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
Content

- Introduction to HySafe
- Development of State-of-the-Art Research Priorities
  - Phenomena
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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**.
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- Introduction to HySafe
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- Conclusions
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)
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

- ICHS2017 – Hamburg, Germany
- ICHS2015 – Yokohama, Japan
- ICHS2013 – Brussels, Belgium
- ICHS2011 – San Francisco, USA
- ICHS2009 – Ajaccio, France
- ICHS2007 – San Sebastian, Spain
- ICHS2005 – Pisa, Italy

- RPW – Berlin, Germany
- RPW – Washington, USA
- RPW – Petten, Netherlands
- CFD – Petten, Netherlands
- PIRT – Update
- PIRT – NoE HySafe

Research Priorities Workshop RPW
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- Conclusions
Defining the NoE („Old“) HySafe Activity Matrix

Phenomena („science sphere“)  „public sphere“

<table>
<thead>
<tr>
<th>Applications („industry sphere“)</th>
<th>Distribution</th>
<th>Fires and Explosions</th>
<th>Mitigation</th>
<th>Risk Analysis</th>
<th>RC&amp;S</th>
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<tbody>
<tr>
<td>Scenario</td>
<td>Production</td>
<td>Transport</td>
<td>Refueling</td>
<td>Street Vehicles</td>
<td>Other Vehicles</td>
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</table>

Risk Control
Defining the NoE („Old“) HySafe Activity Matrix

Phenomena („science sphere“) vs „public sphere“

Risk Control

Applications („industry sphere“)

- Distribution
- Fires and Explosions
- Mitigation
- Risik Analysis
- RC&S

Scenario

- Production
- Transport
- Refueling
- Street Vehicles
- Other Vehicles
- Portables

Preliminary Ranking

- ~ highest priority
- ~ low priority / solved

PIRT (in 2005!)
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

**Phenomena**

- **Session 5**: Accident Physics – Gas phase
- **Session 6**: Accident Physics – Liquid phase
- **Session 7**: Materials, Mitigation
- **Session 8**: Risk Assessment
- **Session 9**: General Aspects (policies, RCS, E&T, ...)

**Applications**

- **Session 3**: HFS, FCV, P2H, Aerospace/Aviation
- **Session 4**: NEW: Railway, NEW: Trucks, NEW: Maritime, NEW: Heat
- **Session 5**: NEW: Railway
- **Session 6**: NEW: Trucks
- **Session 7**: NEW: Maritime
- **Session 8**: NEW: Heat

**Scenario**

- **Session 3**: Scenario 1, 2, 10
- **Session 4**: Scenario 1, 2, 10
- **Session 5**: Scenario 1, 2, 10
- **Session 6**: Scenario 1, 2, 10
- **Session 7**: Scenario 1, 2, 10
- **Session 8**: Scenario 1, 2, 10
- **Session 9**: Scenario 1, 2, 10

**Risk Control**
Prioritization in “Separate” Sessions

Phenomena

Risk Control

Applications

Session 3

Session 5

Session 4

Session 6

Session 7

Session 8

Session 9

Session 1, 2, 10

HFS

FCV

P2H

Aerospace/Aviation

NEW: Railway

NEW: Trucks

NEW: Maritime

NEW: Heat

Storage

Accident Physics – Gas phase

Accident Physics – Liquid phase

Materials

Mitigation

Risk Assessment

General Aspects (policies, RCS, E&T, ...)

Scenario

each Session provided
3-4 Sub-Sessions →
~100 Matrix Entries
each of them with 3-20
issues to be ranked!
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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
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 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**
### Research Priorities for Materials

<table>
<thead>
<tr>
<th>Index</th>
<th>Top Priorities in Materials</th>
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<tbody>
<tr>
<td></td>
<td>Definition of test protocols, selection criteria and relevant standards for polymer materials</td>
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<td>PRW2018 Priority sequential number</td>
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<td>Overall Ranking</td>
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</table>
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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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 →
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
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

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

Only two topics to be voted on; made ranking obsolete
Session Application
Ranking of safety topics for Heavy Duty Trucks

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

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Session Application

Ranking of Maritime safety 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**?

Application - Maritime

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Potentially too large number of topics
Session Application
Ranking of safety topics related to Heat Applications

- **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, ...)

HFS
FCV
P2H
Aerospace/Aviation
NEW: Railway
NEW: Trucks
NEW: Maritime
NEW: Heat
Storage

Tunnel scenario
Plastics
Thermal attack
Over-conservative

2nd responders
Crash standards
Credible scenarios
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 ....
Invitation to

Adelaide, South Australia
September 24-26, 2019

for further details see www.ichs2019.com