HyTunnel Project To Investigate The Use Of Hydrogen Vehicles In Road Tunnels

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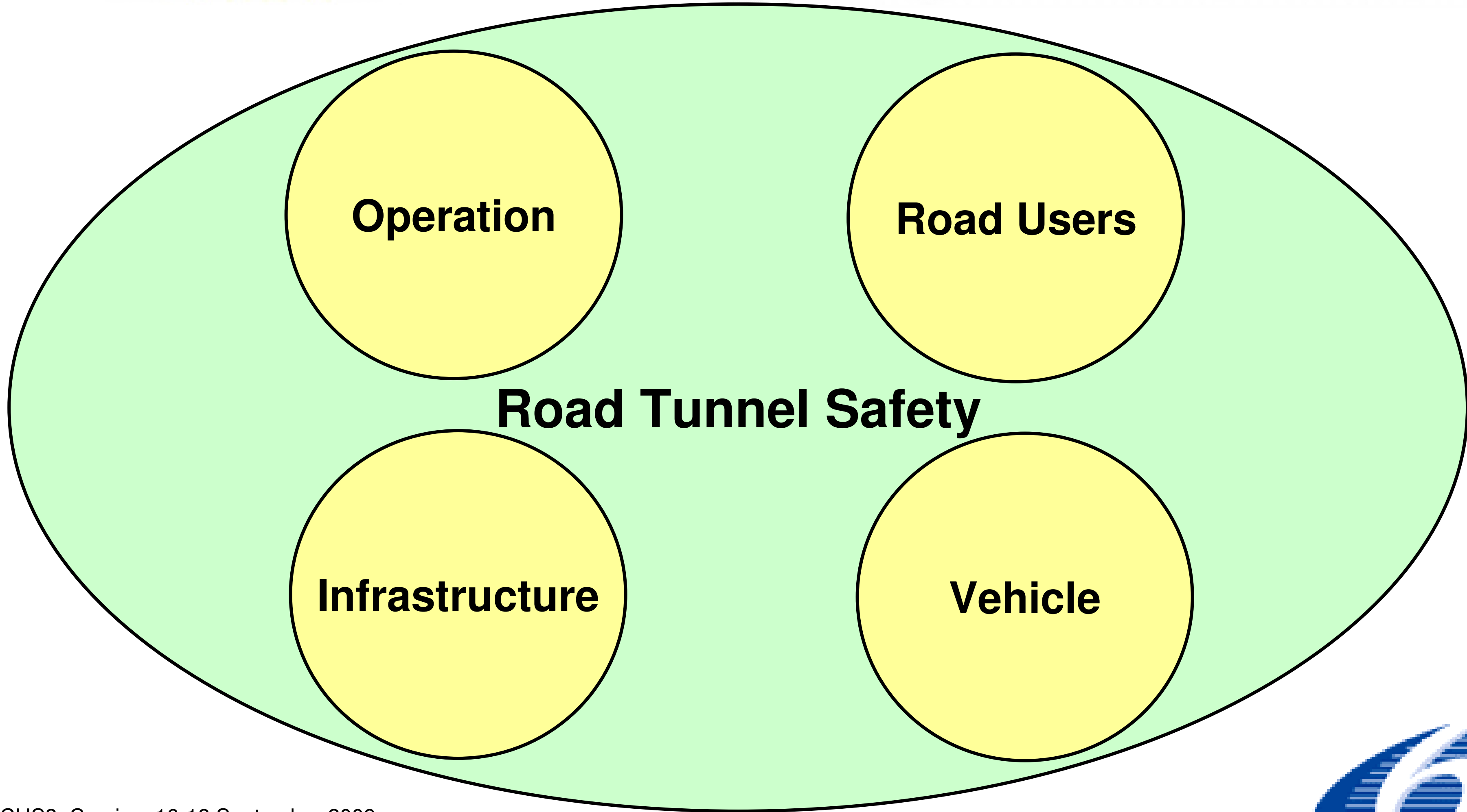
Introduction

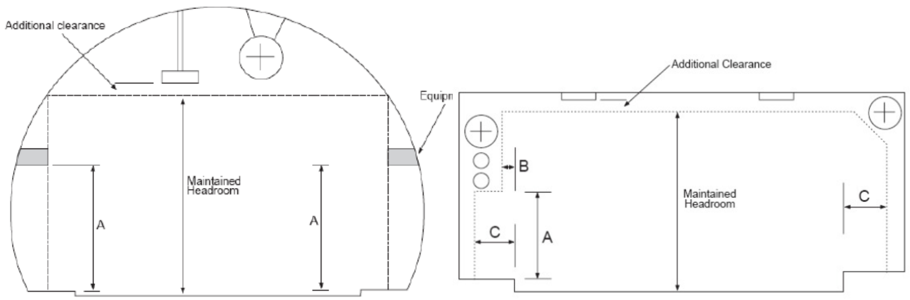
- A HySafe PIRT exercise identified hydrogen vehicles in tunnels as a subject requiring research
- The HySafe internal project “HyTunnel” was established
- HyTunnel’s objectives:
  - To review previous research
  - To review current technology and practice for tunnel design and operation, in the context of hydrogen vehicle technologies
  - To identify areas for research within HySafe
  - To make initial recommendations related to the risk associated with hydrogen vehicles in tunnels
  - Where necessary to identify areas for further study

Road Tunnel Safety



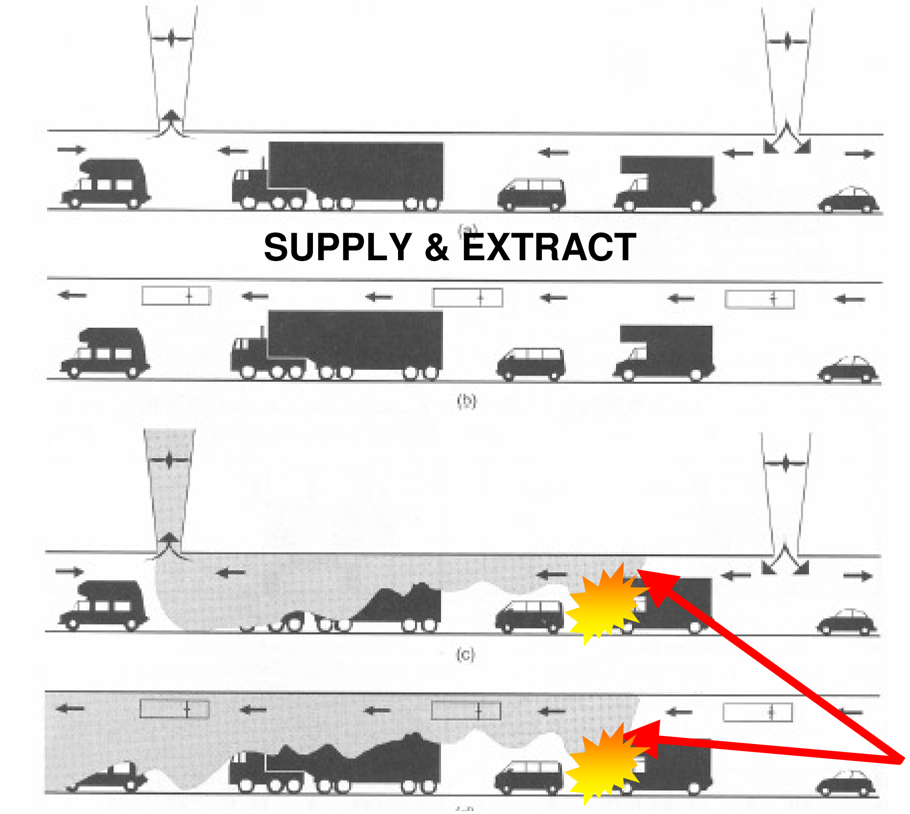
Tunnel Characteristics

- Tunnel characteristics:
  - Length
  - Urban or rural
  - Rectangular or arched cross-section
  - Uni- or bi-directional traffic flow
  - Natural or mechanically assisted ventilation
- Road tunnel design & operating guidance:
  - Avoid collisions (geometry, lighting, etc.)
  - Control emissions (CO, particulates, etc.)
  - Control smoke & fire
  - Prevent major incidents (escorting tankers, etc.)
  - But hydrogen (& other alternative energy carriers) may present new hazards



Source: UK Highways Agency

Tunnel Ventilation



SMOKE FORCED DOWNSTREAM

- In normal operation ventilation removes emissions and provides fresh air

- In a fire, ventilation controls smoke and heat. Generally smoke is ‘pushed’ downstream to allow upstream escape & fire service access

Experimental Work

- Experiments at Health & Safety Laboratory (HSL) and FZ Karlsruhe (FZK) as part of HySafe
- Examine influence of ventilation and congestion on deflagration and detonation in hydrogen-air mixtures and hydrogen stratified layers
- Provides a good basis from which findings can be extended by computer modelling

HSL Explosion Experiments (1)

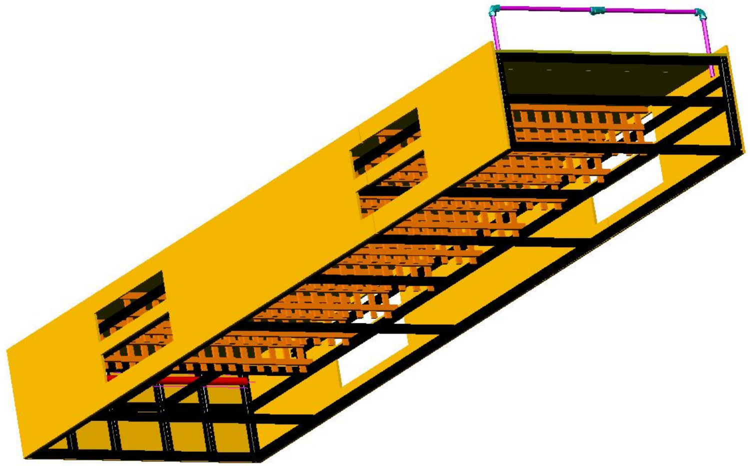
- Performed to examine the effect of congestion and ventilation on the hazard associated with hydrogen gas release
  - Ignition of stoichiometric hydrogen-air mixtures & overpressure measurement
  - Approx. 1/3 scale
  - Comparison against methane explosions

HSL Explosion Experiments (2)

- Main findings:
  - Hydrogen explosion overpressures ~4 times greater than methane under same conditions, and oscillatory in nature (methane smooth)
  - Increasing hydrogen concentration increased explosion pressure
  - Increasing congestion had only modest effect with hydrogen (unlike methane)
  - Significant overpressures can be generated in tunnel like geometries by ignition of hydrogen-air mixture occupying only a few % of the space
  - Risk of DDT?

FZK Explosion Experiments (1)

- Performed to investigate high-speed deflagrations in stratified hydrogen layers (e.g. under tunnel soffit)
  - Hydrogen layer thickness and concentration varied
  - Approx. 1/5 scale
  - Ceiling obstructions added in some experiments



FZK Explosion Experiments (2)

- Summary of results:

		Small scale	Large scale		
		Layer height [m]	Layer height [m]		
		0.40	0.15	0.30	0.60
c(H_2) [Vol.-%]	15	slow deflagration	slow deflagration	slow deflagration	fast deflagration
	20	fast deflagration	fast deflagration	fast deflagration	*(fast deflagration)*
	25	detonation	decaying detonation	detonation	*(detonation)*

Experiment not performed, but result can be inferred

FZK Explosion Experiments (3)

- Main findings:
  - Obstructions in the tunnel ceiling can add turbulence to flame propagation and make explosions more severe
  - Results indicated that DDT is, in principle, possible in the confined space of a tunnel
  - Consequently, ceiling design and mitigation measures may be important
  - Critical hydrogen layer thickness for DDT in the range of 7.5 - 15 detonation cell widths

CFD Studies

- Complement the HSL and FZK experiments
- Simulations were performed by GexCon, Warsaw Univ. of Tech. (WUT) and Univ. of Ulster (UU)
- Two phenomena were modelled:
  - Dispersion of released hydrogen (from PRD) inside the tunnel
    - Examining the size, distribution and concentration of hydrogen-air clouds
  - Ignition of the dispersed hydrogen cloud
    - Pressures generated
- Comparison of hydrogen and natural gas

CFD Scenarios

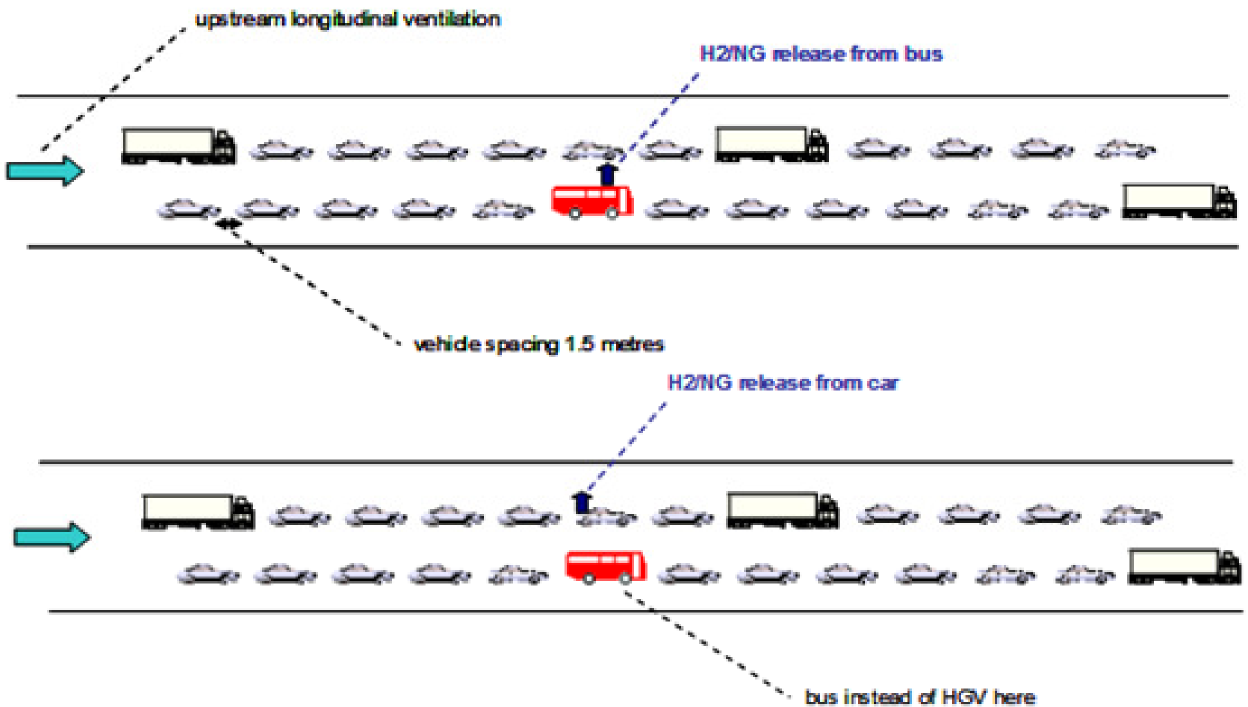
- Scenarios selected to allow the relative significance of various phenomena to be examined:
  - 2-lane, single bore tunnels with uni-directional traffic flow
  - Rectangular and horseshoe cross-sections in range 50 to 60m^2
  - Longitudinal ventilation rates up to 5 m/s
  - Tunnel fully occupied with stationary traffic
  - Fuel release due to the activation of PRD(s) resulting in the release of the entire contents of the cylinder/tank (or group of cylinders/tanks)

CFD Scenarios - Vehicles

- Compressed hydrogen gas city bus
  - A representative city bus with roof mounted compressed gas fuel tanks housing a total 40 kg of hydrogen in 8 cylinders at a storage pressure of 350 bar
- Compressed hydrogen gas car
  - A representative car with an inventory of 5 kg of hydrogen stored in one cylinder at a storage pressure of 700 bar
- Liquid hydrogen car
  - With 10 kg of liquid hydrogen
- For comparative purposes
  - Natural gas city bus (104 kg @ 200 bar) and car (26 kg @ 200 bar)

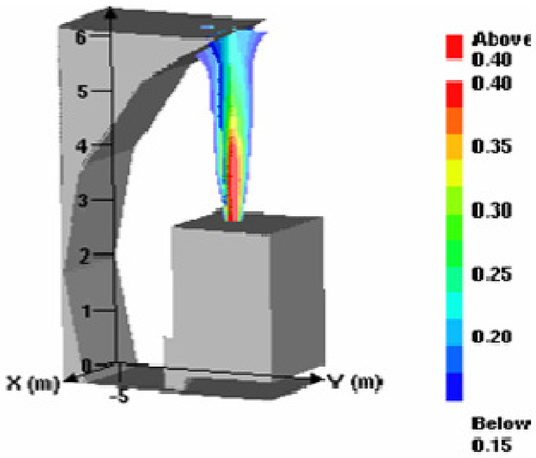
CFD Scenarios - Traffic

- 15% commercial vehicles, i.e. 1 in 7 vehicles



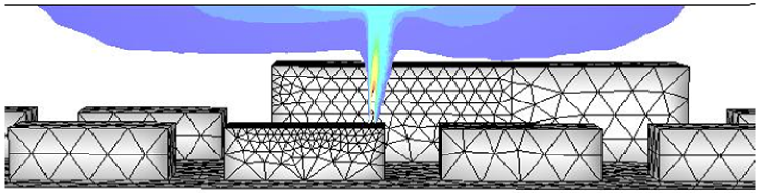
CFD Simulations At GexCon

- Performed using FLACS
  - 3-D CFD code using a Cartesian grid and solving the Reynolds-averaged Navier-Stokes (RANS) equations
  - Modified k-ε turbulence model
  - Specialised sub-models for hazard analysis



- Main findings:
  - The LH_2 car generated only small flammable clouds
  - While the hydrogen dispersion clouds were large in some scenarios (CGH_2 city bus), the resulting explosion pressures were only modest at 0.1 to 0.3 barg
  - The horseshoe cross-section resulted in a smaller flammable cloud
  - Increasing tunnel ventilation has only minimal impact

CFD Simulations At WUT



- Performed using Fluent
  - Dispersion analysis only
  - 3-D CFD general purpose code using an unstructured grid and solving the Reynolds-averaged Navier-Stokes (RANS) equations
  - Long history of hazard analysis applications

- Main findings:
  - The horseshoe cross-section resulted in a smaller flammable cloud
  - The LH_2 car generated larger flammable clouds than for the CGH_2 car
  - Introduction of even a low level of ventilation (1 m/s) significantly reduced the flammable cloud size and its associated hazard

In contrast to GexCon

CFD Simulations At UU

- Performed using hybrid in-house/commercial code
  - Comparison of Large Eddy Simulation (LES) and RANS calculations for a previously published (EIHP-2) scenario involving release from bus
  - Study of the ‘blow down’ scenario of 5 kg of hydrogen released at an initial cylinder pressure of 350 bar through a 6 mm PRD vent
- Main findings:
  - Explosion overpressures may be greater than previously reported
  - Smaller PRD vent diameters may help reduce the consequential explosion hazard

Summary Of CFD Findings

- Increasing height of tunnel ceiling (e.g. horseshoe cross-section) reduces explosion hazard
- Inconclusive results with respect to the benefit of imposing tunnel ventilation
  - GexCon simulations suggest that buoyancy and momentum of release dominates
  - WUT simulations suggest that imposing 3 m/s ventilation has significant benefit
- Relative hazard associated with gaseous and liquid hydrogen storage not yet clear

Overall HyTunnel Conclusions

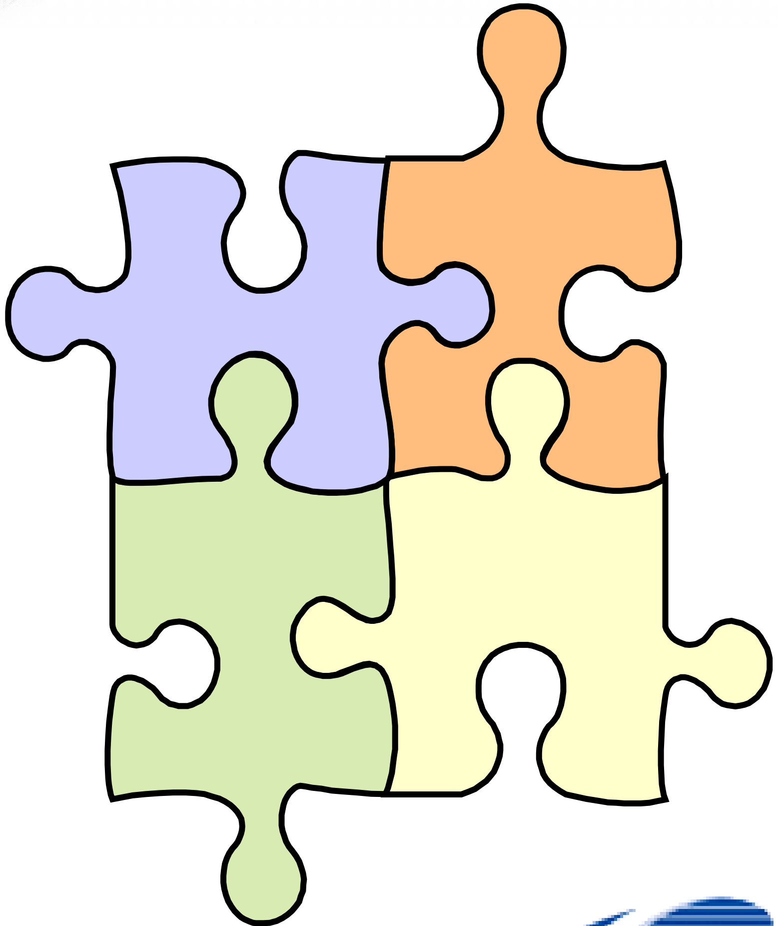
- The hazards have to be considered in the context of the overall fire load resulting from a tunnel accident
- Experimental results need to be viewed in the context of real world situations
- HyTunnel has contributed to the understanding of potential hazards from use of hydrogen vehicles in road tunnels
- Results from HyTunnel and elsewhere indicate that hydrogen vehicles can be used safely, but various issues need to be considered further:
    - Ceiling obstructions may promote risk of explosion
    - Reduced ceiling height may increase explosion risk and produce jet hazard
    - Optimal operation and location of PRDs
- The study of hydrogen vehicle hazards in tunnels is multi-disciplinary & complex
- Other new or alternative energy carriers should also be considered

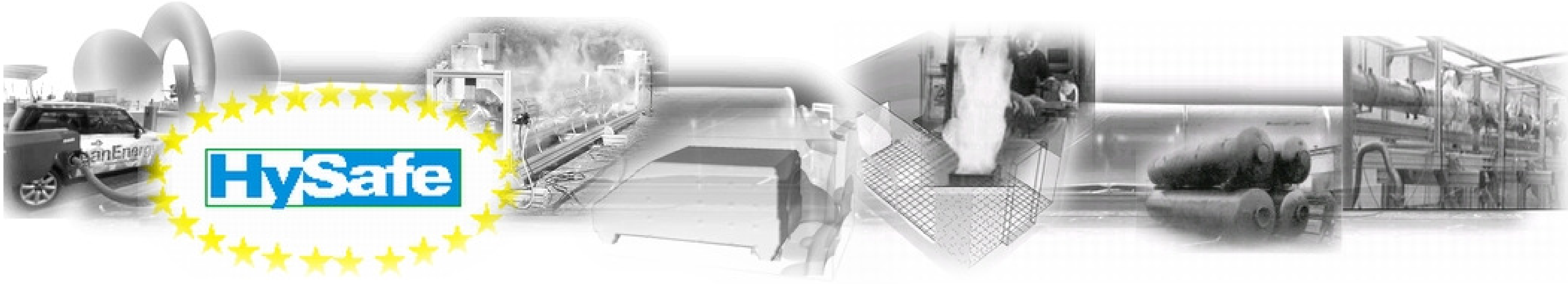
Proposals For Further Work

- HyTunnel has identified the following as warranting further study:
  - To quantify the risk of fast deflagration or detonation associated with ceiling obstructions
  - To examine the hazard & risk associated with ignited jets of hydrogen
  - To establish whether imposing a minimum rate of tunnel ventilation is good practice in respect to diluting any release of hydrogen
  - To consider multiple vehicle releases/fires (hydrogen & conventional)
  - To consider other ventilation methods
- A detailed risk analysis is necessary before final recommendations can be made

Vehicle & Infrastructure Regs

- The automotive industry increasingly has regulations harmonised at a global or regional level.
- Automotive regulations do not regulate the design of structures.
- Buildings and infrastructure are regulated at a national or local level.
- To achieve the safe introduction of hydrogen vehicles without unnecessary restrictions on their use we need to ensure that automotive regulations are compatible with building and infrastructure regulations and vice versa.





Thank you!