HySafe network & HyTunnel project

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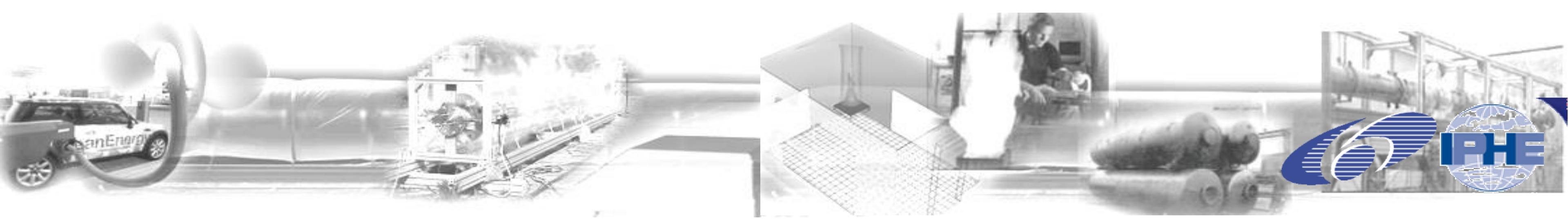
New Energy Carriers in tunnels and underground installations
Frankfurt a. M. Airport
20 November 2008



NoE HySafe - Integration of the EU H2 Safety Research

Consortium

- 24 partners from 12 European countries
  + Kurchatov Institute, Russia + University of Calgary, Canada
- 13 research institutes, 7 industry partners, 5 universities
- ~150 scientists actively involved

Budget

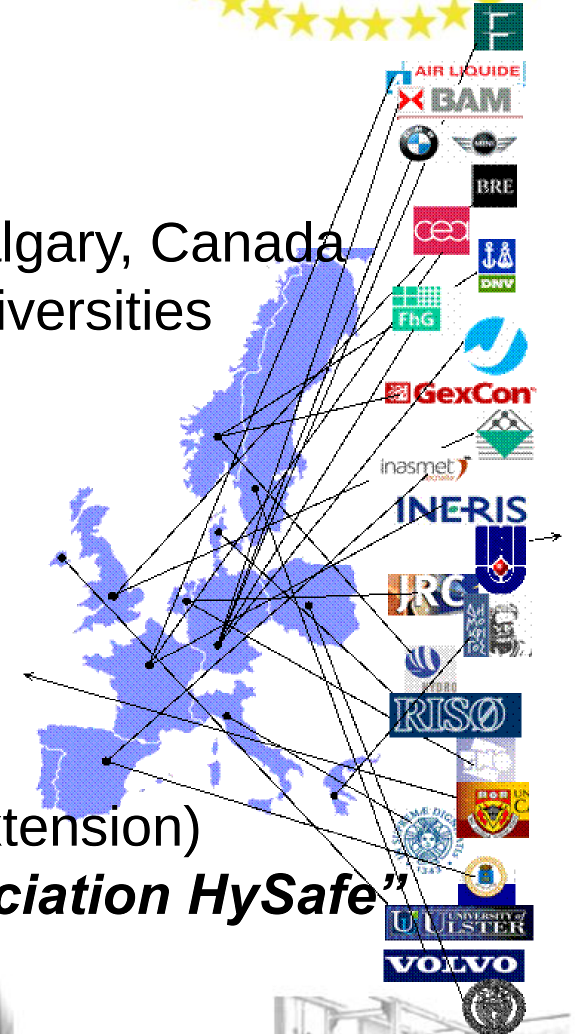
Total > 13 M€ ; EC grant < 7 M€

Time frame

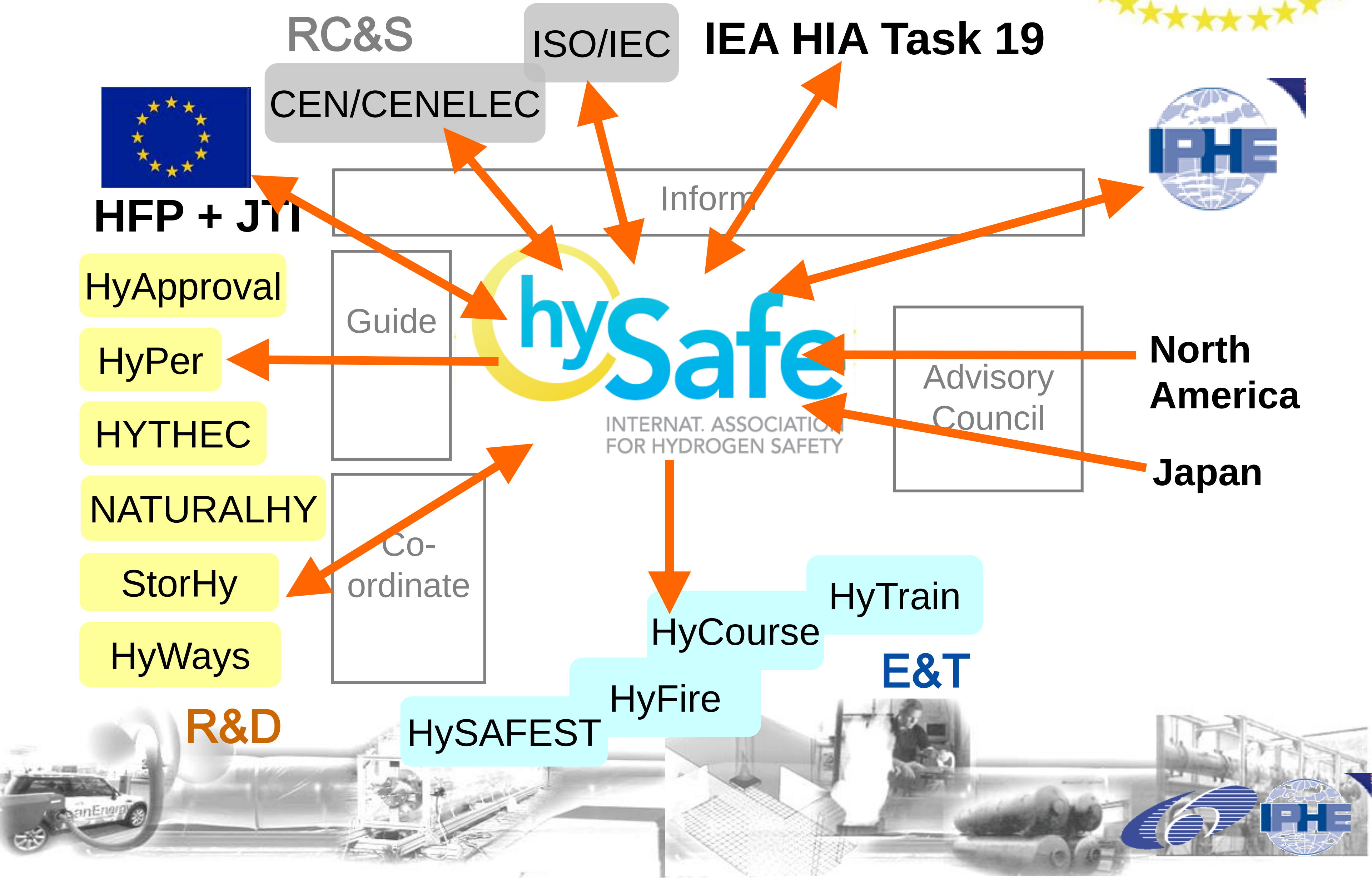
NoE started: 03/2004

duration: 5 years (application for 8 month extension)

→ 02/2009 Founding of the ***"International Association HySafe"***
(self funded Belgian AISBL)



International Networking

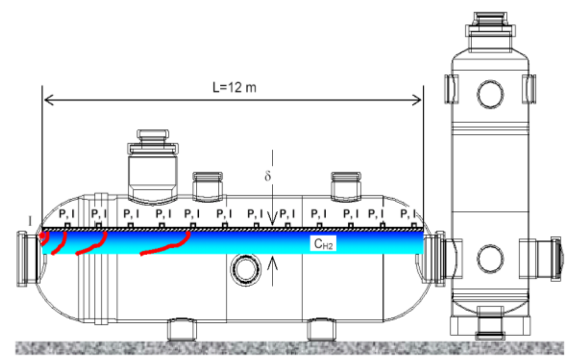


Research Headlines

- **(Partially) Confined Releases**
- **Mitigation**

determined by
- initial PIRT study
- expert questionnaire
- state-of-the-art survey

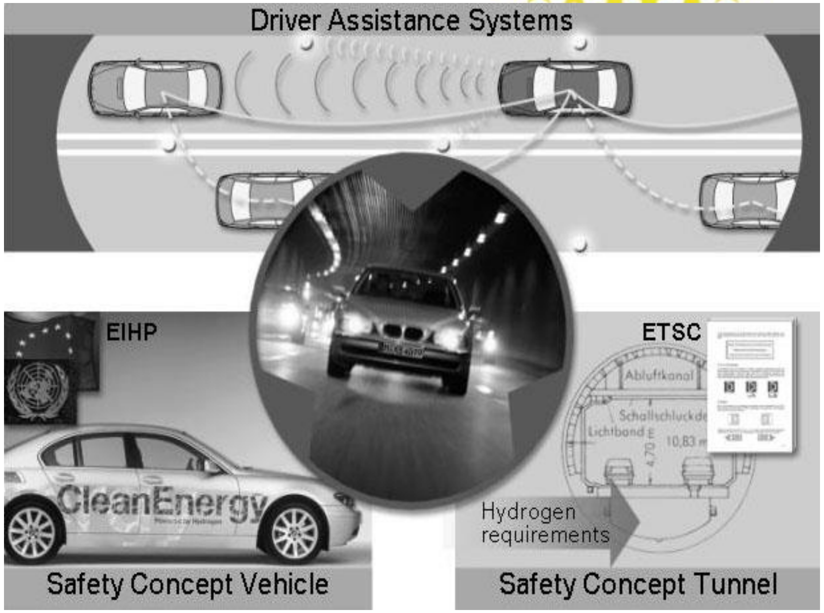
communicate the network's working topics,
orientate the work on intermediate time scale (proposals for experiments, benchmarking, Internal Projects …)



Internal Project "HyTunnel"

Objectives

- review tunnel regulations, standards and practice in respect to the management of hazards and emergencies, e.g. EC directive
- identify appropriate accident scenarios for further investigation
- review previously published experimental and modelling work of relevance
- extend our understanding of hydrogen hazards inside tunnels by means of new physical experiments and numerical modelling activities.
- document suggested guidelines for the safe introduction of hydrogen powered vehicles into tunnels



→ Improved tunnel safety with H_2 as the fuel of the future

COMMISSION OF THE EUROPEAN COMMUNITIES

Brussels, 30.12.2002
COM(2002) 769 final

2002/0309 (COD)

Proposal for a

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on minimum safety requirements for tunnels in the Trans-European Road Network

HyTunnel - Experimental Layout

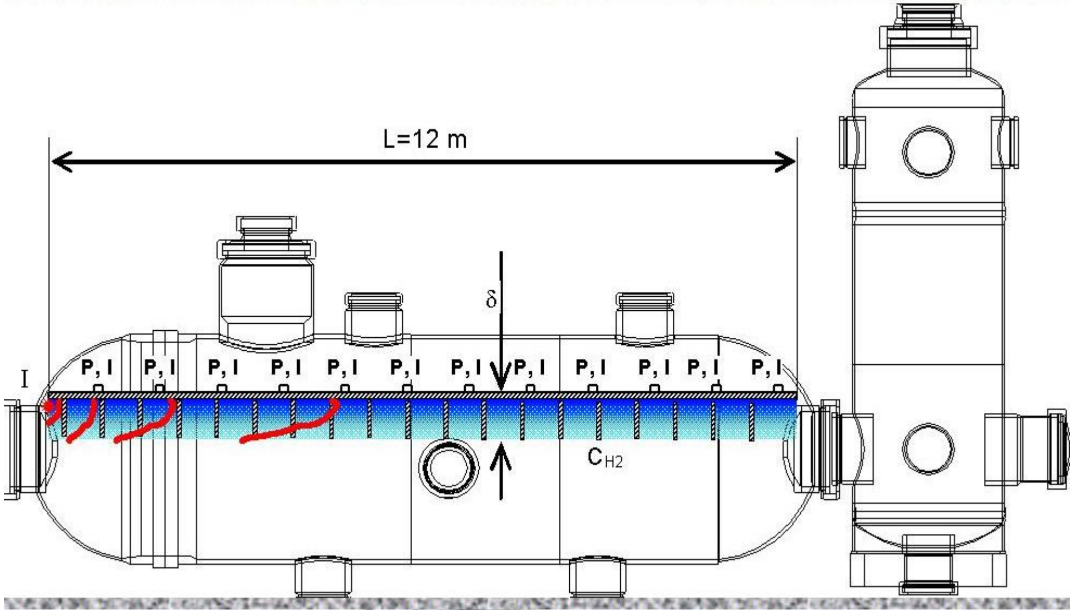
Objective:

Critical conditions for FA and DDT in semi-confined gas mixture layer

Expected data: Dependence of critical σ* and λ* on gas layer height δ

I – ignition point;
P, I – pressure and light gauges.
L = 12 m – A1 length;
D = 3.5 m – A1 diameter;
V = 100 m^3 (+30 m^3)– total volume;
BR = 0.6 (0.3) by obstacle laden grid

C_{H2} –hydrogen concentration;
δ– layer thickness



Some results - of the experimental program

Hydrogen stratified layer experiments completed by FZK:

- Summary included in HyTunnel Deliverable D62
- Full report in deliverable D87
- 10 experiments conducted

Small scale		
		Layer height δ [m]
		0.40
$c(H_2)$ [Vol.-%]	15	slow Deflagration
	20	fast Deflagration
	25	Detonation

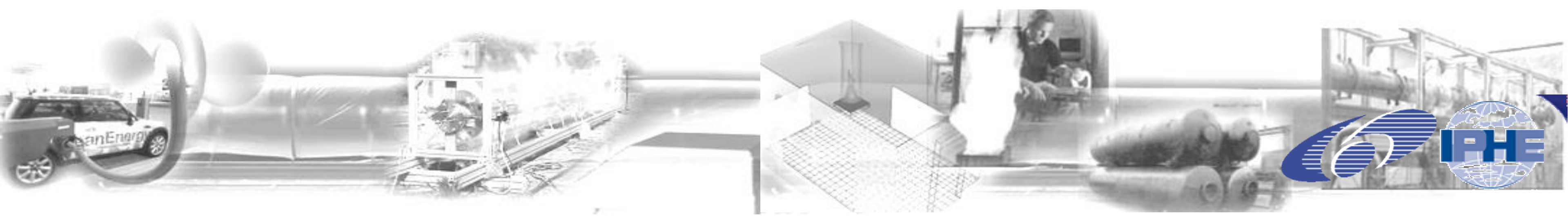
Large scale				
		Layer height δ [m]		
		0.15	0.30	0.60
$c(H_2)$ [Vol.-%]	15	slow Deflagration	slow Deflagration	fast Deflagration
	20	fast Deflagration	fast Deflagration	*(fast Deflagration)*
	25	decaying Detonation	Detonation	*(Detonation)*

HyTunnel – Numerical Simulation

Selected Scenarios

Details of H2 and CNG release (9 variants):

Vehicle	Inventory/ Duration	Initial release rate C=constant V=variable	Release rate sensitivity study (300s)	Orifice	Probability
Car LH_2	10 kg (900s)	11 g/s C	n/a	20 mm	0.375
Car CGH_2 700 bar (vent up)	6 kg (84s)	448 g/s V	112 g/s V	Sonic	0.1875
Car CGH_2 700 bar (vent down)	6 kg (84s)	448 g/s V	112 g/s V	Sonic	0.1875
Bus CGH_2 350 bar	6 kg (147s)	234 g/s V	136 g/s V	Sonic	0.125
Bus CGH_2 350 bar	24 kg (147s)	936 g/s V	272 g/s V	Sonic	0.125
Bus NG	*26 kg*	*375 g/s V*		*Sonic*	*0.125*
Bus NG	*104 kg*	*1500 g/s V*		*Sonic*	*0.125*
Car NG vent up	*26 kg*	*375 g/s V*		*Sonic*	*0.375*
Car NG vent down	*26 kg*	*375 g/s V*		*Sonic*	*0.375*

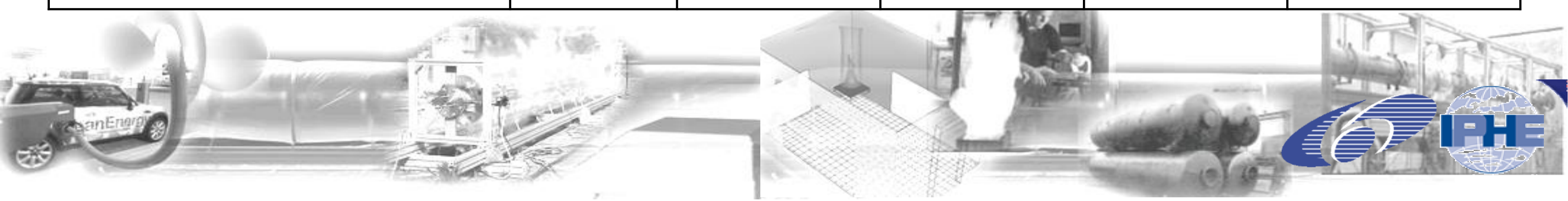


Some results of the simulations

Preliminary set of calculations completed:

example of calculated maximum flammable gas cloud sizes

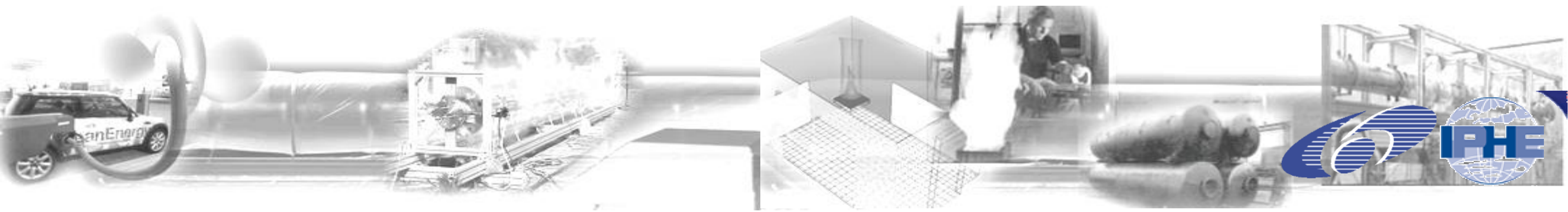
Vehicle/Release Characteristics	Inventory (kg)	Maximum flammable gas cloud size m^3 (& kg)		Maximum equivalent stoichiometric flammable gas cloud size m^3 (& kg)	
		Horseshoe tunnel	Rectangular tunnel	Horseshoe tunnel	Rectangular tunnel
Car LH_2	10 kg	1.4 (0.007)	1.8 (0.009)	0.02 (0.003)	0.02 (0.004)
Car CGH_2 700 bar (vent up)	5 kg	281 (1.14)	273 (1.21)	4.42 (0.07)	4.31 (0.09)
Car CGH_2 700 bar (vent down)	5 kg	268 (1.33)	308 (1.39)	17.75 (0.29)	8.77 (0.18)
Bus CGH_2 350 bar	5 kg	213 (0.89)	190 (0.81)	2.16 (0.04)	1.94 (0.04)
Bus CGH_2 350 bar	20 kg	1795 (7.46)	3037 (13.97)	27.46 (0.45)	24.67 (0.49)
Bus CNG 200 bar	26 kg	3.4 (0.15)	4.6 (0.19)	1.15 (0.08)	1.18 (0.08)
Bus CNG 200 bar	104 kg	45 (2.01)	647 (26.0)	13.47 (0.90)	113.48 (7.60)
Car CNG 200 bar (vent up)	26 kg	2.1 (0.10)	3.4 (0.15)	0.85 (0.06)	1.03 (0.07)
Car CNG 200 bar (vent down)	26 kg	17 (0.78)	15 (0.65)	6.31 (0.42)	5.25 (0.35)



Hazard & risk assessment

performed in terms of

- Dispersion release
  - based on pessimistic hazard level cloud volume and cloud extent
- Ignition probability
  - Ignition source type
- Exposure times for flammable gas cloud volume
- Fire and Explosions
  - Overpressures as a function of gas cloud size
  - Stoichiometeric gas clouds
  - DDT
- Sensitivity of the above hazards to the variation in tunnel geometry (tunnel cross-section, gradient, obstacles), vehicle parameters (liquid, CGH2, release location and direction) , ambient and ventilation conditions



Conclusions - Dispersion

- Horseshoe cross section tunnel indicates lower hazard than equivalent rectangular cross-section tunnel with regards to flammable cloud volume and its longitudinal and lateral spread
- Increasing height of the tunnel indicates safer conditions to tunnel users for buoyant releases of H2
- Compressed gas H2 (CGH2) releases pose greater hazard than natural gas releases, but still not significant
- Increase of ventilation velocity decreases the cloud size and hence results in lower hazard
- CFD simulation results not conclusive on the following aspects:
  - Level and extent of hazard with no ventilation versus ventilation
  - Hazard posed by liquid hydrogen (LH2) versus CGH2 releases

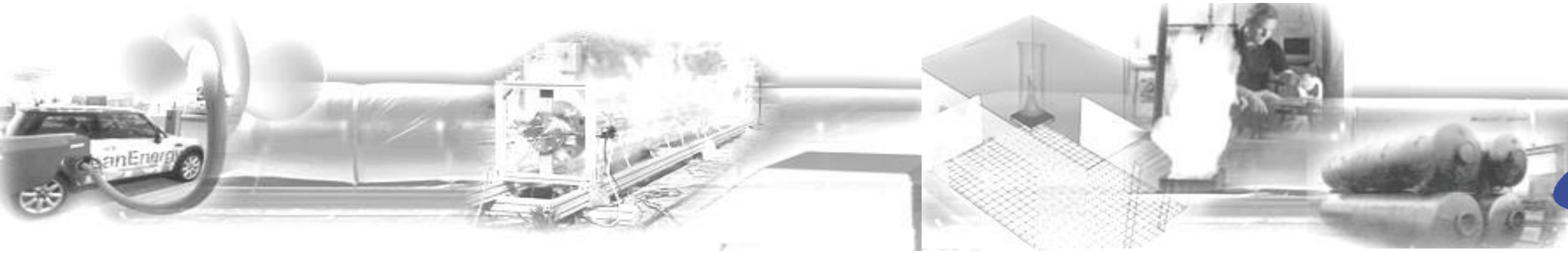
Conclusions - Explosion

- Overpressures registered for different scenarios in the **1/5 scale 78.5 m tunnel SRI experiment** (uniform mixtures, “unessential” obstruction) are in the range 0-1.7 bars
- Overpressures calculated for different scenarios are in the range of 0-12 bars depending on scenarios and tools; Good agreement between CFD simulations and SRI experiment, significant difference between simulations for real scale tunnel (not all models are described in details necessary for reproduction by other groups)
- HySafe concentrated mainly on uniform mixtures (driven by availability of unique SRI experiments) until now. “Step back” compared to **EIHP project**, where non-uniform distribution from different release scenarios and then combustion of non-uniform mixtures were numerically simulated (A. Venetsanos, D. Baraldi, P. Adams, et al.). The second step back compared to EIHP approach, is suggestion to change non-uniform mixture created during dispersion on uniform mixture for combustion (Q9 by GexCon)
- “No pressure decay” environment, i.e. “long safety distances”;
- FZK experiments proved that DDT is possible in principle. Ceiling design and mitigation measures are important.

Recommendations

Need for further research

- **Realistic scenarios** in tunnels (release downwards under the car) with delayed ignition of non-uniform mixtures (start from an EIHP scenario)
- Scientifically grounded requirements to **location and parameters of PRD**
- **Impinging jet fires** and **conjugate heat transfer** in conditions of blowdown
- Releases into congested space with **DDT**
- Develop hydrogen safety **engineering methodology** and apply it to a tunnel scenario (long term)



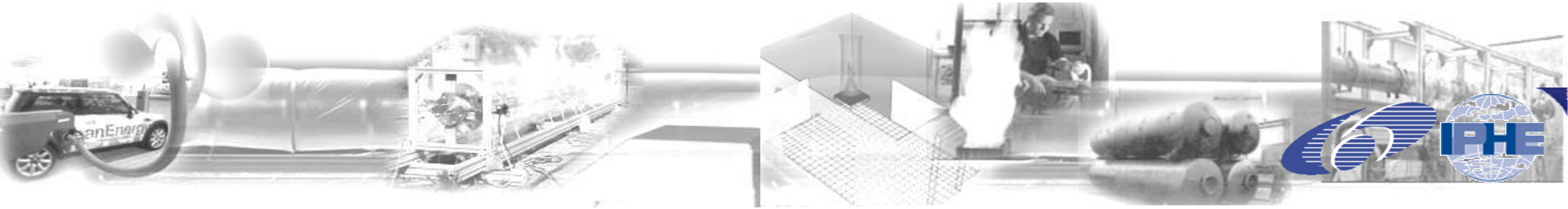
Acknowledgement

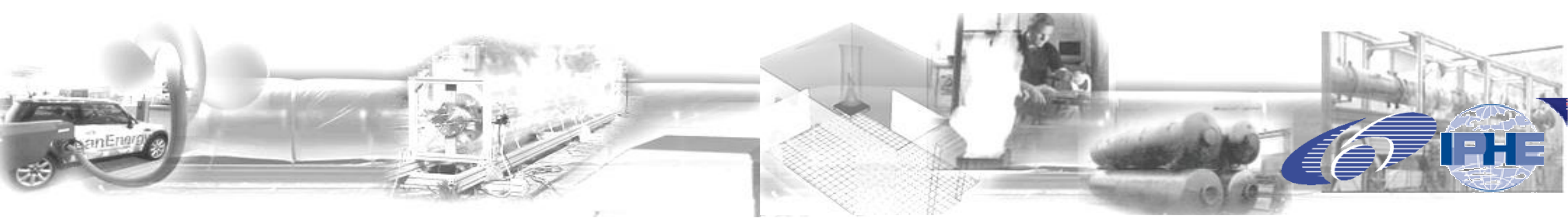
NoE HySafe is co-funded by the European Commission within the 6th Framework Programme (2002-2006); Contract n°: SES6-CT-2004-502630.

The network is contributing to the implementation of the Key Action "Integrating and strengthening the ERA" within the Energy, Environment and Sustainable Development.

Thanks to all HySafe colleagues…

… and thank you for your attention.





Recommendations

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to answer on:

- Do we have competent practitioners (engineers/enforcers) to ensure safe use of hydrogen powered vehicles in tunnels ?
- Is current state of knowledge premature to deliver best practice guidance on the safe use of hydrogen powered vehicles in tunnels ?
- If so, we need to identify gaps in knowledge, and training requirements, e.g., topics on which training would help in improving

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