Session 6: Applications

Chair: Thomas Jordan; Panelists: Wolfram Fleck (Daimler), Frank Graf (DVGW), Gerhard Krühsel (DLR), Pratap Sathiah (Shell), Benno Weinberger (INERIS)

Research Priorities Workshop – 26/27 September 2016, JRC IET Petten, Netherlands

The Focal Point on Integrated Research and Information for Hydrogen Safety

Applications
Status at the time of previous workshop

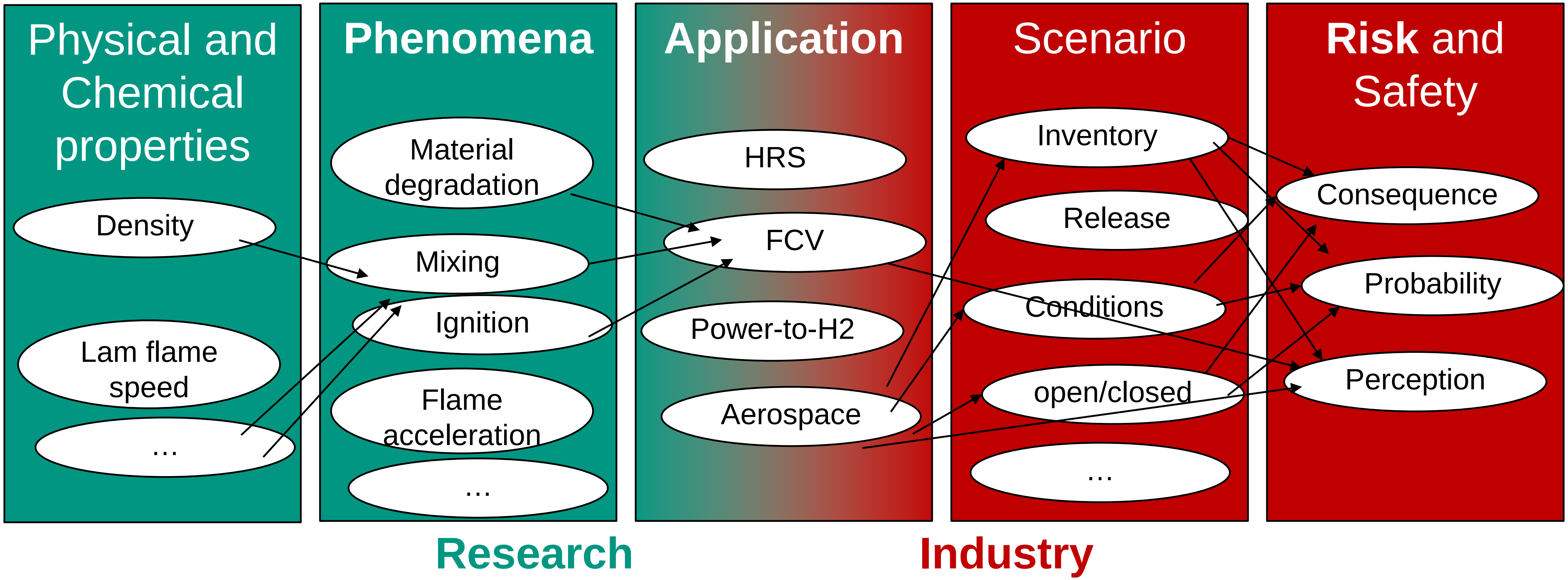
- „Applications“ topic received lowest rank 10 in 2014
- Within „Applications“ the following ranking of sub-topics was derived:

Topic Number	Topic	Number of Votes	% of Votes Received
10.3	Vehicle tank protection	12	50%
10.2	Gas turbines	5	21%
10.1	Power-to-gas	4	17%
10.4	Pre-combustion systems (PCS)	3	13%

Applications – Why?

- „Is hydrogen safe?" is an ill posed question
- Whether hydrogen is handled safe can be answered only by refering to the actual application and a specific scenario (initial and boundary conditions, state of the system,…)

→ Risk and Safety always refer to an Application:



Applications
Session Substructure

→ Safety is always application related (component and system specific)
→ To support the Application session impact a dedicated sub-structure is introduced and maintained also wrt the ranking:

a) HRS
b) FCV
c) Power-to-Hydrogen
d) Aeronautics / Aerospace

Applications - HRS

Applications - HRS

Progress / Closed gaps

- Several high pressure and dispersion experiments (almost 10 years ago, NoE phase, Shirvill, HSE)
- ISO TC197 WG24 making progress for a new HRS standard
- Some feedback of safety critical experience

ICHS2015: Paper ID 109, Comparative study of regulations, codes and standards and practices on hydrogen fuelling stations
Sylvaine Pique, Benno Weinberger, Bruno Debray, et.al. - Presentation
Paper ID 116, ISO 19880-1, hydrogen fueling station and vehicle interface safety technical report
Jesse Schneider, Guy Dang-Nhu, Nick Hart, et.al. - Presentation
Paper ID 117, Hydrogen fueling standardization: enabling FCEVs with "same as today" fueling time and driving range
Jesse Schneider, Graham Meadows, Morten Wistoft-Ibsen, et.al.
ICHS2015: Safety of Fueling
Chair: Guy Dang-nhu
Paper ID 303, KIT Fueling Station Experience
Thomas Jordan
Paper ID 111, Freeze of nozzle/receptacle during hydrogen fueling
Wataru Hiraki, Hiroyuki Mitsuishi
Paper ID 173, Hazard identification study for risk assessment of a hybrid gasoline-hydrogen fueling station with an onsite hydrogen production system using organic hydride
Jo Nakayama, Junji Sakamoto, Naoya Kasai, et.al.

Applications - HRS

Working topics

- Catastrophic failure of vehicle storage considered for risk assessment in the frame of the ISO TC197 WG24 activities

Lessons to be learnt from recent CNG vessel failure in Duderstadt, LK Göttingen, Germany on 9.9.2016?

58 years old driver seriously injured; ARAL and other fuel suppliers stopped CNG fueling of all VW CNG cars.
Claims: „driver was informed before, not to fuel with CNG“; „there was no explosion“

Bild 2 von 7 Quelle: Arne Bänsch
Der Fahrzeugführer stand vor seinem Auto. Er wurde von Trümmerteilen verletzt

- Risk assessment procedures and tools (e.g. HyRAM) accounting for mitigation measures

Applications - HRS

New gaps or directions

- Adverse effects on materail and systems in below design, **idling conditions** (corrosion, T cycles,…)
- **Overconservative** expensive design raising safety and efficiency concerns (e.g. alarm limits, electrical grounding of busses and cooling requirements)
- Still strong doubts wrt safety within authorities, public and users (drivers)
- **Material and processing (welding) issu**es for high pressure components
- Effect of compressor **vibrations** on material
- Still open ventilation requirements for compressor containers
- hydrogen dispersion, jet fire and explosion in particular for scale-up (large bus fleets, trains,….)

Phenomena:
Mixing-Ignition-Combustion
LH2

Applications - FCV

Applications - FCV

Gaps, new directions

only point suggested in RPW2014

- Potential overconservative pre-cooling requirements → more detailed analysis of T evolution during standard (SAE) compliant refueling

RPW2014 Moretto:
http://www.hysafe.info/wp-content/uploads/2016/07/398_RPW2014_Presentations-Research-Priorities-2014-distribution-updated-2016-05-20.pdf

Applications - FCV

Progress / Partially closed gaps

- Enhanced engineering models for tank state (SOC, T, p,…) prediction

ICHS2015: Paper ID 260, Estimation of final hydrogen temperature from refueling parameters
Jinsheng Xiao, Pierre Bénard, Richard Chahine

- Effectiveness of thermal protection of onboard storage against fire evaluated

ICHS2015: Paper ID 229, Modelling heat transfer in an intumescent paint and its effect on fire resistance of on-board hydrogen storage
Yangkyun Kim, Dmitriy Makarov, Sergii Kashkarov, et.al.

- First ideas for identifying state of TPRD after fire/accident

ICHS2015: Paper ID 168, Study of a post-fire verification method for the activation status of hydrogen cylinder pressure relief devices
Koji Yamazaki, Yohsuke Tamura

Applications - FCV

Working topics

- Pressure Peaking
- Effects of blast induced by rupture of high pressure onboard storage (addressed in ISO TC 197 WG24 for HRS)

Applications - FCV

New gaps or directions I/II

- Operations
  - **State of health monitoring** of pressure vessel (fatigue, after crash, thermal events, misuse), non-destructive testing
- Leakage/venting related tasks
  - H2 leakage in **garages**
  - Venting of H2 via TPRD in narrow spaces as a single car garage
  - Remotely initiated venting
- Fire
  - Complex accident situation in **tunnels**
  - Vehicle fire (different locations) and response of storage components to thermal excursion
  - Improved protection in particular of onboard storage against fire and thermal excursions

Source: Panelists Fleck, Daimler and Kunberger, BMW

Applications - FCV 

New gaps or directions II/II

- Extreme events
  - Improved protection against extreme events
  - Pressure vessel rupture mitigation
- Rescue and first responders Post Crash event
  - Identification of tank SOC status (after fire or crash) to protect first responders
  - Identification of tank structure integrity after crash for first and second responders

Source: Panelists Fleck, Daimler and Kunberger, BMW

Phenomena related **Onboard Storage**

Applications – Power-to-Hydrogen

Applications – Power-to-Hydrogen

Progress / Closed gaps

- Several PtH_2 injection plants were connected to the natural gas grid
- hydrogen limits of gas infrastructure components was investigated (e.g. Naturalhy, GERG, DVGW)
- Hydrogen injection in natural gas grid is addressed in various initiatives (e.g. Hyready, HIPSNET)
- First standards were realized (e.g. DVGW G 265-3 for hydrogen injection plants)

⇨ 2 vol.-% hydrogen are non-critical in existing gas infrastructure

Source: DVGW

Applications – Power-to-Hydrogen 

Progress / Closed gaps

For different blends of hydrogen in methane determined:

- Upper and lower explosion limits at SATP
- P max and dp/dt max determined and limit concentration for gas mixture characterisation determined (H2-NG still in same class as NG)
- Flame temperatures, thermal radiation of the flame, viscosity of gas (mass flow) at SATP
- Minimum safety experimental gap / Minimum Ignition Current at SATP
- Flame length of H2-NG

Source: BAM, Panelist Weinberger, INERIS

Applications - Power-to-Hydrogen

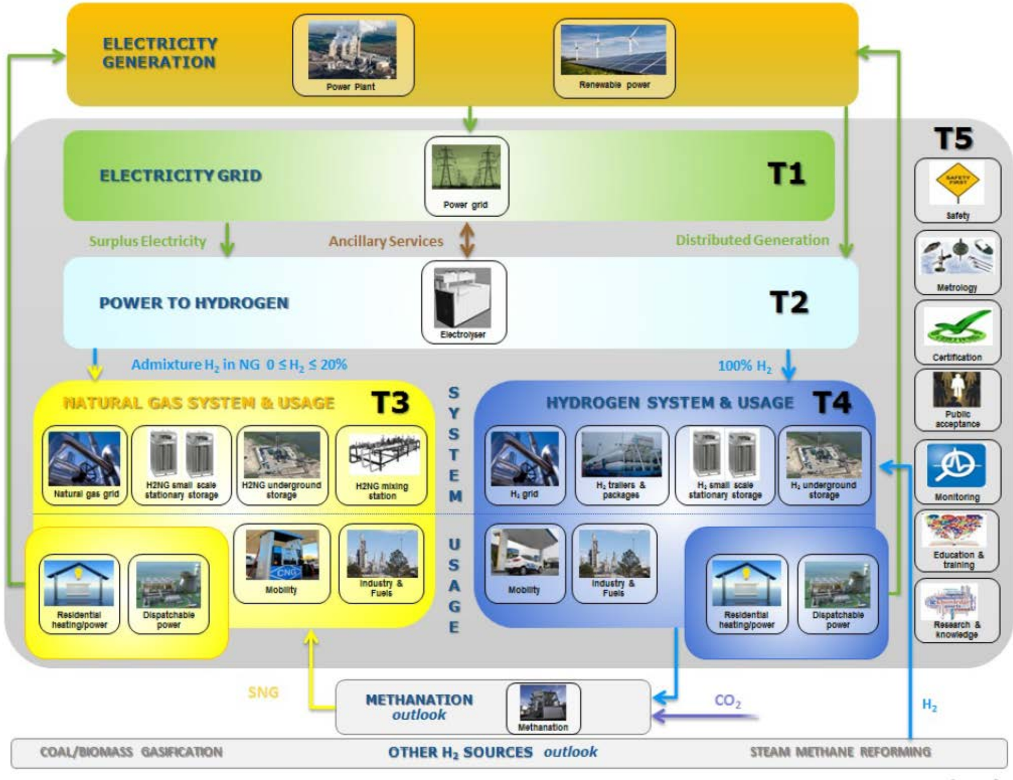
Working topics

- European standardization activities
  - CEN/CLC/TC 6 – Hydrogen in energy systems was launched
  - CEN/TC 234 is in charge of topic “H_2 in natural gas infrastructure“

- New research projects on PtH2
  - underground storage (e.g. Underground Sun Storage, HYPOS)
  - influence of gas quality fluctuations on gas appliances (performance, emissions etc.)

⇨

Limit of 5 - 10 vol.-% hydrogen is pursued



Source: M. Steen, Workshop "Power-to-Hydrogen: key challenges and next steps (2016)

Applications - Power-to-Hydrogen 

Working topics

- Model for flammability limits of H2/CH4 mixtures with N2 and CO2 intertisation
- Characterisation of ignition sources for these mixtures
- Release and distribution simulations for zone definitions
- Guidance, standards for sensors
- Ignition probability of H2-NG blends for typical accidental scenarios
- Diffusion coefficient of H2-NG blends through different materials
- Induction time measurement of H2-NG blends

Sources: BAM, Panelists Weinberger, INERIS, Jordan, KIT

Applications - Power-to-Hydrogen

New gaps or directions

Gas grid related safety issues, H_2 embrittlement & assisted corrosion:

- List of **materials** compatible with H2NG systems, taking into account already collected data and available standardization deliverables such as the technical report ISO/TR 15916:2004 7.
- Behaviour of H2 in H2NG on plastics pipes, valves, fittings in house gas installations, storage cylinders - effect on **components**
- **Metering** and mixture concentration and **homogeneity** control

> Metering and effect of components have been highlighted by the RCS strategy group

- Influence of hydrogen on integrity of underground pore storages
  - hydrogen induced microbiological reactions
  - permeation effects

> A few projects, like HyUnder, H2Store, produced first results, and some findings from nuclear waste research might be applicable

⇨ >10 vol.-% hydrogen should be realized in the future

Applications - Power-to-Hydrogen

New gaps or directions

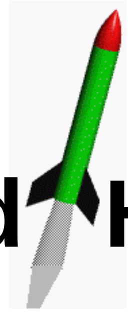
- Testing procedures such as the **fatigue** life test should be reviewed together with industry
- Correlation between specimen and component tests for the characterization of susceptibility to hydrogen embrittlement and enhanced fatigue

- Effect of larger concentration of H2 in H2NG on **flame stability** in standard burners
- All kinds of **mitigating safety measures** (TPRD, Explosion Protection Systems, etc.) have to be certified for H2NG
- Re-assessment of the **ATEX Zoning** should be standardized for H2NG
- Collect available field **data** from Power-to-H2 installations
- Training about the safety aspects of H2/H2NG

Phenomena:
Materials

Applications - Aerospace

Applications - Aerospace
Space Propulsion and H2 Safety Aspects



- …..

  See separate slides of panelist Krühsel, DLR

Applications – Aerospace
New gaps or directions

An **aircraft** is operated in sub-atmospheric pressure environment (about 0,8 bars cabin pressure, and 0,2 bars external ambient pressure for a commercial aircraft), and therefore:

- the physics of hydrogen **ignition and flame propagation** for **low external p and T**
- Venting hydrogen outboard has to take into account airship safety (this situation may arise while in-flight and safety must still be ensured during such operation). Typical criteria to take into account are :
  - Lightning effects / protection means and strategies,
  - H2 plume mixing (high velocity of aircraft) and size of ignitable plume,
  - Consequence of plume ignition on aircraft (flame characteristics, radiated heat, ...).

Phenomena:
LH2, ignition