Webinar on New Energy Carriers in Road Tunnels
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Preliminary results from the HyTunnel-CS project

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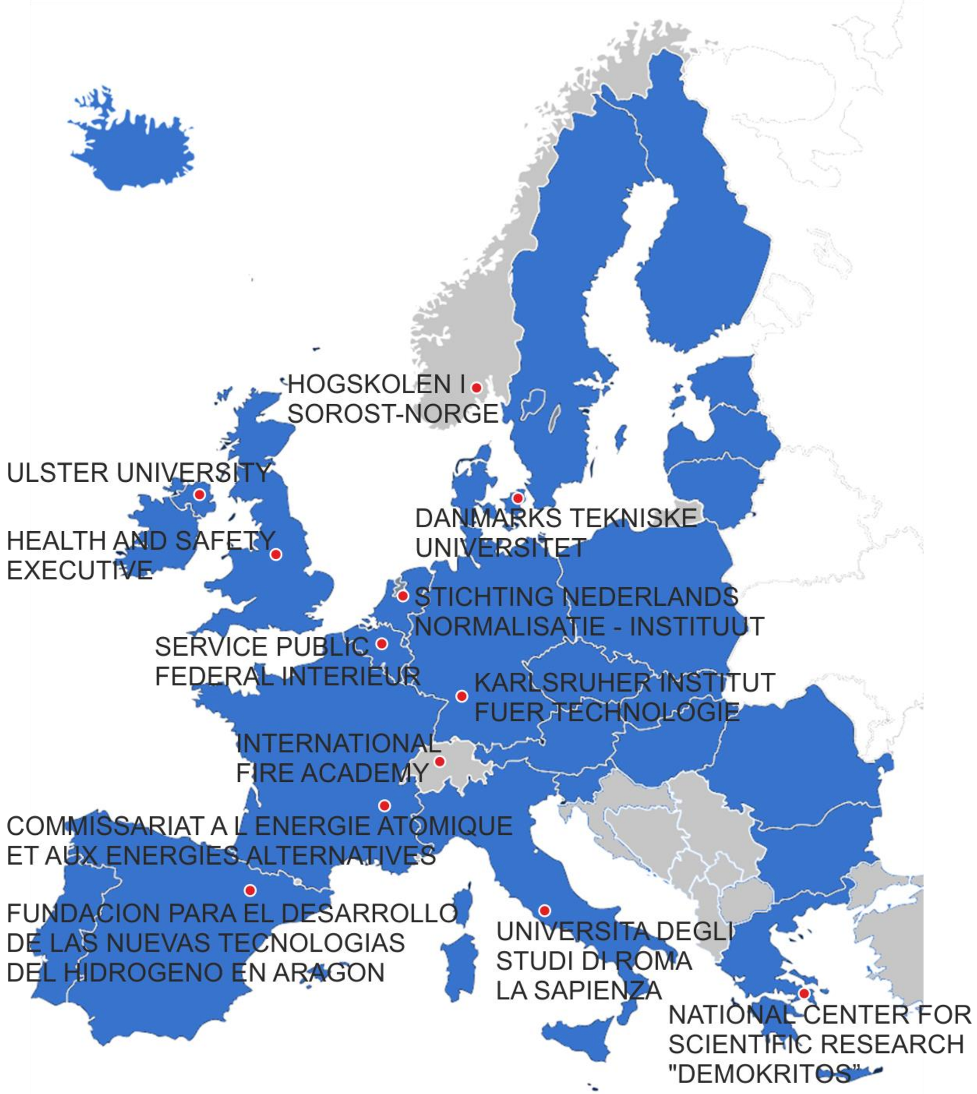
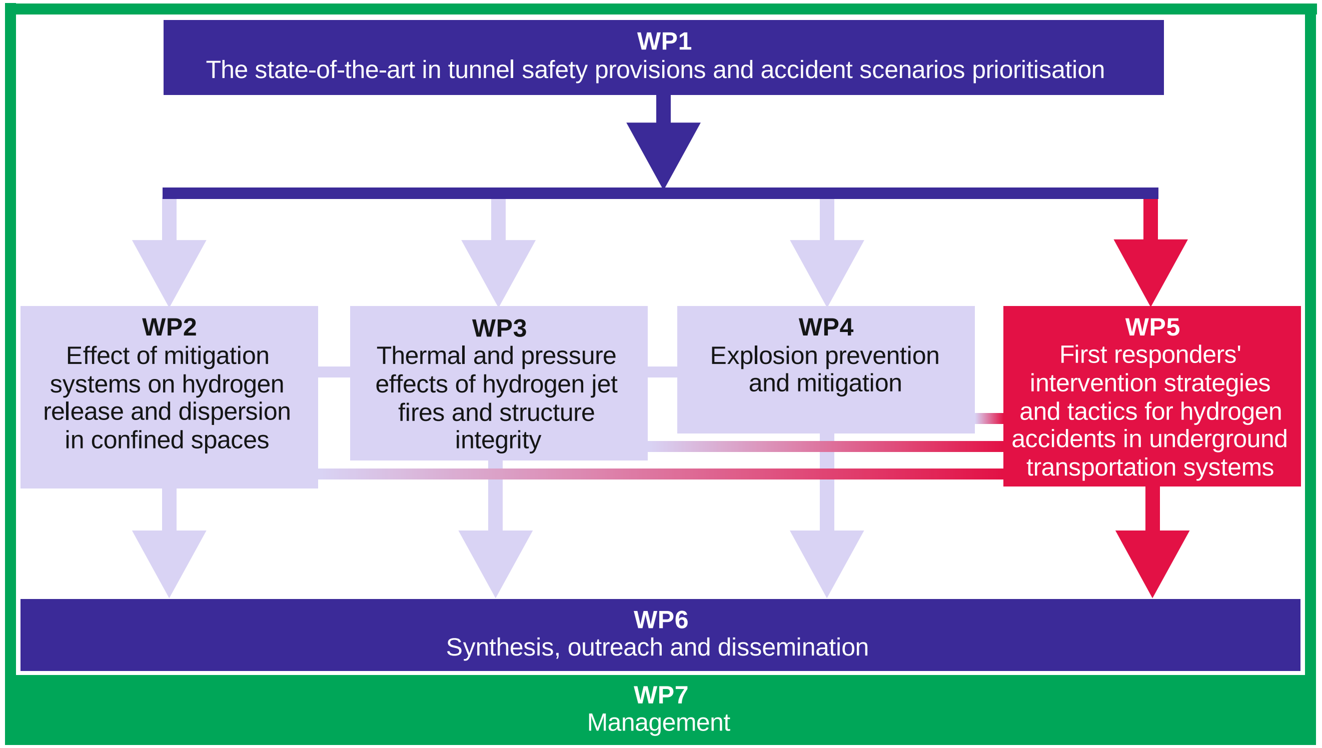
on behalf of the project partners

HyTunnel-CS project (01/03/19–28/02/22→31/08/22)

Details and public deliverables at https://hytunnel.net/



- 13 partners from 11 countries
- Pre-normative research (partner NEN→CEN)
- The overall structure of the work plan (below):



HyTunnel-CS project details

Ambition

- To allow hydrogen-powered vehicles and hydrogen delivery transport enter underground traffic infrastructure

Research approach

- Consider hydrogen vehicle and underground traffic structure as a single system with integrated safety approach

Three principal outcomes

- Harmonised recommendations on response to hydrogen accidents (D5.4, IFA)
- Recommendations for inherently safer use of hydrogen vehicles in underground traffic systems (D6.9, HSE)
- Recommendations for Regulations, Codes and Standards (D6.10, NEN)

HyTunnel-CS: what can go wrong in real life?
New hazards to be addressed

Hazards from hydrogen vehicles in confined spaces (all can be eliminated!):

- Large flammable cloud/layer after hydrogen release with potential to deflagrate.
- Deflagration to detonation transition (DDT) in the flammable cloud.
- Long flames from thermally-activated pressure relief device (TPRD):
  - Obstructing self-evacuation/rescue
  - Spreading fire to other vehicles
  - Affecting underground structure
- Tank rupture in a fire generating devastating (localised fire, failed/blocked TPRD):
  - Blast wave propagating in 1D space with little pressure decay
  - Fireball (thermal hazards and O_2 depletion) that can move with 25 m/s speed
  - Projectiles (former USA test: projectile=vehicle flying 22 m after 70 L, 35 MPa tank rupture)

HyTunnel-CS results

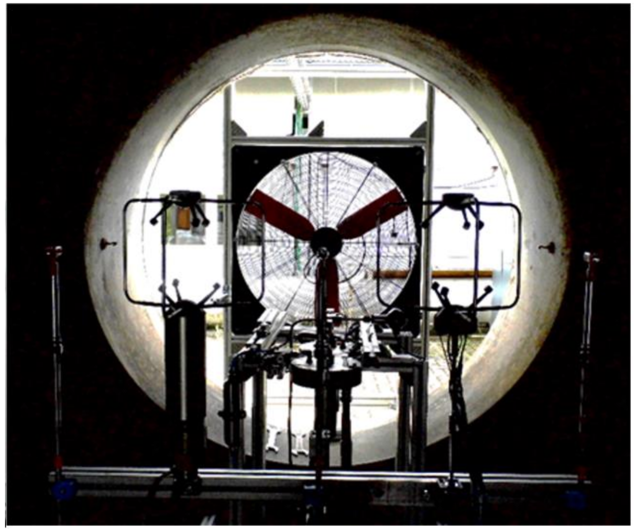
Generic safety strategies for vehicle-structure system

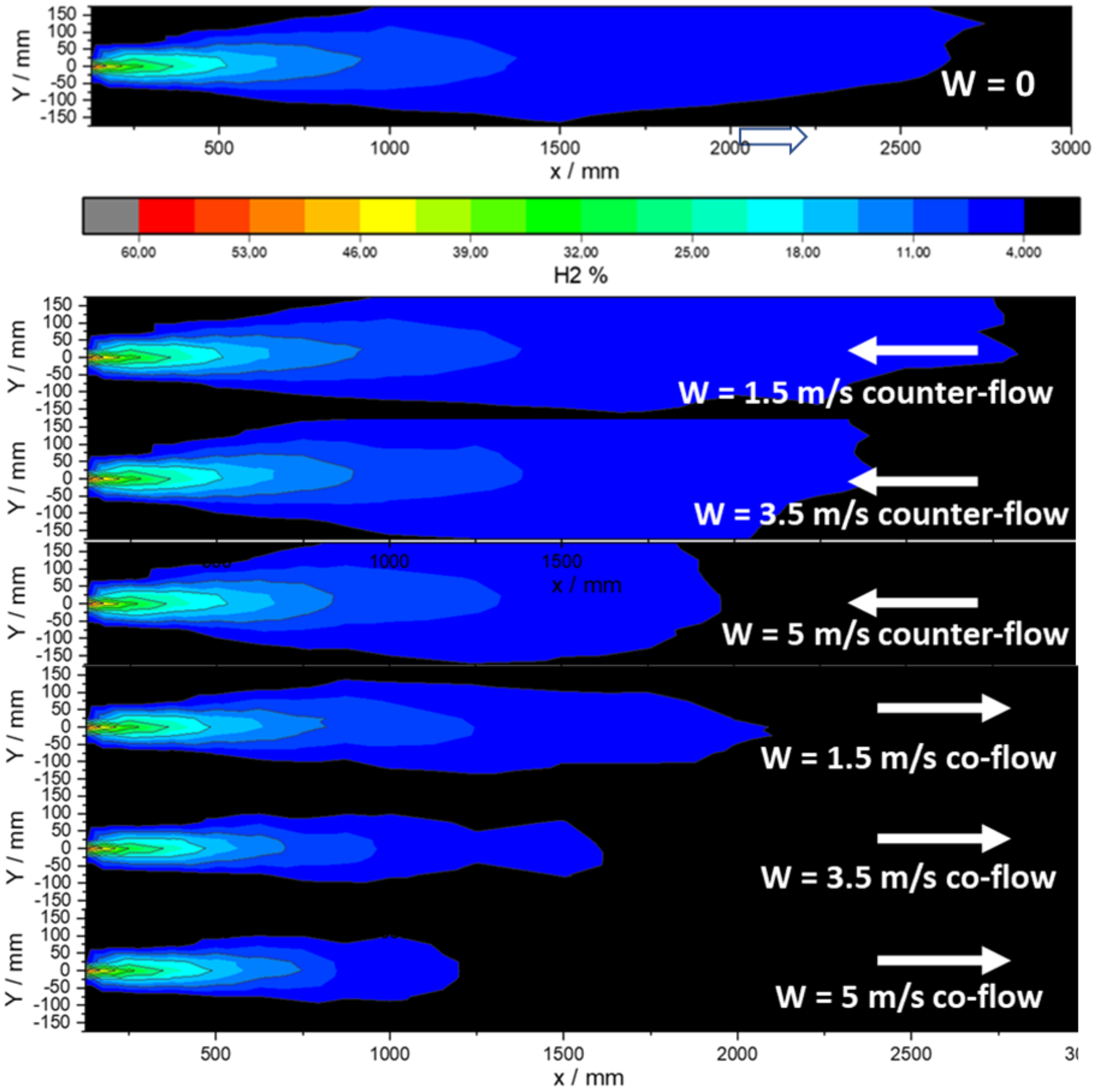
- Design piping and TPRD diameter to exclude large flammable cloud, long flames, the pressure peaking phenomenon, strong turbulent jet deflagration yet to exclude tank rupture in a fire (the TPRD-tank system model is developed for the first time).
- Design TPRD size and direction of release to exclude formation and deflagration (and DDT) of flammable layer under the ceiling (only jet deflagration hazard).
- Design TPRD diameter and optimize the release direction to exclude temperature 300 C in ducts of mechanical ventilation at the ceiling (underground parking).
- Use the technology of explosion free in a fire TPRD-less tank to exclude rupture and its catastrophic consequences (tested up to HRR/A=1 MW/m^2):
  - **No blast wave**
  - **No fireball**
  - **No projectiles**
  - **No long flames**
  - **No pressure peaking phenomenon**
  - **No related life and property losses**

Results example: flammable envelope size

Mechanical ventilation effect

H_2 release: ∅1mm, 5g/s





Mechanical ventilation promotes hydrogen mixing for both co- and counter-flow ventilation directions (reduction of hazard distance defined by LFL)

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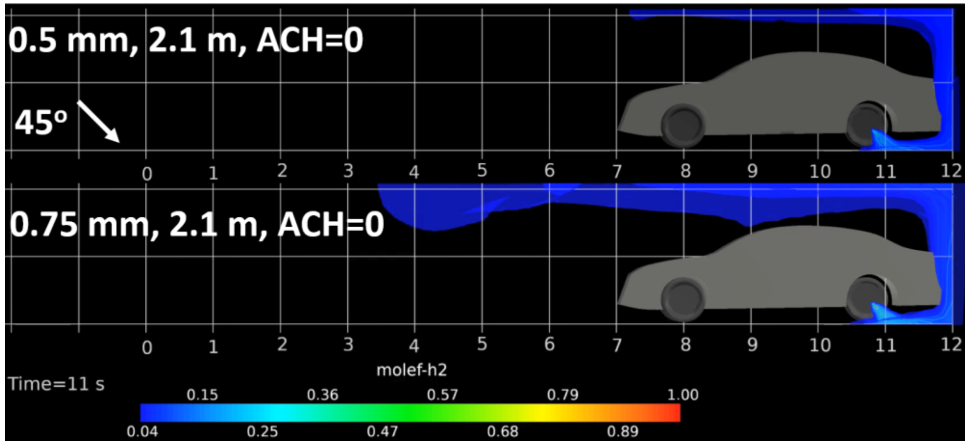
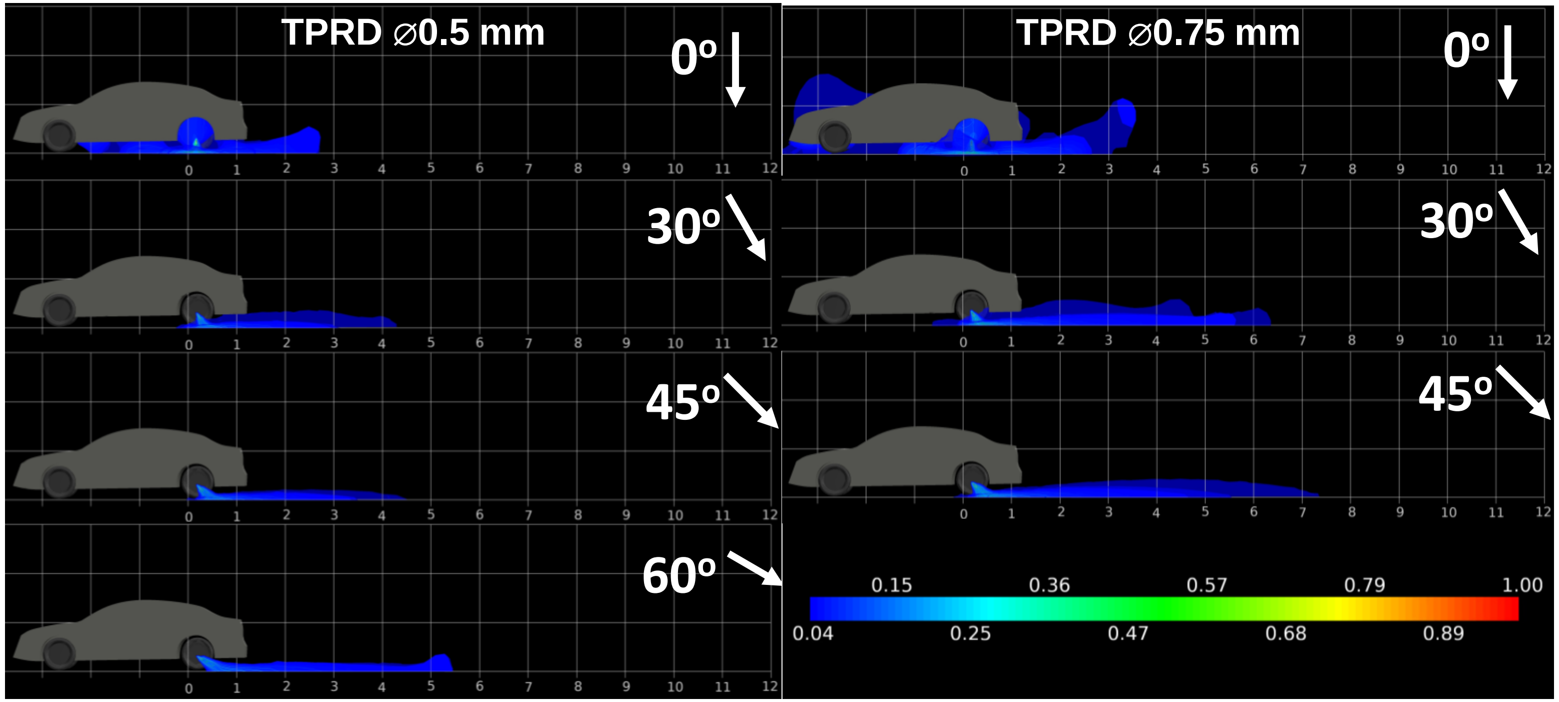
Results example: car in underground parking

TPRD diameter and direction of release (reported to GTR#13)



- Negligible effect of mechanical ventilation on the maximum flammable cloud size for optimised TPRD.
- TPRD release direction at the angle 45° deem to have overall smallest flammable hydrogen envelope.
- Releases from TPRD=0.5 mm and TPRD=0.75 mm don’t result in a flammable layer formation under car park ceiling.
- Releases from TPRD toward obstacles tend to promote formation of a larger flammable cloud.



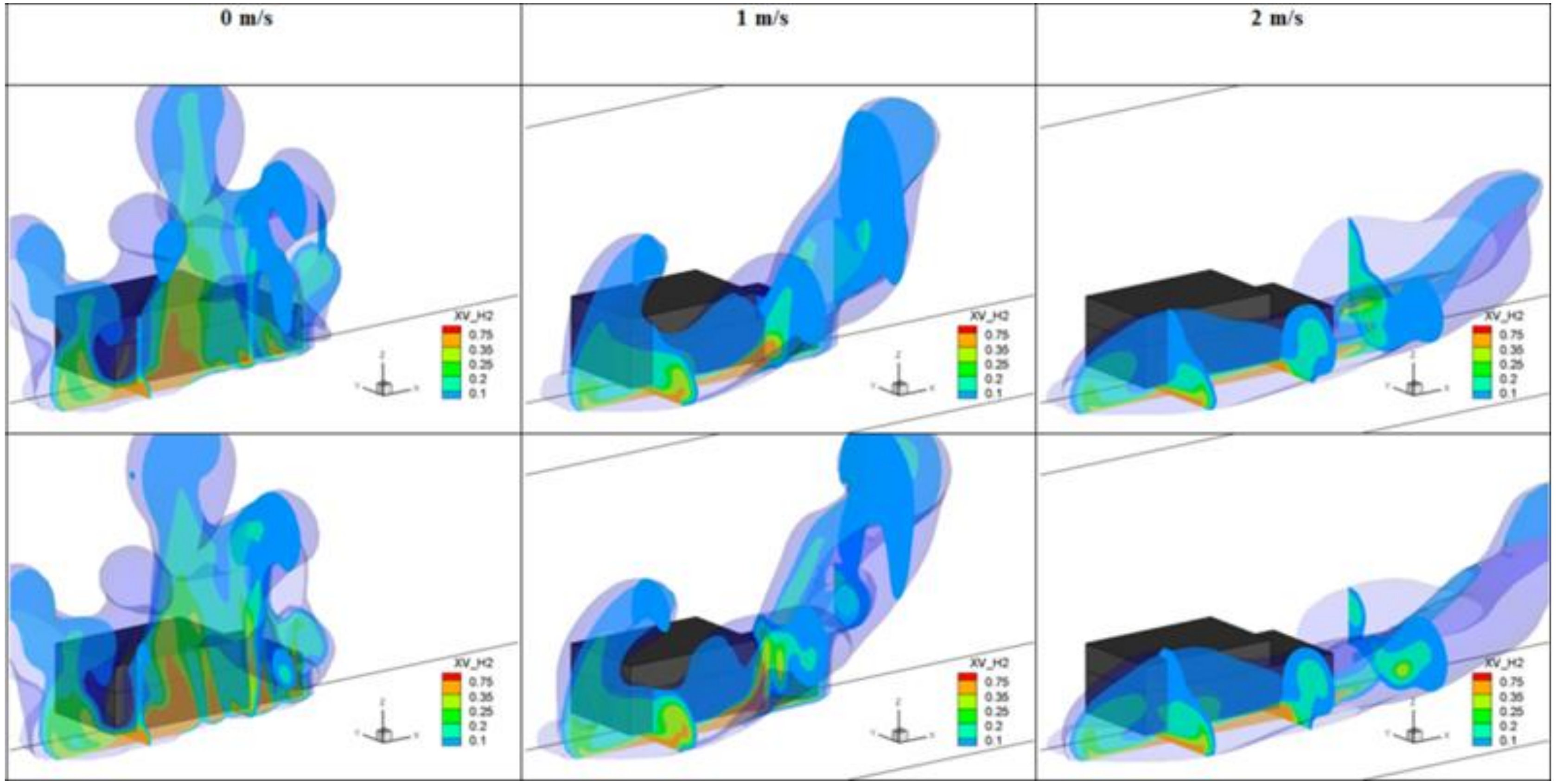
Results example: car in a tunnel

Effect of tunnel slope on hydrogen dispersion

- Vanishingly small effect on flammable envelope size.
- Small effect only around the car.
- No change of design recommendations deem necessary.

Slope 0%

Slope 5%



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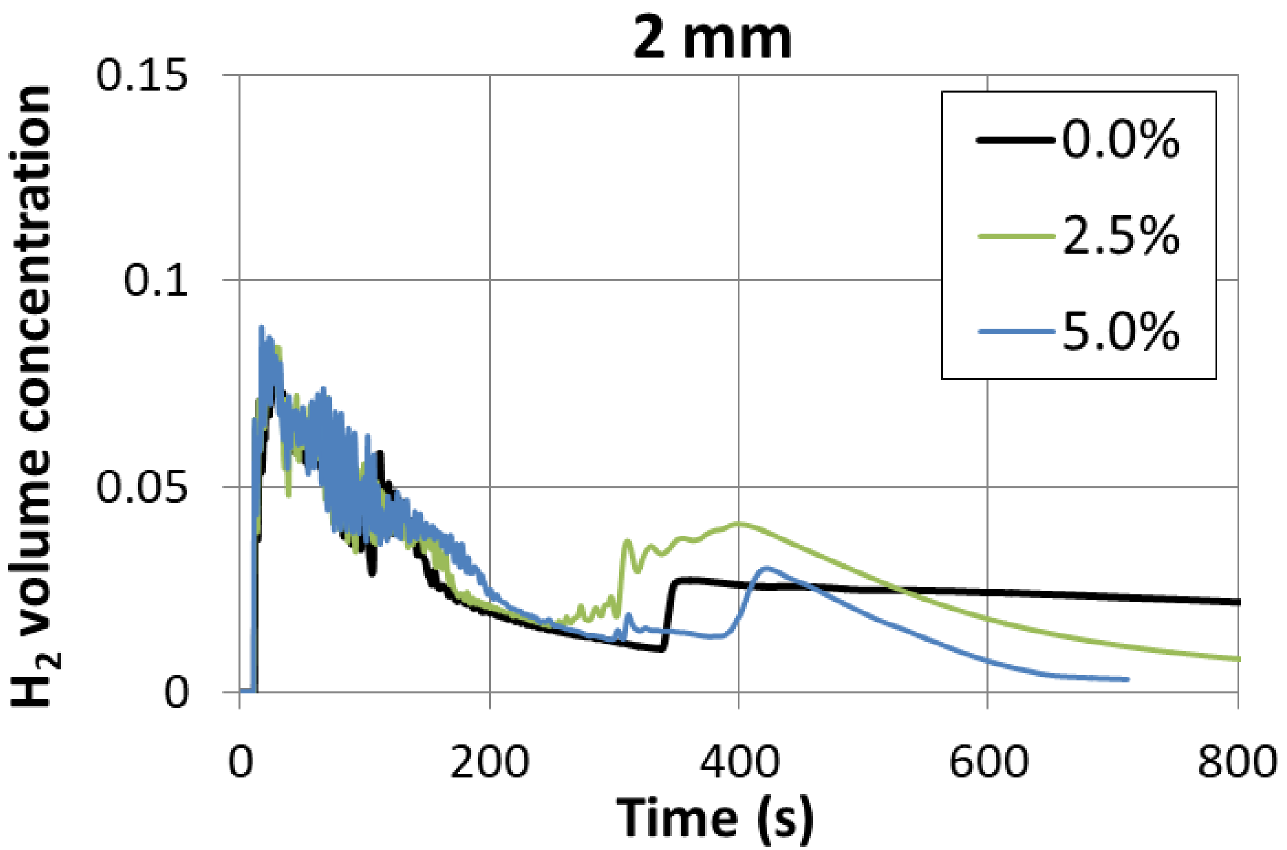
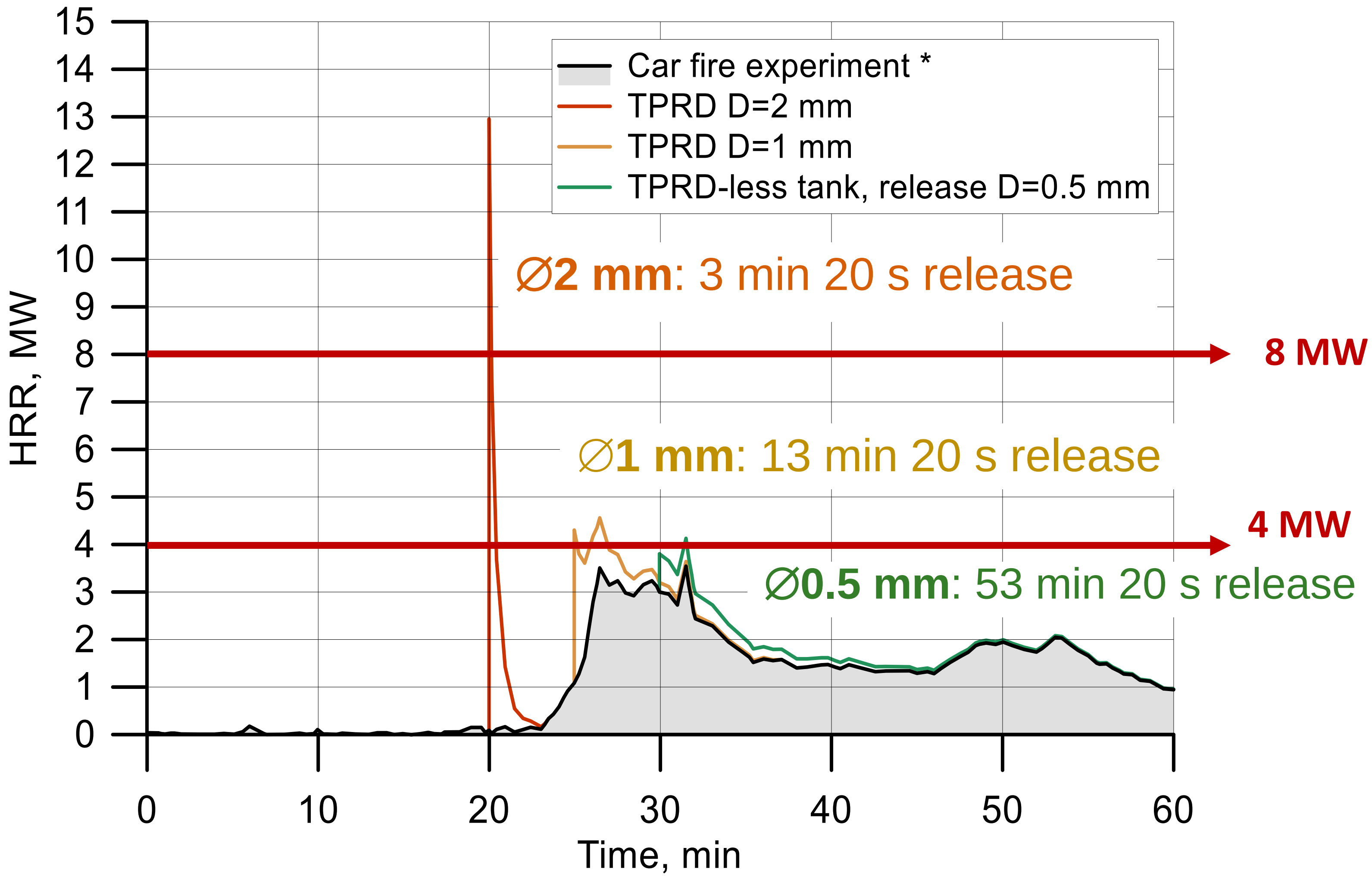


Results example: hydrogen jet fire and vehicle fire

Negligible contribution to Heat Release Rate of vehicle fire

The effect of a hydrogen jet fire on design HRR was found to be negligible for small TPRD diameters



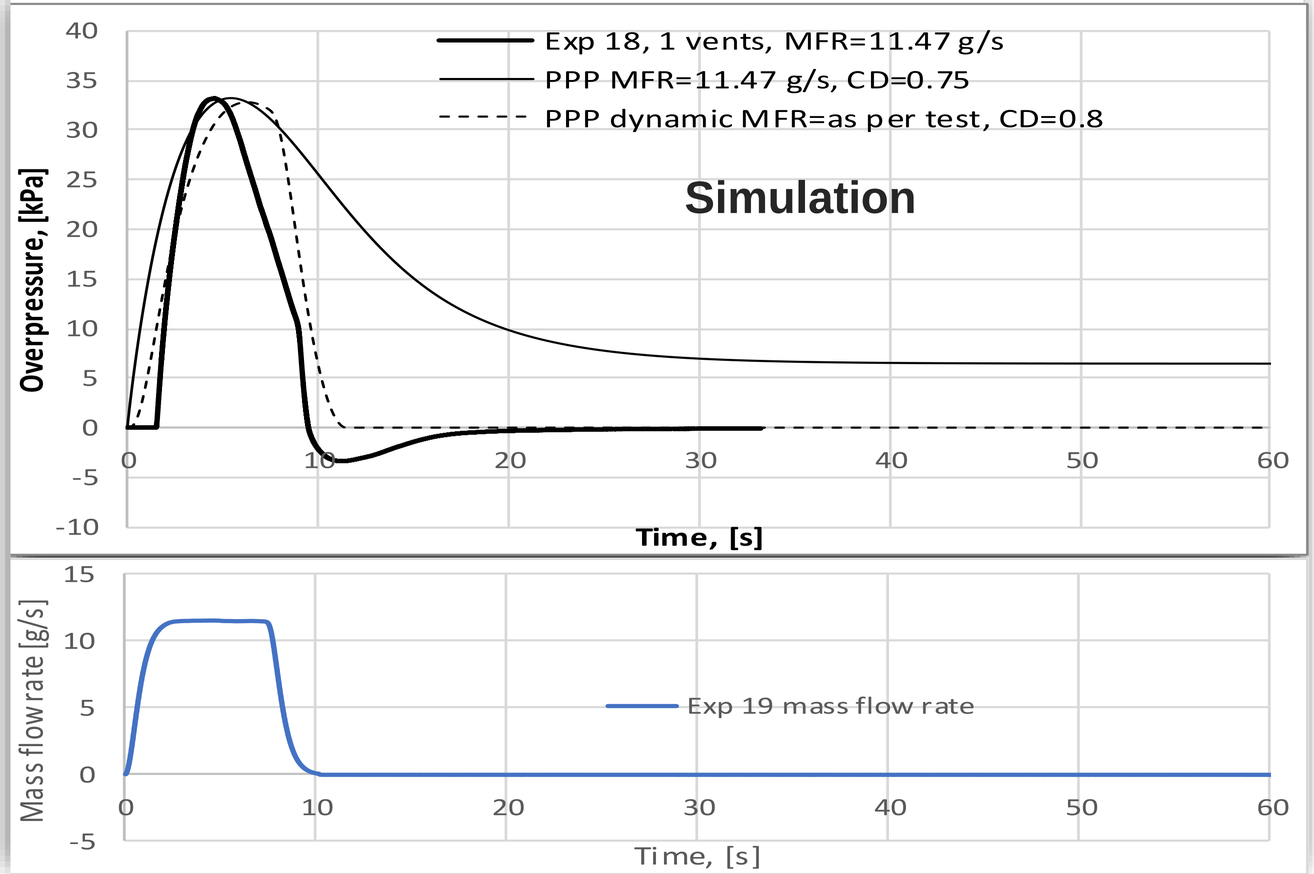
Car fire HRR source: Fire Safety Journal 2013, 62, 272-280

Results example: the pressure peaking phenomenon

Validation for real-scale storage enclosures: tests and theory

Experiment

- Storage enclosure volume14.9 m^3.
- Ignited and unignited releases up to $\dot{m}_{H2}$=11.7 g/s (at the moment).



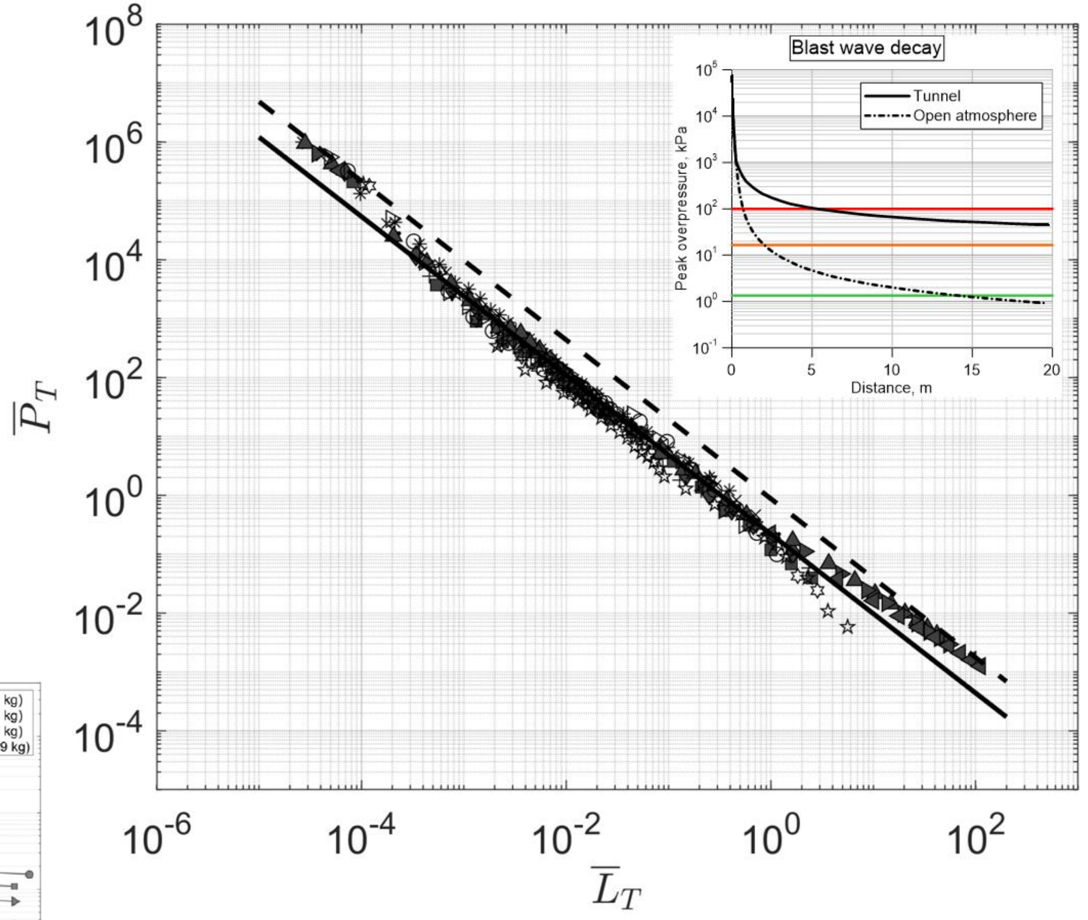
- Validated engineering tool (both ignited & unignited releases).
- Maximum overpressure is the same for dynamic (blowdown) and steady-state releases.

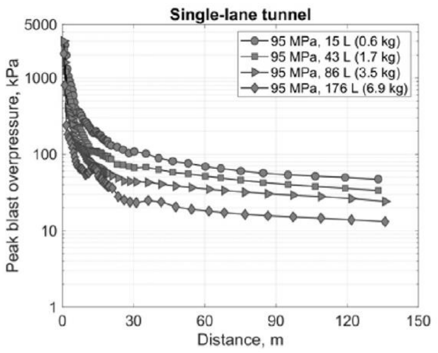
[1]. Lach, Gaathaug, Int. J. Hydrogen Energy, 2021 (DOI: 10.1016/j.ijhydene.2020.12.015)
[2]. Lach, Gaathaug, Knut, Int. J. Hydrogen Energy, V. 45, pp. 32702-32712, 2020 (DOI: 10.1016/j.ijhydene.2020.08.221g)

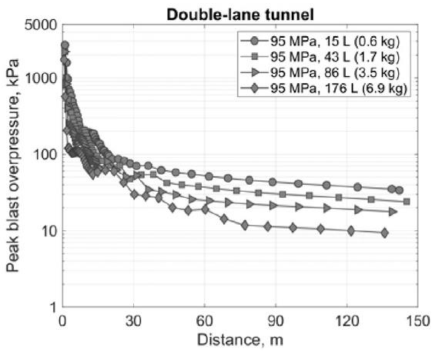
Results example: blast wave decay in a tunnel
The universal correlation

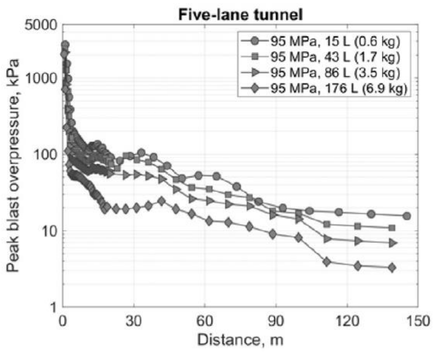
Rupture of tank of any volume and pressure in a tunnel of any cross-section area, aspect ratio and length:

- Dimensionless distance: $\overline{L}_T = \frac{P_0 L A}{E \cdot AR^{0.5}} \left(\frac{fL}{D_T}\right)$
- Dimensionless pressure : $\overline{P}_T = \frac{\Delta P}{P_0} \cdot \frac{1}{\overline{L}_T}$
- Best fit correlation: $\overline{P}_T = 0.22 \cdot \overline{L}_T^{-1.35}$
- Conservative correlation: $\overline{P}_T = 0.87 \cdot \overline{L}_T^{-1.35}$









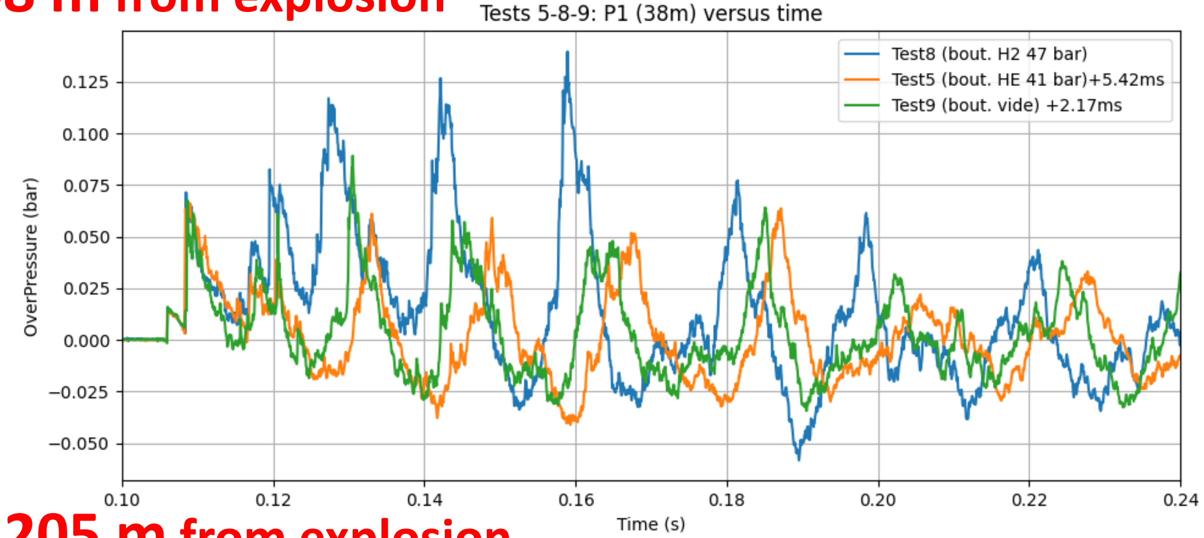
Molkov V., Dery W. The blast wave decay correlation for hydrogen tank rupture, Int. J. Hydrogen Energy, v.45, Iss.5, pp. 31289-31302., 2020; DOI: 10.1016/j.ijhydene.2020.08.062

Results example: blast wave after tank rupture

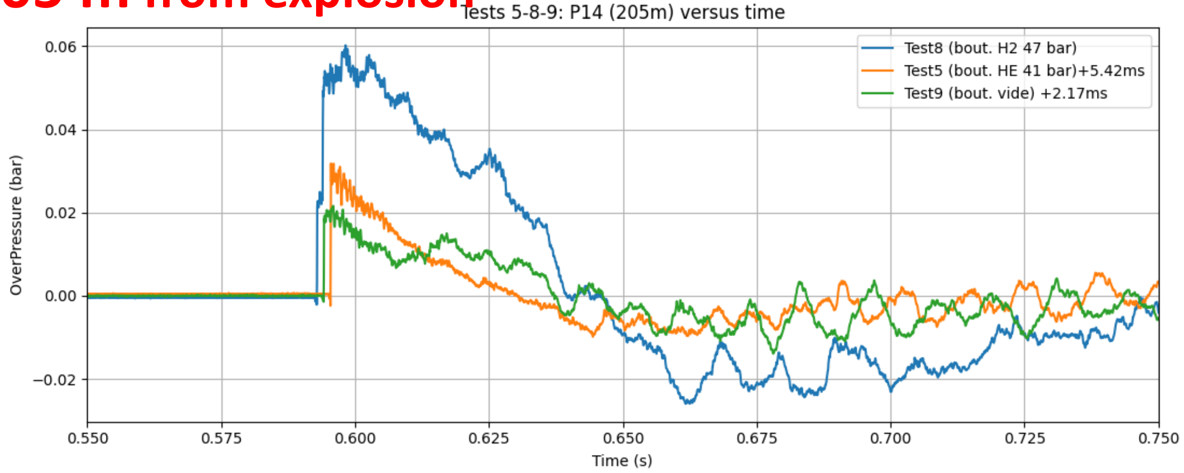
Real tunnel tests: combustion contributes to blast strength

Experimental evidence of hydrogen combustion contribution to blast overpressure in a tunnel (CEA)

38 m from explosion



205 m from explosion

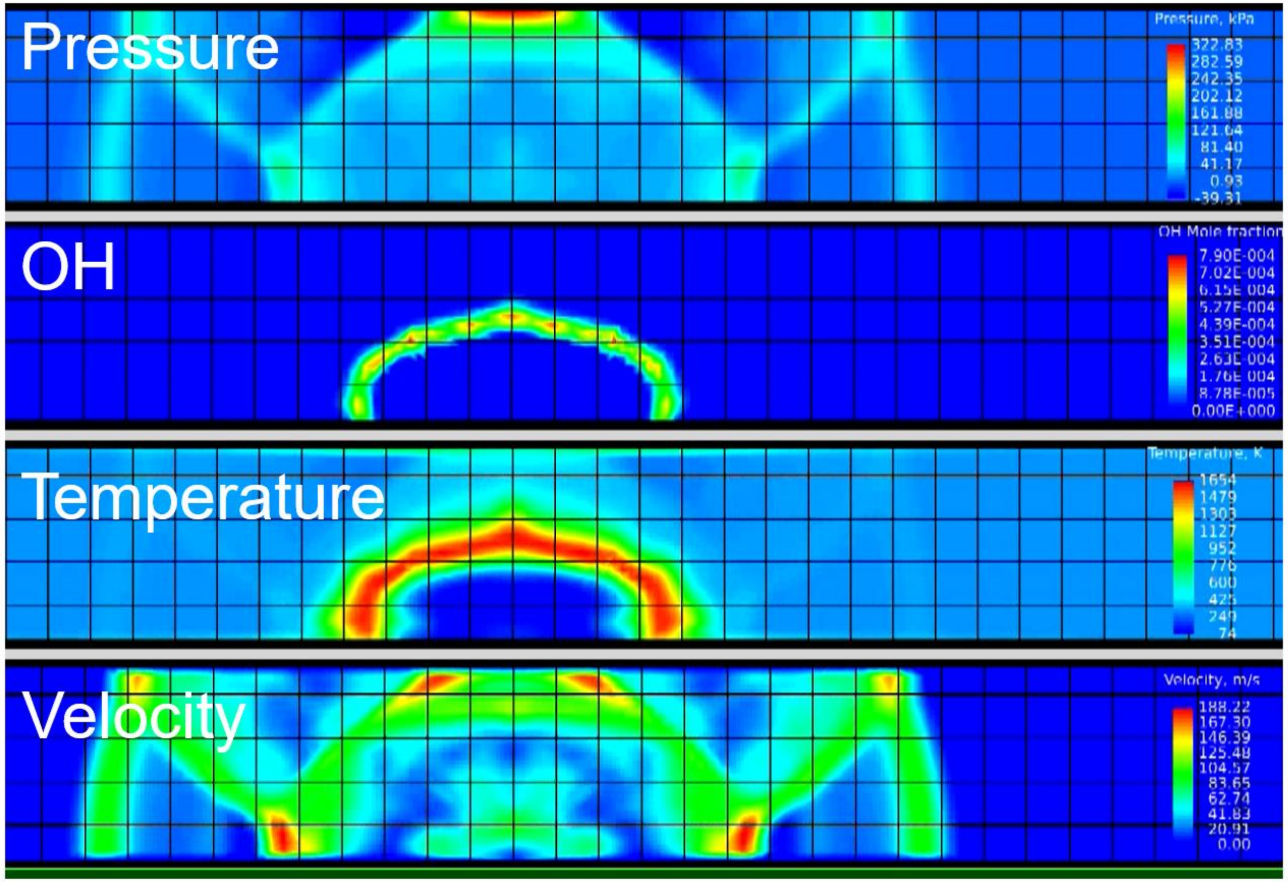


- Three cases for the tank rupture by detonation belt - **GH2**, **GHe**, **Detonation belt alone**
- Similar behaviour of overpressure **GHE** and **Det. Belt**
- Significant contribution of chemical energy from **GH2** combustion

Results example: tank rupture in a tunnel

Real test data (CEA) and simulations (Ulster University)

Initial stage of combustion (later fireball propagates at speed of 25 m/s).



Results example: tank-TPRD system design

Inherently safer TPRD for engulfing fire (the first ever model)

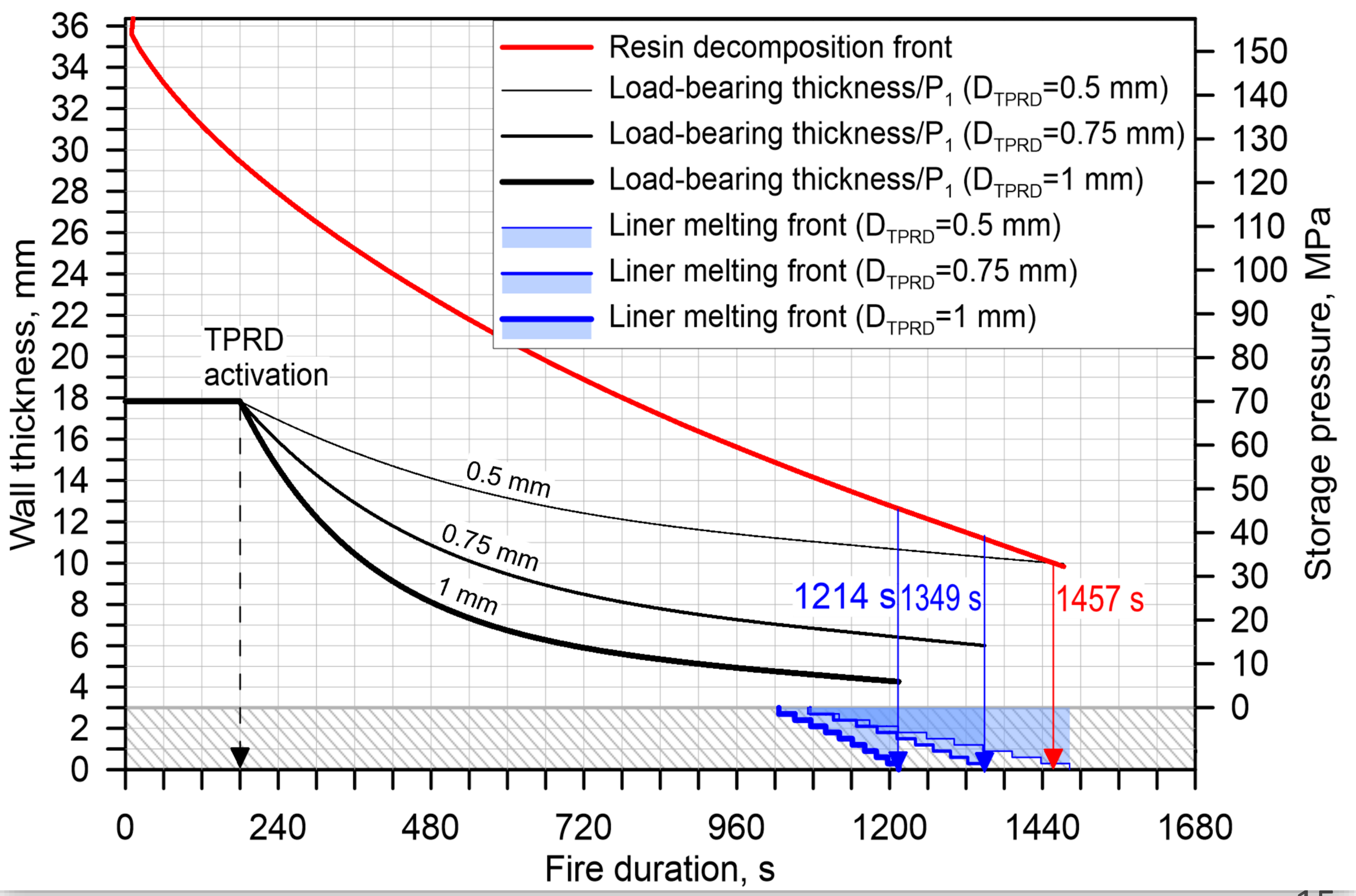
Example: **244 L, 70 MPa tank**

Aim to exclude:

- Tank rupture
- PPP
- Long jet flames
- Flammable mixture formation

Assumptions:

- Challenging gasoline fire HRR/A=1 MW/m²
- Conservative TPRD activation delay 3 min (should be less than experimental FRR=4 min in HRR/A=4 MW/m² fire).



V. Molkov, M. Dadashzadeh, S. Kashkarov, D. Makarov. Performance of hydrogen storage tank with TPRD in an engulfing fire, 2021 (in press).

Breakthrough in hydrogen safety for confined space

Explosion free in a fire TPRD-less tanks (HRR/A=1 MW/m²)

No blast wave!

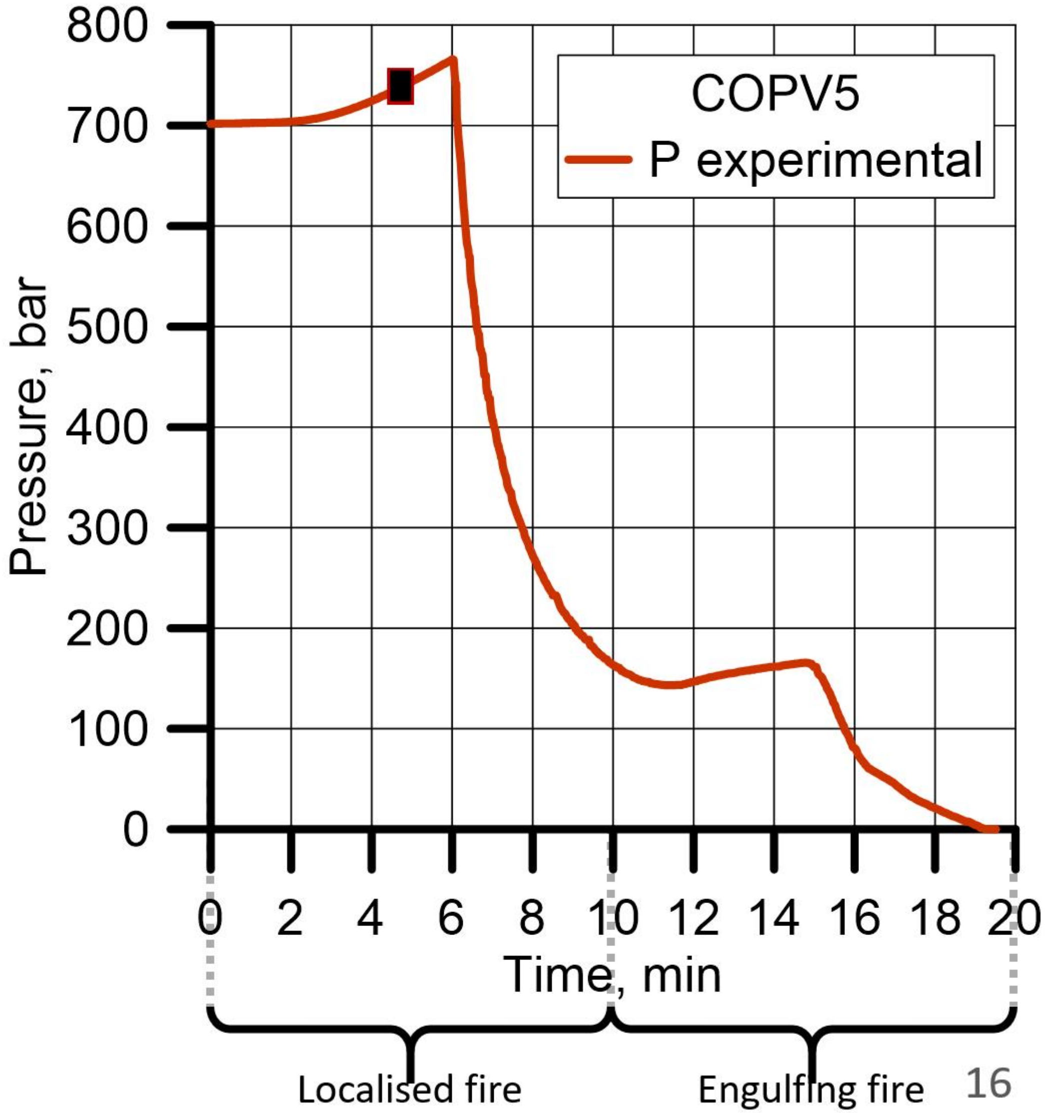
No fireball!

No projectiles!

No long flames!

No pressure peaking!

No loss of life!



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What are knowledge gaps after the project?
Underground traffic infrastructure

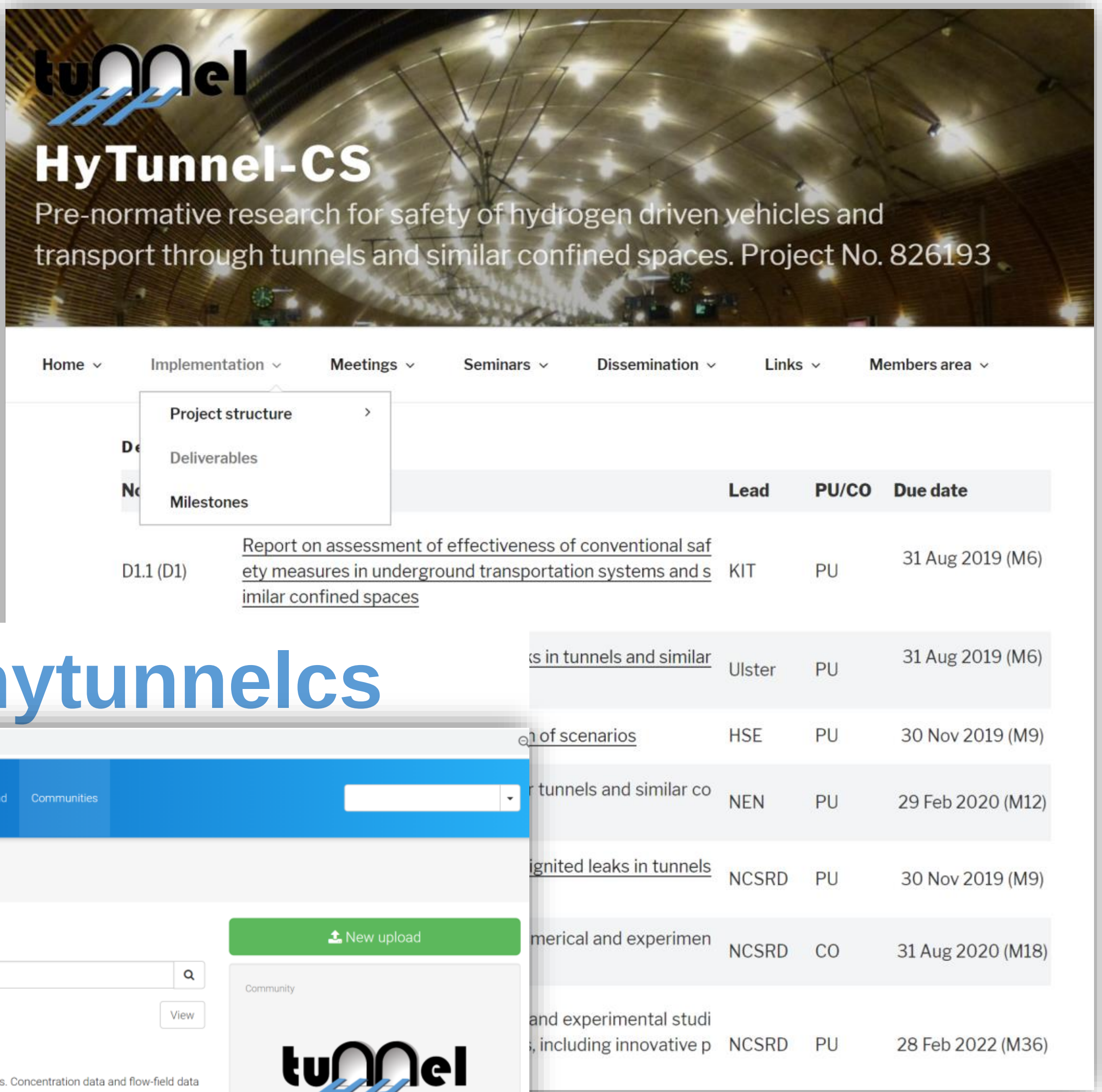
Main knowledge gaps that would require more research after PNR HyTunnel-CS:

- Vehicles using liquid hydrogen LH2 for propulsion (not yet available).
- Hydrogen trains in comparatively narrow rail tunnels (issue can be addressed by TPRD-less tanks).
- Testing and certification of explosion free in a fire TPRD-less tanks of different volumes and pressures, and in different fire conditions (including confined spaces of storage enclosures on trains, ships, planes, etc.).

HyTunnel-CS dissemination events and channels

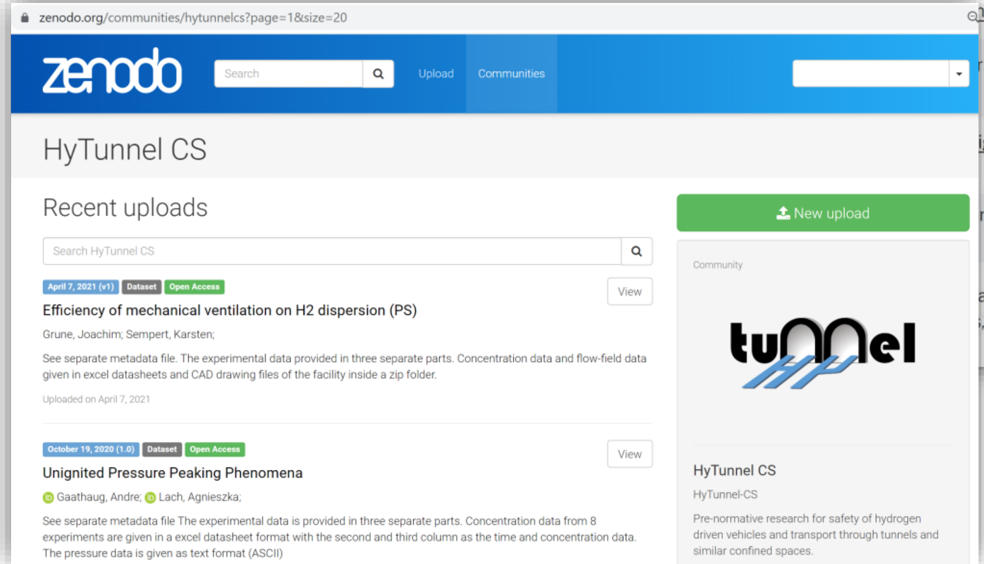
https://hytunnel.net/

- Public deliverables
- Newsletters
- Announcement of dissemination conference



https://zenodo.org/communities/hytunnelcs

- Open access to primary experimental data of selected experimental campaigns



HyTunnel-CS and e-Laboratory of Hydrogen Safety

Free online tool for all stakeholders

New tools developed in HyTunnel-CS for future implementation in the e-Laboratory:

- Non-adiabatic blowdown model
- Time of tank to rupture in a fire in case of TPRD failure
- Parameters of blast wave after hydrogen tank rupture in a tunnel
- Parameters of fireball of hydrogen tank rupture in a tunnel
- DDT in horizontal and vertical ventilation systems with non-uniform hydrogen-air mixtures

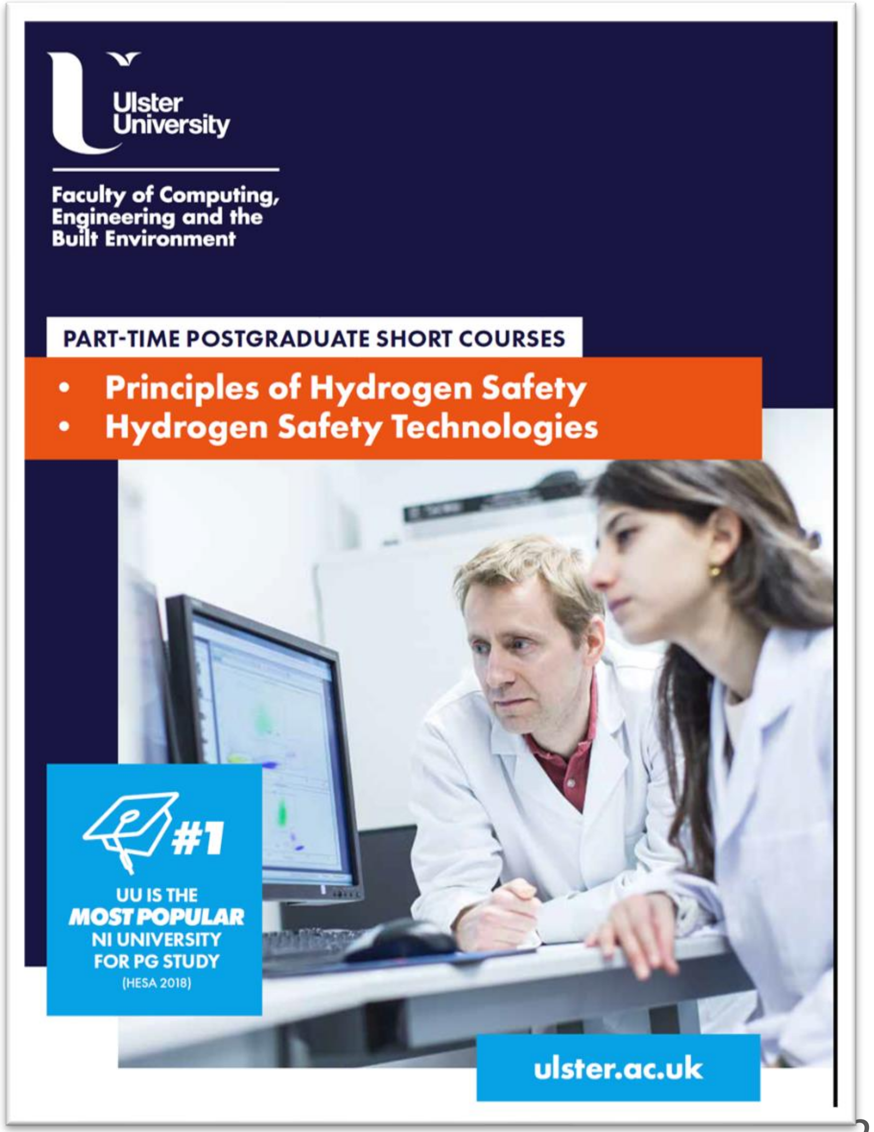
To get access to e-Laboratory please follow 2 steps (contact Dr Volodymyr Shentsov at V.Shentsov@ulster.ac.uk if any questions):

1. URL: https://elab.hysafer.ulster.ac.uk/
2. **Login:** HyResponderTrainer **Pass:** safetyfirst

HyTunnel-CS dissemination events and channels
Education: Postgraduate Certificate in Hydrogen Safety

Distance learning course (will be updated by HyTunnel-CS outcomes), more information at:

https://www.ulster.ac.uk/research/topic/built-environment/hydrogen-safety-engineering/study



Acknowledgements

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