Hydrogen Safety International Perspective

Report on the Research Priorities Workshop 2018

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The focal point on integrated research and information for hydrogen safety

Acknowledgements

- IA HySafe thanks HSE for hosting the Research Priorities Workshop RPW2018 on behalf of HySafe, the EC and the United States Department of Energy (DOE). Specifically the hard work and essential contributions for meeting organization and assembly of the report of the whole team of Stuart Hawksworth is acknowledged.

- The Contributors produced the bulk of the material used during the different sessions of the RPW2018. This material was then summarized and further complemented by the Authors' work. The chapters of the draft report were mainly written by the Authors, but were based on input provided by Contributors.

Content

- Introduction to HySafe
- Development of State-of-the-Art
- Research Priorities
  - Phenomena
  - Applications
- Conclusions

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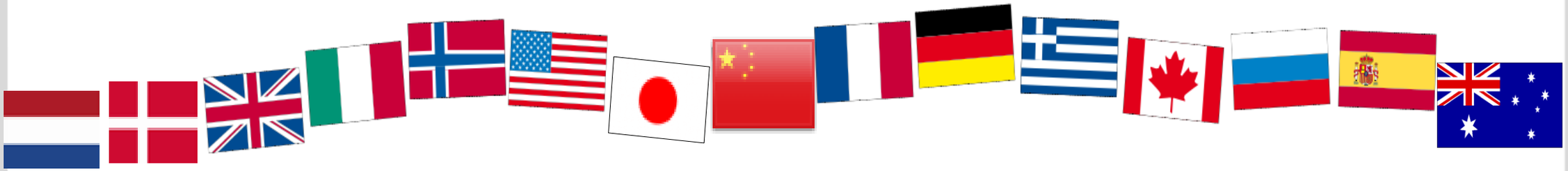
HySafe

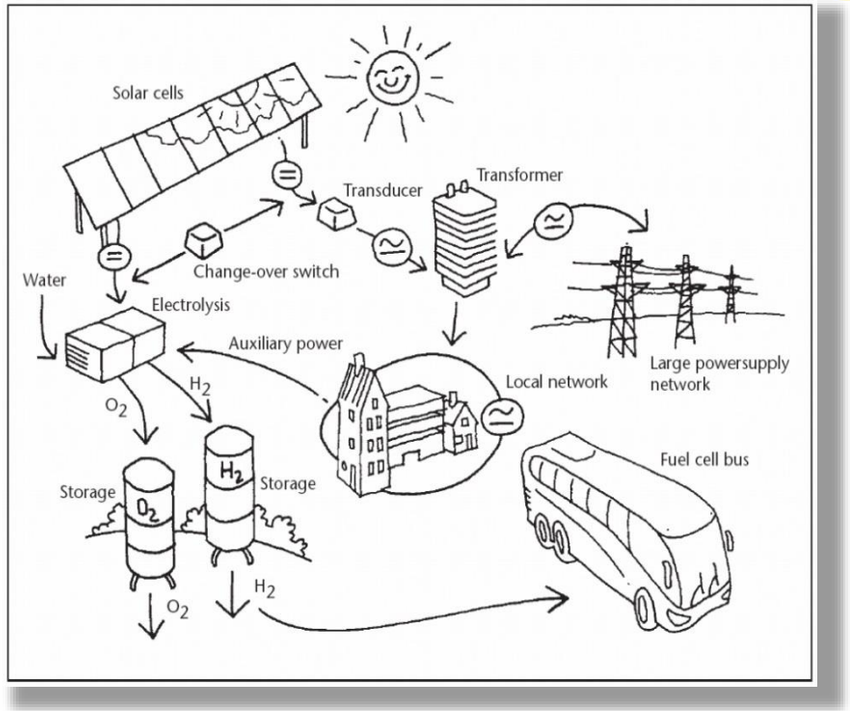
- **Founded in 2009 as a not-for-profit international association** under the Belgian Law following the EC Network of Excellence

- **~40 members**: public institutions, national labs, universities, industry and private companies from 14 countries worldwide



- Activities organized by 6 Committees for **Conference, Research, Industry Relations, Education, Handbook** and **PR & Knowledge Dissemination**

Vision and Mission



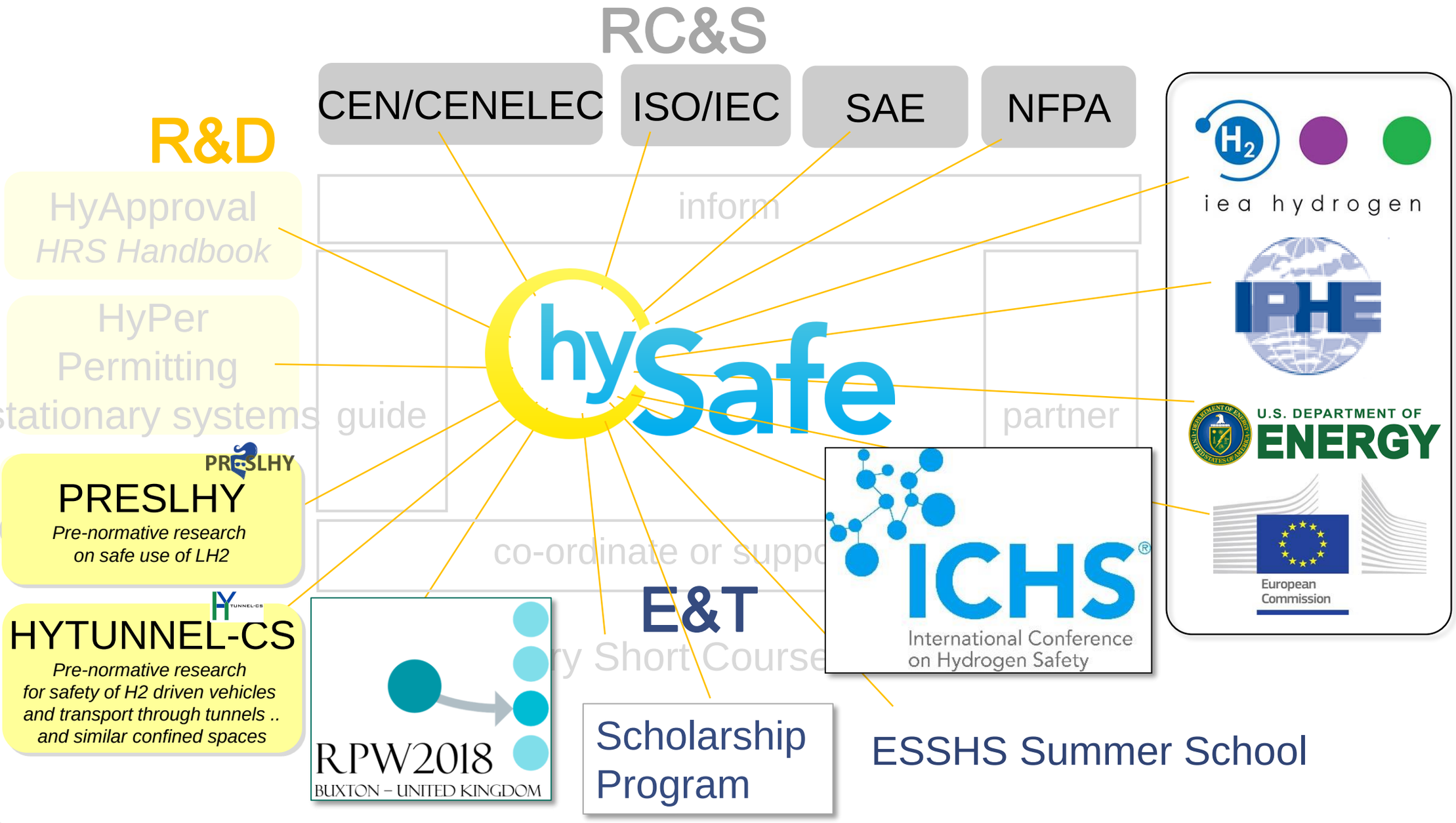
HySafe's Vision:

Hydrogen will be introduced as a ***safe*** and sustainable energy carrier.

HySafe's Mission:

To ***facilitate*** the international coordination, development and dissemination of hydrogen safety knowledge by being ***the focal point*** for ***hydrogen safety research, education and training***.

International Focal Point for H2 Safety



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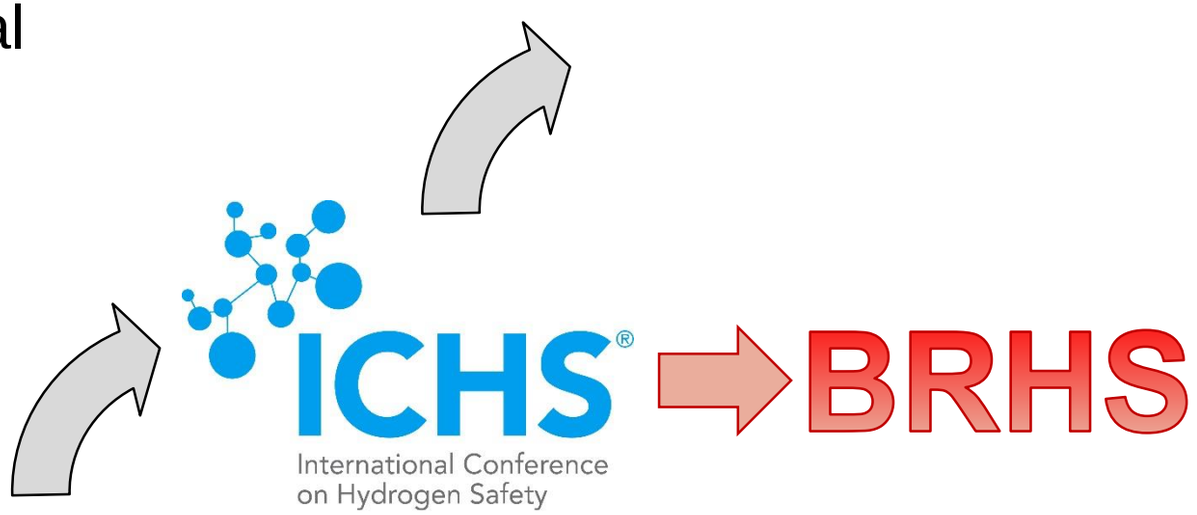
Continuous Development of the State-of-the-Art

Process with 2 years periodicity:
Year 1: Orientation by incremental update of gaps and priorities via Research Priorities Workshop
Year 2: Communication of progress via International Conference on Hydrogen Safety …
and
Update of the BRHS
being the state-of-the-art report
To be published as Hydrogen Safety Handbook (Elsevier)



Research Priorities Workshop RPW

time

Continuous Development of the State-of-the-Art

Process with 2 years periodicity:
Year 1: Orientation by incremental update of gaps and priorities via Research Priorities Workshop
Year 2: Communication of progress via International Conference on Hydrogen Safety

ICHS2019 – Adelaide, Australia
RPW – Buxton, UK
ICHS2017 – Hamburg, Germany
RPW – Petten, Netherlands
ICHS2015 – Yokohama, Japan
RPW – Washington, USA
ICHS2013 – Brussels, Belgium
RPW – Berlin, Germany
ICHS2011 – San Francisco, USA
CFD – Petten, Netherlands
ICHS2009 – Ajaccio, France
PIRT – Update
ICHS2007 – San Sebastian, Spain
PIRT – NoE HySafe
ICHS2005 – Pisa, Italy

Research Priorities Workshop RPW

ICHS International Conference on Hydrogen Safety

time

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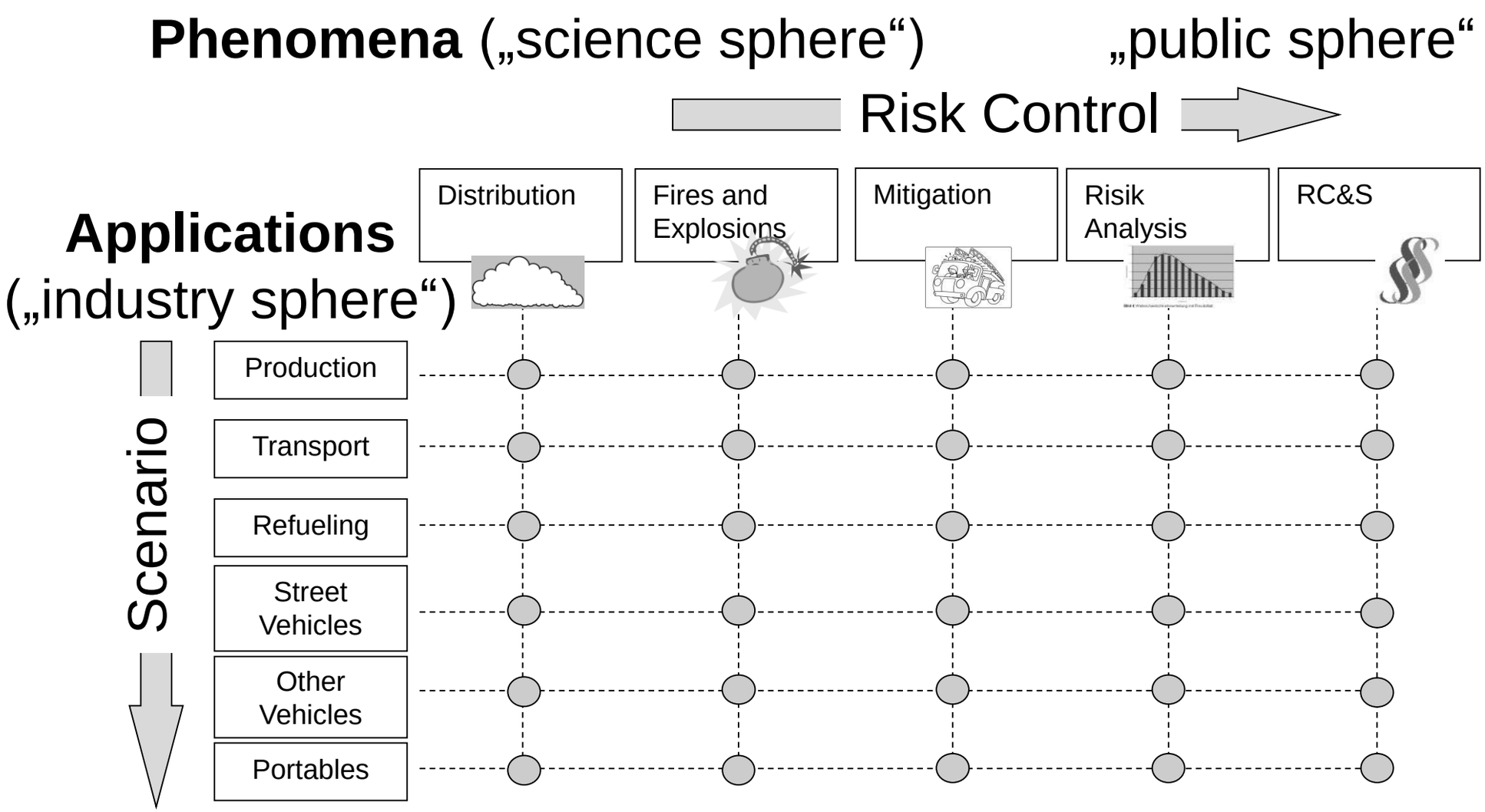
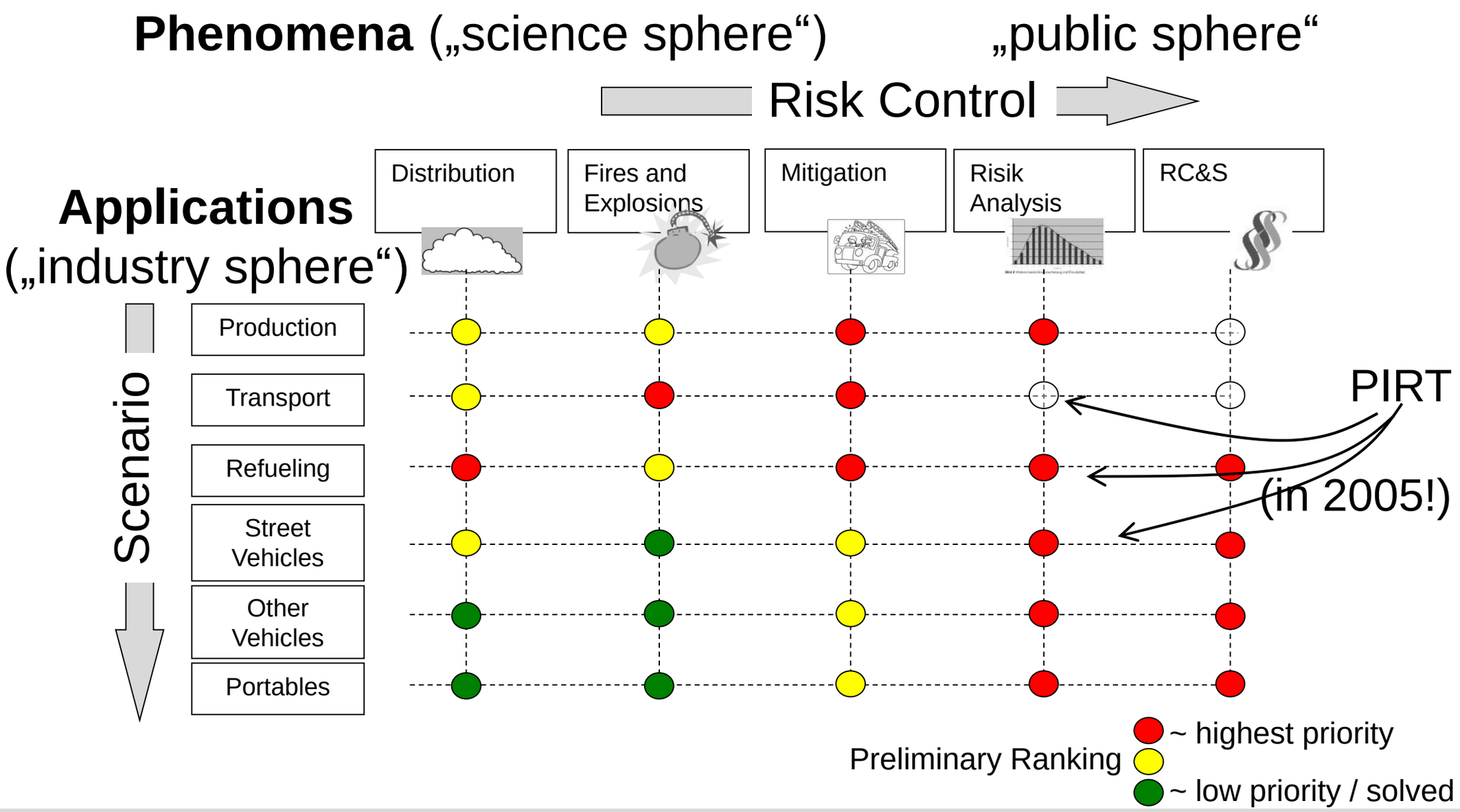
Defining the NoE („Old“) HySafe Activity Matrix



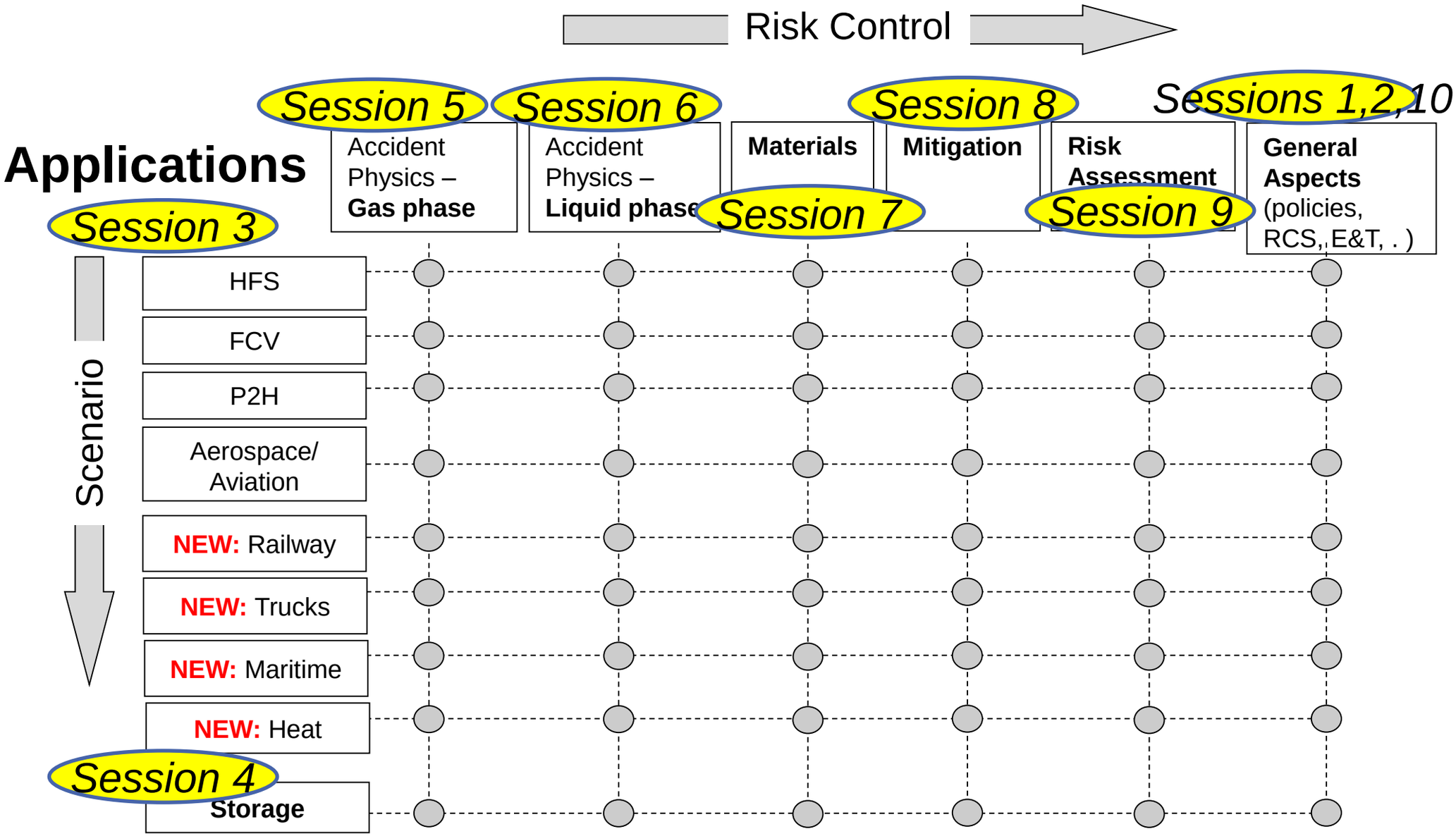
Defining the NoE („Old“) HySafe Activity Matrix



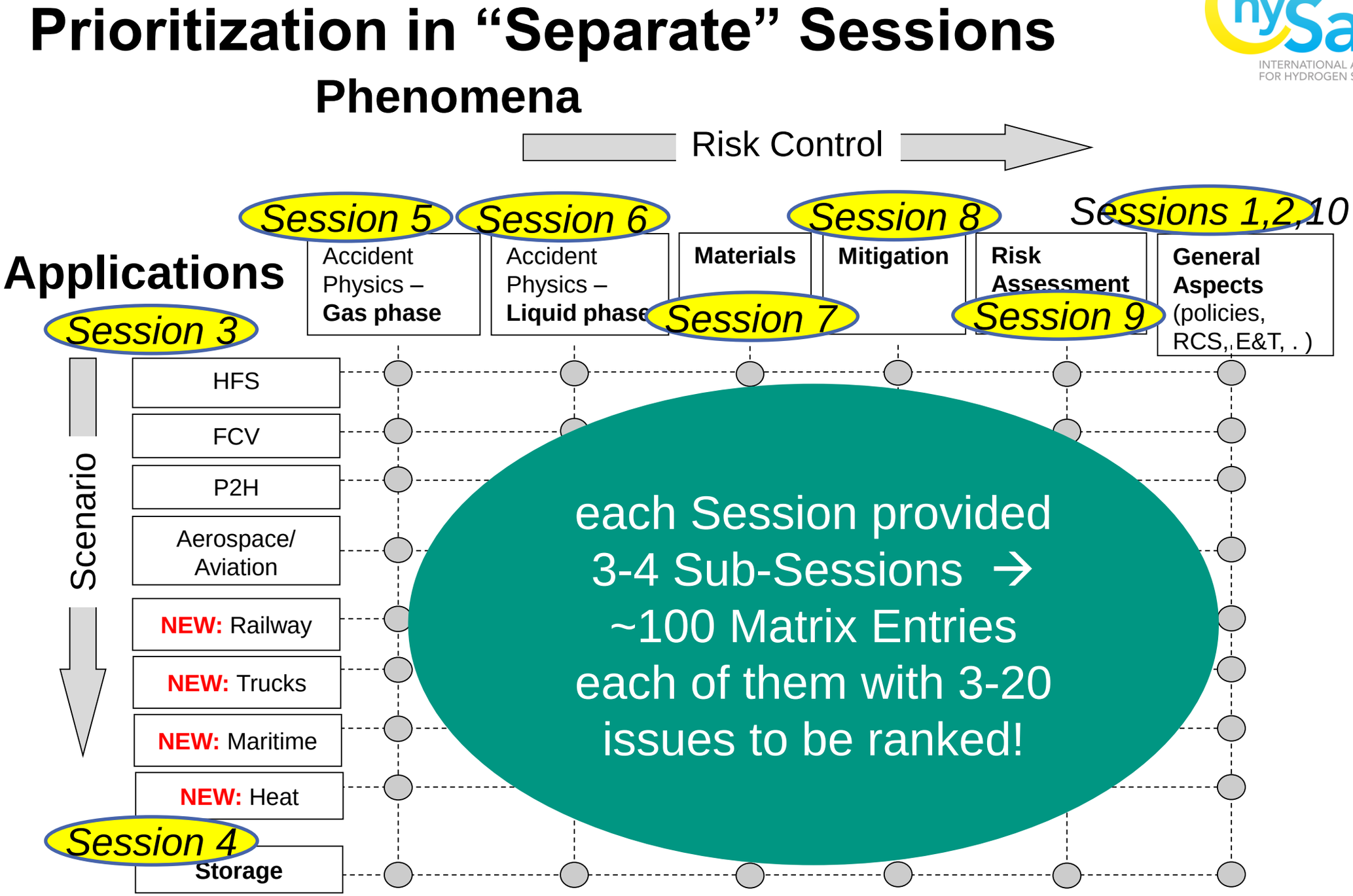
Purpose of Prioritization Effort today

- Identify those **research activities deemed most critical** by workshop attendees
  - Ensure that research priorities are **aligned with the needs of the hydrogen industry**
- Research Priorities Workshop held 19-20 September 2018 at HSE Buxton, UK
  - Attendees included international members of the academic community, national laboratories, funding agencies and industry.
  - Workshop addressed the state of the art in hydrogen behavior understanding with a focus on safety by **updating** the findings of the RPW2016 Petten, Netherlands with the help of published results in particular those of the ICHS2017
  - Attendees **prioritized the topics within each session** during the workshop (before this was a lengthy process organized after the workshop)

Prioritization in “Separate” Sessions



Prioritization in “Separate” Sessions



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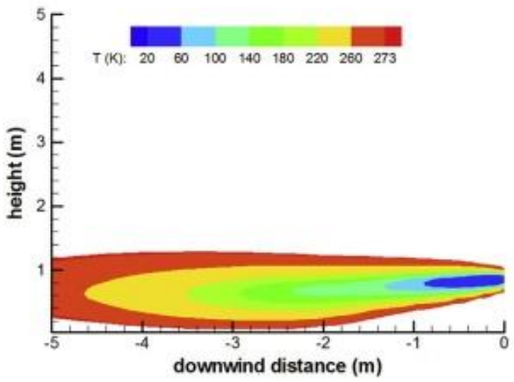
Accident Physics Phenomena
Research Priorities for Gaseous Hydrogen

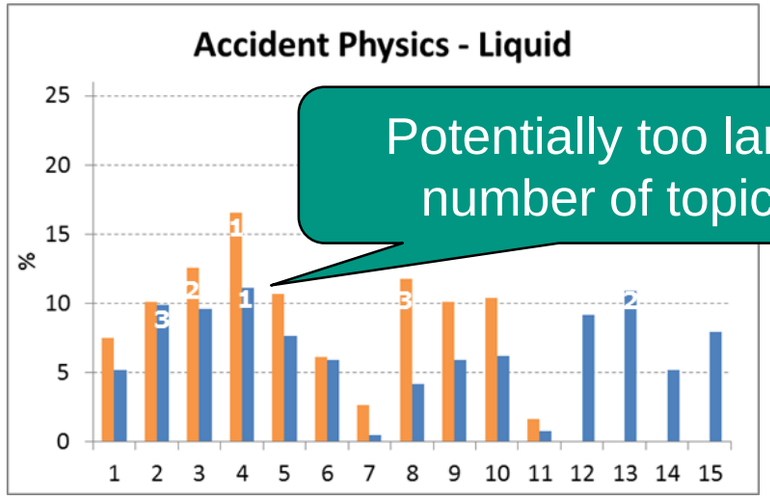
1. Premixed combustion
   - Premixed combustion - further modelling studies are needed for large scale applied problems with obstacles, particularly for DDT, Flame acceleration in confined and obstructed spaces and Blast Waves
2. Ignition
   - Statistical approaches to ignition
   - Spontaneous Ignition

Topics resolved

- Jet fires (of high p releases)
- Shock diffusion ignition

Accident Physics Phenomena
Research Priorities for Cryogenic Hydrogen



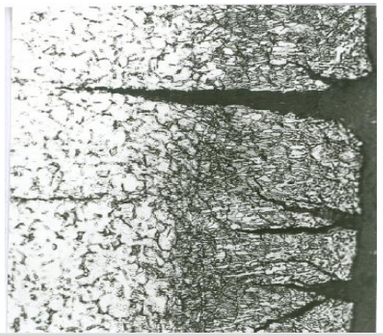


1. **Multi-phase accumulations** with explosion potential (LH2 can condense and freeze oxygen. The resultant mixture can be made to detonate): conditions for occurrence and their the consequences are not understood
2. Combustion properties of cold gas clouds, especially in **congested area**
3. Knowledge and experience related releases involving **large quantities**

Most relevant issues will be assessed in→ PRESLHY

Research Priorities for Materials

Index	Top Priorities in Materials					
	Definition of test protocols, selection criteria and relevant standards for polymer	Activities on seals, gaskets, hoses, valves and joints	Development of non-destructive test methods for liner evaluation	Evaluation and assessment of integrity of existing pipeline networks for pure hydrogen	Assessment of materials for specific liquid hydrogen applications	Evaluation of materials and components of NG grids and appliances to be used with H2/NG
PRW2018 Priority sequential number	1.3	1.5	1.4	2.4	2.7	2.11
Ranking Score	103	86	80	72	52	42
1st rankings	9	8	4	9	2	3
Experts Voting	27	27	27	18	16	15
Overall Ranking	1	2	3	4	5	6



hydride induced embrittlement

Research Priorities for Mitigation

Sensors

- Wide area monitoring (in particular for LH2 based HFS)
- Guidance on selection and placement in different applications

Protective elements (e.g. ventilation, walls, ….)

- Appropriate models accounting for their effect in risk assessment

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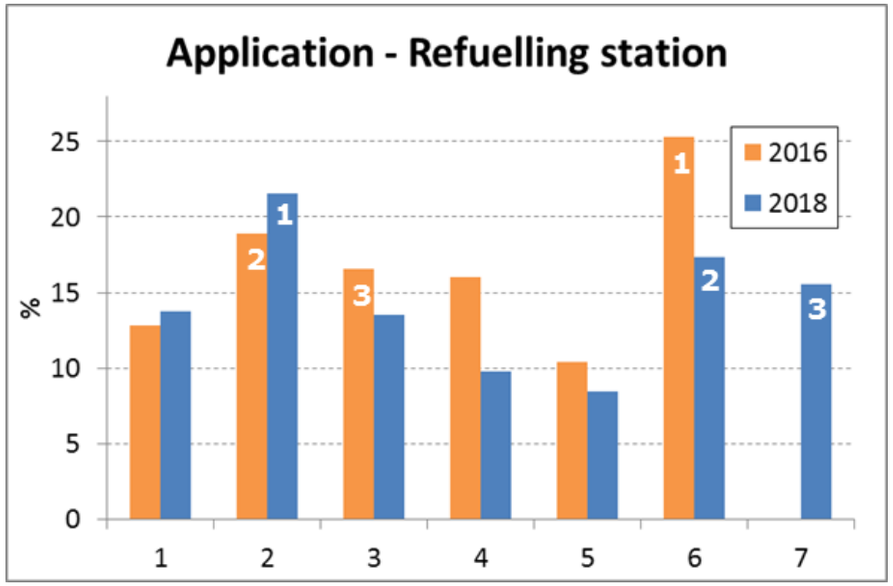
Session Application

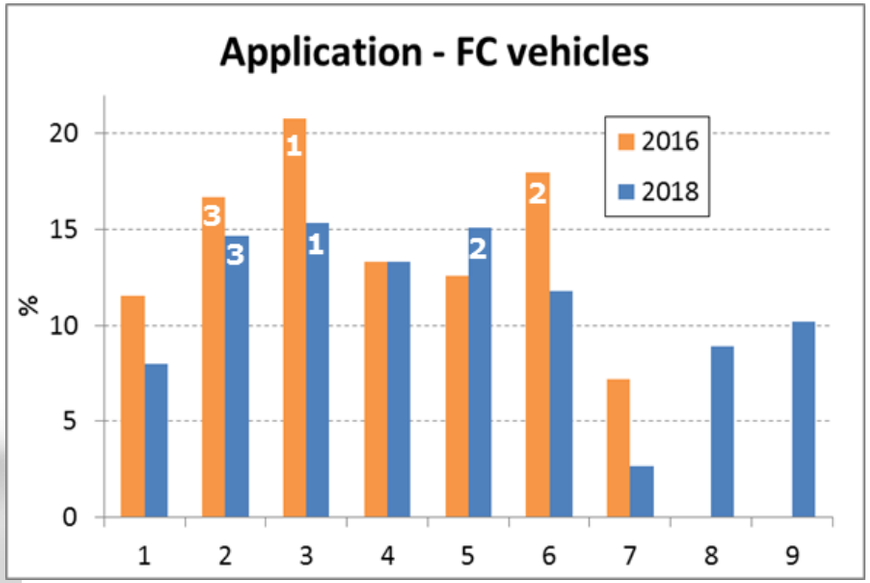
Ranking of safety topics for HFS



1. **Reduction of the over conservative** expensive design raising safety and efficiency concerns
2. Cascade effects: effect of various accidental releases in case of scale-up, complex real geometry including **co-location** with conventional fuels
3. **Vent stack design**, accounting also for cold releases from LH2 transfer and cryostat purging

Session Application

Ranking of safety topics for FCV

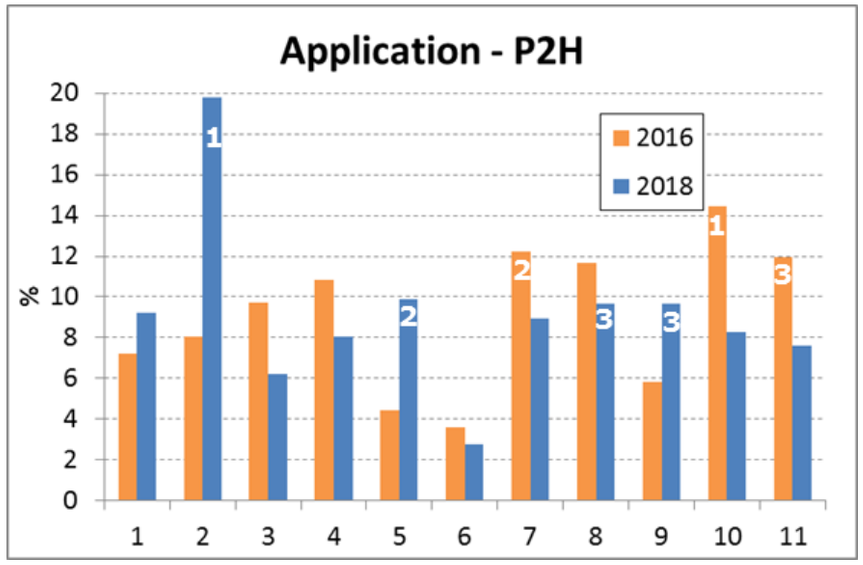


1. **Complex accident situation in tunnels** (issue 3)
2. Understanding vehicle fires and the response of storage components to **thermal excursion** (issue 5)
3. **Hydrogen venting** via TPRD in garages (issue 2)

Succesfully inspired → TUNNEL-CS

Session Application

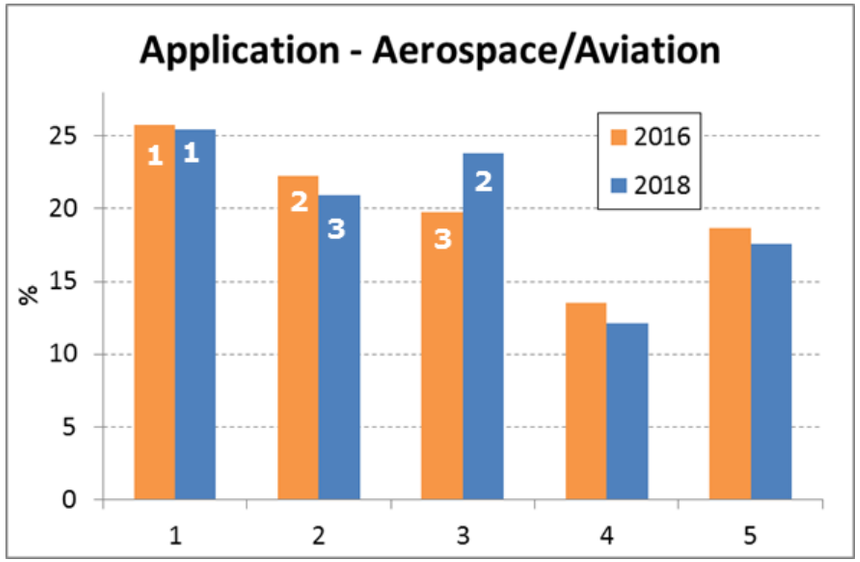
Ranking of safety topics for P2H



1. **Behaviour of H2 in H2/NG on plastics pipes, valves, fittings in house gas installations, storage cylinders** - effect on component (issue 2)
2. Review of **testing procedures** such as embrittlement & fatigue life test for H2/NG (issue 5)
3. **Certification of mitigating safety measures** (TPRD, Explosion Protection Systems, etc.) for H2/NG
4. Re-assessment of the **ATEX Zoning** should be standardized for H2/NG

Session Application

Ranking of safety topics for Aerospace/Aviation



1. Multi-phase physical processes in heat transfer, mixing with air, and initial thermodynamic status of LH2
2. Behaviour of liquid hydrogen and liquid oxygen mixtures
3. Determining the probability of detonation with inhomogeneously premixed gaseous clouds

Session Application

Ranking of safety topics for Railways

Only two topics to be voted on;
made ranking obsolete

- H2 in railway tunnels and other enclosed rooms (station halls, repair workshop, etc.)
- H2 safety in the presence of high voltage systems

Session Application

Ranking of safety topics for Heavy Duty Trucks

Application - Truks

Q	TOT	%	RANK
1	125	27.78	1
2	100	22.22	3
3	106	23.56	2
4	80	17.78	4
5	39	8.67	5

1. Crash norms and implications of vehicle high pressure CGH2 or LH2 tanks
2. Credible scenarios
3. Safety aspects of large inventory (~100kg and more) fillings including LH2 and CCH2

Session Application

Ranking of Maritime safety topics

Application - Maritime			
Q	TOT	%	RANK
1	44	9.78	2
2	65	14.44	1
3	22	4.89	10
4	31	6.89	7
5	36	8.00	5
6	23	5.11	9
7	43	9.56	3
8	36	8.00	5
9	17	3.78	13
10	44	9.78	2
11	20	4.44	11
12	19	4.22	12
13	7	1.56	16
14	26	5.78	8
15	8	1.78	15
16	9	2.00	14

Potentially too large number of topics

1. **Optimal large scale venting strategies** – radiation/blast loads from ignited events
2. **Tolerable blast and impulse loads** (how high pressures are tolerable for structures and people when duration is only a few ms?),
3. **Significant releases** (5, 10, 20 g/s) into confinement **acceptable**?

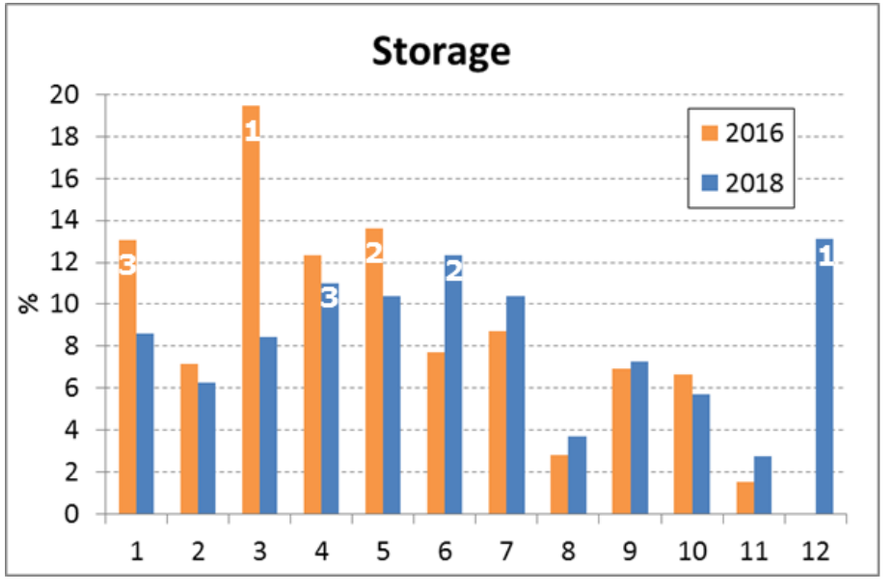
Ranking of safety topics related to Heat Applications

Application - Heat				
Q	TOT	%		RANK
1	93	20.67		2
2	88	19.56		4
3	92	20.44		3
4	72	16.00		5
5	105	23.33		1

- **Leaks in buildings and buried pipework** including tracking etc.
- Gas Distribution Networks (New & Re-purposed)
- **H2 / NG mixtures** (Detection, mixing local and downstream in large grids with multipoint injection, appliance testing, compliance)
- **Materials Issues** (Steel, PE etc. including effects of long exposure and jointing)
- Pure hydrogen systems (production, purity, odorants, colorant)

Session Storage

Ranking of safety topics related to H2 Storage



- **Tank fire resistance test protocol** (more realistic bonfire test)
- **Non-destructive-techniques** for ensuring constant manufacturing quality and required performance (number of cycles, tightness, etc.)
- Understanding **effect of overheating** on the structural performance and lifetime of the whole storage systems in case of extreme hot filling scenarios, and other temperature excursions

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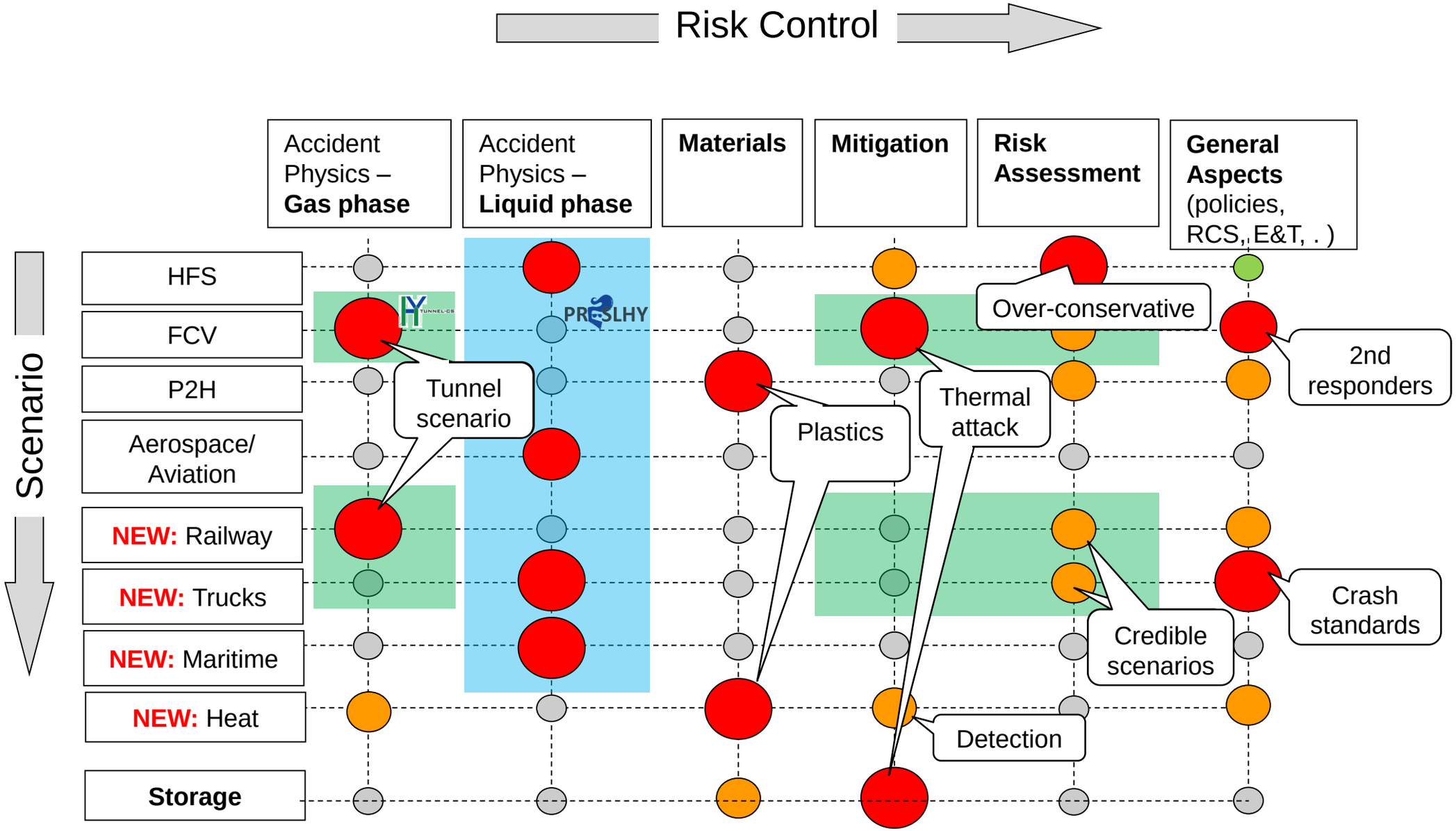
Summary


Risk Control
Accident Physics – Gas phase
Accident Physics – Liquid phase
Materials
Mitigation
Risk Assessment
General Aspects (policies, RCS,, E&T, .)
Scenario
HFS
FCV
P2H
Aerospace/ Aviation
NEW: Railway
NEW: Trucks
NEW: Maritime
NEW: Heat
Storage
Tunnel scenario
Plastics
Thermal attack
Over-conservative
2nd responders
Credible scenarios
Crash standards
Detection

Concluding Remarks

Report will be available as HSE publication

and together with the previous reports on the HySafe website

https://www.hysafe.info/activities/research-priorities-workshops

A more detailed description and the final version will be presented at ….


Pisa (IT) 2005


Ajaccio (FR) 2009


San Francisco (USA) 2011

Invitation to

ADELAIDE CONVENTION CENTRE

SOUTH AUSTRALIA

Adelaide, South Australia
September 24-26, 2019

... for further details see www.ichs2019.com

ICHS®

Brussels (BE) 2013


Yokohama (JP) 2015


Hamburg (DE) 2017