)
15:50-16:10	Effect of heat transfer through discharge line on parameters of cryogenic hydrogen releases (Donatella Cirrone, UU)
16:10-16:30	CFD benchmark on cryogenic hydrogen jets (Elena Vyazmina, AL)
16:30-16:50	High-pressure cryogenic hydrogen releases (Andreas Friedrich, PS)
16:50-17:10	An engineering tool for discharge calculations (Alexandros Venetsanos, NCSRD)
17:10-17:30	**Round table discussion and closure of Day 1 (Thomas Jordan, KIT)**
6 May 2021	
Session on LH_2 applications, part 2. Chair: Simon Jallais, AL	
09:00-09:20	LH_2 coupling with superconductors (Walter Fietz, KIT)
Session on ignition of cryogenic hydrogen-air mixtures. Chair: Simon Coldrick, HSE	
09:20-09:40	Ignition parameters of cryogenic hydrogen–air mixtures (Christophe Proust, INERIS)
09:40-10:00	Analytical and numerical determination of MIE by spark ignition (Donatella Cirrone, UU)
10:00-10:20	Electrostatic charge in multiphase hydrogen releases (Simon Coldrick, HSE)
10:20-10:40	Ignition and flame propagation over a LH_2 pool (Andreas Friedrich, PS)
10:40-11:00	Coffee break
Session on combustion of cryogenic hydrogen-air mixtures. Chair: Mike Kuznetsov, KIT	
11:00-11:20	Results from modelling of BLEVE: model validation and preliminary calculations for SH2IFT experiments (Federico Ustolin, NTNU) Planned experimental work on BLEVE: how will tests answer the questions arising from modelling? (Kees van Wingerden, Gexcon)
11:20-11:40	Characterisation of high pressure cryogenic hydrogen jet fires (Andreas Friedrich, PS)
11:40-12:00	Thermal hazards from cryogenic hydrogen jet fires (Donatella Cirrone, UU)
12:00-12:20	The dynamics and flame characteristics of cryogenic hydrogen jets – a numerical study (Jennifer Wen, UWAR)
12:20-12:40	Flame propagation regimes at cryogenic temperature (Mike Kuznetsov, KIT)
12:40-13:00	Effect of congestion/confinement on a cold plume combustion (Simon Coldrick, HSE)
13:00-14:00	Lunch break
Session on implementation and impact of the research outcomes. Chair: Donatella Cirrone, UU	
14:00-14:20	Societal perception and barriers to hydrogen fuel application (Cyriac George, Institute of Transport Economics)
14:20-14:40	A chapter on LH_2 safety for the Handbook of Hydrogen Safety (Thomas Jordan, KIT - Karl Verfondern, Research Center Juelich)
14:40-15:00	Engineering correlations and tools for cryogenic hydrogen hazards assessment (Donatella Cirrone, UU)
15:00-15:20	Guidelines for safe design and operation of LH_2 infrastructure (Laurence Bernard, AL)
15:20-15:40	Coffee break
15:40-16:00	Analysis of current standards and regulations (Andrei Tchouvelev, AVT)
16:00-16:20	PRESLHY recommendations for RCS (Deborah Houssin, AL)
16:20-16:40	PWI “Safe use of LH_2 in non-industrial settings” for ISO/TC 197 (Thomas Jordan, KIT)
16:40-17:00	**Round table discussion and concluding remarks (Thomas Jordan, KIT)**

Appendix B - PRESLHY project overview

(please double click on the figure below to open the presentation or use the link: PRESLHY project)

Appendix C - Final 5th Newsletter

PRESLHY

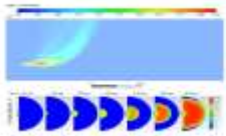
Newsletter

ISSUE 5 | MAY 2021

Top stories in this newsletter

PRESLHY
Dissemination conference

Project key outputs



Conclusions from experimental, analytical and computational studies

PRESLHY dissemination conference

PRESLHY dissemination conference on pre-normative research for safe use of liquid hydrogen was held on the **5-6 May 2021** as a virtual event. The conference recorded about 340 registrations from 25 different countries and approximately 250 attendees to the event. Speakers from PRESLHY consortium presented the results of the outstanding research performed on the major phenomena associated to the release and dispersion of liquid and cryo-compressed hydrogen, the ignition of cryogenic hydrogen-air mixtures and their combustion. The conference addressed the potential impact of the project outputs on the international community working on hydrogen and fuel cell technologies. Presentations by invited international speakers enriched the conference program, providing a throughout overview of the state of the art and worldwide research on safety of liquid hydrogen. If you missed the event or could not attend all sessions, you can find the conference presentations and videorecordings on PRESLHY website.

Find out more about PRESLHY project key outputs

The pre-normative research outcomes and advancement of knowledge beyond the state-of-the-art were implemented into publicly available documents underpinning the inherently safer deployment of hydrogen and fuel cell technologies using LH_2 and cryo-compressed hydrogen:

- Chapter on LH_2 safety for the Handbook on Hydrogen Safety
- White paper
- Novel engineering correlations and tools for LH_2 safety
- Guidelines for safe design and operation of LH_2 infrastructure
- Recommendations for RCS

The documents address several aspects inherent to LH_2 and cryo-compressed hydrogen safety, spanning from LH_2 safety science, role and potential benefits of LH_2 systems, to practical guidelines and recommendations for Regulations, Codes and Standards (RCS). Documents are available on PRESLHY website.

Conclusions from experimental, analytical and computational studies: closed knowledge gaps and models for hydrogen safety engineering

The extensive experimental campaigns enhanced the current understanding of the phenomena associated to LH_2 safety:

- Multi-phase accumulations with explosion potential:
  - Repeated spill in gravel bed might generate dangerous condensed phase mixtures; not for other substrates;
  - Water sprays on LH_2 and LH_2 spill on a small water pool seem to be non critical.
- Combustion properties of cold gas clouds, especially in congested area:
  - Higher expansion ratios come with higher critical expansion ratios;
  - Uncongested mixtures behave less critical;
  - Density effects might promote strong pressure effects in particular for congested areas.
- Knowledge and experience related to releases involving large quantities:
  - Large discharges do not generate static electricity or promote spontaneous ignition under normal weather conditions.

The performed analytical and numerical studies provided validated models for the determination of consequences and hazards from incidents involving LH_2 systems and infrastructure:

- Modeling of steady state and transient cryogenic releases accounting for heat transfer effect or a discharge line friction and extra resistances.
- Characterisation of concentration decay in momentum cryogenic hydrogen jets.
- Definition of the final state resulting from mixing LH_2 and moist air, and assess potential for O_2 condensation.
- Prediction of the extent of LH_2 pools and characterization of evaporation processes on different ground substrates.
- Determination of Ignition Energy for hydrogen-air mixtures.
- Assessment of electrostatic field-up generated during hydrogen releases.
- Evolution of laminar burning velocity and expansion ratios for cryogenic hydrogen-air mixtures.
- Determination of hydrogen jet fire flame length and thermal load.
- Determination of the maximum pressure load from delayed ignition of turbulent hydrogen jets.
- Characterisation of Pressure Peaking Phenomena for cryogenic hydrogen releases in an enclosure.
- Critical conditions for flame acceleration and detonation transition for cryogenic hydrogen-air mixtures.
- Estimation of the overpressure generated by a BLEVE and a fireball size after LH_2 spill combustion.

Future work, open issues and priorities

The performed pre-normative research highlighted some areas where further research may be needed:

- Fundamental/Modelling: clarify material issues with cryogenic hydrogen; improve thermodynamic modelling in multiphase, non-equilibrium, reaction kinetics (< 200K); determine induction times and detonation cell sizes (< 200K).
- Dispersion phenomena: ventilation of closed rooms and interaction with other mitigation concepts; multiphase effects on large scale dispersion with obstruction and/or (partial) confinement.
- Combustion phenomena: broader assessement of FA and DDT for varying congestion and confinement at larger scale; evaluation of detonation potential of solid O_2 in LH_2 pools; potential for spontaneous ignition of cryogenic hydrogen releases; further experimental and numerical research on BLEVEs.
- Risk assessment and mitigation strategies: proper design and approval of safety valves; integral (applied) tests (dispersion and combustion in closed rooms) for mitigation strategies, including sensor placement and performance; crash test for vehicle tank systems.

In December 2020, the ISO TC 197 committee has established the working group **WG29 subtask 2** for the update of ISO TR 15916 with regards to LH_2 applications. Activities of WG29 will be kicked-off in June 2021.

Forthcoming events

Please note that future events may be affected by current restrictions associated to Covid-19 pandemic.

- International Conference on Hydrogen Safety, 21-24 September 2021, Edinburgh, UK.

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FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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