9th HySchool Webinar
08.10.2024

Numerical modelling of liquid hydrogen tanks performance during fire engulfment

Alice Schiaroli [a,b], Giordano Emrys Scarponi [b], Valerio Cozzani [b], Federico Ustolin [a]

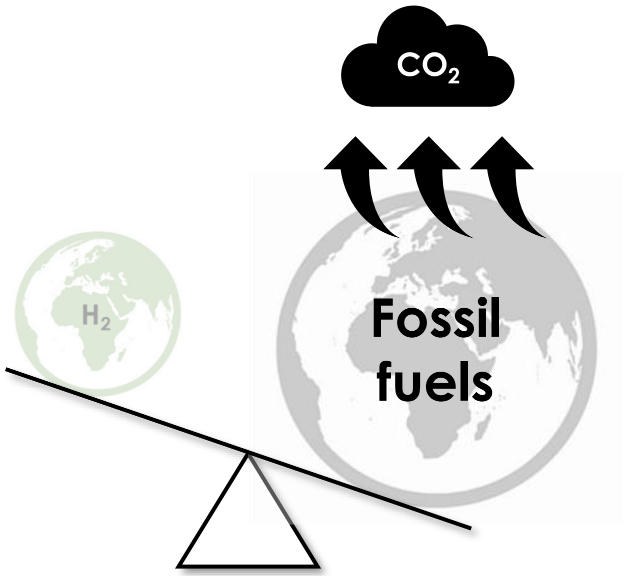
[a] Norwegian University of Science and Technlogy, Department of Mechanical and Industrial Engineering (MTP), Trondheim, Norway

[b] University of Bologna, Department of Civil, Chemical, Enviromental and Materials Engineering (DICAM), Bologna, Italy

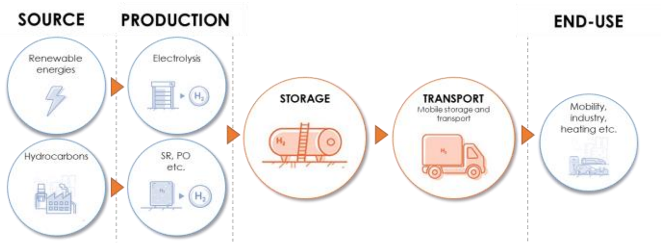
Outline

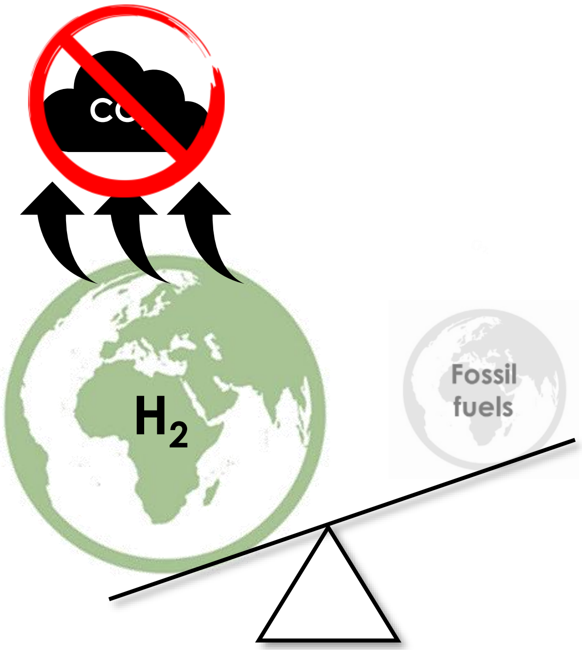
Background: why hydrogen?

Energy transition



- Development of the **hydrogen value chain** (infrastructure, storage technologies…)

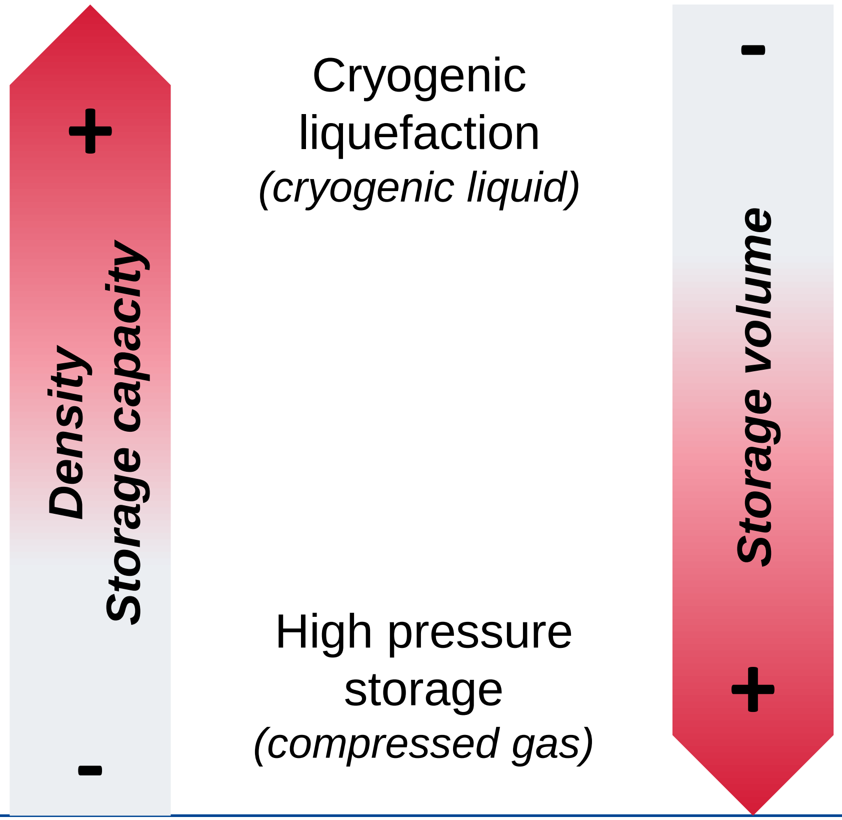




Background: why liquid hydrogen?

1

Efficient storage and transport technologies are crucial to satisfty the market's needs and handle large amount of fuel.

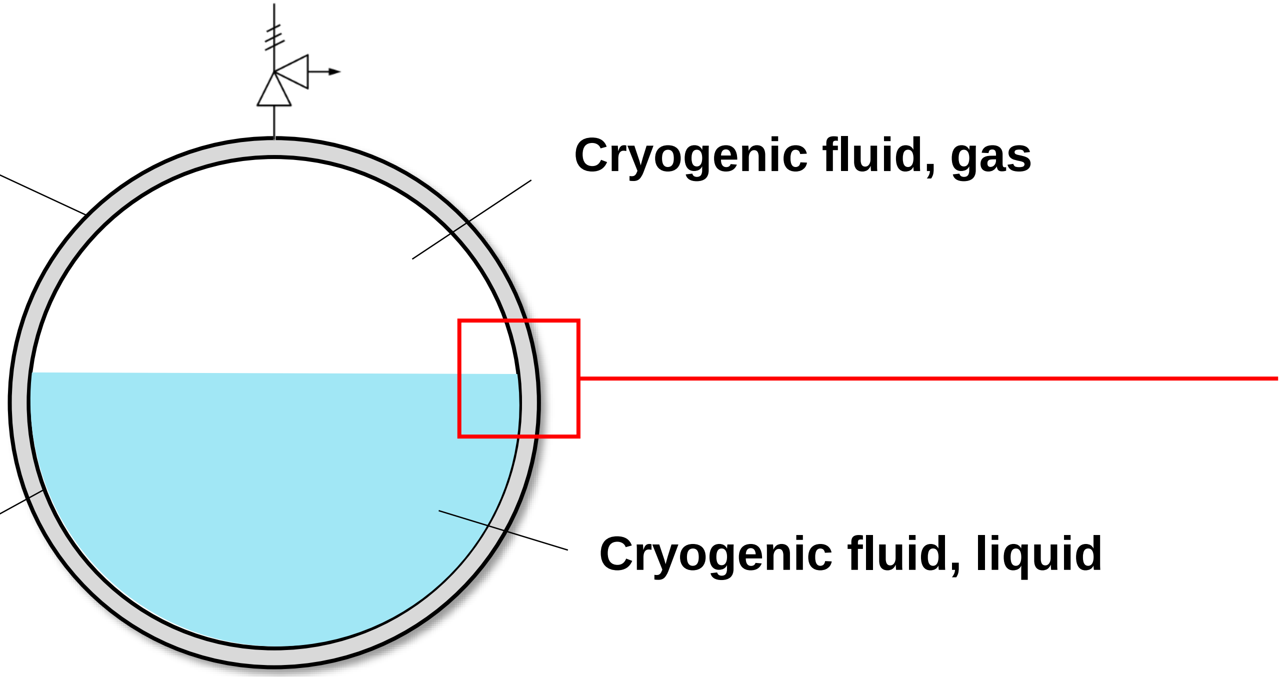


Common cryogenic fluids:

- **Hydrogen**
- Helium
- Nitrogen
- Oxygen
- Natural Gas
- Carbon dioxide
- …

Background: hydrogen safety

Cryogenic fluids are stored in **double-walled super insulated tanks** designed to minimize the heat losses with the surrounding warm environment.



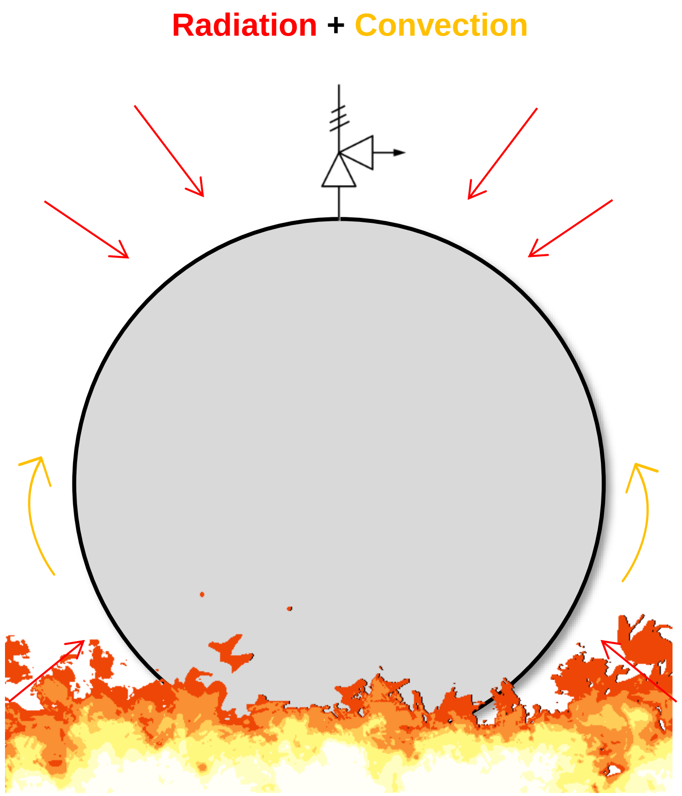
Annular space
(superinsulation)

Background: hydrogen safety

From a safety standpoint, the **fire exposure** is the most critical scenario involving cryogenic storage components.

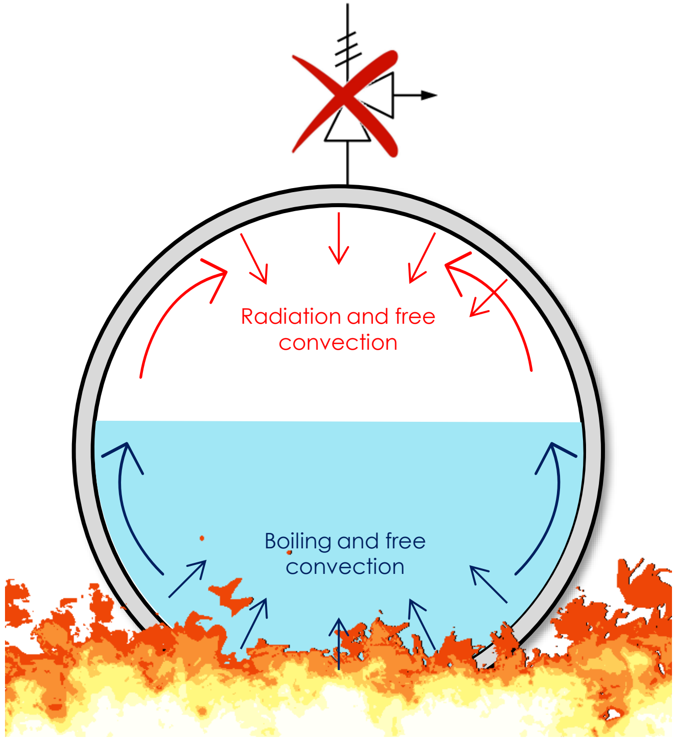
Possible **hazardous consequences** of this scenario are:

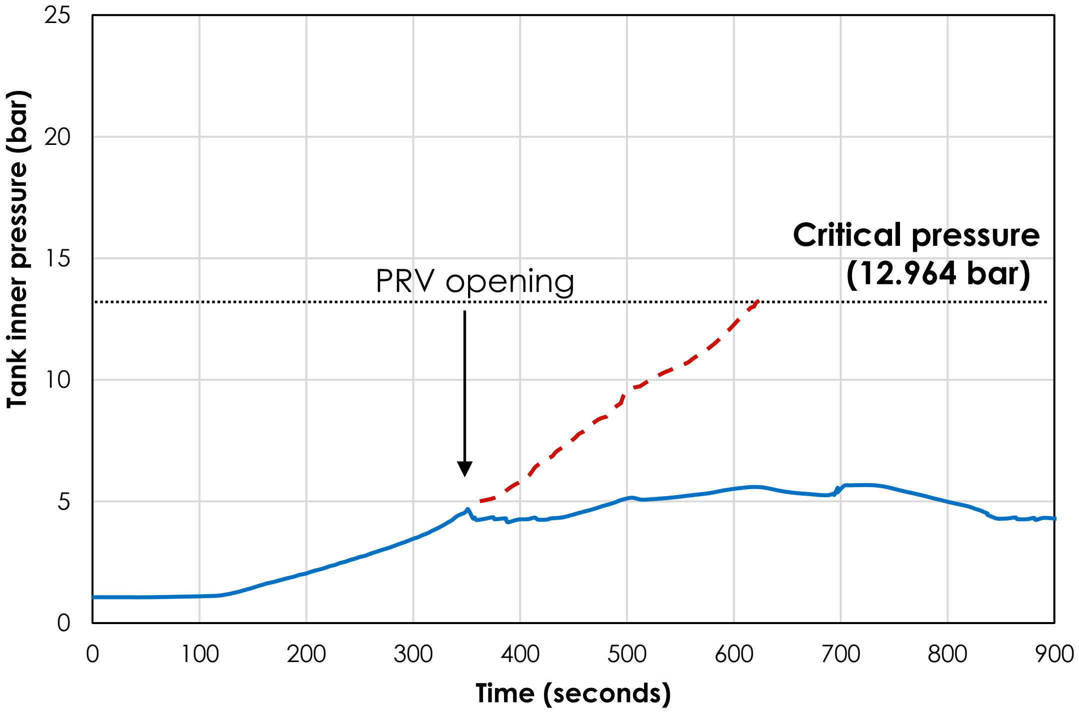
- **Degradation** of the insulation system with consequent loss of thermal performance
- Vaporization of the liquid content and formation of the boil-off gas (BOG) with consequent **overpressurization** of the equipment
- Hydrogen **loss of containment** (LOC)
- **Fires and explosions**
- **Failure** of the component



Background: hydrogen safety

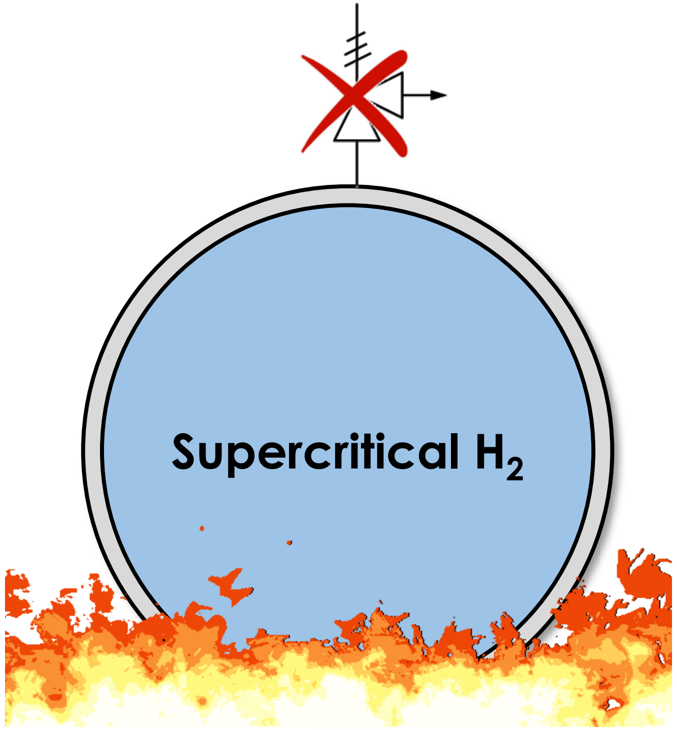
Typically, pressure variations are managed thorugh the PRV. However, in case of failure of the device, the **pressure build-up** is not mitigated.





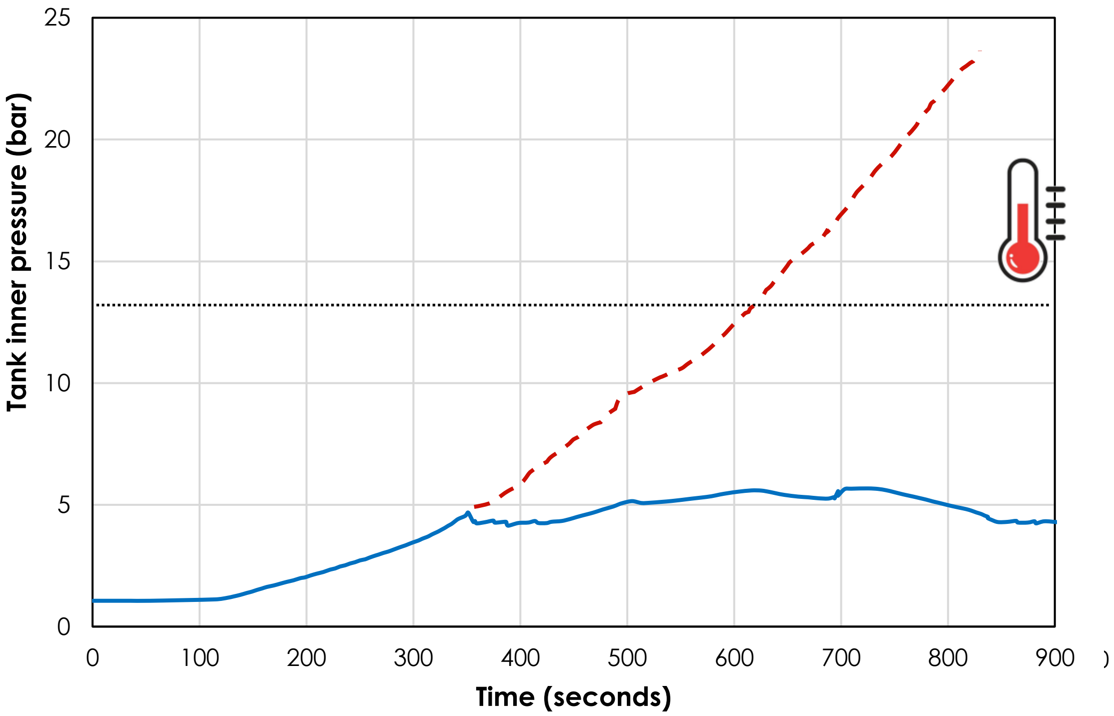
Background: hydrogen safety

Typically, pressure variations are managed thorugh the PRV. However, in case of failure of the device, the **pressure build-up** is not mitigated.



Inner pressure > Critical Pressure (12.964 bar)

Liquid temperature > Critical temperature (33.145 K)



Scope of the research

What happens inside the tank when it is exposed to an external fire?

Which is the **time to failure (TTF)** of the cryogenic tank?

Scope of the research

Ansys

FLUENT

Development of a CFD model to simulate hydrogen tanks engulfed in fires:

- ❑ Model set-up
- ❑ Computational domain definition
- ❑ Boundary conditions definition to represent the fire

Validation of the model:

- ❑ Comparison of the results with validated models

Case study

**Scenario = + **

Cryogenic tank for liquid hydrogen engulfed in an external fire for 15 minutes with failure of the PRV

- Propane full engulfing fire
- Flame temperature = 1193. 15 K

- Initial pressure = 1.06 bar
- Initial temperature = 26.076 K
- Internal radius = 0.23 m
- Insulation thickness = 35 mm
- Filling degree = 55%
- PRV opening pressure = 4 bar
- MLI insulation

BMW Hydrogen 7

Modelling

Submodels	Material properties	Initial/boundary conditions
• Volume of Fluid (**VOF**) • k-ω shear stress transport (**SST**) → turbulence • **Lee** model → evaporation-condensation	• Hydrogen → **piecewise linear** functions of temperature (Data from NIST database) • Insulation: ρ = 167 kg/m^3 C_p = 881.5 J/ kg K $k = \begin{cases} 1.5\ mW & t < 115\ s \\ 160\ mW & t \geq 115\ s \end{cases}$	• Initial inner pressure = **4 bar** • Initial inner temperature = **Tsat** • Initial temperature at the outer wall = 1193 K

Results

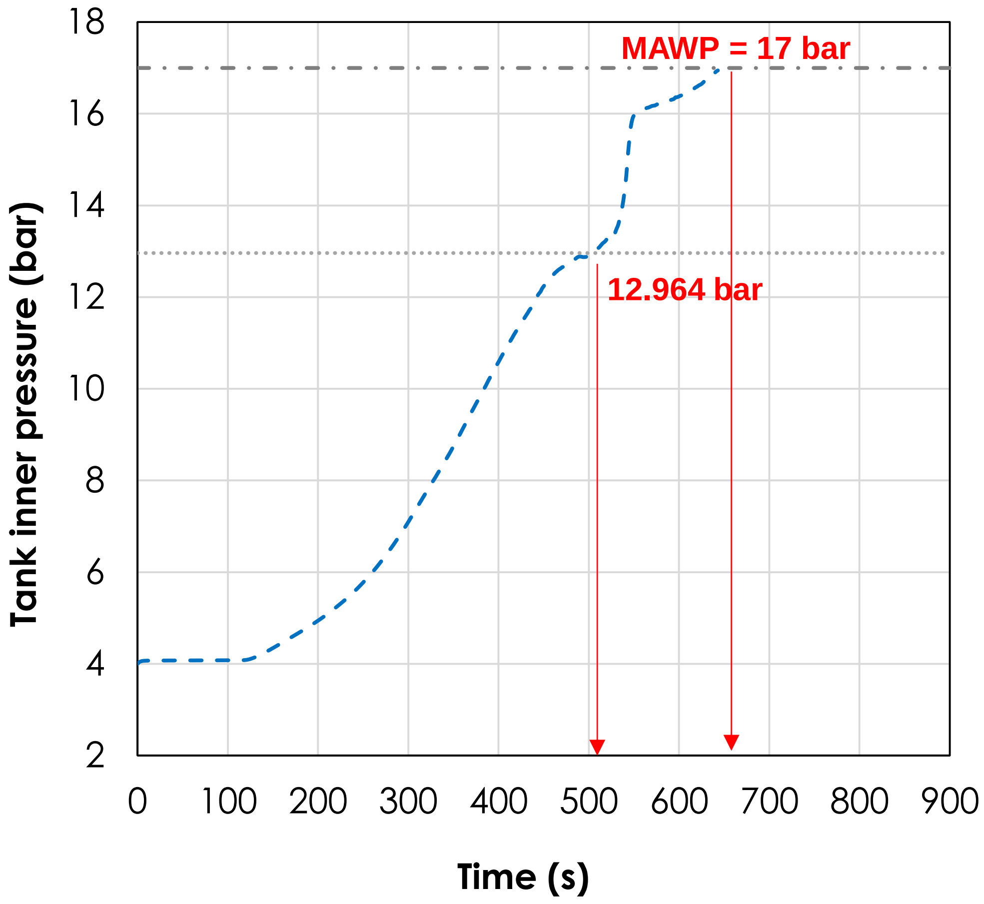
The critical pressure is reached after **504 s**

The tank catastrophically fails after **643 s (TTF)**; this corresponds to an inner pressure of 17 bar

Assumption:

Inner shell material 5083 Al alloy

Max $\boldsymbol{\sigma_{amm}}$ = 112.5 Mpa



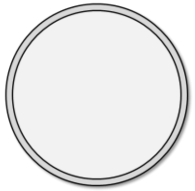
The model cannot be validated in supercritical conditions with the data of the BMW test

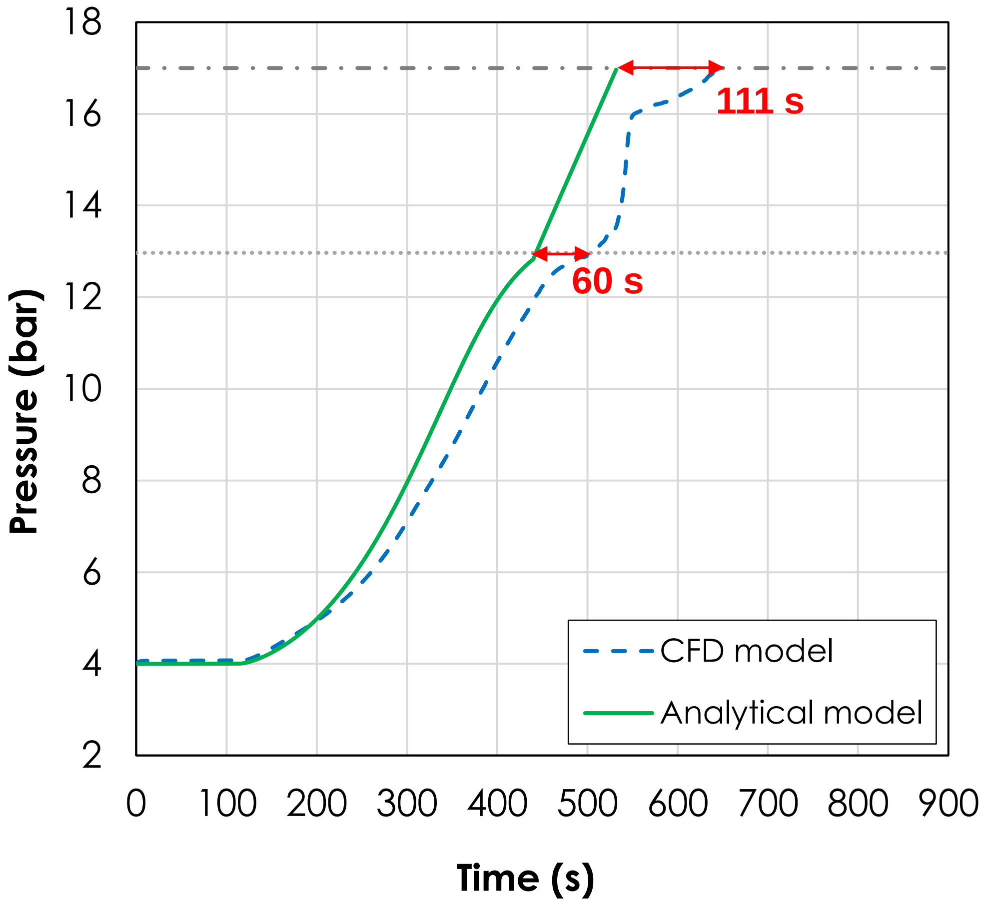
Results

The results of the CFD model are compared with the ones of the analytical model proposed by Ustolin et al. (2021).

	CFD	Analytical
Time to reach **Pc**	504 s	444 s
Time to Failure (**TTF**)	643 s	532 s

The models consider a different geometry, 2D and 3D





Conclusions and future work

- The proposed model can simulate hydrogen behaviour in both sub- and **supercritical conditions**
- The pressure trend shows anomalies after the **critical point**, probably due to the imported thermodynamic properties database for hydrogen

- Further research is required to improve the functions impelemented for **hydrogen properties** (accounting for pressure and temperature dependence)

9^{th} HySchool Webinar
08.10.2024

Thank you for your attention!

alicesc@stud.ntnu.no

alice.schiaroli@unibo.it

NTNU
Norwegian University of Science and Technology