FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

Analysis of H2 related incident and accident database HIAD

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http://www.fch.europa.eu/page/european-hydrogen-safety-panel

European Hydrogen Safety Panel (EHSP)

Expert group on hydrogen safety assisting the FCH 2 JU at project and programme level

The EHSP assists the FCH 2 JU both at **programme** and at **project level**

- in **assuring that hydrogen safety is adequately managed**, and
- to **promote and disseminate hydrogen safety culture**

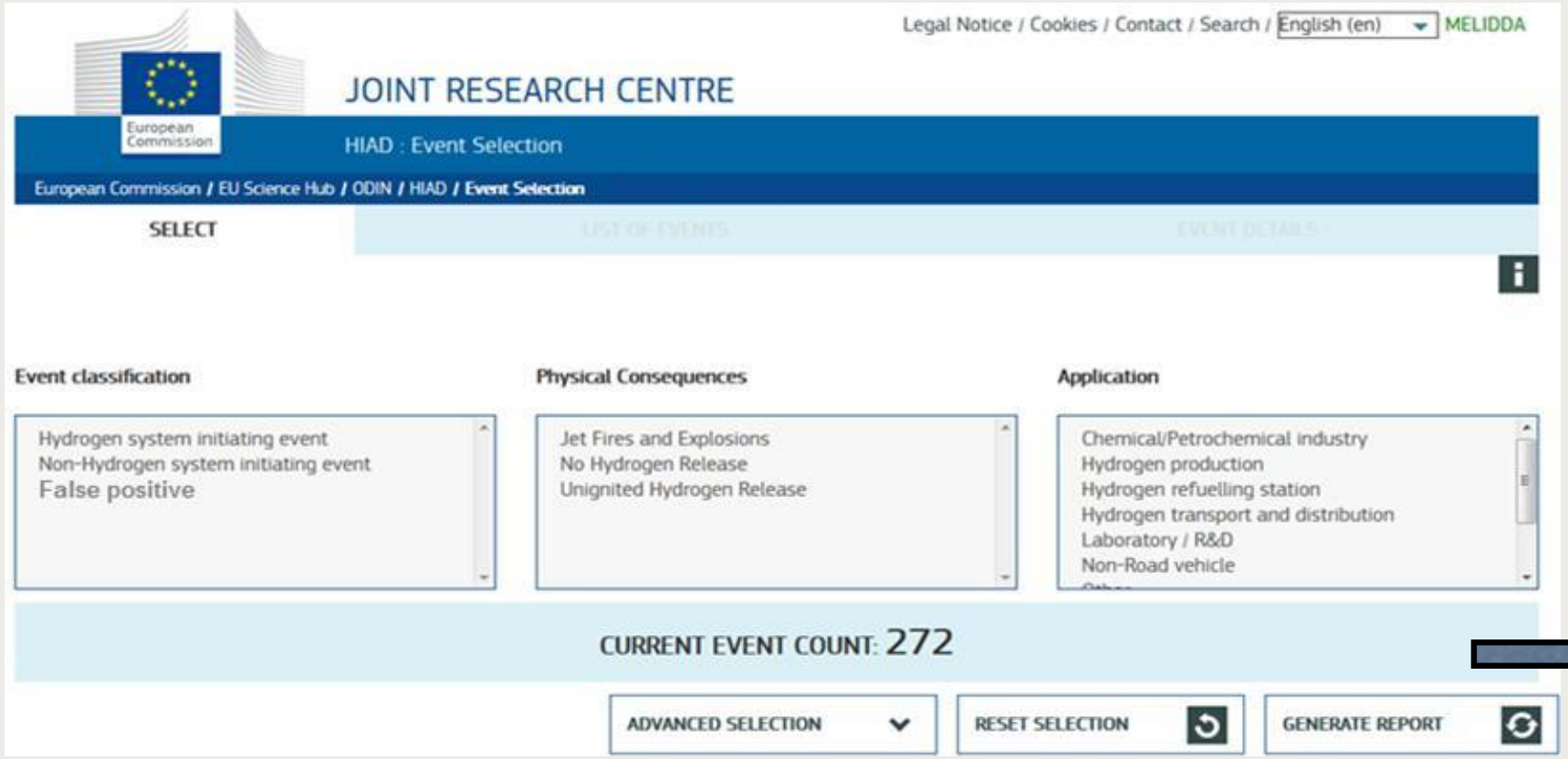
Activities in 4 Task Forces (TF):

- **TF1** Project level
- **TF2** Program level
- **TF3** Data Collection
- **TF4** Public Outreach

https://www.fch.europa.eu/page/european-hydrogen-safety-panel

Assessment and lessons learnt from Hydrogen Incidents and Accidents Database HIAD 2.0

EHSP Task Force TF3 – Outcome of 2018 activities



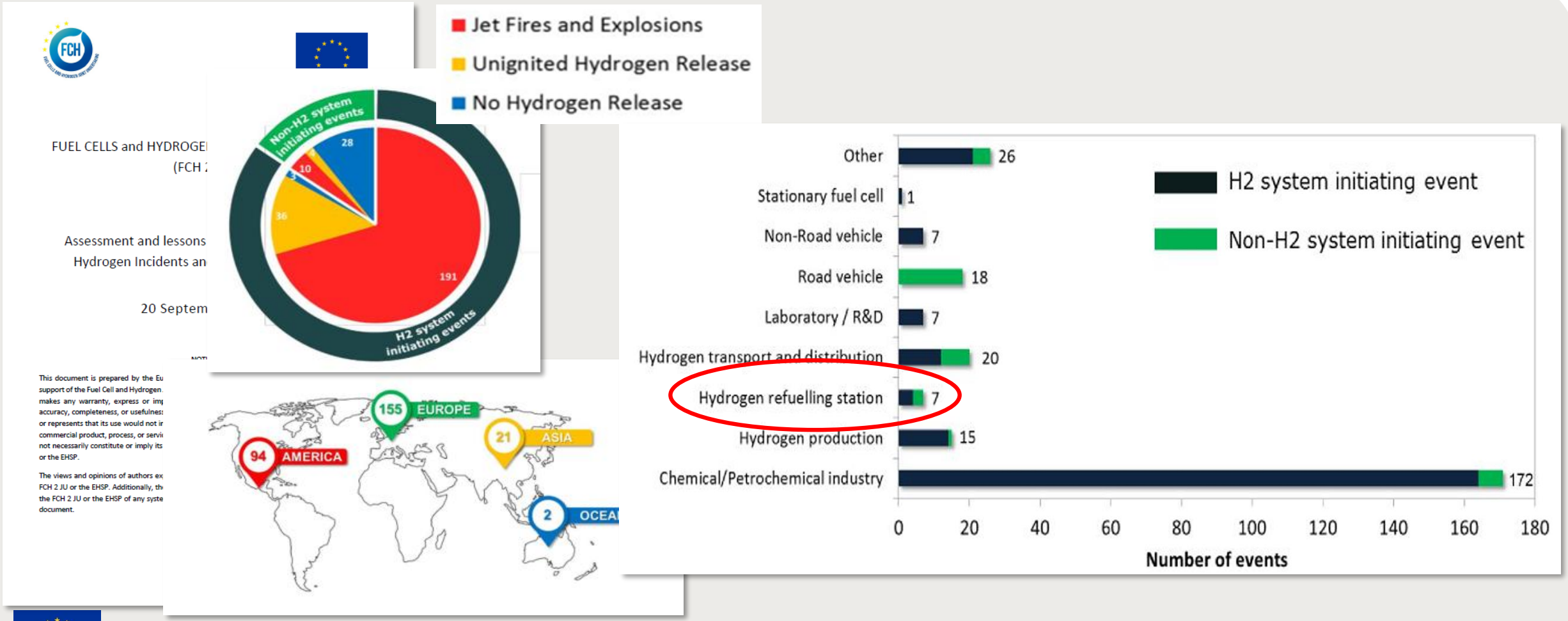
In 2018, 10 members of the **EHSP Task Force 3** analysed the 272 events in HAID 2.0 with the aim to identify, report and summarise the **lessons learnt**.

CURRENT EVENT COUNT: 425

Access to HIAD 2.0: https://odin.jrc.ec.europa.eu/giada/

Report on the assessment and lessons learnt from Hydrogen Incidents and Accidents Database HIAD 2.0

EHSP Task Force TF3 – Outcome of 2018 activities



Source: https://www.fch.europa.eu/page/european-hydrogen-safety-panel

Report on the assessment and lessons learnt from Hydrogen Incidents and Accidents Database HIAD 2.0

EHSP Task Force TF3 – Outcome of 2018 activities

Case No.	Summary of events	Country	Year
382	Near the end of the process of filling a gaseous hydrogen tube trailer at a liquid hydrogen transfilling station, a safety pressure-relief device (PRD) rupture disc on one of the tube trailer's ten tubes burst and vented hydrogen gas. The PRD vent tube directed gas to the top of the trailer where the hydrogen vented and ignited, blowing a flame straight up in the air. The operator filling the tube trailer heard a loud explosion from the sudden release of hydrogen gas and saw flames immediately. The operator closed the main fill valve on the tube trailer, stopping the hydrogen fill; however, the ten cylinders on the tube trailer were almost full (2500 psig/173 bar). The tube trailer involved in this incident was one of two tube trailers being filled simultaneously and was second in a line up of five tube trailers parked adjacent to one another at this location.		
395	An air pipe in the fuelling compound was disconnected at pressure. This caused minor injury to an Air Products employee who was struck in the leg by the loose piping.	UK	2011
396	A hydrogen leak was detected in the dispenser pump causing the alarm to sound.	UK	2012
401	Drive performed filling and the station was shut down due to a gas detection. The leak was extremely small and difficult to locate but the gas was directed upwards towards the gas sensor which shut down the station. The safety equipment performed well as it should and safely shutdown the station. The tiny leak was located about 8cm from the end fitting in the middle of the hose. Discovered during inspection.	Norway	2012
403	Dispenser A shutdown. Air Products were called and confirmed there was an issue with the dispenser so we switched to dispenser B. Fuelling was not interrupted.	UK	2013
404	Dispenser A is not operating (will be fixed 25/07/13) so dispenser B was being used. Fuelling was taking too long and was very slow. Air Products was called and it was found that the solenoids were not opening correctly due to a lack of air.	UK	2013
411	An oil leak in compressor 2 was identfied in the end of Aug 2015 by an Air Liquide technician p the compressor. The oil leak had caused a contamination of the entire system from the compre		

…too few HRS specific entries

Report on the assessment and lessons learnt from Hydrogen Incidents and Accidents Database HIAD 2.0

EHSP Task Force TF3 – Outcome of 2018 activities

Insights from some of the lessons learnt stemmed from the expert´s assessment

- Overall, the overarching lesson learnt is that accidents might consist of **several causal** events that, if occurred separately, might have little consequences; but if these minor events **occurred simultaneously**, they could still result in extremely serious consequences.
- Accidents are often initiated under **special conditions**, like maintenance, revision or restart after changing the system.
- Most of the cases are attributed to the human factor (wrong design, wrong operation).
- The lessons learnt and recommendations are grouped into several sub-sections according to whether they were related to inspection and maintenance, personnel, or whether the events resulted in recommendation for process/plant modification. Last, any lessons outside these were group as miscellaneous cases.

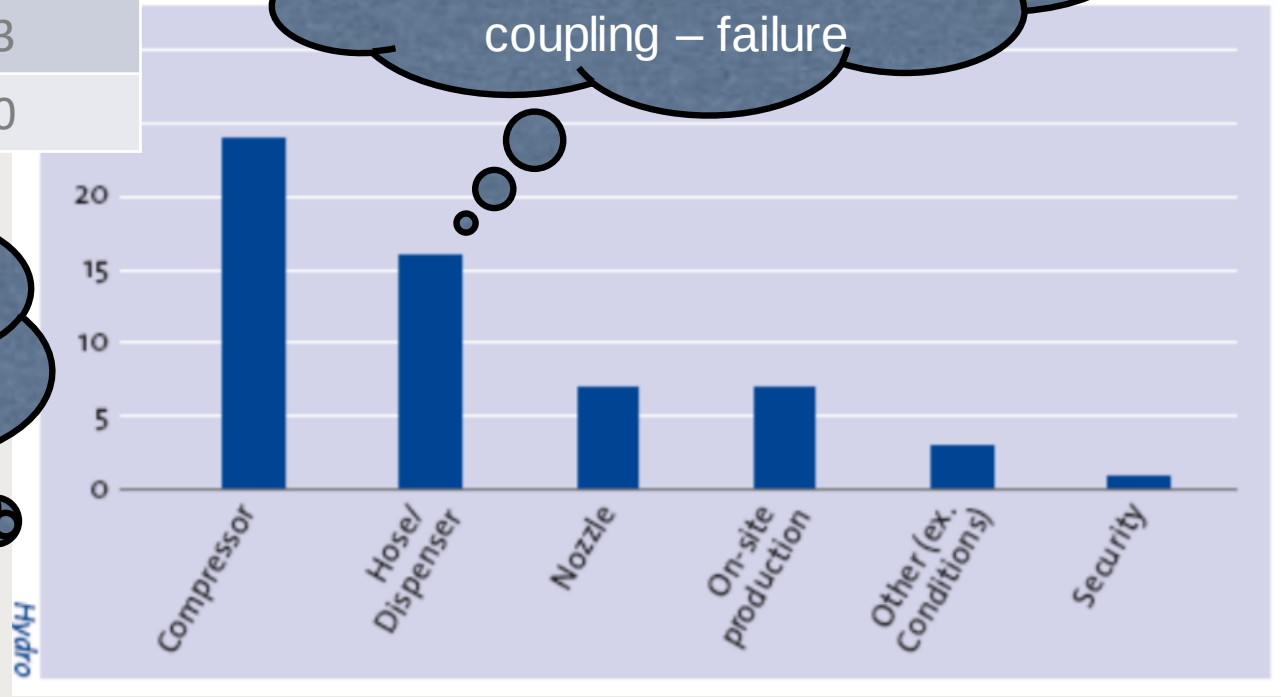
Some further „protected“ data: Incidents from CUTE, HyFLEET:CUTE 2003 - 2009

Data collection and interpretations beyond HIAD

Program	Terms	No of incidents	% attributed to UI
CUTE	2004-2006	65	33
HyFLEET:CUTE	2006-2009	100	40

Incident Madrid HRS: Wrong material selection - embrittlement of coupling – failure

Incident ECTOS HRS Reykjavik: Replacement of tube element – wrong material – erosion - release - fire



Source: T. Haugerod and A. Hansen
http://conference.ing.unipi.it/ichs2007/fileadmin/user_upload/FIN_ICHS2007_Paper2.1.81_final010707.pdf

Basis 2007: ~ 165 HRS

Analysis of HRS Leak-type Based Accidents in Japan and USA 2004 – 2014 Cases Reported by 2016

Data collection and interpretations beyond HIAD

Table 1 – Database of hydrogen incidents and accidents.

Database name	Country/area of incident occurrence	Number of incidents (number of hydrogen fueling station incidents)	Database administrator
High Pressure Gas Safety Act Database	Japan (2005–2014)	(21)	High Pressure Gas Safety Institute of Japan
HIRD	USA (2004–2012)	216 (22) 2016/2/23 access	Pacific Northwest National Laboratory, USA
HIAD	Entire world	271 (2) 2016/2/24 access	European Commission's Joint Research Center, Petten, Netherlands

should be corrected to:
272 (7)

Basis 2013: ~ 224 HRS

Analysis of HRS Leak-type Based Accidents in Japan and USA 2004 – 2014 - Definitions

Data collection and interpretations beyond HIAD

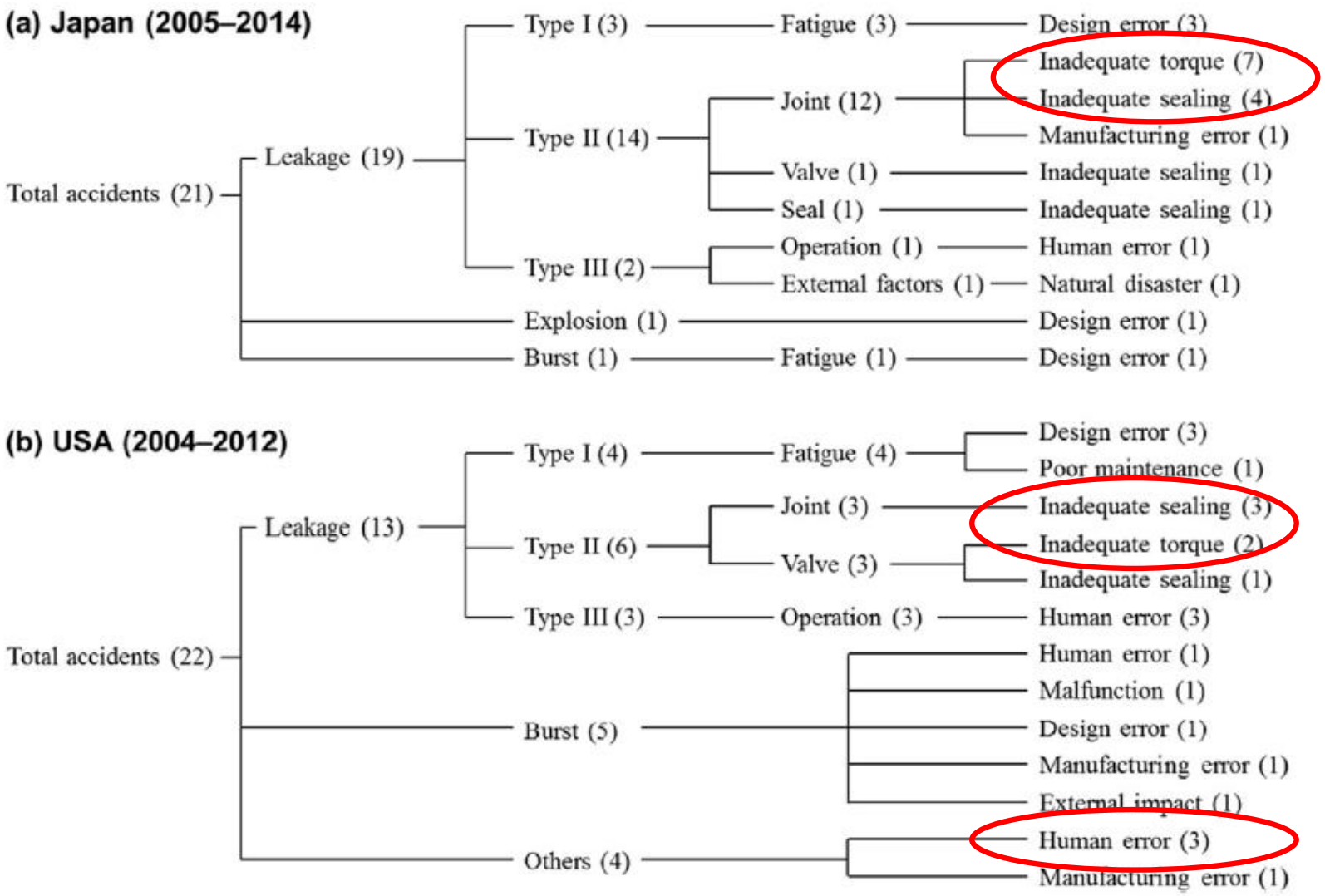
Table 3 – Classification of accidents and incidents involving hydrogen fueling stations in the USA from 2004 to 2012.

Incident type	Apparatus & parts	Cause
Leakage I (4)	Crankshaft bearing of compressor	Design error (fatigue)
	Welded part of pipe	Design error (fatigue)
	Pressure relief valve	Design error (nonconforming material use)
	Filling hose	Poor maintenance
Leakage II (6)	Joint in filling system	Inadequate sealing
	Joint of cylinder surrounding accumulator (screw joint)	Inadequate sealing
	Joint between LH_2 lorry and LH_2 pipeline (flange joint)	Inadequate sealing
	Valve in LH_2 pipeline	Inadequate torque
	Valve	Inadequate torque
	Valve	Inadequate sealing
Leakage III (3)	Filling hose	Human error
	Flexible hose from LH_2 lorry	Human error
	Valve	Human error
Burst (5)	Emergency detaching coupler	Malfunction
	Emergency detaching coupler	External impact
	Compressor	Manufacturing error
	Compressor head fastener	Design error
	LH_2 lorry	Human error
Others (4)	Filling system – FCV	Human error
	Filling system – FCV	Human error
	Hose	Human error
	Adapter	Manufacturing error

Source: Sakamoto J, et al., IJHE (2016) http://dx.doi.org/10.1016/j.ijhydene.2016.08.060

Analysis of HRS Leak-type Based Accidents in Japan and USA 2004 – 2014

Data collection and interpretations beyond HIAD



Lessons Learnt from (HyFLEET)CUTE and Japan/USA study

Data collection and interpretations beyond HIAD

Material / Fatigue / HE

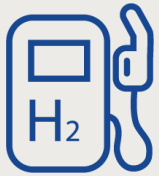
The main cause of leakage I in Japan and the USA is design error, that is, poorly planned fatigue. Considering the indicents in EU, Japan and the USA, it is very important to adequately consider the operational conditions in the design. Important issue is control of compressor induced vibrations.

Sealings / Weldings

Leakage II is mainly caused by screw joints and inappropriate sealings. If welded joints are to be used instead, it might be important to obtain data on the strength of welded parts and develop technology and techniques for improving quality of welding of hydrogen compatible material and reducing the pipe thickness.

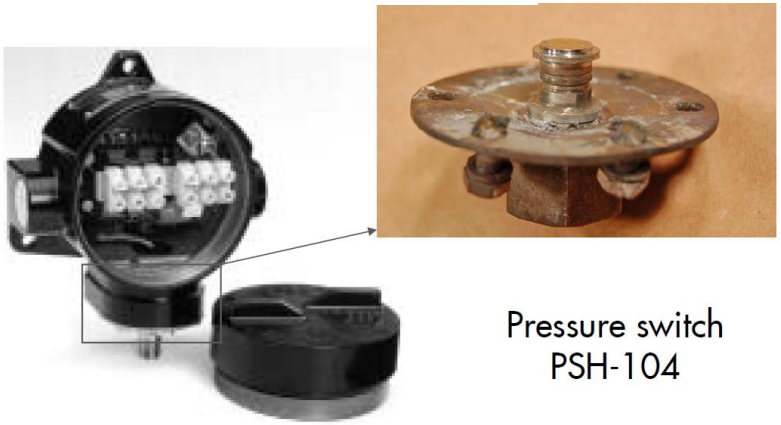
Human Error / UI

The main cause of leakage III in Japan and the USA is human error. To realize self-serviced hydrogen fueling stations, safety measures should be developed to prevent human error by FCV users.



City of White Plains NY, USA – 21 August 2008

Major HRS accidents involving fire and explosion

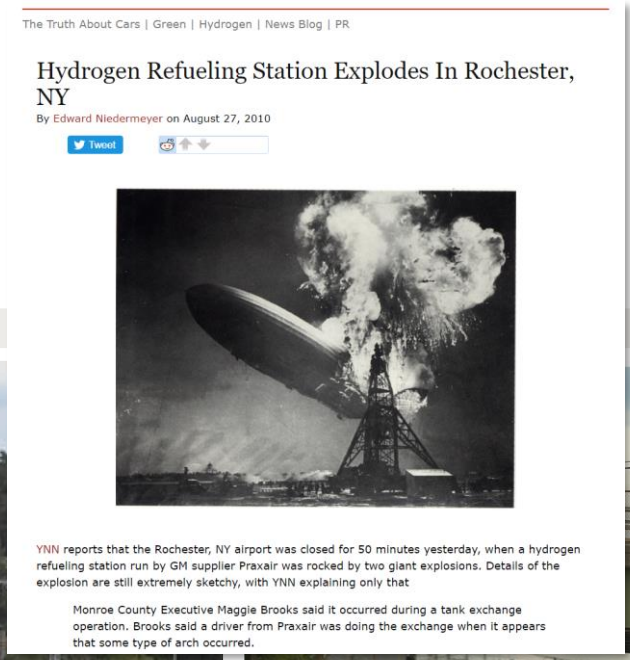


- Increased scrutiny for selecting components (→ materials selection, welding)
- More robust design preventing escalation

Source: L. Shirvill, 2010

Rochester NY, USA – 26 August 2010

Major HRS accidents involving fire and explosion



The Truth About Cars | Green | Hydrogen | News Blog | PR

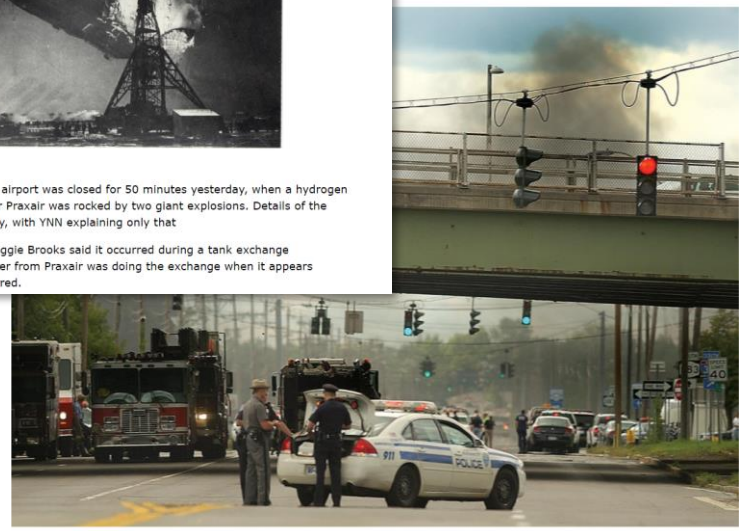
Hydrogen Refueling Station Explodes In Rochester, NY

By Edward Niedermeyer on August 27, 2010

Tweet

YNN reports that the Rochester, NY airport was closed for 50 minutes yesterday, when a hydrogen refueling station run by GM supplier Praxair was rocked by two giant explosions. Details of the explosion are still extremely sketchy, with YNN explaining only that

> Monroe County Executive Maggie Brooks said it occurred during a tank exchange operation. Brooks said a driver from Praxair was doing the exchange when it appears that some type of arch occurred.



- Root cause unknown
- Escalation with trailered hydrogen
- Two injured persons

http://www.yourepair.com/774/alternative-fuels-aug-26-2010-hydrogen-explosion-at-rochester-ny-truck-fueling-station.html

https://www.mpnnow.com/x1178704228/Explosion-closes-Rochester-International-Airport

https://eu.democratandchronicle.com/story/news/local/rocroots/2019/08/24/hydrogen-tanks-exploded-this-week-in-history-find-out-what-happened-rochester/2076855001/

https://www.cars.com/articles/hydrogen-explosion-deals-blow-to-fuel-cell-advocates-1420663195229/

Sandvika (Kjorbo), Norway – 10 June 2019

Major HRS accidents involving fire and explosion

→ see next presentation …

Hands-on Safety Experience with a small bus HRS

Lessons learnt with KIT HRS

Karlsruher Institut für Technologie

Hydrogen Source

In the beginning, 100 % delivery of by-product hydrogen from BASF/ALD.
Medium-term use of own-produced “green“ hydrogen (bioliq, VERENA, high-pressure electrolysis).

Storage Capacity

at 45 bar: 300 kg H_2(g)
at 450 bar: 120 kg H_2(g)
420 kg H_2(g)

Refueling Capacity

- 350 bar and 700 bar fillings
- 80 kg (uncooled) dispense quantity
  ~ 3 bus refuelings + 10 cars per day
  20 min refueling (~30 kg bus, 3 kg car)

Avoid Mixing Standards!

Lessons learnt with KIT HRS

Refueling station was designed (and in operation) for North American destination vs. European / German regulations requires in specification

→

- Major components were designed along ASME
- Posterior CE marking of system, which was in service before, not possible

→

Major components, e.g. pulsation damper, high pressure cooler, etc. had to be replaced;
other components, like container ventilation had to be modified

Do Not Mix Standards!

North American type ventilation system was considered as ignition source in EU (→ fixed)

Permanent forced ventilation outlet with instable flow control

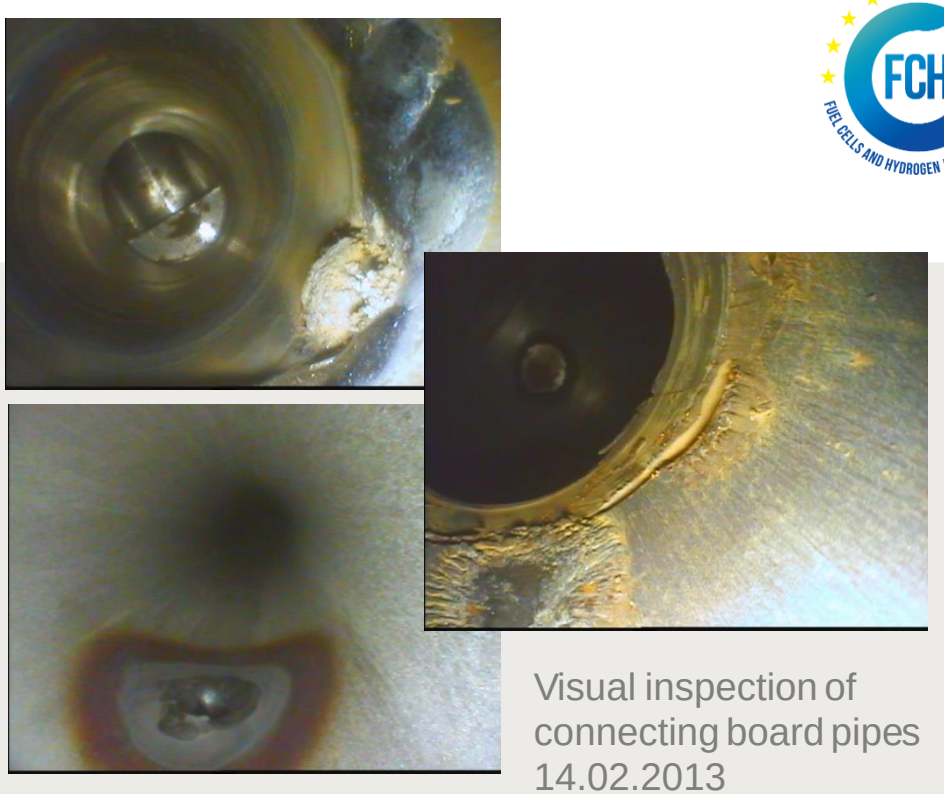
Rear side (northern) of compressor container

Check Quality of Weldings!

Lessons learnt with KIT HRS

To reduce number of potential leaks (ATEX zones) welded connections should be preferred, however…

- Several weldings of high p piping proved to be defective in sample testing
- Several weldings of connecting board proved to be falsely designed, corroded or defective
- Pipe network connecting the high pressure vessels done wrong; tubes of different dimensions were welded face to face



Visual inspection of connecting board pipes 14.02.2013

Do careful statistical checks of weldings and control certificates and capabilities of suppliers

Control Installation Quality!

Lessons learnt with KIT HRS

Sandvika Accident

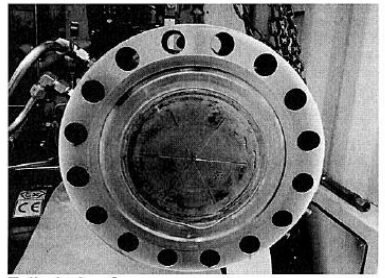
Installation QA failure (21.10.2011)

- Torque of the screws fixing the driving wheel on the motor shaft of the compressor were not checked

→
Driving wheel and belt ripped off during test refueling.
Emergency shut-down initiated manually.

Membran Gasseite

Innere Membrane



Zylinderkopf

Installation QA failure (26.1.2012)

- Clamping of the compressor membrane was not mounted properly and not checked

→
Compressor indicated hydrogen loss; faulty installation was detected
Action:
membrane was replaced

Insist on full quality control, appropriate checks and prompt documentation of the installation procedures

Appropriate Selection, Installation and Test of Sealings!

Lessons learnt with KIT HRS

False Initial Installation of Seals (1.3.2012)

After additional checks seals were left for subsequent replacement in main yearly revision

Service of 700 bar Dispenser (15.4.2014)

After minor modifications the 700 bar dispenser was taken into service after pressure test with nitrogen

→

Minor hydrogen release from booster initiated alarm

Make sure your sealings are installed by capable staff and that leak tests are done appropriately; consider regular (weekly) leak tests

Appropriate Sensors and Alarm Reaction!

Lessons learnt with KIT HRS

Malfunction of Flame Detector (3.2.2012)

- UV flame detector gave several false alarms because of interference with low winter sun

→

Detector was taken out of service corrupting the safety strategies

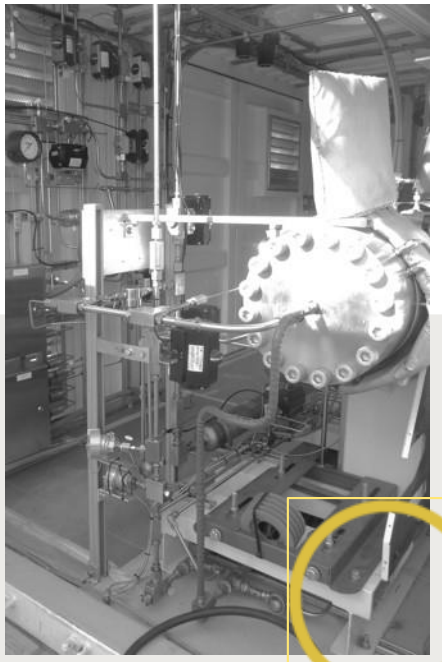
Action: Replacement of flame detector

Make sure your safety sensors comply with the specific operational conditions and appropriate reactions are initiated (Alarm Plan)

Revise your Safety Plan after any change

Control Compressor Vibrations!

Lessons learnt with KIT HRS



Anchor bolts of Compressor Skid Broken after 1 year operation (10.7.2014)

Incorrect foundation of the compressor led to strong vibrations
→
Several anchor bolts of the compressor skid found broken

Actions:

- Foundation was changed (high costs) to reduce vibrations
- Regular control of vibrations and anchors was included in daily checks

Insist on well engineered foundation, check and control continuously vibrations and fixing of compressor skid (and other rotating machinery)

Summary of Lessons Learnt with additions from major accidents and KIT HRS operations

Data collection and interpretations beyond HIAD

Robust Design

Use and enforce barriers. Check the safety principles and try to avoid escalation by right choice of mitigation techniques (preferentially passive) and introducing appropriate separation distances.
Combine sensors with appropriate reaction in your alarm plans (avoid also over-conservatism)

Material / Fatigue / HE

Sealings / Weldings

Human Error / User Interface

Quality Assurance

Make sure your installation is set-up with properly documented quality assurance with experienced and qualified staff. If possible chose components certified for hydrogen under the same regulatory sphere.
Be aware HRS are not yet standard and require additional efforts also for daily operations.

Outlook for the 2020 activities of the EHSP TF3

European Hydrogen Safety Panel (EHSP)

- HIAD 2.0 has been substantially enlarged through the efforts of the EHSP.
  It is anticipated to contain 600 events by mid-2020
  (including a **larger number of cases related to HRS**)

- EHSP will analyse the new events which have been added to HIAD 2.0.

- On the basis of the analysis and of further information published or exchanged on international level, EHSP will **summarise lessons learnt and formulate recommendations**
  (also addressing HRSs).

- EHSP will also develop an approach to generate statistics from the enlarged and continuously updated HIAD 2.0.

EUROPEAN HYDROGEN SAFETY PANEL (EHSP)

Acknowledgements

Thank you
for your attention…

… and many thanks to the
FCH 2 JU PO for the support!