WHEN TRUST MATTERS

CostFX - Full-scale explosions of gaseous hydrogen jets in congestion

With reference to earlier hydrocarbon tests

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Overview

- Objectives of the experimental part of the CostFXII JIP
- Comments on earlier experiments with natural gas
- Videos of large scale hydrogen experiments
  - Free jets
  - Quiescent homogenous mixture into pipework congestion
  - Gas jets into congestion that mimics pipework and hydrogen storage possibilities

Objectives of experimental programme

Objectives

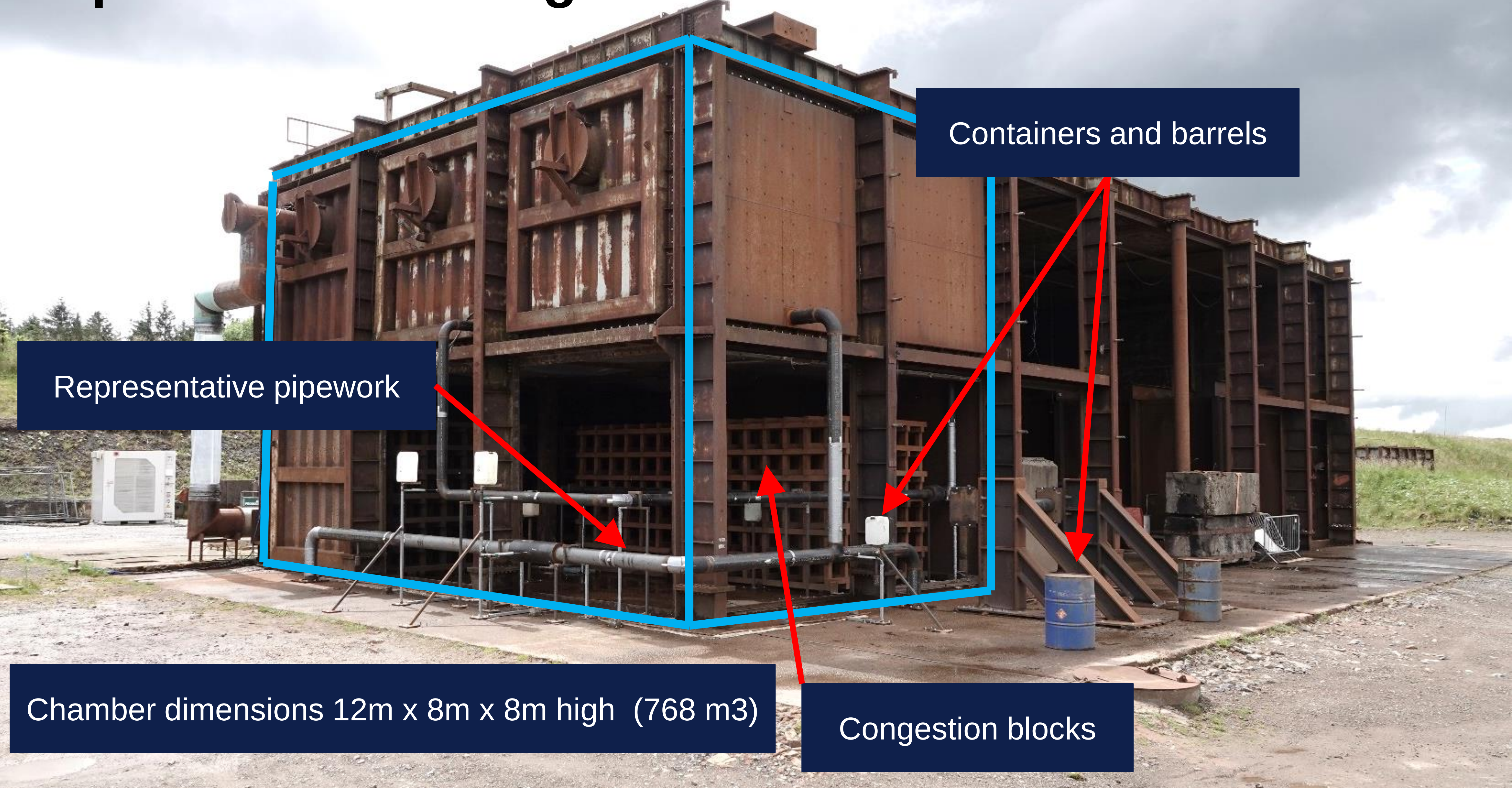
- Primary objective of the experiments:
  - To provide data to support modelling activities on **hydrocarbon** explosion loading
  - To provide empirical data on the explosion characteristics of **hydrogen** for realistic releases

- **Hydrocarbons (natural gas)**
  - To provide data on explosion loading generated by realistic releases in semi-confined and irregularly congested regions
    - (help understand the temporal and spatial variation of explosion loading)
  - To measure the response of representative pipework structures to the explosions

- **Hydrogen**
  - To provide data on the conditions that can lead to deflagration to detonation transition (DDT)
    - Realistic high pressure hydrogen jets
    - Quiescent homogenous mixtures at well-defined concentrations

Natural gas experiments

Experimental Arrangement

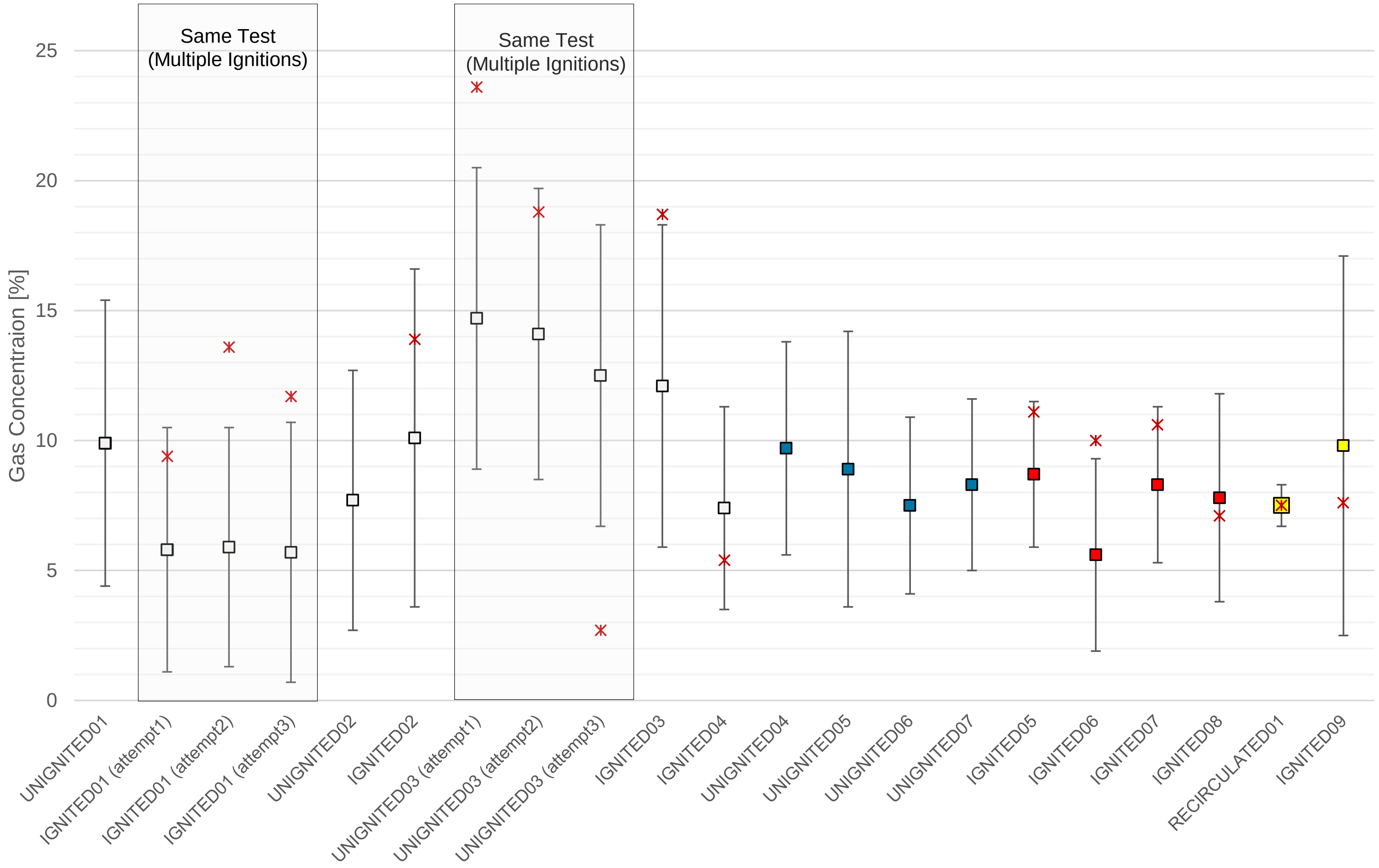


Achieving High Explosion Loads

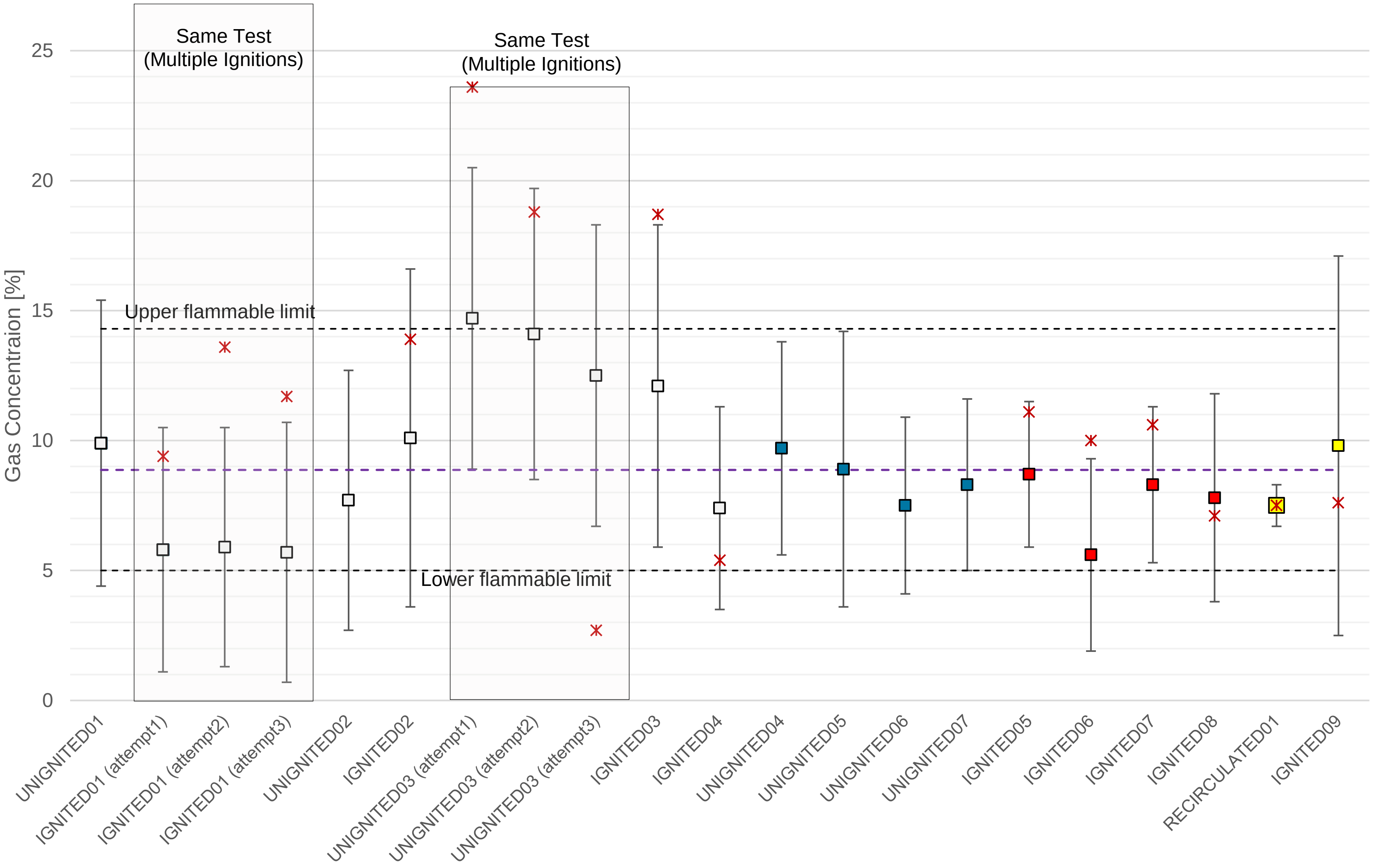
- Variation in release location and mass release rates
  - High pressure natural gas jets of 0.33 to 0.65 kg/s

- Initial release configurations based on experimental judgement
  - Overpressures were too low
  - Significant proportions of the gas cloud were at poorly reactive concentrations

- Conducted CFD analysis as programme progressed (with assistance from Equinor)
  - Achieved significantly higher pressures



Same Test
(Multiple Ignitions)
Same Test
(Multiple Ignitions)
Gas Concentraion [%]
25
20
15
10
5
0
UNIGNITED01
IGNITED01 (attempt1)
IGNITED01 (attempt2)
IGNITED01 (attempt3)
UNIGNITED02
IGNITED02
UNIGNITED03 (attempt1)
UNIGNITED03 (attempt2)
UNIGNITED03 (attempt3)
IGNITED03
IGNITED04
UNIGNITED04
UNIGNITED05
UNIGNITED06
UNIGNITED07
IGNITED05
IGNITED06
IGNITED07
IGNITED08
RECIRCULATED01
IGNITED09


Same Test
(Multiple Ignitions)
Same Test
(Multiple Ignitions)
25
20
15
10
5
0
Gas Concentraion [%]
Upper flammable limit
Lower flammable limit
UNIGNITED01
IGNITED01 (attempt1)
IGNITED01 (attempt2)
IGNITED01 (attempt3)
UNIGNITED02
IGNITED02
UNIGNITED03 (attempt1)
UNIGNITED03 (attempt2)
UNIGNITED03 (attempt3)
IGNITED03
IGNITED04
UNIGNITED04
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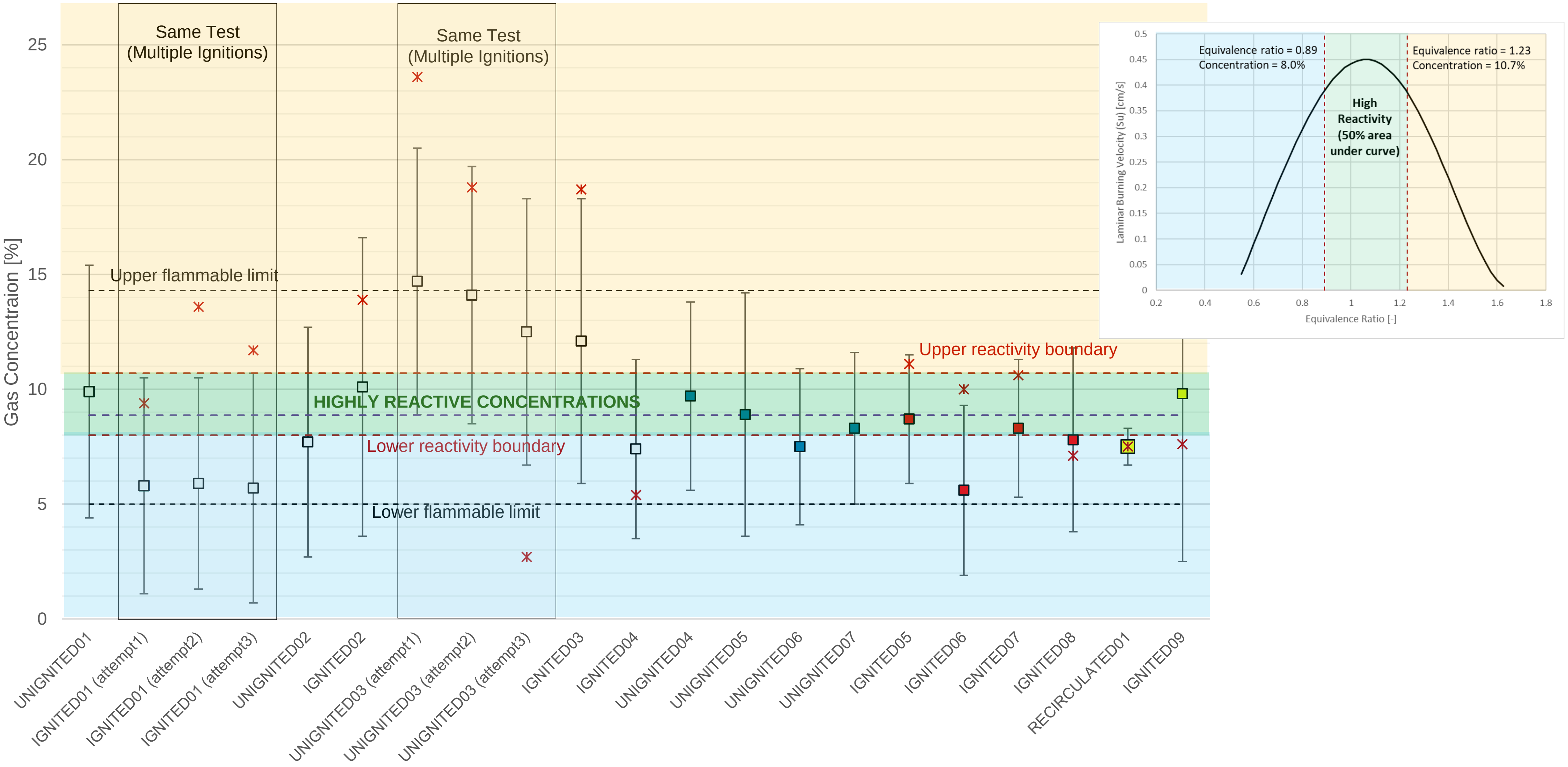
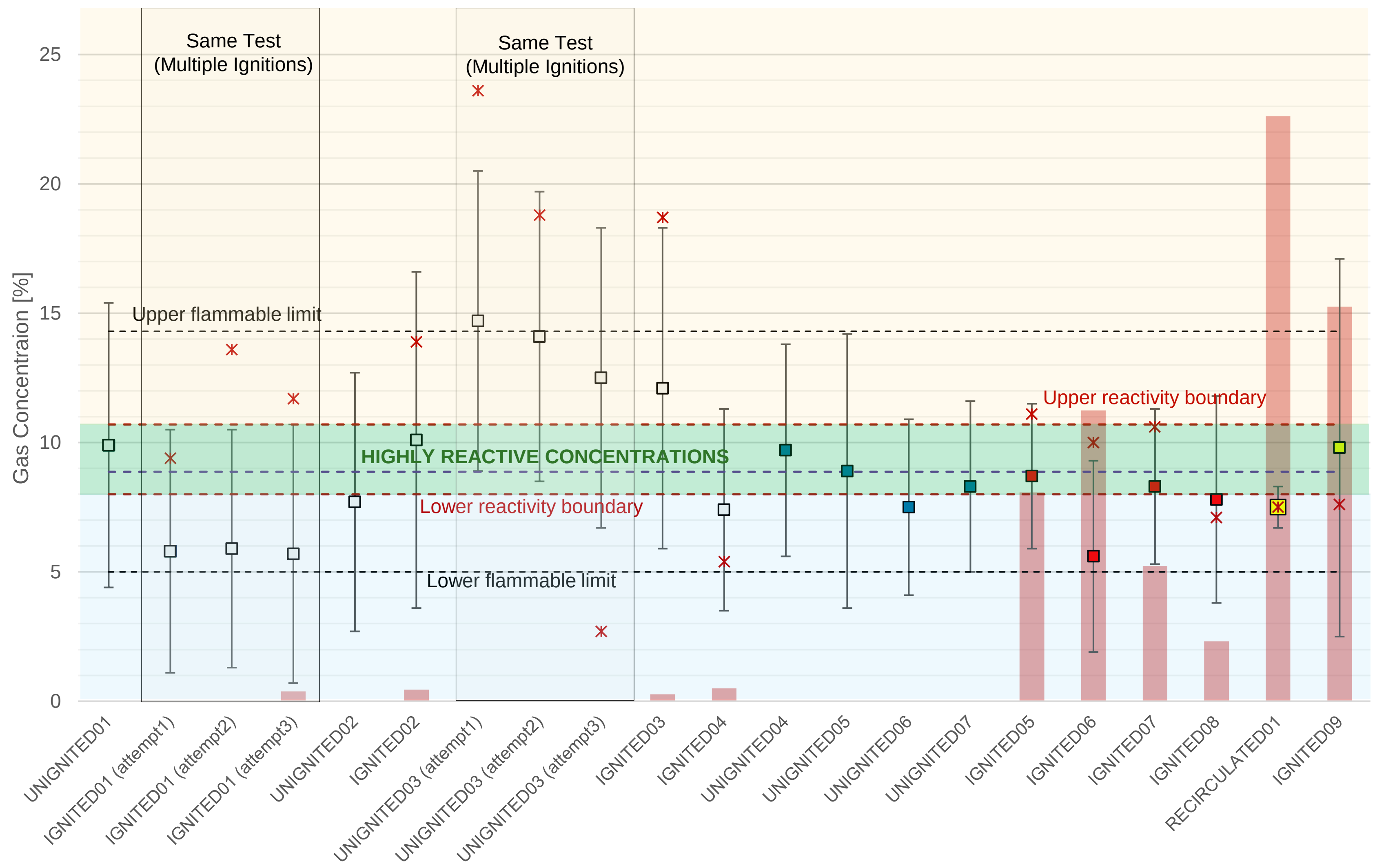
UNIGNITED06
UNIGNITED07
IGNITED05
IGNITED06
IGNITED07
IGNITED08
RECIRCULATED01
IGNITED09



Same Test
(Multiple Ignitions)
Same Test
(Multiple Ignitions)
Upper flammable limit
Upper reactivity boundary
HIGHLY REACTIVE CONCENTRATIONS
Lower reactivity boundary
Lower flammable limit
Gas Concentraion [%]
25
20
15
10
5
0
UNIGNITED01
IGNITED01 (attempt1)
IGNITED01 (attempt2)
IGNITED01 (attempt3)
UNIGNITED02
IGNITED02
UNIGNITED03 (attempt1)
UNIGNITED03 (attempt2)
UNIGNITED03 (attempt3)
IGNITED03
IGNITED04
UNIGNITED04
UNIGNITED05
UNIGNITED06
UNIGNITED07
IGNITED05
IGNITED06
IGNITED07
IGNITED08
RECIRCULATED01
IGNITED09
Equivalence ratio = 0.89
Concentration = 8.0%
Equivalence ratio = 1.23
Concentration = 10.7%
High
Reactivity
(50% area
under curve)
Laminar Burning Velocity (Su) [cm/s]
Equivalence Ratio [-]


Same Test
(Multiple Ignitions)
Same Test
(Multiple Ignitions)
Upper flammable limit
Upper reactivity boundary
HIGHLY REACTIVE CONCENTRATIONS
Lower reactivity boundary
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IGNITED01 (attempt1)
IGNITED01 (attempt2)
IGNITED01 (attempt3)
UNIGNITED02
IGNITED02
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UNIGNITED04
UNIGNITED05
UNIGNITED06
UNIGNITED07
IGNITED05
IGNITED06
IGNITED07
IGNITED08
RECIRCULATED01
IGNITED09

IGNITED01


T+: +339.653 ms
Cam: Phantom v.8001 AcqRes: 1280 x 504 Rate: 5100 Exp: 18 µs

IGNITED05


T+: +247.142 ms
Cam: Phantom v.8031 AcqRes: 1728 x 600 Rate: 3000 Exp: 10 µs

IGNITED05

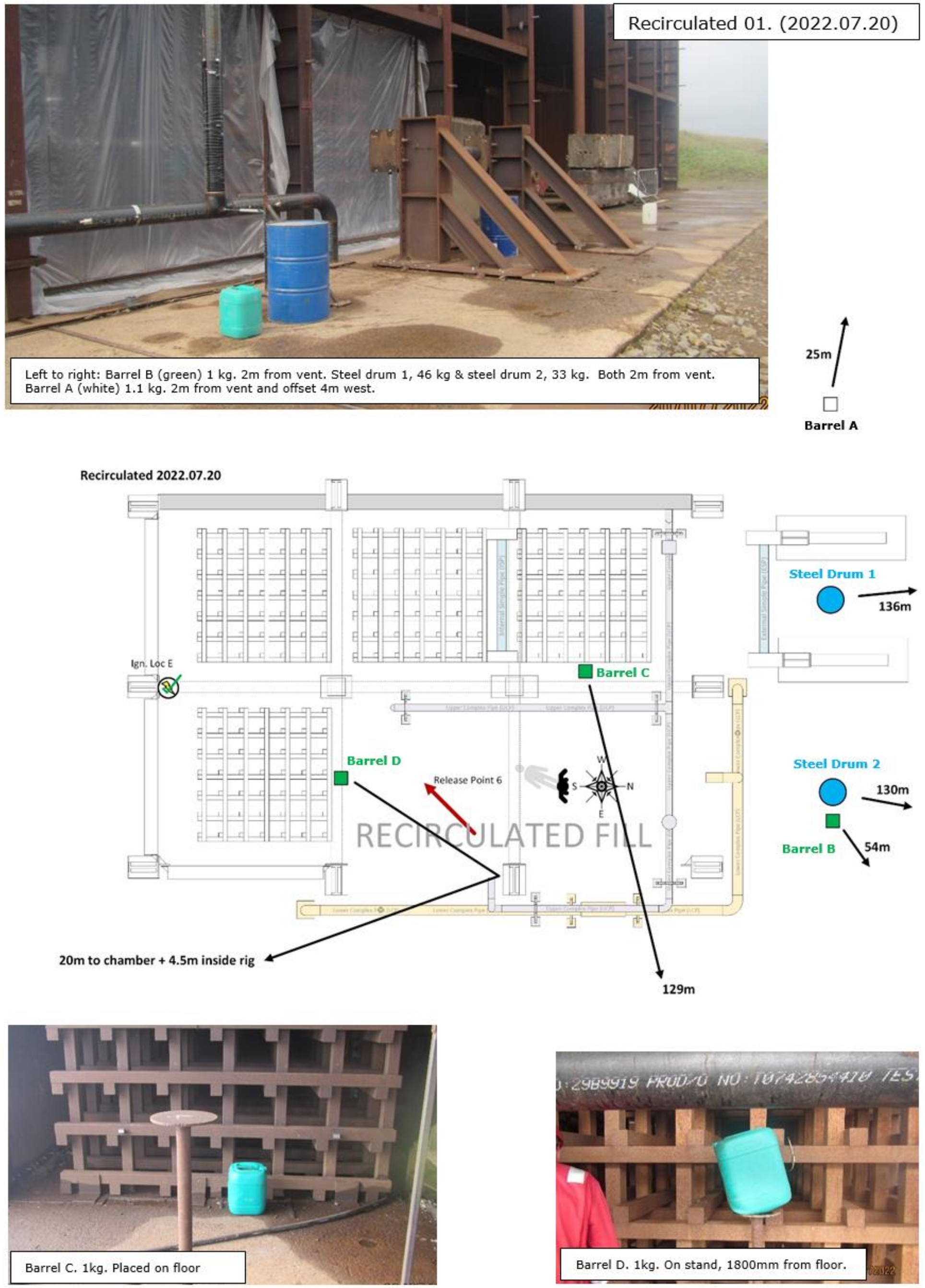


Figure E11. Throw distances from test RECIRCUATED 01. Plan and photos of barrels/drums

Figure E13. Throw distances from test RECIRCULATED 01. Movement c

Figure E14. Throw distances from test RECIRCULATED 01. Movement of steel drums

Experimental Summary

- Provided data to allow the ability of CFD modelling to predict:
  - Accumulation of natural gas from transient releases.
  - Temporal and spatial variations in explosion loading.

- Information of structural response also gained
  - Strain and pressure data
  - Allows assessment of structural modelling

Hydrogen experiments

Overview of Test Programme

- Free jet (no congestion) – 3 experiments at different mass release rates

- Quiescent homogeneous tests – 5 experiments
  - Each test had a specific concentration
  - Determining the concentration that could lead to DDT within the selected congested region

- Congested realistic releases – 34 experiments
  - Three types of congestion
  - Partial confinement by wall on one side for one of these congested regions
  - Variation in mass release rates, release location and ignition location
  - Mass release rates 0.2 kg/s to 2.0 kg/s

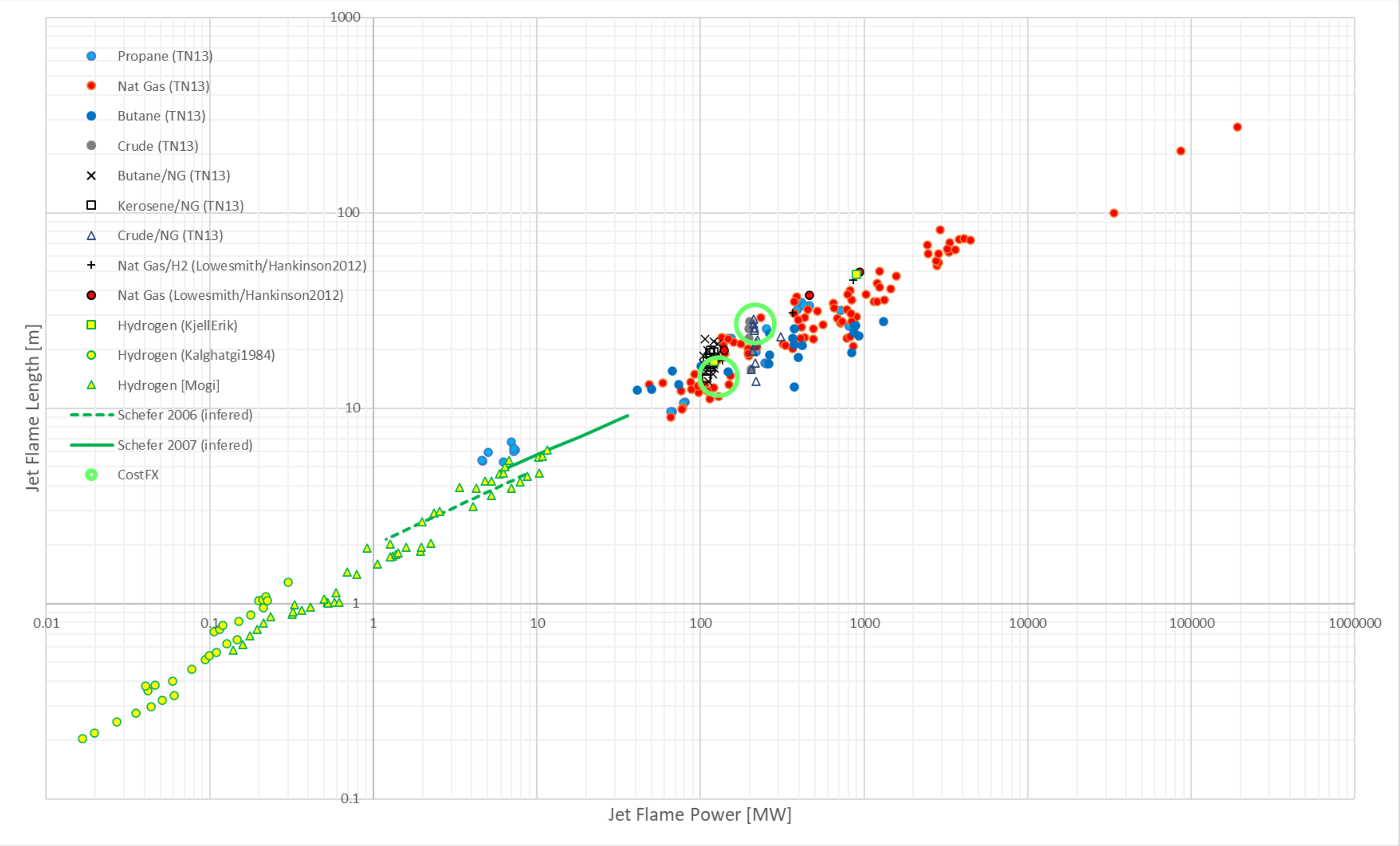
Free Jet Release

Jet Flame Behaviour

- Flame was **luminous**

- Previous work has shown that flame length correlates with energy release rate
  - Hydrocarbons and hydrogen
  - CostFX follows the same correlation

- Pressure generated by ignition of the jet
  - No DDT

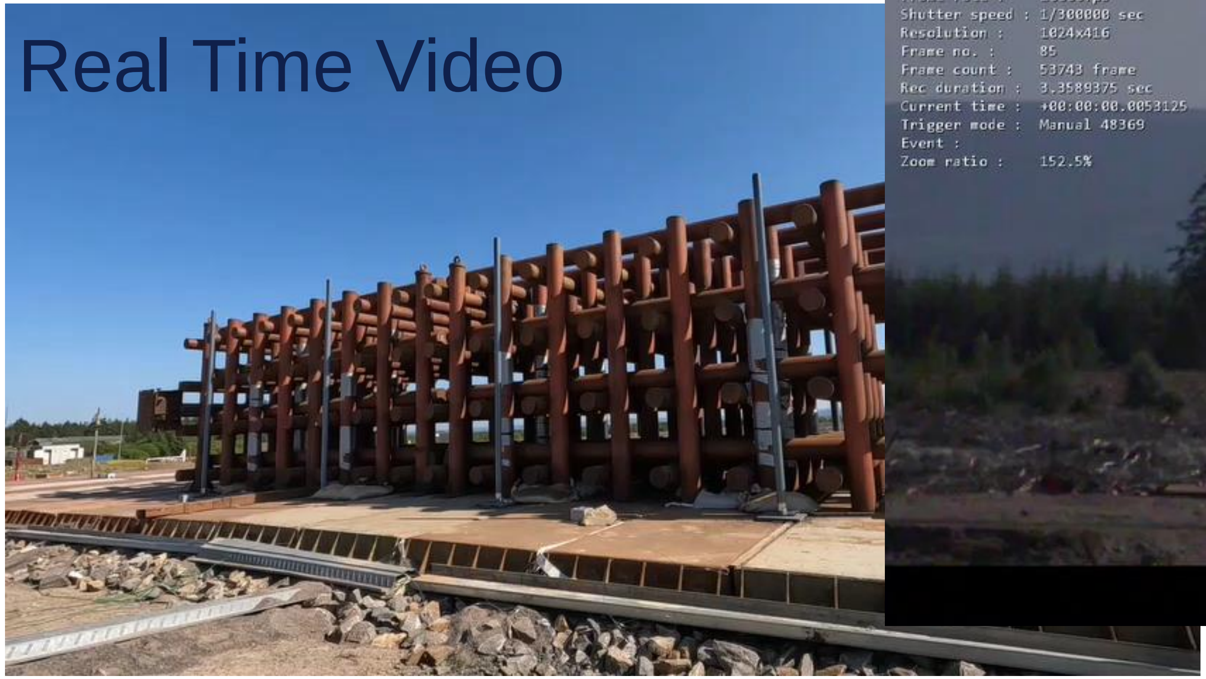


Lattice Congestion

Quiescent Tests

- Used lattice congestion
- Concentration range tested 21 to 30% hydrogen

No DDT


Real Time Video


Memory info.
Camera_1
Head 1
P-001
Frame rate : 16000fps
Shutter speed : 1/300000 sec
Resolution : 1024x416
Frame no. : 85
Frame count : 53743 frame
Rec duration : 3.3589375 sec
Current time : +00:00:00.0053125
Trigger mode : Manual 48369
Event :
Zoom ratio : 152.5%
High Speed Video

DDT


Real Time Video


Resolution : 1024x320
FASTCAM Nova S16 type 1100K-C-64GB 10GbE model
Frame rate : 48000fps
Date : 2023/6/9
High Speed Video

Axial Release – Lattice with Wall

Vessel Storage Array Congestion

Sparse configuration

Dense configuration

Wider Spacing in Storage Array

Closer Spacing with Additional Cylinders

Explosion consequences

Explosion consequences

Life-sized Mannequin

Metal Drum 1/3rd Full with Water

Debris

Summary

Experiments

Series of natural gas tests to assess variation in drag loading

Hydrogen free-jets

Quiescent homogeneous hydrogen mixtures in one type of congestion

Hydrogen jet releases into 3 congested regions

Findings

Validation data for variation of drag loading on pipework

Understanding of conditions that can lead to DDT with hydrogen

Data for model assessment (for the deflagration part only)