Sikkerhetsaspekter ved bruk av hydrogen på skip

Olav Roald Hansen, LR Bergen

NCE Maritime Cleantech – klyngemøte Haugesund 22 februar 2017

Lloyd's Register

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Sikkerhetsaspekter ved bruk av hydrogen på skip

Innhold

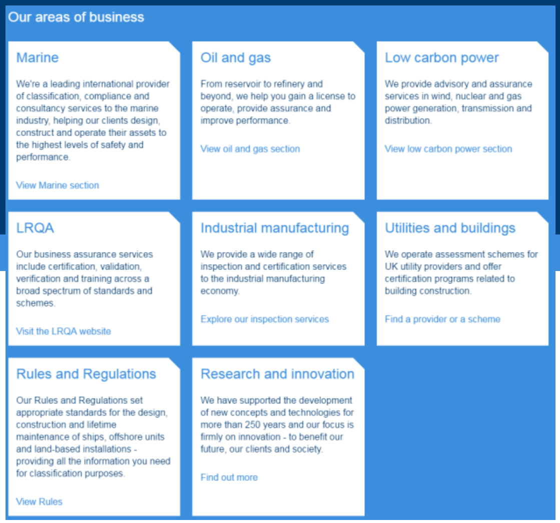
- Kort intro Lloyd's Register og Olav RH
- Hendelser/ulykker med hydrogen
- Spesielle egenskaper ved hydrogen
- Hydrogen konsekvensmodellering
- Oppsummering – viktig mhp hydrogen sikkerhet

Noen viktige ord:

CFD - numerisk strømningsmekanikk

FLACS – ledende H_2 CFD konsekvensmodell

Lloyd's Register og hydrogensikkerhet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Lloyd's Register

Energy - consulting

- Risikoanalyser, QRA, konsekvensberegninger osv.
- Offshore – F.eks. Johan Sverdrup (DP, P1, RP,LQ) FEED/DE/AB
- På land – LNG terminaler, tankanlegg, landanlegg, industri og infrastruktur

Relevante hydrogenstudier:

- Hydrogen-veien – diverse studier(2006-2012)
- HyOP Høvik/Gardermoen, Uno-X Kjørbo/Åsane (2015-2017)
- 2 sikkerhetsstudier H2 produksjonsenhet (2016)

Lloyd's Register og hydrogensikkerhet

Olav Roald Hansen

- 24 år spredning/eksplosjon, CFD utvikling og validering (FLACS)
- 19 år CMR/GexCon, 2 år GL Noble Denton og 3 år LR

Hydrogen-erfaring

- FoU 2001-2004 (sprednings- og eksplosjonstester)
- 2001-2008 – ansvarlig FoU og salg av FLACS CFD
- 2004-2010 EU-prosjekt HySAFE (25 aktører i Europa)
- 2004-2012 IEA Ekspertgruppe hydrogensikkerhet
- Solgt FLACS og lært opp Sandia NL (DoE), SRI, HRI, BNFL, IRSN
- Diverse konsulentstudier hydrogensikkerhet
- 15 hydrogensikkerhets-artikler i internasjonale tidsskrift

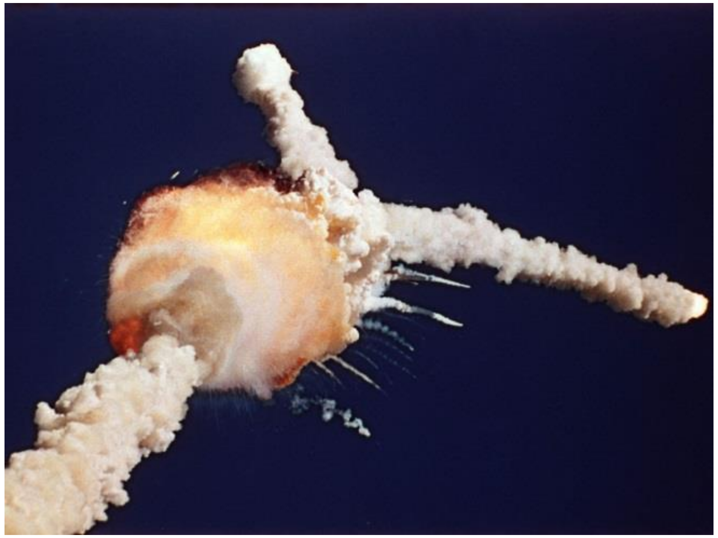
LR kolleger har lang erfaring fra oljeselskap/gassbransje

Hendelser og ulykker hydrogen

- Hydrogenbombe - ikke relevant

  analog til NIMBY (LNG-tanker vs 40 atombomber)
- Tsjernobyl (1986) & Fukushima (2013) – noe relevans

  - kjernekraft: også utfordringer med avfall + trykksatt hydrogen
- Hindenburg (1937) – bekrefter at hydrogen brenner
- Challenger (1986) – flytende H_2 og O_2 svært reaktivt



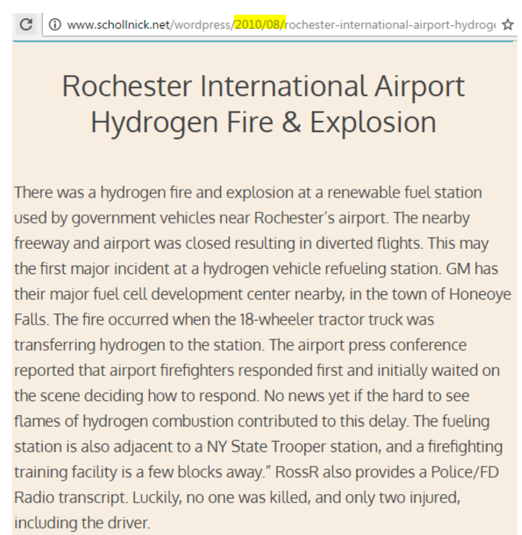
Hendelser og ulykker hydrogen

- Herøya-ammoniakkfabrikken (1985)
  - –10-20 kg, ødela bygg, knust vindu 700m unna
- Stockholm Brahegatan (1983)
  - –gassflasker på bil, knust vindu 90m unna
- Gassgenerering fra batterier
  - -kan båter synke pga. knallgasseksplosjon i skrog?
- Langsom hydrogengenerering i innelukket rom
  - - bioanlegg, metallavfall i vann, kjernekraft

Mange mindre hendelser:

Se h2tools.org/lessons

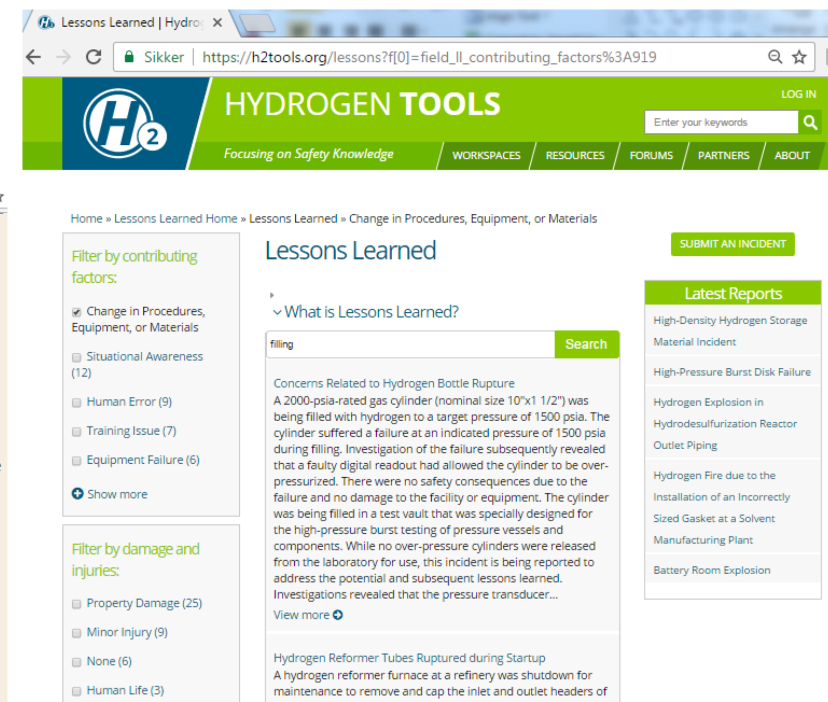
(fare for underrapportering)



www.schollnick.net/wordpress/2010/08/rochester-international-airport-hydrog

Rochester International Airport Hydrogen Fire & Explosion

There was a hydrogen fire and explosion at a renewable fuel station used by government vehicles near Rochester's airport. The nearby freeway and airport was closed resulting in diverted flights. This may the first major incident at a hydrogen vehicle refueling station. GM has their major fuel cell development center nearby, in the town of Honeoye Falls. The fire occurred when the 18-wheeler tractor truck was transferring hydrogen to the station. The airport press conference reported that airport firefighters responded first and initially waited on the scene deciding how to respond. No news yet if the hard to see flames of hydrogen combustion contributed to this delay. The fueling station is also adjacent to a NY State Trooper station, and a firefighting training facility is a few blocks away." RossR also provides a Police/FD Radio transcript. Luckily, no one was killed, and only two injured, including the driver.



Lessons Learned | Hydro

Sikker | https://h2tools.org/lessons?f[0]=field_ll_contributing_factors%3A919

HYDROGEN TOOLS

Focusing on Safety Knowledge

LOG IN | Enter your keywords | WORKSPACES | RESOURCES | FORUMS | PARTNERS | ABOUT

Home » Lessons Learned Home » Lessons Learned » Change in Procedures, Equipment, or Materials

SUBMIT AN INCIDENT

Lessons Learned

Filter by contributing factors:

- Change in Procedures, Equipment, or Materials
- Situational Awareness (12)
- Human Error (9)
- Training Issue (7)
- Equipment Failure (6)
- Show more

Filter by damage and injuries:

- Property Damage (25)
- Minor Injury (9)
- None (6)
- Human Life (3)

What is Lessons Learned?

filling | Search

Concerns Related to Hydrogen Bottle Rupture
A 2000-psia-rated gas cylinder (nominal size 10"x1 1/2") was being filled with hydrogen to a target pressure of 1500 psia. The cylinder suffered a failure at an indicated pressure of 1500 psia during filling. Investigation of the failure subsequently revealed that a faulty digital readout had allowed the cylinder to be over-pressurized. There were no safety consequences due to the failure and no damage to the facility or equipment. The cylinder was being filled in a test vault that was specially designed for the high-pressure burst testing of pressure vessels and components. While no over-pressure cylinders were released from the laboratory for use, this incident is being reported to address the potential and subsequent lessons learned. Investigations revealed that the pressure transducer...
View more

Hydrogen Reformer Tubes Ruptured during Startup
A hydrogen reformer furnace at a refinery was shutdown for maintenance to remove and cap the inlet and outlet headers of

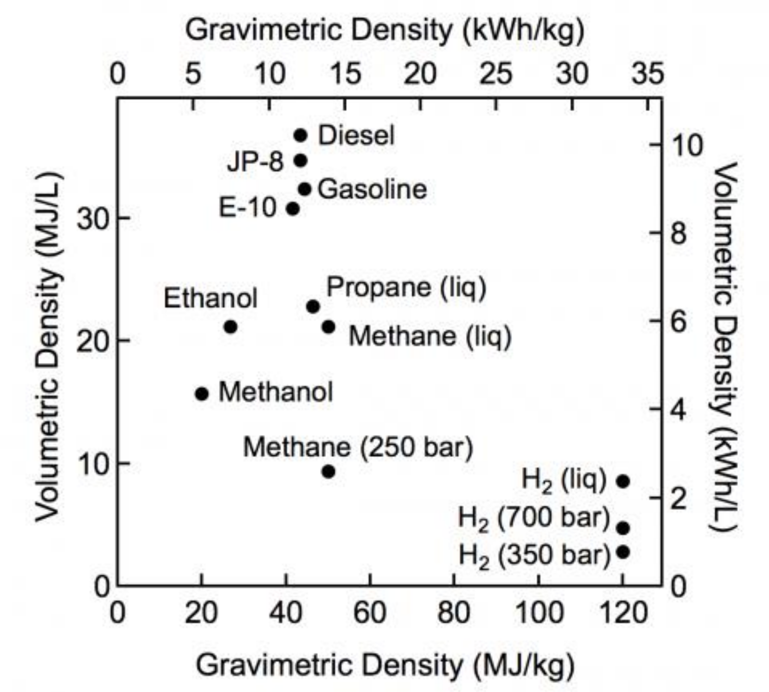
Latest Reports

- High-Density Hydrogen Storage Material Incident
- High-Pressure Burst Disk Failure
- Hydrogen Explosion in Hydrodesulfurization Reactor Outlet Piping
- Hydrogen Fire due to the Installation of an Incorrectly Sized Gasket at a Solvent Manufacturing Plant
- Battery Room Explosion

Hydrogen egenskaper - lekkasjer

Generelt høyt sikkerhetsnivå ved innføring av hydrogen

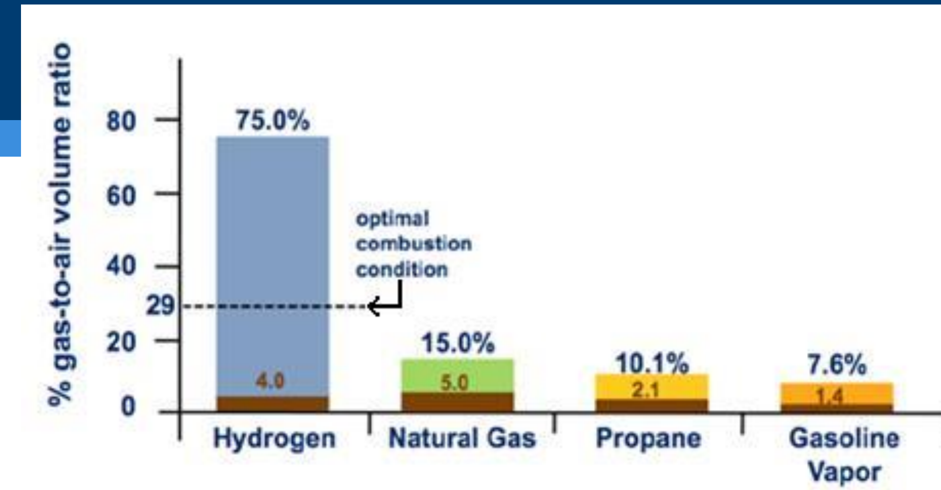
- Utfordring mhp lagring – ekstreme trykk eller temperatur
- H_2 lite molekyl, kan diffundere gjennom materialer
- Hydrogen cracking – spesielle stålkvaliteter trengs

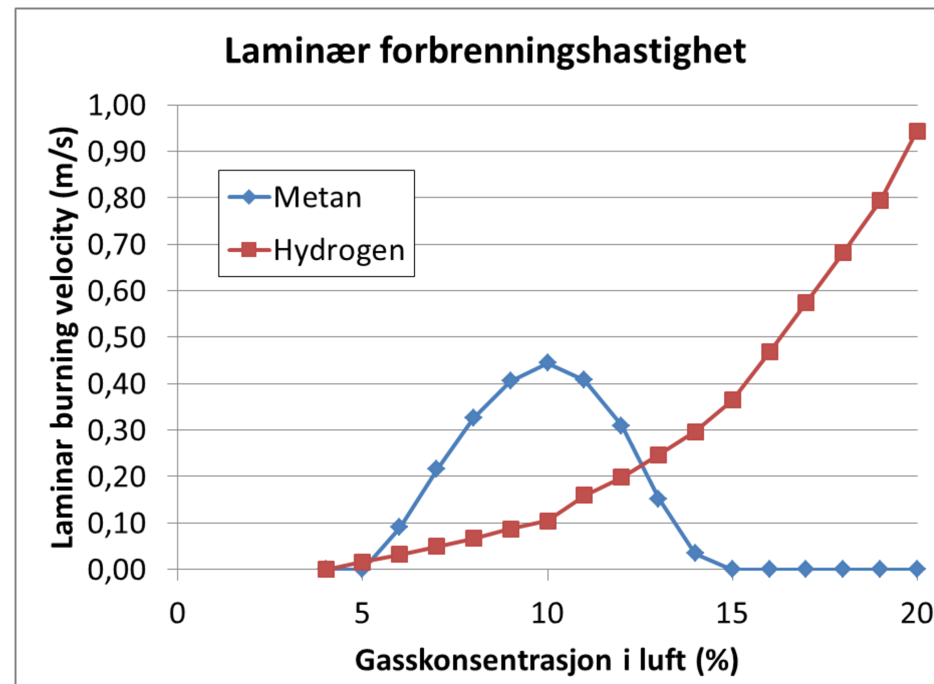


Kostbart og utfordrende å holde høyt sikkerhetsnivå på sikt?

Hydrogen egenskaper - reaktivitet

Egenskap	Hydrogen	Metan (NG)
Brennbar i luft	4 til 75%	5 til 15%
Forbrenningshastighet	~3 m/s	0.45 m/s
Energi for detonasjon	1 g TNT	1 kg TNT





Eksplosjonstrykk $P \sim S_L^2$ dvs.

Hydrogen < 10% - begrenset reaktivitet

Hydrogen > 15% - reaktivitet passerer NG

Hydrogen egenskaper – utslipp (1)

Katastrofalt brudd 350-700+ bar

- mye energi

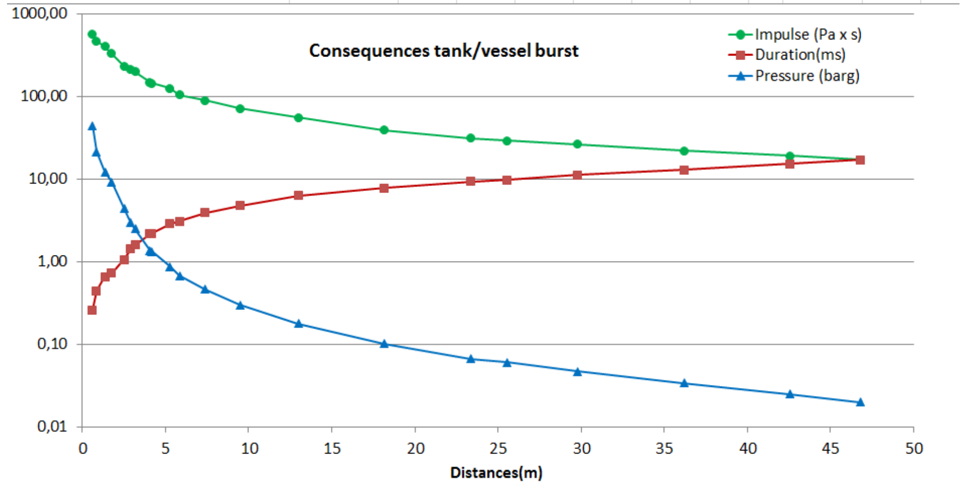
  - kan begrense risiko ved plassering og valg av tanker

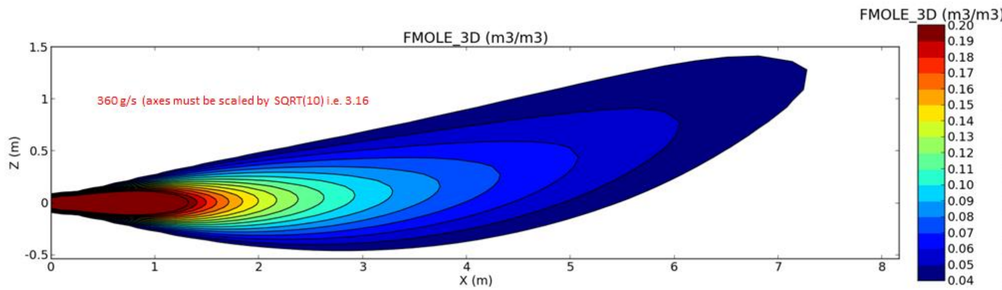
LR screeningsverktøy for tankeksplosjon =>

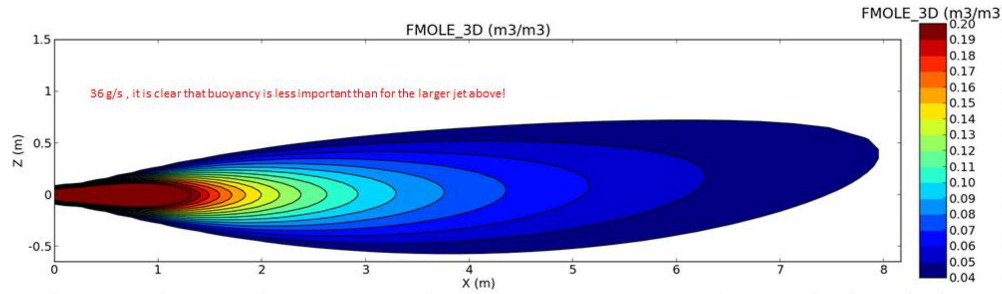
Input in orange cells only		
Tank temperature	323	K
Pressure in tank	700	bara
Volume of tank	100	litre

With too high risk level or non-tolerable consequences it is recommended to perform CFD calculations to evaluate and optimize mitigation measures, e.g. installing barrier walls.

	Distance to pressure level						Pressure level			Distance	
Safety distances and loads	1 barg		0.2 barg		0.05 barg		0,14	bar		10	m
Distance	5,07	m	12,65	m	29,25	m	16,16	m	Pressure	0,287	barg
Pressure impulse at this distance	128,2	Pa s	57,0	Pa s	26,69	Pa s	45,6	Pa s		69,3	Pa s
Pressure duration	2,75	ms	6,13	ms	11,01	ms	7,16	ms		5,00	ms
Reflected loads									Reflected		
Reflected pressure	2,00	barg	0,40	barg	0,10	barg	0,28	barg		0,57	barg
Reflected impulse	256,4	Pa s	114,1	Pa s	53,4	Pa s	91,2	Pa s		138,6	Pa s
Reflected pressure duration	2,75	ms	6,13	ms	11,01	ms	7,16	ms		5,00	ms





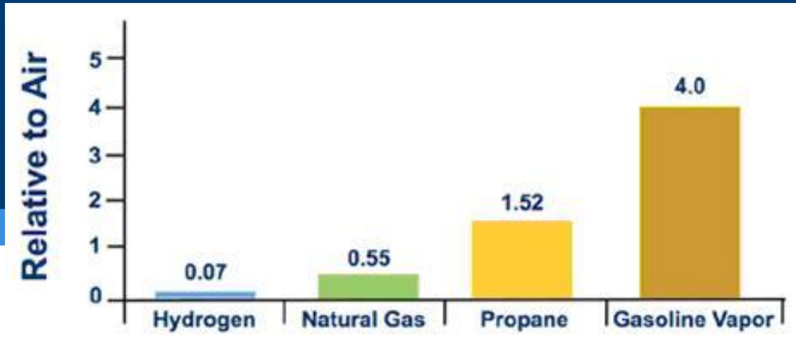


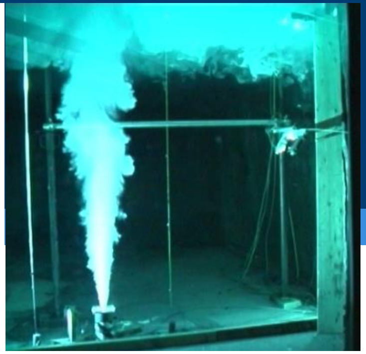
Sonisk lekkasje - lydhastighet 1270 m/s (2.8 x metan)

⇒ Rask uttynning i luft ved fri jet

Ved installasjoner ute vil tilstrekkelig avstand til vegger/objekter hindre gassoppsamling > 15% H_2 i luft

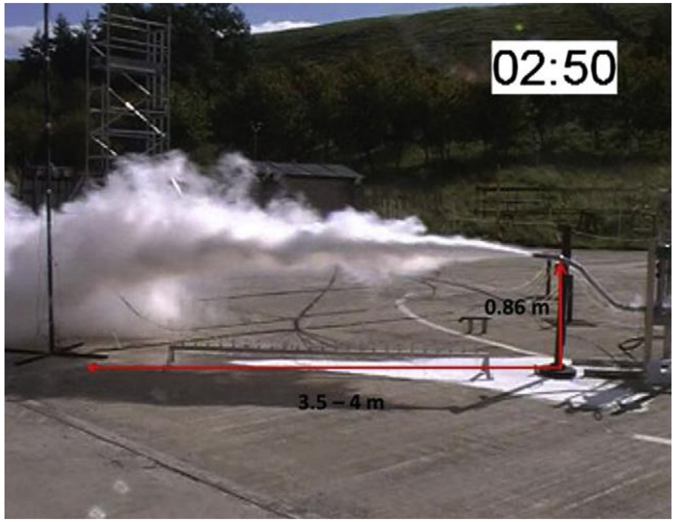
Hydrogen egenskaper – utslipp (2)





H_2 letteste molekyl – 0.07 x tetthet til luft

- Viktig sikkerhetsprinsipp – hydrogen skal forsvinne til værs



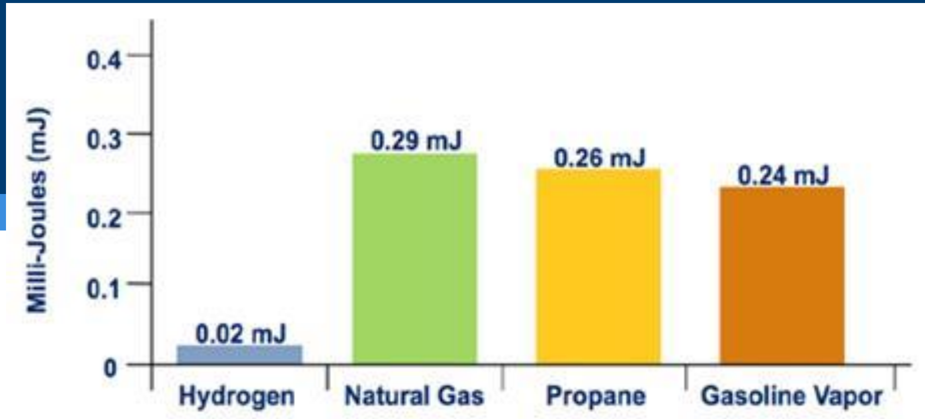
Unntak: Flytende hydrogen (~20 K)

- Kostbart å kjøle ned (1/3 av forbrenningsenergi)
- Tyngre enn luft ved fordampning, særlig ved utslipp ved trykk
- Utfordring: O_2 og N_2 "snø" pga kondensering/frysing av luft
- O_2-dopet luft gir sterk økning i gassreaktivitet

Foto fra:

Ichard, M., Hansen, O.R., Middha, P. & Willoughby, D. (2012). CFD computations of liquid hydrogen releases. International Journal of Hydrogen Energy, 37: 17380-17389

Hydrogen egenskaper – tenning

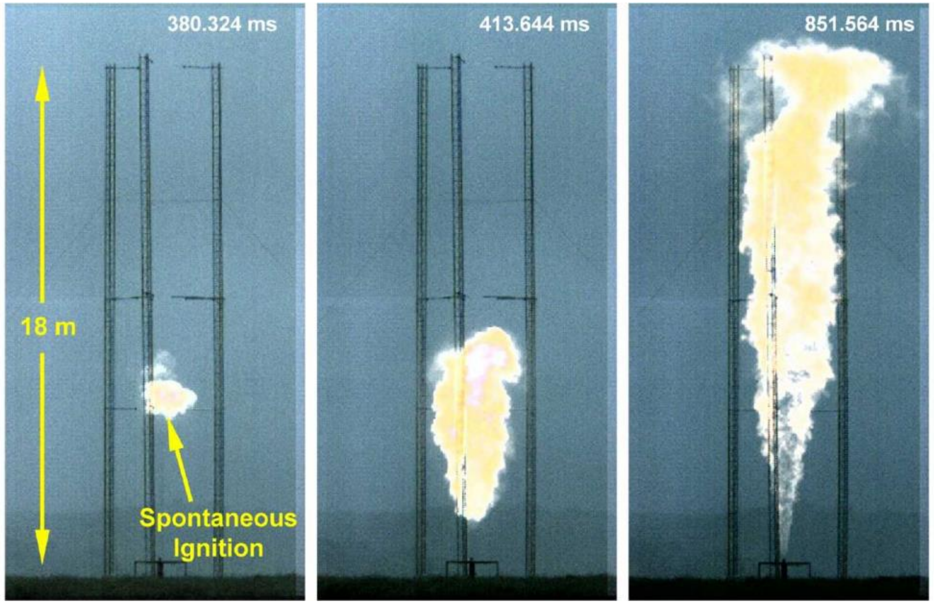


Minimum tennenergi 0.019 mJ (metan 0.29 mJ)

Antenner ofte "uforklarlig"

- Atmosfærisk utslipp (lavhastighet) ved snø eller torden
- Opplading av utstyr - statisk elektrisitet og utlading
- Gnister fra støv/partikler i jet
- Sjokkbølger varmer opp gasslommer til over AIT

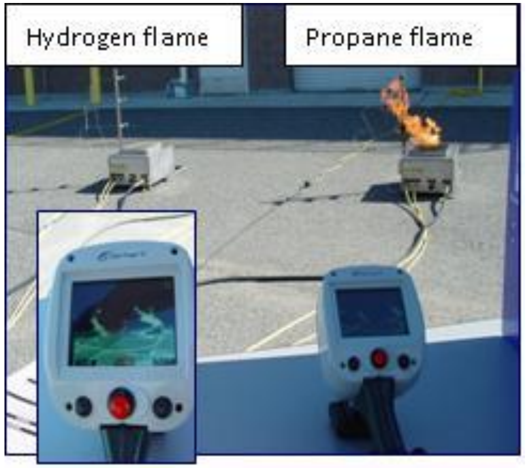
(Invers Joule-Thomson effekt neppe tennkilde)



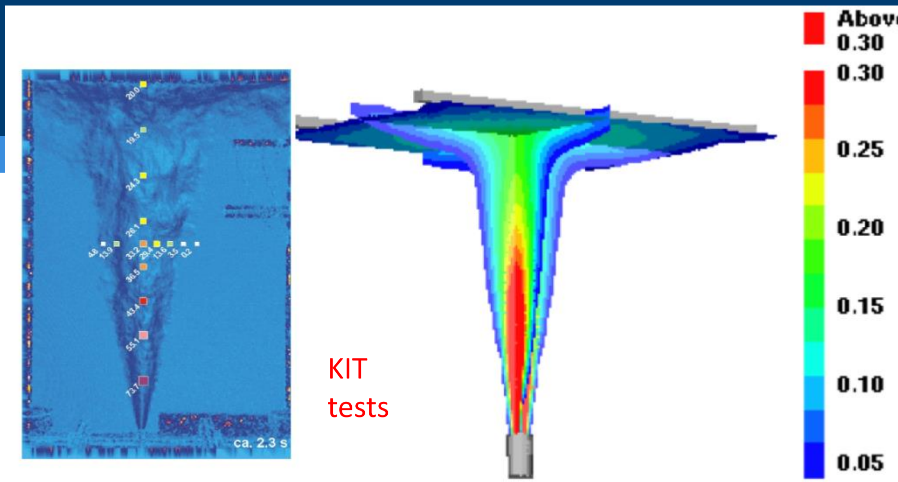
1 kg/s SRI-utslipp (DoE-Sandia)
Så godt som alltid spontan antennelse

Jetbrann:

- Forferdelig støy
- Ofte usynlig
- Varm flamme, lite stråling



Hydrogen konsekvensberegninger



Hydrogen svært annerledes

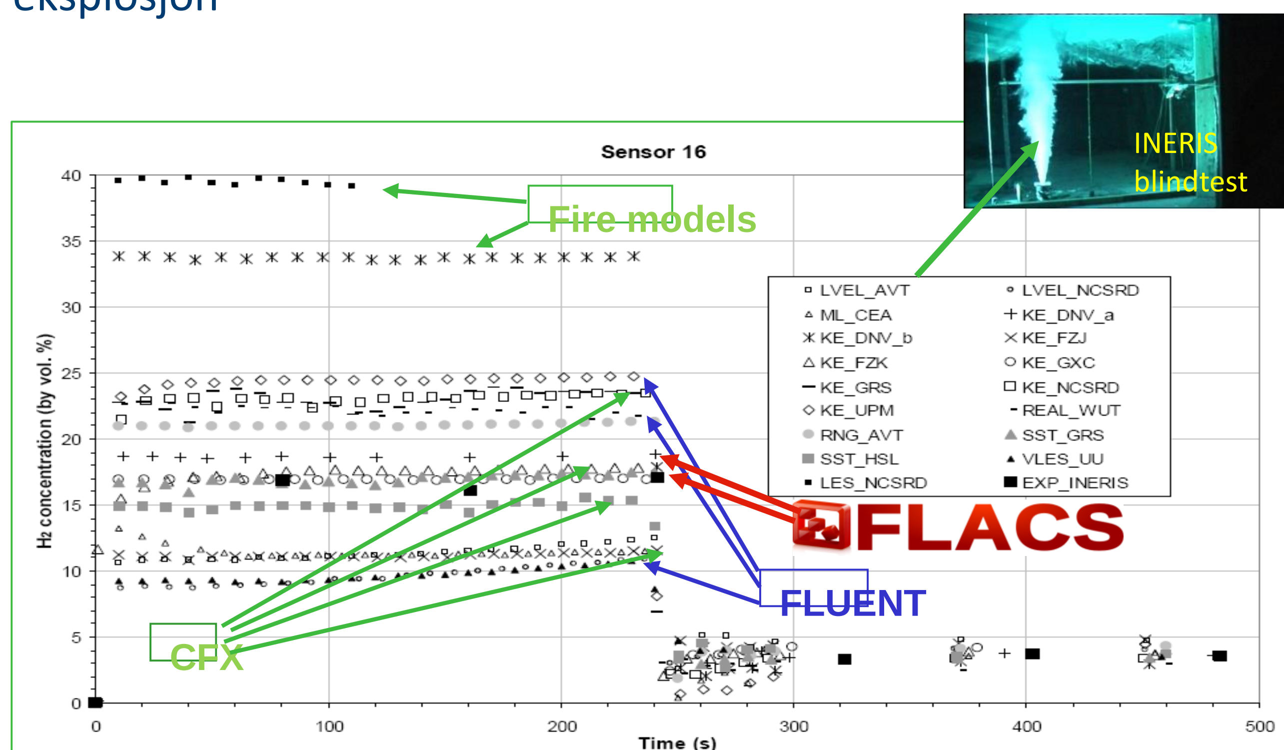
⇒ Viktig med spesialistkunnskap og gode CFD-beregninger

FLACS –godt validert og gode retningslinjer

⇒ Gode resultater i blindtester, gasspredning og eksplosjon

Mye brukte CFD-verktøy

- "Colourful fluid dynamics"



Hydrogen DoE/Sandia & NFPA-2

- Sandia(DoE) Ledende hydrogenmiljø i USA
- Holdt FLACS kurs for dem – viste hvordan

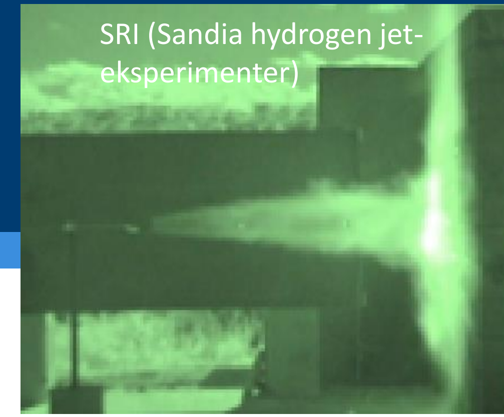
Senere diverse papers FLACS vs experiment

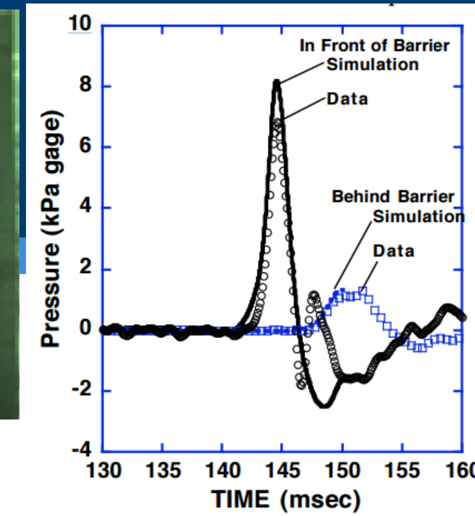
- Antent jet – trykk foran og bak vegg
- Utslipp og eksplosjon i tunnel
- Utslipp og eksplosjon i garasje

Sandia/DoE ledere:

"Vi forstår hydrogen, modellene virker"

Results of the modeling and experiments were presented to the DOE Technical Team, the Hydrogen Industrial Panel on Codes and Standards, and at the Annual Fuel Cell and Hydrogen Energy Conference. Based on feedback from these presentations a new indoor refueling task group was formed within NFPA 2 to utilize the experimental data and validated model in a science-based risk-informed process to develop new indoor refueling codes and standards for NFPA 2.





Dedrick – Sandia National Laboratories

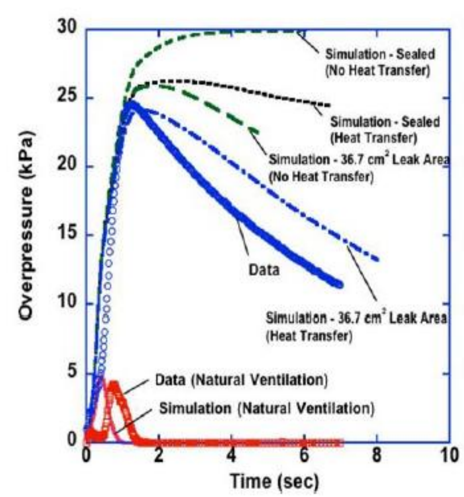


FIGURE 4. Comparison of Measured Ignition Overpressure in the SRI International Subscale Warehouse Facility with Results from FUEGO/FLACS Model Simulations

IX. Safety, Codes & Standards

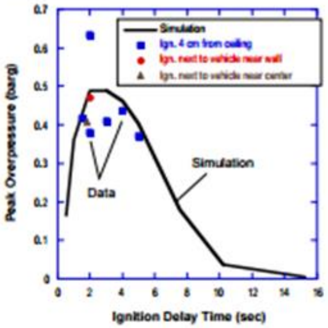


FIGURE 1. Comparison of Measured Peak Ignition Overpressure in the SRI International Test Tunnel Facility with Results from FUEGO/FLACS Model Simulations

PRD vents on the bottom of the scale-model vehicle. As part of the work a dispersion model and deflagration model of the test tunnel and vehicle geometry were developed. These models were used prior to the tests to estimate the placement of concentration and pressure sensors in the tunnel test geometry and to determine the amount of expected overpressure from ignition of the hydrogen releases. Pretest ignition deflagration simulations of the test tunnel geometry using three-dimensional concentration maps from the dispersion

Viktige prinsipper (hydrogen fra trykktanker 350-700 bar)

Unngå gassoppsamling med konsentrasjon > 10-15%

- Begrense mengde vs romstørrelse ELLER design så gass raskt finner veien ut (oppdrift)
- Begrense obstruksjoner – høytrykkslekkasje bør tynnes i luft OG flammeakselerasjon bør unngås
- Spesielt DDT (detonasjon) må unngås – utfordring for design
- Tennkildekontroll bra, men alene ikke godt nok
- Hindre at trykkbølger eller flammer utgjør fare for folk eller integritet

Oppbevaringstanker – plasseres høyt og luftig (?)

- Hindre støt mot tanker, unngå brudd, hindre at folk skades om det likevel skulle skje

Motorrom (samt alle segmenter med hydrogen)

- Vurder mengde hydrogen, maks lekkasjerate MOT romvolum, ventilasjon/congestion ...
- Gjelder særlig innelukkede områder under vannlinjen…

Konklusjon

Optimal og sikker design må oppnås gjennom risikobasert design

a) Tidlig vurdering av design og fareidentifikasjon av hele leveransekjeden
b) Vurdere gasstanker mhp personsikkerhet og integritet ved brudd og større lekkasjer
c) Sjekk alle hydrogen rør&systemer med tanke på å unngå oppsamling > 10-15% ved utslipp
d) Ved enhver tvil, verifisere design med (gode) CFD-beregninger

LR i god posisjon til å bistå slike prosesser på en effektiv måte

Risk Consulting: Olav Roald Hansen 911 71 787
Klassifisering: Leif Gunnar Sandvik 909 36 736

Olav Roald Hansen
Sjefsingeniør
Bergen
T +47 91 17 17 87   E olav.hansen@lr.org

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Vitenskaplige artikler innen hydrogensikkerhet

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