Air Liquide
creative oxygen

Fire tests carried out in FCH JU Firecomp project, recommendations and application to safety of gas storage system

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7th Int. Conf. on Hydrogen Safety - Hamburg, Germany – Sept. 11-13, 2017 - P. Blanc-Vannet, S.Jallais, B.Fuster, F.Fouillen, D.Halm, T.van Eekelen, S.Welch, P.Breuer, S.Hawksworth

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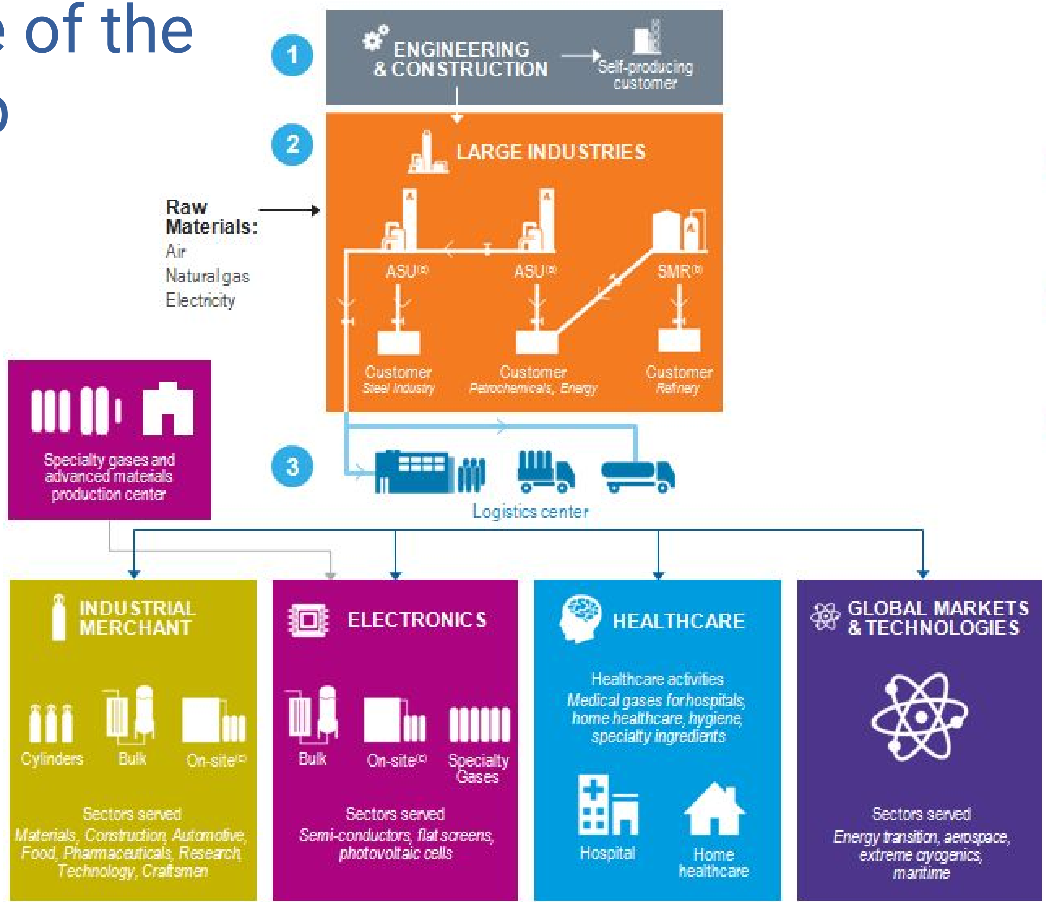
Composite pressure vessels @Air Liquide

Structure of the AL Group



A three-stage development model

1. **Engineering & Construction**
designing and building state-of-the-art production units for Air Liquide as well as for third-party customers.

2. **Large Industries**
investing long-term to produce large quantities of gases for our customers and to meet the Group's needs.

3. Part of the production capacity of **Large Industries** is used to serve **Industrial Merchant**, **Healthcare**, **Electronics** and **Global Markets & Technologies** within a geographic radius of about 250 km.
Products are distributed in liquid form (in cryogenic trucks driven directly to storage units on the customer's premises) or in gaseous form (in cylinder) depending on the quantities required.
Gas production is actually a local activity, as gases are not transported over long distances, with the exception of some rare and specialty gases used mainly in electronics.

(a) **ASU :** Air Separation Unit

(b) **SMR :** Hydrogen and carbon monoxide production unit (Steam Methane Reformer)

(c) **On-site :** Small local production unit

AL in the hydrogen value chain

Applications & Customers

AL in the hydrogen value chain

Composite cylinders as **customer's storage to be filled**

Distribution

Transport

Composite cylinders for **AL supply chain operations**

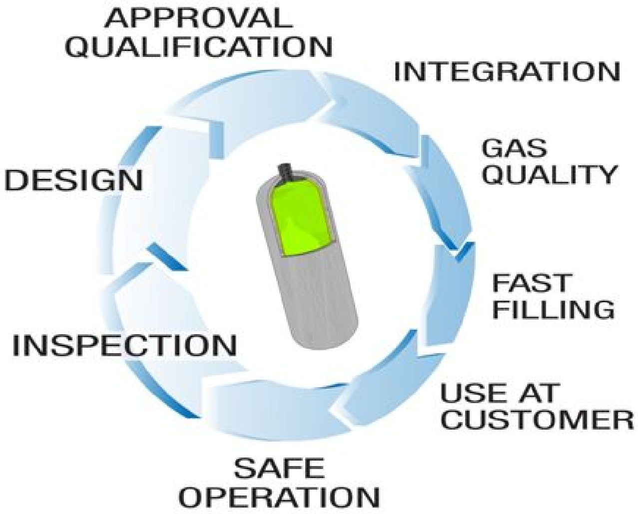
Storage

Production

Applications & Customers

R&D activity in composite pressure vessels

R&D knowledge covering **all aspects of cylinder's lifetime within AL operations**
Targeting a **safe & efficient use** of composite cylinders



Ensure **structural integrity** of vessels through their lifetime, beyond existing standards

Assess the **consequences** of accidental events and **mitigate** the industrial risk

Reduce the total cost of safely operating
composite pressure vessels
through better understanding

Fire risk with composite cylinders

In fire, burst due to
Inner pressure increase

In fire, burst due to
Material degradation

- **Shorter time to burst**
- **High energy content**
- **No pressure increase**

Need to adapt fire strategy

fireCOMP

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FireCOMP project and results

fireCOMP

2013 - 2016 FCH JU funding

A EUROPEAN PROJECT SUPPORTED THROUGH THE SEVENTH FRAMEWORK PROGRAMME FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT

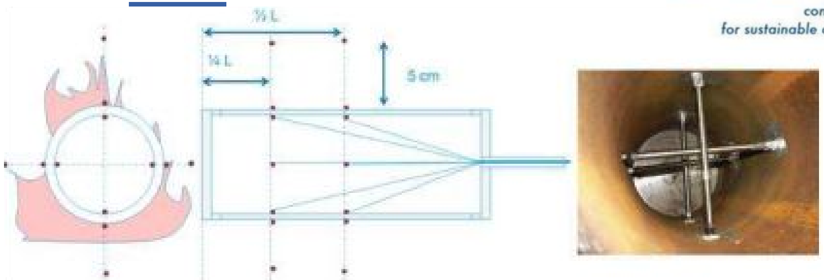
New Energy World JU
fuel cells & hydrogen for sustainability

Pre-normative research on fire safety of composite pressure vessels

- **Risk analysis**
  - Identification and quantification of fire scenarios depending on applications
  - Comparison with metallic cylinders
- **Experimental work**
  - Heat transfer, thermal degradation & loss of strength
  - Material (lab) & cylinder (full) scale
  - Bonfire tests matrix based on relevant scenarios
- **Modelling**
  - Thermo-mechanical behaviour of the vessels
  - Model validated by full scale fire tests

Calibration of thermal aggression

INERIS
controlling risks for sustainable development



Thermocouples inside and around steel cylinder

↓

The evolution of the **gas temperature** inside the metallic cylinder allows determining the **net heat flux** it absorbed

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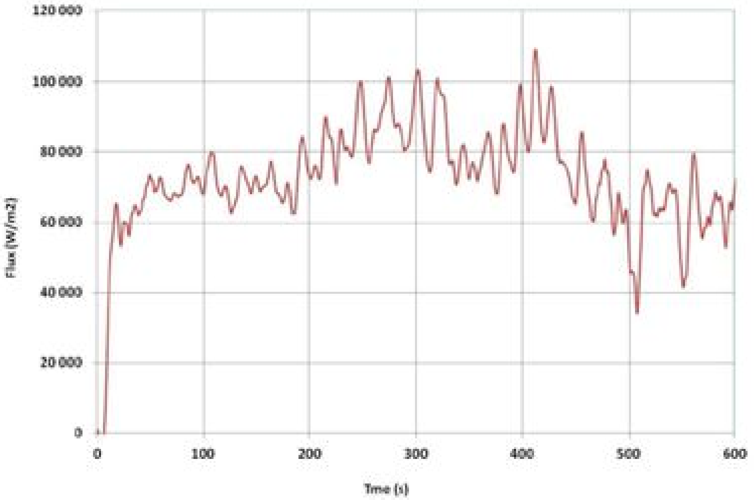
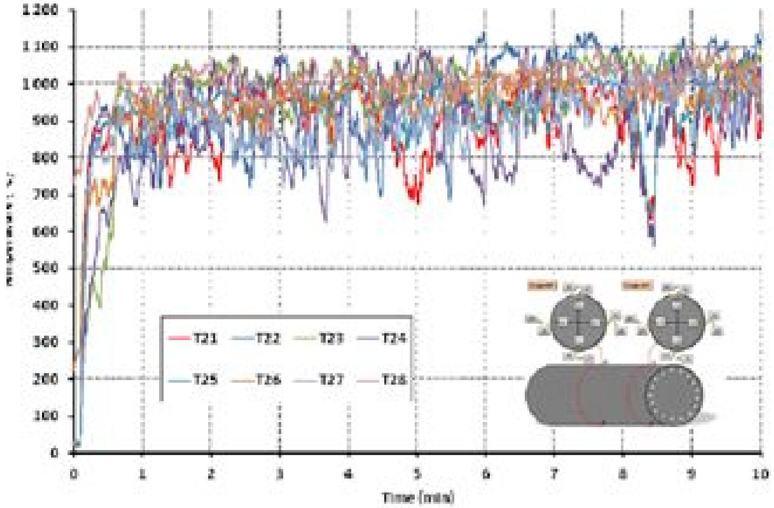
Calibration of heat flux and temperature

Net heat flux absorbed by the metallic cylinder

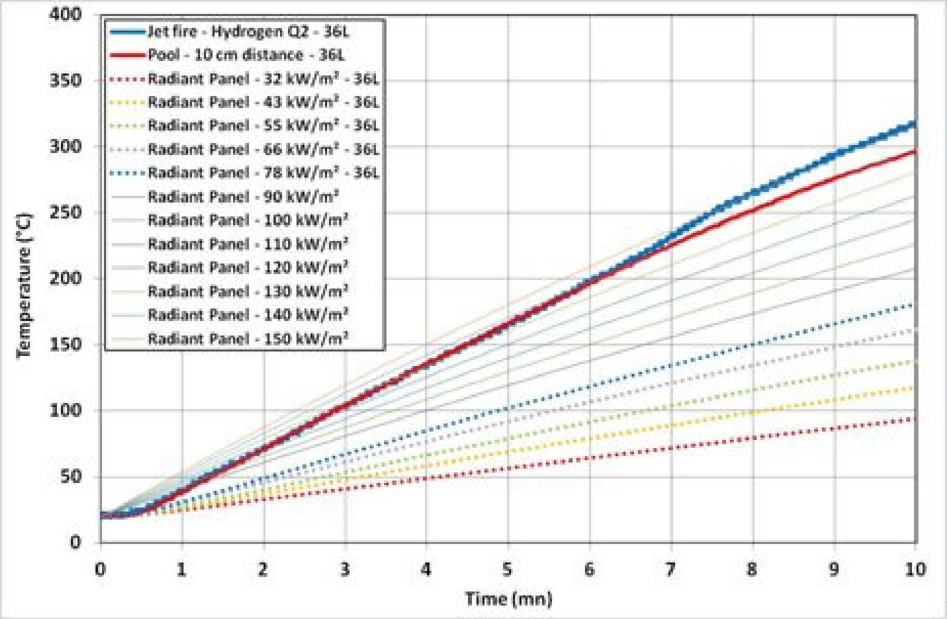
Average **90 kW/m2** between 200 s and 400 s



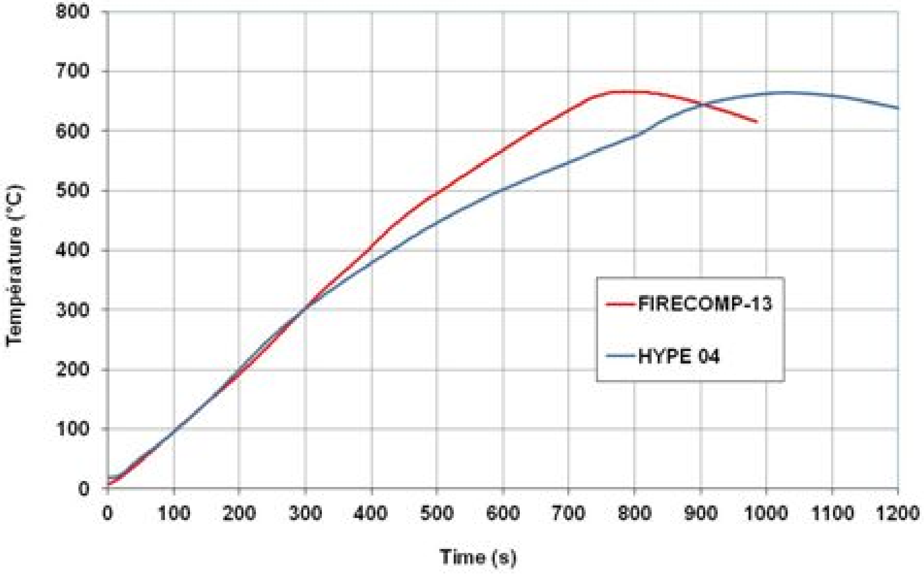
Temperatures recorded at 5 cm outside of the cylinder display a good homogeneity and fluctuate between **800°C and 1000°C**



Calibration of thermal aggression H_2 burners vs. pool fire



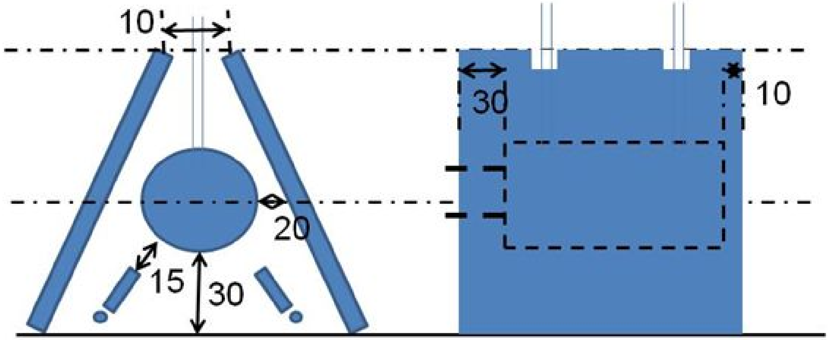
For 36 L cylinders, the injection flow rates retained allow to reach the **same temperatures as with classical pool fire**

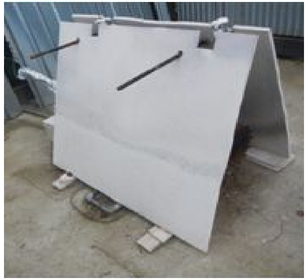


With results that **meet bonfires performed in the past**

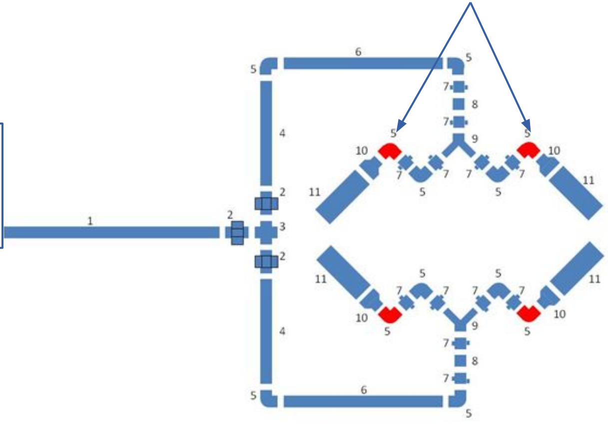
Fire test setup @INERIS

controlling risks for sustainable development





Oxygen alimentation points



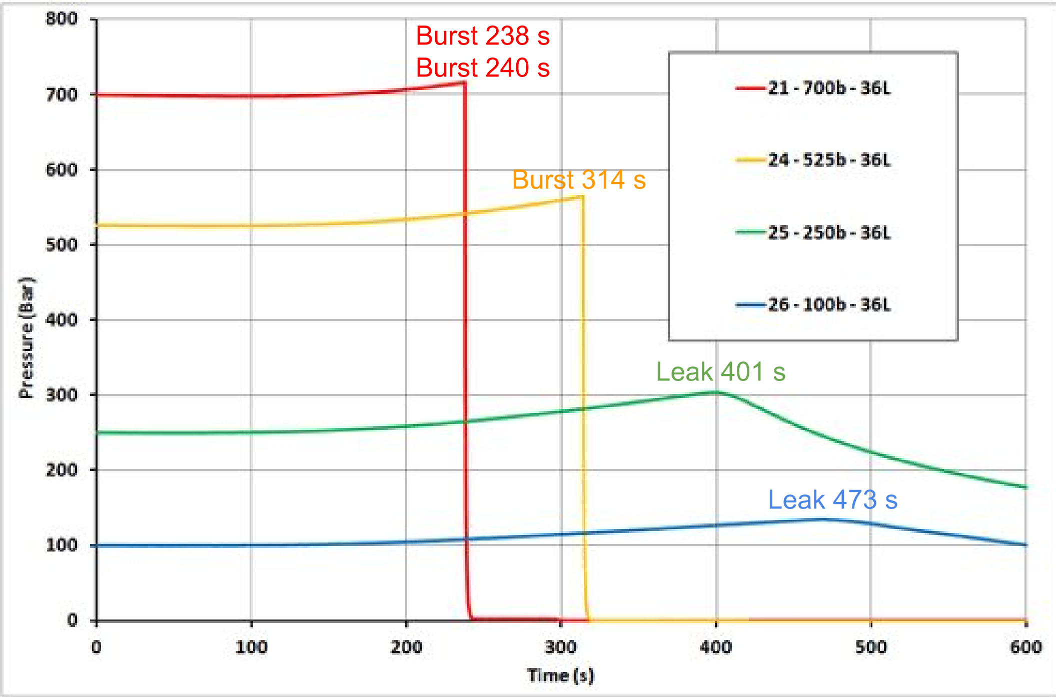
Hydrogen gas burners

4 burners, with each
1,5 g/s hydrogen
0,5 g/s oxygen

- Hydrogen gas fire is a realistic scenario
- Gas fires are easier to calibrate and more reproducible than pool bonfire
- Calibration tests performed on steel cylinders to optimise:
  - The confinement
  - The needed hydrogen flow rate
  - The oxygen injection
- Complete definition regardless of the cylinder size

Results of fire tests on Hexagon 36 L type IV vessels without any protection

- **Two failure modes**
  - Burst when initial pressure 525 or 700 bar
  - Leak when initial pressure 100 or 250 bar
- **Cylinders equipped with thermocouples**
  - Wound inside the composite
  - Slightly decrease the time to burst
  - Allowed checking the heat transfer model
- **Good reproducibility**
  - Two vessels @700 bar burst at rsp. 238 s and 240 s
  - Temperature evolutions inside composite thickness are similar



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FireCOMP recommendations and example of application

Methodology proposed for fire testing

Current practice is to test both cylinder and TPRD simultaneously and **regardless of their integration** in a structure.

FireComp project aimed at understanding the behaviour of a composite pressure vessel in fire. Hence it is proposed, when qualifying a cylinder, to focus on getting information on what the cylinder can endure.

The proposed methodology is to separate

1 Performance of the cylinder alone

Fire test without protection in order to establish a **pressure relief curve** = “safe” pressure vs. time zone in a fire

By **cylinder manufacturer**, during **qualification** process

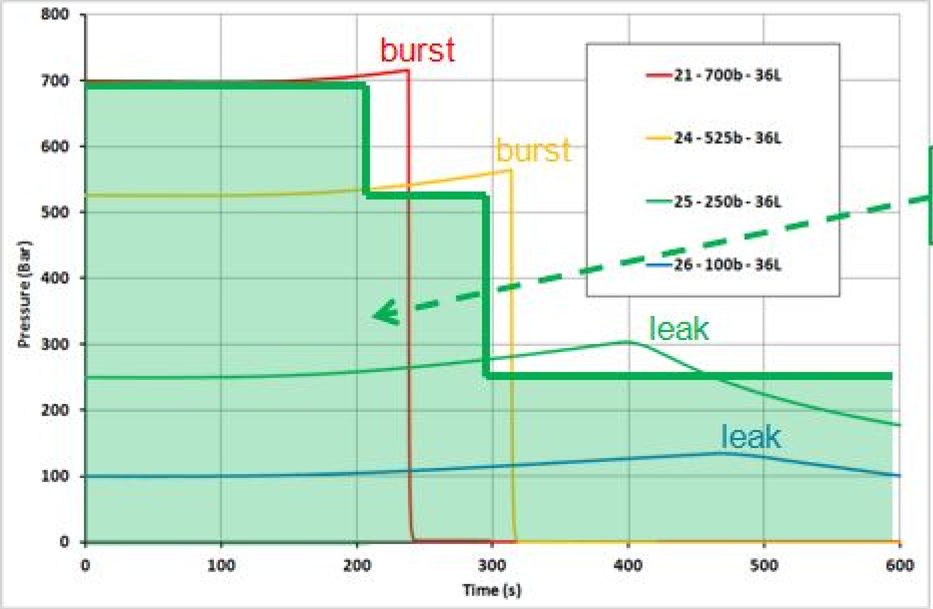
2 Safety of the complete structure

(e.g. Bundles, trailers, cars,...)

With a safety **strategy depending on the risk analysis** for the application; possibly including metallic frames, protections, fire detectors, pressure relief system...

By cylinder **end-user**, when designing a fire safety **strategy at structure level**

Safe pressure relief curve

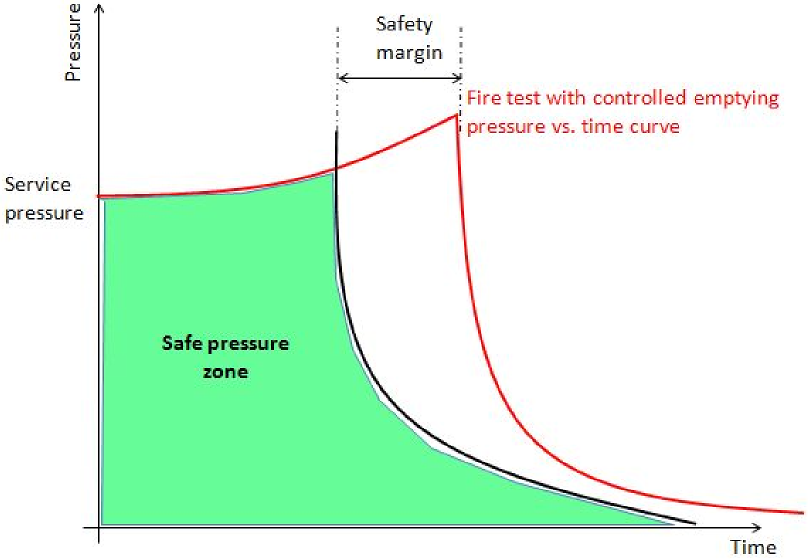


Safe pressure zone

The pressure relief system shall be designed for pressure to always be in this area in case of fire

Safe pressure relief curve

Possibly determined using only one tank...



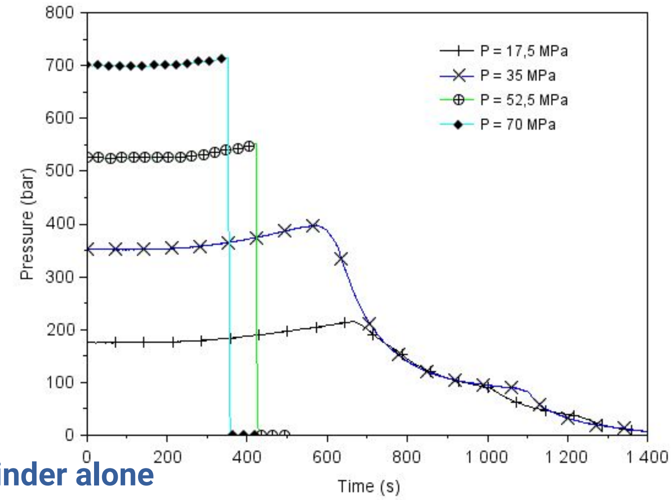
...or numerically predicted using models developed in the project

Information can be found in the following paper and its references:
D. Halm, F. Fouillen, E. Lainé, M. Gueguen, D. Bertheau, T. van Eekelen, Composite pressure vessels for hydrogen storage in fire conditions: Fire tests and burst simulation, *International Journal of Hydrogen Energy · July 2017 · DOI:10.1016/j.ijhydene.2017.06.088*

Example of application AL hydrogen bundle

High pressure bundle

- 4 * 143 L @700 bar
- Safety distance for 50 mbar overpressure in case of burst: 34 m => not acceptable for this application



Fire tests on cylinder alone

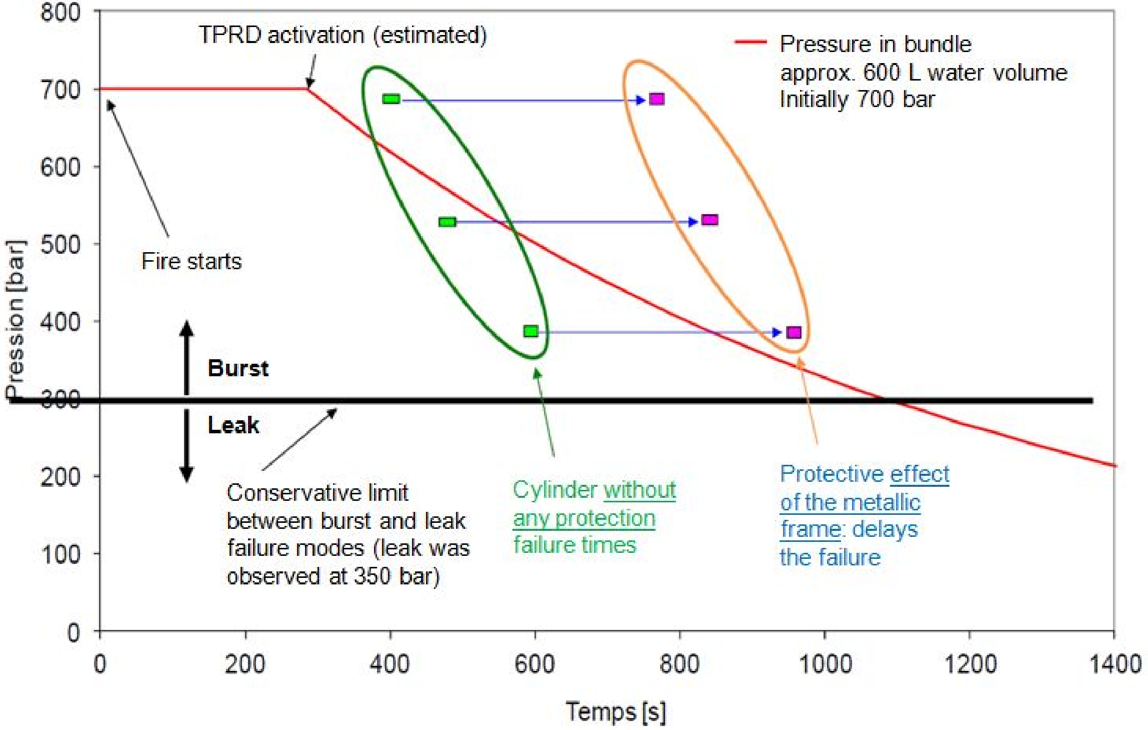
- Measure of the time to burst / leak
- Too short time for an acceptable flame length if ignited release => metallic frame to delay the fire

Fire tests with the frame

To assess the delay provided

The frame also makes the **fire detection** by TPRD more reliable and **protects vs. local fires**

Summary of the fire safety strategy for the bundle



Thank you for your attention.