Clean Hydrogen Partnership

European Hydrogen Safety Panel (EHSP)

Statistics, lessons learnt and recommendations from the analysis of HIAD 2.0 database

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European Hydrogen Safety Panel (EHSP)

24 May 2022

Co-funded by the European Union

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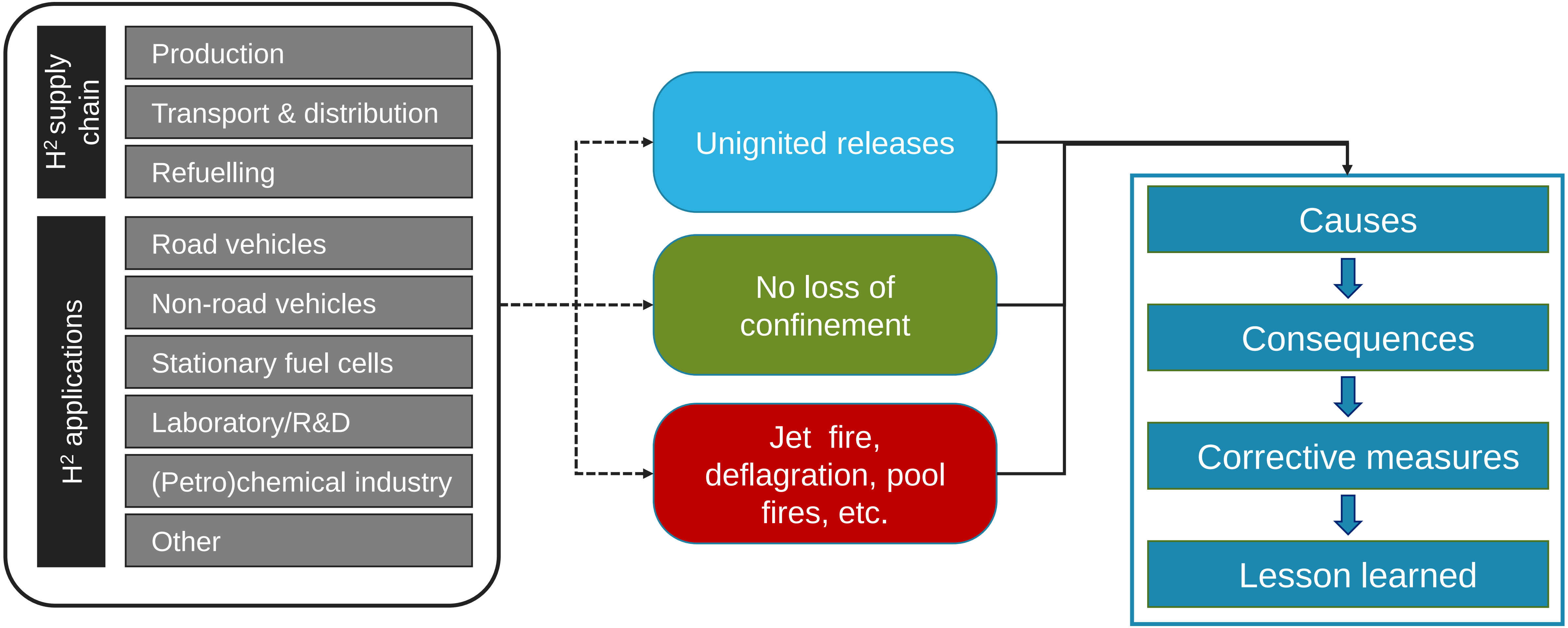
Background

- The Hydrogen Incidents and Accidents Database (HIAD) was firstly developed within the HySAFE Network of Excellence by the Joint Research Centre of the European Commission (JRC) .
- Updated by JRC as HIAD 2.0 in 2016.
- Since its launch in 2017, the EHSP has been working closely with JRC to enlarge and improve HIAD 2.0.

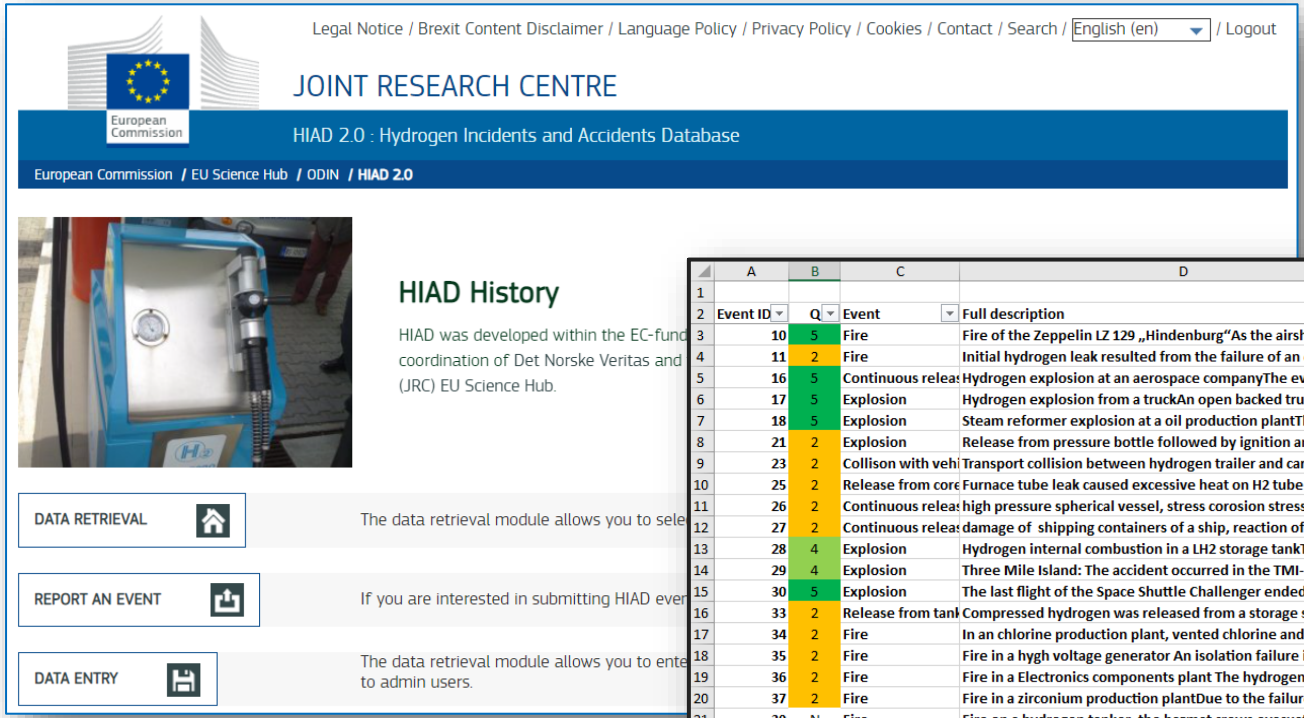
- Sources of HIAD 2.0:
  - Public, from scientific literatures, news.
  - Other public not hydrogen-specific databases such as French ARIA, European (SEVESO) eMARS, US CSB, NTSB ,OHSA national nuclear authorities, etc.

HIAD 2.0 Database structure



How to access HIAD

While HIAD 2.0 database is offline due to maintenance, those who need to access the information should contact pietro.moretto@ec.europa.eu



Since 2021 not accessible online, but via an Excel file

	A	B	C	D	E	F	G	H	I	J
1										
2	Event ID	Q	Event	Full description	Classification	Physical consequences	Application sta	Systems involv	Region	Country
3	10	5	Fire	Fire of the Zeppelin LZ 129 „Hindenburg"As the airship approached	Hydrogen system initiating event	Jet Fires and Explosions	Non-Road vehicle	zeppelin, gas stor		UNITED STATES
4	11	2	Fire	Initial hydrogen leak resulted from the failure of an elbow welded	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	Failure of a 2-inch		UNITED STATES
5	16	5	Continuous releas	Hydrogen explosion at an aerospace companyThe event occurred in	Hydrogen system initiating event	Unignited Hydrogen Releas	Chemical/Petroch	support buildings		UNITED STATES
6	17	5	Explosion	Hydrogen explosion from a truckAn open backed truck was deliverir	Hydrogen system initiating event	Jet Fires and Explosions	Hydrogen transpo	Industrial pressur		SWEDEN
7	18	5	Explosion	Steam reformer explosion at a oil production plantThe event occurr	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	steam reformer		CANADA
8	21	2	Explosion	Release from pressure bottle followed by ignition and perhaps fast	Hydrogen system initiating event	Jet Fires and Explosions	Hydrogen transpo	Compressed hydr		PEOPLE REPUBLIC
9	23	2	Collison with vehi	Transport collision between hydrogen trailer and car, without hydro	Non-Hydrogen system initiating event	No Hydrogen Release	Road vehicle	gaseous hydroger		
10	25	2	Release from core	Furnace tube leak caused excessive heat on H2 tube causing rupture	Hydrogen system initiating event	Unignited Hydrogen Releas	Chemical/Petroch	hydrogen pipeline		UNITED STATES
11	26	2	Continuous releas	high pressure spherical vessel, stress corosion stressing by hydogen	Hydrogen system initiating event	Unignited Hydrogen Releas	Chemical/Petroch	high pressure spe		GERMANY
12	27	2	Continuous releas	damage of shipping containers of a ship, reaction of phosphorpentc	Hydrogen system initiating event	Unignited Hydrogen Releas	Non-Road vehicle	high pressure sph		CANADA
13	28	4	Explosion	Hydrogen internal combustion in a LH2 storage tankThe accident occ	Hydrogen system initiating event	Jet Fires and Explosions	Laboratory / R&D	liquid hydrogen cı		FRANCE
14	29	4	Explosion	Three Mile Island: The accident occurred in the TMI-2 reactor (the pl	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch			UNITED STATES
15	30	5	Explosion	The last flight of the Space Shuttle Challenger ended 73 seconds afte	Hydrogen system initiating event	Jet Fires and Explosions	Non-Road vehicle	external fuel tank		
16	33	2	Release from tank	Compressed hydrogen was released from a storage system due to tl	Hydrogen system initiating event	Unignited Hydrogen Releas	Chemical/Petroch	hydrogen storage		UNITED STATES
17	34	2	Fire	In an chlorine production plant, vented chlorine and hydrogen, auto	Hydrogen system initiating event	Jet Fires and Explosions	Other	chlorine electroly		UNITED STATES
18	35	2	Fire	Fire in a hygh voltage generator An isolation failure in starter coil of	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	hydrogen pipe, hi		UNITED STATES
19	36	2	Fire	Fire in a Electronics components plant The hydrogen release of a de	Hydrogen system initiating event	Jet Fires and Explosions	Other	hydrogen supply l		UNITED STATES
20	37	2	Fire	Fire in a zirconium production plantDue to the failure of a exhaust s	Hydrogen system initiating event	Jet Fires and Explosions	Other	hydrogen exhaust		UNITED STATES
21	39	N	Fire	Fire on a hydrogen tanker, the hazmat crews evacuated the workers	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	Hydrogen tanker		UNITED STATES
22	40	5	Explosion	Hydrogen-air explosion in an ammonium plant.This resulted in the	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	hydrogen vessel,		NORWAY
23	43	A	ntinuous releas	Hydrogen release from a road truck transporting liquid hydrogen	Hydrogen system initiating event	Unignited Hydrogen Releas	Hydrogen transpo	vent system, LH2-		UNITED STATES
24	44	5	Explosion	Hydrogen explosion and fire in a petrochemical complex. The explo	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	litol benzene onv		CANADA
25	46	2	Fire - hydrogen	Lightning caused fires at plant near Hamburg after igniting a hydroge	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	Ventilation pipe		GERMANY
26	47	3	Explosion	An explosion occurred involving a COY Microbiological Anaerobic Cl	Hydrogen system initiating event	Jet Fires and Explosions	Laboratory / R&D	microbiological ar		
27	49	2	Explosion	Explosion at chemical plant in Akita Prefecture involving hydrogen k	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch			JAPAN
28	51	2	Explosion	Explosion at Shreveport refinery involving hydrogen injured a work	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch			UNITED STATES
29	52	4	Explosion	Hydrogen explosion in a unit of a nuclear power plant.The explosion	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	reactor cooling sy		
30	53	2	Explosion	3 workers were injured in the hydrogen explosion	Hydrogen system initiating event	Jet Fires and Explosions	Chemical/Petroch	-		FINLAND

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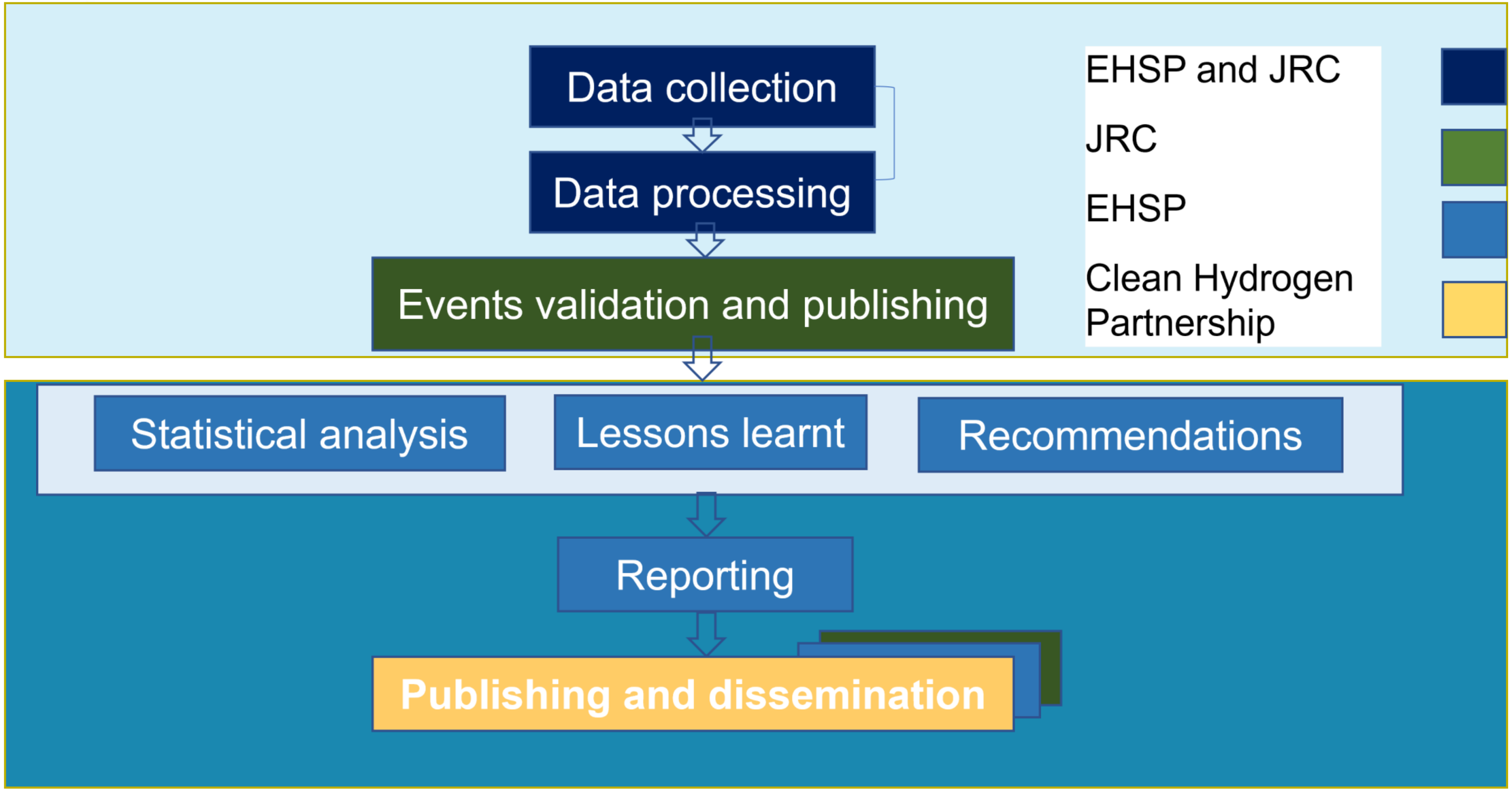
Overview of the data collection and assessment process



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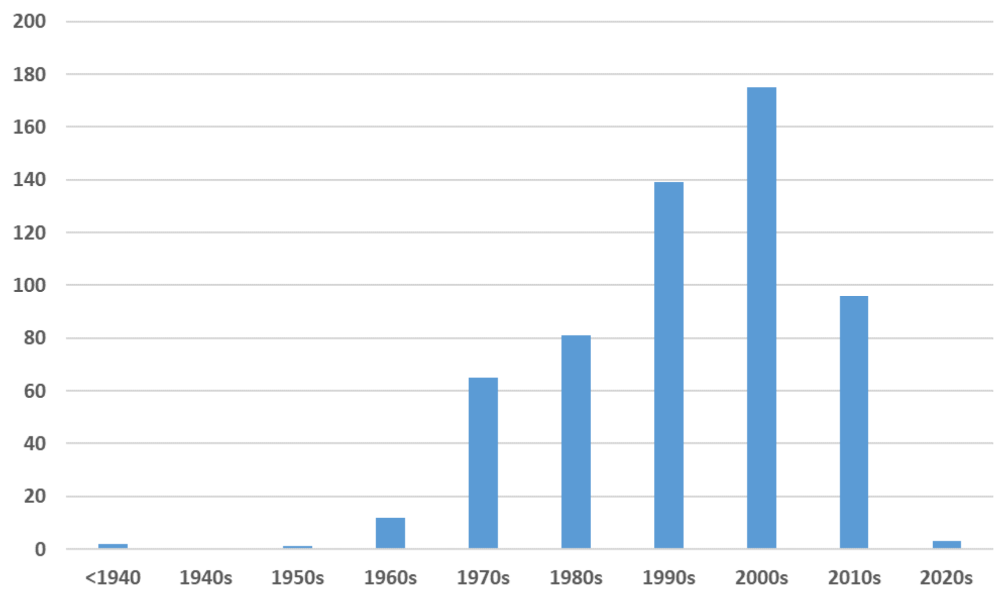
The methodology

- **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 (Seveso threshold or the amount of hydrogen involved)
  - 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 *https://www.fch.europa.eu/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects_Release1p31_20190705.pdf*)

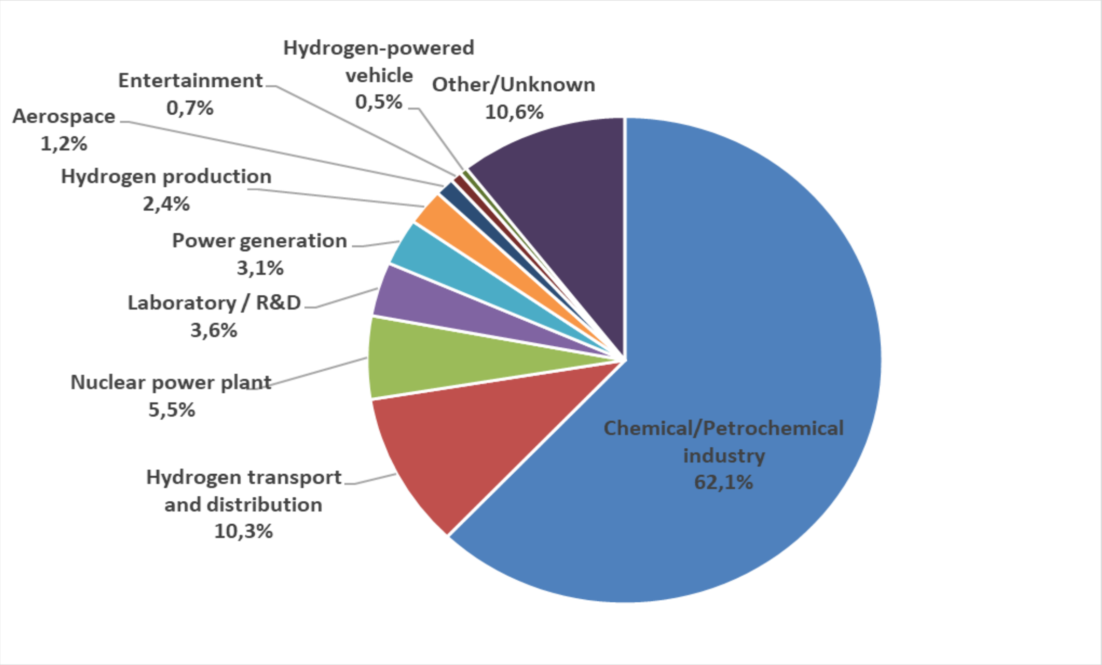
Results from the statistics analysis (1)

The analysis reported here is based on the 706 incidents, which were in the database as of May 2021. A total of 576 of these events were considered to be statistically relevant and formed the basis for the statistical analysis to inform lessons learned and recommendations.

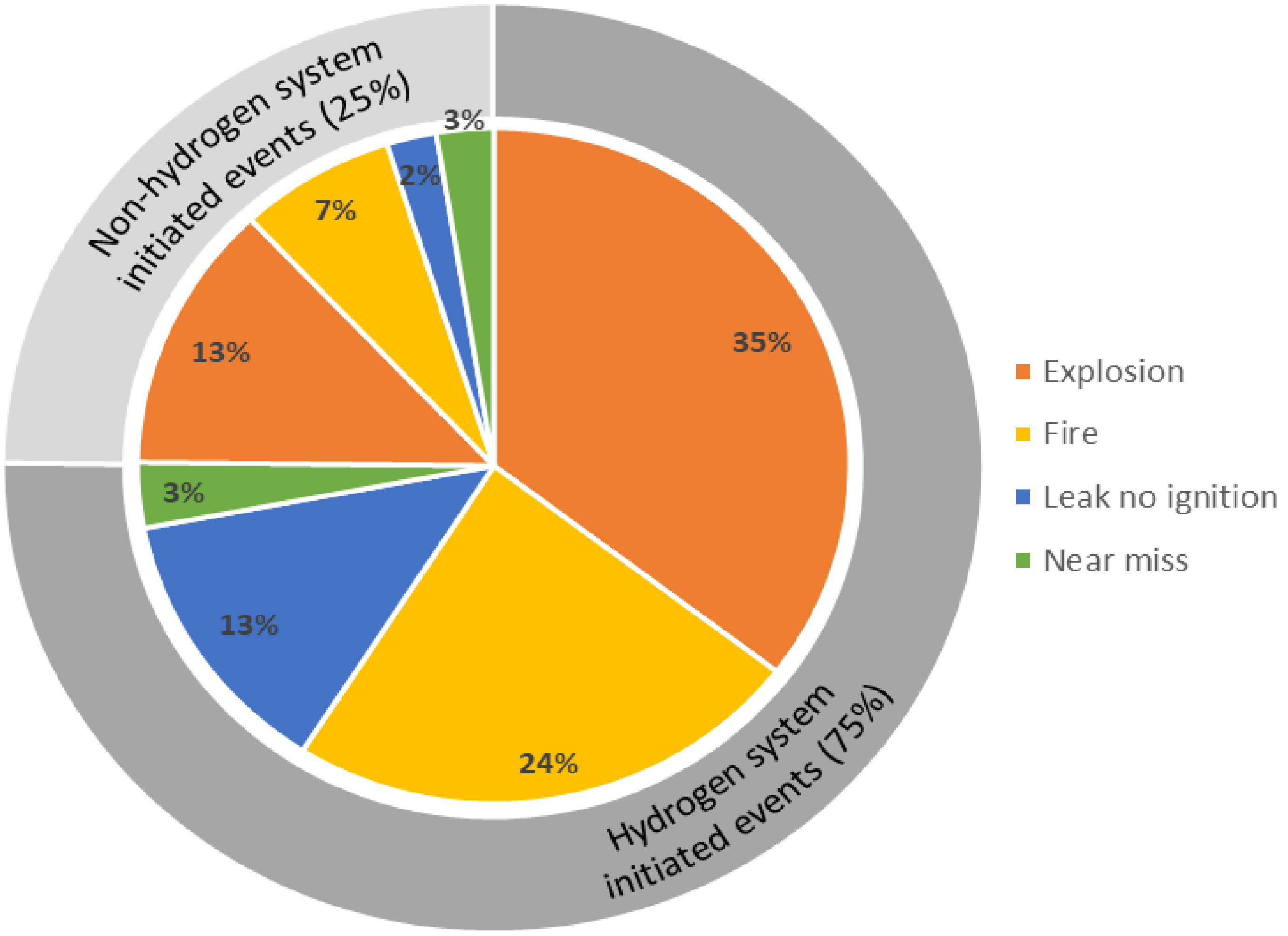
Years



Industrial sectors

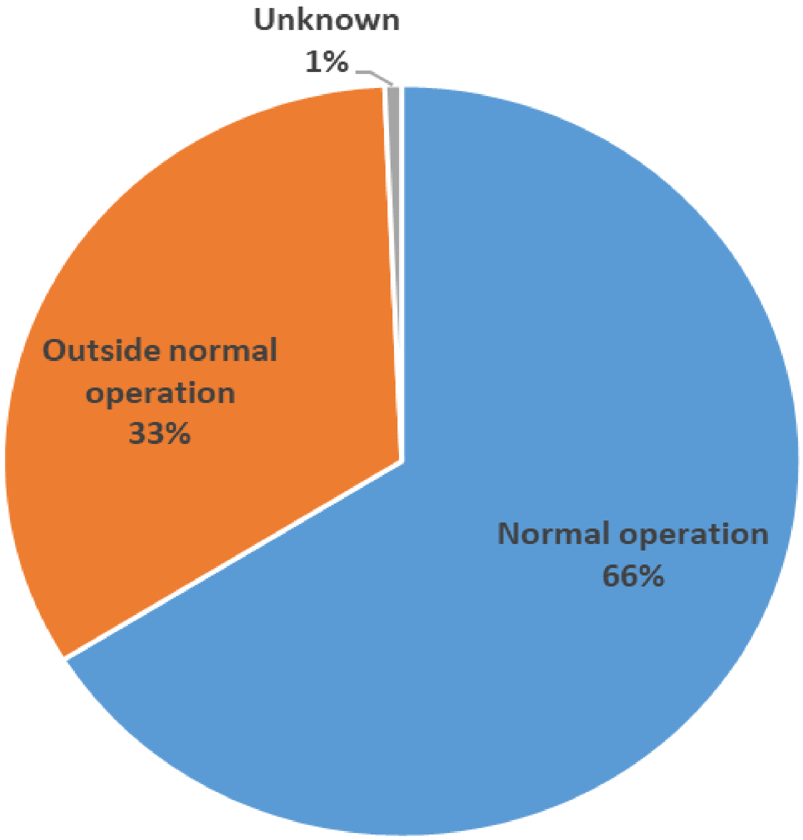


Results from the statistics analysis (2)

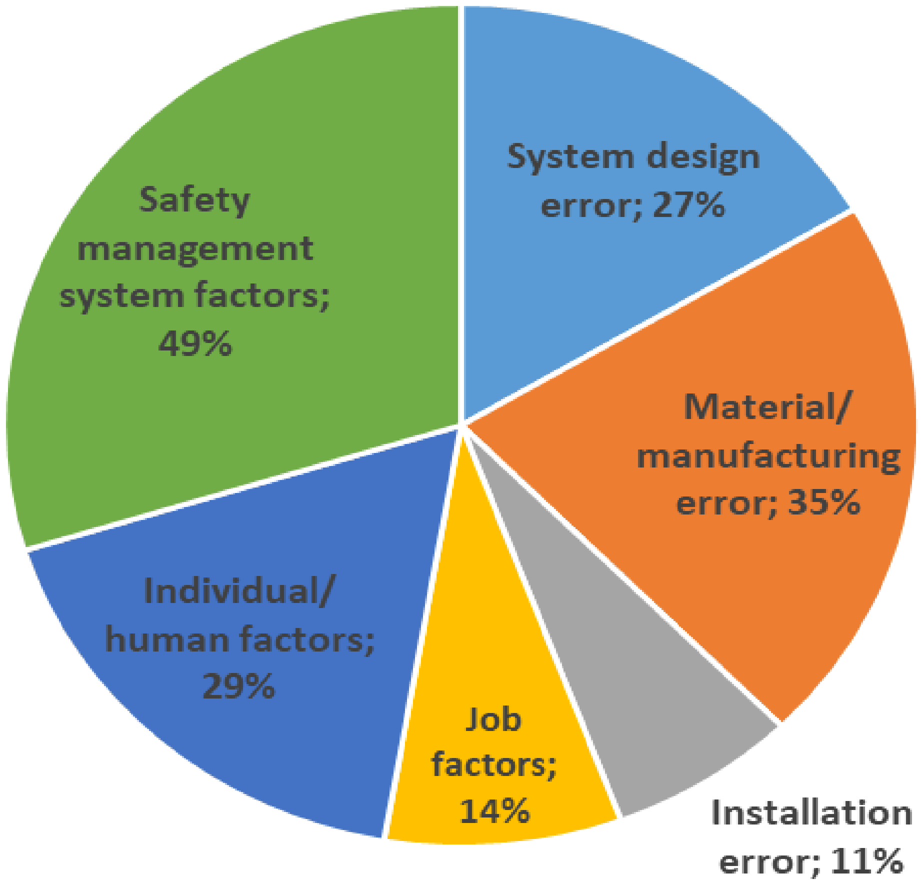


Results from the statistics analysis (3)

Operational mode



Causes (multiple entries per incident possible)



Lessons learnt

The lessons learned are grouped into the following four main categories:

- System design
- System manufacturing, installation, and modification
- Human factors
- Emergency response

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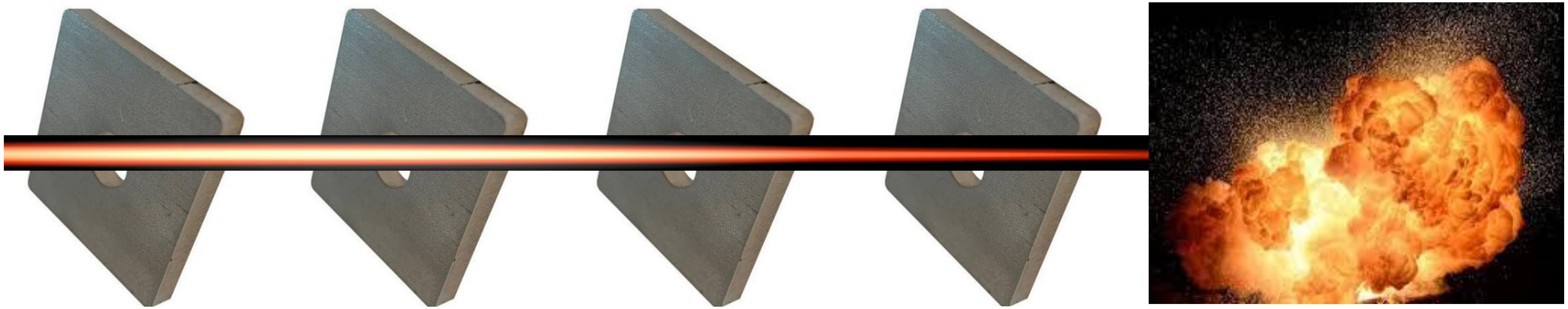
Lessons learnt in relation to cascading effects

James Reason's Swiss Cheese theory *https://en.wikipedia.org/wiki/Swiss_cheese_model*

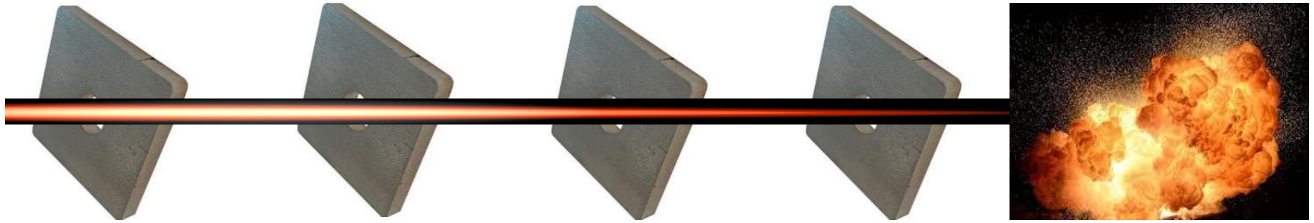
Cascading effects of minor events could result in extremely serious consequences



Example (Event ID**477) of cascading effects:** Gangeung Hydrogen Tank Explosion Accident, May 2019, South Korea

Example (Event ID477) of cascading effects

- Prosecutor's report on Gangeung Hydrogen Tank Explosion Accident, May 2019, South Korea
- The following text is adapted from the English translation by INERIS about the contributing factors:
  - Oxygen removing component omitted in the system …
  - Buffer tank static spark remover was omitted during construction…
  - Operator made fault by running water electrolysis system lower than operation power level, which induced increase of O_2 concentration…
  - 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.



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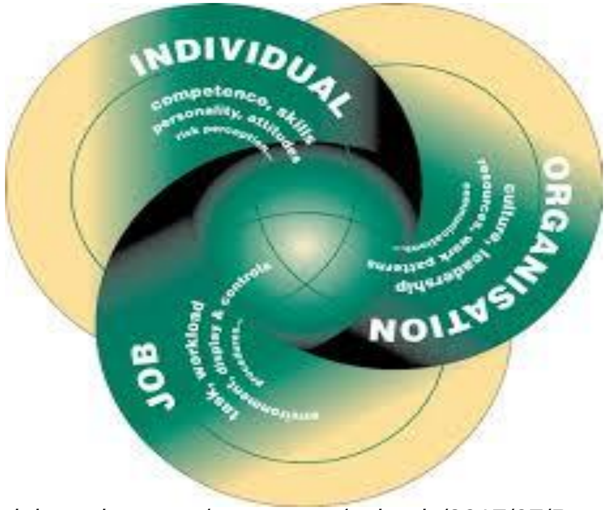
Lessons learnt related to human factor

- 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



https://www.ciobacademy.org/wp-content/uploads/2017/07/Root-Cause-Analysis-2018.pdf

Definition of Health and Safety Executive (HSE)

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Example of recent incident - Hydrogen fuelling station explodes in Norway

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

- The incident was attributed to an **assembly error** of a specific plug in a high-pressure hydrogen storage tank.
- It 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.

Statistics related to EHSP identified safety principles (SP#)

Tier 1

0. Design and material compatibility with H_2 safety
1. Limit H_2 inventories, especially indoors
2. Limit formation of H_2 cloud, e.g. by ventilation
3. ATEX zoning analysis

Tier 2

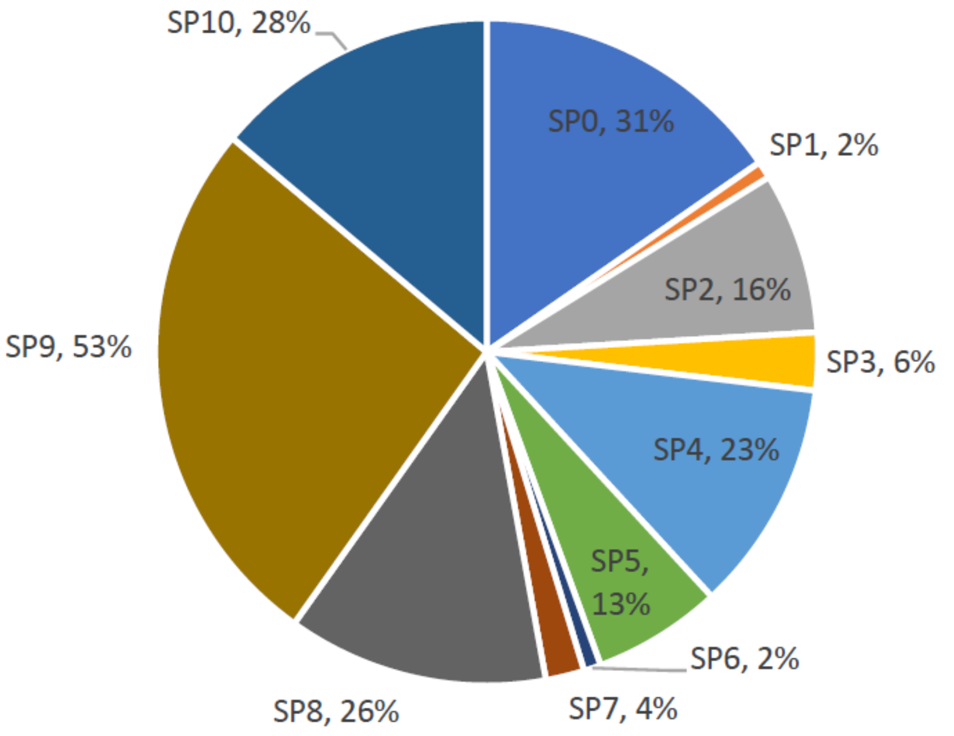
4. Combined measure to detect and counter H_2 leak and fire
5. Avoid ignition sources using appropriate materials or installations in different ATEX zone, e.g. by removing electrical systems or provide electrical grounding
6. Avoid/reduce congestion in respective ATEX zones

Tier 3

7. Avoid confinement. Place storage in open or spaces with large openings.
8. Provide efficient passive barriers as second defence line

Organisational

9. Train and educate staff in hydrogen safety
10. Report near misses, incidents and accidents to suitable databases and include lessons learned in your safety plan



https://www.fch.europa.eu/sites/default/files/documents/Safety_Planning_Implementation_and_Reporting_for_EU_Projects-Final.pdf

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Structure of recommendations at a glance

Table 3: Structure of the recommendations at a glance

Recommendations	Operational mode		
	Industrial sectors	Hydrogen energy	H_2 transport and distribution
			H_2 powered vehicles
			Laboratory / R&D
			Power generation
		Other industrial sectors	*Nuclear*
			Aerospace
			Chemical/petrochemical
	Human factors		

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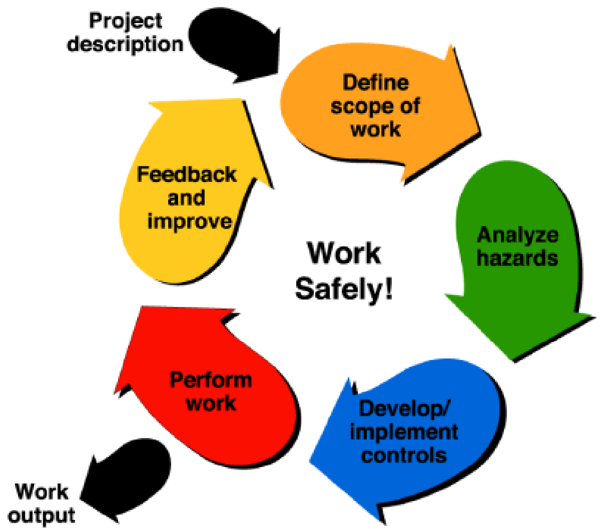
Recommendations for different operational modes

- Adequate training of personnel is key (SP9) - training of new personnel as well as periodic updated training of existing personnel.
- Both passive and active safety measures should be appropriately considered (SP7, SP8).
- Leak detection (SP4) and ATEX zoning (SP3, SP5) should be applied to improve safety.
- Regular inspection and maintenance.
- When operational/equipment changes are made, the maintenance/inspection procedures should also be updated accordingly.



https://eta-safety.lbl.gov/content/integrated-safety-management-ism

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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 (SP0);
- Install adequate leak detection and mitigation barriers (SP4, SP8) for critical systems.

https://risk-engineering.org/safe-design/

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THANK YOU!

- The report from the analysis can be found at https://www.fch.europa.eu/sites/default/files/documents/Lessons%20learnt%20from%20HIAD%202.0-Final.pdf

- A paper based on the analysis was presented at the International Conference on Hydrog ty 2021 and awarded the best paper prize.

- A modified version of the above paper has been published in the International Journal of Hydrogen Energy in Gold Open Access. It can be downloaded free at the following link:

https://reader.elsevier.com/reader/sd/pii/S0360319922012976?token=B67B5AC502387E7B7CE7CC15DABAE2731A101F1BEF7D7A2DEDBF4B0DE060A2CD430485A0C110D758A00ADE1D884ADF5D&originRegion=eu-west-1&originCreation=20220414145607