WHEN TRUST MATTERS

Hydrogen safety and Enclosures

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Presentation overview

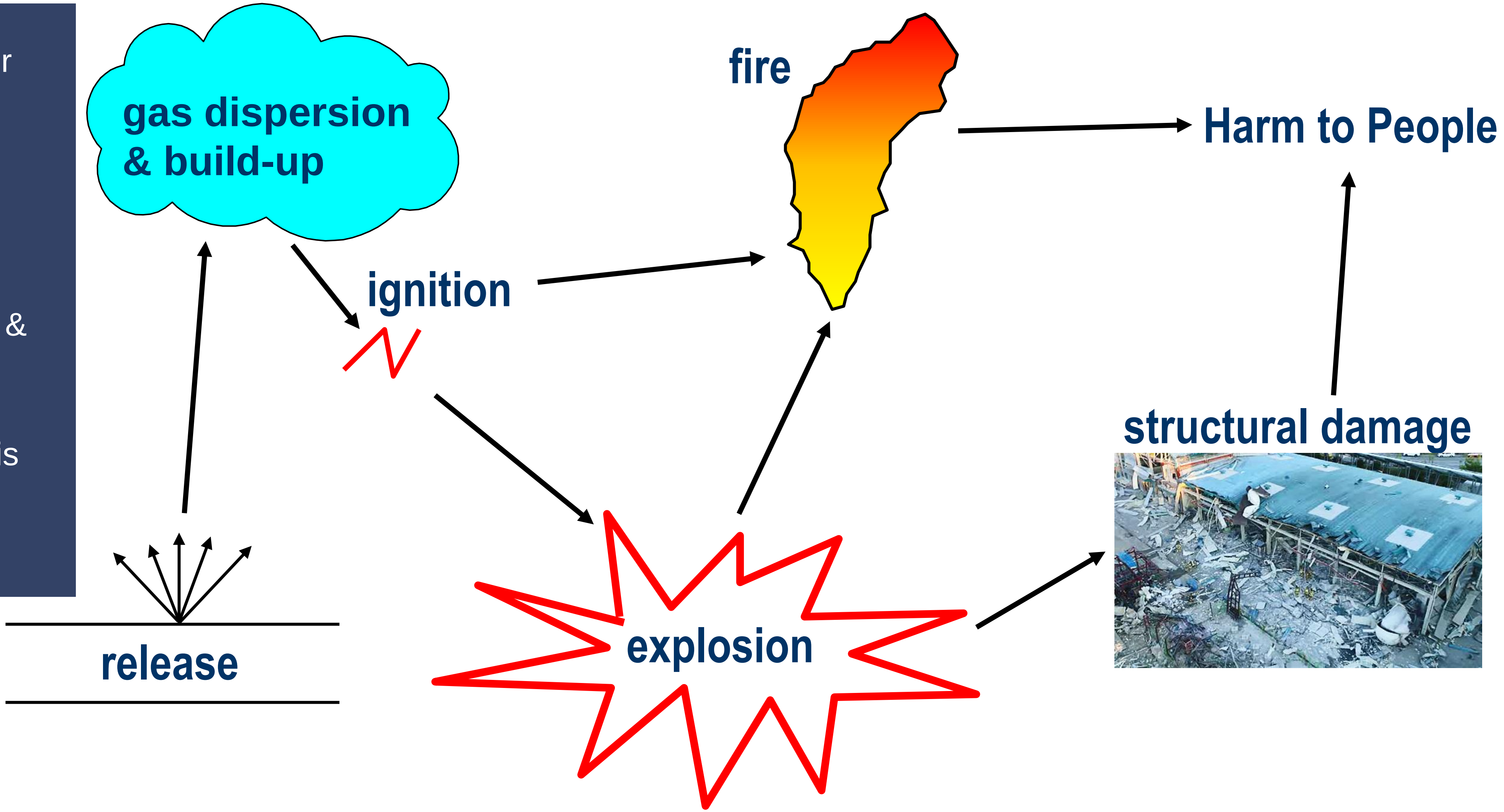
- Hydrogen Properties
- Jet Fires
- Explosions
- Deflagration to Detonation Transition (DDT)
- Operating Site Considerations
- Gas Turbine Enclosures

Hazards from Flammable Gases

Design to prevent or break the chain of events

Techniques are nothing new – standard for any oil & gas project

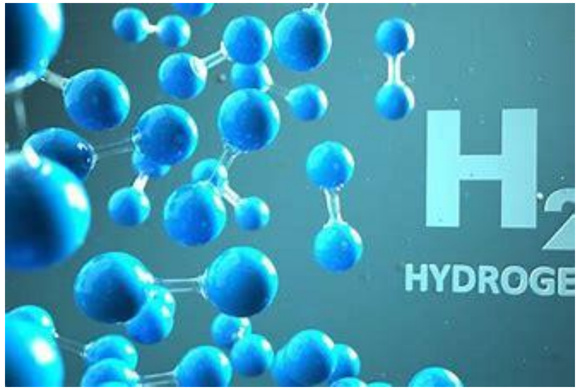
The key difference is the properties of hydrogen



Hydrogen Properties

Basic Hydrogen and Methane Properties

	Hydrogen	Methane	Unit
Density*	0.09	0.72	kg/m^3
Lower Heating Value	120	50	MJ/kg
	10.8*	36*	MJ/m^3
LFL$^+$	4	5	% (v/v)
UFL$^+$	75	15	% (v/v)
Min Ign Energy	0.02	0.30	mJ



To deliver the same energy flow through a pipe at the same pressure, hydrogen flow speeds need to be over 3 times that of methane

** @ STP, 0 deg C, 1 atm*

+ - Lower and Upper Flammable Limits

Hazardous Gas Releases

- For large leaks from pipework (ideal gas):

$$Volume\ Flowrate \propto \sqrt{\frac{Pressure}{Density}}$$

- Ratio of densities of methane and hydrogen ~8, √8 = 2.8
- So for same hole size and pressure in the pipe:

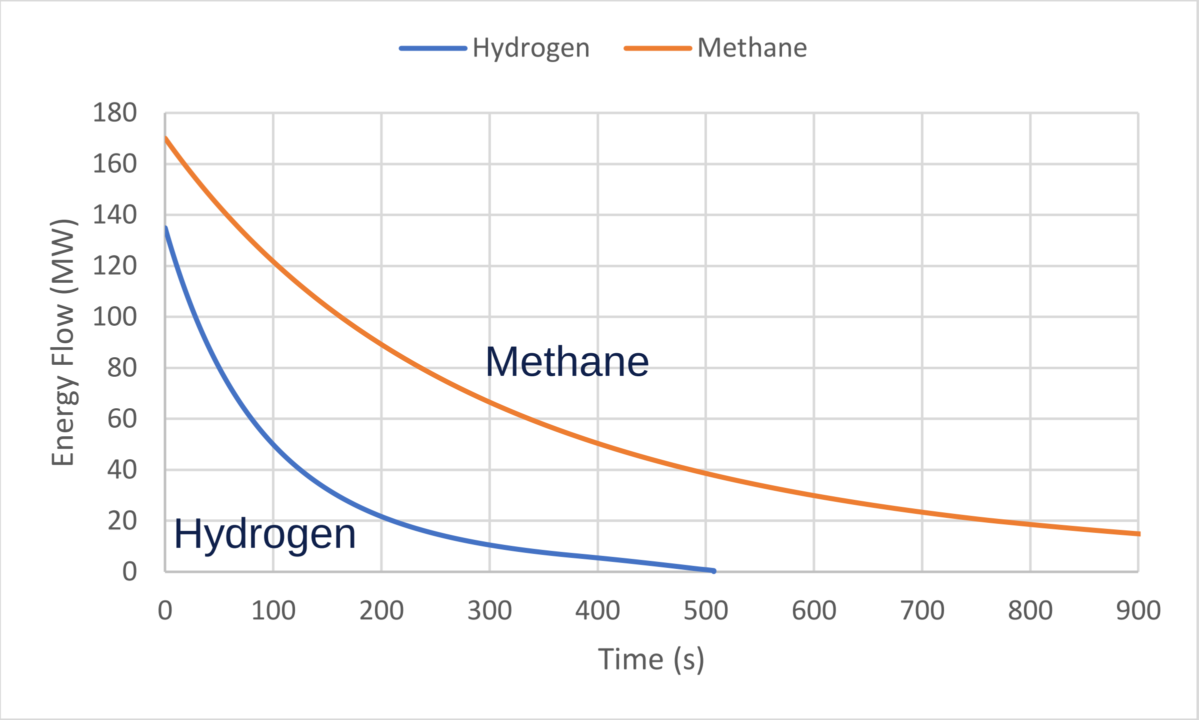
Hydrogen <u>volume</u> flow rate will be 2.8 times that of methane

Methane <u>mass</u> flow is 2.8 times that of hydrogen

Hydrogen Outflow

- Hence, energy release rate from same hole size and pressure starts out very similar to methane

- Vessels containing the same pressure will depressurise in a shorter time for hydrogen compared to methane
  - Potentially bigger flammable clouds
  - Shorter duration fire loads



20 mm release from 27 m^3 vessel @70 bar

Jet Fires

Hydrogen Fires – Large Releases

- Jet fire flame lengths correlate with energy flow
  - Hydrogen jet fires are very similar to methane/natural gas

- Hydrogen Jet Fire
  - 7.5 kg/s

Explosions

Terminology: Burning Velocity and Flame Speed

- **Burning Velocity** is the speed the flame burns relative to the mixture immediately ahead
  - A fundamental property of the fuel air mixture in well defined conditions (e.g. fuel type, fuel concentration and turbulence intensity)
  - ‘Laminar burning velocity’ if initial turbulence is zero

- **Flame Speed** is the speed of the flame relative to an external fixed observer
  - Includes the flow speed of the fuel air mixture
  - Flow is almost always generated in gas explosions

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Burning Velocity and Flame Speed

Burning Velocity is analogous to the speed of a person walking along a train viewed by someone on the train.

Flame Speed is analogous to the speed of the person viewed by someone watching from outside the train.

- The speed of the train represents the speed of the gas that the flame is burning through.

Enclosures – Damaging Pressures

Start with explosions in buildings or enclosures

Why do we get damaging pressures?

Within a confining structure:

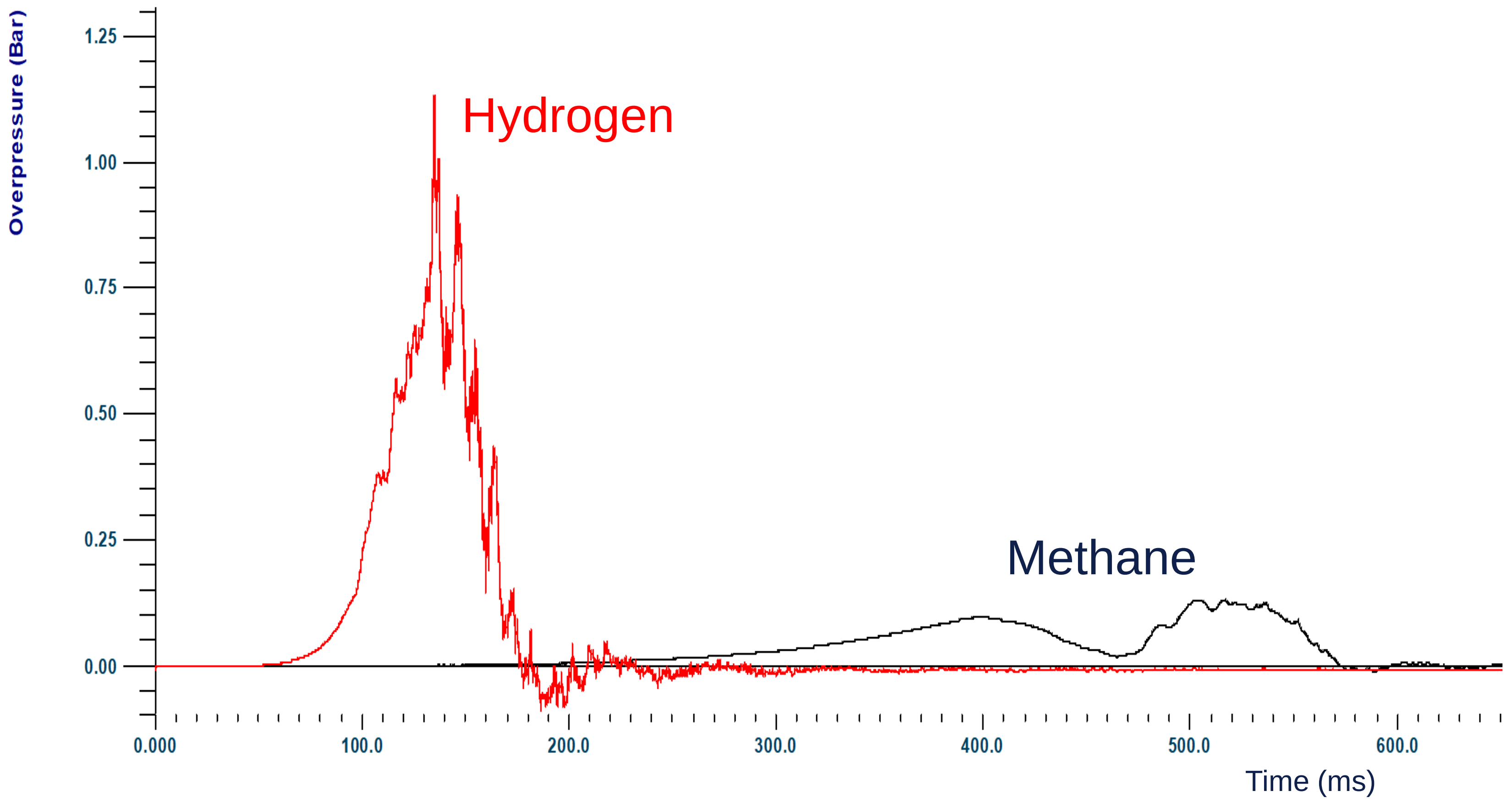
- Flame converts ambient to high temperature
- Gases can’t expand so pressure rises
- Structure fails

Internal Pressures

- Peak rate of pressure rise:
  - Hydrogen ~10 mbar/ms
  - Methane ~ 0.5 mbar/ms

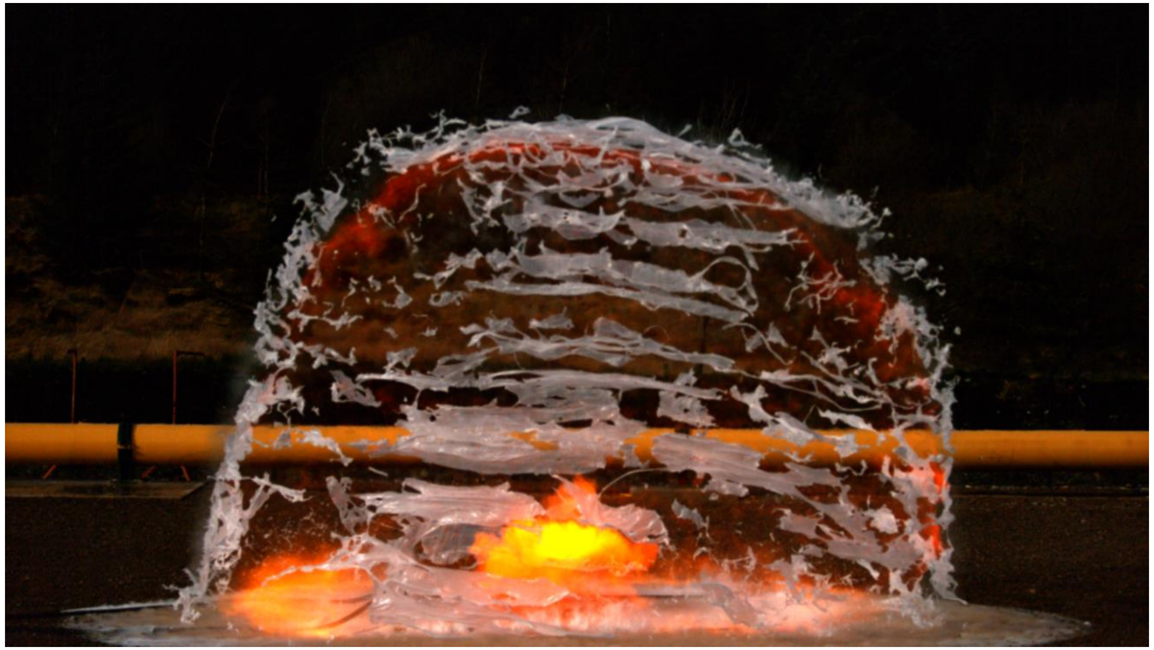
- Time taken for structural failure is critical for hydrogen

- Results in much higher pressures being generated



Detonation

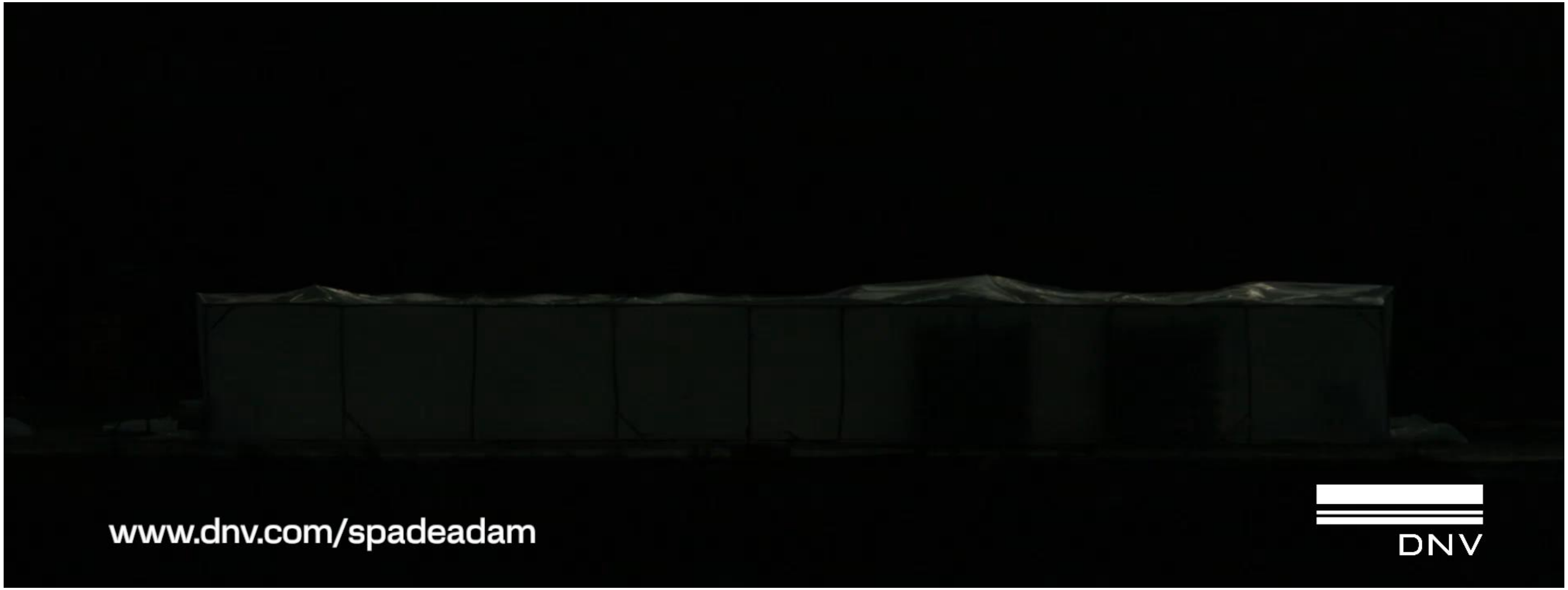
- Shock wave of 20 bar compresses fuel mixture to auto-ignition temperature
- Immediate combustion of fuel provides energy to maintain the shock wave
- Self sustaining and will propagate through the flammable mixture at 1800 m/s



Deflagration to Detonation Transition

Observed in major industrial explosions on process plant

Experiment involves flame accelerating in two congested pipework regions with DDT at the exit



Summary - Hydrogen

Safety in Design

Management through barriers to a major accident

Hierarchy from avoidance to emergency response

Inherently safer design is important and not necessarily expensive in early design

Hydrogen Properties

Hydrogen has high reactivity and is much more detonable than hydrocarbons

Need to avoid situations where high (>15%) hydrogen concentrations are present as much as practicable

Use natural buoyancy where possible

Design to Operations

Lack of standardisation, knowledge and history introduces uncertainty

Original design intent needs to be communicated and embedded in procedures and maintenance

Risk perception is important for future hydrogen developments

Plant considerations

Suggested areas for consideration – high level overview

Identify	Review	Determine	Formulate
Identify key operating areas of specific plant	Review consequence of introducing hydrogen for all components in each area	Determine actions to mitigate the consequence	Formulate action plan and readiness roadmap

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GT Enclosures

Gas Turbine Enclosures – ventilation and gas detection

- The assessment of explosion resistant design in ISO 21789 includes a requirement to validate the ventilation of gas turbine enclosures.
- The aim is to
  - Manage the detectable size of a leak
  - Prevent it reaching a size which will create an overpressure beyond that specified in the standard
- Hydrogen if it ignites can produce an overpressure beyond what is stated in the standard.
  - Can be managed by lowering the detectable level that the system initiates a trip
- Issues that need to be addressed are:
  - Is it possible for clouds with volumes 0.1% of an enclosure volume to generate high flame speeds or to detonate in realistic circumstances?
  - Does the $1m^3$ upper limit need to be reduced for hydrogen?
  - What other benefits are achieved by reducing the trigger level for gas detectors in the ventilation outlet?
  - What is the change in risk due to hydrogen releases requiring smaller more likely holes?

Methodology 1

- Engagement with gas turbine packaging organisations to identify and confirm maximum design pressures for enclosures and key safety equipment within the enclosure (e.g. fire suppression system, door seals etc).
  - Detection of gas clouds smaller than 0.1% of enclosure volume is likely to be extremely challenging. It will be beneficial to future hydrogen systems if it can be demonstrated that larger pressures than the current 10 mbar threshold can be withstood in an enclosure without failure of key systems, as this will allow larger threshold gas clouds.

Methodology 2

- Modelling and experimental work to identify overpressures experienced when hydrogen gas clouds are ignited.

- To resolve the question around threshold volume, the following scope could be applied:

1. Experimental testing of hydrogen explosions in representative enclosures
2. Modelling of analogous enclosures using industry standard consequence modelling or CFD tools (this step is used to assess appropriateness of modelling tool)
3. Expanded modelling, covering a wide range of sensitivities, including:
   a. Small and large enclosures – range of gas cloud sizes, simple congestion configurations (as a function of enclosure volume)
   b. Sensitivities on above, considering differing congestion configurations, ignition locations, cloud shapes and concentrations.
   c. Modelling of ‘real’ congestions (i.e. utilising CAD models of existing enclosures, and capturing piping, grating etc)

- This approach is suggested as it will allow the experimental program to be limited, whilst ensuring a wide range of enclosure/gas cloud configurations have been assessed. The experimental stages are required to ensure that the computational analysis results are validated.

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Questions?

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