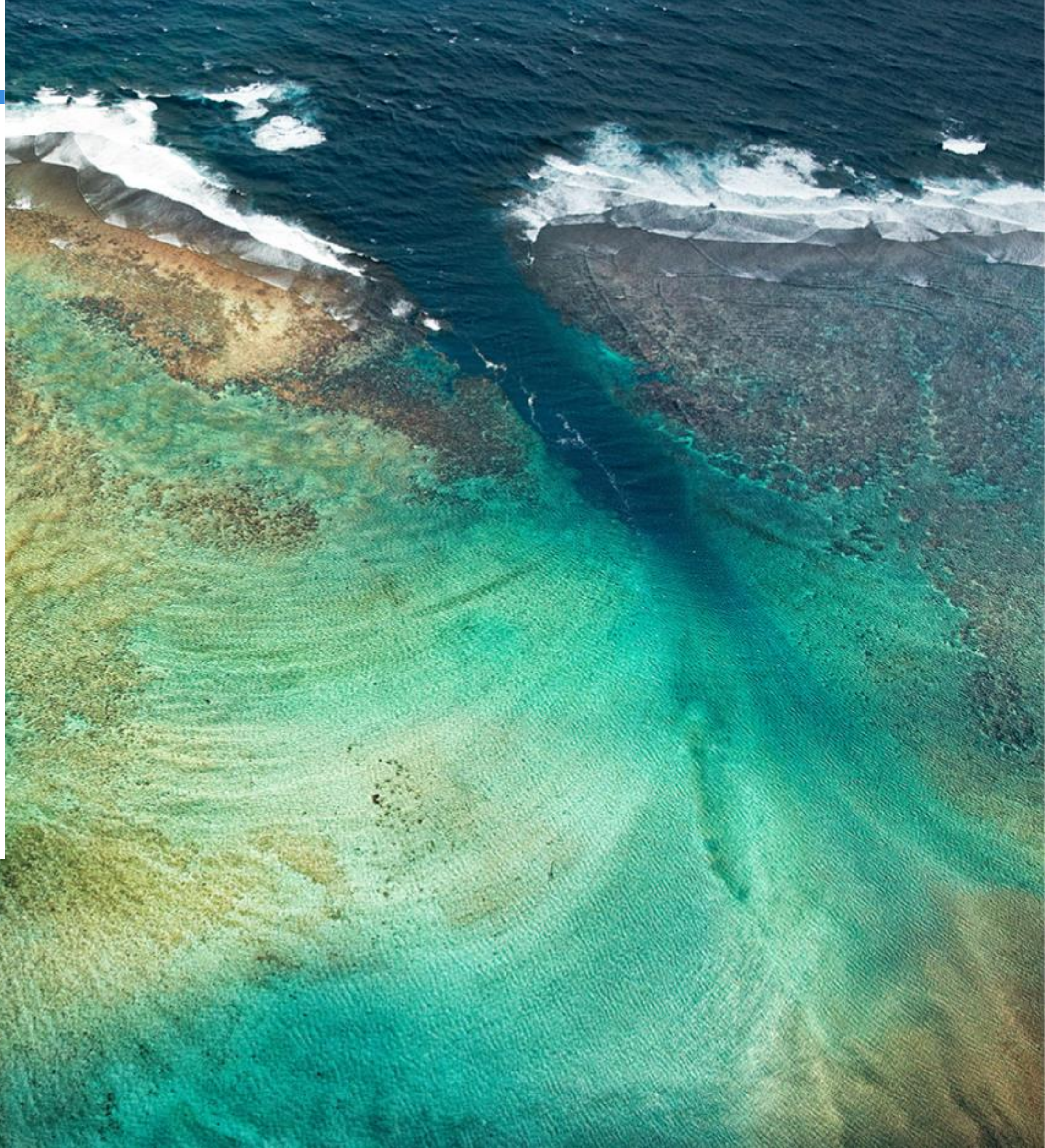
H_2@Ports Workshop

Session VII
Regulations, Codes & Standards

Olav Roald Hansen

San Francisco, September 11, 2019

Lloyd's Register



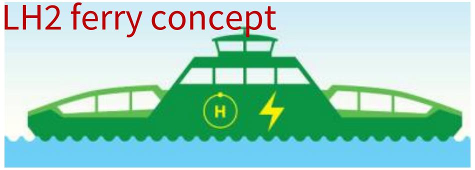
Hydrogen Risk Based Design LR

Lloyd's Register

- **UK & Europe**
  - HyDime - UK Innovate (ongoing)
  - HySeas III (ongoing)
  - Hydroville (in operation)
  - 2 superyachts (VSY + another) (ongoing)
  - 2 other vessels (ongoing)
  - Type approval H_2-fueled engine
  - Review LH2 carrier technologies and AIP of design
- **Norway (RBD-support)**
  - LH2 hydrogen ferry concept (AIP)
  - Brødrene Aa fast ferry concept (IJHE article)
  - Kystruten (ongoing)
  - 1-2 new vessels (starting soon)
  - Bunkering studies (ISO 20519)
  - Expert group Trøndelag County Development Project

Illustration: Ferguson Marine

MOZEES
Mobility Zero Emission Energy Systems



Hydrogen safety experience

Previous experience Olav RH

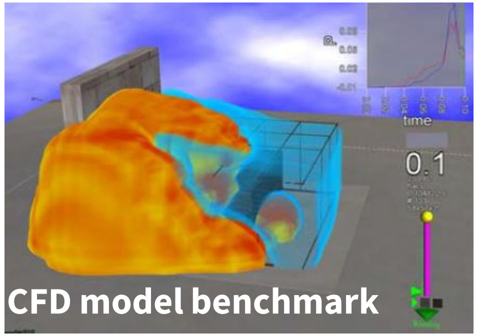
- 25y FLACS CFD, testing, R&D, sale/support, consulting
- 2004-2010 EU-project HySAFE (25 partners in Europe)
- 2004-2012 IEA HIA Task 19/31 Expert Group H_2 Safety
- ~20 scientific articles H_2 safety

LR risk consulting work H_2 safety since 2016

- 6x Hydrogen Refueling Stations
- 5x Studies Hydrogen Production Units & Plants
- 2x Hydrogen to store renewable energy
- 5x Ammonia plants, metal industry/electrolysis

R&D involvement LR

- PresLHy, H2Maritime, MoZEES and IEA Task 39
- HyMethShip (methanol to H_2 with CCS before IC-engine)



CFD model benchmark

FCV test drive 2007

H_2 train risk study

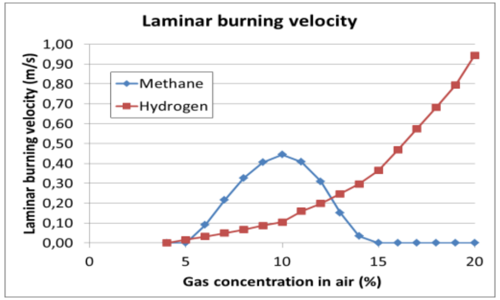

SRI test site California

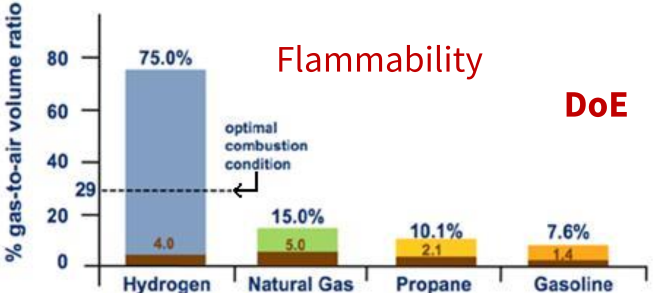

Ammonia plant accident 1985

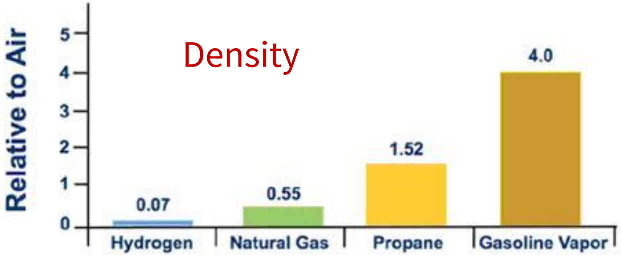
Refueling station

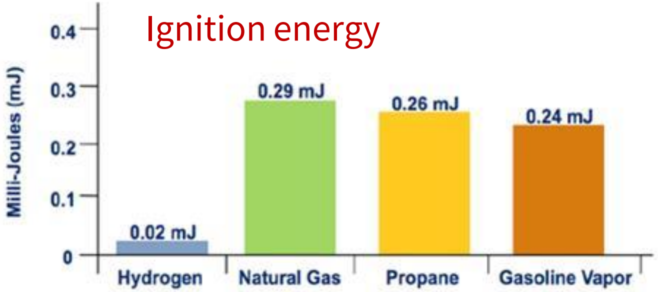
Hydrogen properties extreme

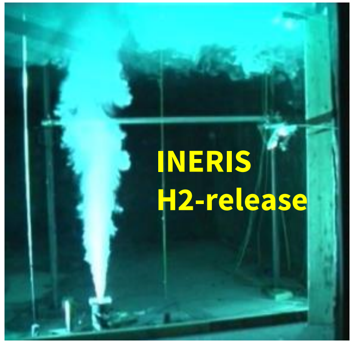
Property	Hydrogen	Methane
Flammability in air	4%-75%	5%-15%
Burning velocity	~ 3 m/s	~0.4 m/s
Detonation energy	1 g TNT	1 kg TNT

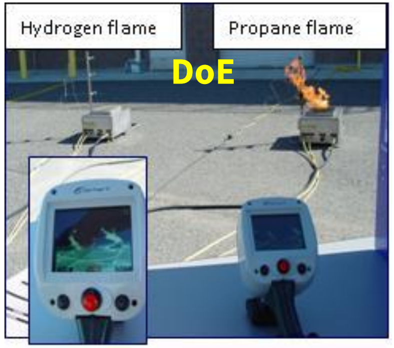












How to document acceptable safety levels?

- For low flashpoint fuels like hydrogen **IGF-code** applies
- No (prescriptive) rules for hydrogen => **Alternative Design Approach (**risk based)
- New field, lack of experience and extreme H_2 properties
- Risk assessment & explosion study required
- Quantitative criteria useful
  - Fatalities per 10^8 work hours (FAR – typical average **1.0**)
  - Fatalities per 10^9 pax km (NMA criterion 2002: **+1**)

system and its components with the applicable rules, guidelines, design standards used and the principles related to safety, availability, maintainability and reliability.

3.2.18 A single failure in a technical system or component shall not lead to an unsafe or unreliable situation.

4 GENERAL REQUIREMENTS

4.1 Goal

The goal of this chapter is to ensure that the necessary assessments of the risks involved are carried out in order to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship.

4.2 Risk assessment

Recommendation

- LH2/hydrogen is not “just like LNG “…
- Assume there WILL BE a worst-case release that WILL ignite at worst moment in time
- Then start counting for the IGF-3.2.18 “single failure … shall not …” requirement

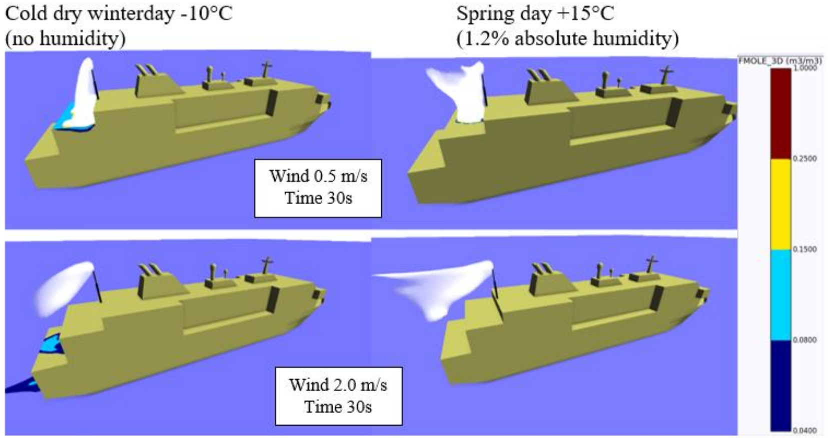
Main risks for a hydrogen vessel?

- Bunkering (HRS, LH2 road tanker, swap container/tank, …)
  - Can limit simultaneous operations at vessel and in harbor, consider early!
- Storage (liquid, compressed, other hydrogen carriers)
  - Safe solutions below deck required for wider commercial implementation
- Conversion (LOHC, NH_3, methanol, …)
- Tank connection space (LH2 or HP => LP H_2)
  - Safe arrangements for LH2/HP piping critical
- Low pressure fuel lines
- Fuel Cell Compartment or Engine
  - Both LP lines and FC compartment can be designed safe
- Gas mast (excess boil-off or P/T/leak emergency venting)
  - Optimize to limit falling LH2-vapor or HP-blast, radiation or noise

Risk varies with design, main challenges often:

- Storage&TCS > LP/FC-room > Bunkering > Gas mast

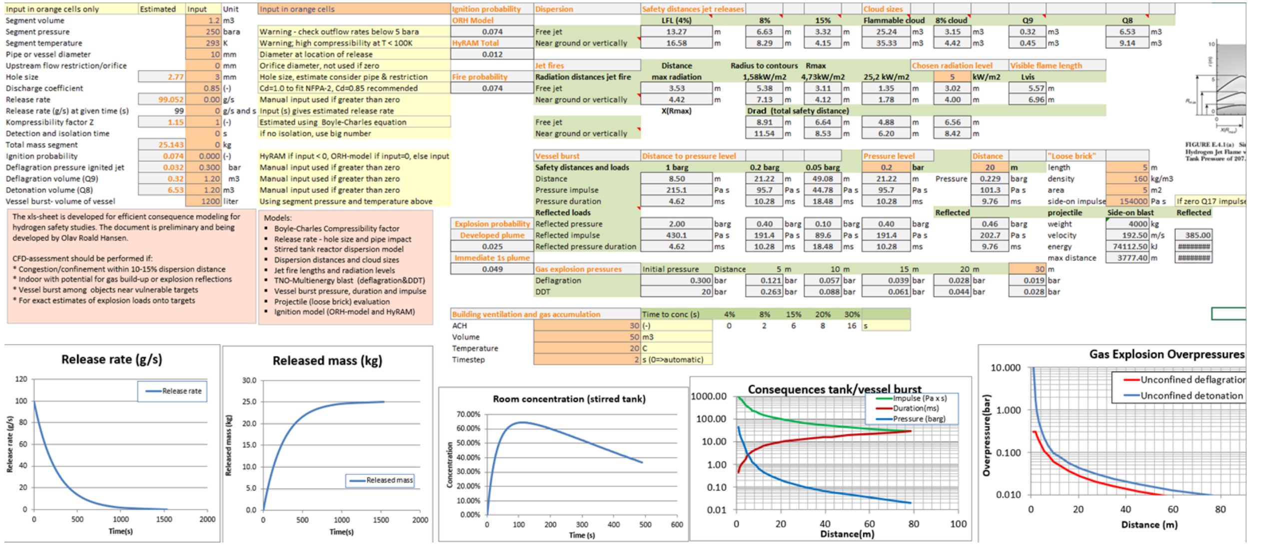
Illustration: Ferguson Marine



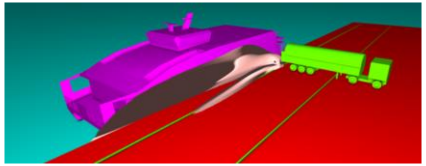
LH2-plumes initially dense, becomes buoyant with dilution in humid air

LR consequence modeling tools for hydrogen

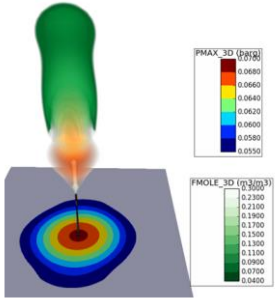
- **LR consequence screening tool**
  - Transient release rates
  - Sonic jet hazard distances and cloud sizes
  - Concentration inside ventilated room
  - Ignition probability
  - Jet fire radiation
  - Tank burst blast/impulse
  - Simple projectile model
  - Deflagration/detonation blast



- **CFD-tool (FLACS)**
  - LH2 release scenarios e.g. bunkering distances, vent mast & confined TCS releases
  - Compressed gas dispersion/explosion in confined/semi-confined situations
  - Ventilation outlets (low momentum) with hydrogen mixed with air or inerts
  - Explosion loads from vessel burst, gas cloud deflagration or detonations
  - Scenarios where better precision or visualization is required



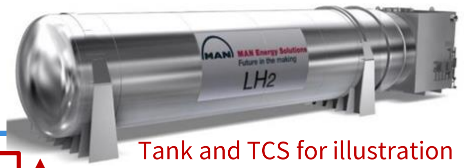
LH2 bunkering risk study



Gas mast LFL&blast

Most relevant physics can be modelled, often more to learn from CFD-studies than expensive experiments

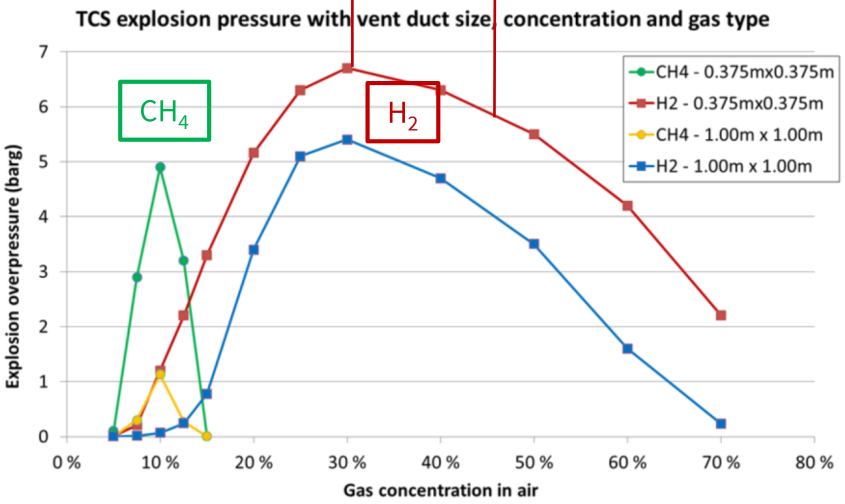
Example: Tank connection space



Tank and TCS for illustration

LH2 – Typical TCS, normal and emergency (o) ventilation

Release rates Leak diameter @ pressure	LH2	H_2-gas 30K	H_2-gas 20˚C	Ratio H_2 leak rate L:30K:20°C	Maximum H_2 % concentration (time to LFL is reached)		
					LH2	H_2- 30K	H_2- 20°C
1mm @ 3 barg	3.1 g/s	0.52 g/s	0.17 g/s	18 : 3.1 : 1	8.7% (57s)	1.7% (-)	0.56% (-)
2mm @ 3 barg	12.2 g/s	2.1 g/s	0.67 g/s	18 : 3.1 : 1	25% (12s)	6.5%(94s)	2.2% (-)
3mm @ 3 barg	27.5 g/s	4.7 g/s	1.5 g/s	18 : 3.1 : 1	39% (5s)	14% (34s)	4.6%(190s)
5mm @ 3 barg	76.3 g/s	13 g/s	4.2 g/s	18 : 3.1 : 1	59% (1s)	30% (11s)	11% (38s)
1mm @ 6 barg	4.3 g/s	0.91 g/s	0.29 g/s	15 : 3.1 : 1	11% (37s)	3.0% (-)	0.96% (-)
2mm @ 6 barg	17 g/s	3.6 g/s	1.2 g/s	15 : 3.1 : 1	30% (8s)	10% (45s)	3.8% (-)
3mm @ 6 barg	39 g/s	8.2 g/s	2.6 g/s	15 : 3.1 : 1	46% (3s)	21% (17s)	7.5%(70s)
5mm @ 6 barg	108 g/s	23 g/s	7.3 g/s	15 : 3.1 : 1	64% (1s)	43% (6s)	17 %(20s)



High pressure hydrogen storage

- Often high number of bottles 10s-100s, 200-350 bar
- Each bottle can give worst-case explosion, ignition energy low
- Leaks may not always be stopped at detection (ref. Kjørbo)
- Jet fires may impinge onto other tanks and threaten integrity

⇒ **TCS solution may be required also for high pressure tanks**

LNG: Strong TCS-explosion **bad luck** if possible at all
LH2/H2 Strong TCS-explosion **to be expected** if possible

Hydrogen: higher safety standard required
If a non-tolerable leak scenario CAN happen, quantitative QRA acceptance criteria WILL LIKELY FAIL

Frequently misunderstood hydrogen safety issues

Fake news or alternative truths?

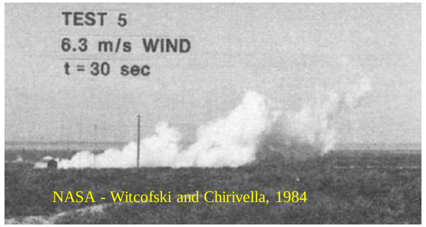
- Hydrogen explosion limits are 18-59% (Wikipedia)
  - 10-15% H_2 can give strong explosions below deck

Examples [edit]

The flammable/explosive limits of some gases and vapors are given below. Concentrations are given in percent by volume of air.

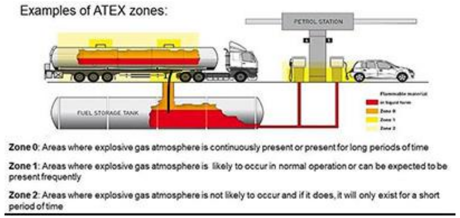
Substance	LFL/LEL in % by volume of air	UFL/UEL in % by volume of air
Hexane, n-hexane	1.1	7.5
Hydrogen	4/18.3[25]	75/59
Methane (natural gas)	5.0	15

- Liquid hydrogen vapour is extremely buoyant
  - Dense plume initially, becomes buoyant gradually diluted in humid air



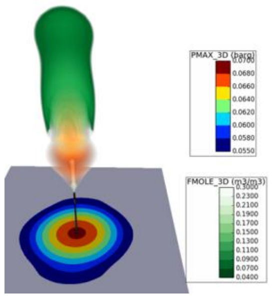
- Hydrogen is so much safer than …
  - Parameter dependent, more effort generally required to ensure safety with H_2

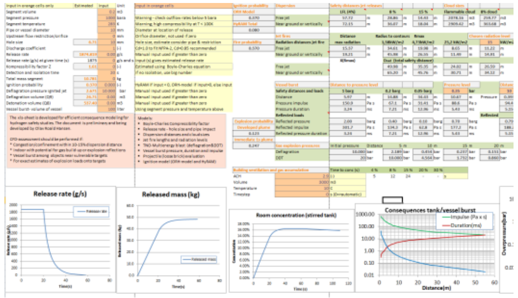
- Leak rates from IEC60079-10-1 Table B.1 to be used for risk assessment
  - No, these are for hazardous are zoning, 100-1000x higher leak rates relevant for QRA



Summary

- Too early to develop prescriptive rules
  - Too little global experience, rules would kill innovation and be non-optimal for most designs
- LR is developing Risk Based Design Guidance
  - Good RBD-studies important to ensure safety and allow innovative and cost-efficient design
- Bunkering – risk studies required (consider early)
  - Norway: Authorities to require certification of all gas bunkering (ISO20519 so far applicable for LH2)
- Learning by doing required
  - By performing RBD-studies using alternative design approach, knowledge and understanding will increase
- Start early with risk and safety assessments – should influence design and choice of technology



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Concept risk assessment of a hydrogen driven high speed passenger ferry

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ABSTRACT

A concept risk assessment of a hydrogen and fuel cell driven high speed passenger ferry has been performed. The study focused on fatality risk related to the hydrogen systems on

Questions?

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