



Engineering tool to assess consequences of a BLEVE explosion

ELVHYS Dissemination Conference

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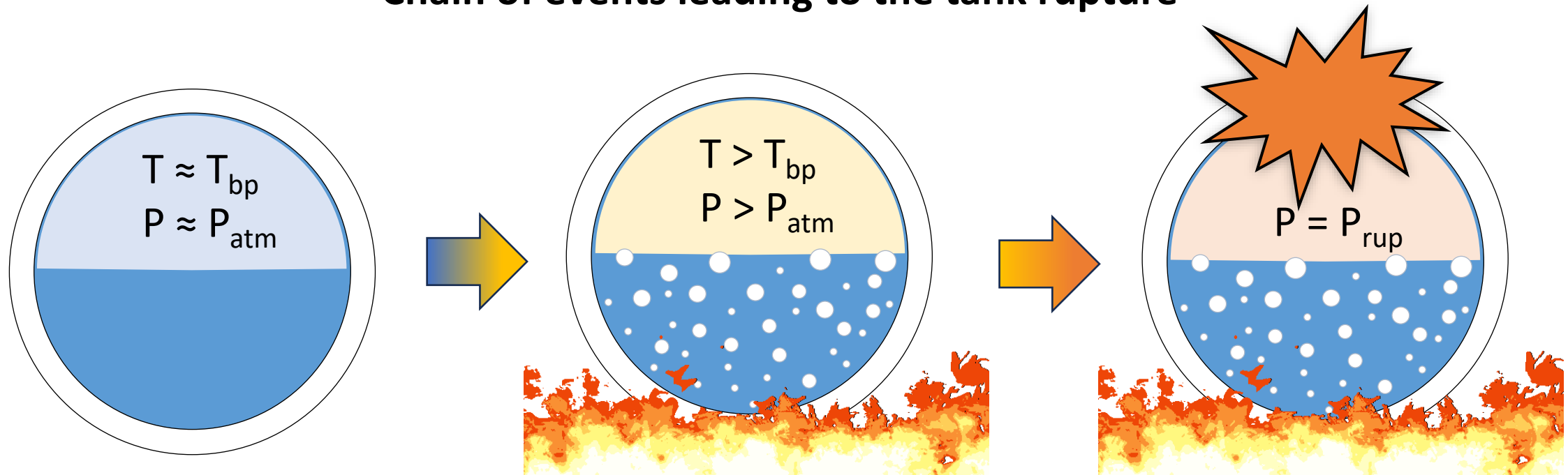
Content

1. BLEVE phenomenon
2. LH2 BLEVE
3. BLEXCOM model
4. Case studies
5. Results
6. Conclusions and recommendations

Boiling Liquid Expanding Vapour Explosion

BLEVE is a physical explosion might result from the catastrophic rupture of a tank containing a superheated liquid due to the rapid depressurization.

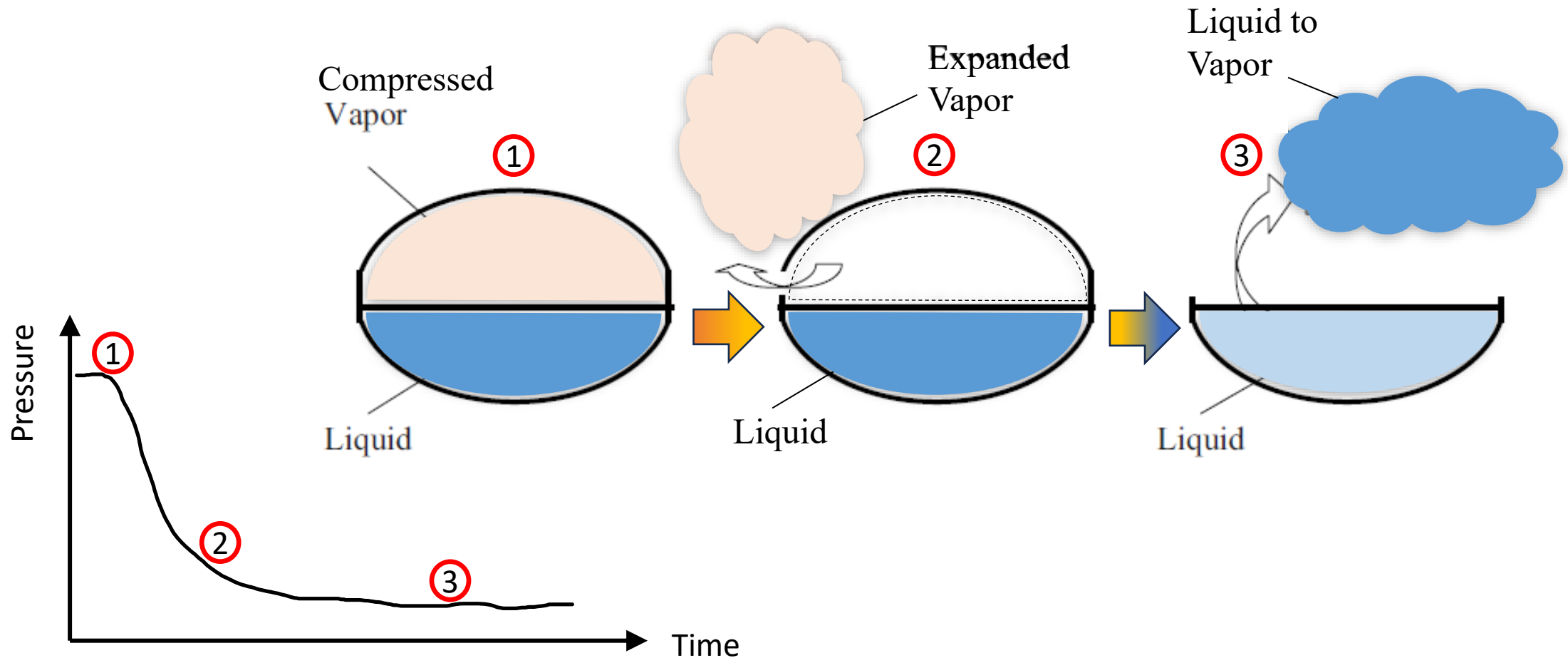
Chain of events leading to the tank rupture



Cross section of a liquefied gas storage tank exposed to external fire

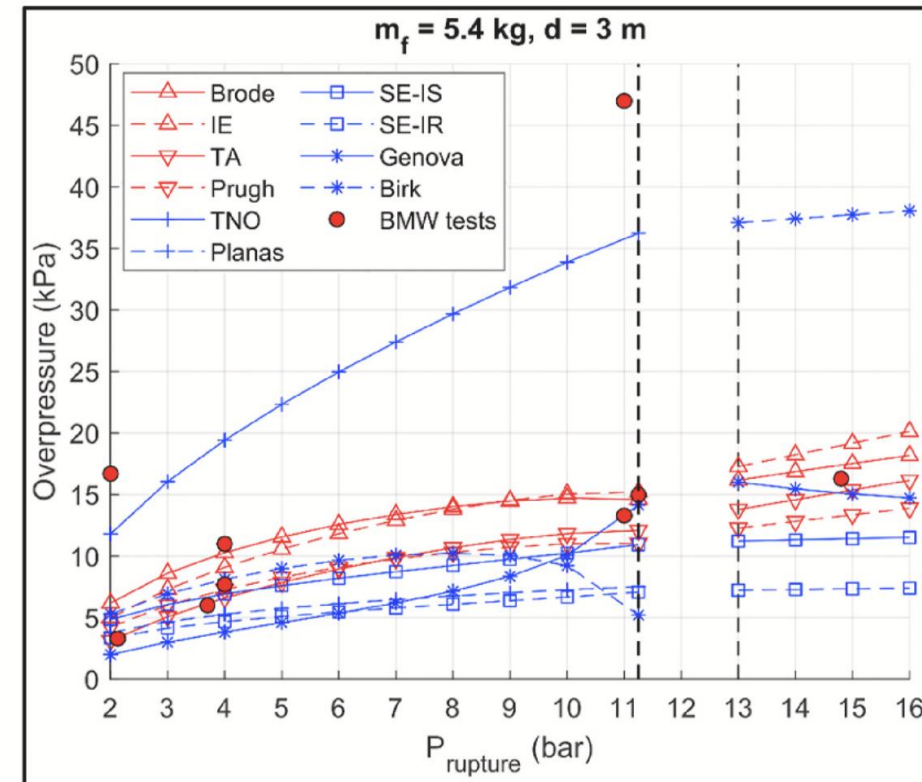
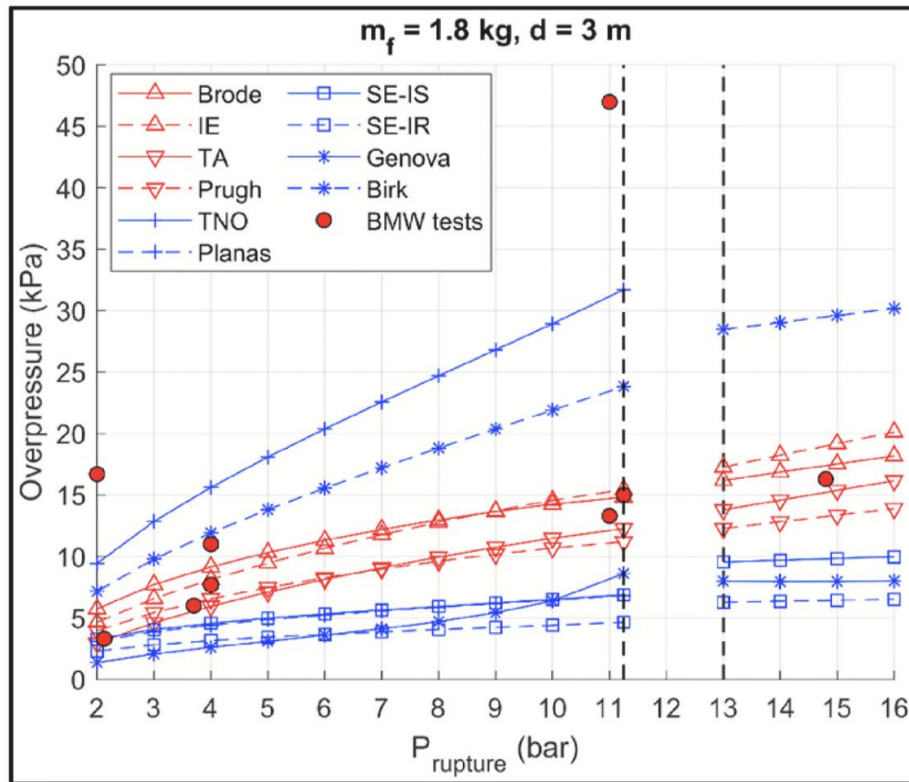
Boiling Liquid Expanding Vapour Explosion

Sudden depressurization of tank lading (adapted from (Casal, 2008))



Understanding LH2 BLEVE

Issue: conventional BLEVE models developed and validated for hydrocarbons **underestimate** the intensity of BLEVE explosions for LH2 storage tanks.

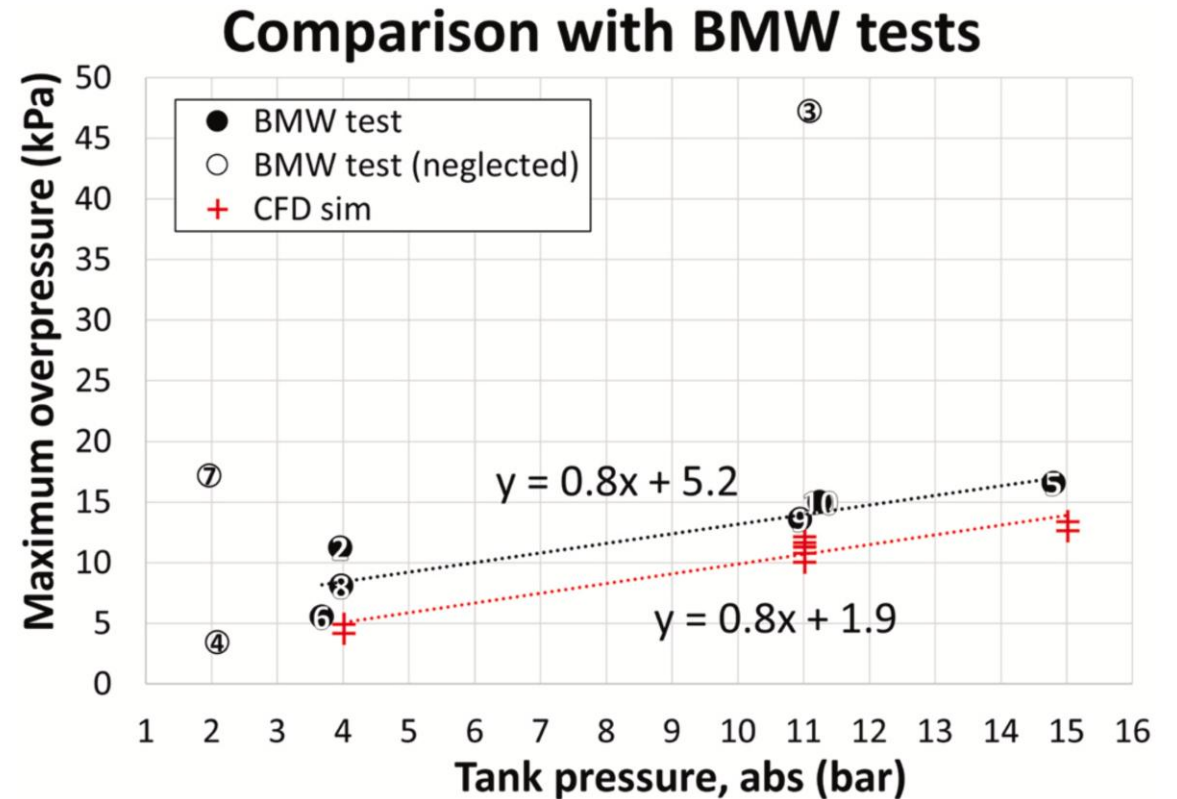


Comparison of different BLEVE integral models used to simulate the blast wave overpressure of BMW tests (Ustolin et al., 2020)

Understanding LH2 BLEVE

CFD analysis of **cold BLEVE**, i.e. disregarding the combustion contribution to the blast wave, **underestimated** the explosion consequences as well.

Speculation: H₂ combustion contributes to the blast wave effects.

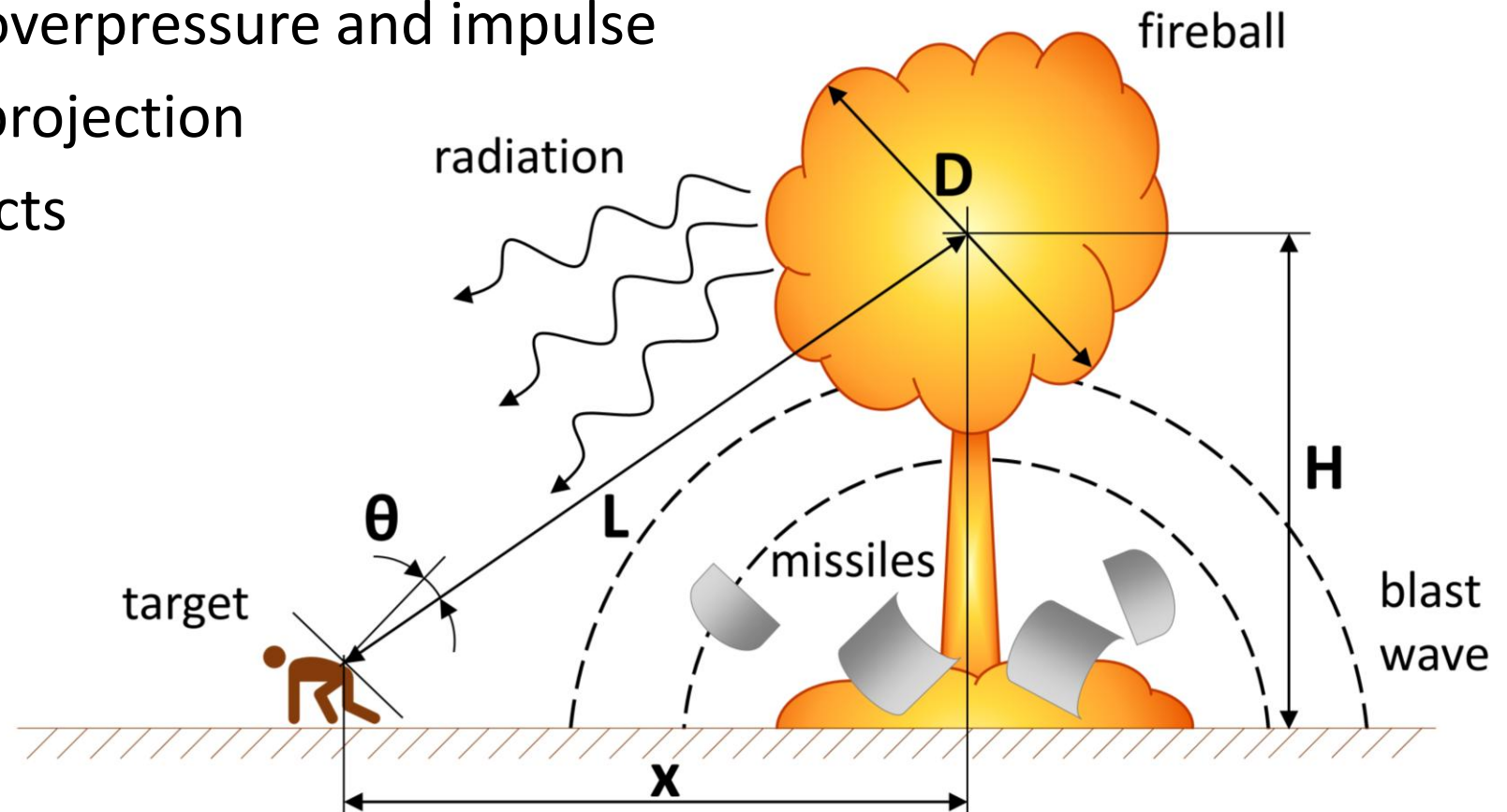


CFD analysis of LH₂ BLEVE (Ustolin et al., 2022)

BLEXCOM model

BLEVE Explosion Consequence Model (BLEXCOM) is an integral model developed by **NTNU** capable of estimating the main BLEVE consequences:

1. Blast wave overpressure and impulse
2. Fragments projection
3. Fireball effects



BLEXCOM model

Blast wave effects

- **Real gas behavior and isentropic expansion** approach (van den Bosch and Weterings, 2005).
- **Combustion process** (chemical energy) contributes (approx. 5%) to the blast wave: $E_{ch} = St \cdot m_g \cdot H_c$

Fragments projection

- **Aerodynamic forces** are considered and **drag factors** are specifically obtained for each main fragment as determined by Collina et al. (2023).

Fireball effects

- **Dimensions and duration:** correlations validated by Giannini et al. (2023).
- **Thermal effects:** solid flame model

Case study 1

SH2IFT BLEVE 02 test for validation



Video of BLEVE02 SH2IFT project fire test carried out at the Federal Institute for Materials Research and Testing (BAM) Test Site Technical Safety in 2021

Characteristics of the LH2 tank and its content

INNER TANK VOLUME (m ³)	BURST PRESSURE (MPa)	H2 TEMPERATURE BEFORE EXPLOSION (K)	TANK FILLING DEGREE (%)
1.00	4.85	53–153	35–40

Consequences of blast wave overpressure (OP) and fireball (FB)

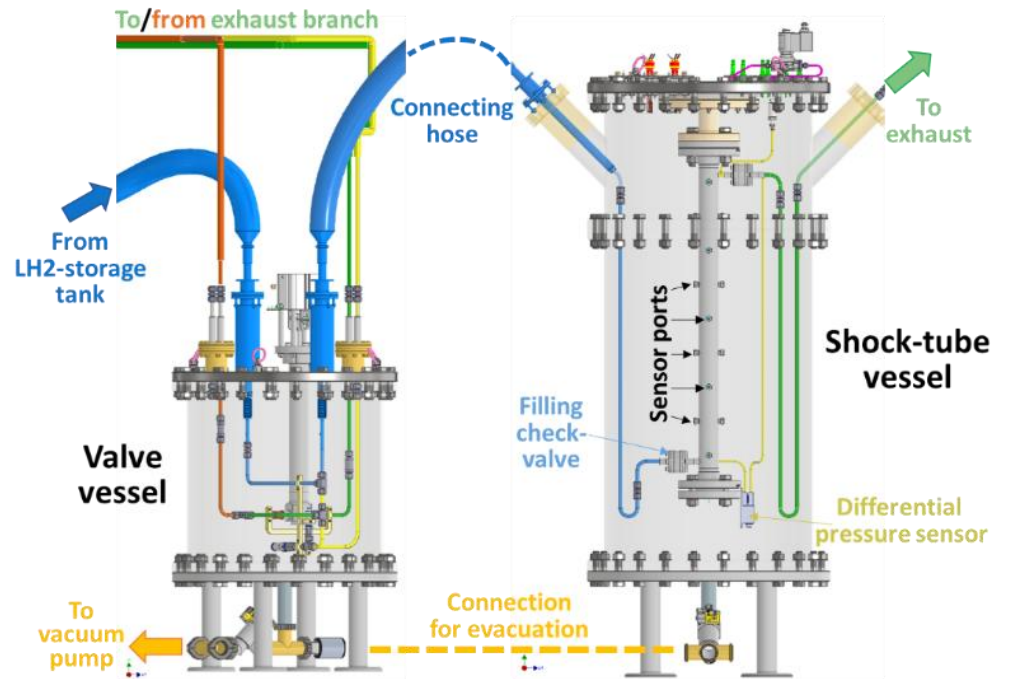
OP AT 22.5 m (kPa)	OP AT 26.4 m (kPa)	FB DIAMETER (m)	FB DURATION (s)	FB RADIATION AT 70 m (W/m ²)	FB RADIATION AT 90 m (W/m ²)
13.3	9.9	25.8	5	2,122	1,242

Case study 2

Prediction of ELVHYS shock tube tests

Shock tube built by KIT partner and use in the Task 4.3.1 experiments

Parameter	Value
Volume (L)	1.5
Inner diameter (mm)	51.2
Aspect ratio H/D	1 or 2
Length (mm)	102.4



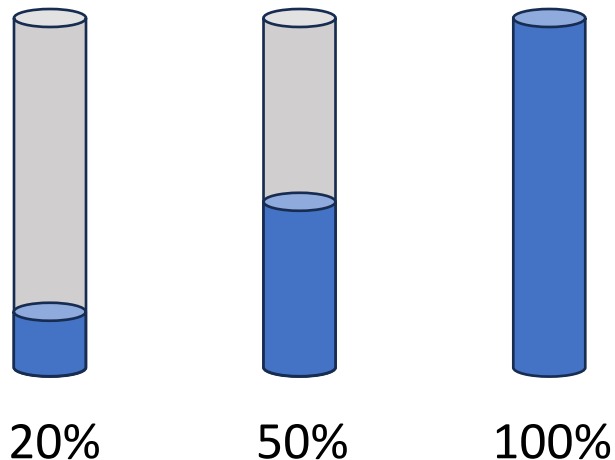
Shock tube test rig designed and developed by KIT partner and used in the Task 4.3.1 experiments

Case study 2

Prediction of ELVHYS shock tube tests

Three **LH2** masses were analysed:

- $m_{LH2} = 20 \text{ g}$
- $m_{LH2} = 50 \text{ g}$
- $m_{LH2} = 100 \text{ g}$



Filling degrees

Initial conditions of the Task 4.3.1 experiments performed by KIT partner for initial LH2 mass of **20 g**

Opening pressure (bar)	Status	LH2 temp. (K)	GH2 temp. (K)	LH2 density (kg/m ³)	GH2 density (kg/m ³)	LH2 volume (L)	GH2 volume (L)	LH2 mass (g)	Total H2 mass (g)
5.3	Subcritical	20.27	27.43	71.4	6.5	0.280	1.220	20.0	28.0
8.5	Subcritical	20.27	30.20	71.8	11.3	0.278	1.222	20.0	33.8
11.6	Subcritical	20.27	32.24	72.2	18.9	0.277	1.223	20.0	43.1
14.8	Comp. liquid	20.27	50.00	72.6	8.2	0.276	1.224	20.0	30.0
18.0	Comp. liquid	20.27	50.00	72.9	10.2	0.274	1.226	20.0	32.5
21.2	Comp. liquid	20.27	50.00	73.3	12.4	0.273	1.227	20.0	35.2
24.4	Comp. liquid	20.27	50.00	73.6	14.6	0.272	1.228	20.0	38.0
27.6	Comp. liquid	20.27	50.00	74.0	17.0	0.270	1.230	20.0	40.9
14.8	Supercritical	-	38.45	-	13.3	-	1.500	-	20.0
18.0	Supercritical	-	43.17	-	13.3	-	1.500	-	20.0
21.2	Supercritical	-	47.94	-	13.3	-	1.500	-	20.0
24.4	Supercritical	-	52.73	-	13.3	-	1.500	-	20.0
27.6	Supercritical	-	57.54	-	13.3	-	1.500	-	20.0

Case study 2

Prediction of ELVHYS shock tube tests

Three regimes were analysed:

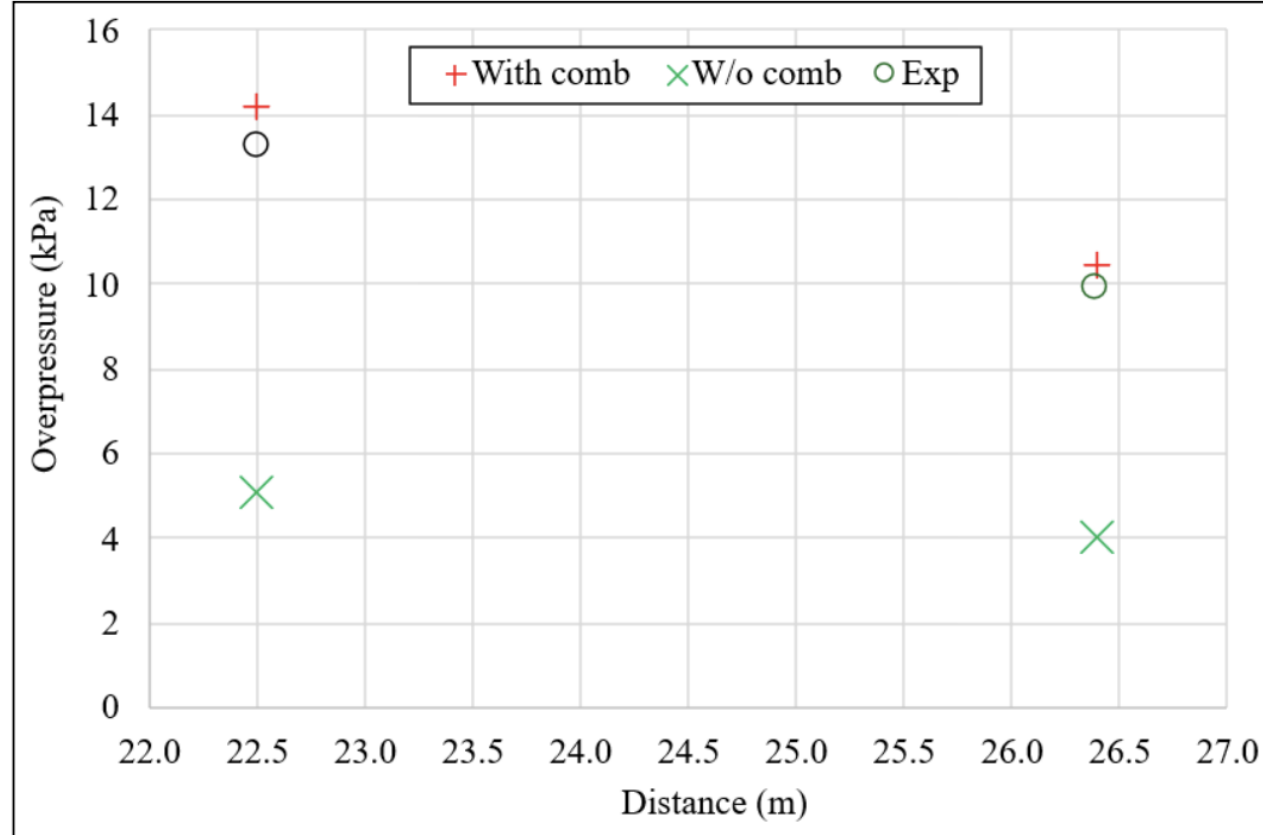
- **Subcritical:** $T < T_C$; $P < P_C$
- **Compressed liquid:** $T < T_C$;
 $P > P_C$
- **Supercritical:** $T > T_C$; $P > P_C$

Initial conditions of the Task 4.3.1 experiments performed by KIT partner for initial LH2 mass of **50 g**

Opening pressure (bar)	Status	LH2 temp. (K)	GH2 temp. (K)	LH2 density (kg/m ³)	GH2 density (kg/m ³)	LH2 volume (L)	GH2 volume (L)	LH2 mass (g)	Total H2 mass (g)
5.3	Subcritical	20.27	27.43	71.4	6.5	0.700	0.800	50	55.2
8.5	Subcritical	20.27	30.20	71.8	11.3	0.696	0.804	50	59.1
11.6	Subcritical	20.27	32.24	72.2	18.9	0.693	0.807	50	65.2
14.8	Comp. liquid	20.27	50.00	72.6	8.2	0.689	0.811	50	56.6
18.0	Comp. liquid	20.27	50.00	72.9	10.2	0.685	0.815	50	58.3
21.2	Comp. liquid	20.27	50.00	73.3	12.4	0.682	0.818	50	60.1
24.4	Comp. liquid	20.27	50.00	73.6	14.6	0.679	0.821	50	62.0
27.6	Comp. liquid	20.27	50.00	74.0	17.0	0.676	0.824	50	64.0
14.8	Supercritical	-	33.9	-	33.3	-	1.500	-	50
18.0	Supercritical	-	35.4	-	33.3	-	1.500	-	50
21.2	Supercritical	-	36.9	-	33.3	-	1.500	-	50
24.4	Supercritical	-	38.4	-	33.3	-	1.500	-	50
27.6	Supercritical	-	39.9	-	33.3	-	1.500	-	50

Results

SH2IFT test - Blast wave effects



Blast wave overpressure generated by the supercritical LH2 BLEVE measured during the SH2IFT fire test and compared with the values assessed by the BLEXCOM tool with and without considering the combustion contribution

Results

SH2IFT test - Blast wave effects

DISTANCE (m)	OVERPRESSURE			ERRORS	
	EXPERIMENTS (kPa)	BLEXCOM WITH COMB (kPa)	BLEXCOM W/O COMB (kPa)	BLEXCOM WITH COMB (%)	BLEXCOM W/O COMB (%)
22.5	13.3	14.2	5.1	+6.7	-61.9
26.4	9.9	10.4	4.1	+5.4	-59.1

DISTANCE (m)	IMPULSE			ERRORS	
	EXPERIMENTS (PA·S)	BLEXCOM WITH COMB (PA·S)	BLEXCOM W/O COMB (PA·S)	BLEXCOM WITH COMB (%)	BLEXCOM W/O COMB (%)
22.5	83.1	90.1	42.0	+8.4	-49.4
26.4	69.3	69.1	36.9	-0.4	-46.7

Blast wave overpressure and impulse simulated with BLEXCOM and compared with the SH2IFT experimental results

Results

SH2IFT test - Fireball effects

FIREBALL PARAMETER	EXPERIMENTS	BLEXCOM	ERROR (%)
Diameter (m)	25.8	32.2	+24.8
Duration (s)	5	5.58	+11.6

DISTANCE FROM FIREBALL (m)	RADIATION (W/m ²)		
	EXPERIMENTS	BLEXCOM	ERROR (%)
70	2,120	2,570	+21.2
90	1,240	1,580	+27.4

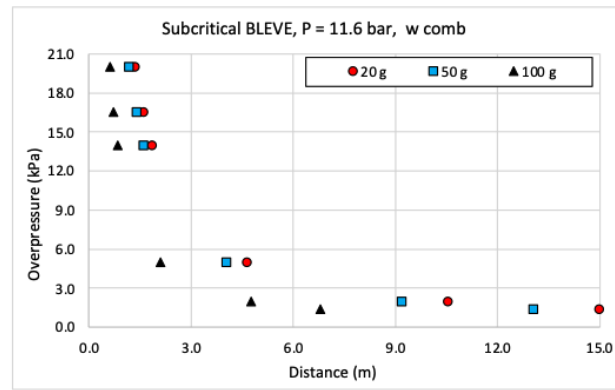
DISTANCE FROM FIREBALL (m)	THERMAL DOSE (kW/m ²) ^{4/3} s		
	EXPERIMENTS	BLEXCOM	ERROR (%)
70	13.6	19.6	+44.3
90	6.7	10.3	+54.2

Fireball diameter, duration, radiation, and thermal dose simulated with BLEXCOM and compared with the experimental results.

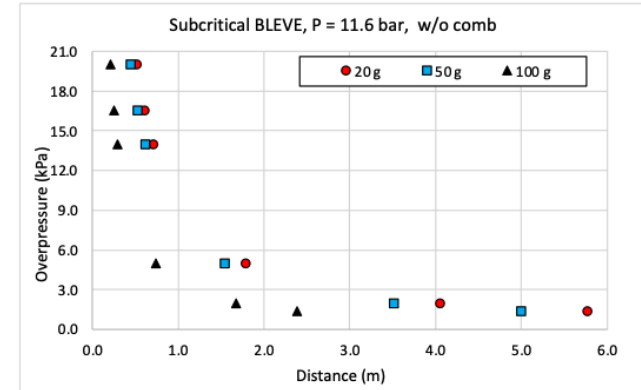
Results

ELVHYS shock tube test Blast wave effects

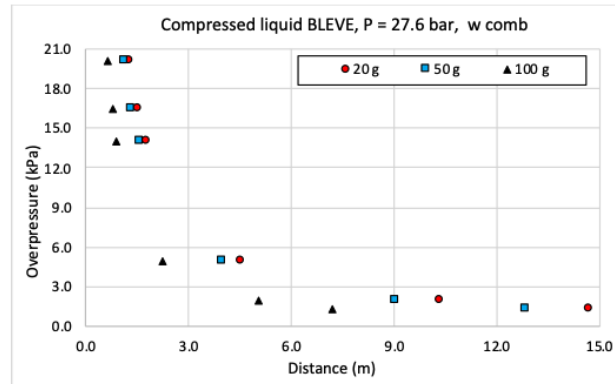
- **Combustion process** is the dominant factor.
- Tank **rupture pressure** has a limited effect with combustion.
- **Worst-case:** 50% filling in supercritical regime.
- Combustion has **no effect** for the 100% filling.



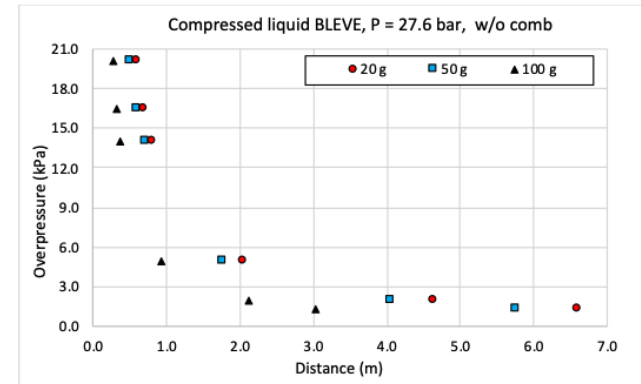
(a)



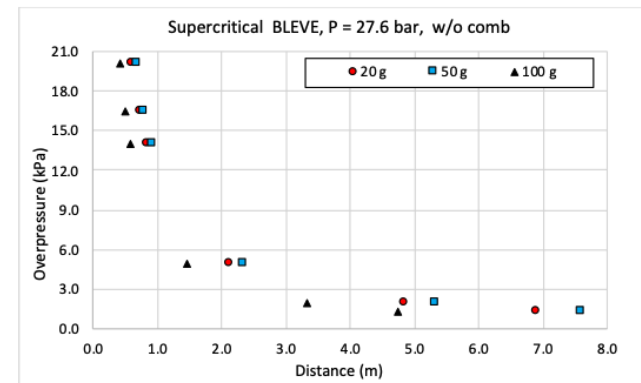
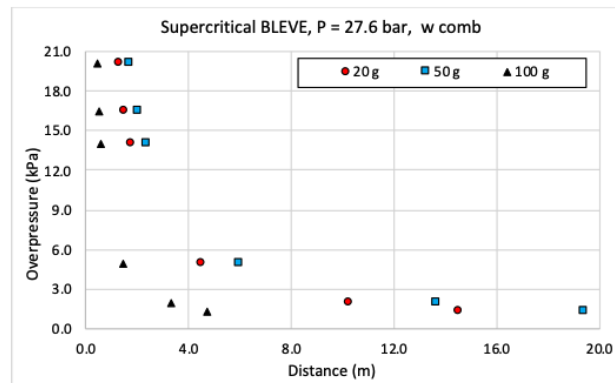
(b)



(c)



(d)



Results

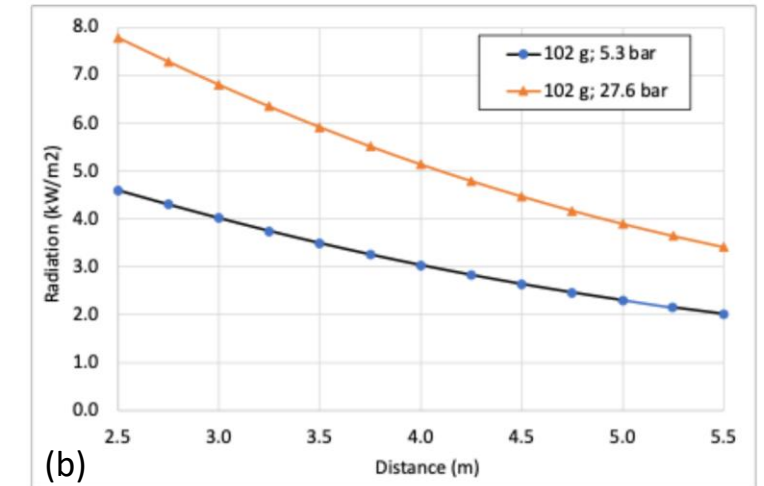
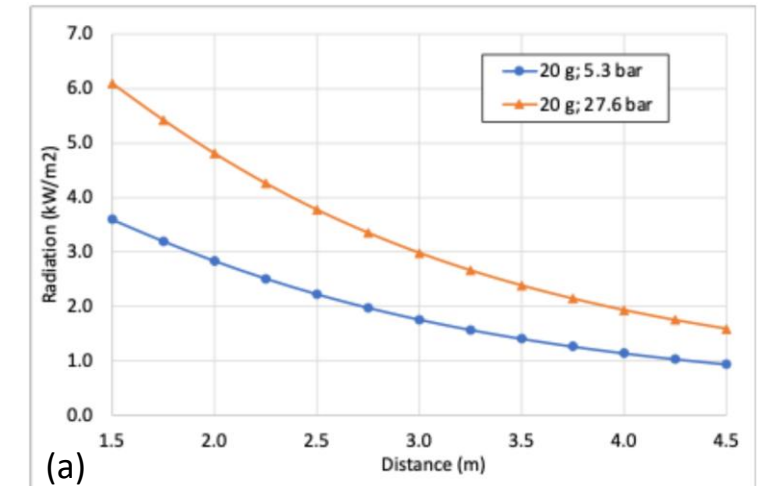
ELVHYS shock tube test - Fireball effects

Fireball diameter and duration for the 20 and 102.2 g cases.

H ₂ mass (g)	D _{fb} min (m)	D _{fb} max (m)	t _{fb} min (s)	t _{fb} max (s)
20.0	3.0	4.5	1.7	1.9
102.2	5.1	7.7	2.2	2.5

Fireball radiation and thermal dose calculated for the 20 and 102.2 g cases.

H ₂ mass (g)	Opening pressure (bar)	Distance (m)	Radiation (kW/m ²)	Thermal dose ((kW/m ²) ^{4/3} s)
20.0	5.3	1.5	3.6	4.9
20.0	27.6	1.5	6.1	10.0
102.2	5.3	2.5	4.6	17.0
102.2	27.6	2.5	7.8	34.4



Radiation estimated at different distances for initial hydrogen mass of (a) 20 and (b) 102.2 g and opening pressure at 5.3 and 27.6 bar

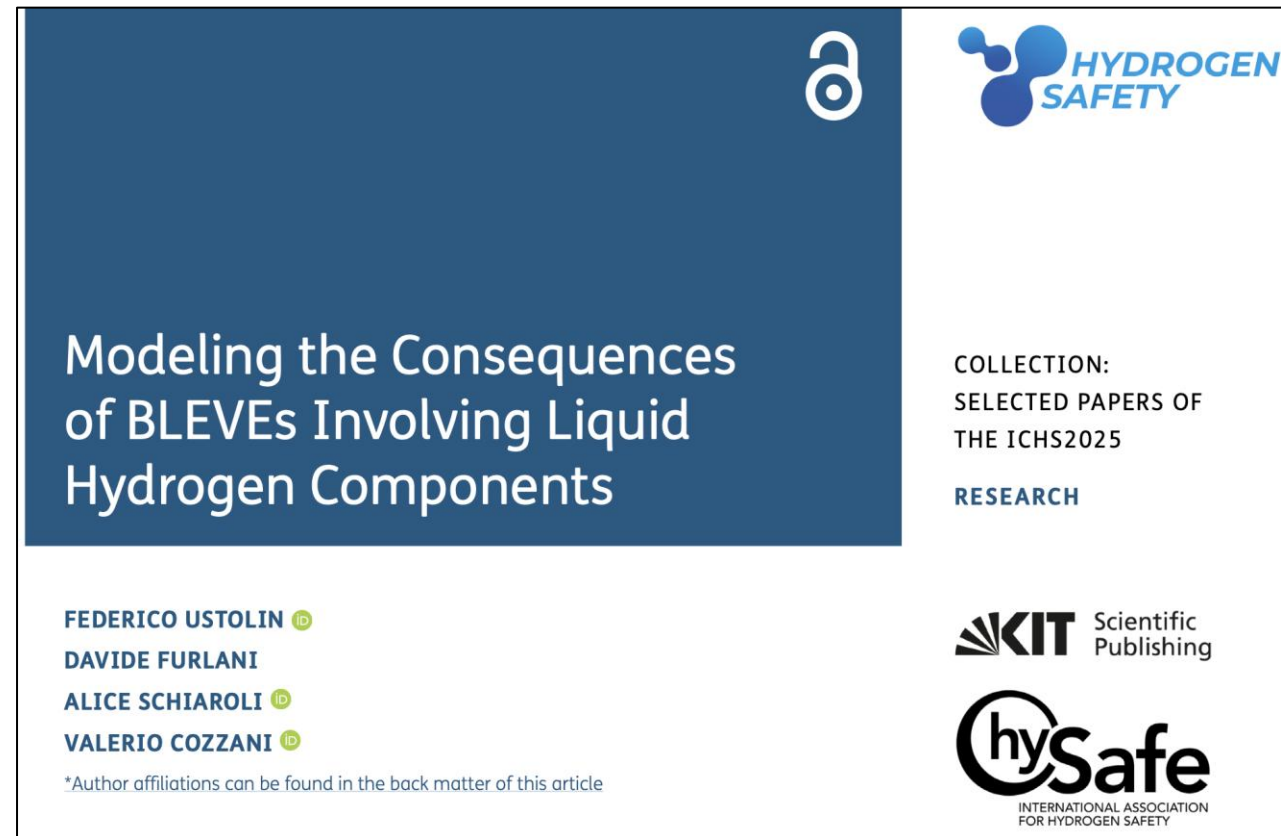
Conclusions and recommendations

- BLEXCOM was **validated** against both sub- and supercritical LH2 BLEVEs.
- **BLEXCOM** provides a comprehensive, fast and practical tool for assessing the consequences of LH2 BLEVEs.
- **Uncertainties:** conditions prior the explosion (e.g. temperature gradient, mass distribution between GH2 and LH2).
- Insights on the **combustion process** from ELVHYS project could confirm previous speculations.
- **Large-scale testing** is needed to improve the LH2 BLEVE understanding and determine the scale effect.

Reference

Additional details on BLEXCOM model can be found here:

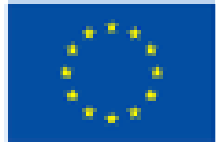
<https://hysafejournal.org/articles/10.58895/hysafe.68>





Thank you for your attention

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