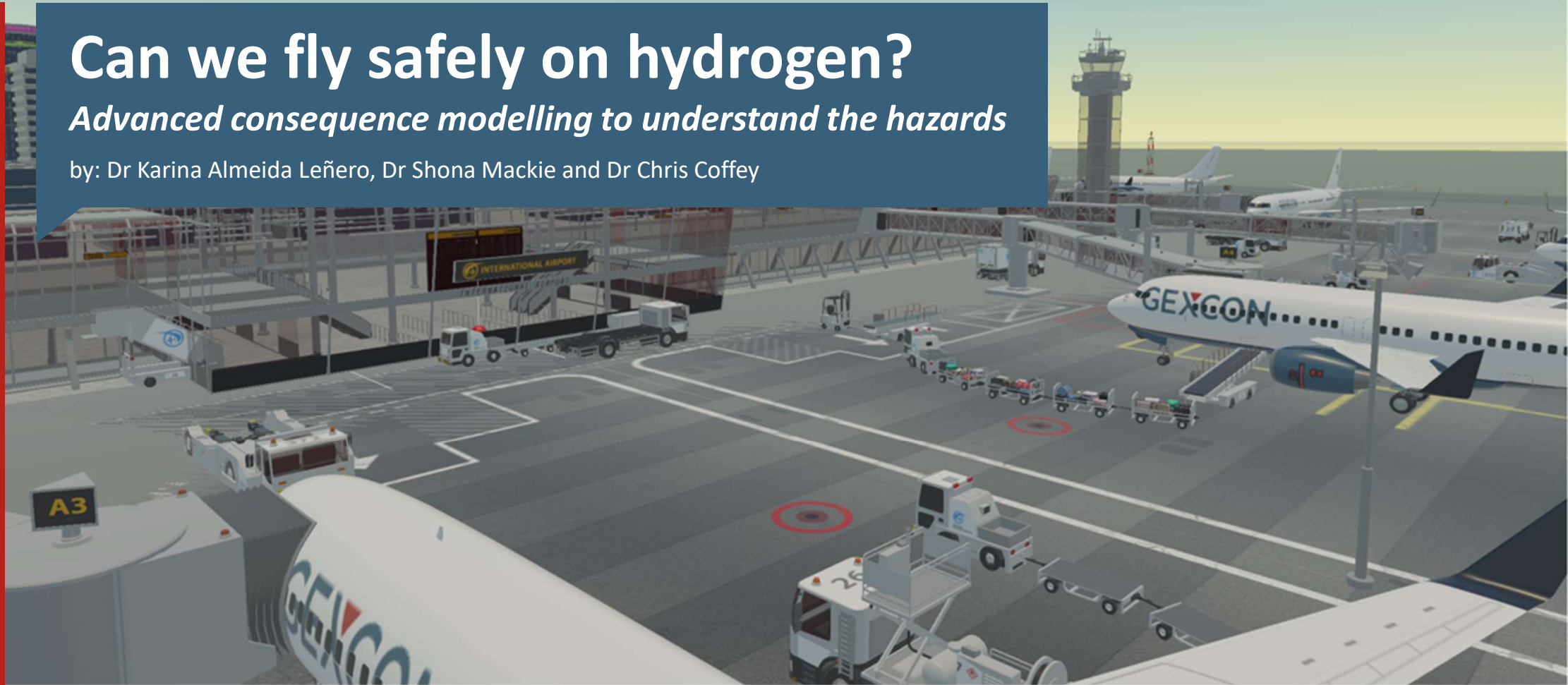


Can we fly safely on hydrogen?

Advanced consequence modelling to understand the hazards

by: Dr Karina Almeida Leñero, Dr Shona Mackie and Dr Chris Coffey



Outline

What makes hydrogen special?

About Gexcon

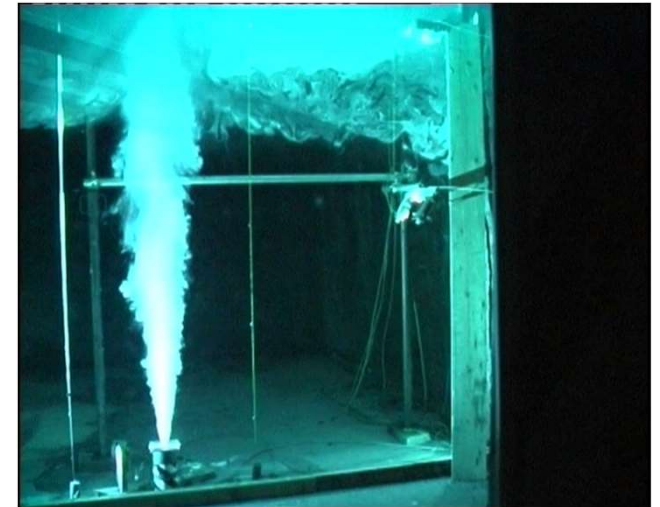
Case Study: Liquid hydrogen release during hydrogen refuelling

What makes hydrogen special?

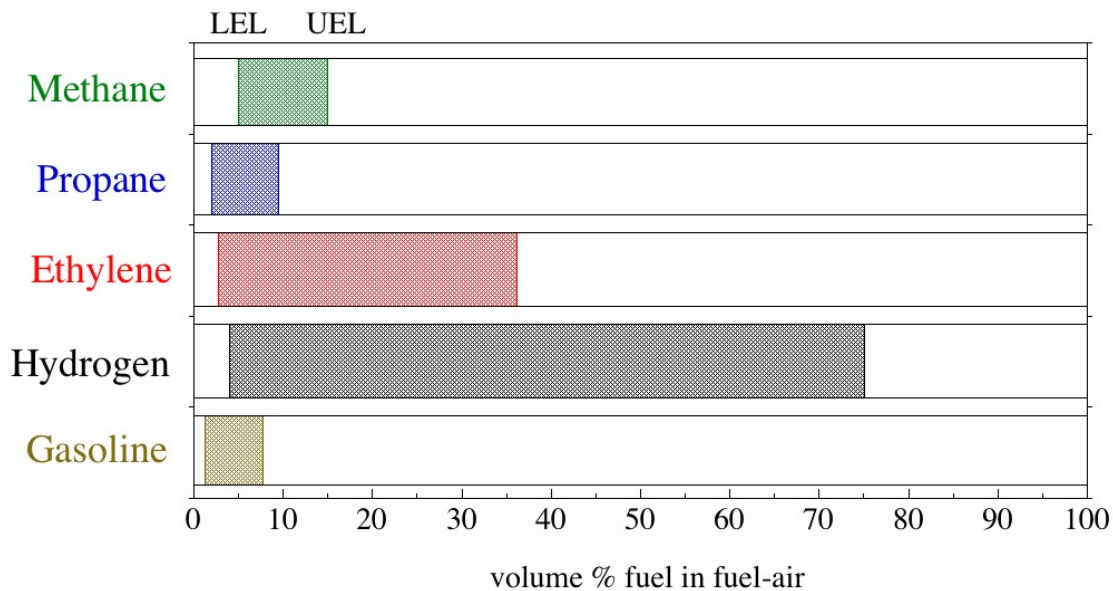


Hydrogen at a glance

- Extremely buoyant:
 - ✓ 14 times lighter than air
 - ✓ Rises 6 times faster than natural gas
- Odourless and non-toxic
- Wide flammability range: 4 -75 %
- Very small molecule – leaks easily
- Laminar burning velocity about 3 m/s.
 - 6 times faster than hydrocarbon gases
- Low ignition energy: ~10% of the ignition energy for hydrocarbon gases
- Negative Joule-Thompson effect and tendency for auto-ignition of leakages from high pressure



Flammability & Ease of Ignition



Ignition Sources

- Electrostatics
- Frictional Heat and sparks
- Spontaneous ignition

Minimum ignition energy (electric spark)

- Acetone 1.15 mJ
- Jet A1 (@ 55°C) ~1 mJ
- Gasoline 0.80 mJ
- Methane 0.28 mJ
- Butane 0.26 mJ
- Ethylene 0.07 mJ
- Acetylene 0.017 mJ
- **Hydrogen 0.011 - 0.017 mJ**
- Carbon disulphide 0.009 - 0.015 mJ

Fuel Reactivity

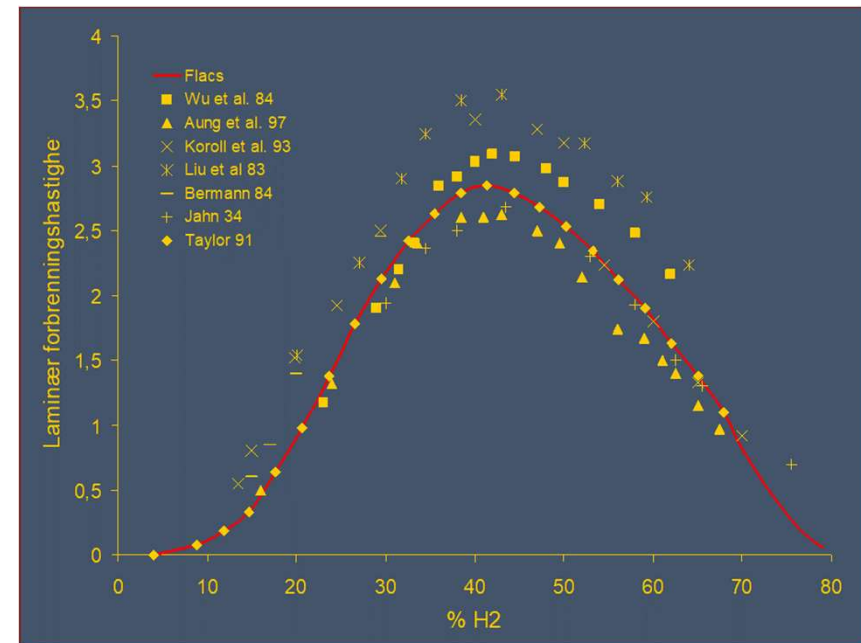
What is an explosion?

Violent release of energy resulting from a **rapid chemical** or nuclear reaction, especially one that produces a shock wave, loud noise, heat and light.

(Collins English Dictionary)

Typical laminar burning velocities

- methane: 0.40 m/s
- propane: 0.46 m/s
- ethylene: 0.75 m/s
- acetylene: 1.55 m/s
- **hydrogen: 3.25 m/s**



Why worry?

- Hydrogen has been used in industry for decades.
- Novel applications of hydrogen, some much closer to the public.
- Increased used of liquid hydrogen – it's not just like LNG!
- To achieve the correct design and operating routines, it is important to understand the physical characteristics of hydrogen and its behaviour in a safety context.
- Need to accurately predict what happens upon loss of containment and to investigate a variety of scenarios.
- Gexcon has taken a leading role in research and development on hydrogen safety

Who is Gexcon?



Our Goal

TO UNDERSTAND CAUSES

Increase Knowledge & Understanding of the Physical Phenomena Which Result in Occupational Accidents



TO MITIGATE CONSEQUENCES

Limit the Impacts or Damage to Plant and Environment Due to Incidents Occurring



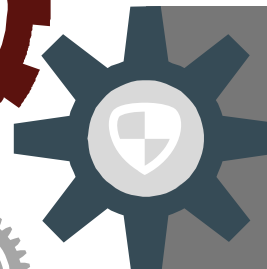
TO PREVENT

Procedures, Material Properties, Correct Choice of Equipment to Prevent Accidents From Occurring



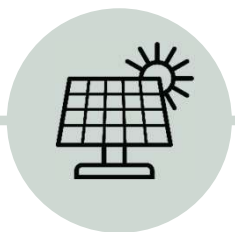
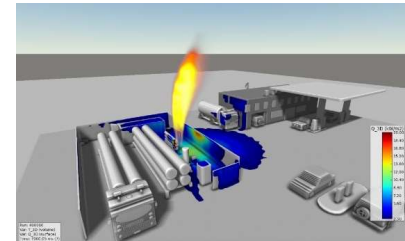
TO PROTECT HUMAN LIFE

Develop Standard of Safety Practice to Prevent Any OSH Accident To Happen

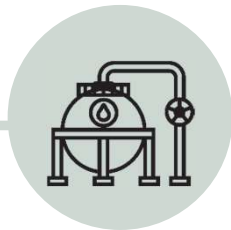


Expertise in Hydrogen Safety

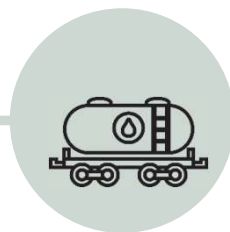
- Gexcon has already acquired a strong experience on various H₂ related projects
 - Process safety and safety reviews
 - Assistance for conceptual phase : safety distances, arrangement/layout optimization
 - Modeling of accidental events : dispersion, explosion and fire
 - Optimization of ventilation and gas detection
 - Prevention and mitigation measures
 - Design of structures and equipment to withstand accidental events



PRODUCTION



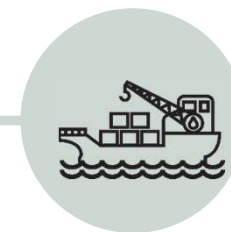
STORAGE



TRANSPORT



DISTRIBUTION



MOBILITY

Our Offering



Software

Consulting

Fire & Explosion
Testing

Courses



Aircraft refuelling hazards – A case study



Questions about the refuelling operation

- Can liquid hydrogen powered aircraft be refuelled next to the terminal, as with conventional fuels?
 - Is a “H₂ refuelling hub” away from the terminal & other planes required?
- Is it acceptable to have passengers aboard the aircraft while refuelling?
- Is it necessary to establish a “safety perimeter” while refuelling?
- Which sort of equipment is required?
- Is the existing inspection & maintenance regime adequate?
- What are the emergency procedures in case of a hydrogen leak?

Case Study: Leak during bunkering operation



- Assume pure liquid hydrogen at 5 barg.
- Assume all liquid vapourises (no pool formation)
- 25mm leak size
- Leak occurs either at truck-hose connection or at plane-hose connection

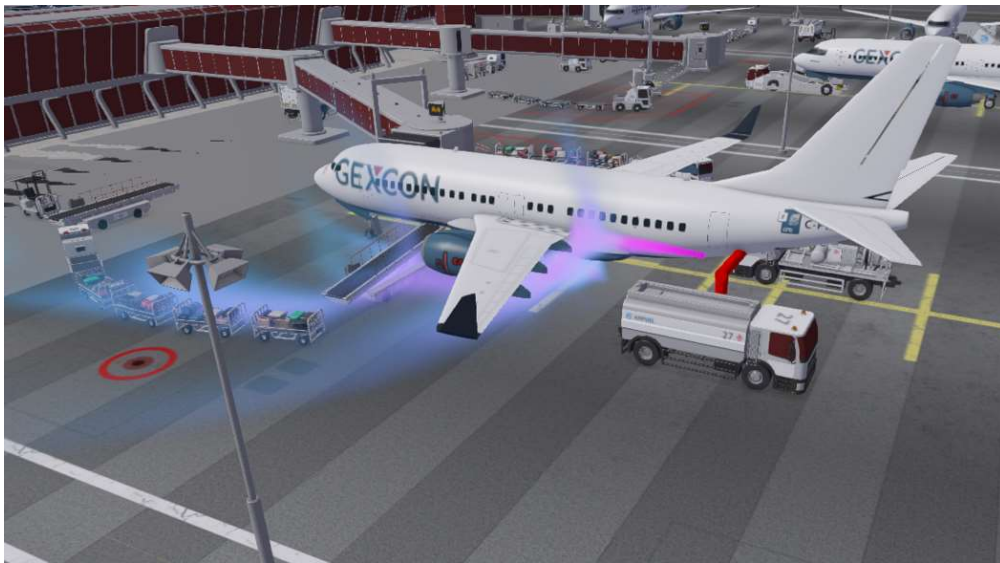
Hydrogen Dispersion- Leak under plane



Hydrogen Dispersion - Leak next to refuelling truck



Hydrogen Dispersion – Effect of leak position



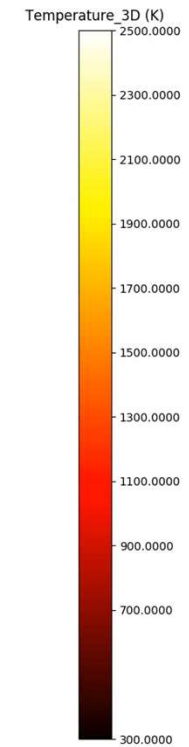
Leak under plane



Leak at refuelling tanker

And if the cloud were to be ignited?

Leak under plane



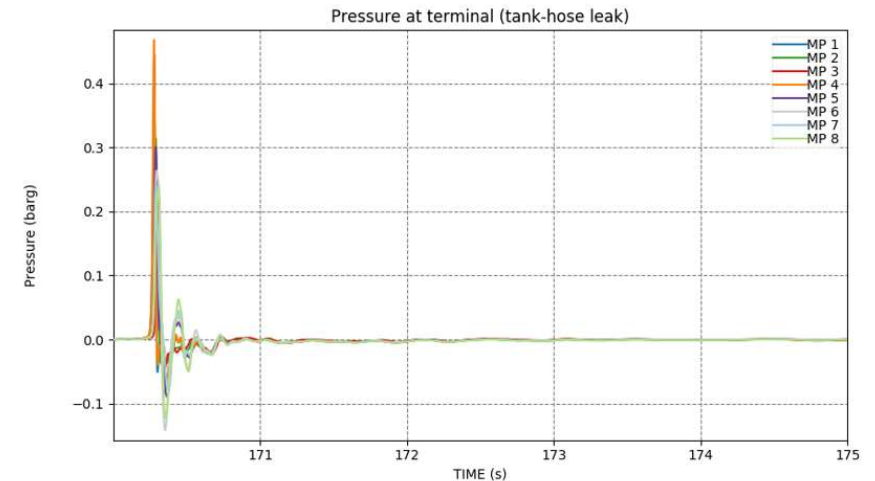
And if the cloud were to be ignited?

Leak at refuelling truck

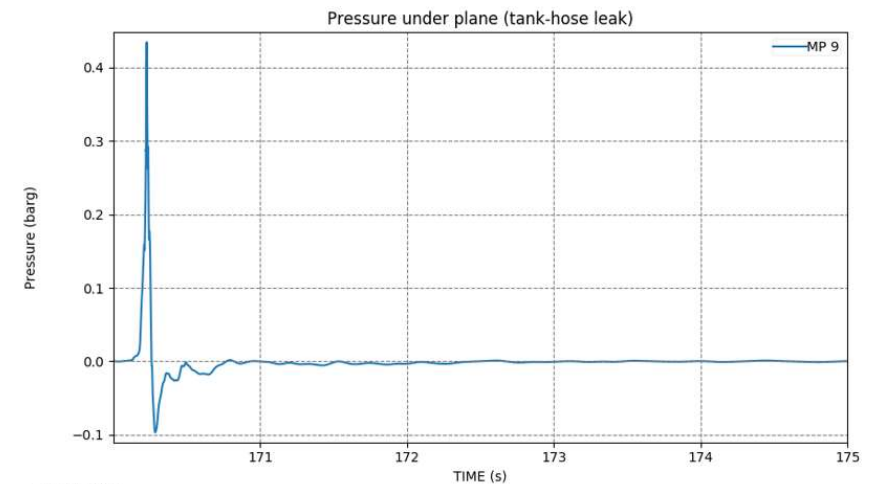


Potential Impact of Ignited Leak

- Potential for high overpressure at terminal building – likely to cause injuries and structural damage
- Potential for damage to the plane
- Fireball is transient, but presents a severe hazard to people around the plane



Run: 090025
Var: Pressure



Run: 090025
Var: Pressure



Conclusions

- The aviation industry has a strong safety culture, but the hazards from hydrogen are different.
- The refuelling operation for hydrogen planes can present a significant hazard to people and infrastructure.
 - Adequate process safety management required from the concept stage
- The risks can be mitigated by sound design and operation according to strict safety protocols.
- Advanced consequence modelling tools can help understand the hazards posed by unintended hydrogen releases and evaluate different mitigation measures.
- NOW is the right time to take a holistic approach to the safety of hydrogen in aviation.

Designing for Safety

- Process safety teams & consultants can add the most value at the beginning of a project, when options are open.
- Changes are easier & cheaper at the design phase
- Avoid nasty surprises
- Avoid over-designing or mitigating the wrong hazard



If in doubt, come talk to us!!!

Thank you for your attention

GEXCON

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