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# Safety on GT Enclosures

## H2 fuel GT


Stefano Rossin

11/10/2022

# Hydrogen safety management in Gas Turbines

## Engine and package modifications

- Equipment validation & ATEX certification
- Sealing & Gasket
- Material compatibility
- Overall Gas turbine performance & durability analysis
- Start-up and shut-down procedures

### Auxiliary systems

| | | |
|---|---|---|
| Combustion System hydrogen ready | Fuel gas system, piping and valves | Blending skid |
| Ventilation system | Fire fighting system | UCP: Hardware & Software |
| Instrumentation, Fire&Gas and Flame detection sensors | Package purge requirements | Fuel gas analyzer |



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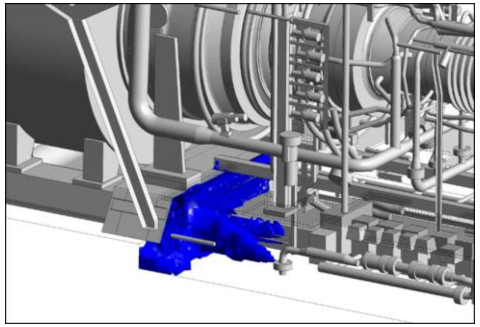
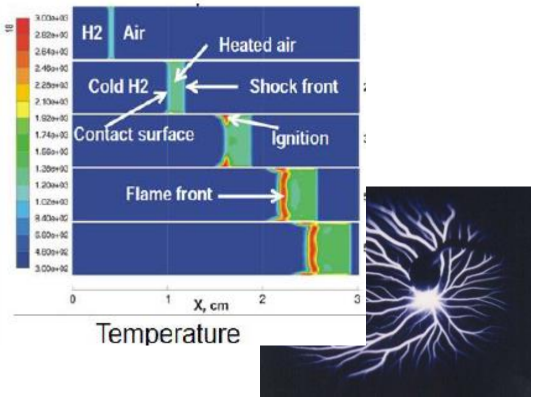
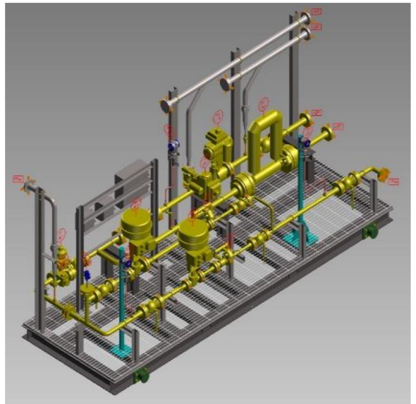
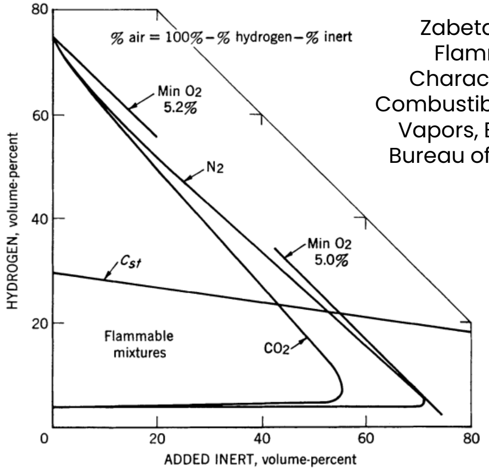
# Auxiliary System Safety





Fuel gas system




Zabetakis , M.G., Flammability Characteristics of Combustible Gases and Vapors, Bulletin 627, Bureau of Mines, 1970.

Fire Fighting system

## Gas Detection system:

Possible leaks and formation of combustible mixtures easily ignitable make the gas detection system utmost important. Local gas detectors on the fuel gas skid is often required.

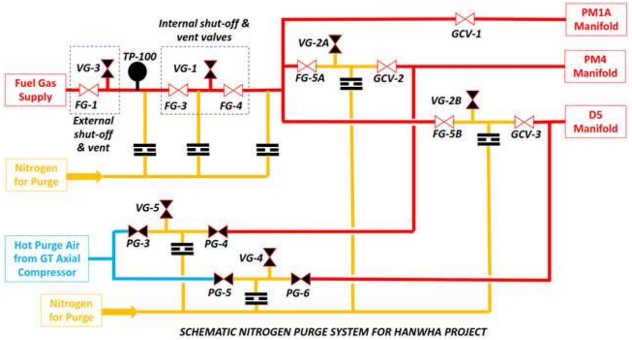
## Ignition phenomena:

As the engine is confined in an enclosed space any potential ignition source needs to be considered to avoid auto-ignition mechanisms to happen;

- Hot Surface Ignition
- Hot gas ignition,
- Diffusion Ignition
- Electrostatic Discharges

## The Nitrogen purge system :

it is often implemented in fuel lines to provide a proper barrier between air and hydrogen fuel.




## $CO_2$ Firefighting System:

hydrogen is highly reactive and requires a higher concentration of extinguishing agent.
There is a potential Increase of the number of $CO_2$ cylinders

NFPA12 requires 75% by volume of CO2 concentration to extinguish the fire, while it is required only 34% for pure methane.





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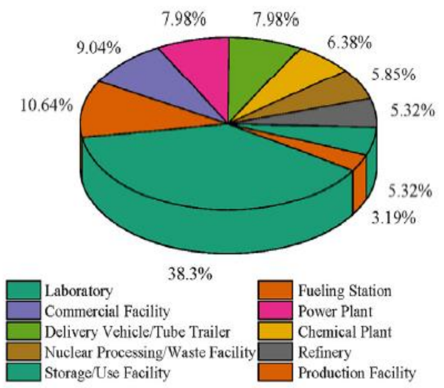
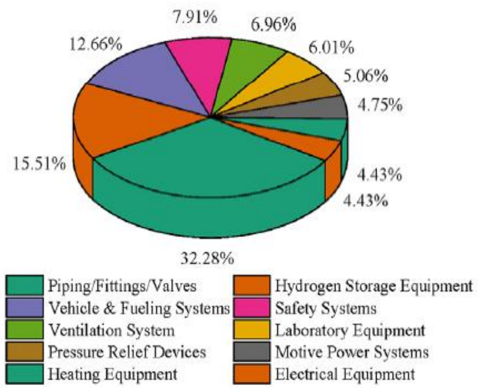
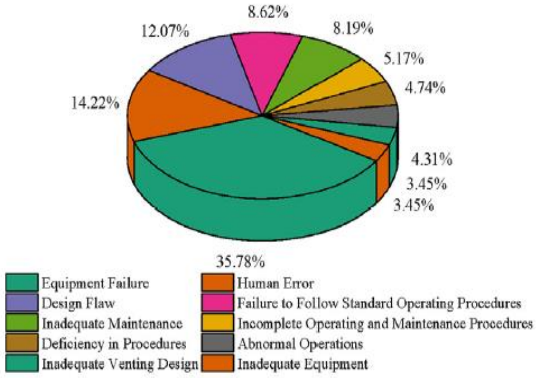
# H2 risk overall path



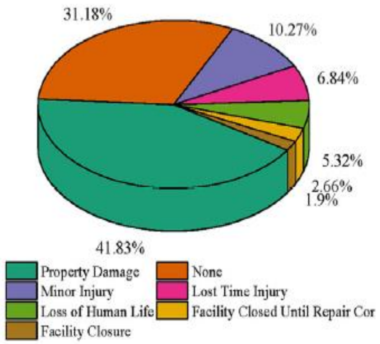

Incident location




Incident equipment




Probable causes



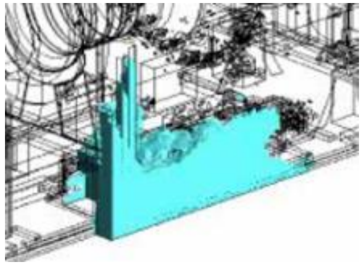

Damages and injuries

Yang F. et al., *Review on hydrogen safety issues: Incident statistics, hydrogen diffusion, and detonation process*

## Leak

To reduce all the possible source

## Dispersion



Gas dispersion inside enclosure and flammable mixture formation

## Detection

detect leak asap with suitable instrumentation

## Potential Ignition

remove possible source of ignition

## Explosion

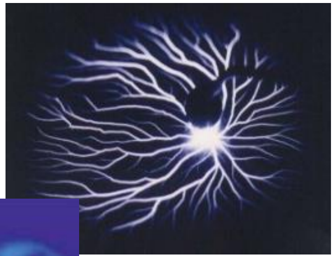
mitigate consequences

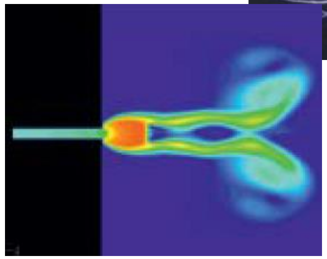
# Autoignition Mechanism

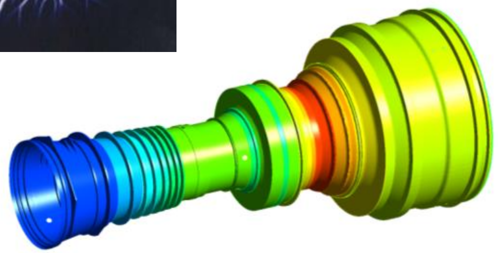
**Ignition phenomena:**

As the engine is confined in an enclosed space any potential ignition source needs to be considered to avoid auto-ignition mechanisms to happen:

- Hot Surface Ignition
- Hot gas ignition,
- Diffusion Ignition
- Electrostatic Discharges







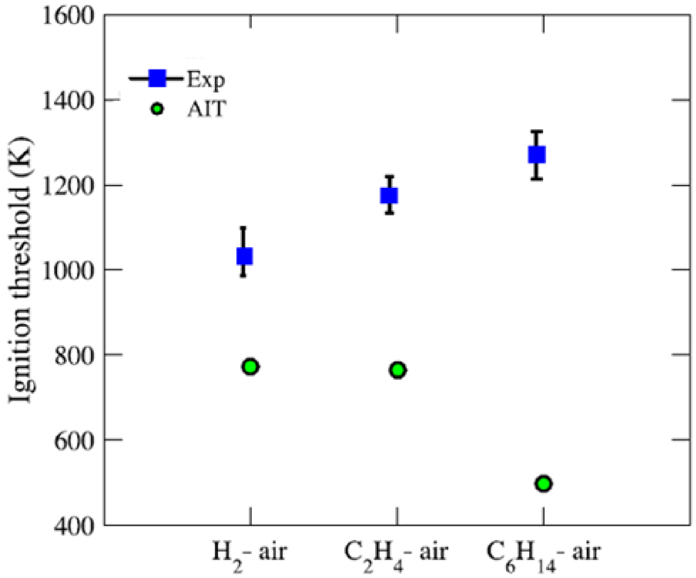
Hot gas ignition temperatures **HGIT** is close to the **HSIT** when the heat source diameter is the same. Both are higher than the AIT of the mixtures.

| Combustible Gas | HGIT *(air jet) | HSIT | AIT |
|---|---|---|---|
| Methane | 760°C | 780°C | 600°C |
| Hydrogen | 720°C | 750°C | 560°C |

Hot Gas Ignition Temperatures of Hydrocarbons Fuel Vapor-Air Mixtures, J.M. Kuchta, U.S. Department of the Interior Bureau of Mines

## Critical Parameters

- Exposure time
- Surface Temp
- Gas Type
- Surface Shape
- Surface Size
- Surface Material
- Surface Roughness
- Turbulent Flow




Boeck, L.R., Meijers, M., Kink, A., Mével, R., Shepherd, J.E., Ignition of fuel–air mixtures from a hot circular cylinder, Combustion and Flame 185 2,65–277, 2017.

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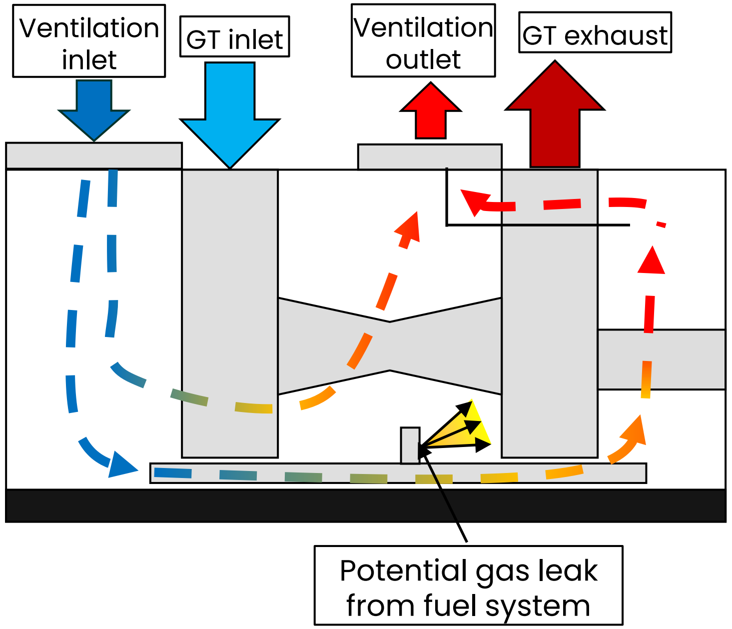
# Ventilation System

Gas Turbine is installed inside an acoustic enclosure to isolate the engine from the external environment

Ventilation system is required in order:

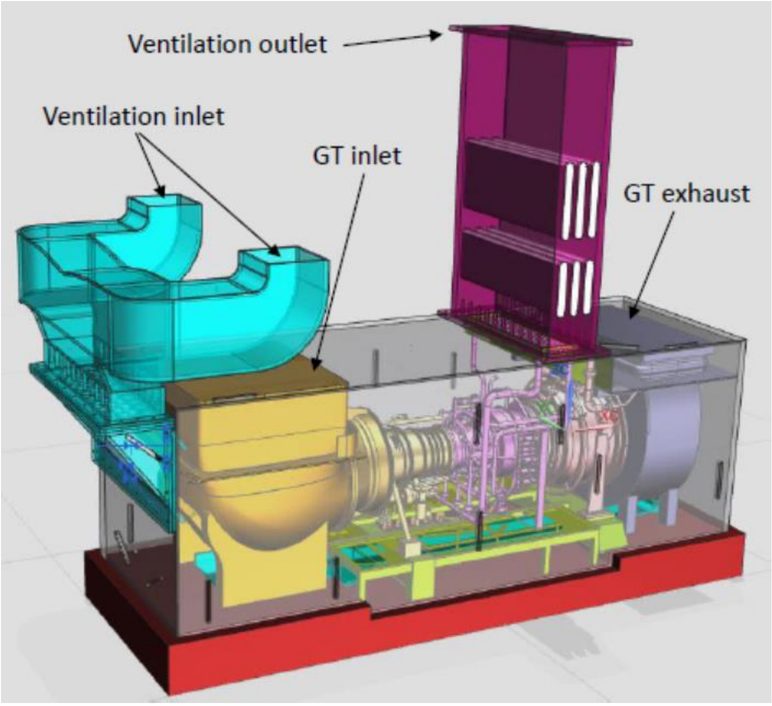
- ❑ to **limit the temperature** inside the packge under items certification temperature
- ❑ to **dilute accidental fuel gas leaks**

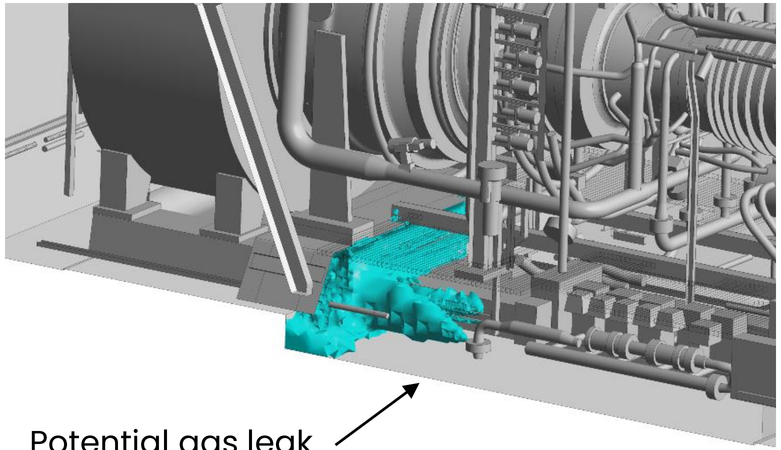



Fresh ventilation flow is injected upstream the package

Heat is removed and discharged downstream the package

Accidental gas leakages must be properly diluted



Potential gas leak from fuel system





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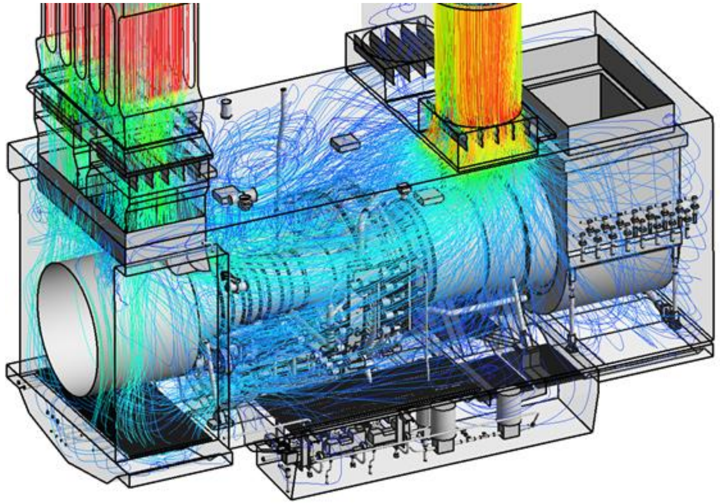
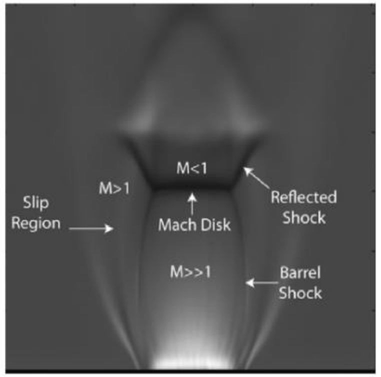
# Leak – Underexpanded jet

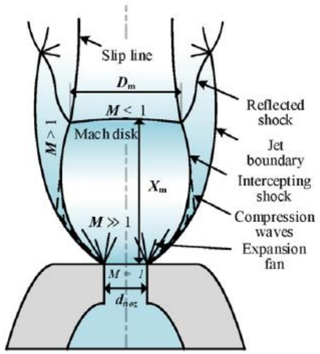
Complex geometry



Complex phenomenon

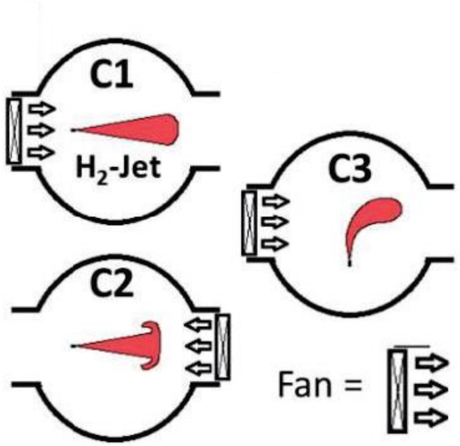



**a.** Hydrogen vertical jet morphology at 0.98 MPa

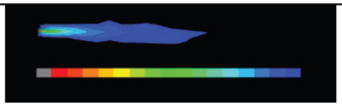
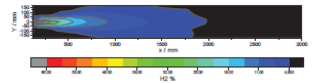
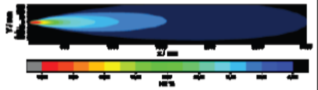
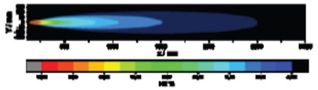
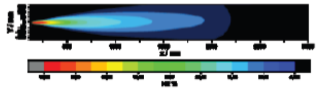
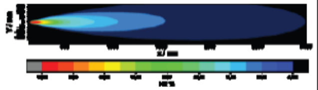
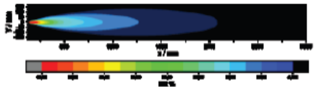
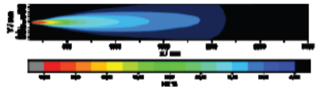



**b.** Structure of gas flow compression and expansion

Yang F. et al., *Review on hydrogen safety issues: Incident statistics, hydrogen diffusion, and detonation process*




Krune J., *Hydrogen jet structure in presence of forced co-, counter- and cross-flow ventilation*

| | No ventilation | Co-flow | Counter-flow |
|---|---|---|---|
| Experiment |  |  |  |
| UU-open atmosphere/ uniform profile |  |  |  |
| UU-vessel/ linear source term |  |  |  |

Giannissi S.G., Modelling of ventilated hydrogen dispersion in presence of co-flow and counter-flow

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# Sudden Rupture

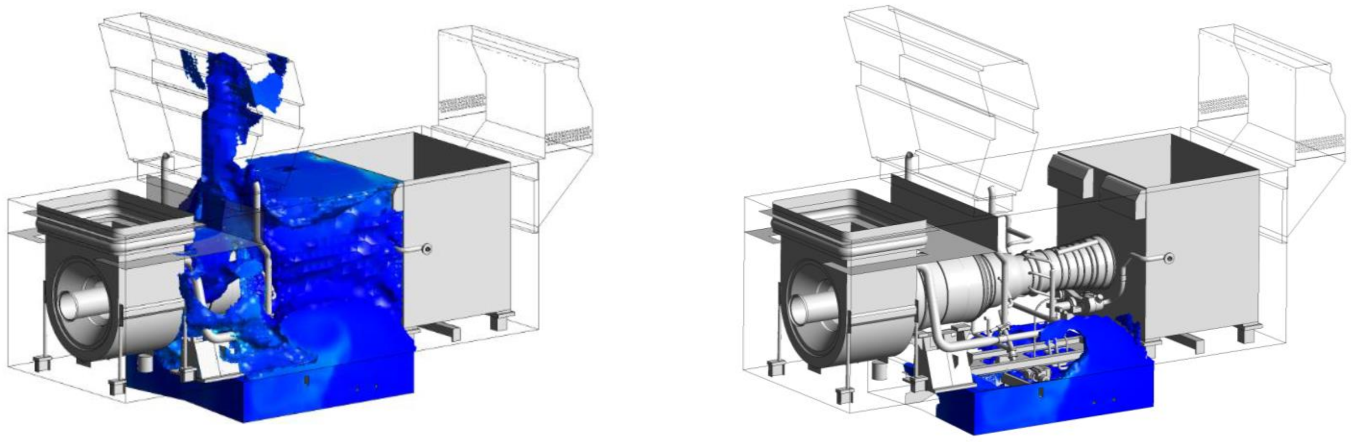
After less than a seconds from sudden rupture, $H_2$ cloud volume inside GT enclosure reaches value above ISO 21789 limit (0.15% net enclosure volume).

**<u>Sudden rupture</u>**
**Fuel Gas Pressure ≥ 30 barg**
**Leak mass flow rate ≥ 50 g/s**
**Leak section 16.5 mm² (1/4'' tubing section)**

<u>Detectable leakages</u>
Leak mass flow rate < 5 g/s
Leak section < 2 mm²

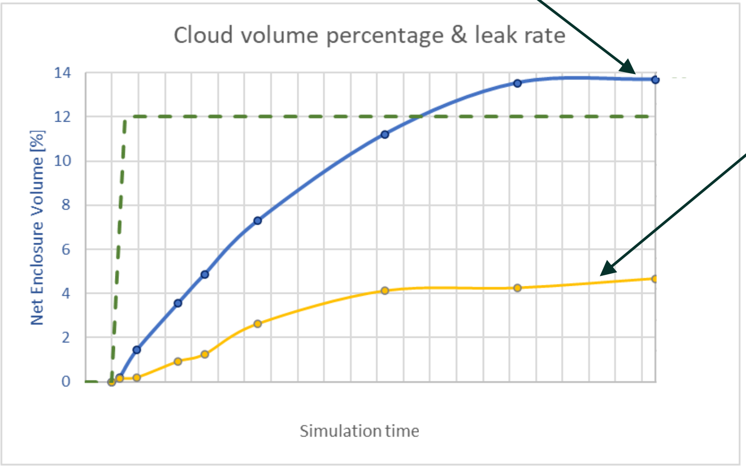
To be investigated:
- early gas detection;
- Reduce number of connections/leak sources
- orifice for tubing, where it is feasible.

*Transient evolution of leak cloud*



4% vol (100% LFL)

18% vol







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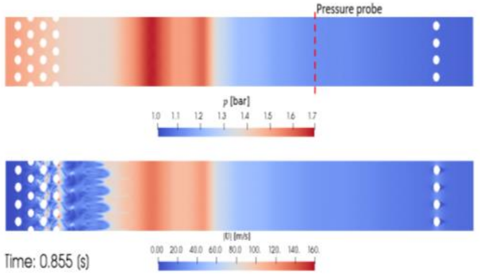
# Gas Leak Analysis – Exploring CFD options

## *openFoam*

**Smaller Domains**

Pro
- Dispersion
- Fire and Explosion
- Chemistry

Cons
- Higher computational cost




## *PowerFlow (LBM)*

**Diffusive Dominated**

Pro
- Multiphase study
- “meshless” approach

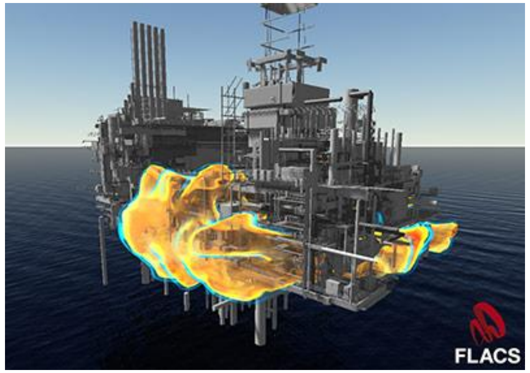
Cons
- Accuracy to be proven with high gradients


## *Flacs*

**Large Domains**

Pro
- Dispersion
- Fire and Explosion
- Chemistry

Cons
- Based on Distributed Porosity approach, cannot resolve all obstacles

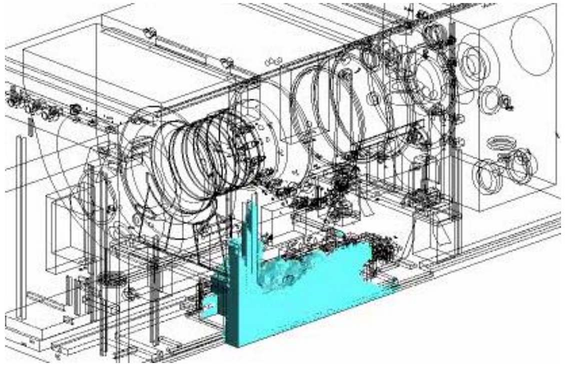



## *CFX - Fluent*

**Turbulent Flow**

Pro
- consolidated experience
- proven accuracy

Cons
- Long execution time mainly for transient study



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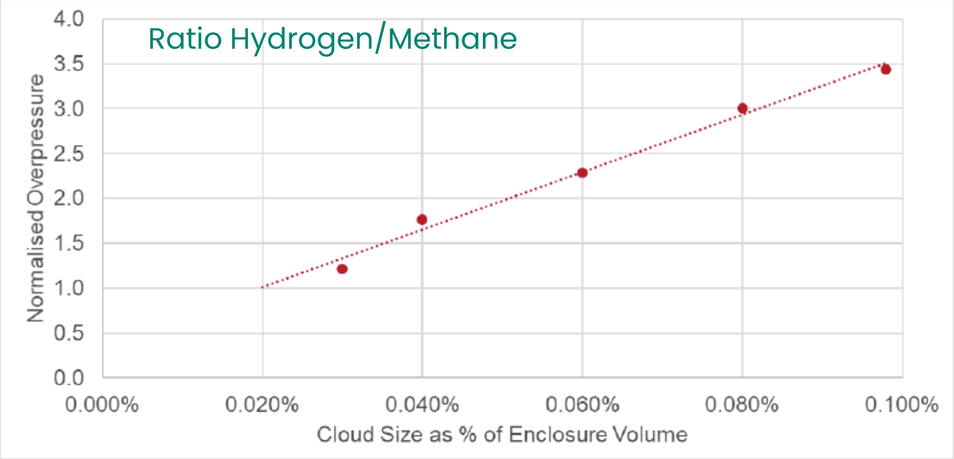
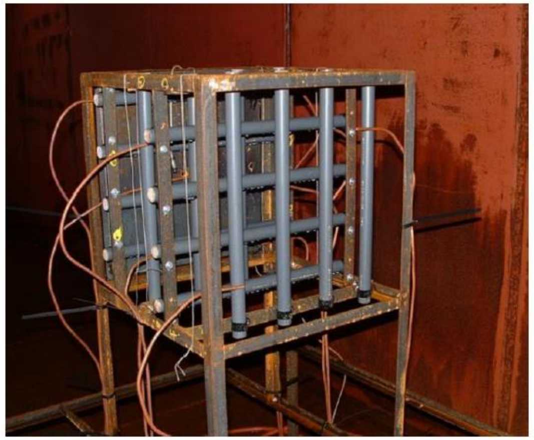
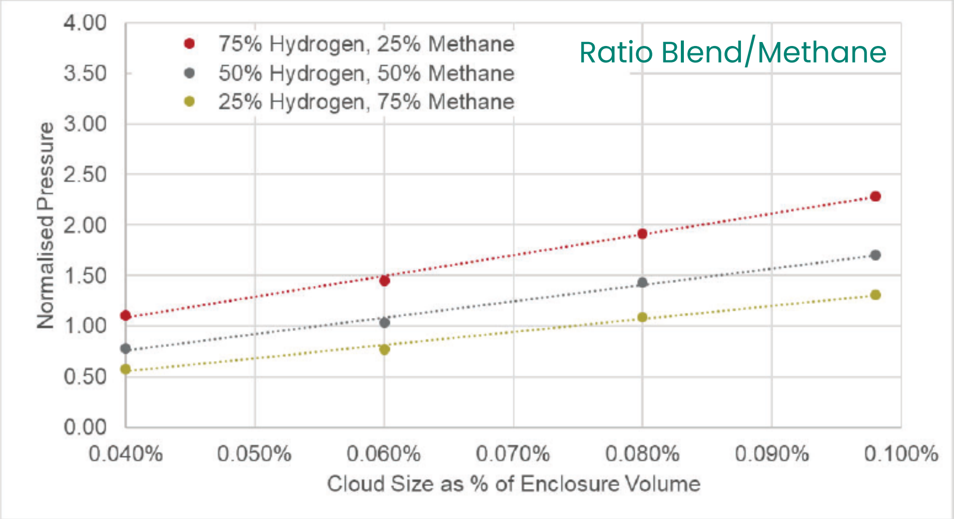
# Hydrogen blending - overpressure severity



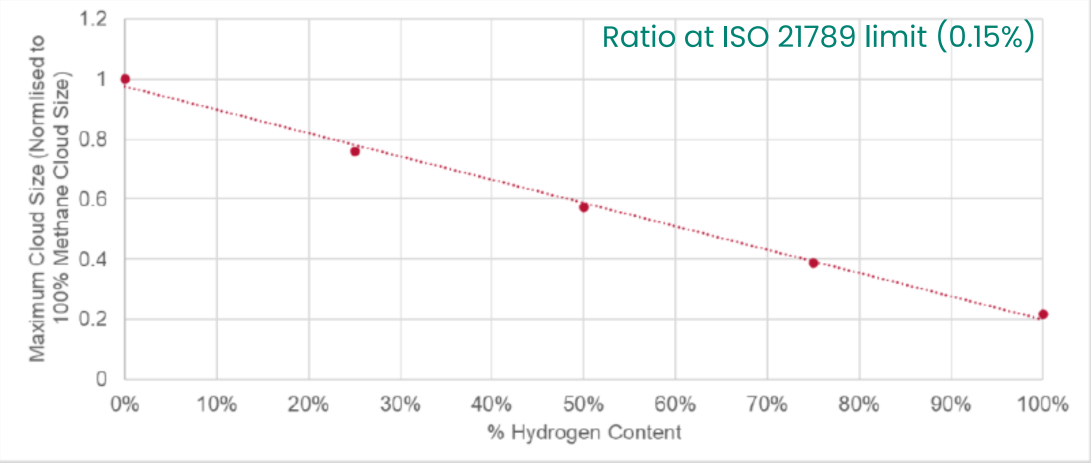

FLACS simulation of enclosure with centrally located congested volume

Hydrogen explosion severity is estimeted around 5 times more than methane






T. S. Vye and D. Miles, *Gas turbine enclosures: determining ventilation safety criteria using hydrogen explosion modelling*




A. Wimshurst, *Assessment of Enclosure Ventilation Safety for Hydrogen Fuelled Gas Turbines*





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# Prevention & Mitigation

**PREVENTION:**

- *Items selection for hazardous area classification* (IEC60079-10)
- *list all potential causes of ignition (EN1127) + Ignition source control*
- *adequate dilution to avoid dangerous concentration of fuel gas*

**MITIGATION:**

## *Explosion relief panels*

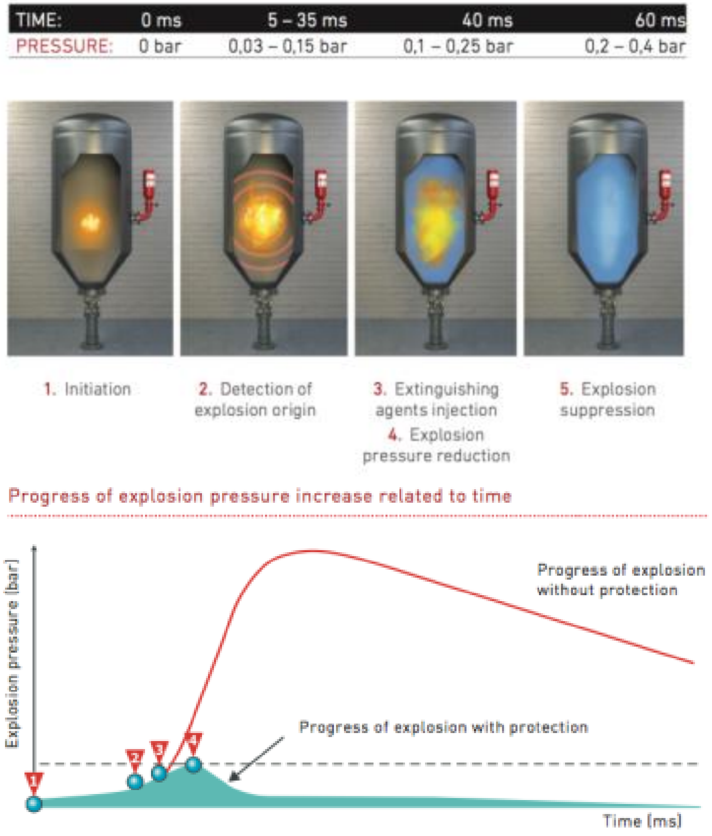
T. Skjold et al., *Vented hydrogen deflagrations in containers: Effect of congestion for homogeneous and inhomogeneous mixtures*

PROS
- Overpressure reduction

CONS
- Effective only in case of deflagration
- Concerns for installation (snow, ice) and risk due to fire ball release

## *Suppression system*

**NFPA67: "Guideline on Explosion Protection for Gaseous Mixtures"**:
$CO_2$ or $N_2$ discharge inside the enclosure to reduce risk of detonation and to lower deflagration pressure




http://vsbfiltration.com/en/fire-and-explosion-protection/

***Suppression Media:***
- Deluge
- Water mist
- Co2
- N2

PROS
- Overpressure reduction
- Explosion inhibition

CONS
- Reaction time
- Effectiveness with turbulent flow

***Enclosure cannot be designed to withstand pressure generated by deflagration***



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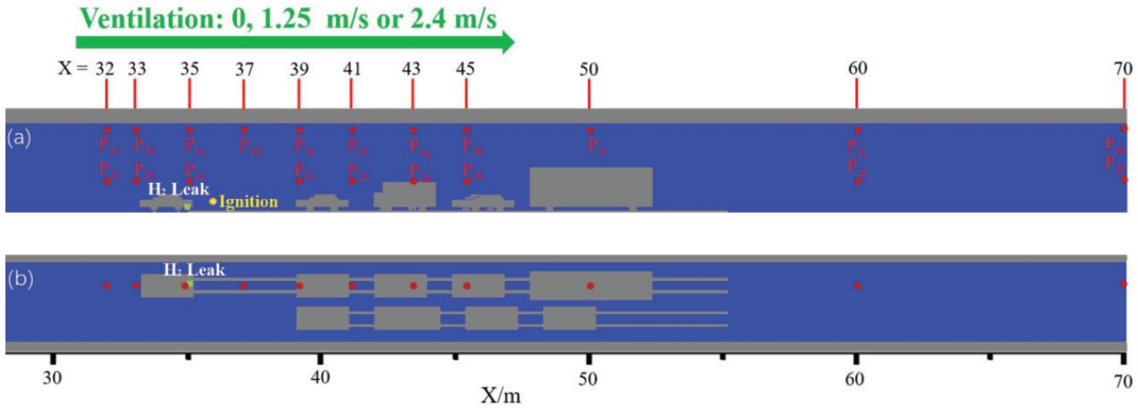
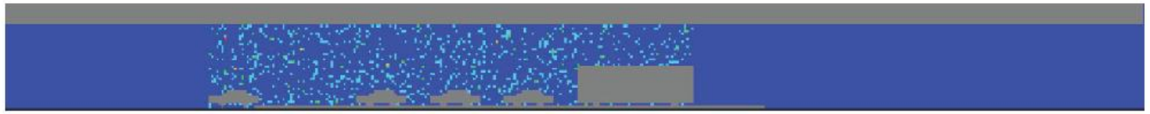
# Suppresion Efficacy – Influence of Ventilation

Water injection reduces overpressure ~ 30-40%

Ventilation increases overpressure… Effect of turbulence

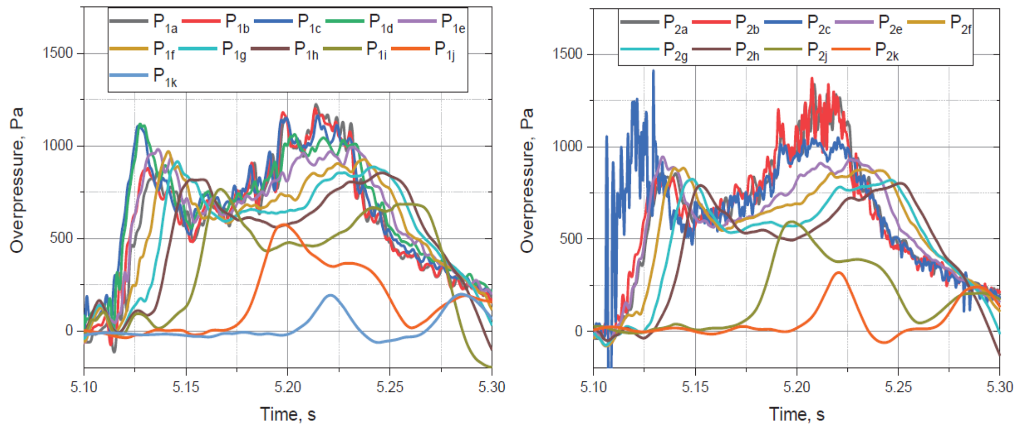


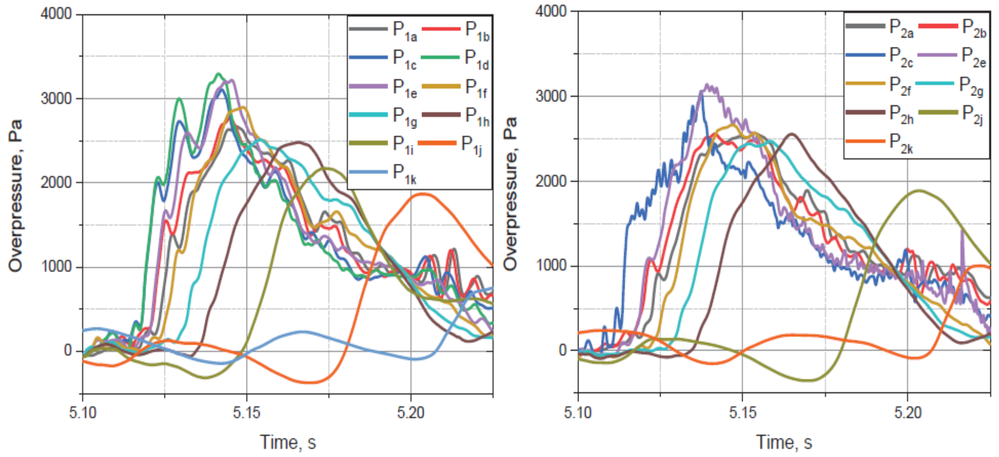
Mist distribution

| | Maximum overpressure: Pa | | | |
|---|---|---|---|---|
| | Without mist | | | With mist |
| Ignition time / Ventilation | 2.5 s | 5.1 s | 9.2 s | 5.1 s |
| 0 m/s | 2335 | 2075 | 1514 | 1413 |
| 1.25 m/s | 4226 | 5305 | 3882 | 3058 |
| 2.4 m/s | 4550 | 4909 | 4473 | 3294 |

Z. Xu et al. *Numerical simulations of suppression effect of water mist on hydrogen deflagration in confined spaces*




Overpressure (ignition 5.1) without ventilation, with mist




Overpressure (ignition 5.1) 2.4 m/sventilation, with mist





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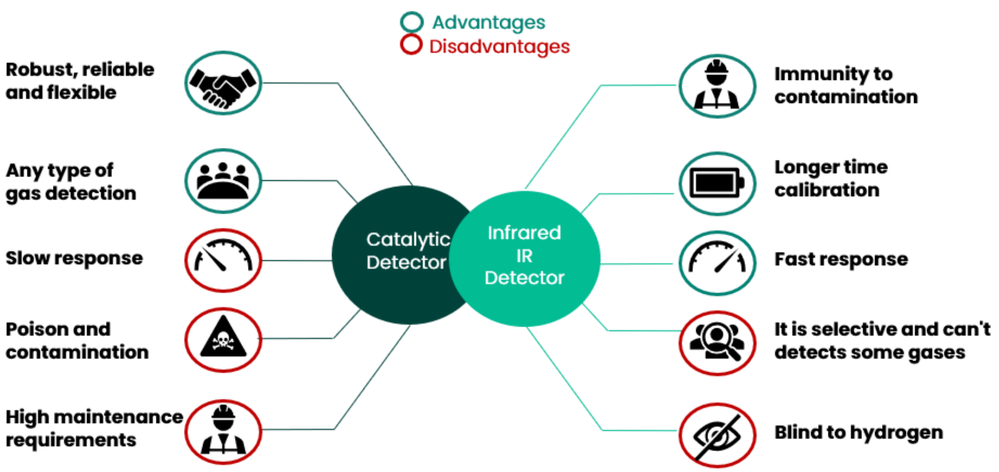
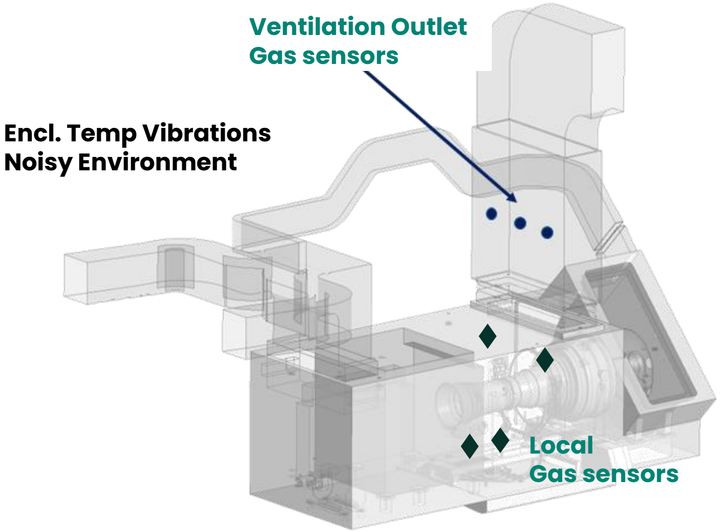
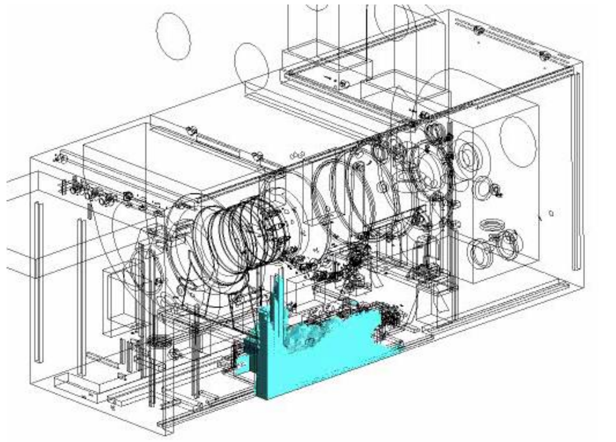
# Gas Detection philosophy

## Catalytic & IR Gas Leak Detection



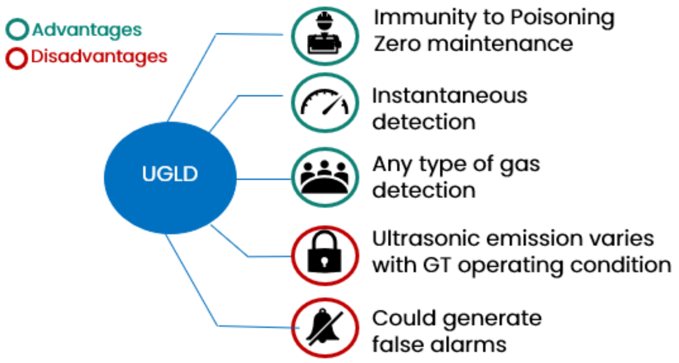



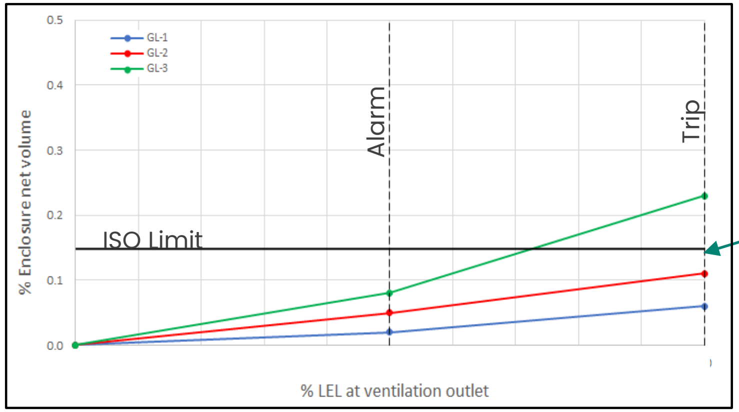
## Gas Detection:

Hydrogen does not absorb IR energy
It is not detectable with an Infrared gas detector

## Ultrasonic Gas Leak Detection-UGLD




Iso-volume cloud 100% LEL




ISO Limit **0.15%** is related to enclosure overpressure design to contain explosion





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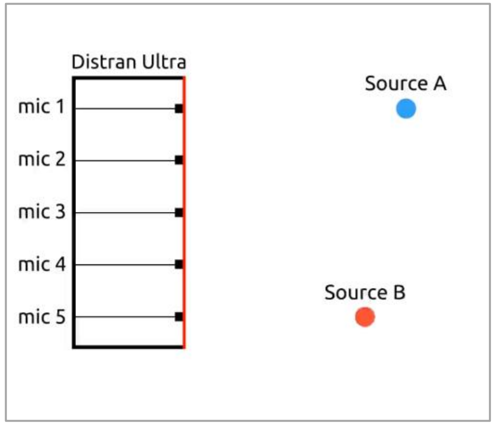
# Leakage detection – Ultrasound

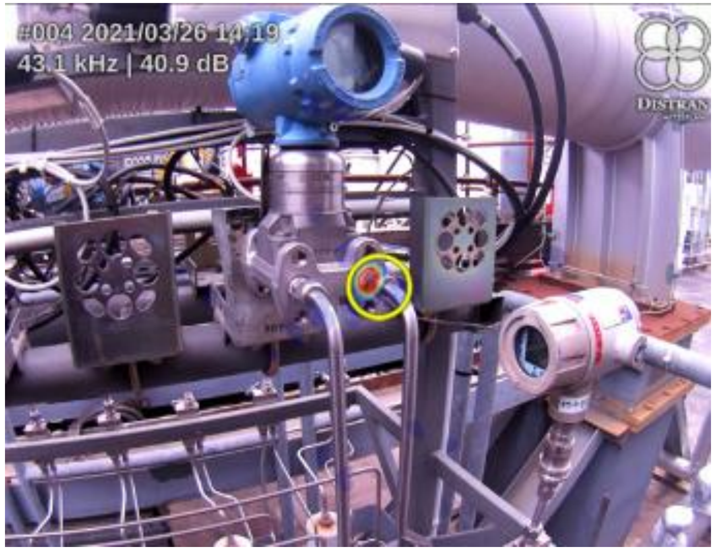
**Multiple Vendors Under Investigation**
- MSA Safety
- Honeywell
- DetTronics
- Emerson
- *Distran (tested on Air)*

***DISTRAN:***
- *Detected leakages as low as* ***~0.1 g/s (120 l/h)*** *on Air*
- *Good to detect leak position*
- *Increase accuracy on quantitative prediction*
- *Excellent background noise filtering (check on enclosed spaces)*
- *To be tuned on H2*
- *Instantaneous detection*

**Specs**:
- *128 microphones*
- *ATEX certified*
- *Works with all types of gas*
- *Distance from leakage from 0.3 to 100 m*
- *Down to 0.3 L/h*
- *Pressure from 50 mbar*


*pilot leak tests*









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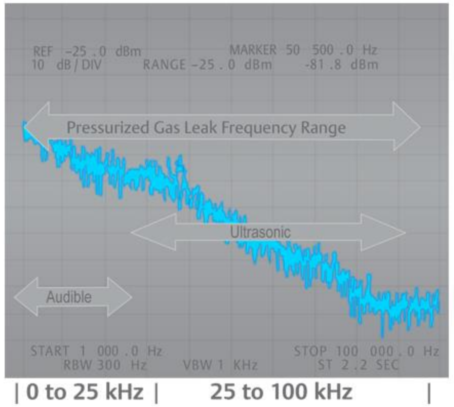
# Sensing Technologies under scrutiny

## Ultrasonic Detector (TRL 7)

Unlike traditional gas detectors, sensitive to gas concentration, the ultrasonic gas detector "hear" the leak.
The sensing element is an acoustic sensor that measures noise fluctuations where gas species leak frequencies are placed (ultrasonic range).

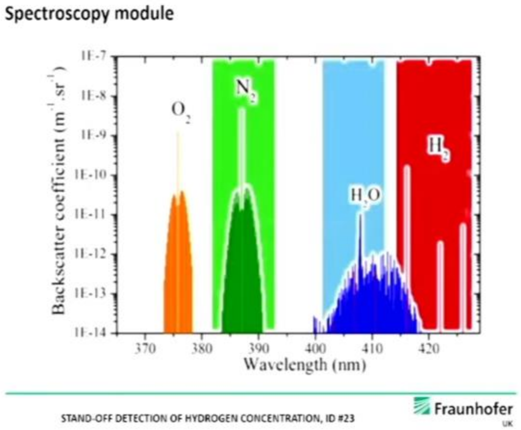
| Pros | Cons |
|---|---|
| Fast response (<1s) | False alarm (bkgnd noise) |
| Proven in process | Low sensitivity |




## Spectroscopy (TRL 5)

This sensing technology uses pulsed laser source (LIDAR) exploiting the Raman interaction of hydrogen with an incident light. Scattered light shift is characteristic of the species, its intensity to gas concentration and time-of-travel to position

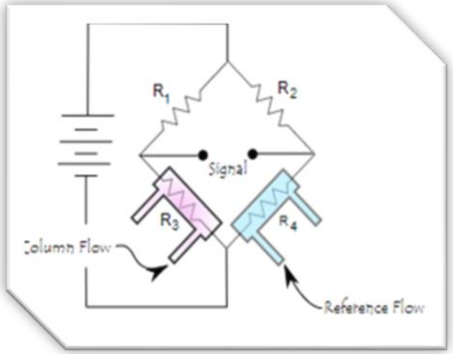
| Pros | Cons |
|---|---|
| Fast response (<1s) | Expensive |
| Highly accurate | Complex |




## Thermal Conductivity Detectors (TRL 6)

Thermal Conductivity Detectors sense changes in the thermal conductivity of the column eluent and compares it to a reference flow of carrier gas.
When the analyte elutes, the thermal conductivity of the column effluent is reduced causing the filament to heat up and change resistance (and so voltage).

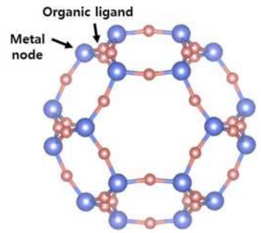
| Pros | Cons |
|---|---|
| Med response (<3s) | Low accuracy |
| Low cost | |

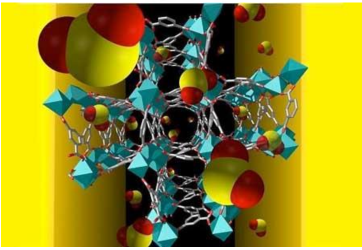



## Metal Organic Framework (TRL 4)

MOF made with different metal atoms and organic linkers can selectively absorb specific gases into tailor-made pockets within the structure. MOFs' high surface area is a beneficial aspect for high-performance gas sensors.
A thin film of a tailor-made MOF, coated onto an electrode, forms an electronic sensor that could detect traces of gas.

| Pros | Cons |
|---|---|
| Low cost | Gas specific |
| Highly sensitive | Unclear performance |



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# Next Steps

| Tests | Current status | Next steps |
| --- | --- | --- |
| Validation of fast Hydrogen sensors | Application in open field | sensor inside GT enclosure in all operating scenarios, to detect hydrogen leak vs. air leak |
| Dispersion inside confined volume | Different application (e.g. Car parking, quiet volume) | test inside confined, congested and ventilated volume including buoyancy (heat source) |
| Hot surface ignition | Different conditions (no turbulence, small scales) | Hot surface ignition (temperature and residence time) of hydrogen in ventilated enclosures |
| Ignition inside enclosure | Different conditions (empty volume, simplified obstacles) | Ignition in ventilated enclosures with suppression system as mitigations solution |
| Overpressure with H2 Blend | Currently known for 100% Ch4 and H2 | Overpressure detection for Ignition of gas blend pocket in confined spaces @ different blend ratio |




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