FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

# Statistics, lessons learnt and recommendations from the analysis of HIAD database


**Jennifer WEN**
European Hydrogen Safety Panel EHSP


**FABIG Webinar 21 April 2021**

# Outline

European Hydrogen Safety Panel (EHSP)

**Part I Introduction about the European Hydrogen Safety Panel (EHSP)**

**Part II Statistics, lessons learnt and recommendations from the analysis of HIAD database**

- Introduction
- Enlargement and enhancement of HIAD
- Overview of the analysis approach
  - Statistics
  - Lessons learnt
  - Recommendations

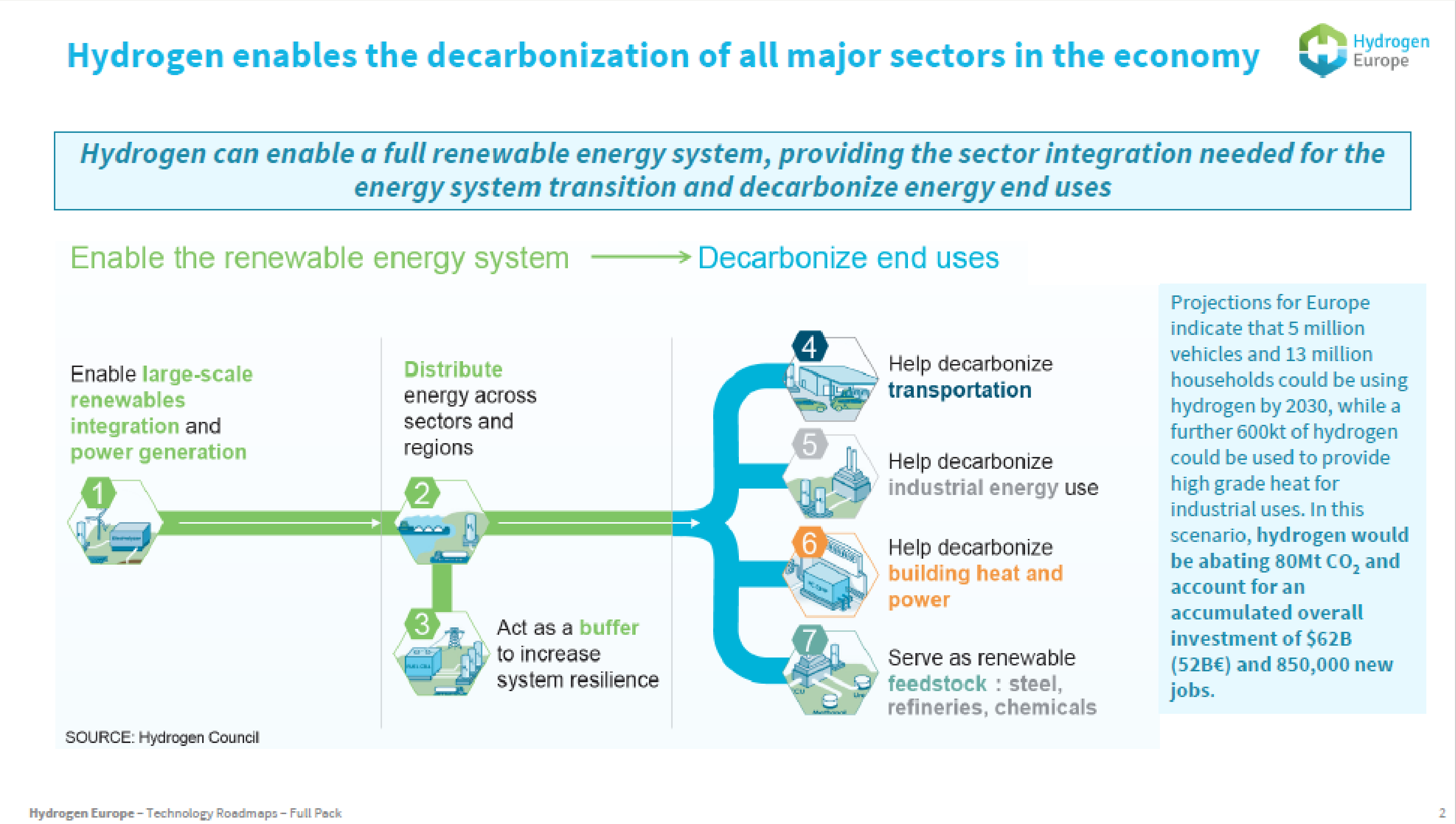
# European Hydrogen Safety Panel (EHSP)

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

## Reflecting the FCH 2 JU vision

- Hydrogen plays a key role in the energy system constituting a safe and sustainable energy carrier.

- Hydrogen is an enabler of the energy transition towards a decarbonised global energy mix.



# EHSP - from vision to the strategic role

European Hydrogen Safety Panel (EHSP)

<u>**Safety is of paramount importance to the development of fuel cell and hydrogen technology:**</u>

- **Quantitative growth** across "established" applications in mature markets increases the demand for hydrogen, and hence increases the number and size of hydrogen supply units and hydrogen fuelling stations.

- **Qualitative change**, new applications building on the success of established applications. (50-100 kg H2 for trucks, 200-500 kg for rail, and potentially many tons of hydrogen for maritime)

<u>EHSP ROLE</u>: to provide independent safety expertise, objective information, education and training in different forms for various groups of stakeholders and support the anticipated upscaling of hydrogen energy application

# Current EHSP Members

European Hydrogen Safety Panel (EHSP) https://www.fch.europa.eu/page/european-hydrogen-safety-panel


Inaki Azkarate


Stuart Hawksworth


Thomas Jordan


Georg Wilfried Mair


Marta Maroño


Vladimir Molkov


Ernst-Arndt Reinecke


Pratap Sathiah


Ulrich Schmidtchen


Etienne Studer


Trygve Skjold


Tom Van Esbroeck


Elena Vyazmina


Jennifer Wen

# Scope of activities

European Hydrogen Safety Panel (EHSP)

TF1 Support at Project level
*(Led by Thomas Jordan)*

Safety Planning

TF2 Support at Programme level
*(Led by Stuart Hawksworth)*

Emergency/crisis management

TF3 Data collection and assessment
*(Led by Jennifer Wen)*

Statistics, lessons learnt, recommendations

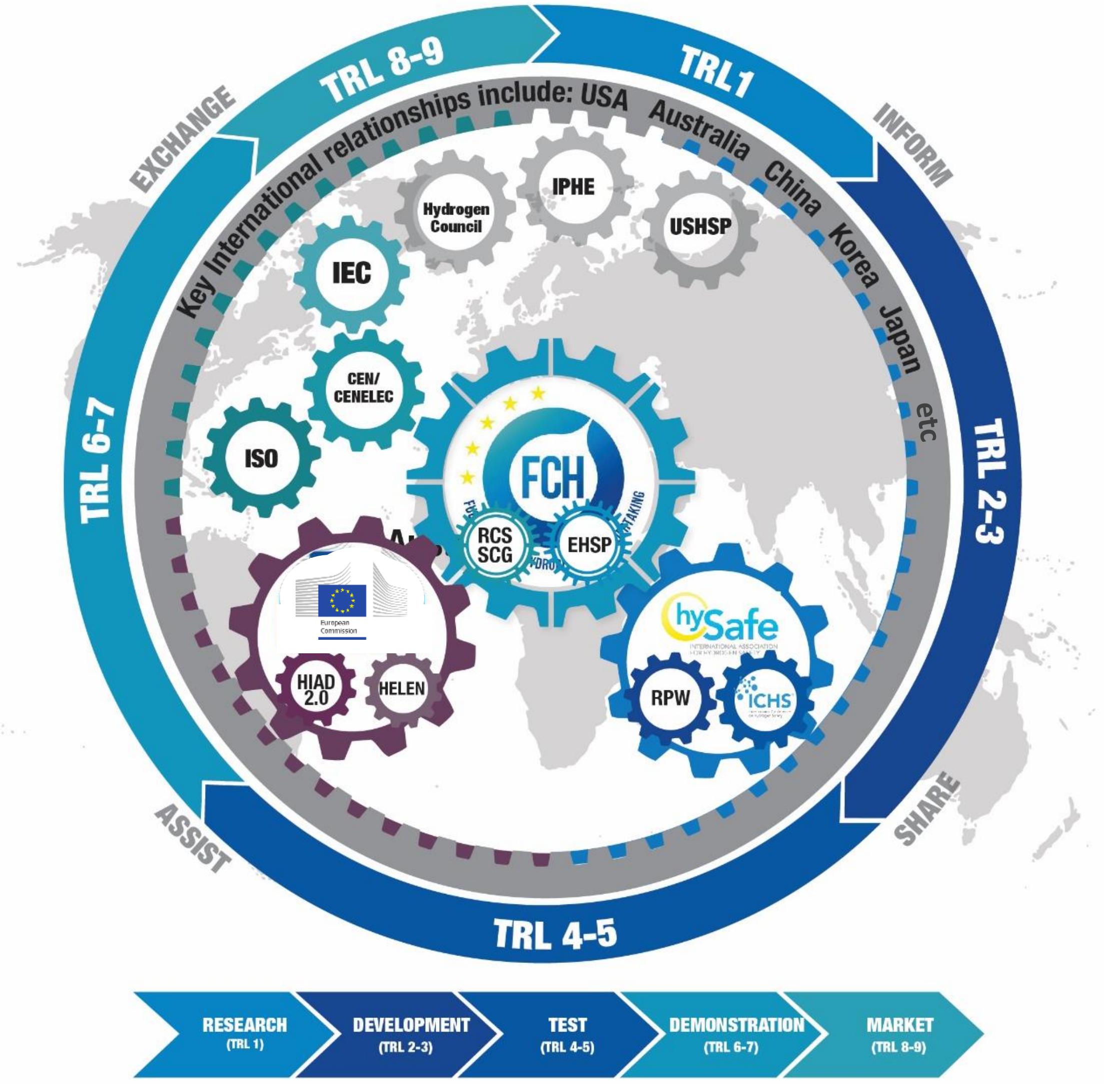
TF4 Public outreach
*(Led by Trygve Skjold)*

Communication, web page, FAQs

# EHSP in the “Big Picture“

International relations for strategic orientation

- Ensure appropriate engagement for hydrogen safety at program level.
- Identify and prioritise gaps with respect to hydrogen safety in close cooperation with RCS SCG, JRC and IA-HySafe.
- Share information and cross fertilisation with similar international activities.
- Support demonstrations of safety.
- Ensure safe implementation and operations for a broader roll-out.



# Highlights (1) - Safety Planning for Hydrogen and Fuel Cell Projects (TF1)

European Hydrogen Safety Panel (EHSP)

- Published on FCH 2 JU website in 2019 and highlighted in CALL in 2020.
- Positive response and feedback from interactions with project and wider stakeholders.
- Lead interactions with current and potential projects.

FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING
(FCH 2 JU)

SAFETY PLANNING FOR HYDROGEN AND FUEL CELL PROJECTS

05 July 2019

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# Highlights (2) - Workshop on Safety of Electrolysis (TF1)

European Hydrogen Safety Panel (EHSP)

- Organised by EHSP Task Force 1 (TF1) with three main objectives:

  - Summarise the state-of-the-art and standardisation with regards to electrolyser safety
  - Review the available experience with regard to safe design and operations, and lessons learned from past accidents
  - Exchange experiences and best practices related to hydrogen safety beyond project boundaries.

- 85 participants and 9 projects presented their experience with regard to safety planning.

- **First in a series of workshops on different safety topics, more to be organised in 2021.**

# Highlights (3) - Crisis\ Emergency Management Work Flow (TF2)

European Hydrogen Safety Panel (EHSP)

- Developing a formalised approach to dealing with safety related incidents, crisis, emergencies etc.
- Aim to provide support to stakeholders i.e. project partners, FCH JU etc.
- Stages:

  Reporting & Initial Response,

  Information gathering,

  Advise & possible site visits
- Challenges of operating in multiple jurisdictions, etc.
- Important part in sharing lessons learnt.

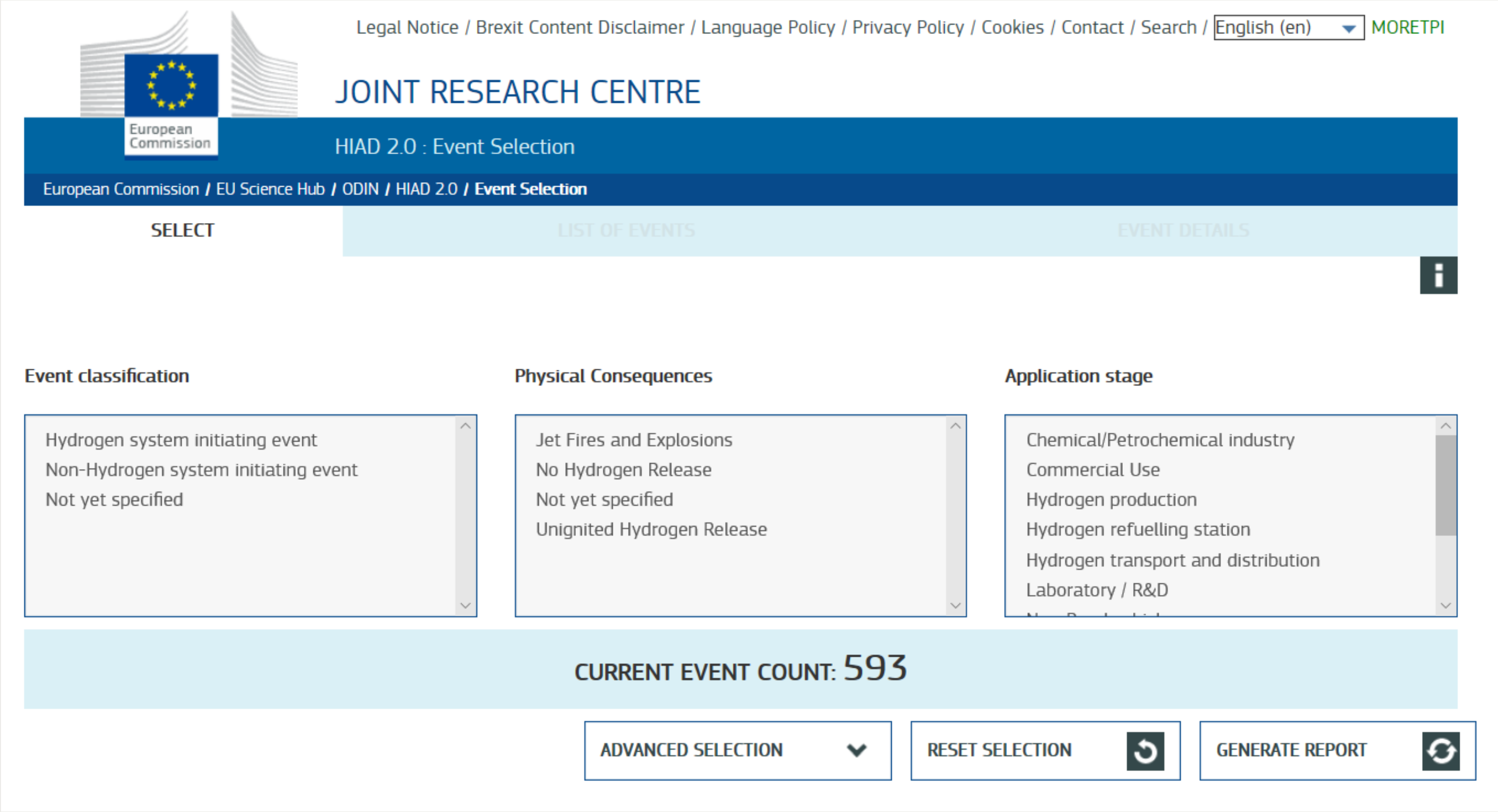
# Highlights (4) Statistics Lessons Learnt from Incidents and Accidents. Enlargement and enhancement of HIAD (TF3)

European Hydrogen Safety Panel (EHSP)

**HIAD front page**

https://odin.jrc.ec.europa.eu/giada/

The number of validated incidents in HIAD increased from 272 in 2018 to **593** in 2021




*Sources of incidents in HIAD:*

*- Scientific literature and news items.*

*- Other public not hydrogen-specific databases, such as the French ARIA, the European (SEVESO), eMARS, US CSB, NTSB ,OHSA national nuclear authorities, etc.*

# Highlights (5) - Public outreach (TF4)

European Hydrogen Safety Panel (EHSP)

## Prioritised areas and activities

- Establish a solid foundation for the public outreach activities, including a communication strategy.
- Develop generic presentations and a dedicated web page.
- Organise workshops with selected target audiences
- Present at selected conferences, seminars and meetings

**EHSP & FCH 2 JU CONFIDENTIAL**

FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING (FCH 2 JU)

European Hydrogen Safety Panel (EHSP)

Communication strategy 2021–2024 (Final draft)

10 December 2020

# Statistics, lessons learnt and recommendations from the analysis of HIAD database

**Jennifer WEN**
European Hydrogen Safety Panel EHSP

FABIG Webinar 21 April 2021

# Part II: Statistics, lessons learnt and recommendations from the analysis of HIAD database

European Hydrogen Safety Panel (EHSP)

- Introduction
- Enlargement and enhancement of HIAD
- Overview of the analysis approach
- Statistics
- Lessons learnt
- Recommendations

# Introduction

European Hydrogen Safety Panel (EHSP)

## Background

- The Hydrogen Incidents and Accidents Database (HIAD) is an international open communication platform collecting systematic data on hydrogen-related undesired incidents. It was firstly developed by JRC within the HySAFE Network of Excellence, funded by the 6th Framework Programme of the European Commission.

- Updated by JRC as HIAD 2.0 (now simply referred to as HIAD) in 2016 with the support of Fuel Cell and Hydrogen Joint Undertaking (FCH 2 JU).

- Since its launch in 2017, the EHSP has worked closely with JRC to upload additional and new events to HIAD; and to improve the overall quality of the published events whenever possible.

# Introduction

## European Hydrogen Safety Panel (EHSP)

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European Commission

JOINT RESEARCH CENTRE

HIAD 2.0 : Hydrogen Incidents and Accidents Database

European Commission / EU Science Hub / ODIN / HIAD 2.0

### HIAD History

HIAD was developed within the EC-funded Network of Excellence HySAFE (FP6) under the coordination of Det Norske Veritas and the European Commission Joint Research Centre (JRC) EU Science Hub.

| | |
|---|---|
| DATA RETRIEVAL | The data retrieval module allows you to select and view HIAD events. |
| REPORT AN EVENT | If you are interested in submitting HIAD events, please provide details of the event via this link. |
| DATA ENTRY | The data retrieval module allows you to enter and manage your events in HIAD. This option is only available to admin users. |

**Disclaimer**

JRC Petten and the ODIN site administrator cannot be held responsible for the validity or integrity of the data that you will view on this site, regardless of the original source of this data. However, only acknowledged experts are allowed to enter data. They are held responsible for the data quality and have to validate the data before final release. An additional check is performed by JRC Petten experts.

# Introduction

European Hydrogen Safety Panel (EHSP)

### Assessment and lessons learnt from HIAD

- The EHSP under Task Force TF3 started analysing the incidents in HIAD since 2018.
- About 250 events were analysed in 2018 with the first report published in September 2019.

FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING
(FCH 2 JU)

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

20 September 2019

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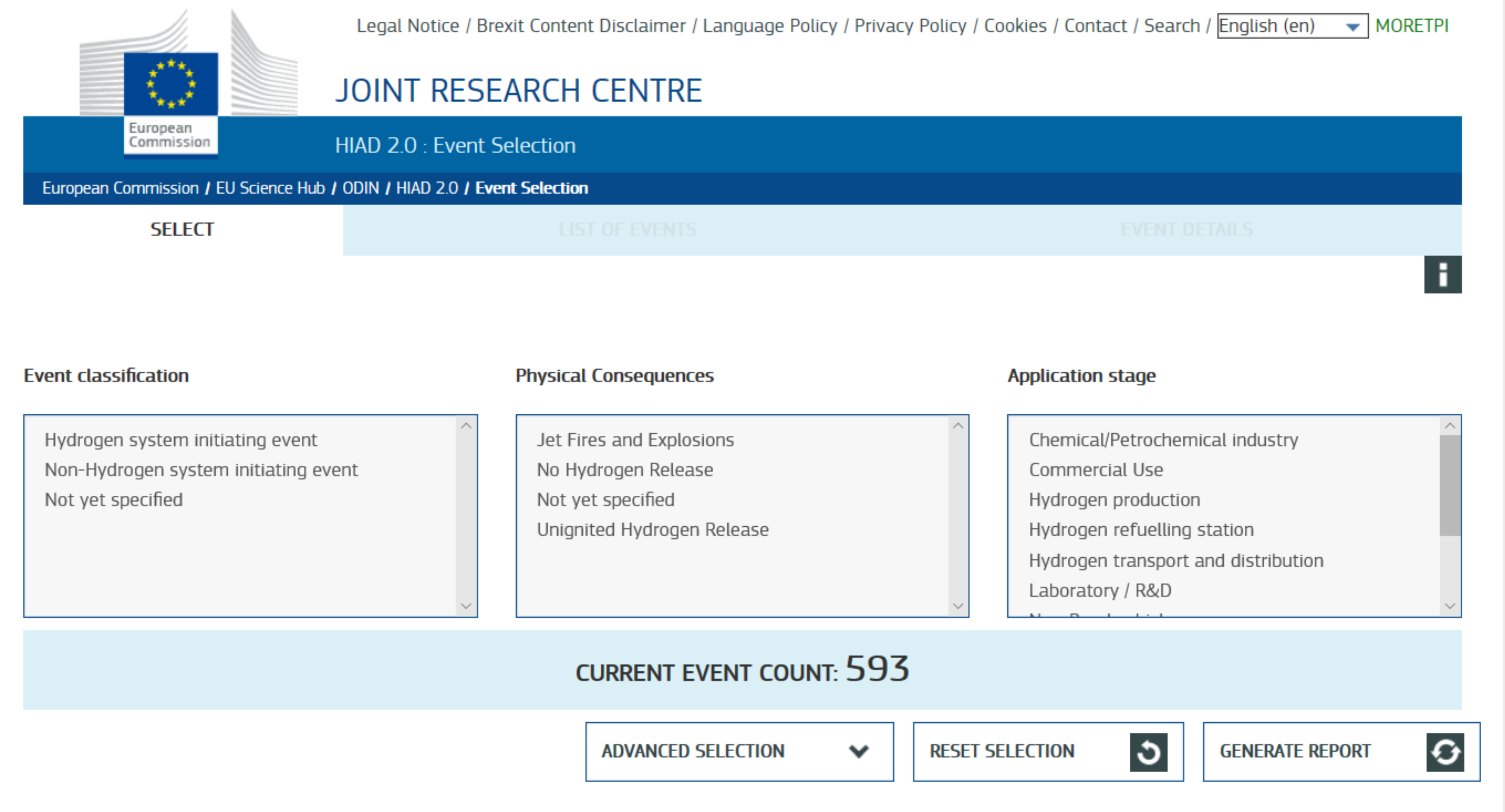
*https://www.fch.europa.eu/sites/default/files/Assessment%20and%20lessons%20learnt%20from%20HIAD%202.0%20-%20Final%20publishable%20version%20%28version%201.3%29.pdf*

# Enlargement and enhancement of HAID

European Hydrogen Safety

## HIAD front page




Sources of HIAD:

- Scientific literatures and news items.
- Other public not hydrogen-specific databases such as French ARIA, European (SEVESO) eMARS, US CSB, NTSB ,OHSA national nuclear authorities, etc.

# Enlargement and enhancement of HAID 2.0

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European Commission

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HIAD 2.0 : Event Details

European Commission / EU Science Hub / ODIN / HIAD 2.0 / Selection / List of Events / **Event Details**

SELECT | LIST OF EVENTS | EVENT DETAILS | EXPORT

Event | Description of the Facility | Consequences | Lessons learnt | Event Nature | References | Provider

Event details

| | |
|---|---|
| **ID** | 884 |
| **Provider** | Pietro Moretto |
| **Event** | Fire - hydrogen |
| **Event classification** | Hydrogen system initiating event |
| **Physical consequences** | Jet Fires and Explosions |
| **Application stage** | Hydrogen refuelling station |

# Enlargement and enhancement of HAID 2.0

Event | Description of the Facility | Consequences | Lessons learnt | Event Nature | References | Provider

### Technical details of the Event

| | |
|---|---|
| **Emergency action** | 17:30 Hydrogen leaked from tank and ignited 17:37 First emergency responders on the scene 17:40 Nel receives first report of the incident 17:41 E18 and E16 closed 17:47 Security zone of 500 meters established 19:28 Robot used to cool down site 20:14 E18 in Sandvika is open for traffic 20:14 Fire department confirms fire under control |
| **Emergency evaluation** | Estimation is up to 3 kg of hydrogen leaked over few seconds. Fire continued on station equipment. |
| **Release type** | Gas |
| **Release substance** | hydrogen |
| **Release concentration** | 100 |
| **Release amount** | 3 |
| **Release pressure** | 900 |
| **Ignition source** | Unknown source |
| **Detonation (Y/N)** | Y |
| **Flame type** | Jet flame |

## Lessons learnt

| | |
|---|---|
| **Lessons Learnt** | The system passed inspection, but was not safe. The gasket was far more resilient than assumed, and hid a faulty assembly for over 2 years. High-pressure components need to follow precise procedures for assembly, with double witnesses. Manufacturer of the storage system enacted strict protocols for assembly with double-witness (as in aviation industry). A more robust design of the outer perimeter of the refuelling station would shield members of the public from projectiles would presumably be a good start. |

Event | Description of the Facility | Consequences | Lessons learnt | Event Nature | References | Provider

## Sources , Link and Documents

| ID | Type | Name | Comments |
|---|---|---|---|
| 450 | Document | HIAD_882 FCBulletin.pdf | FC Bulletin, July 2019 |
| 451 | Document | HIAD_882 NEL Q&A.pdf | Manufacturer report statement (Published: 27 June, 2019; Updated: 29 June, 2019) https://nelhydrogen.com/status-and-qa-regarding-the-kjorbo-incident/ (accessed June 2020) |
| 452 | Document | HIAD_882 GEXCON 2019_06_28.pdf | GEXCON Report shown at the NEL press conference of 28 June 2019 (permission to publish obtained from author) |

# HIAD 2.0 – examples of recent incidents

European Hydrogen Safety Panel (EHSP)

| Date | Location | Brief description | Fatality | Injury |
|---|---|---|---|---|
| Jan 2007 | Muskingum, USA | An explosion of compressed hydrogen during delivery at the Muskingum River Coal Plant (owned and operated by AEP) caused significant damage | 1 | |
| March 2011 | Fukushima, Japan | During Fukushima nuclear accident, hydrogen explosions damaged three reactor buildings | | |
| 2015 | Taiwan | Explosion at the Formosa Plastics Group refinery due to hydrogen leaking from a pipe. | | |
| 7 Apr 2019 | Yunlin county, Taiwan | An explosion at a chemical plant in an industrial zone shattered glass in buildings up to 2 km away, shook houses 5 km away. | | |
| Feb. 2018 | Diamond Bar, Angeles, CA, USA | On the way to an FCV hydrogen station, a truck carrying about 24 compressed hydrogen tanks caught fire. This caused the evacuation initially of a one-mile radius area of | | |
| Aug. 2018 | El Cajon CA, USA | A delivery truck carrying liquid hydrogen caught fire | | |
| 3 May 2019 | Waukegan, IL, USA | Explosion and Fire at AB Specialty Silicones Facility | - | 5 |
| 24 May 2019 | Gangneun, South Korean | Explosion at hydrogen fuel-cell power system | 2 | 6 |
| June 2019 | Bærum, Norway | Uno-X fueling station in Norway experienced an explosion | | 2 |
| Dec. 2019 | Waukesha, Wisconsin, USA | Explosion at an Airgas facility injured one worker and caused 2 hydrogen storage tanks to leak | | 1 |
| 07 Apr 2020 | North Carolina, USA | Explosion at the OneH2 plant, damaging 60 buildings | - | - |
| 11 June 2020 | Texas, USA | An explosion occurred at the Praxair Inc., a hydrogen production plant. | | |
| 30 Sep. 2020 | Taiwan | A hydrogen tanker crashed and exploded in Changhua City, Taiwan | 1 | - |

# HIAD 2.0 – reporting new events to HIAD



All the potential event providers not belonging to the EHSP can report to HIAD through an ad-hoc EUSurvey:

https://ec.europa.eu/eusurvey/runner/HIAD_v2_event_report

JRC will translate this entry into an HIAD entry.

The event providers using EUSurvey should email pietro.moretto@ec.europa.eu to notify him as the system does not send him automatic notification of a new entry in EUSurvey.

# Overview of the analysis approach

European Hydrogen Safety Panel (EHSP)

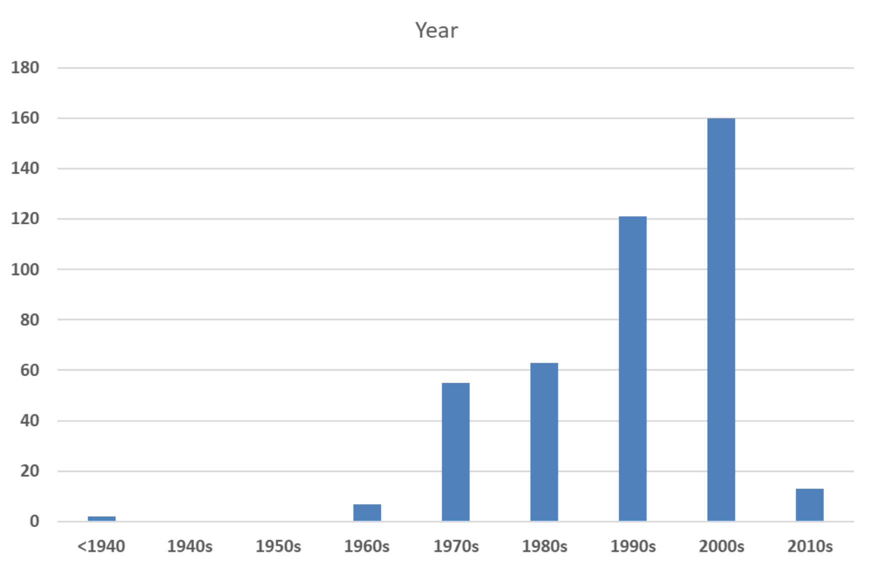
## Categories

- **Severity** (based on European scale of industrial accidents *https://www.aria.developpement-durable.gouv.fr/wp-content/uploads/2014/08/European-scale-of-incidents.pdf*)
  - Quantities of hydrogen involved (releases accident to Seveso threshold or the amount of hydrogen involved, explosions accident to TNT equivalent)
  - Human consequences (fatalities, injured with hospitalisation, slightly injured)
  - Economic consequences (property damage or economic cost)
- **Nature** of event (explosion, fire, unignited release, near miss)
- **Cause** (system design error, material/manufacturing error, installation error, job factors, Individual/human factors, organization and management factors
- **Recommendations** (based on EHSP safety principles)

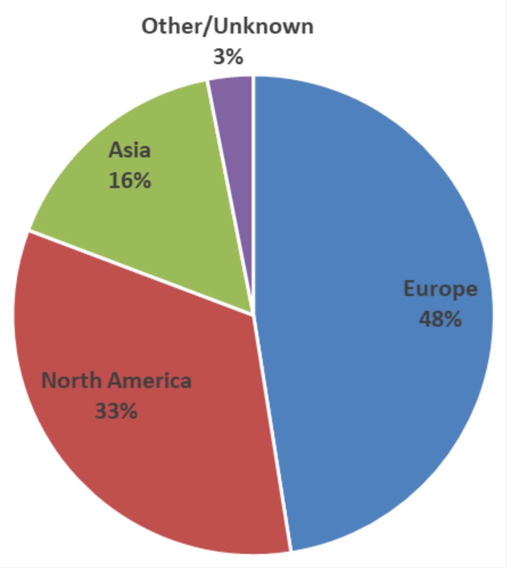
# Statistics analysis of the enlarged HIAD 2.0

European Hydrogen Safety Panel (EHSP)

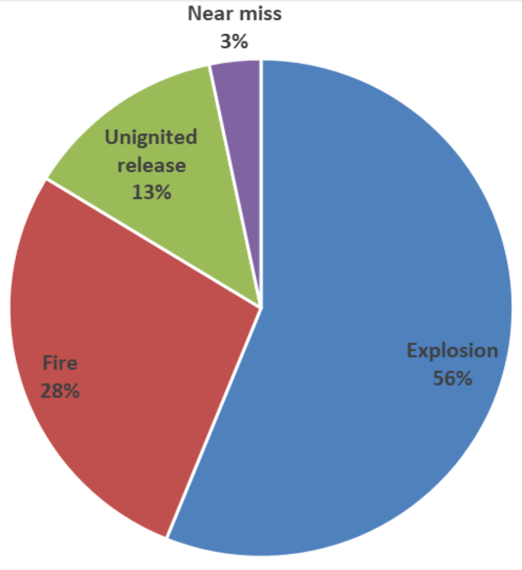
## Years




## Location




## Nature of the events

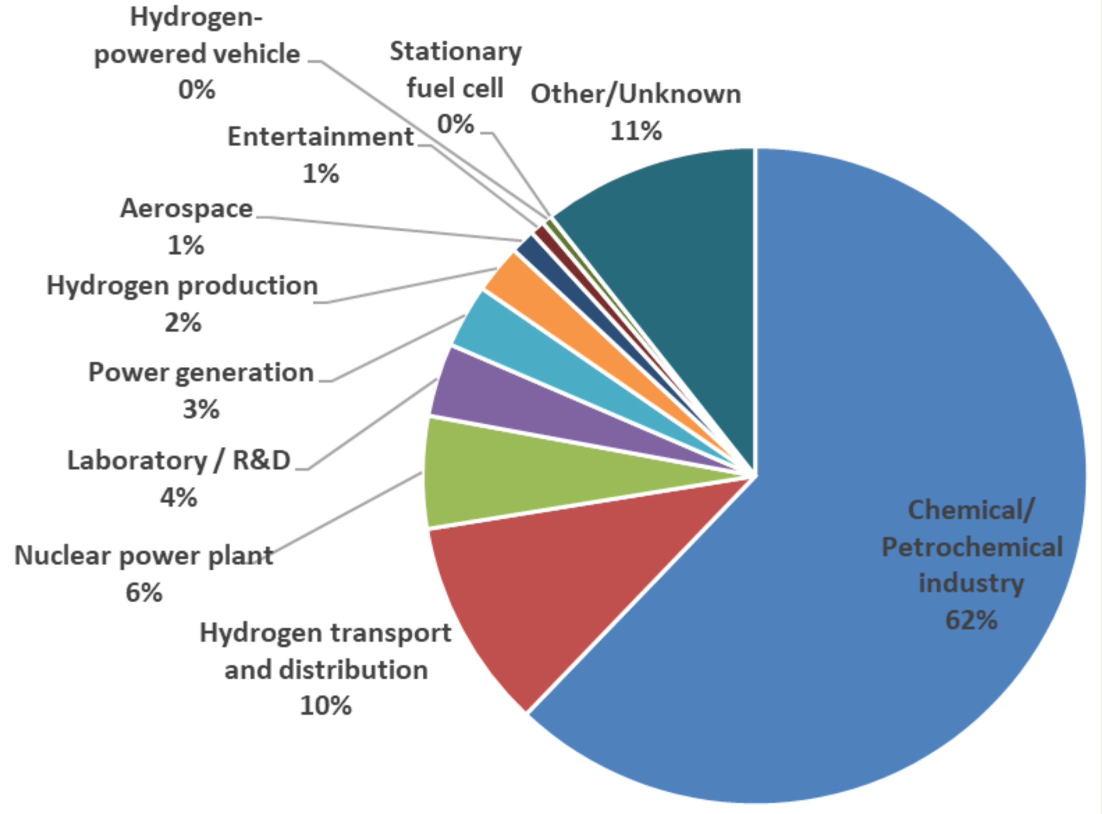



The analysis reported in this presentation is based on the 485 incidents which were in the database in July 2020. Out of these, the experts identified 426 events which were statistically relevant with meaningful information.

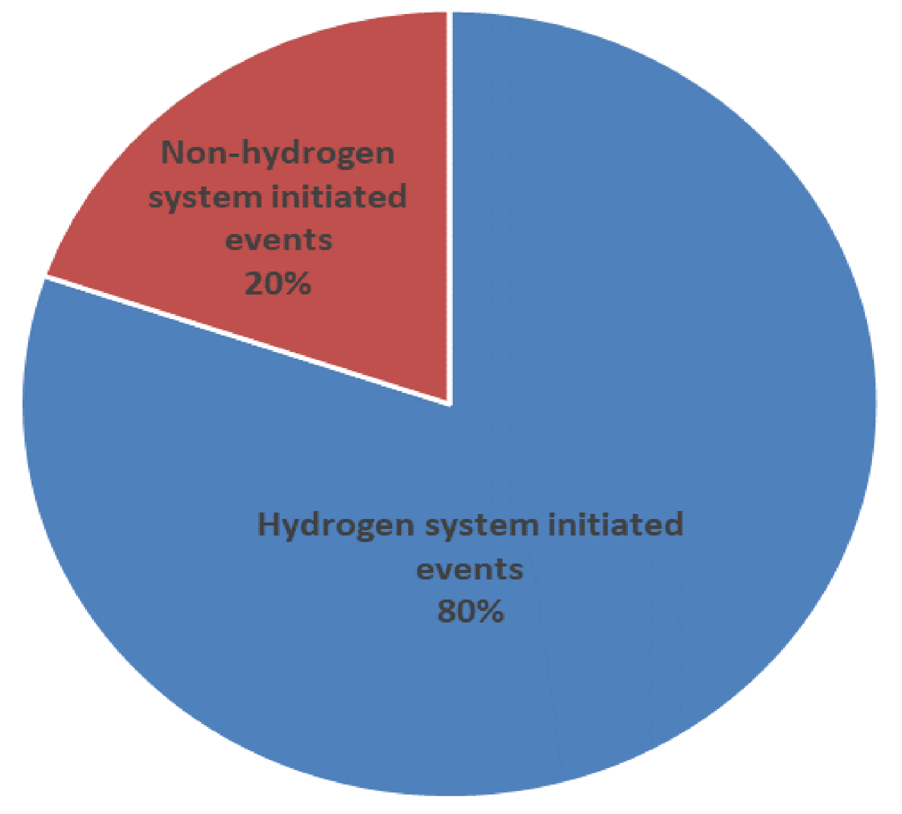
# Statistics analysis of the enlarged HIAD 2.0

European Hydrogen Safety Panel (EHSP)

### Industrial sectors




### Hydrogen systems/Non-hydrogen systems

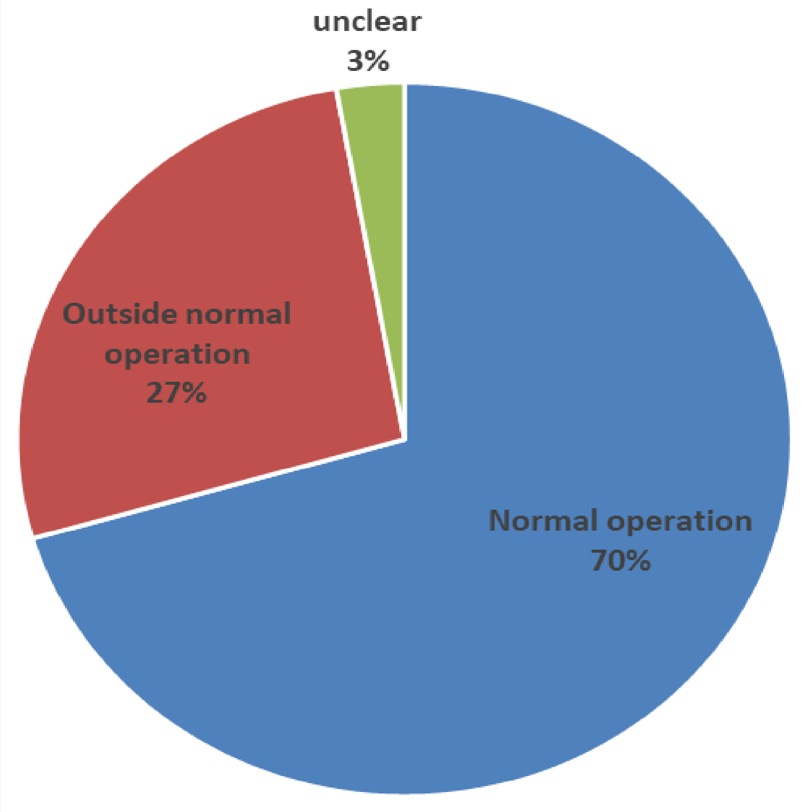


# Statistics analysis of the enlarged HIAD 2.0

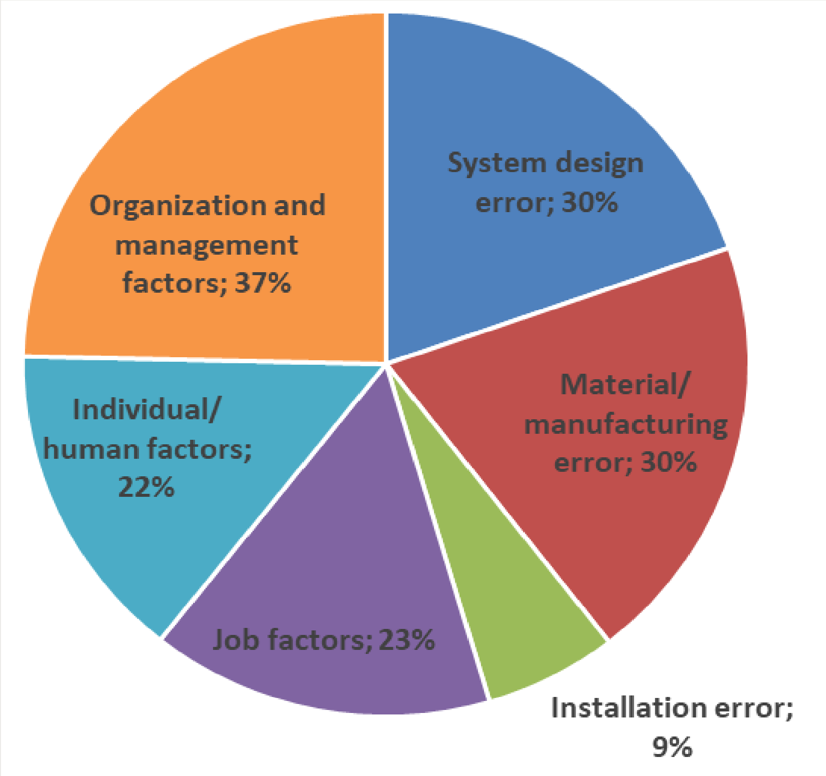
European Hydrogen Safety Panel (EHSP)

**Normal operation**

**Outside normal operation:** during maintenance or special services or immediately after returning to routine operation



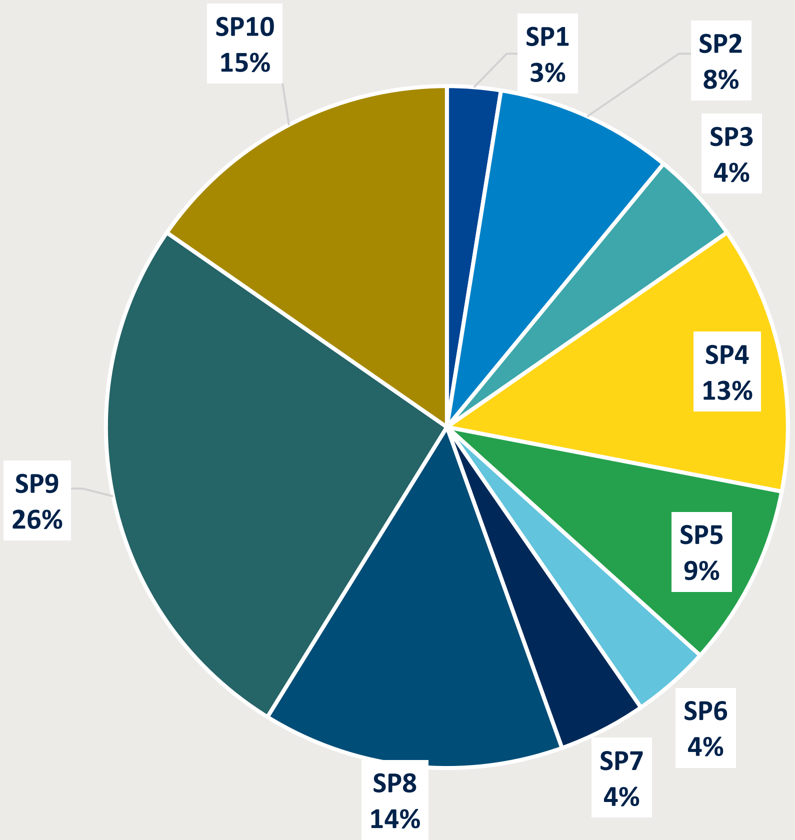

**Causes** (multiple entries per incident possible)



# Statistics analysis of the enlarged HIAD 2.0

European Hydrogen Safety Panel (EHSP)

## Statistics showing the number of cases reported with different safety principles (SP#)




| Number | Safety Principle *https://www.fch.europa.eu/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects_Release1p31_20190705.pdf* |
|---|---|
| SP1 | Limit hydrogen inventories, especially indoors, to what is strictly necessary. |
| SP2 | Avoid or limit formation of flammable mixture, by applying appropriate ventilation systems, for instance. |
| SP3 | Carry out ATEX zoning analysis. |
| SP4 | Combine hydrogen leak or fire detection and countermeasures. |
| SP5 | Avoid ignition sources using proper materials or installations in the different ATEX zones, remove electrical systems or provide electrical grounding, etc. |
| SP6 | Avoid congestion, reduce turbulence promoting flow obstacles (volumetric blockage ratio) in respective ATEX zones. |
| SP7 | Avoid confinement. Place storage in the free, or use large openings which are also supporting natural ventilation. |
| SP8 | Provide efficient passive barriers in case of active barriers deactivation by whatever reason. |
| SP9 | Train and educate staff in hydrogen safety. |
| SP10 | Report near misses, incidents and accidents to suitable databases and include lessons learned in your safety plan. |

Proposing to add SP11 “ensure that the design of hydrogen system and material selection are compatible with hydrogen services”

# Statistics analysis of the enlarged HIAD 2.0

European Hydrogen Safety Panel (EHSP)

## Statistics on severity (1)

The severity of the incidents has been assessed according to the European scale of industrial accidents which is based on the Seveso directive: https://www.aria.developpement-durable.gouv.fr/wp-content/uploads/2014/08/European-scale-of-accidents.pdf

**European severity scale parameters**

| Quantities of dangerous substances | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Q1 | Quantity Q of substance actually lost or released in relation to the "Seveso" threshold * | Q < 0.1% | 0.1% ≤ Q < 1% | 1% ≤ Q < 10% | 10% ≤ Q < 100% | 1 to 10 times the threshold | ≥ 10 times the threshold |
| Q2 | Quantity Q of explosive substances having actually participated in the explosion (equivalent in TNT) | Q < 0.1 t | 0.1 t ≤ Q < 1 t | 1 t ≤ Q < 5 t | 5 t ≤ Q < 50 t | 50 t ≤ Q < 500 t | Q ≥ 500 t |

* Use the upper thresholds of the current Seveso directive. In the event of an accident involving several specified substances, the highest level reached shall be retained.

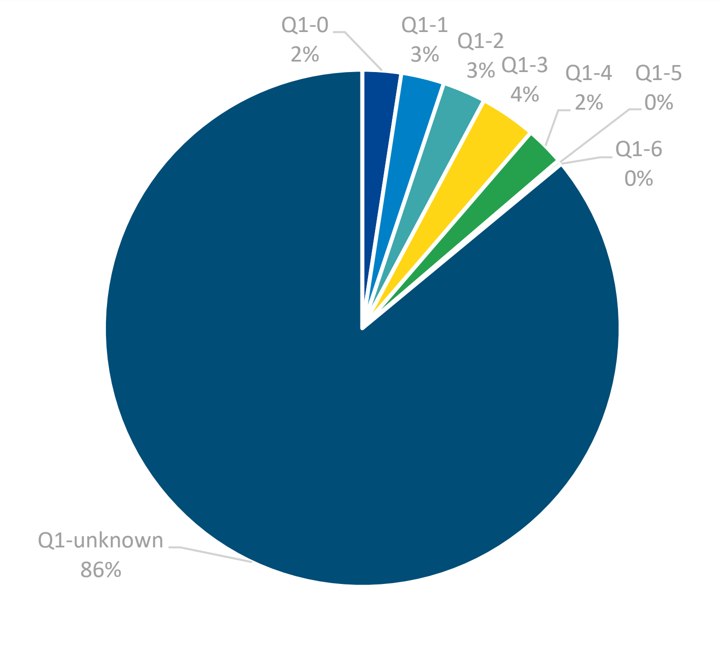
| Human and social consequences | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| H3 | Total number of deaths:<br>including - employees<br>- external rescue personnel<br>- persons of the public | -<br>-<br>-<br>- | 1<br>1<br>-<br>- | 2 – 5<br>2 – 5<br>1<br>- | 6 – 19<br>6 – 19<br>2 – 5<br>1 | 20 – 49<br>20 – 49<br>6 – 19<br>2 – 5 | ≥ 50<br>≥ 50<br>≥ 20<br>≥ 6 |
| H4 | Total number of injured with hospitalisation ≥ 24 hours:<br>including - employees<br>- external rescue personnel<br>- persons of the public | 1<br>1<br>1<br>- | 2 – 5<br>2 – 5<br>2 – 5<br>- | 6 – 19<br>6 – 19<br>6 – 19<br>1 – 5 | 20 – 49<br>20 – 49<br>20 – 49<br>6 – 19 | 50 – 199<br>50 – 199<br>50 – 199<br>20 – 49 | ≥ 200<br>≥ 200<br>≥ 200<br>≥ 50 |
| H5 | Total number of slightly injured cared for on site or with hospitalisation < 24 hours:<br>including - employees<br>- external rescue personnel<br>- persons of the public | 1 – 5<br>1 – 5<br>1 – 5<br>- | 6 – 19<br>6 – 19<br>6 – 19<br>1 – 5 | 20 – 49<br>20 – 49<br>20 – 49<br>6 – 19 | 50 – 199<br>50 – 199<br>50 – 199<br>20 – 49 | 200 – 999<br>200 – 999<br>200 – 999<br>50 – 199 | ≥ 1,000<br>≥ 1,000<br>≥ 1,000<br>≥ 200 |

For explosion, the quantity of hydrogen having actually participated in the explosion (Q2) is based on the equivalent in TNT. Considering that 1 t TNT corresponds to a released energy of 4,184 GJ, we obtain a theoretical value of 1 t of hydrogen representing 28.7 t TNT .

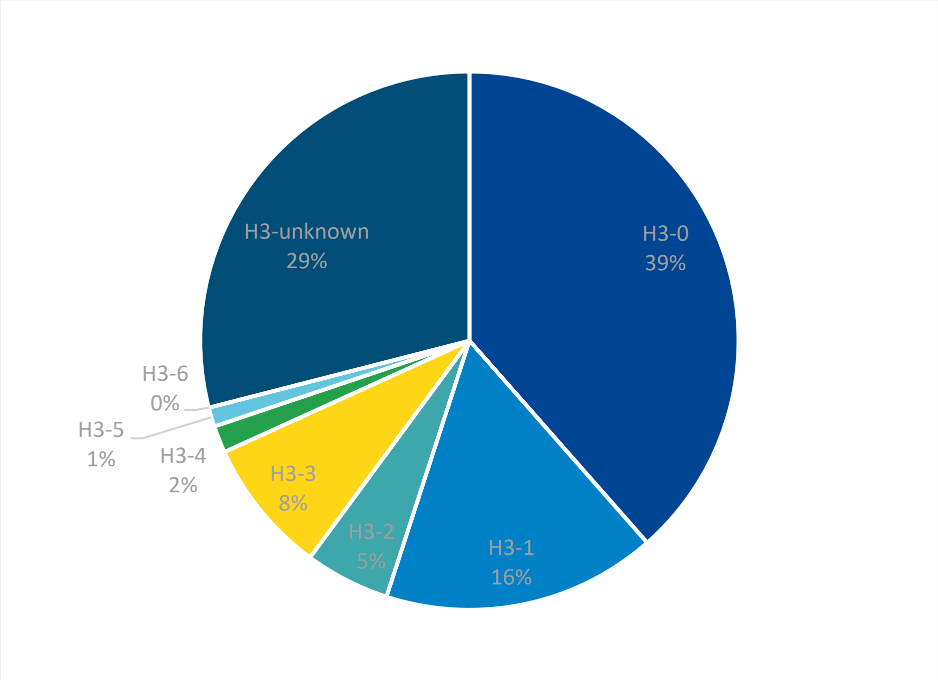
# Statistics analysis of the enlarged HIAD 2.0

European Hydrogen Safety Panel (EHSP)

## Statistics on severity (2)




*Statistics showing the number of incidents reported with quantity of hydrogen substance definition, Q1.*

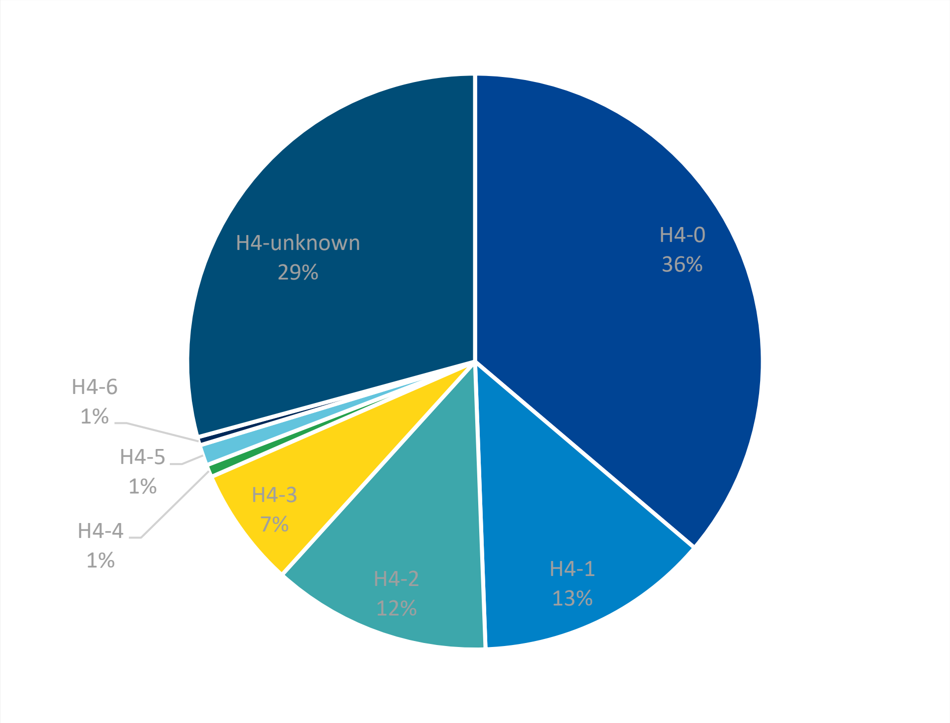



*Statistics showing the number of incidents reported with fatality.*

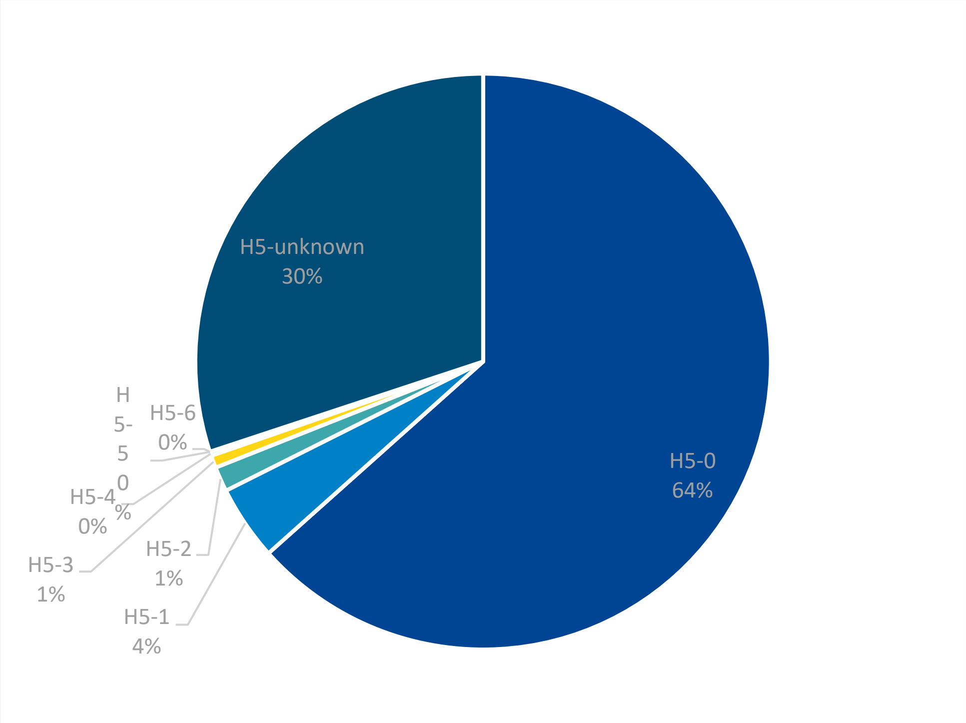
# Statistics analysis of the enlarged HIAD 2.0

European Hydrogen Safety Panel (EHSP)

## Statistics on severity (3)




*Statistics showing the number of incidents reported with significant injury.*




*Statics showing the number of incidents reported with minor injury.*

# Lessons learnt

European Hydrogen Safety Panel (EHSP)

## Examples for lessons learnt (1/3)

- **Cascading effects of minor events could result in extremely serious consequences.**
- **Many incidents were caused by multiple factors.**
- **Typical examples of design related lessons learnt**
  - Lack of precaution during the design stage to limit hydrogen inventory
  - Lack of protection of vessels against thermal attacks
- **Typical weak points**
  - Gauge glass for liquid tank level monitoring
  - Flange connections
  - Welding joints

# Example of a historic incident

European Hydrogen Safety Panel (EHSP)

**<u>ID526, 1992 USA:</u> A serious chemical accident in a petrochemical company, which resulted in injuries to several workers and extensive damage to the plant, as well as minor damage to nearby residential property. Damage to the facility was estimated at $101 million and major transportation routes were closed for several hours.**

- The incident was traced  back to internal structural failure and drive shaft blow-out of a 36-inch diameter check valve.
- The check valve's failure resulted in a large flammable gas leak, forming a vapor cloud that ignited.
- Fractography revealed typical hydrogen embrittlement damage.
- Explosion energy calculation assessed the hydrogen content in the vapour cloud to be around 20%.
- The EPA/OHSA Shell report of 1998 identified these several design issues:
    1) inadequate valve design
    2) failure to learn from prior incidents
    3) inadequate process hazards analysis
    4) inadequate mechanical integrity measures
    5) inadequate operating procedures plus the following contributing factors: no indication of hydrocarbon leak, delayed operator response to leak and inadequate communications practices.

# Example of a recent incident: explosion of hydrogen storage tanks of a small fuel-cell power system in Gangneung (South Korea) in 2019

European Hydrogen Safety Panel (EHSP)

- The incident occurred during a test operation at a venture complex.
- Three tanks of 40 $m^3$ capacity were all destroyed in the explosion which sent debris scattered in an area well over 3,000 square meters.

https://www.google.co.uk/url?sa=i&url=https%3A%2F%2Fm.ajudaily.com%2Fview%2F20190524113435564&psig=AOvVaw3DNSw8auj82KAzQcNeS3Pv&ust=1618137823890000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCND94K2_8-8CFQAAAAAdAAAAABAP

https://pulsenews.co.kr/view.php?year=2019&no=346776

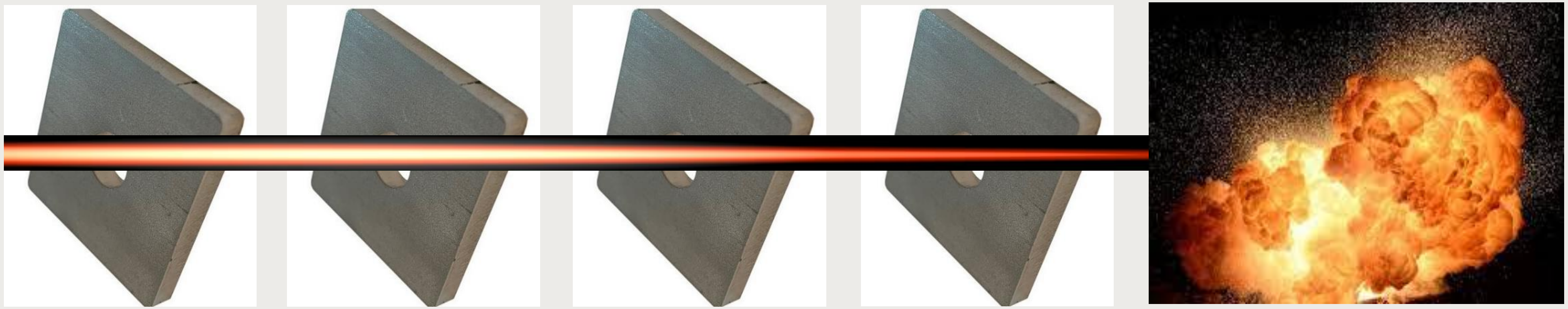
https://www.tellerreport.com/tech/2019-05-23----hydrogen-tank-explosion--explosion-from-8km-outside------visiting-deviations-.ryWeyoEaV.html

# Example of recent incident ID477: An explosion of hydrogen storage tanks of a small fuel-cell power system in Gangneung (South Korea) in 2019

European Hydrogen Safety Panel (EHSP)

## Prosecutor's report on Gangeung Hydrogen Tank Explosion Accident (adapted from the English translation by INERIS)

**Summary:** The hydrogen and buffer tanks exploded due to static spark in buffer tank while oxygen ($O_2$) concentration exceeded 6%, which is within the explosion threshold.



# Example of recent incident ID477: An explosion of hydrogen storage tanks of a small fuel-cell power system in Gangneung (South Korea) in 2019

European Hydrogen Safety Panel (EHSP)

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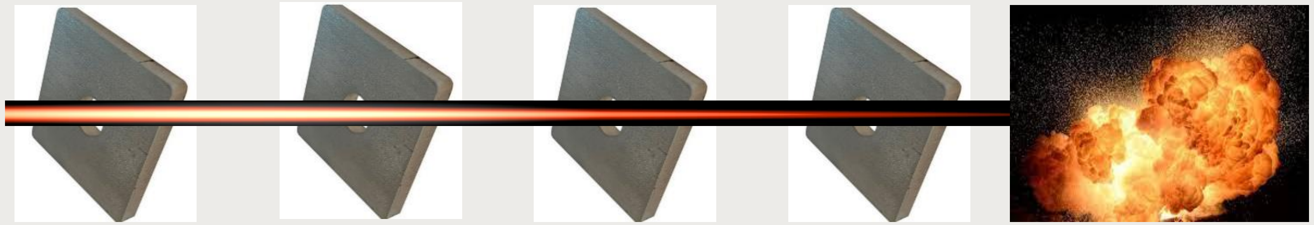
**Contributing factors:**

- Oxygen removing component was omitted in the system (*included in the initial design, removed when constructor notified no oxygen remover was available)*
- Buffer tank static spark remover was omitted during construction *(should be connected to earth, but not as the constructer found there is concrete foundation underneath)*.
- Operator made fault by running water electrolysis system lower than operation power level, which induced increase of $O_2$ concentration *(The system has to be operated higher then 98kwh since the water electrolysis has asbestos type separation membrane and low limit power is 50%. However, due to solar panel characteristics the system often operates lower then 98kwh)*
- The $O_2$ concentration was detected as > 3%, which required $O_2$ detector and remover. However, the operator ignored this issue and continued operation to reach 1000 hours of required experiment validation time.
- Safety management team did not follow safety regulation to daily test hydrogen quality.



# Lessons learnt

European Hydrogen Safety Panel (EHSP)

## Examples for lessons learnt (2/3)

### Job factor

- Lack of regular maintenance or inspection, special attention for safety devices during maintenance
- Reoperation after repair
- Individual/human factors, lack of clear instructions
- Reusing tanks or pipes previously containing flammable liquid or gas without thorough purging.

# Example of recent incident: Hydrogen fuelling station explodes in Norway

European Hydrogen Safety Panel (EHSP)

*https://www.petrolplaza.com/news/22174*

The *explosion* set off the airbags in a nearby non-*fuel cell vehicle*, in which two occupants suffered injuries. An area of 500-metre radius around the station was evacuated.

# Example of recent incident: Hydrogen fuelling station explodes in Norway

European Hydrogen Safety Panel (EHSP)

Nel investigation into explosion at Kjørbo hydrogen station. Fuel Cells Bulletin 2019; 2019(7): 7

- GexCon was commissioned to investigate the incident, which was attributed to an assembly error of a specific plug in a high-pressure hydrogen storage tank.
- The incident started with a hydrogen leak from a plug in one of the tanks in the high-pressure storage unit.
- This leak created a mixture of hydrogen and air that ignited and created a pressure wave.
- The specific source of ignition is yet to be identified.
- The low-pressure steel and composite storage units were neither the source of the leak, nor the ignition source, and no tanks ruptured in the incident.

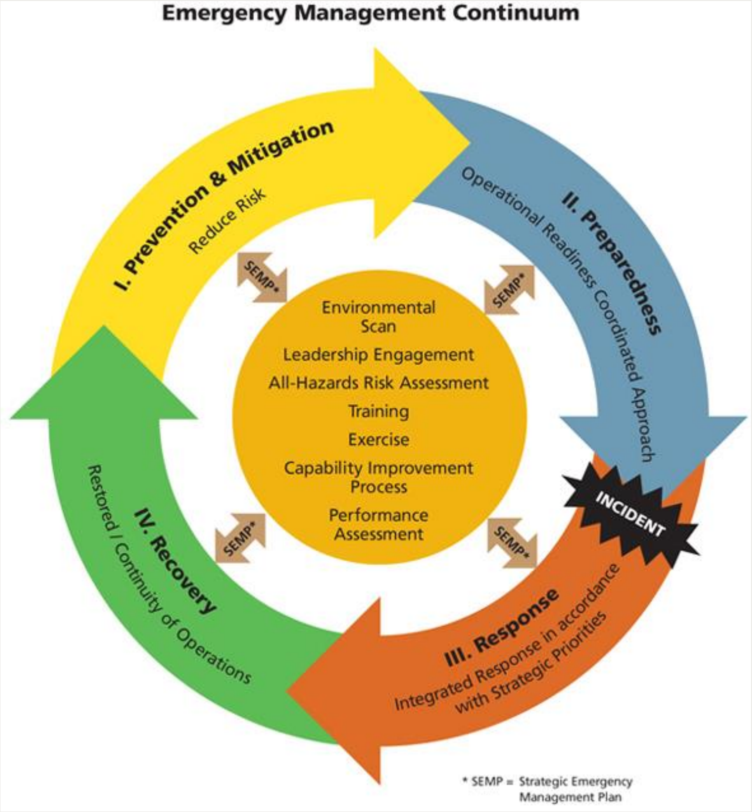
# Lessons learnt

European Hydrogen Safety Panel (EHSP)

## Examples for lessons learnt (3/3)

### Lessons learnt for the first responders

- First responders are generally too ignorant of the various accident scenarios they may encounter and do not know enough how to respond concerning emerging technologies.
- The installation and the specific emergency operation in function of the different incident scenarios must be known to the intervening emergency service. Dedicated consultation and common exercises and trainings as are very important.
- Delayed action to limit inventories could contributing to escalating the severity of an incident
- Firewater drainage was a longstanding problem found at many accident sites. Installation of a draining system should be considered in the construction plans of the plant (fire prevention advice).
- Domino events such as fires were common after many explosion accidents




*https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/mrgnc-mngmnt-pnnng/i*

# Recommendations

European Hydrogen Safety Panel (EHSP)

| Number | Safety Principle<br>*https://www.fch.europa.eu/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects_Release1p31_20190705.pdf* |
|---|---|
| **SP1** | Limit hydrogen inventories, especially indoors, to what is strictly necessary. |
| **SP2** | Avoid or limit formation of flammable mixture, by applying appropriate ventilation systems, for instance. |
| **SP3** | Carry out ATEX zoning analysis. |
| **SP4** | Combine hydrogen leak or fire detection and countermeasures. |
| **SP5** | Avoid ignition sources using proper materials or installations in the different ATEX zones, remove electrical systems or provide electrical grounding, etc. |
| **SP6** | Avoid congestion, reduce turbulence promoting flow obstacles (volumetric blockage ratio) in respective ATEX zones. |
| **SP7** | Avoid confinement. Place storage in the free; or use large openings which are also supporting natural ventilation. |
| **SP8** | Provide efficient passive barriers in case of active barriers deactivation by whatever reason. |
| **SP9** | Train and educate staff in hydrogen safety. |
| **SP10** | Report near misses, incidents and accidents to suitable databases and include lessons learned in your safety plan. |

# Recommendations

European Hydrogen Safety Panel (EHSP)

## Recommendations for different operational modes

- An adequate training of personnel is key (SP9). This includes training of new personnel as well as periodic updated training of existing personnel.
- Both passive and active safety measures should be appropriately considered. At least 19% of the considered incidents were related to inadequate safety devices or passive protection measures (SP7, SP8). Leak detection (SP4) and ATEX zoning (SP3, SP5) should be applied to improve safety.
- It is necessary to keep the equipment and systems up to date with appropriate surveillance and maintenance.
- When operational or equipment changes are made, the maintenance/inspection procedures should also be updated accordingly.

# Recommendations

European Hydrogen Safety Panel (EHSP)

## Recommendations for hydrogen energy applications – system design

- Perform Process Hazard Analysis for any new/updated installations (SP1-10);
- Use materials which are compatible with hydrogen services. In some incidents, such problem resulted in the need to change standards and codes for pressure vessels;
- Install high fidelity leak detection and other extra mitigation barriers (SP4, SP8) for critical systems.

# Example of recent incident: Explosion and Fire at AB Specialty Silicones Facility, 3 May 2019

https://www.csb.gov/assets/1/20/ab_specialty_silicones_factual_update.pdf?16532
U.S. Chemical Safety and Hazard Investigation Board (CSB)



- A silicone manufacturing process generated a flammable gas inside an enclosed production building at the AB Specialty Silicones ("AB Specialty") facility in Waukegan, Illinois (Figure 1).
- At approximately 9:30 p.m., the flammable vapor cloud found an ignition source and ignited, causing an explosion and fire.
- The flammable vapor originated from the area where AB Specialty was making a silicon hydride emulsion.
- The explosion fatally injured four AB Specialty employees [1] and caused serious injury to another AB Specialty employee.
- The explosion heavily damaged the AB Specialty's production building. Additionally, the force from the explosion was felt up to 20 miles away in the surrounding communities, and some nearby businesses sustained damage from the blast.

# Example of recent incident: Explosion and Fire at AB Specialty Silicones Facility, 3 May 2019

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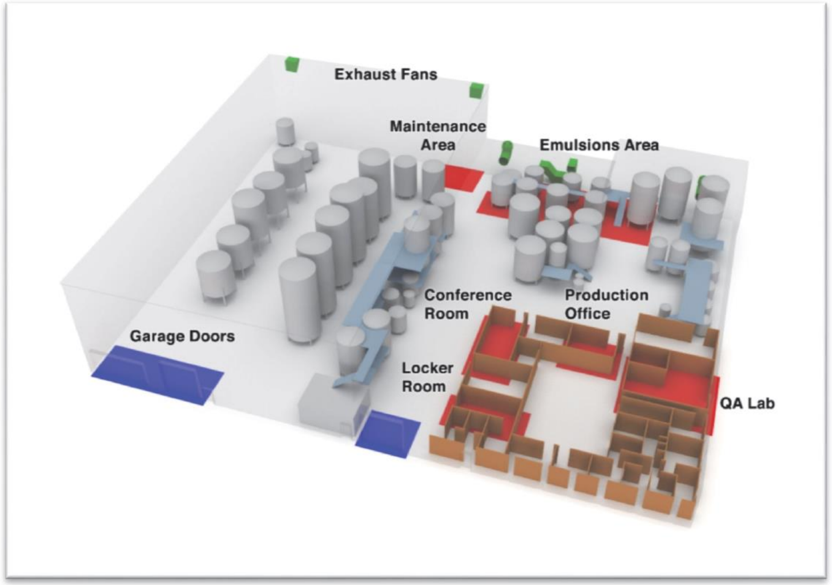
European Hydrogen Safety Panel (EHSP)


Operator 2 headed towards the garage doors and he was outside the locker room (**Figure 8**) when the explosion occurred. Operator 3 was not able to turn on the fans before the explosion occurred.




There were no flammable gas detectors or hydrogen gas detectors with alarms to warn workers of a flammable gas. The generation of gas in the Thick Phase tank could produce foaming, however, foaming does not normally occur during this portion of the EM 652 process. The placement of the main air mover near the EM 652 process further increased the potential explosion danger from flammable gases generated in the emulsions area.

# Concluding remarks

European Hydrogen Safety Panel (EHSP)

- HIAD is being continuously enlarged and enhanced by EHSP and JRC
- Currently 593 events have been validated and released online.
- Since June 2020, EHSP has analysed 485 incidents which were in the database in July 2020 with the following outcome which are included in an updated report to be published by FCH 2 JU in 2021:
  - Statistics
  - Lessons learnt
  - Recommendations
- Analysis will be conducted for new events added/consolidated in 2021 following current calibration of the analysis to improve consistency between different experts. Statistics will be further improved to include equipment/components.

# Acknowledgement

## Contributors:

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- Joint Research Centre of the European Commission:
  Pietro Moretto

# HIAD 2.0 – reporting new events to HIAD



All the potential event providers not belonging to the EHSP can report to HIAD through an ad-hoc EUSurvey:

https://ec.europa.eu/eusurvey/runner/HIAD_v2_event_report

JRC will translate this entry into an HIAD entry.

The event providers using EUSurvey should email pietro.moretto@ec.europa.eu to notify him as the system does not send him automatic notification of a new entry in EUSurvey.