Clean Hydrogen Partnership

European Hydrogen Safety Panel (EHSP)
Webinar "Safety planning and management in EU hydrogen and fuel cell projects“, 22 April 2022

Safety plan implementation, monitoring and reporting

Chapter 4 of “Safety planning and management in EU hydrogen and fuel cells projects - guidance document”, EHSP, 21 September 2021.
https://www.fch.europa.eu/page/european-hydrogen-safety-panel

Vladimir Molkov
Member of European Hydrogen Safety Panel (EHSP)

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Presentation outline

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PREPARATION OF SAFETY PLAN

- Project brief
- Description of technical hydrogen safety activities
- Description of organisational safety activities
- Other relevant documentation, safety procedures and outreach activities

SAFETY PLAN IMPLEMENTATION, MONITORING AND REPORTING

- Performing safety reviews (in 2 slides)
- Implementation of hydrogen safety engineering process (in 5 slides)
- Examples of best practices in hydrogen safety engineering (in 5 slides)
- Project safety documentation (in 1 slide)

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Performing safety reviews 1/2

- The **safety review** is the formal mean for identifying potential hazards and associated safety issues.
- **Hazardous materials.** The storage and handling of hydrogen (either CGH2 or LH2) must be seriously scrutinised, including leaks and dispersion, possible accumulation and ventilation system, ignitions, pressure and thermal effects of fires and explosions, including deflagrations, detonations and storage tank rupture in a fire, hydrogen interaction with material, detection, etc.
- **Failure modes.** Safety plan identifies immediate (primary) failure modes and secondary failure modes that may come about because of other failures. Every possible failure, from catastrophic failures to benign failures. Identification and discussion of benign failures may lead to the identification of more serious potential failures.
- Typical safety review and risk assessment methods are described in Appendix 4.

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Performing safety reviews 2/2

The safety reviews must be documented and include at least the following:

- The selected safety review method(s).
- The leader of the safety review team and the team composition.
- The responsible person to implement the review results and assisting team composition.
- Hazards and associated risks identified.
- Incident scenarios, including high consequence low-frequency events, etc.
- Safety-critical equipment, processes, elements of infrastructure, etc.

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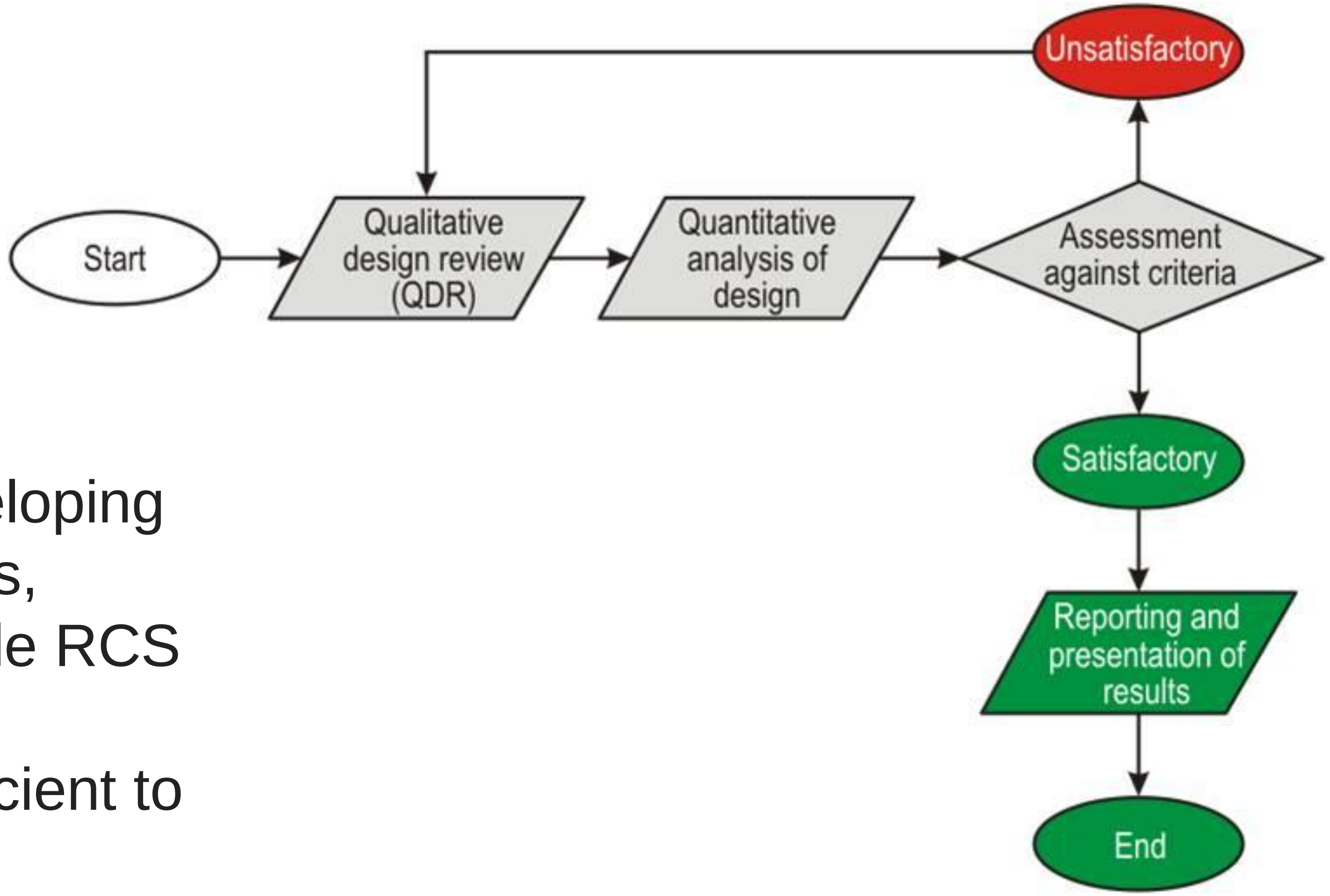
Hydrogen safety engineering process 1/5

- **Hydrogen safety engineering** is defined as application of scientific and engineering principles to the protection of life, property and environment from adverse effects of incidents involving hydrogen.
- It is the most efficient way of developing inherently safer hydrogen systems, processes and infrastructure (while RCS in the emerging areas is under development and can not be sufficient to fully underpin safety design).



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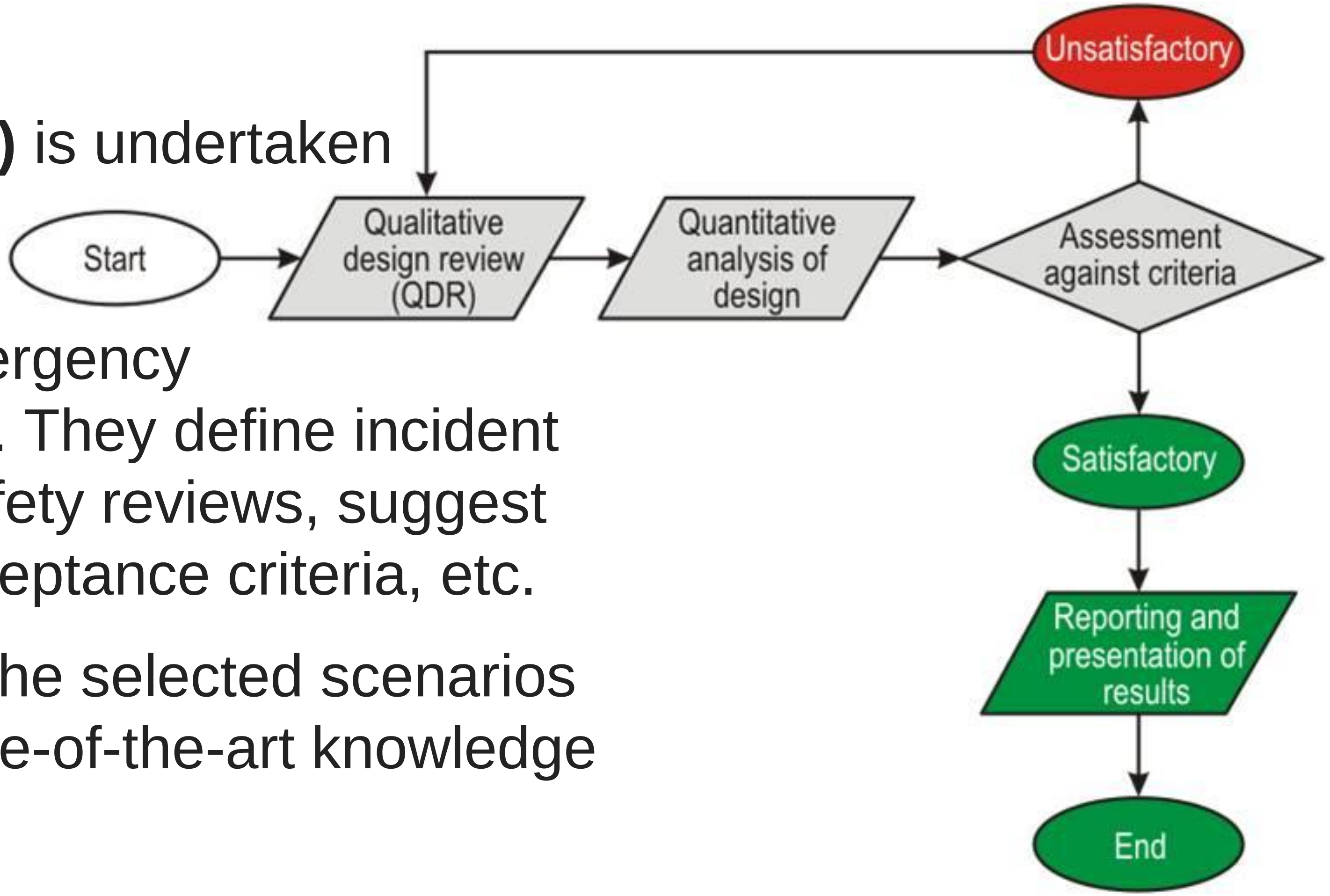
Hydrogen safety engineering process 2/5

Three main steps (in gray):

- **Qualitative design review (QDR)** is undertaken by a team (managers, owners, safety engineers, architects and designers, representatives of emergency services, and other stakeholders). They define incident scenarios, e.g. by undertaking safety reviews, suggest trial safety designs, formulate acceptance criteria, etc.
- **Quantitative safety analysis** of the selected scenarios and trial designs by using the state-of-the-art knowledge in hydrogen safety engineering.
- **Assessment against acceptance criteria** (predefined).



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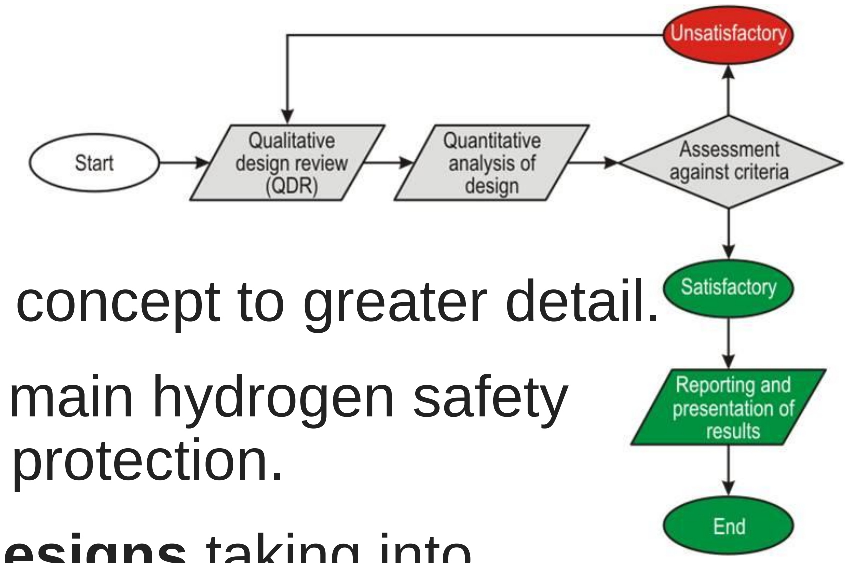
Hydrogen safety engineering process 3/5



- **QDR** allows to establish a range of safety strategies and engineering solutions. The QDR process is likely to involve some iterations as the design process moves from a broad concept to greater detail.
- **Safety objectives** should be defined during the QDR. The main hydrogen safety objectives are safety of life, loss control and environmental protection.
- The QDR team should establish one or more **trial safety designs** taking into consideration selected incident scenario(s) and relevant regulations.
- The QDR team has to establish the **acceptance criteria** against which the performance of a design can be judged. Three main methods can be used to assess the performance:
  - Deterministic
  - Comparative
  - Probabilistic
- The QDR team should then **decide whether the quantitative analysis is necessary** to demonstrate that the design meets the hydrogen safety objective(s).

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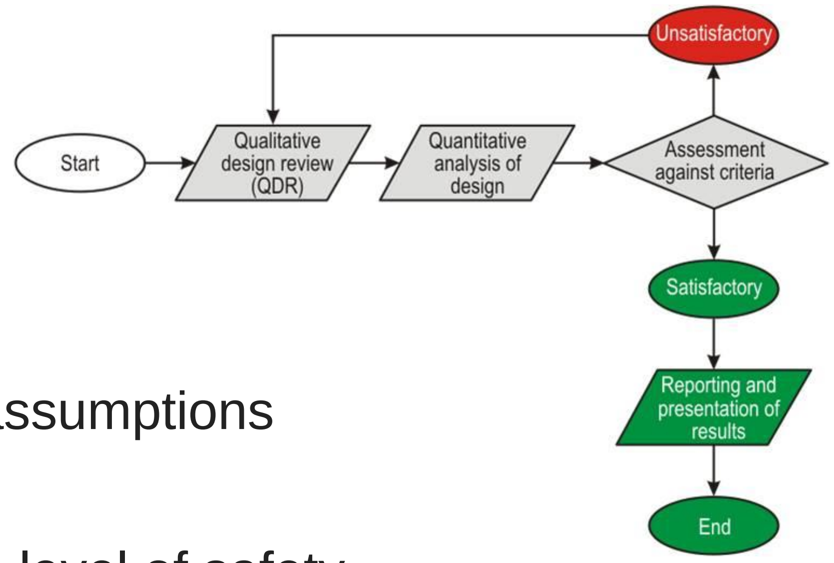
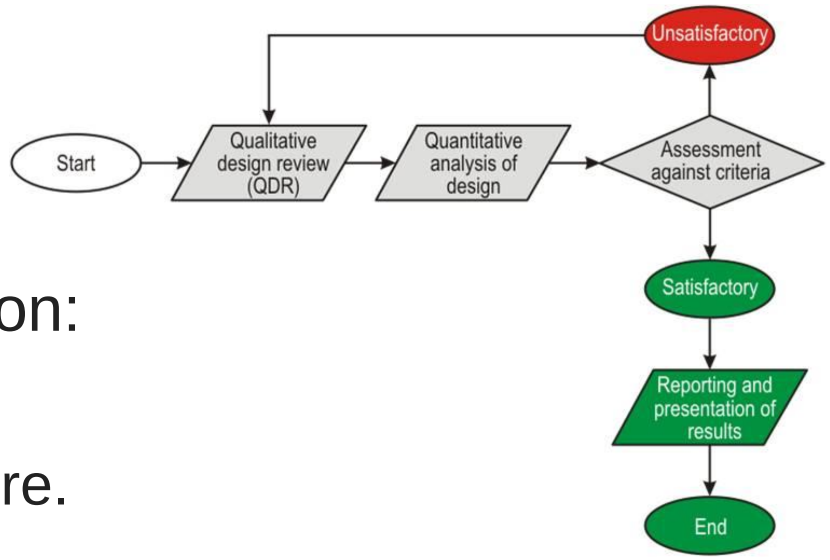
Hydrogen safety engineering process 4/5



- Three basic types of approach can be considered to access the performance of safety system against acceptance criteria:
  - The **deterministic** approach shows that based on the initial assumptions a defined set of consequences will not occur.
  - The **comparative** approach shows that the design provides a level of safety equivalent to that in similar systems and/or conforms to prescriptive codes.
  - The **probabilistic** approach shows that the risk of a given event occurring is acceptably low, e.g. equal or below the established risk for similar existing systems.
- If none of the trial designs developed by the QDR team satisfies the specified acceptance criteria, QDR and quantification process should be repeated until a hydrogen safety strategy satisfies acceptance criteria and other design requirements.

Hydrogen safety engineering process 5/5

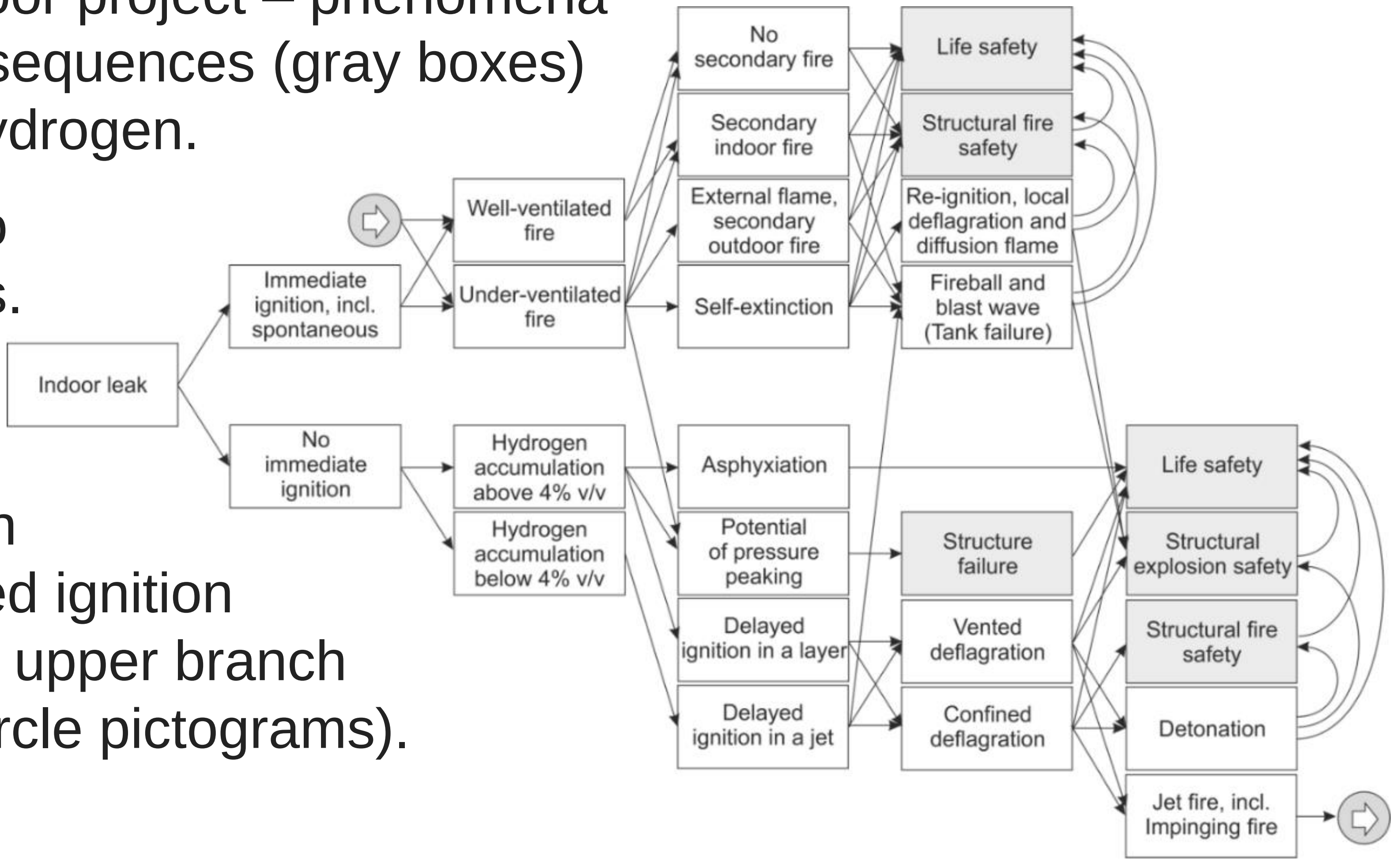


Depending on the particularities and scope of the hydrogen safety engineering study, the **reporting** of results and findings could contain the following information:

- Objectives of the study.
- Description of the hydrogen system/process/infrastructure.
- Results of the QDR.
- Quantitative analysis, including assumptions; engineering judgments; calculation procedures; validation of methodologies; sensitivity analysis, etc.
- Assessment of analysis results against criteria.
- Conclusions: safety strategy; engineering solutions; management requirements; any limitations on use, etc.
- References, e.g. drawings, design documentation, technical literature, etc.

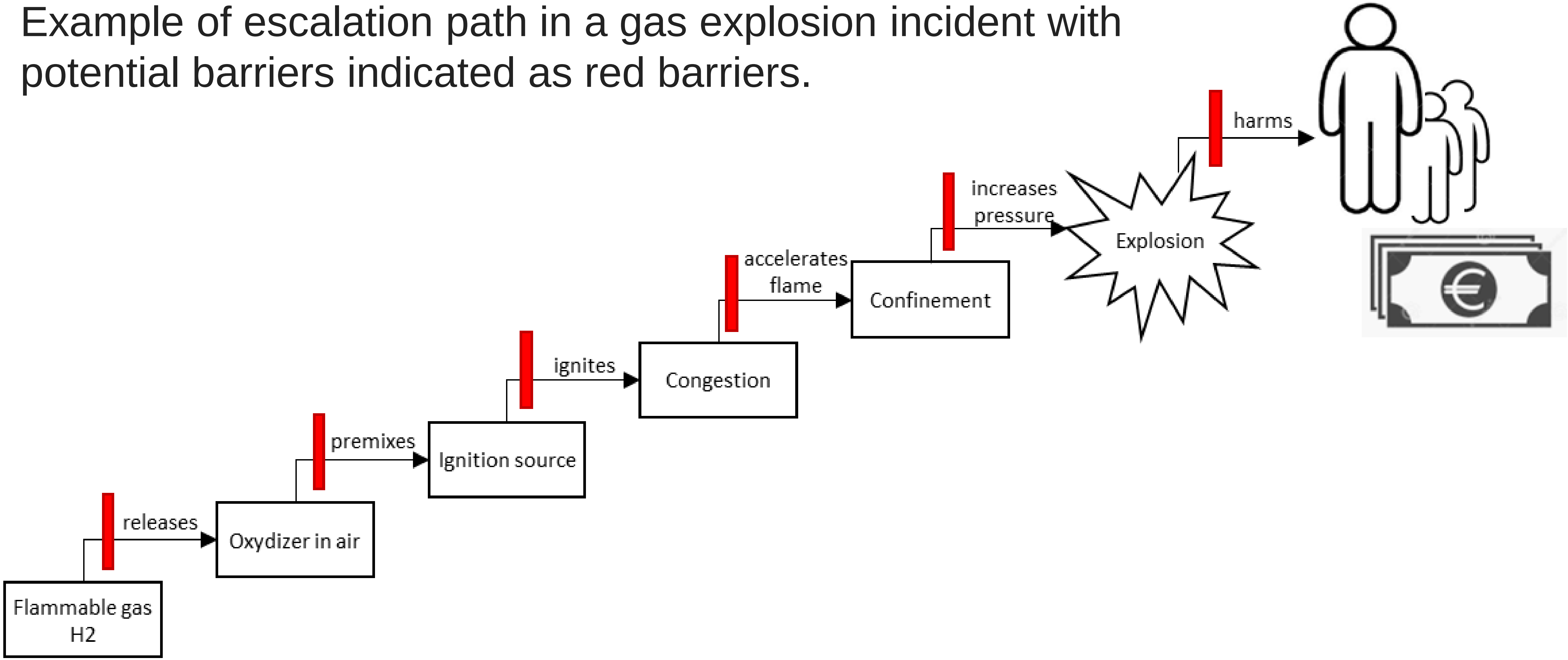
Best practices in safety engineering 1/5

- The safety plan is expected to incorporate best practices in hydrogen safety.
- Example of the PNR HyIndoor project – phenomena (white boxes) and their consequences (gray boxes) diagram for indoor use of hydrogen.
- The diagram can be used to formulate incident scenarios.
- Note: if no immediate ignition has occurred (lower branch), a subsequent chain of events can lead to delayed ignition leading to a transition to the upper branch (indicated by the arrow in circle pictograms).



Best practices in safety engineering 2/5

Example of escalation path in a gas explosion incident with potential barriers indicated as red barriers.



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Best practices in safety engineering 3/5

The widely used safety principles/strategies and organisational measures.

No.	Exemplars of safety principles/strategies
1	Make a proper selection of materials for hydrogen technologies.
2	Limit hydrogen inventories, especially indoors, to what is technologically necessary.
3	Avoid/limit the formation of a flammable mixture, e.g. by using ventilation or reducing release size.
4	Carry out ATEX zoning analysis. Avoid ignition sources using proper materials or devices in different ATEX zones, remove electrical systems where appropriate or provide electrical grounding, etc.
5	Avoid congestion. Reduce turbulence promoting flow obstacles in respective ATEX zones.
6	Avoid confinement. Place storage in the open if possible or use proper size openings in the enclosure.
7	Combine hydrogen leak or fire detection and counter-measures.
8	Provide efficient passive barriers in case of active barriers deactivation for whatever reason.
9*	Train and educate staff in hydrogen safety to establish a new hydrogen safety culture.
10*	Report near misses and incidents to databases and include lessons learned in your documentation.

Note: * - organisational measures.

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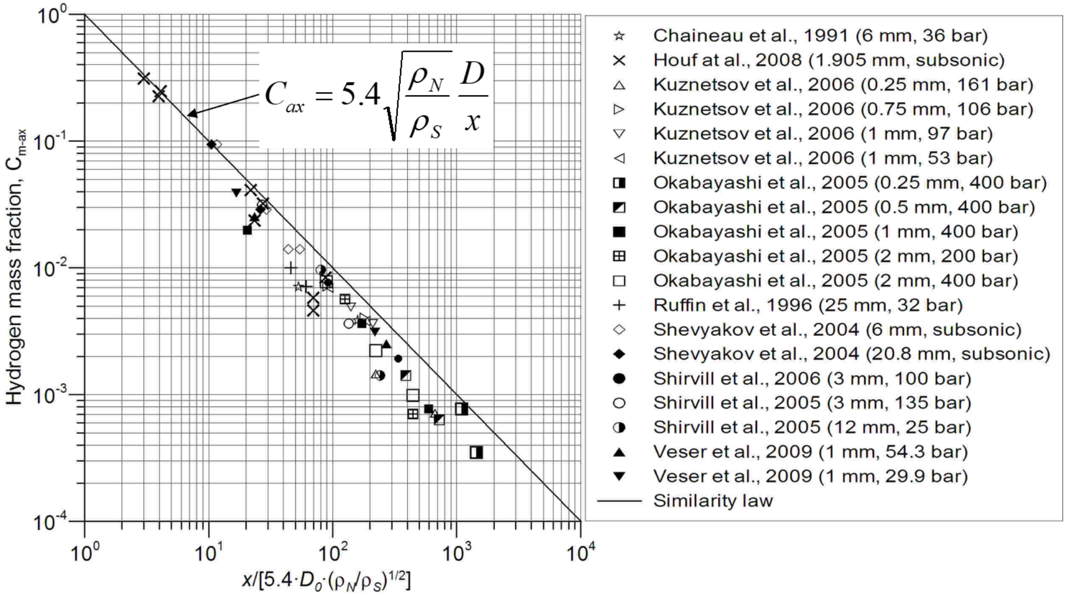
Best practices in safety engineering 4/5

Examples from “Fundamentals of hydrogen safety engineering” (www.bookboon.com).

The similarity law

Concentration decay in unignited jets



Hazard distance, i.e. the flammable envelop size (up to LFL=4%), is **proportional to the leak diameter**. **Conclusion**: decrease a pipe diameter as much as possible.

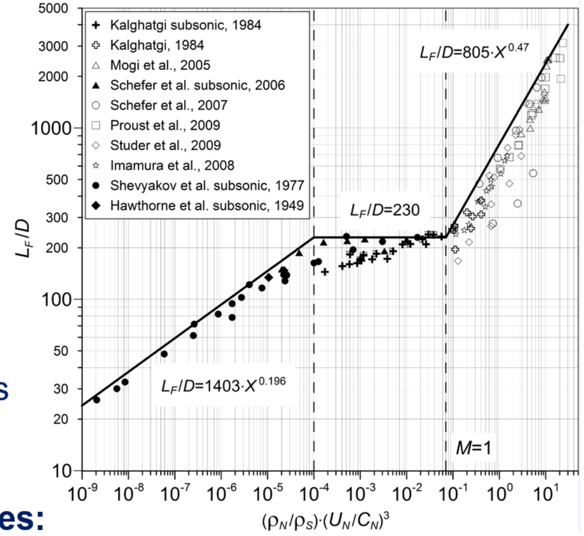
Hydrogen jet flame length

The dimensionless correlation

$$\frac{\rho_N}{\rho_S}\cdot\left(\frac{U_N}{C_N}\right)^3 = \frac{g\cdot\mu_N}{\rho_S\cdot C_N^3}\cdot \mathrm{Re}\cdot Fr$$

Validation domain:

- Storage pressure 0.1-90 MPa
- Release diameter 0.4-51.7 mm
- Laminar and turbulent flows
- Sub-sonic, sonic, supersonic flows



Three hazard distances from flames:

- “Fatality”: $x=2L_F$ (third degree burns 309°C, 20 s)
- “Injury”: $x=3L_F$ (pain limit 115°C, 5 min)
- “No harm”: $x=3.5L_F$ (70°C)

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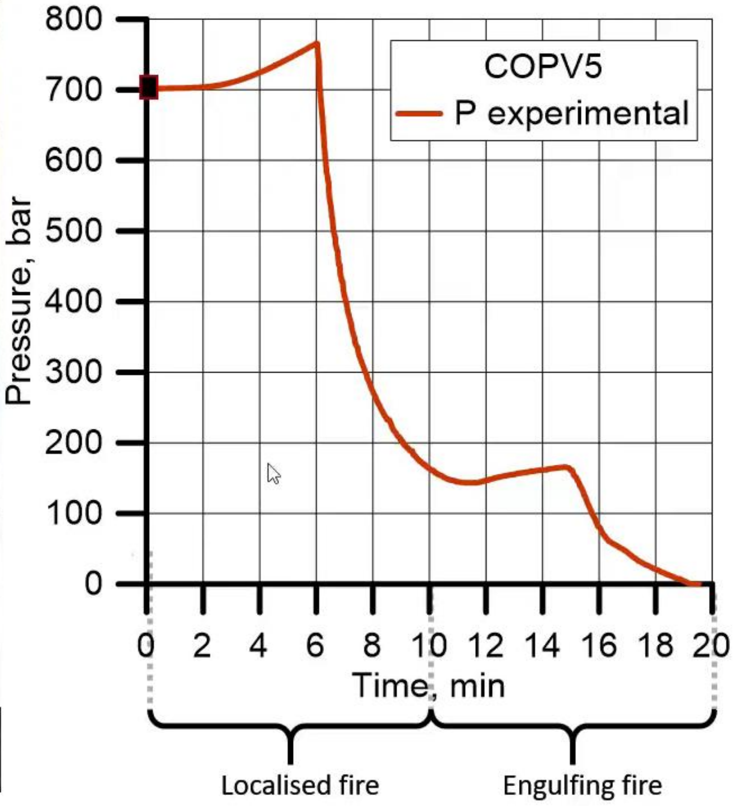
Best practices in safety engineering 5/5

Breakthrough safety technology of explosion free in a fire self-venting (TPRD-less) CGH2 composite tank (nominated for Best Innovation Award 2021 by FCH JU):

- No blast wave!
- No fireball!
- No projectiles!
- No long flames (microflames)!
- No formation of flammable cloud!
- No pressure peaking phenomenon!
- No life and property loss!



Allows hydrogen-powered vehicles enter and park in any confined space.

Project safety documentation

During the project implementation, the following documentation on safety should be prepared, maintained and updated as required. Project safety documentation includes:

- **Information about the technology** of the project: A block flow diagram or simplified process flow diagram, PID (see Appendix 6. “Example of Safety Plan”); Process chemistry if applicable; Maximum intended inventory of materials; Safe upper and lower limits for such items as temperatures, pressures, flows, and concentrations; An evaluation of the consequences of deviations, including those affecting the safety and health of personnel.
- **Information about the equipment or apparatus**: Materials of construction; Material and energy balances; Electrical classification; Pressure relief system design and design basis; Ventilation system design; Design codes and standards employed; Alternatives to the use of listed equipment; Safety check before starting;
- **Other information**: Map of ATEX zones, e.g. drawings of zones 0 and 1, is included in the installation plan when justified; Safety systems, e.g. alarms, interlocks, detection or suppression systems; Procedures to follow in case of emergency; Safety review documentation, including hazards and associated risk assessment; Operating procedures, including response to deviation during operation; Material Safety Data Sheets; References such as handbooks and RCS; Siting issues (alternatives to required setbacks distances).

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Thank you

Vladimir MOLKOV
European Hydrogen Safety Panel
EHSP@clean-hydrogen.europa.eu

For further information
v.molkov@ulster.ac.uk

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