Uncertainties in Explosion Risk Assessment for a Hydrogen Refuelling Station

Koos Ham, Matthijs de Maaijer, Vincent van den Hoogenband,
Marcel Weeda, Jaco Reijerkerk and Gert Jan Kramer

The THRIVE project – Towards a Hydrogen Refuelling Infrastructure for Vehicles

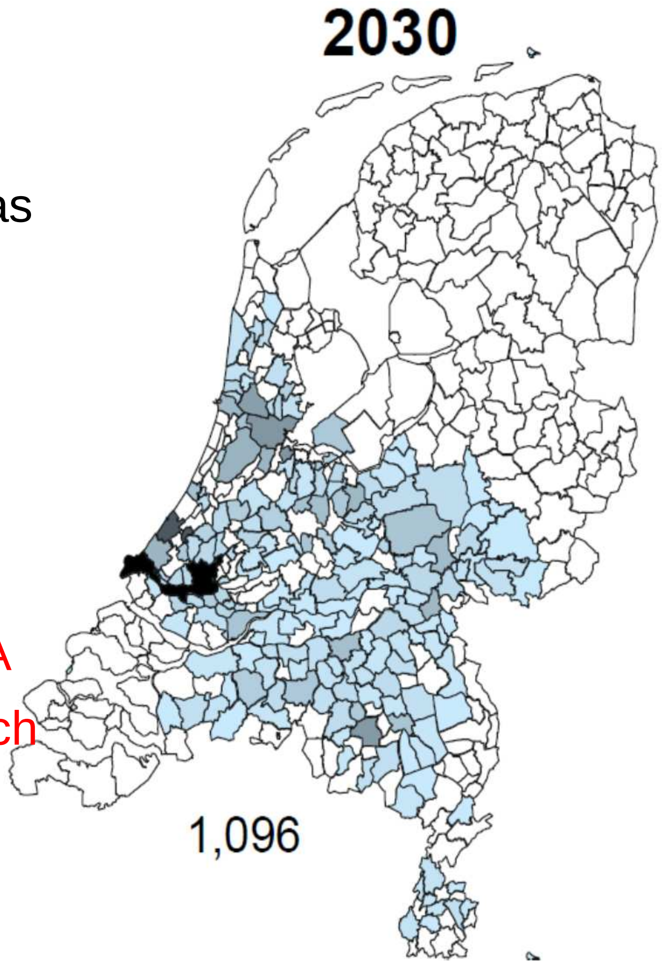
Joint effort of:

- Energy research Centre of the Netherlands (ECN) - coordinator
- TNO
- Linde Gas Benelux B.V.
- Shell Global Solutions International B.V.

The THRIVE project – Towards a Hydrogen Refuelling Infrastructure for Vehicles

Objectives:

- Requirements for the development of a sustainable infrastructure of hydrogen as a car fuel in The Netherlands.
- Evaluation of economic drivers and environmental opportunities.
- Scenarios for expected growth of this infrastructure between 2010 and 2050.
- Requirements for a (standardised) QRA model for HRS, to be formalised in Dutch legislation



QRA requirements in The Netherlands

Objectives:

- Environmental legislation: QRA necessary for licence to operate
- Land-use planning: no vulnerable objects within risk zones
- Emergency preparedness: scenarios determined by QRA

Regulatory instrument:

- Generic set of scenarios: loss of containment events (LOCs)
- Generic set of failure frequencies, for each LOC
- Prescribed methodology, in Guidelines HaRi-2009 and software

QRA for ‘new’ activities should -in principle- follow the existing structure

The THRIVE project – the risk study

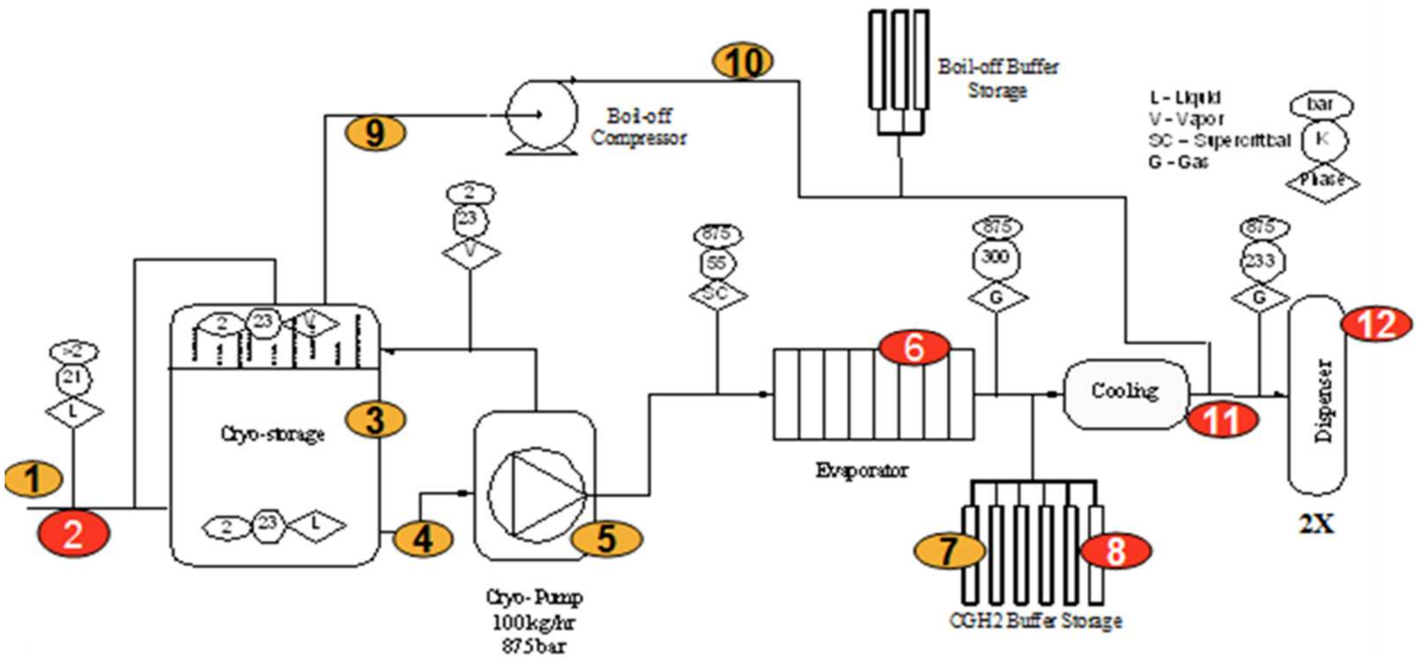
- Project included a study into possible safety risks of accidents with hydrogen in a hydrogen refuelling station (HRS)
- What is needed in risk assessment methodology for HRS within Dutch QRA regulations? Would HRS fit within risk contours of LPG?
- Focus on risks to the surroundings (the built environment)


Uncertainties and knowledge gaps in performing QRA for an HRS

1. (Variations in) type of refuelling installation for hydrogen: technology and lay-out
2. Uncertainties in scenario identification: which LOC’s are credible?
3. Knowledge gaps in effects modeling and consequence assessment: how to deal with extreme conditions of temperature, pressure and gas density?
4. Uncertainties in failure rates and incident frequencies

Reference refuelling station for THRIVE

- LH_2 delivery (truck) and storage in above-ground cryogenic tank
- Transfer by Cryo-pump, via evaporator, to high pressure CGH_2 buffer
- Refuelling of CGH_2 to vehicles via dispenser, at p ~ 75 MPa
- Boil-off recovery and storage is provided.

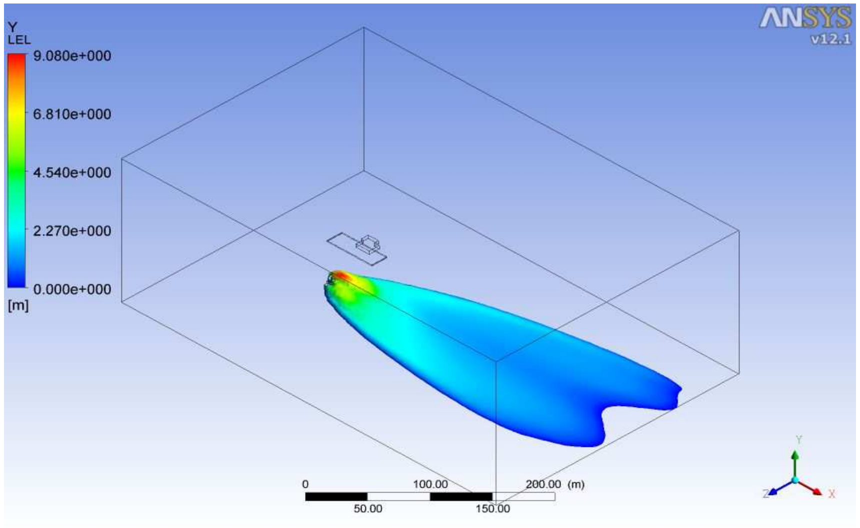


Explosion risk modelling: effects, parameters and tools

Parameter uncertainties	Effect / Consequence	Data, tools and gaps
• Type of fracture • Direction of release • Composition Liquid/Vapour	LOC event: release LH_2	• Scenario definition (e.g. HaRi guide recommendations) • Frequency data (scarce)
• Presence of obstacles • Subsoil • Temperature / humidity • Cloud density • Initial concentration upon mixing with air	↓ Initial gas cloud + pool evaporation	• Local conditions • Physics, e.g. Yellow Book (LH_2 conditions beyond validity range) • Expert's definitions for source term fit for dispersion model
• Weather conditions (wind velocity) • Thermodynamics and interaction with air; phase transition • Atmospheric turbulence / boundary layer • Geometry of obstacles	↓ Cloud formation & dispersion	• CDF modelling (FLUENT code) • Expert's judgement on code specification, to obtain convergence for far field • Sensitivity to definition of pseudo source and initial velocity • Impact due to confinement (e.g. roof) • Integration of flammable mass
• Turbulence of flow • Cloud confinement • Nature and location of ignition	↓ Explosion: Overpressure + damage	• Multi-energy method • Worst case approach for ignition location and time • Probabilistic approach not feasible

Dispersion calculations with CFD

- CFD is increasingly used to study complex dispersion phenomena. It provides insight into influences on dispersion, not available from other models.
- No validated models are available for modelling dispersion of a large spill of liquid hydrogen.

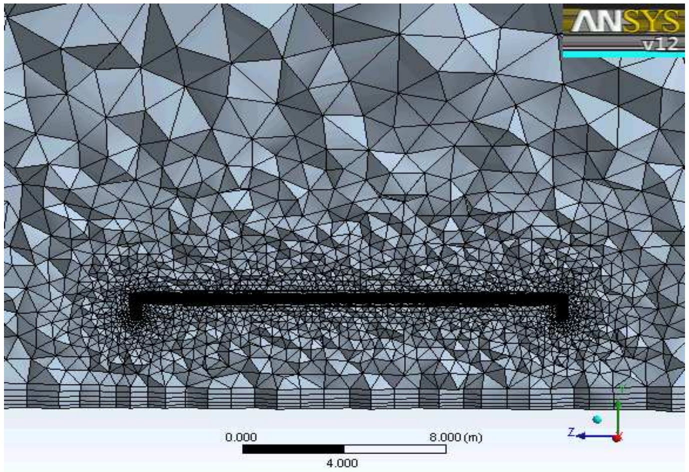


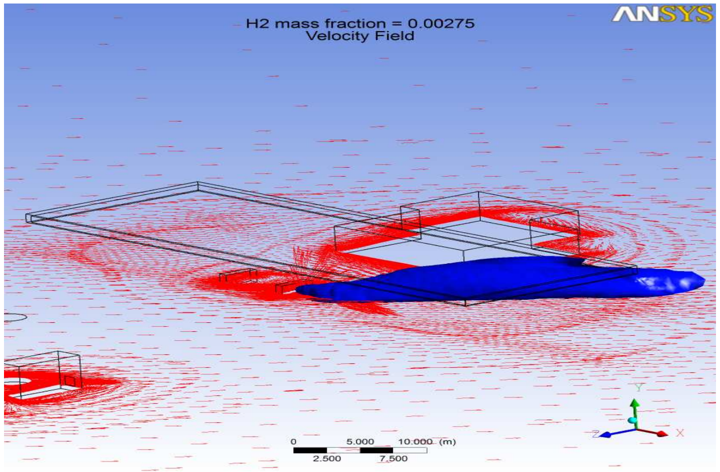
Models need to be developed and validated in order to properly assess the potential consequences of LOC events in an HRS.

Dispersion calculations with CFD

Known challenges in atmospheric dispersion calculation with CFD:

- Source term modelling: strong influence on outcome; high velocity releases require fine local mesh and long calculation times.
- Atmospheric boundary modelling: velocity and turbulence of boundary layer profile; determination of roughness and turbulence model.





The use of CFD for atmospheric dispersion calculation is still under development. Ideally, the used models should be validated with actual releases.

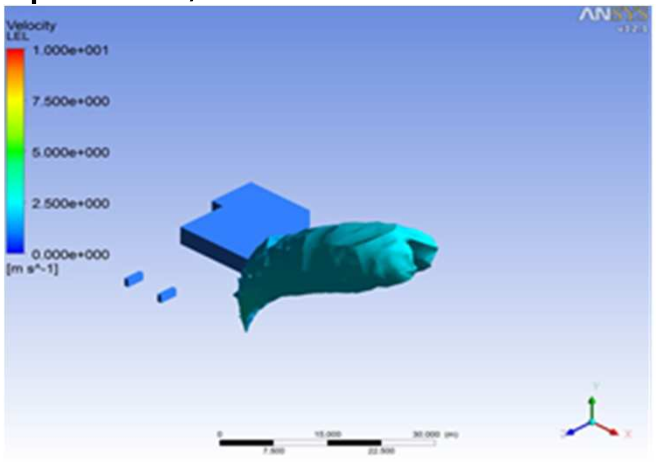
 

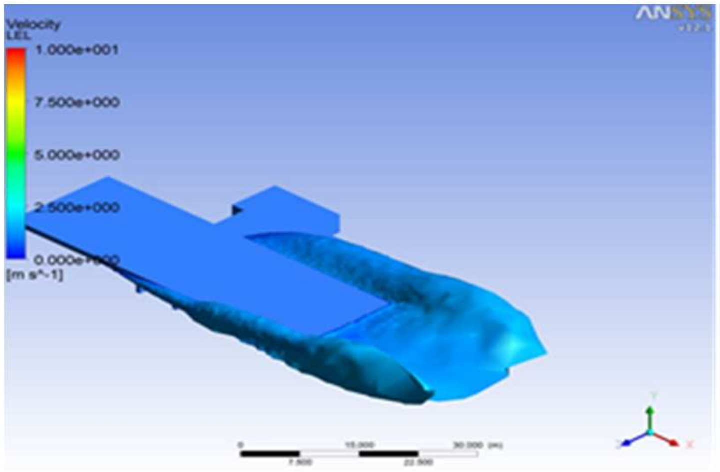
TNO innovation for life

Example Case 11a:
Pipe rupture between buffer storage and dispenser

Release: Q = 1.36 kg/s, at p = 85 MPa; D_{pseudo} = 85 mm

Dispersion, at u = 1.5 m/s:





Without roof	With roof
m_{expl} = 10.9 kg	m_{expl} = 33.0 kg
$R_{3\ kPa}$ = 191 m	$R_{3\ kPa}$ = 276 m
$R_{10\ kPa}$ = 68 m	$R_{10\ kPa}$ = 98 m
$R_{30\ kPa}$ = 32 m	$R_{30\ kPa}$ = 46 m

What is needed for an appropriate QRA?

- A clear and closed design of the installation, its way of operation, its equipment and control systems and the spatial layout.

- Identification of realistic scenarios by LOPA and/or HAZOP (including efficacy of protective measures).

- Consensus about the incident scenarios (loss of containment events), involving the ‘minimum setting’ as per [HaRi, 2009] and modified for the hydrogen specific aspects and system designs.

What is needed for an appropriate QRA?

- State-of-the-art effect models for release, evaporation and dispersion of hydrogen

- Modelling recommendations from recent research

- Validation of models (particularly for dispersion modelling with CFD tools)

- Further experimental research on:
  - evaporation and dispersion of LH_2 releases,
  - explosion effects of large scale hydrogen clouds
  - heat radiation from hydrogen fires

What is needed for an appropriate QRA?

- Validation and further improvement of failure frequencies for hydrogen equipment. Demonstrate whether properties of this equipment justify the application of specific failure data, deviating from the generic [HaRi, 2009] figures.

- Evaluation of the ignition probability of hydrogen releases and dispersed mixtures of hydrogen-air, and possibly modification of the generic [HaRi, 2009] figures, thus accounting for hydrogen's high reactivity.

Acknowledgment

The THRIVE project was gratefully supported by:

NL Agency (formerly SenterNovem), of the
Dutch Ministry of Economic Affairs, Agriculture and Innovation

THRIVE partners are acknowledged:

ECN, Linde Gas Benelux, Shell Global Solutions and TNO

Thank you for your attention

koos.ham@tno.nl