EUROPEAN COMMISSION
6th FRAMEWORK PROGRAMME

Network of Excellence HySafe

"Safety of Hydrogen as an Energy Carrier"

Contract No SES6-CT-2004-502630

Minutes of the HYTUNNEL Meeting
at FZK, Karlsruhe
October 19th, 2005

S. Miles, BRE
Draft Version 1

Participants

Luc Bauwens (UC)
Marco Carcassi (UNIPI)
Stuart Hawksworth (HSL)
Thomas Jordan (FZK)
Alexei Kotchourko (FZK)
Dmitriy Makarov (UU)
Stewart Miles (BRE)
Vladimir Molkov (UU)
Ernst Reinecke (FZJ)
Claus Schitter (BMW)
Alexandros Venetsanos (NCSRD)

Apologies

Paul Adams (Volvo)
Daniele Baraldi (JRC)
Frank Markert (Riso)

List of Actions

Action 1 - all partners: To provide any further information on national road tunnel regulation and practice regarding hazardous materials and emergency ventilation and operations (not those who have already done so).

Action 2 - HSL, BRE, UU: To contribute to the review on physical and numerical work that has been reported and that is relevant to tunnel scenarios.

Action 3 - BRE: To develop a template of proposed scenarios for addressing with CFD during the remainder of Phase 1 of HyTunnel.

1. Opening

The meeting opened at about 9.30. Apologies were announced (see above).

S Miles welcomed the attendees and provided a quick resume of HyTunnel and the material covered at the kick-off meeting held at BRE on 22 April 2005. Details are included in the slides shown in section 8 of these minutes below. An outline of the sub-tasks is shown in the slides.

S Hawksworth noted that HSL were still not included as HyTunnel participants in the JPA for months 13 to 30. Also, UU were not currently included as participants. It was confirmed that both HSL and UU were definitely part of HyTunnel.

HyTunnel was now referred to as Internal Project number 2 (IP2).

A new HyTunnel mail group had been set up on the HySafe web page.

2. Review of regulations & practice

Information had been provided by INASMET and UPM on the Spanish regulations and practice and Volvo for Sweden & Norway. Further information had been collected for UK, North America and the European Union (i.e. Directive). The North American information (NFPA Guidelines etc) is used quite widely worldwide also. Information for France was also available.

This information would be included in the first HyTunnel deliverable (D49) due for January 2006, to be compiled by BRE. Any further information from partners would also be included.

Action 1 - all partners: To provide any further information on national road tunnel regulation and practice regarding hazardous materials and emergency ventilation and operations (not those who have already done so).

3. Review of accident Scenarios

S Miles presented the material which had been supplied by BMW and Volvo on accident scenarios and H2 release mechanisms - see relevant slides in Section 8 of these minutes. The review of accident scenarios will be documented in the first HyTunnel deliverable (D49) due for January 2006, to be compiled by BRE.

Following discussions it was agreed that during Phase 1 of HyTunnel the main focus would be on the pre-ignition dispersion of gaseous hydrogen following the collision of a hydrogen-powered car or bus. Some attention would be given also to the catastrophic release of liquid hydrogen from a tanker. For the car and bus the scenario to be studied (e.g. by CFD) would be the release of hydrogen from a pressure relief device (PRD). A total release of 6 kg of hydrogen for a car and 40 kg for a bus would be considered. For the catastrophic release of liquid hydrogen from a tanker the total mass of hydrogen would be 3500 kg.

It was emphasised that the risks associated with hydrogen vehicle accidents should be set in context with those for natural gas and LPG.

4. Review of physical & numerical work

Good progress had been made on this task by NCSRD, and a draft report produced. This report reviews both physical experiments and CFD work for internal releases of hydrogen, produced in support of the two internal projects InsHyDe and HyTunnel, forms a Deliverable within Work Package 8, sub-task 8.1.

Further input from HSL and BRE on fire experiments and CFD studies, and from UU on explosions work, relevant to hydrogen releases inside tunnels, was expected.

Action 2 - HSL, BRE, UU: To contribute to the review on physical and numerical work that has been reported and that is relevant to tunnel scenarios.

The findings would be summarised as part of the second HyTunnel deliverable (D62), due August 2006.

5. Numerical simulations & experiments

As noted above, it was agreed at the meeting that the focus for Phase 1 of HyTunnel would be on CFD simulations to understand the consequences of alternative ventilation conditions inside a road tunnel given the accidental release scenarios now identified. This work would extend that previously undertaken in the EIHP 1 & 2 projects. It would also build upon other CFD work that had been undertaken, e.g. the Japanese work reported by Mukai et al the First International Conference on Hydrogen Safety in Pisa. This work had indicated that the buoyancy of hydrogen and the tunnel ventilation could help diffuse and remove the hydrogen to minimise the risk of explosion.

The earlier modelling work on hydrogen dispersion and ignition had examined only some aspects of tunnel ventilation. It was suggested that a more comprehensive study of the effect of different ventilation conditions was required. This would look at the distribution of, say, gas mixture above the lower flammability limit as a function of time for the two PRD release scenarios identified in Section 3 above (i.e. 6 kg H2 for a car and 40 kg H2 for a bus).

HyTunnel partners with modelling capabilities would be asked to contribute top the modelling programme. The activity would belong also to one or more of the main HyTunnel Work Packages, e.g. WP 3 on practical applications of CFD.

Action 3 - BRE: To develop a template of proposed scenarios for addressing with CFD during the remainder of Phase 1 of HyTunnel. THIS IS INCLUDED AS SECTION 9 OF THESE MINUTES.

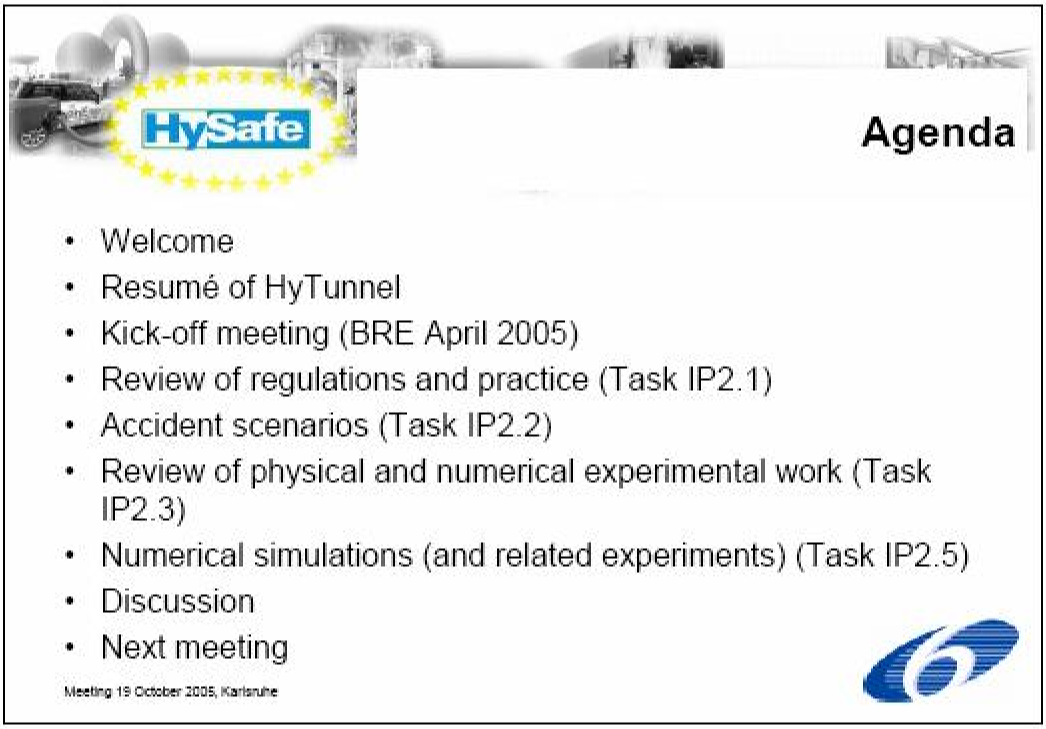
6. Next meeting

A possible HyTunnel sub-meeting will be held at the CC meeting hosted by Inasmet in the period 12 to 14 December 2005. Details to follow.

7. Close

The meeting closed at about 11.00.

8. Presentation by S. Miles on HyTunnel resume, progress and planned activities - not all slides used at meeting



Participants and apologies

- Final set of participants
  - BRE, BMW, FZK, HSL, JRC, INASMET, NCSRD, UC, UPM, UU, VOLVO, ?
  - new Hytunnel mail group on web site
- Apologies:
  - Paul Adams (Volvo)
  - Daniele Baraldi (JRC)
  - Frank Markert (Riso)

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Introduction

- Hydrogen safety in tunnels identified as important issue at Athens CC meeting
  - suggested as topic for an internal project
  - BRE presented outline ideas at NGB meeting in Paris
  - decision taken to proceed with HyTunnel in next stage of HySafe
  - added to JPA for months 13-30 as internal project HyTunnel

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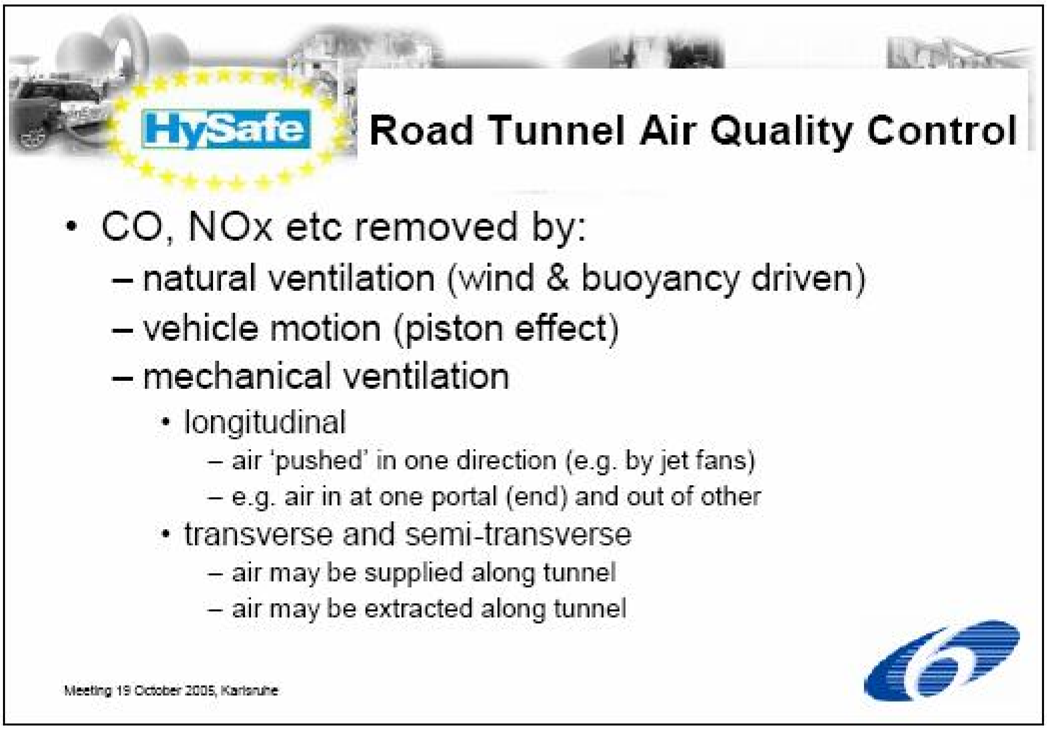
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Road Tunnel Air Quality Control
• CO, NOx etc removed by:
– natural ventilation (wind & buoyancy driven)
– vehicle motion (piston effect)
– mechanical ventilation
• longitudinal
– air 'pushed' in one direction (e.g. by jet fans)
– e.g. air in at one portal (end) and out of other
• transverse and semi-transverse
– air may be supplied along tunnel
– air may be extracted along tunnel
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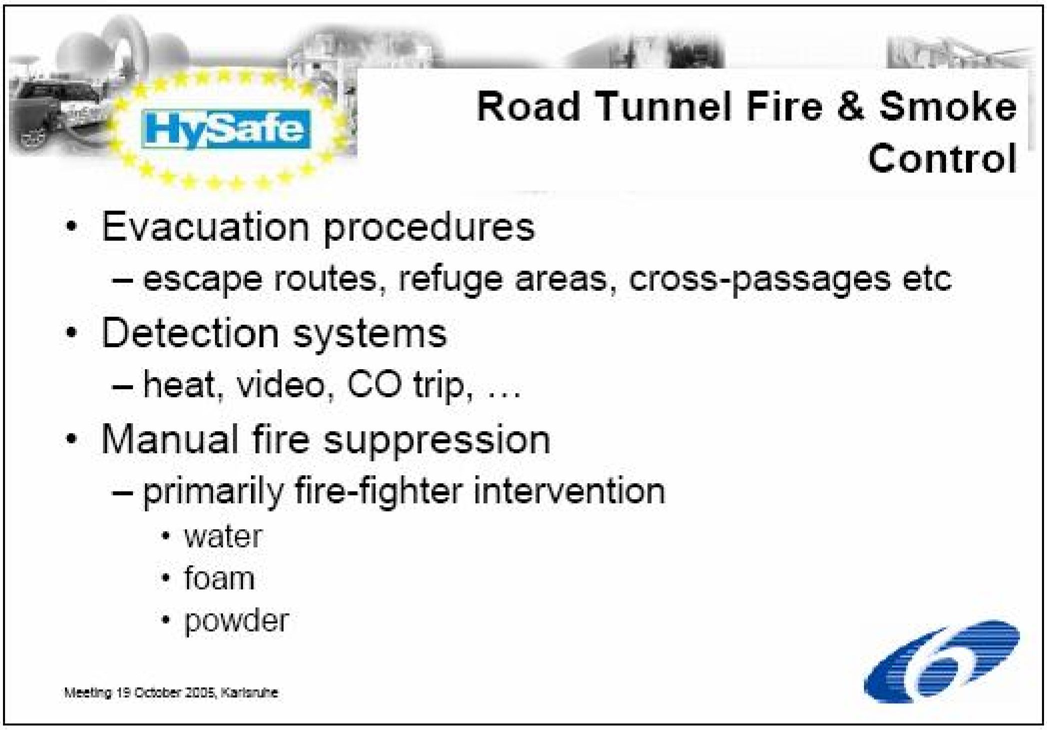
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Road Tunnel Fire & Smoke Control
• Evacuation procedures
– escape routes, refuge areas, cross-passages etc
• Detection systems
– heat, video, CO trip, …
• Manual fire suppression
– primarily fire-fighter intervention
• water
• foam
• powder
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Road Tunnel Fire & Smoke Control

- Other fire suppression
  - foams
  - water sprays/mists
    - not yet widely used
    - when to activate ?
    - still controversial
      - effect of smoke stratification
      - hazard of hot water droplets and steam ?
  - air plugs ?
  - oxygen starvation ???

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Road Tunnel Fire & Smoke Control

- Ventilation
  - as for air quality but in ‘emergency mode’
  - important issues:
    - whether one way or two way traffic has important bearing
    - attempt to extract smoke at ceiling level and maintain stratification ?
      - smoke may then travel in both directions
    - force all smoke in one direction ?
      - and most likely lose any stratification downstream

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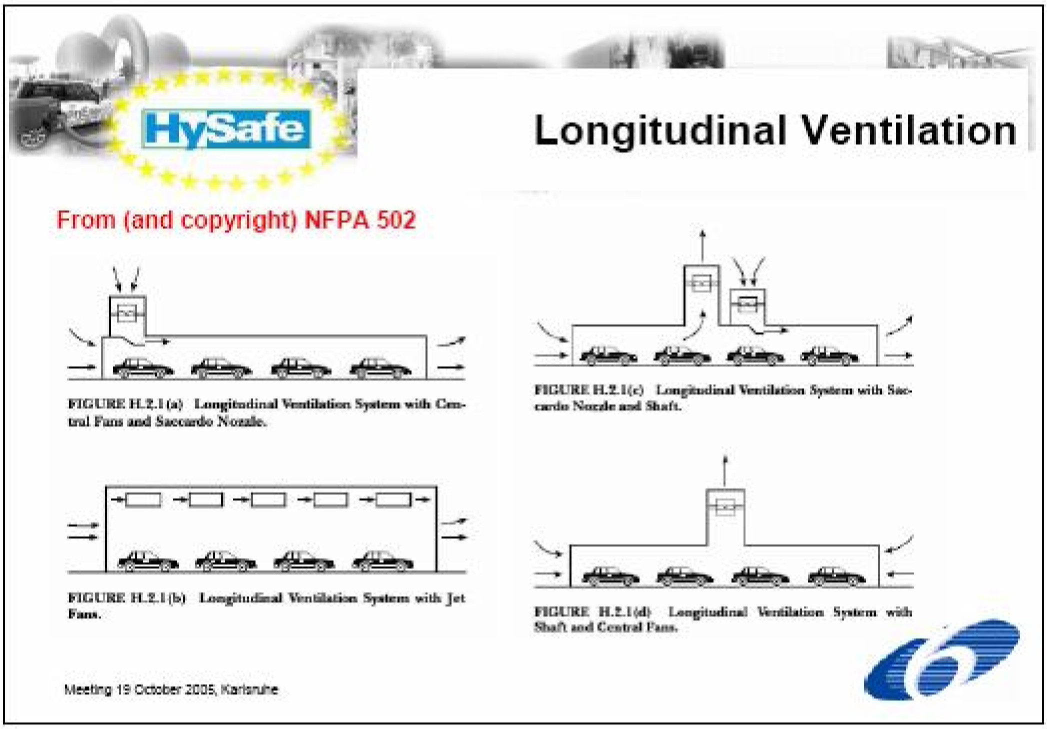
HySafe
Longitudinal Ventilation
From (and copyright) NFPA 502
FIGURE H.2.1(a) Longitudinal Ventilation System with Central Fans and Saccardo Nozzle.
FIGURE H.2.1(b) Longitudinal Ventilation System with Jet Fans.
FIGURE H.2.1(c) Longitudinal Ventilation System with Saccardo Nozzle and Shaft.
FIGURE H.2.1(d) Longitudinal Ventilation System with Shaft and Central Fans.
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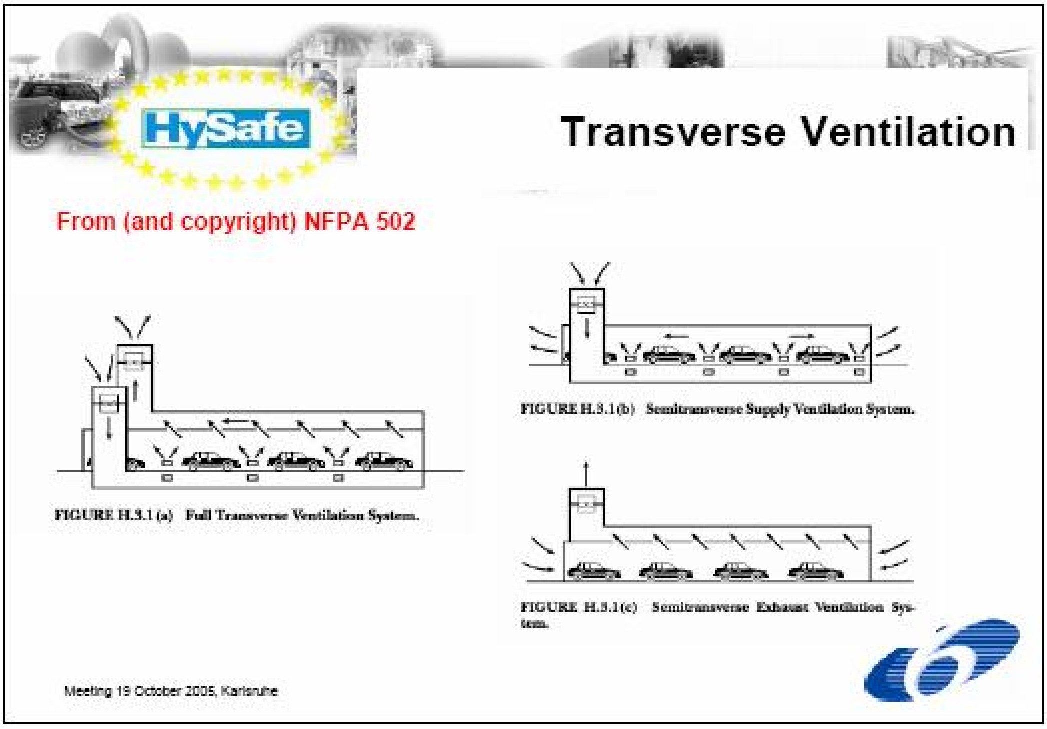
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Transverse Ventilation
From (and copyright) NFPA 502
FIGURE H.3.1(a) Full Transverse Ventilation System.
FIGURE H.3.1(b) Semitransverse Supply Ventilation System.
FIGURE H.3.1(c) Semitransverse Exhaust Ventilation System.
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Novel Ventilation

- e.g. upgraded emergency ventilation system in the Mont Blanc Tunnel
  - semi-transverse
    - supply at ground level along tunnel
    - extraction at ceiling level vents
  - plus
    - jet fans to control longitudinal air/smoke movement to assist stratification and extraction of smoke
  - computer controlled with manual override

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Effect of air speed

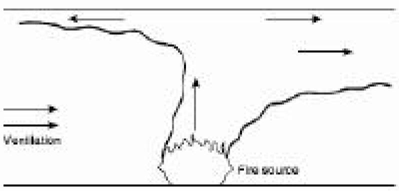

FIGURE A.3.3.5(b) Underventilated Tunnel Fire Causing Backlayering.

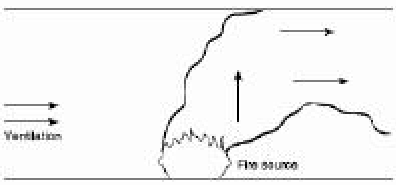

FIGURE A.3.3.5(c) Tunnel Fire Sufficiently Ventilated to Prevent Backlayering.

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Kick-off meeting

- Held at BRE on 22 April 2005
- Tasks agreed
- Initial responsibilities identified
- Issues identified
  - e.g. what does different tunnel ventilation strategies mean for H2 release, explosion risk or fire combustion?

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Phase 1 (months 13-30)

- Sub-task IP2.1
  - review regulations, standards & practice for ventilation and emergency response
  - BRE lead
- Sub-task IP2.2
  - review and identity accident scenarios
  - BRE lead coordinator
  - BMW & Volvo main contributors

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Phase 1 (months 13-30)

- Sub-task IP2.3
  - review relevant experimental and modelling work
  - areas of responsibility identified
- Sub-task IP2.4
  - road map for further activities
    - for HySafe months 31 – 48
    - for beyond HySafe

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Phase 1 (months 13-30)

- Sub-task IP2.5
  - numerical simulations
  - to support design of experiments?
  - as part of SBEP?
  - part of Phase 2?

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Phase 2 (months 31-48)

- Sub-task IP2.6
  - numerical simulations cont.
  - blind simulations of new experiments ?
- Sub-task IP2.7
  - new experiments
  - could be transferred partly to Phase 1 ?
- Sub-task IP2.8
  - open numerical simulations of new experiments

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Phase 2 (months 31-48)

- Sub-task IP2.9
  - develop guidelines for safe introduction of hydrogen powered vehicles in tunnels
- Sub-task IP2.10
  - road map for introduction of guidelines

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HySafe
Sub-task IP2.1
• Review regulations, standards & practice for ventilation and emergency response
– contributions from all partners
– link to WP16 ? (standards & legal requirements)
– new EU Directive on tunnel fires
– PIARC, NFPA, ISO, national guidelines
– lead by BRE
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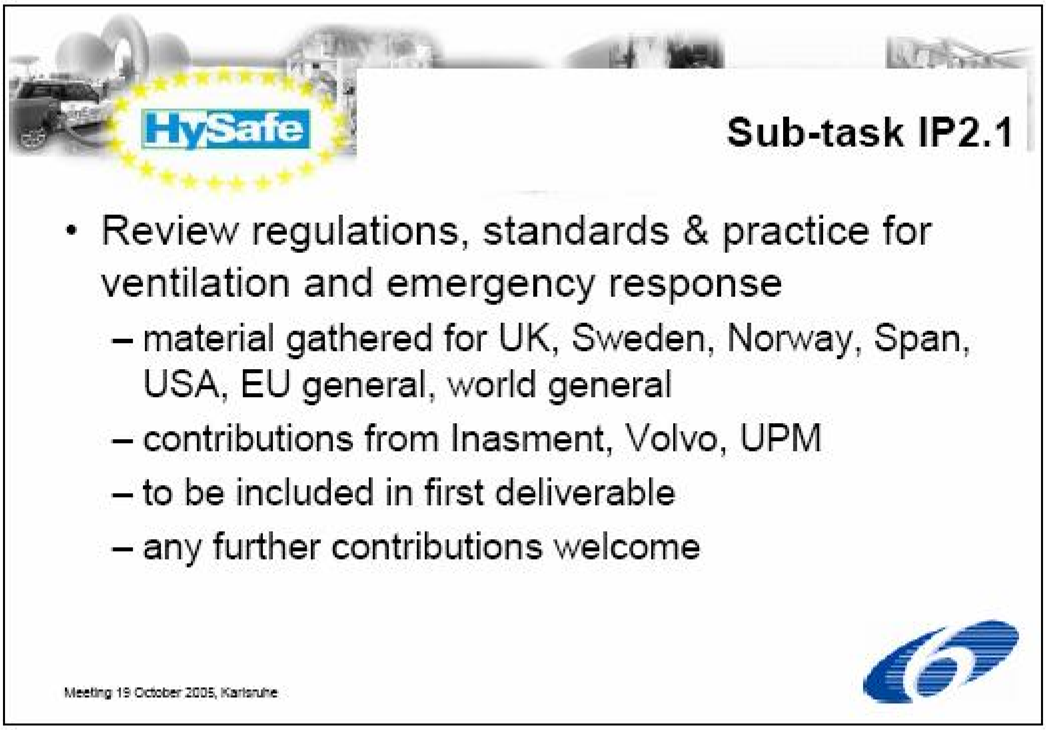
HySafe
Sub-task IP2.1
• Review regulations, standards & practice for ventilation and emergency response
– material gathered for UK, Sweden, Norway, Span, USA, EU general, world general
– contributions from Inasment, Volvo, UPM
– to be included in first deliverable
– any further contributions welcome
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Sub-task IP2.2

- Review and identify accident scenarios and scope of work
  - contribution to WP4 (PIRT)
  - main contributions from Volvo and BMW
  - other ideas ?
    - e.g. tanker failure and major release
  - to be included in first deliverable

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BMW accident scenarios

Scenario	amount [kg]
tank truck crash with car, large leak	?
tank truck crash with car, no leak but fire	?
tank truck crash with car, PRD-release	?
2 hydrogen cars crash, both leak	10+6
LH2 car crash, instantaneous release	10
CGH2 car crash, instantaneous release	6
LH2 car break down, boil-off release	10
LH2 car crash, PRD-release	10
CGH2 crash, PRD-release	6
fire in tunnel, CGH2 Bus, PRD-release	30

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BMW accident scenarios

length of tunnel		
	underpass	100m
	short	500m
	long	5 km

pressure		[bar]
	CGH2	200
		350
		700
	LH2	6
		13
		50

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Volvo accident scenarios

- Tunnel traffic accidents involving front/rear impacts leading to:
  - pressure relief device (PRD) operating
  - H2 fuel system leakage
- Approximate H2 stored on vehicles:
  - car: 6 kg
  - city bus: 40 kg

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Volvo accident scenarios

- Upper bounds of possible H2 releases from city bus

Release i)	**Maintenance depressurisation** A single release of 100NL over a period of 1 second. A typical fitting is shown in Figure A of Appendix 2, and possible leak paths from a loosened fitting are shown in Figure B of Appendix 2. The release can be assumed to occur on the roof of the bus along the centre line, 5.5m from the front of the bus.
Release ii)	**Permeation from the surface of the pressure vessels** 0.05NL/min. The permeation area is approximately 35m², on the roof of the bus between 2 and 5m from the front of the bus. A continuous supply would be available up to the storage quantity of the vehicle.
Release iii)	**Fuel cell purging** 10 NL/min (via a vent). It can be assumed that the vent (0.01m²) is at roof level on the centre line of the bus, and 0.5m from the back of the bus. A continuous supply would be available up to the storage quantity of the vehicle, however, the release would only occur while the fuel cell system is in operation.
Release iv)	**Possible leak from a connection** 500 NL/min. A typical fitting is shown in Figure A of Appendix 2, and a possible leak path from a fitting is shown in Figures B & C of Appendix 2. The leak can be assumed to occur on the roof of the bus along the centre line, 5.5m from the front of the bus. A continuous supply should be assumed to be available up to the storage quantity of the vehicle.
Release v)	**Release via a PRD** Possible releases are described in Appendix 1.

tunnels

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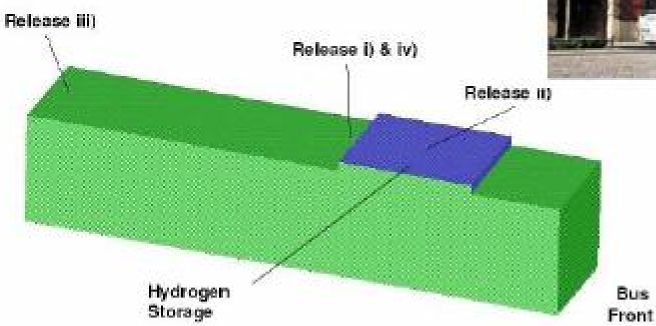
Volvo accident scenarios

- Possible fuel release locations on a typical city bus



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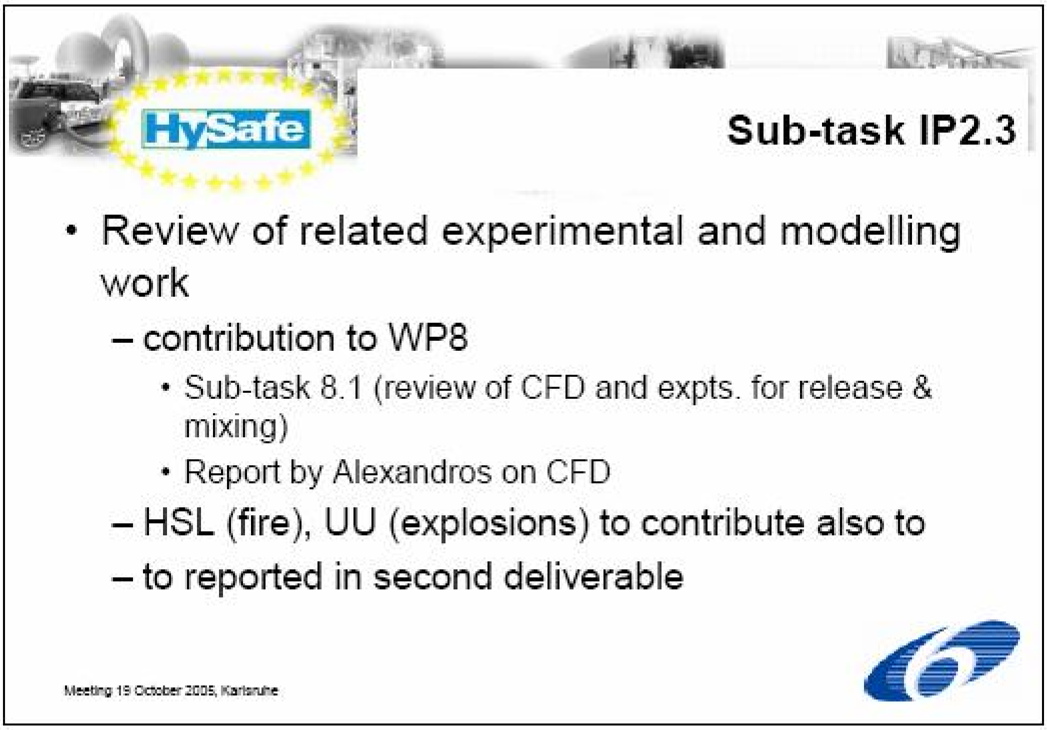
HySafe
Sub-task IP2.3
• Review of related experimental and modelling work
– contribution to WP8
• Sub-task 8.1 (review of CFD and expts. for release & mixing)
• Report by Alexandros on CFD
– HSL (fire), UU (explosions) to contribute also to
– to reported in second deliverable
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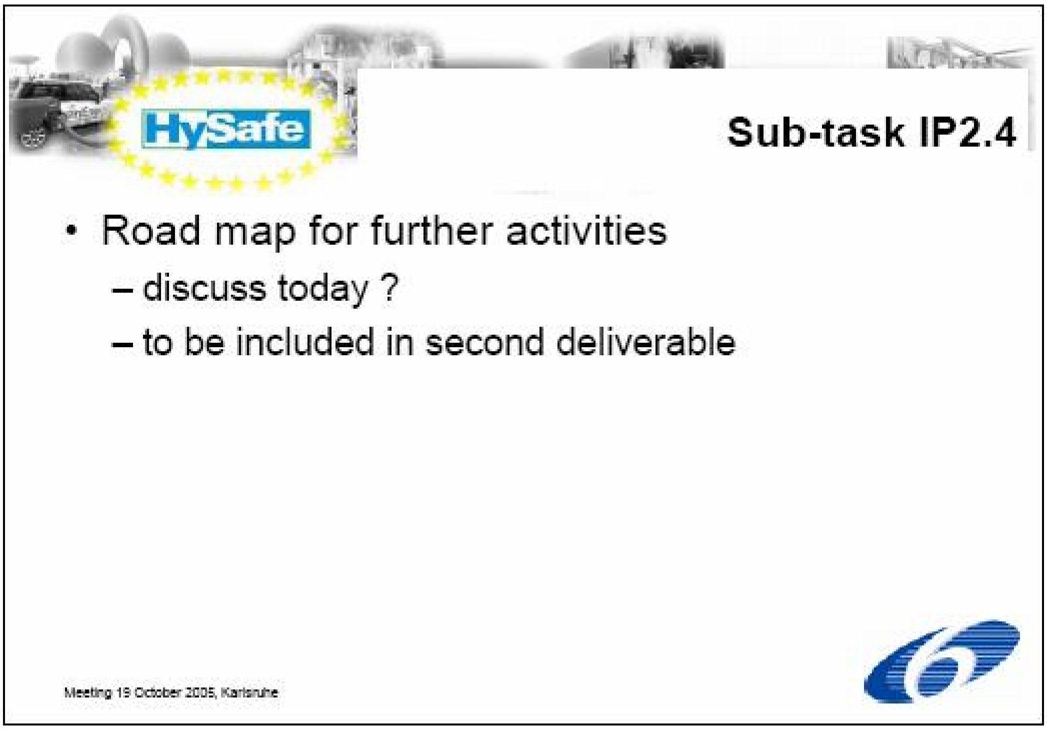
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Sub-task IP2.4
• Road map for further activities
– discuss today ?
– to be included in second deliverable
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Sub-task IP2.5

- Numerical simulations
  - to support experiment design ?
  - as part of WP3/6 SBEP ?
  - as part of WP8 (release & mixing) ?
  - as part of WP11 ?
    - simulation of ventilation mitigation benchmark cases
  - to investigate effect of alternative ventilation
    - to be discussed today ?

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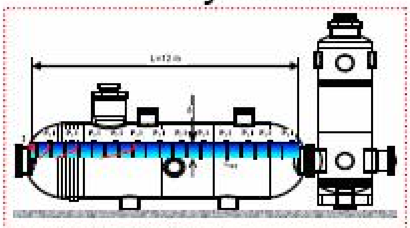
FZK tunnel experiments

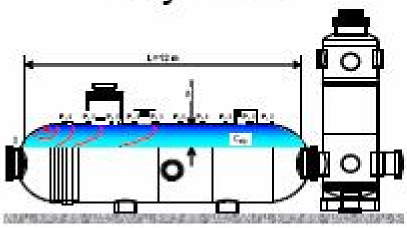
Layout 1:



I – ignition point;
P, I – pressure and light gauges.
L = 12 m – A1 length;
D = 3.5 m – A1 diameter;
V = 100 m³ (+30 m³)– total volume;
BR = 0.6 (0.3) by obstacle laden grid

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

Layout 2:



- Mixture is in plastic balloon
- Both vessels A1 and A3 are connected
- BR is changed along the axis

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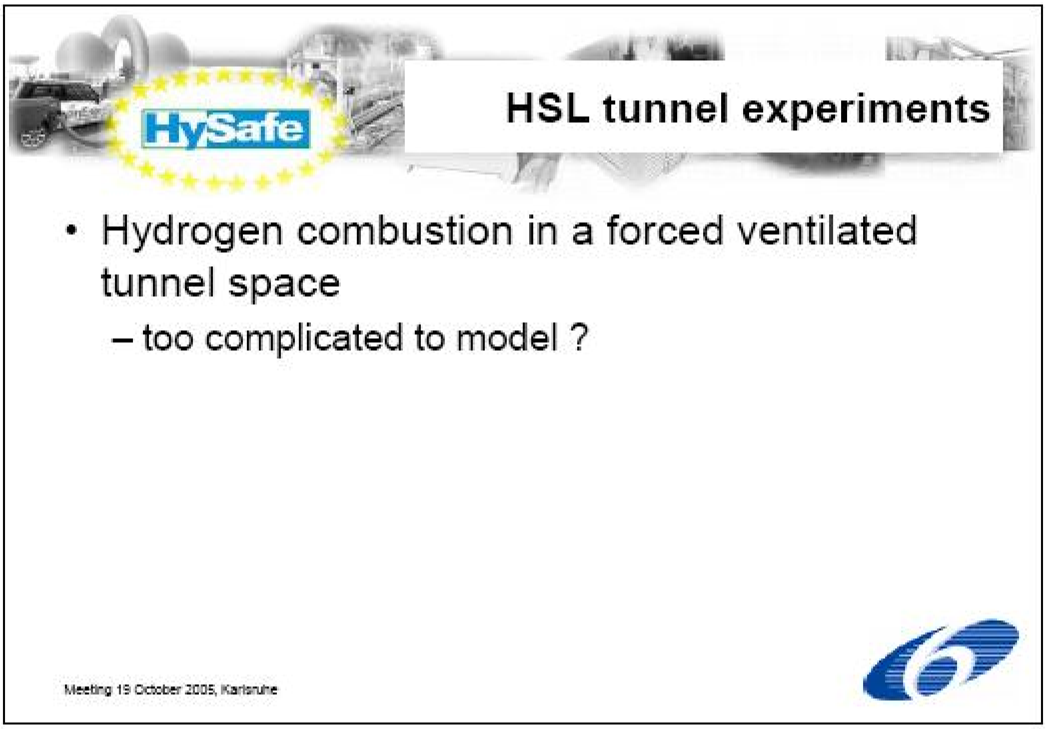
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HSL tunnel experiments
• Hydrogen combustion in a forced ventilated tunnel space
– too complicated to model ?
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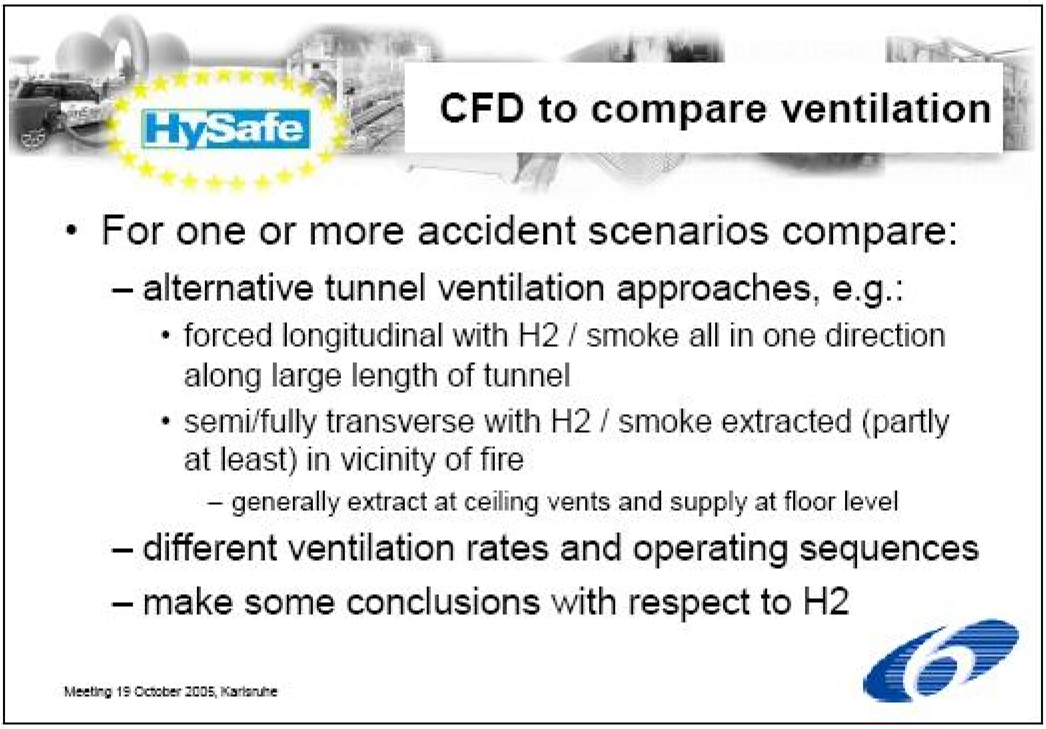
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CFD to compare ventilation
• For one or more accident scenarios compare:
– alternative tunnel ventilation approaches, e.g.:
• forced longitudinal with H2 / smoke all in one direction along large length of tunnel
• semi/fully transverse with H2 / smoke extracted (partly at least) in vicinity of fire
– generally extract at ceiling vents and supply at floor level
– different ventilation rates and operating sequences
– make some conclusions with respect to H2
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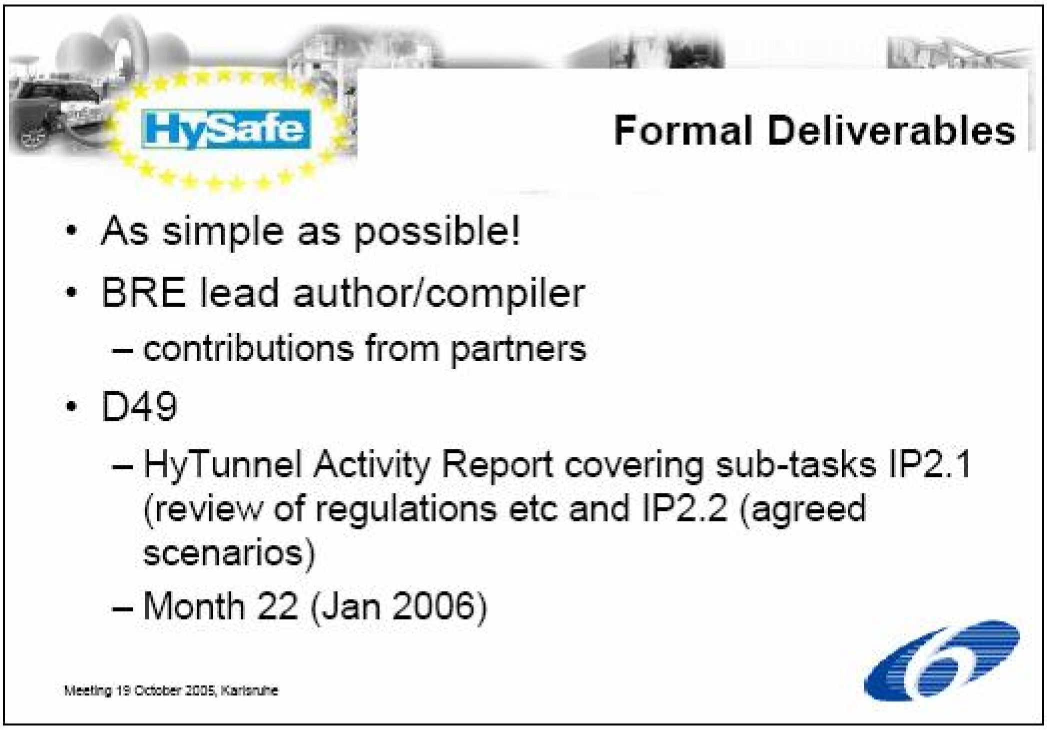
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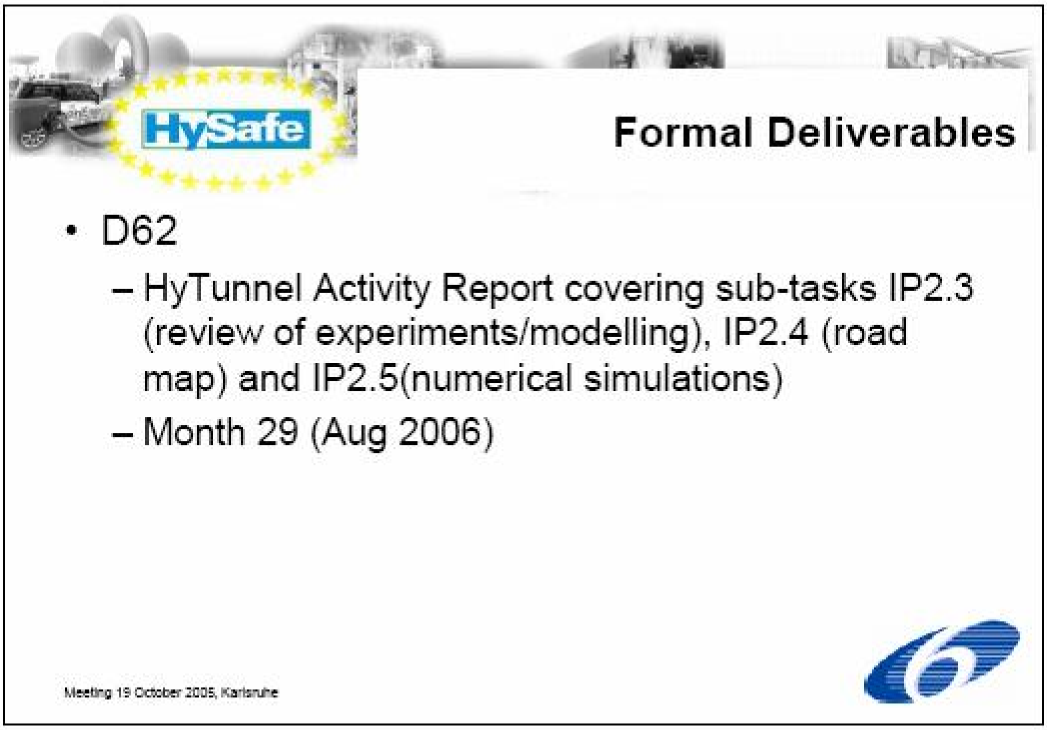
Formal Deliverables
• As simple as possible!
• BRE lead author/compiler
– contributions from partners
• D49
– HyTunnel Activity Report covering sub-tasks IP2.1 (review of regulations etc and IP2.2 (agreed scenarios)
– Month 22 (Jan 2006)
Meeting 19 October 2005, Karlsruhe


HySafe
Formal Deliverables
• D62
– HyTunnel Activity Report covering sub-tasks IP2.3 (review of experiments/modelling), IP2.4 (road map) and IP2.5(numerical simulations)
– Month 29 (Aug 2006)
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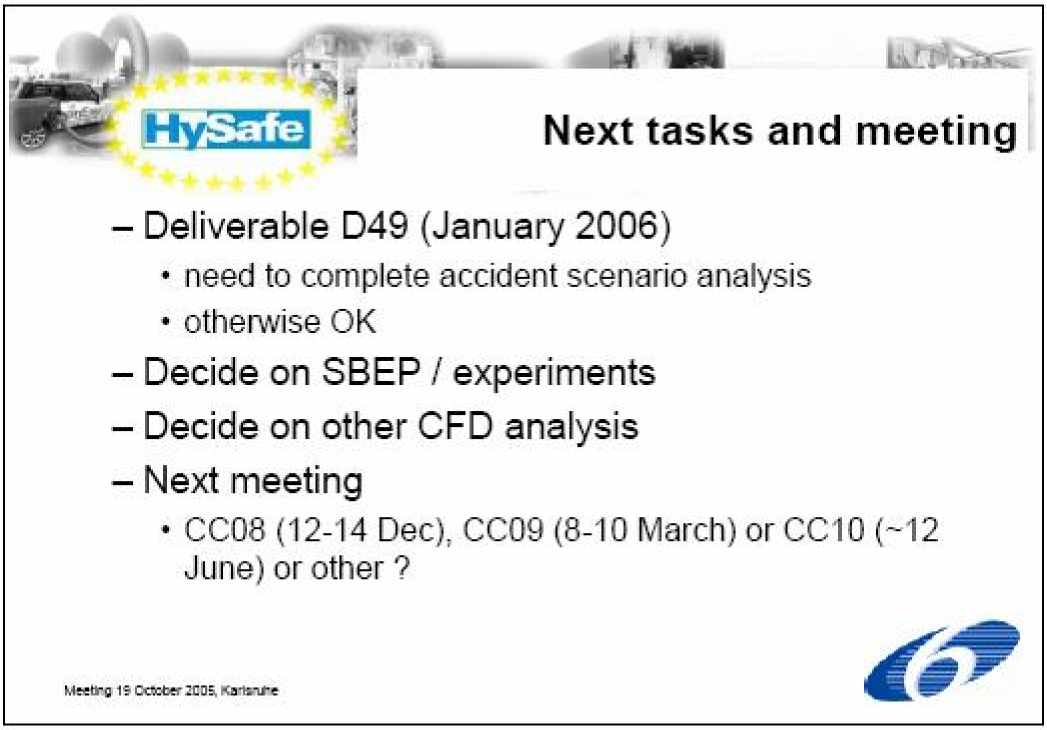
HySafe
Next tasks and meeting
– Deliverable D49 (January 2006)
• need to complete accident scenario analysis
• otherwise OK
– Decide on SBEP / experiments
– Decide on other CFD analysis
– Next meeting
• CC08 (12-14 Dec), CC09 (8-10 March) or CC10 (~12 June) or other ?
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9. Proposed scenarios for CFD analysis of H2 pre-ignition dispersion inside road tunnels

As agreed during the meeting (Karlsruhe 19 October 2005), the focus during the first phase of HyTunnel will be on the pre-ignition dispersion of gaseous hydrogen caused by the operation of a pressure relief device (PRD) following an accident. Ignition of the hydrogen can be addressed in the second phase of HyTunnel (it is noted that this will be a challenging task). The study of the release of a large quantity of liquid hydrogen from a tanker may also be addressed.

Road tunnel ventilation methods may be categorised broadly into four categories:

1. Natural ventilation. Airflow is generated by the movement of the vehicles (piston effect) and by meteorological/thermal conditions. Air enters/leaves at the portals, and optionally also at ventilation shafts at one or more locations along the tunnel. Other than short tunnels, natural ventilation alone will not be sufficient to maintain healthy/safe conditions inside tunnel during normal operation, or be able to control the movement of smoke and heat in the event of a fire.

2. Mechanical longitudinal ventilation. The basic remit here is to move air (and smoke in the event of a fire) in one direction, along either the whole tunnel or a section of tunnel. The air movement is provided either by axial jet (impulse) fans located in the ceiling region of the traffic space or by an arrangement of supply and/or exhaust ducts. In the event of fire or other hazardous release scenario this method is suited primarily to one-way traffic tubes, as the basic idea is to push all the smoke in the direction of the traffic flow, maintaining clear conditions upstream of the incident where stationary vehicles will be located and the emergency services will need to make their approach.

3. Mechanical (fully) transverse ventilation. Here air is supplied at vents located continuously along the tunnel (at floor or ceiling level), and extracted through vents (generally at ceiling level). This method is better suited, in case of emergency ventilation, to two-way tubes compared to longitudinal ventilation, but is by comparison more demanding in terms of engineering and cost.

4. Mechanical semi-transverse ventilation. Here air is either supplied or extracted (but not both) at vents located continuously along the tunnel. The make-up air, or exhaust path, may be provided by the tunnel portals and/or by one or more ventilation shafts located along the tunnel. Locally, a semi-transverse ventilated tunnel may have the characteristic of a longitudinally-ventilated tunnel, with the predominant air flow direction along the tunnel.

The cross-sectional geometry of road tunnels can be divided into two main types:

1. Rectangular, with a float ceiling. This is typical of cut-and-cover tunnels and circular-bore tunnels where a suspended ceiling separates the traffic space from ventilation ducts above.

2. Horseshoe, with a curved ceiling. This is typical of bored tubes where there is no suspended ceiling.

Figures 1 and 2 show proposed tunnel cross-sections for the HyTunnel study. These are taken from work being undertaken in the 5th Framework EU project UPTUN, developing methodologies to upgrade the fire safety of existing tunnels. As part of this project the development of hazardous conditions are being modelled for large HGV fires given different ventilation regimes.

- Horseshoe profile cross-section
  - Area=60m^2
  - HGV shown
    - *H2 bus and car smaller!*

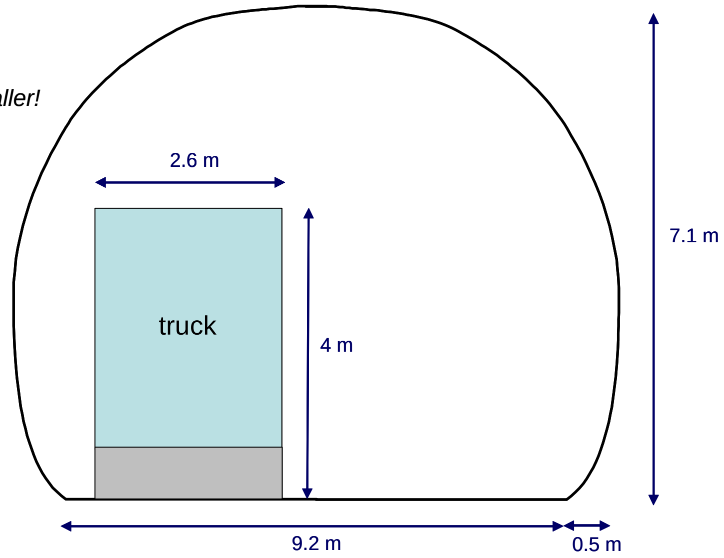

Figure 1 **Proposed horseshoe cross-section**

- Rectangular profile cross-section
  - Area=50m^2

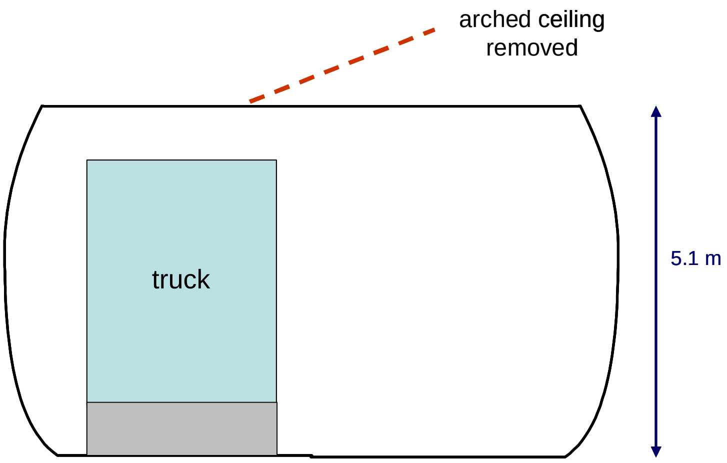

Figure 2 **Proposed rectangular cross-section**

It is proposed to investigate a range of ventilation regimes for both cross-sections. Figure 3 shows schematically the ventilation arrangements. By setting combinations of the three ventilation sources V_1 to V_3 it is possible to replicate a wide range of tunnel arrangements. For example, setting V_2 and V_3 to zero, the value of V_1 then defines the longitudinal source of ventilation. Or, with V_3 set to zero, the combination of V_1 and V_2 defines a semi-transverse system where there is locally a longitudinal bias due to the piston and meteorological effects.

- Modelled tunnel section
  - Not to scale!
  - H2 release from PRD of either car or bus
  - Combinations of one or more V_1, V_2 & V_3 provide wide range of ventilation regimes

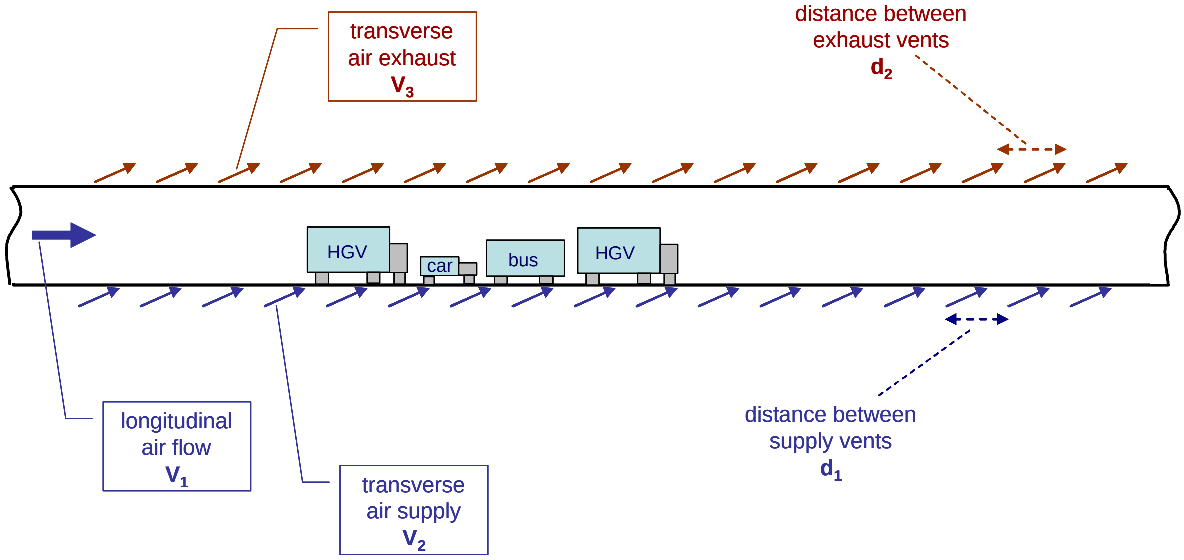

Figure 3 Schematic tunnel ventilation arrangement

It is proposed, initially at least, to study a range of scenarios for longitudinal and fully-transverse ventilation. For the case of longitudinal ventilation it is more convenient to express V_1 as a air speed rather than a flow rate, e.g. an upstream longitudinal air speed of 1.5 ms^{-1}. For the case of fully-transverse ventilation the values of V_2 and V_3 can be matched, given in terms of flow rate (m^3s^{-1}) per unit distance along the tunnel. For the latter it is here assumed that the exhaust rate is evenly divided over the section of modelled tunnel. In practice, the exhaust may in the case of emergency be focussed in the vicinity of the accident, so that a higher local extraction capability is achieved, and air and smoke are not drawn down the tunnel. This can be studied later in the HyTunnel project if required.

Table 1 lists a provisional set of ventilation regimes to study. For each ventilation regime it is proposed that both tunnel cross-sections are examined, and both the 6 kg (car) and 40 kg (bus) hydrogen releases are modelled.

Table 1 Ventilation regimes for initial HyTunnel CFD analysis

Ventilation Type	V_1	V_2 and V_3 (matched supply & exhaust)
Natural	0	0
Longitudinal	0.5 ms^{-1}	0
Longitudinal	1 ms^{-1}	0
Longitudinal	1.5 ms^{-1}	0
Longitudinal	2 ms^{-1}	0
Longitudinal	3 ms^{-1}	0
Longitudinal	5 ms^{-1}	0
Transverse	0	50 m^3s^{-1} per km tunnel
Transverse	0	100 m^3s^{-1} per km tunnel
Transverse	0	200 m^3s^{-1} per km tunnel
Transverse	0	400 m^3s^{-1} per km tunnel
Other ?		

Each simulation would be undertaken for at least the duration of the hydrogen release. The exact dimensions of the vehicles, the location of the hydrogen release its details (aperture size and outflow velocity) are to be decided.