WHEN TRUST MATTERS

Towards gigascale PtX
Safety concepts and constraints

3rd European Conference Hydrogen & P2X

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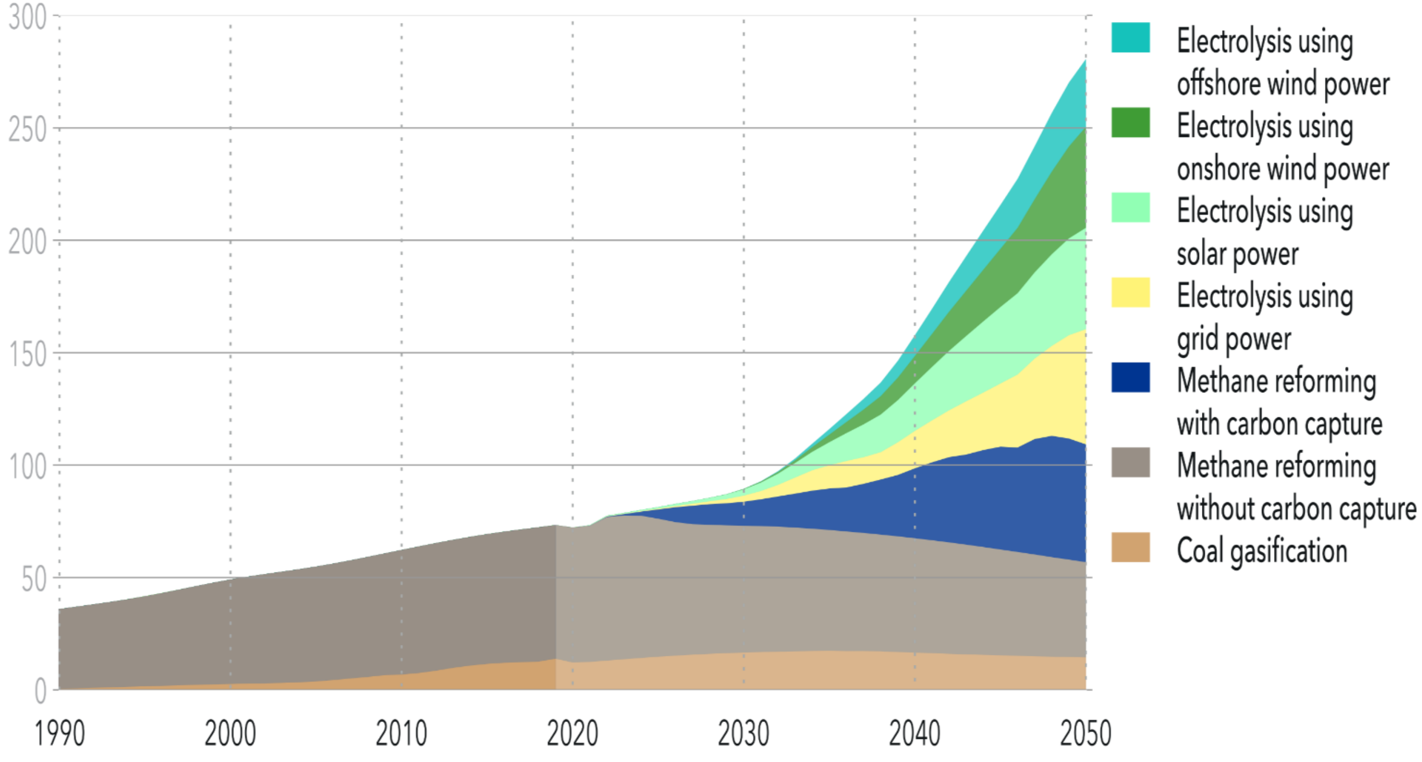
Thursday, June 16, 2022

World Hydrogen production by source
Outlook forecast (best estimate) vs. Pathway to Net Zero

ETO – Most likely future

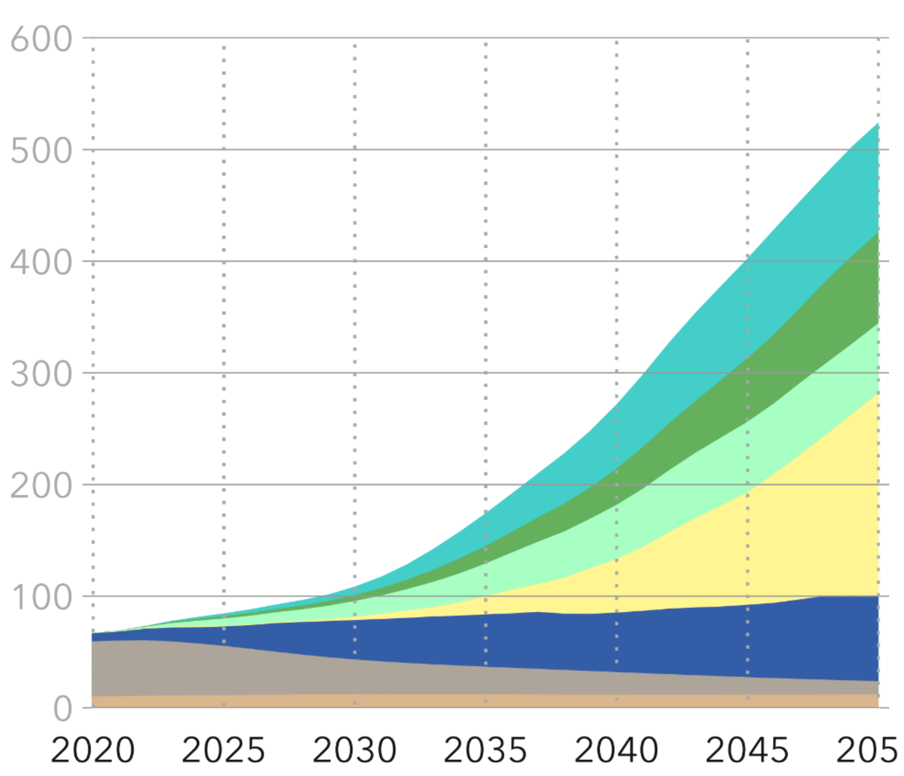
5% of energy demand



Only includes pure hydrogen supply. Historical data source: IEA Future of Hydrogen (2019)

ETO – Pathway to Net-Zero

14% of energy demand



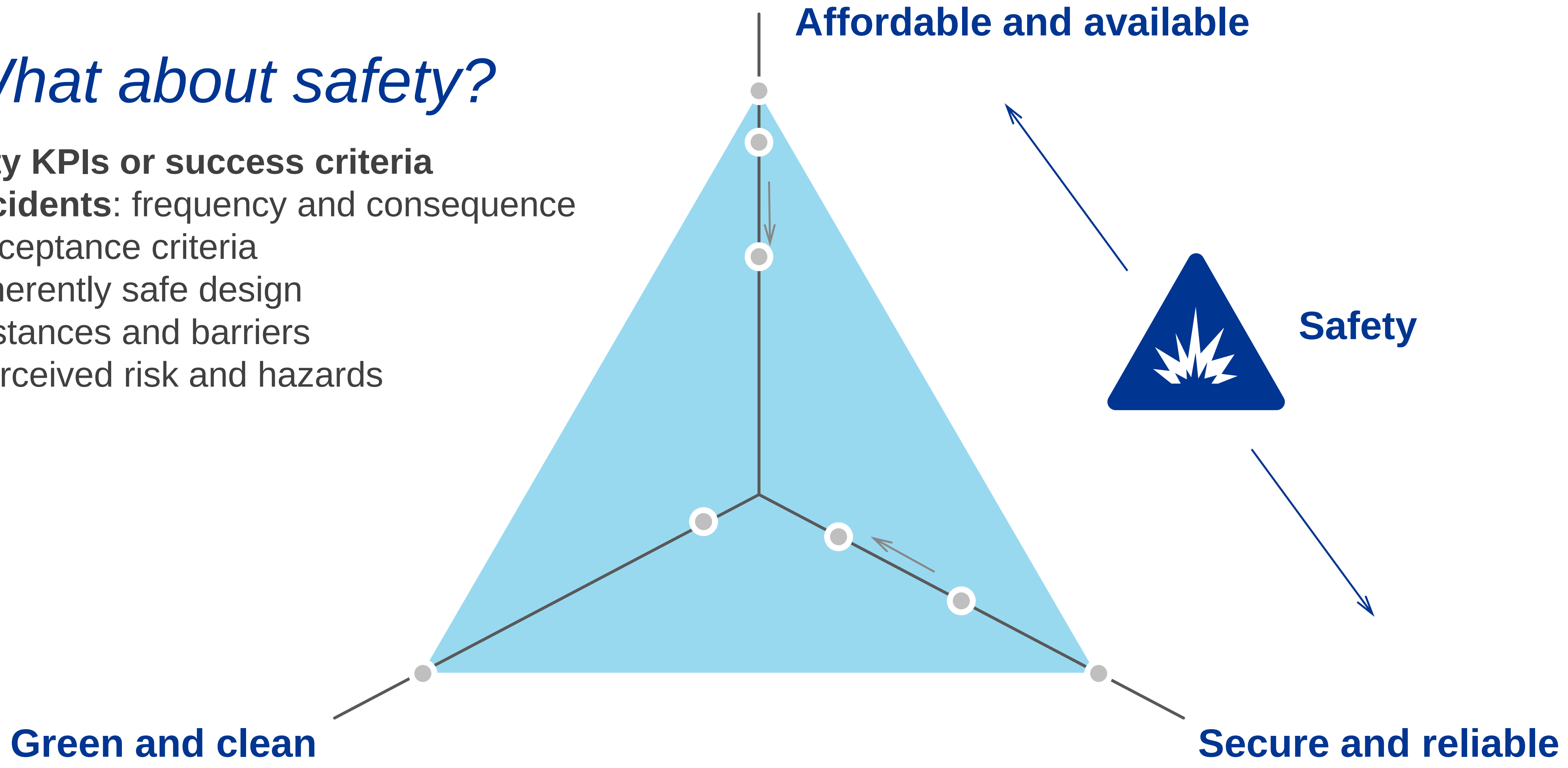
The trilemma for scaling hydrogen…

…chose two of the three below?

- What about safety?

Safety KPIs or success criteria

1. **Incidents**: frequency and consequence
2. Acceptance criteria
3. Inherently safe design
4. Distances and barriers
5. Perceived risk and hazards



The challenge ahead – risk profiles and hazards

“Inside the fence”

1. Decarb. fossil H2 – Existing use, new H2
2. Fuel switching – New use, *and* new H2

“Outside the fence”

1. New use *and* in new locations
2. New storage and transport

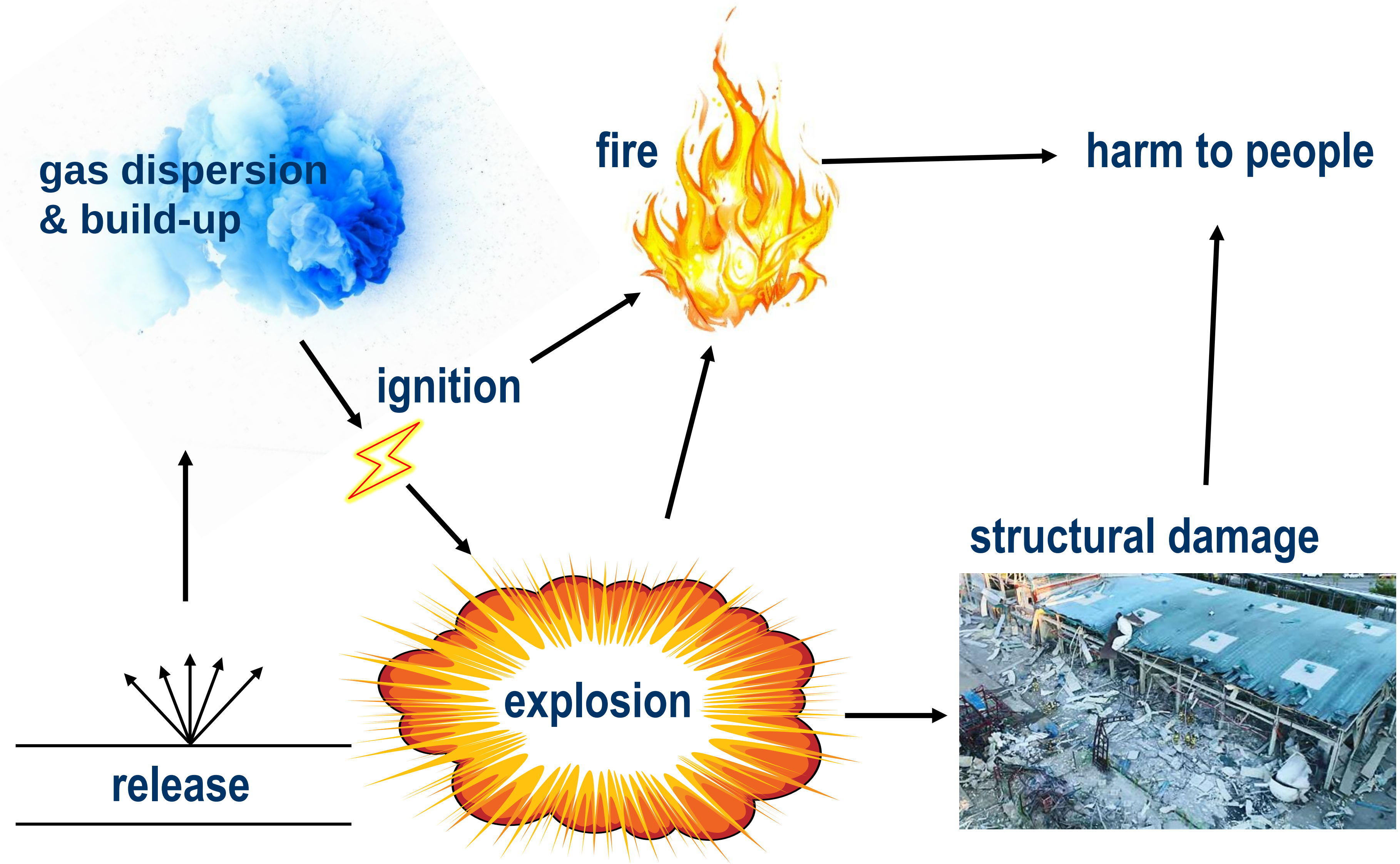
Gas Release

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



Natural gas versus hydrogen – selected features

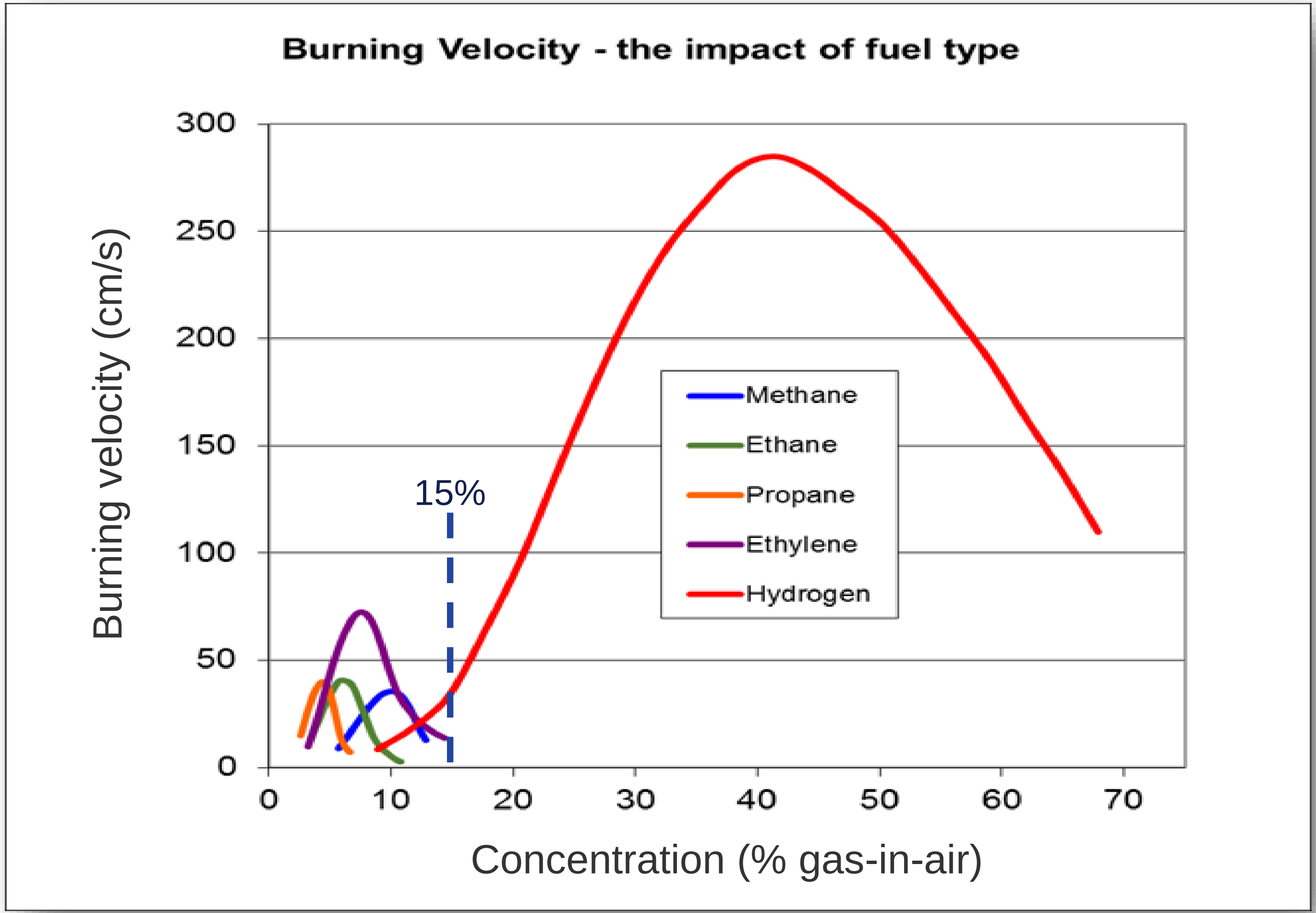
	Hydrogen	Natural gas
Flammable range	Ignites in a much wider mix range (4% to 75% of volume)	Narrow flammability mix range (5,3% to 15% of volume)
Ignition energy	Ignitable by low energy sources - phones, and human static electricity (0.020mJ)	10 times higher than H2 (0.29mJ)
Flame velocity	3.2 m/s 8 times faster flame velocity than NG - much higher explosion pressure potential	0.4 m/s
Dispersion	Disperses much faster than NG. Limited potential for ground accumulation	Large gas cloud may form. In some conditions as heavy gas on the ground (LNG)

Key Hydrogen Properties - Burning Velocity

Hydrogen has a much higher burning velocity than hydrocarbons

Again, the higher the burning velocity, <u>the more severe the explosion</u>

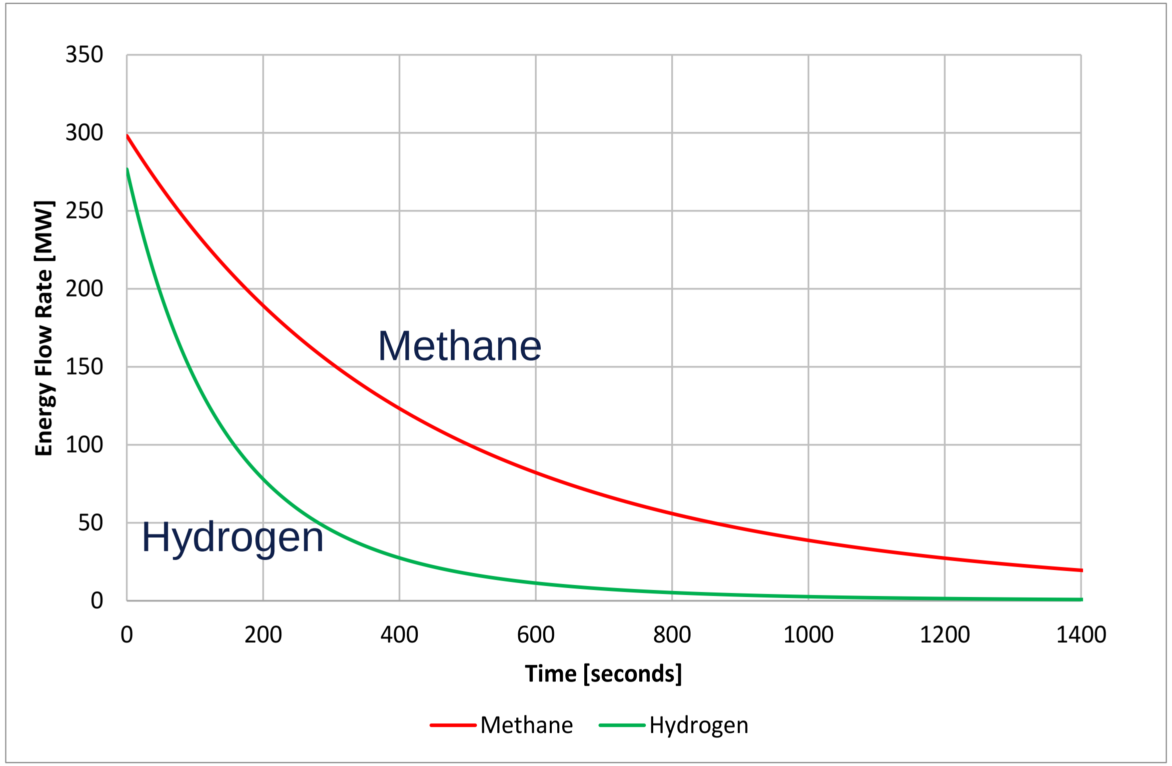
However, if the hydrogen concentration is kept below ~15% then same severity than natural gas



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 @150 bar

Major Hazard Management

DNV

What has to be done?

Formal and informal acceptance criteria, inside and outside the fence

Explosion and fire protection

Primary
Avoidance of explosive mixtures

Secondary
Avoidance of ignition sources

Tertiary
Inherently safe design with barriers

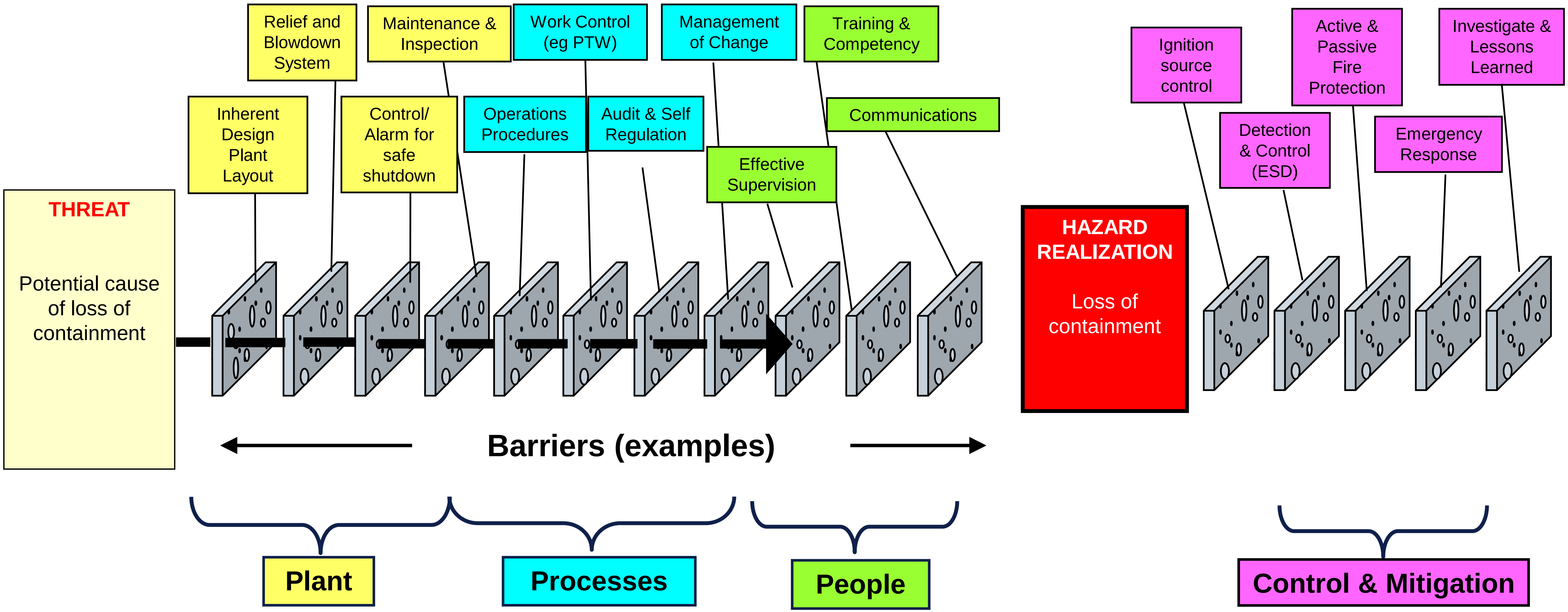
Design Philosophy - Hierarchy

- Risk reduction measures have a hierarchy in terms of preference, e.g.:
  - **Avoidance** – elimination of the hazard
  - **Prevention** – reducing the likelihood of loss of containment (LoC)
  - **Control** – limitation of scale or duration of LoC event
  - **Mitigation** – protection from effects, avoidance of escalation from LoC event
  - **Emergency Response** – e.g. evacuation of people, involvement of emergency services

- In reality all of these measures are generally used
  - Major accidents are rare, so personal experience is a poor guide to risk
  - Control risks by ensuring ‘barriers’ to a major accident are maintained

DNV

Design Philosophy - Barriers



Design Philosophy – Inherently Safer

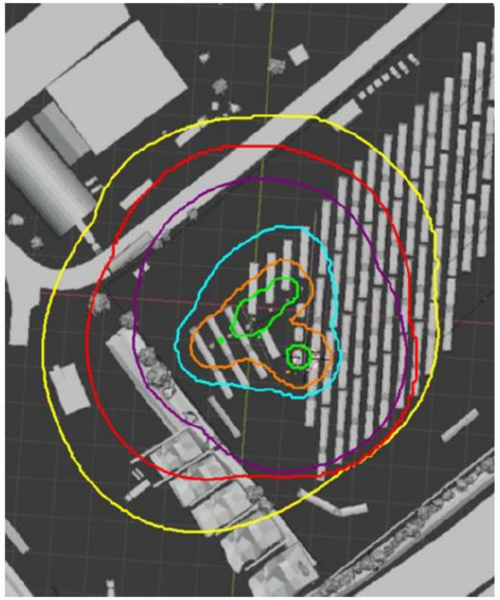
- Though definitions vary, ‘inherently safer design’ involves design changes that improve safety without the need for active protective systems

- Where practicable, inherently safer design can be very effective and has reduced uncertainty

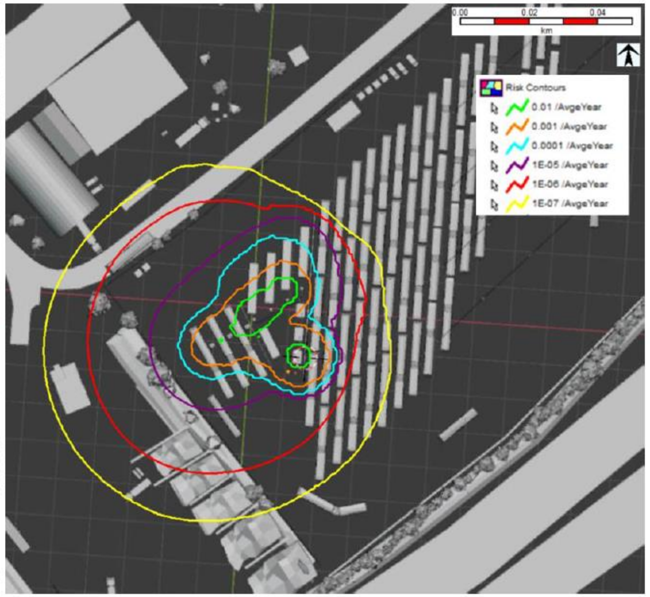
- For example:
  - Reduction in inventory or pressure
  - Separation of hazardous inventories from people
  - Passive barriers that prevent escalation
  - The engineered design naturally results in reduced consequences and greater safety
    - Using our understanding of hydrogen properties to reduce risk

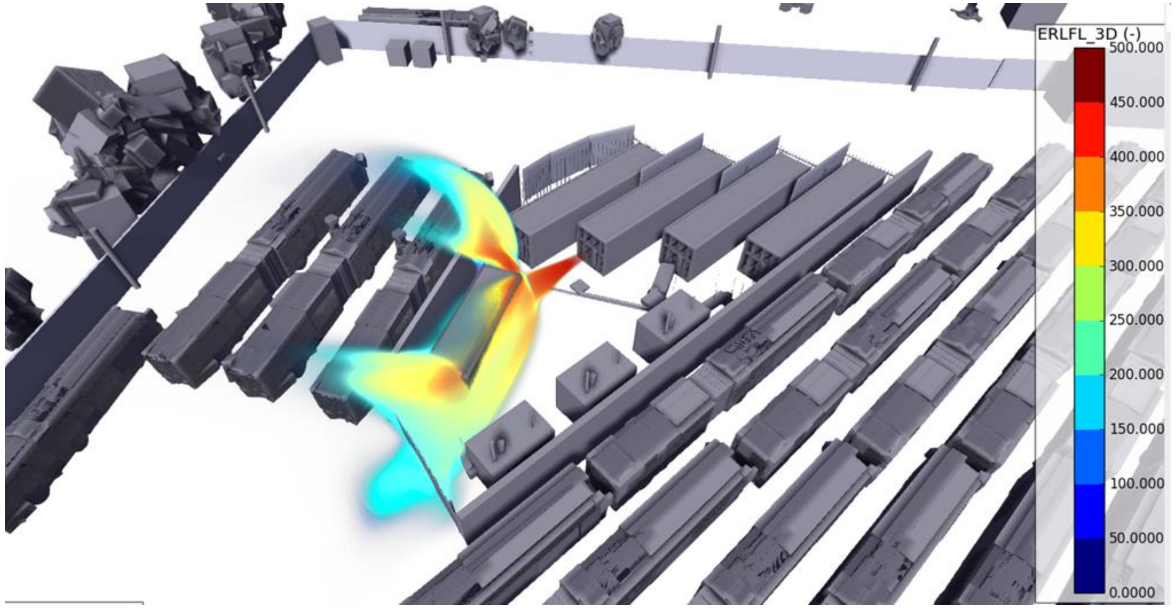
Critical leak and dispersion effects in open areas

- Without blastwalls



- With blastwall all around





- Leak rates from 0.1 kg/s can cause critical cloud sizes (1 kg/s for methane)
- Leak duration from 1-3 s can create critical cloud sizes (10-20 s for methane)
- Gas clouds can collect at lower elevations due to jet release

Effect of Burning Velocity

- Fuel concentration also affects the burning rate and, as a consequence, the maximum pressure
- Illustrate with tests in a mock H_2 refuelling station

8% H_2

26% H_2

Methane & Hydrogen Explosion Comparison

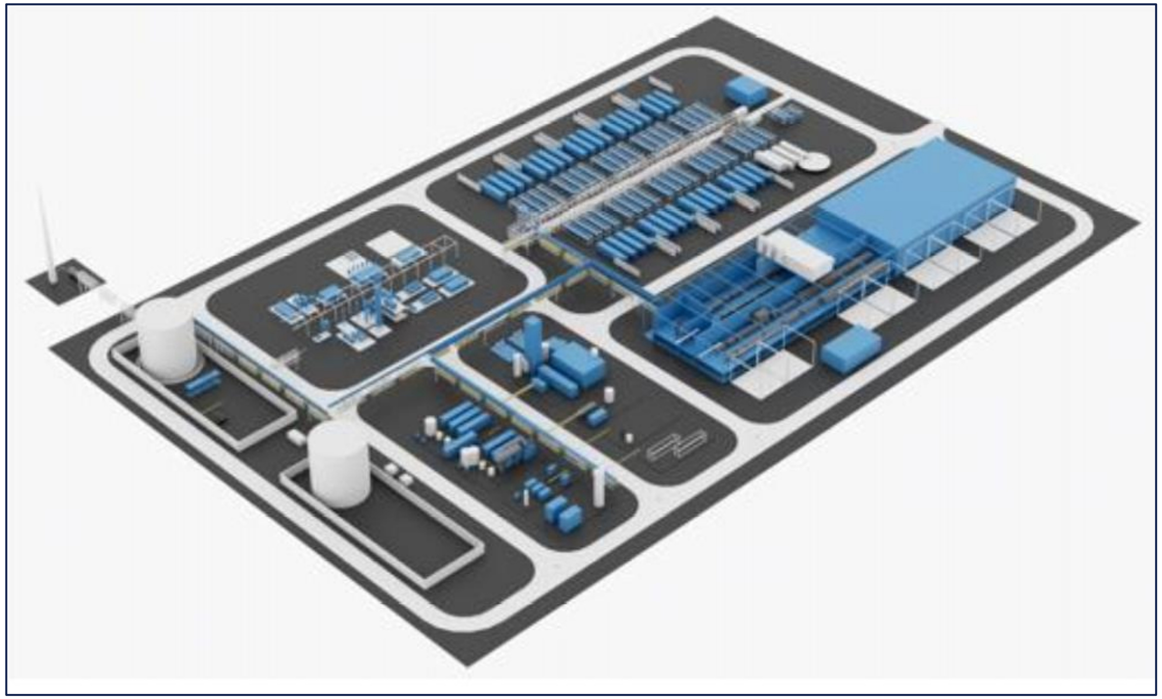
Methane and Hydrogen releases at same pressure and with same hole size

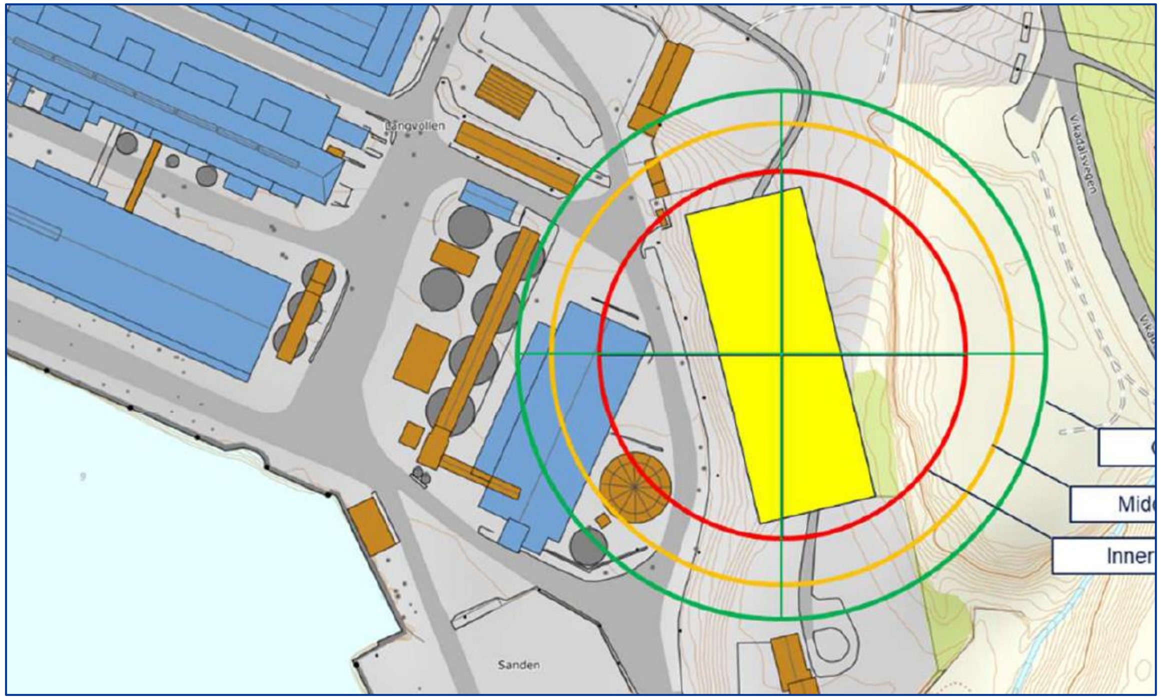
Methane (10%vol layer)

Hydrogen (20%vol layer)

Siting study is critical to ensure inherent safety

Also consider total risk from all facilities

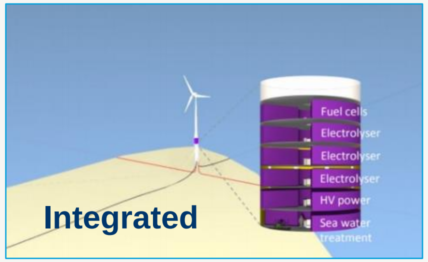




PtX wind: on- and offshore centralized and distributed

Centralized | **Decentralized**

Offshore



Onshore

Risk & Risk Perception

- Maintaining public confidence will be important for some applications
- Risk perception will be a key factor
- Need to recognise there are significant uncertainties

HOME › GENERAL › RECENT EXPLOSIONS SHUTDOWN HYDROGEN VEHICLE REFUELING IN NORCAL AND NORWAY

Recent explosions shutdown hydrogen vehicle refueling in NorCal and Norway

BY JEFF NISEWANGER on JUNE 11, 2019 · (1)

Explosions at a hydrogen fueling depot in Northern California and at a retail station in Norway have left owners of fuel cell cars in those regions without their usual source of refueling.

Monday's explosion in Sandvika, Norway near Oslo occurred at a hydrogen station operated by the company Uno-X adjacent to a major shopping center at around 5:30pm local time. As a result, some of the company's other fuel cell stations have been taken offline until an investigation reveals more information about the cause of the explosion.

Summary – PtX and Hydrogen upscaling

Safety in Design

Management through barriers to prevent 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

Questions?

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