HySchool Webinar

Detonations in risk assessment of hydrogen systems

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PROCESS SAFETY, COMBUSTION AND EXPLOSION RESEARCH GROUP

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University of South-Eastern Norway

HYDROGENi

RA4 Safety and material integrity

Table of Content

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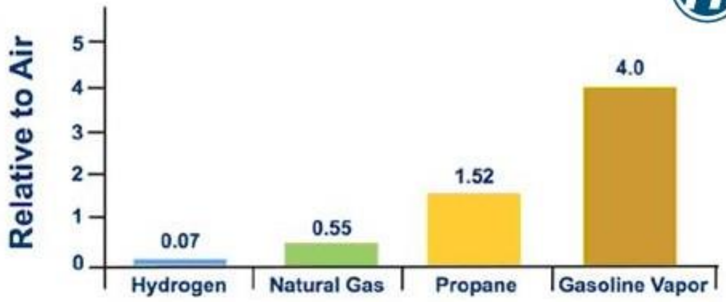
INTRODUCTION

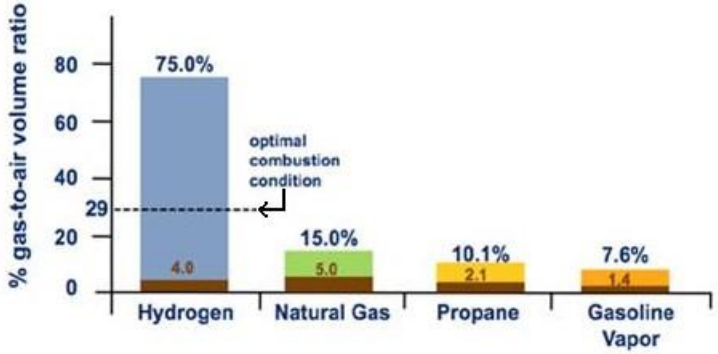
H2 properties:

- LHV: **119.96 MJ/kg**
- ρ = **0.0883 kg/m3**
- Minimum ignition energy: **0.017mJ**
- Flammability range in air: **4-75 %vol**
- D = **120 pm** (atom) ; **74 pm** (molecule)
- Non-toxic and non-corrosive
- Flame visibility: low
- Colour and odour: non

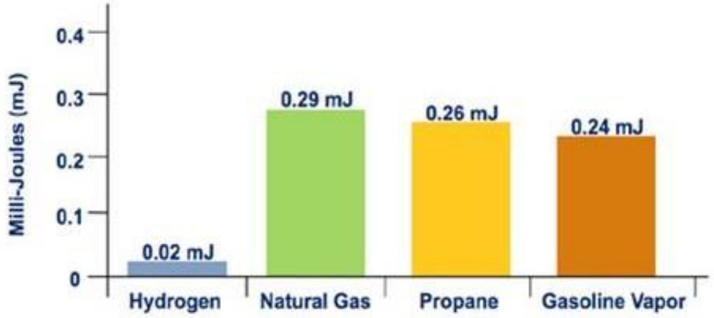
Property	Hydrogen	Methane
Laminar Flame Speed [m/s]	2.7	0.4
LHV [MJ/kg]	120	50
Detonation Energy	1 g TNT	1 kg TNT



Relative Vapour Density



Flammability Range in Air



Minimum Ignition Energy

Accidental Explosion

- June 10, 2019
- Blast from explosion felt miles away
- 75 kg wall elements found 40m from the main building
- No fatalities
- Possible fail: End flange of the high-pressure H2 storage unit (composite tank)
- Possible DDT

Uno-X Station Explosion in Sandvika, Norway

- **Learning** from accidents
- Implement better **standards** and **regulations**

RESEARCH AREAS

PRODUCTION

TRANSPORT & STORAGE

END-USE

SAFETY & MATERIAL INTEGRITY

SUSTAINABLE HYDROGEN ECONOMY

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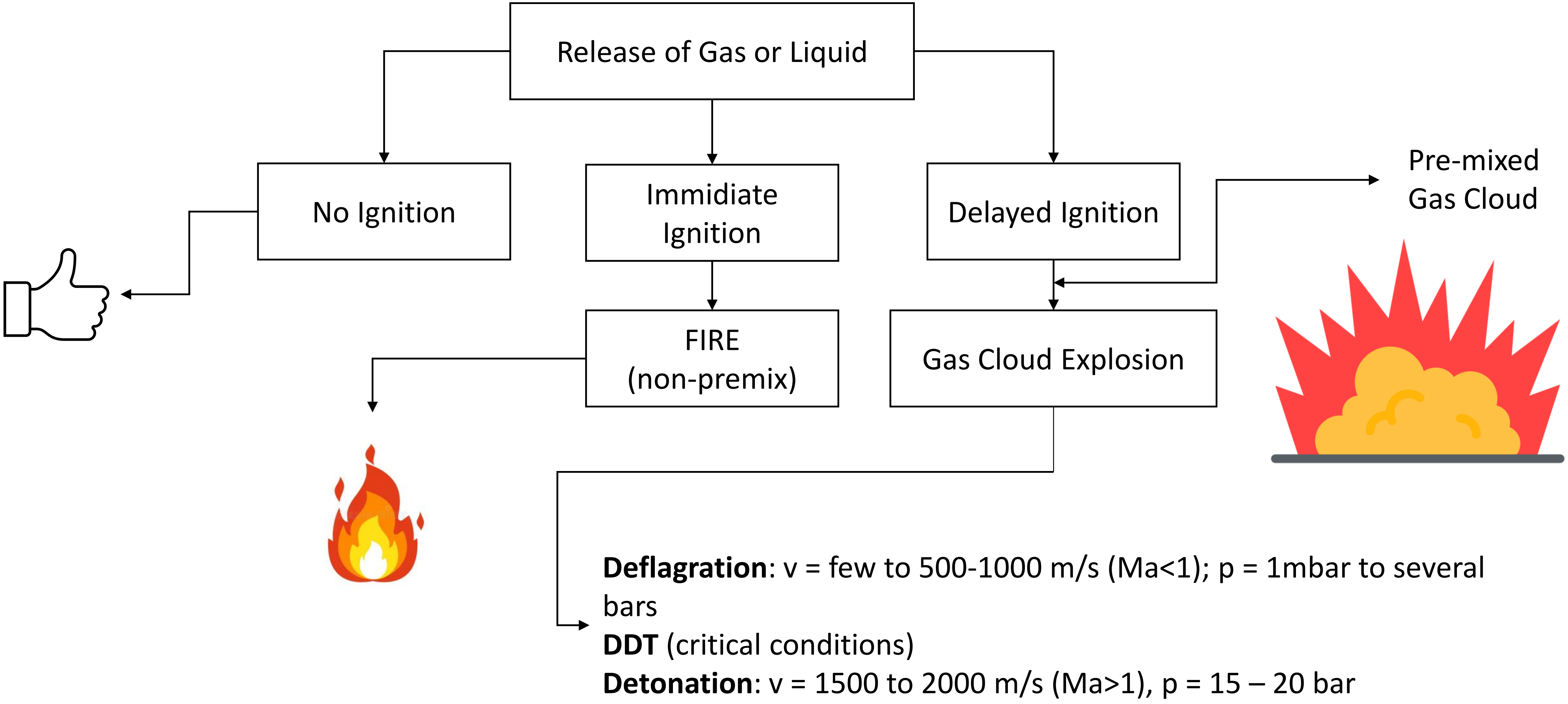
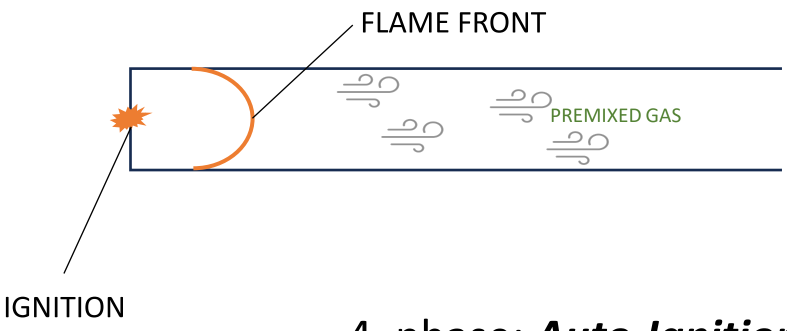
Gas Explosion

Combustion

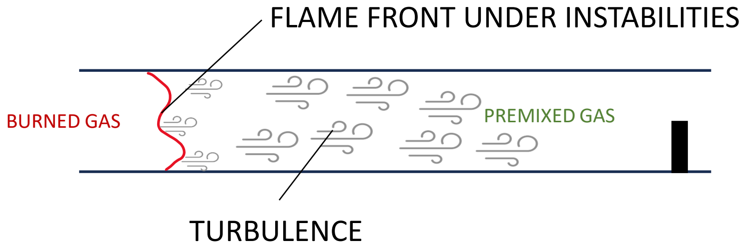

Release of Gas or Liquid
No Ignition
Immidiate Ignition
Delayed Ignition
Pre-mixed Gas Cloud
FIRE (non-premix)
Gas Cloud Explosion
Deflagration: v = few to 500-1000 m/s (Ma<1); p = 1mbar to several bars
DDT (critical conditions)
Detonation: v = 1500 to 2000 m/s (Ma>1), p = 15 – 20 bar

Process : Deflagration Detonation Transition (DDT)

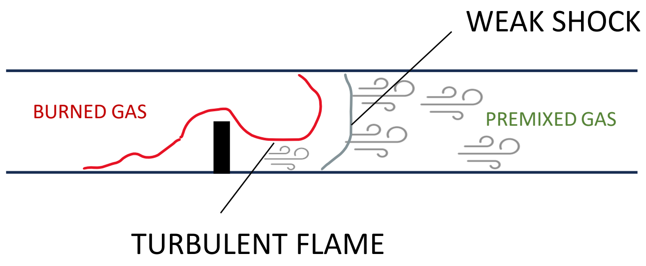
1. Phase: ***Laminar Flame***



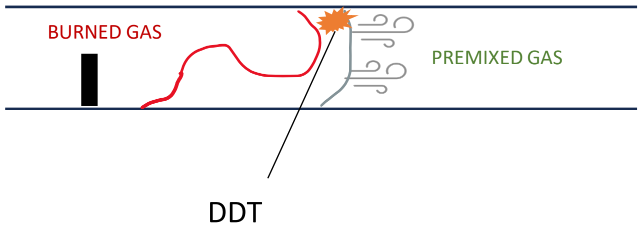
2. Phase: ***Wrinkled*** **Flame**



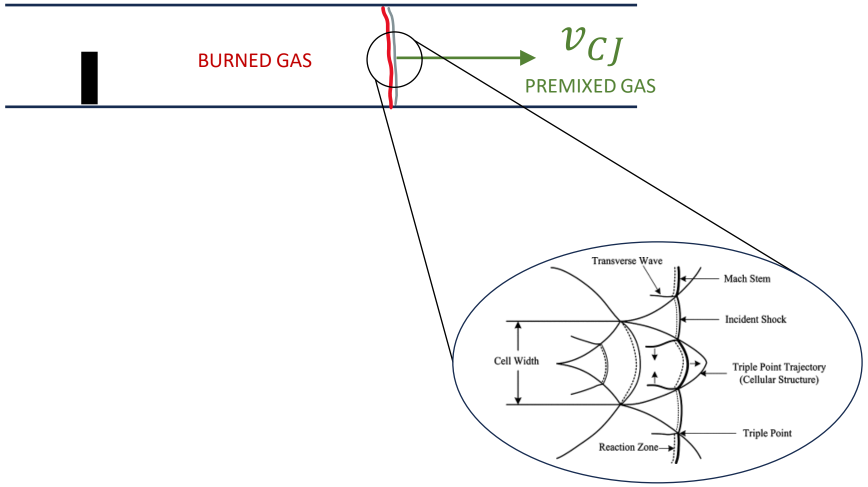
3. Phase: **Turbulent Flame Brush**



4. phase: ***Auto-Ignition*** (DDT)



5. phase: **Freelly propagating Detonation Wave**



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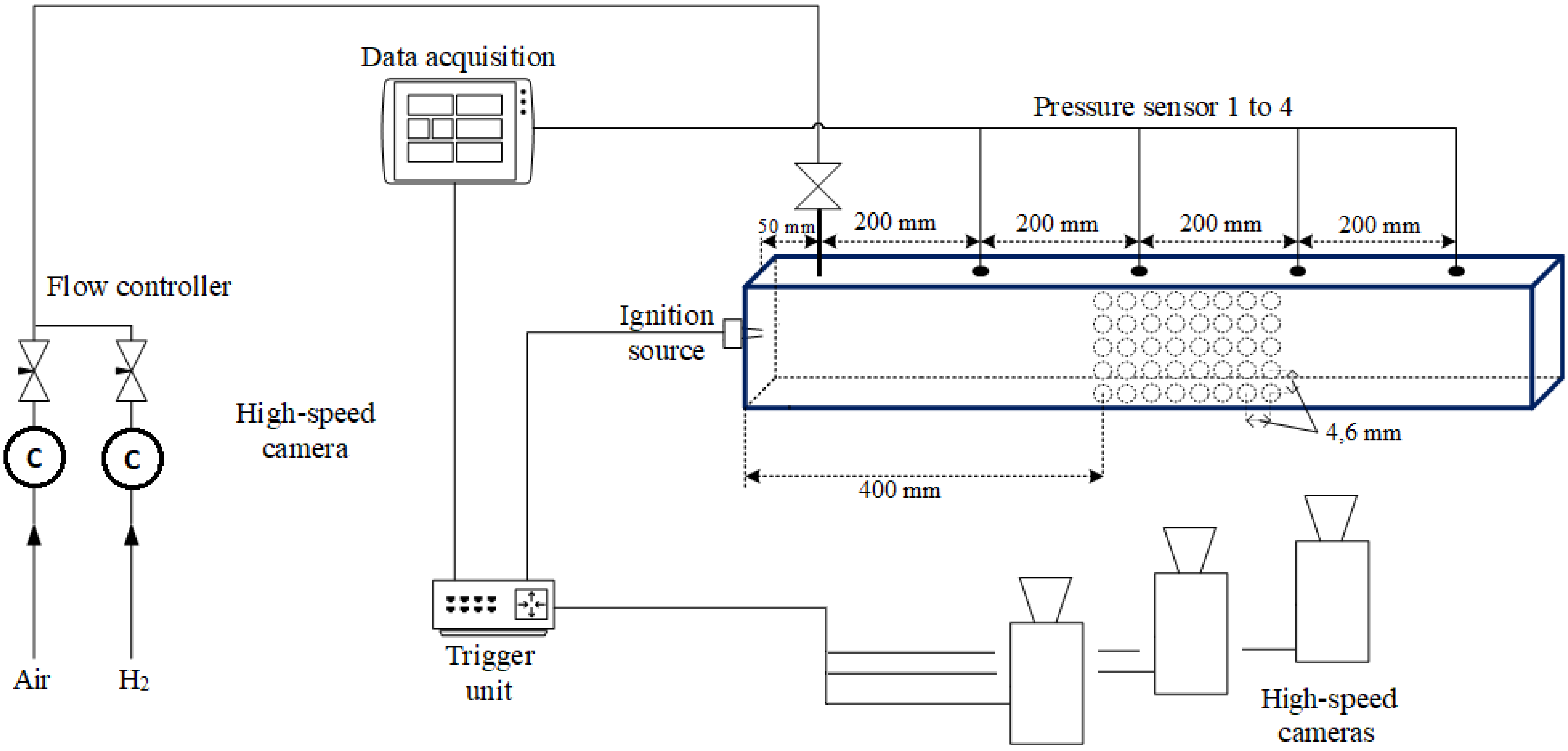
Explosion Experiments

SMALL SCALE

1m Explosion Channel with Obstructions



Ref: Mathias Henriksen

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South-Eastern Norway
MOZEES
Mobility Zero Emission Energy Systems

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Explosion Modeling

1. CASE

Model Validation

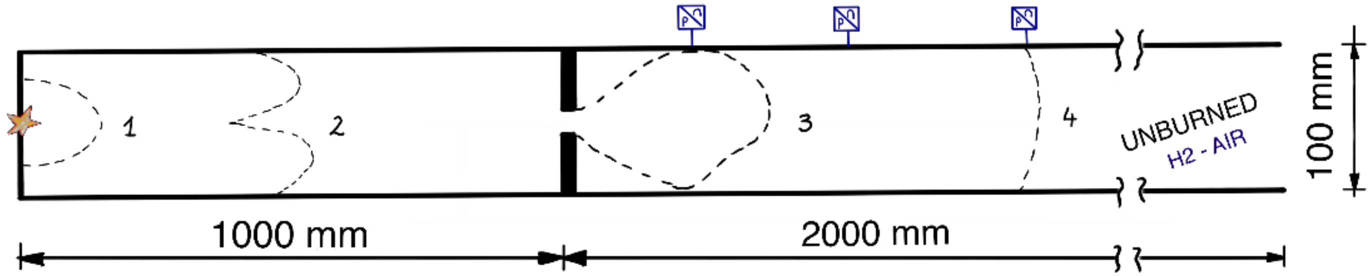
Numerical Model

- The solver ***blastXiFoam*** developed on the OpenFOAM platform by Synthetic Applied Technologies is an extension of the standard OpenFOAM ***XiFoam*** solver
- ***Flame-wrinkling combustion model***
- ***k-omega SST*** turbulence model with wall functions
- ***HLLC Riemann solver*** is used to calculate numerical fluxes (DENSITY BASED SOLVER)

A. V. Gaathaug, K. Vågsæther, and D. Bjerketvedt, 'Experimental and numerical investigation of DDT in hydrogen–Air behind a single obstacle', *Int. J. Hydrog. Energy* (2012)

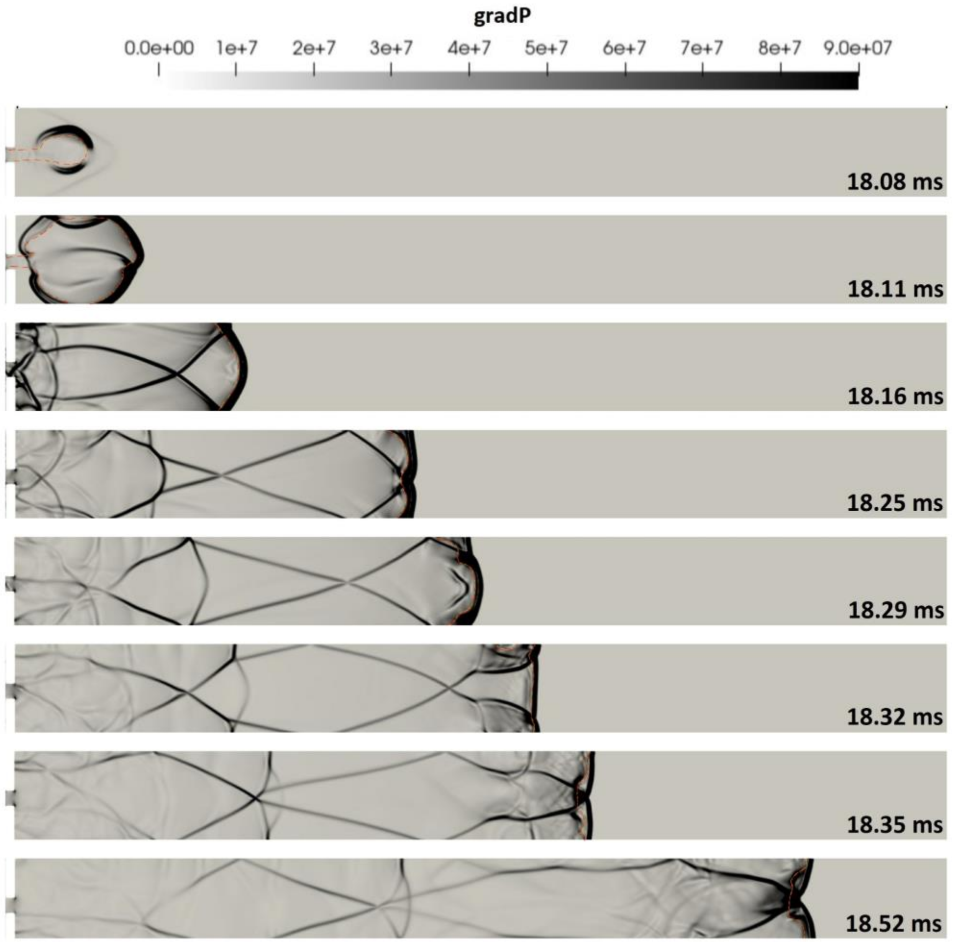
Numerical Setup

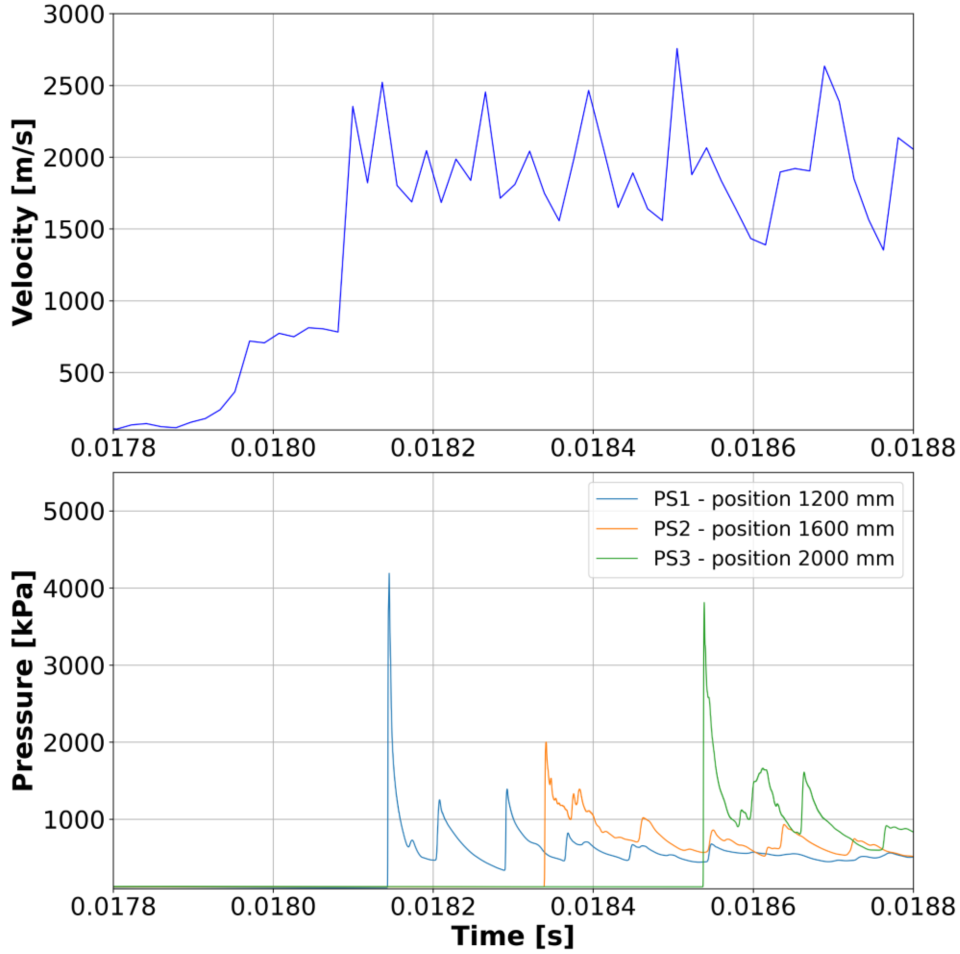
- The gas mixture → homogeneous blend of hydrogen and air with a hydrogen concentration of 35%
- 3 m long channel with a 0.1 x 0.1 m^2 square cross-section, where one end was closed, while a single obstacle was placed 1m from the close end (creating an 84% blocked ratio)
- The resolution of the 2D mesh is 1 mm per square cell, which comprises ***299 160*** orthogonal hexahedral elements with an aspect ratio of 1
- The thermophysical and transport properties of the gas mixture were obtained using the open-source code ***mech2Foam*** developed by Mathias Henriksen



Experimental/Numerical configuration (the change from laminar to turbulent deflagration occurs in Regions 1-3, while detonation occurs in Region 4)

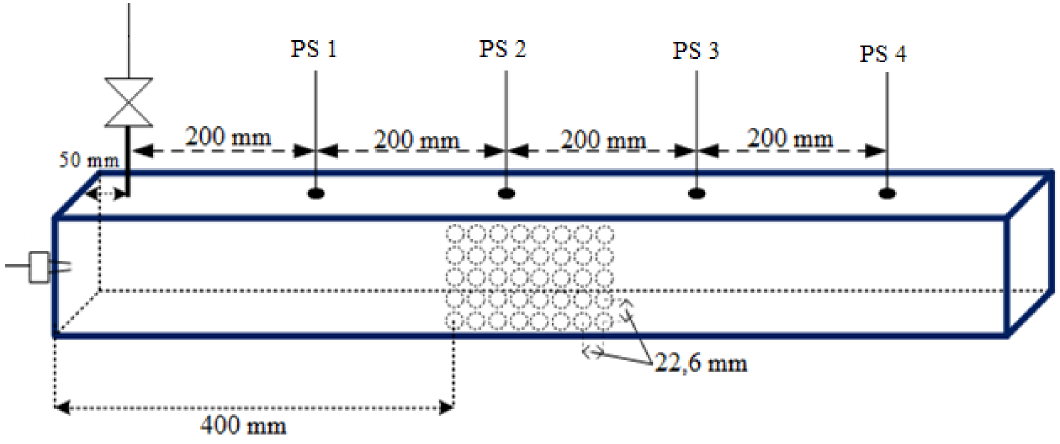
Results – after the obstacle

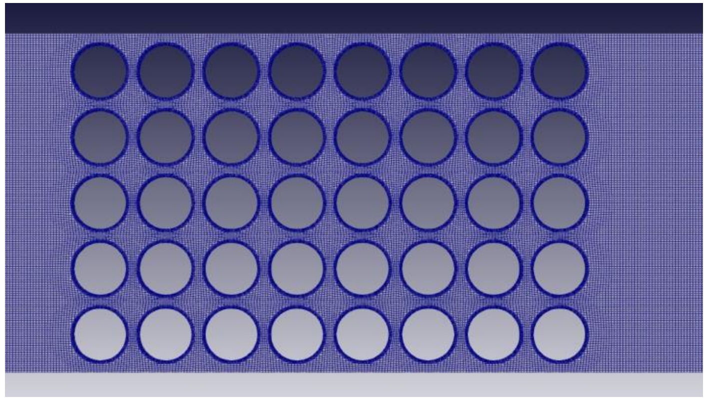




2. CASE

BLIND-PREDICTION

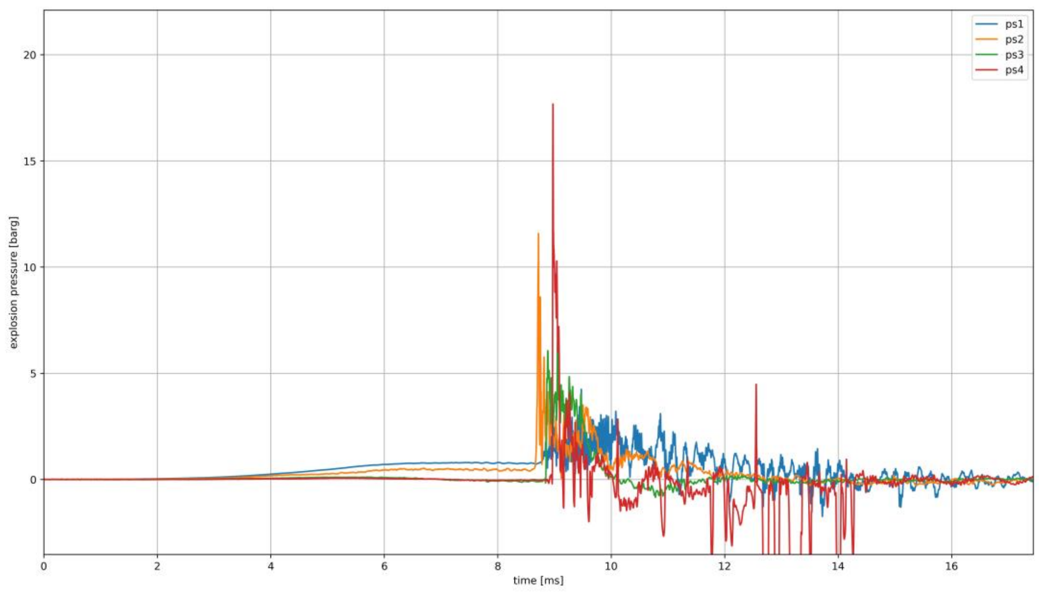




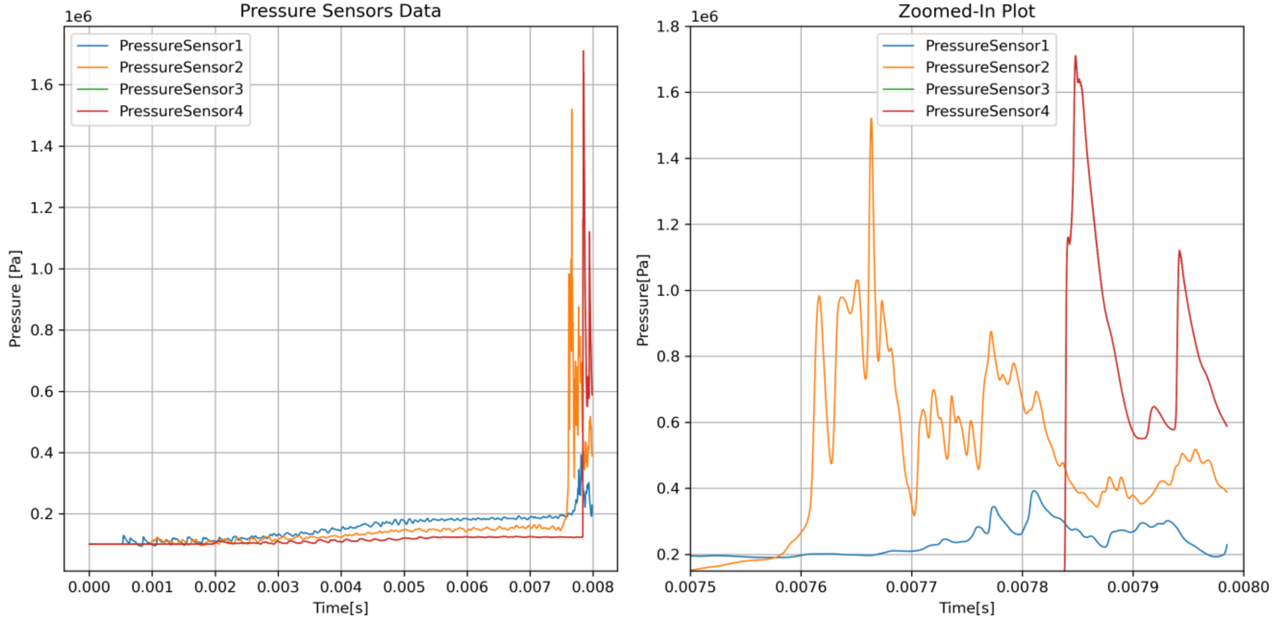
Filling time: 300 s
H2 vol%: 32%
H2 mass: 2.7 g
AIR mass: 83.3 g

Mesh: 165 974 cells (2D)
Numerical Setup: same as 1. CASE
Simulation Time: 6 core → 23h

	Concentration	max PS 1 [barg]	max PS 2 [barg]	max PS 3 [barg]	max PS 4 [barg]
Experiment	1.129	4.2	11.6	6.9	17.7
Simulation	1.1	2.9	14.3	/	16.1



Experiment Data



Simulation Data

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Conclusion

& FUTURE RESEARCH DIRECTION

CONCLUSIONS:

- **blastXiFoam** solver on the OpenFOAM platform to study flame dynamics
- Flame acceleration and Deflagration to Detonation Transition (**DDT**)
- Premix homogeneous hydrogen-air mixture within channel with an obstacle
- Benchmarked against two setups (CASE 1: model validation; CASE 2: blind prediction)
- **Shock/Flame Front interaction → Local "explosions"** that **lead** to transition to detonation
- Good **agreement** with **experiments** regarding **overpressure** and flame front **velocity** predictions
- **DDT** occurs in the numerical analysis
- Unterstanding modeling of DDT in blastFOAM (reaction rate model)

FUTURE WORK

- Experimental Research: addressing the stochastic nature of DDT through 180 random concentration experiments ranging from 24vol% to 40vol% of H_2 → hot-spot initiation probability, DDT probability, flame propagation inside obstructed geometry and channel mapping
- Numerical Research: Understanding reaction rate modeling in blastXiFoam and implementing new approaches to calculate turbulent flame speed ($Xi=S_{tubulent}/S_{laminar}$)

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Norwegian Centre for Environmentfriendly Energy Research

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