Bergen Energy Lab

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Towards widespread use of hydrogen as an energy carrier in society

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Outline

- Hydrogen
  - Potential "green" energy carrier
  - Promoting hydrogen:
    "Safer than gasoline!?"
- Hydrogen safety
  - Safety and risk
  - Challenges and knowledge gaps
  - European Hydrogen Safety Panel
- Prospects
  - Summary
  - Selected initiatives

HySEA project: vented hydrogen deflagration.
www.hysea.eu

HySEA

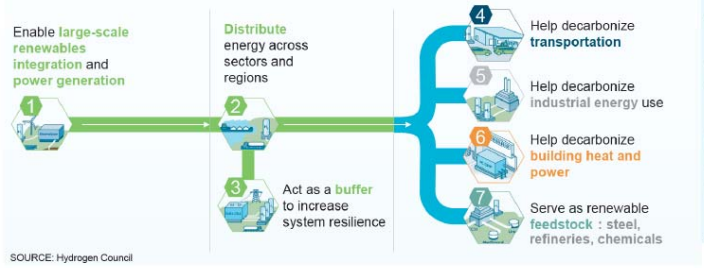
Hydrogen

Hydrogen enables the decarbonization of all major sectors in the economy

Hydrogen Europe

Hydrogen can enable a full renewable energy system, providing the sector integration needed for the energy system transition and decarbonize energy end uses

Enable the renewable energy system ⟶ Decarbonize end uses



SOURCE: Hydrogen Council

Projections for Europe indicate that 5 million vehicles and 13 million households could be using hydrogen by 2030, while a further 600kt of hydrogen could be used to provide high grade heat for industrial uses. In this scenario, **hydrogen would be abating 80Mt CO_2 and account for an accumulated overall investment of $62B (52B€) and 850,000 new jobs.**

Hydrogen Europe – Technology Roadmaps – Full Pack

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hydrogen.no

English

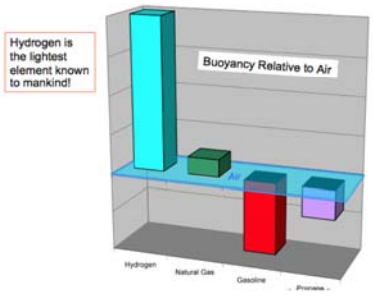
Kjøretøy | Stasjoner | Maritimt | Miljøfordeler | Ressurser | Hva skjer? | Norsk Hydrogenforum

Hydrogen og sikkerhet

Sikkerhetsfakta om hydrogen: Hvorfor er hydrogen tryggere enn fossile drivstoff?

Hvorfor er hydrogen et trygt drivstoffalternativ? Her er noen viktige egenskaper ved hydrogen:

- **Det er 14 ganger lettere enn luft:** Hvis hydrogen slippes ut, stiger det raskt oppover i atmosfæren med en hastighet på 20 meter per sekund (ved normale omgivelsestemperaturer). Til sammenligning er propan- og bensindamp tyngre enn luft og ved lekkasje synker disse ned på bakkenivå, der en utilsiktet tenning gir en økt fare.

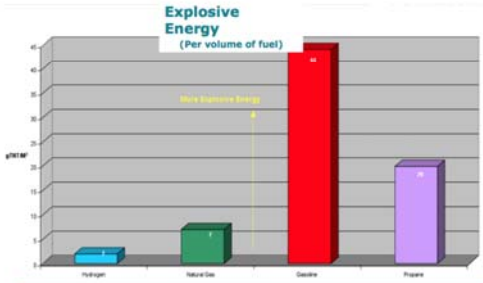


But what about:

- **Tunnels?**
- **Buildings?**
- **Containers?**
- **Parking facilities?**
- **Ships, including ferries?**
- **Local DDT events → above-ground detonations in buoyant clouds and Mach stem formation in the blast?**
- **Other practical application?**

Promoting hydrogen

- **Flammene gir lav strålingsenergi** , noe som betyr at de er mindre tilbøyelige til å flytte til omkringliggende områder og spre brann.
- **Det er giftfritt:** lekkasje eller utslipp forurenser ikke miljøet.
- **Det er mindre brennbart** : bensin i luften er brannfarlig ved en lavere konsentrasjonsgrense på 1,4%, sammenlignet med hydrogenens 4%. For å si det på en annen måte, er bensin to til tre ganger mer brannfarlig i luften. Den optimale blandingen for hydrogenforbrenning er 29%, som i den virkelige verden er ganske uvanlig, siden hydrogen stiger og generelt vil diffundere.Bensindampens optimale blanding for forbrenning er bare 2% - et forhold som er veldig lett å nå.



The worst-case explosion scenario for each fuel. Hydrogen gas does not have a lot of "bang-power" volume-wise compared to other common fuels.

But what about:

- Impingement of hydrogen jet flames on painted surfaces or volatile materials/substances?
- Entrainment of other fuels?
- Extremely low ignition energy?
- Extremely high burning velocity?
- Extremely wide flammability range?
- Formation of highly reactive stratified mixtures in enclosures?
- Propensity for DDT and detonation?

Promoting hydrogen

- Brennbare blandinger av hydrogen har relativt **lav energitetthet** sammenlignet med andre brenselstoffer.

Mens hydrogen er trygt , er det ikke helt fri for potensielle farer. Her er noen hydrogen gass sikkerhetsproblemer operatører må være klar over:

- Den har et stort eksplosivt område, sammenlignet med andre drivstoff
- Det brenner med en usynlig flamme
- Du kan ikke lukte, se eller smake på det

(Relatert innlegg: Brenselsikkerhet: Viktige fakta for transittoperatører)

But what about:

- The amount of energy required for a given application, such as a ship?
- The need for compressing gaseous hydrogen to 700+ bars for cars?
- The need for reducing the temperature of liquid hydrogen to less than 33 K (in practice closer to 20 K) for ships, rockets, etc.?
- The relatively advanced, and hence complex, systems required for handling liquid or gaseous hydrogen in society?

Promoting hydrogen

- One-sided promotion of the favourable aspects of hydrogen is problematic, for several reasons:
  - Owners and operators are likely to under-estimate hazards, and may accept and develop solutions that result in losses.
  - Consultants with limited experience from hydrogen may be convinced that their competence acquired from conventional fuels is sufficient to assess the risk for hydrogen systems.
  - Serious accidents can delay or terminate the development and implementation of emerging energy technologies
  - It is questionable from an ethical point to favour short-term financial gain over the development of safe and sustainable energy solutions (that may or may not be more costly …).

Legacy of hydrogen


Hindenburg (1937)


Ammonia plant, Herøya


Challenger (1986)


Chernobyl (1986)

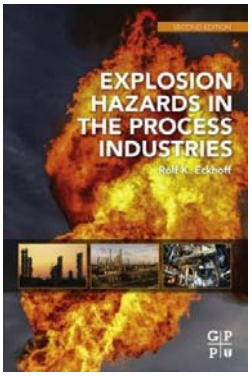

Fukushima Daiichi (2011)


Gangneung (2019)


Sandvika (2019)

Hydrogen safety

*"Widespread acceptance and use of hydrogen in society will require significant progress in the field of **hydrogen safety** – the discipline of science and engineering that deals with safe production, handling and use of hydrogen in industry and society in general."*

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3D risk management for hydrogen installations

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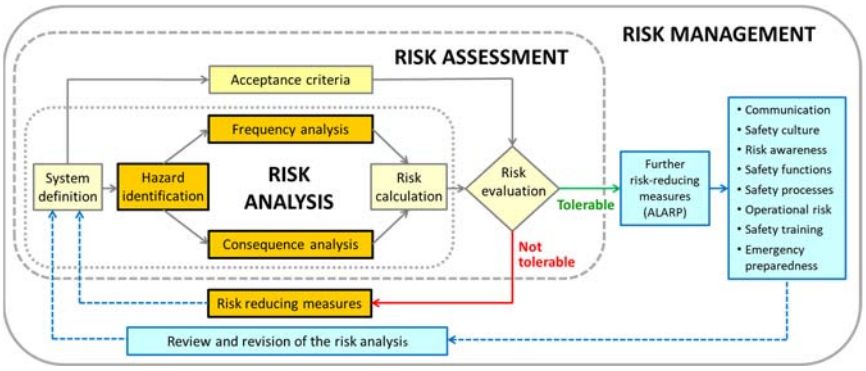
ABSTRACT
This paper introduces the 3D risk management (3DRM) concept, with particular emphasis on hydrogen installations (Hy3DRM). The 3DRM framework entails an integrated solution for risk management that combines a detailed site-specific 3D geometry model, a computational fluid dynamics (CFD) tool for simulating flow-related accident scenarios, methodology for frequency analysis and quantitative risk assessment (QRA), and state-of-the-art visualization techniques for risk communication and decision support. In order to reduce calculation time, and to cover escalating accident scenarios involving structural

Safety and risk

- The evaluation of the safety for a technical system will typically entail a qualitative or quantitative risk analysis.



Air Liquide hydrogen refuelling station in Paris

Hydrogen refuelling station in Sandvika

- Recent accidents demonstrate the importance of energy-related safety and security for emerging technologies, including hydrogen.

Hydrogen refuelling station at Sandvika on 10 June 2019. Photo: https://www.nrk.no/nyheter/eksplosjon-ved-hydrogenstasjon-1.14582944

Knowledge gaps

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Perspective

Fires and explosions

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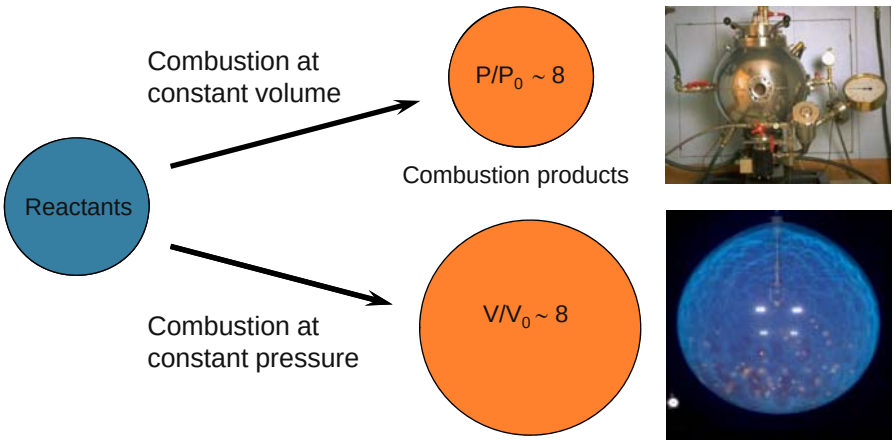
Keywords: Fires, Explosions, Safety, Loss prevention, Risk assessment, Scaling, Knowledge gaps

1. Introduction

Accidental fires and explosions cause severe losses in society. Examples of such events range from domestic accidents, such as dwelling fires, to devastating fires in densely populated areas and high-rise buildings, such as the recent fire in the Grenfell Tower (14 June 2017, about 80 fatalities), and large industrial disasters, such as Flixborough (1 June 1974, 28 fatalities), Piper Alpha (6 July 1988, 167 fatalities), Buncefield (11 December 2005), Deepwater Horizon (20 April 2010, 11 fatalities) and Fukushima Daiichi (11 March 2011). Many of the largest property losses in industries over that solve conservation equations for mass, momentum, energy and chemical species. It is essential for the quality of loss-prevention standards, risk assessments, and hence for loss prevention, safety and security, that engineers understand the underlying assumptions and inherent limitations of the tools they use, as well as the level of accuracy they can expect in the results.

Although the governing equations for turbulent fluid flow with chemical reactions are well established, there are still many gaps in the fundamental understanding of fire and explosion phenomena. This understanding is being explored using analytical methods, Direct Numerical Simulation (DNS), and high-fidelity Large Eddy

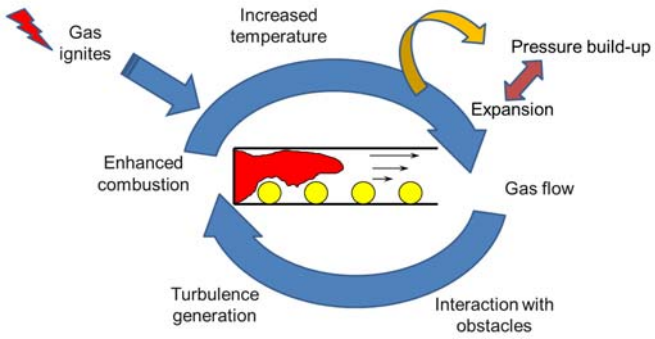
Premixed combustion



$$pV = nR_uT = \frac{m}{M_w}R_uT \quad \Rightarrow \quad \rho = \frac{m}{V} = \frac{pM_w}{R_uT}$$

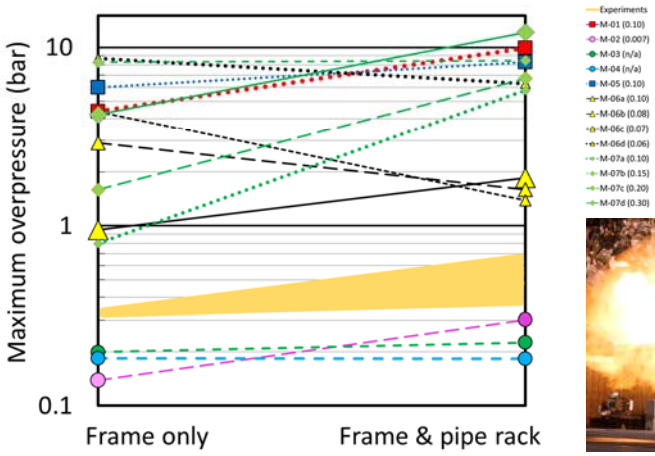
Flame acceleration

- The positive feedback between expansion of combustion products, generation of turbulence in the unreacted mixture, especially in wakes behind obstacles, and enhanced rate of turbulent combustion causes flame acceleration in congested geometries.



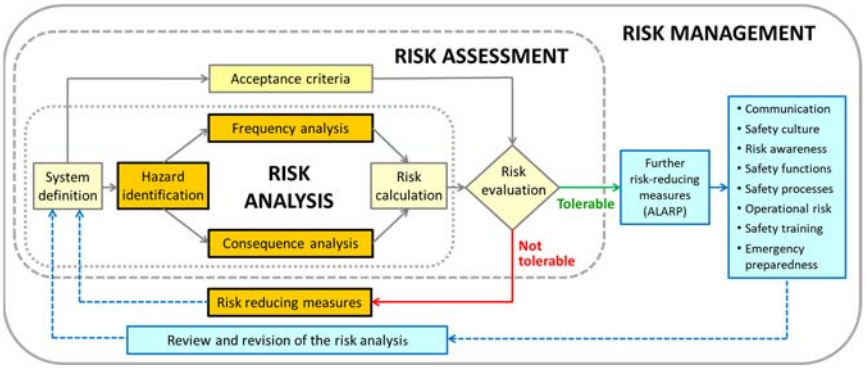
HySEA blind-prediction study

- The blind-prediction benchmark studies conducted as part of the HySEA project (FCH 2 JU & Horizon 2020) revealed severe lack of predictive capabilities for state-of-the-art tool used for risk assessments in industry.

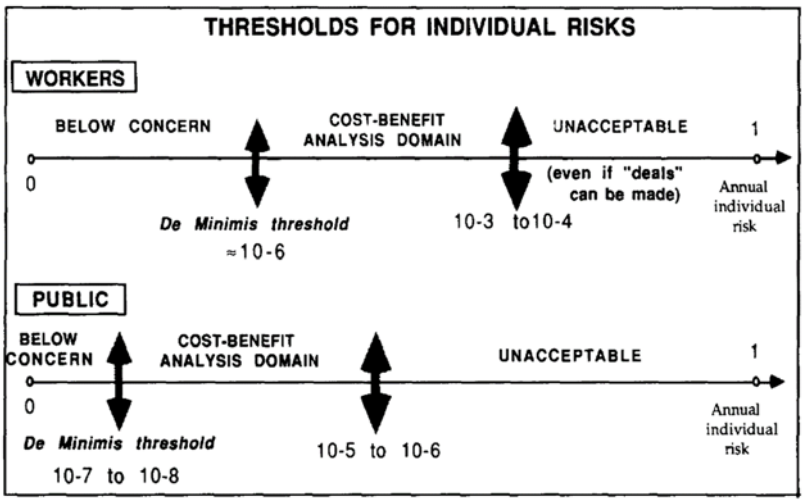


Safety and risk

- There is significant difference between the acceptance criteria for workers in a closed facility and the public.



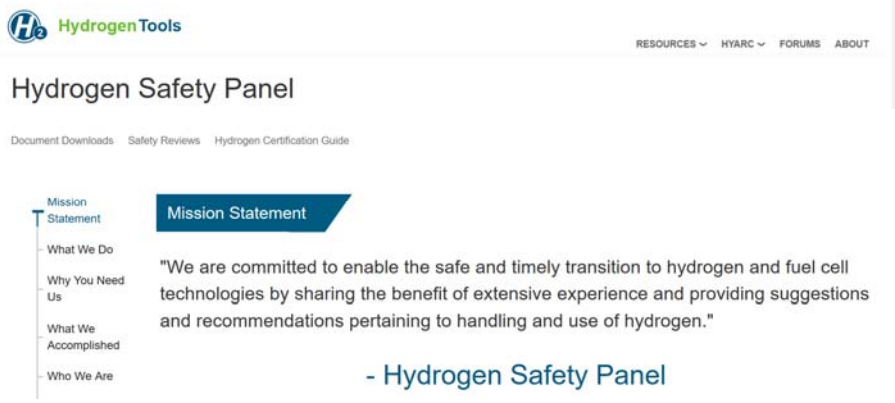
Acceptance criteria



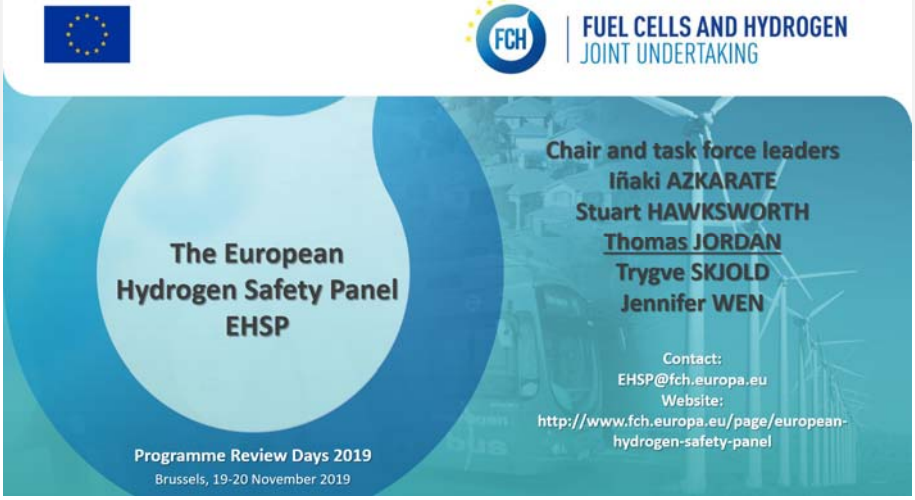
Paté-Cornell, M.E. (1994). *Structural Safety*, 13: 145-157.

US Hydrogen Safety Panel (HSP)

- Web: https://h2tools.org/hsp



European Hydrogen Safety Panel (EHSP)



European Hydrogen Safety Panel (EHSP)

- FCH JU launched the European Hydrogen Safety Panel (EHSP) in 2017.
- The EHSP shall 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 applications**.
- Web page: https://www.fch.europa.eu/page/european-hydrogen-safety-panel

FCJ JU PRD, Brussels, 19-20 November 2019

Activities of the EHSP

Summary

- Hydrogen and fuel cell technology is expected to play an important role in future energy systems.
- However, specific properties of hydrogen, and hydrogen-air mixtures, imply that accidental **fires and explosions represent a serious hazard** for systems where hydrogen is used as an energy carrier.
- Hydrogen safety is an **active area of research**.
- Remaining knowledge gaps imply **significant uncertainty** in risk assessments for hydrogen systems – this should be reflected in design and safety measures!
- Several of the conventional methods for risk assessment and risk-reducing measures are not directly applicable or sufficient for hydrogen systems.
  - It takes time to accumulate significant data for event frequencies
  - There is significant uncertainty associated with consequence modelling
  - The inherent uncertainty in risk assessments must be reflected in sufficiently robust design of hydrogen installations.
  - **Optimal design requires reliable consequence models!**

Activities at UiB

- **PhD project** on solid suppressants for hydrogen explosions
  - Supported by Total (patented concept), start-up 1 April 2020
- Centre for research-based innovation (SFI-IV) **RESPONSE**
  - Submitted in 2019, focus on hydrogen in industry and society
- Hydrogen as an energy carrier in society: risk picture, risk awareness and public acceptance (**HySOCIETY**)
  - Internal proposal submitted to UiB
- Centre for Electrocatalytic Ammonia Production from Offshore Wind (**CEAPOW**)
  - Proposal for VISTA-centre submitted on 29 February 2020
- EU proposal on hydrogen-based fuels for passenger ships
  - Proposal deadline 21 April 2020

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Questions?

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