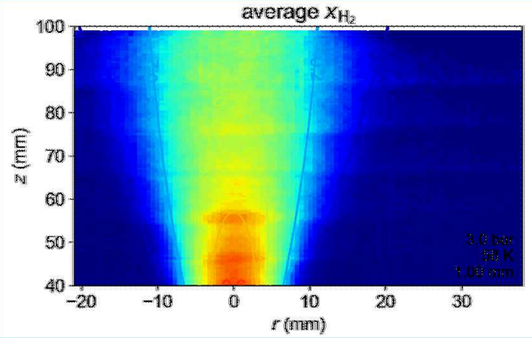
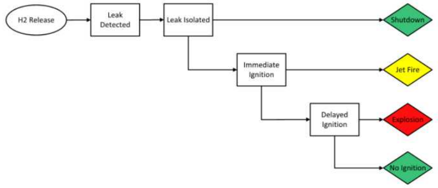
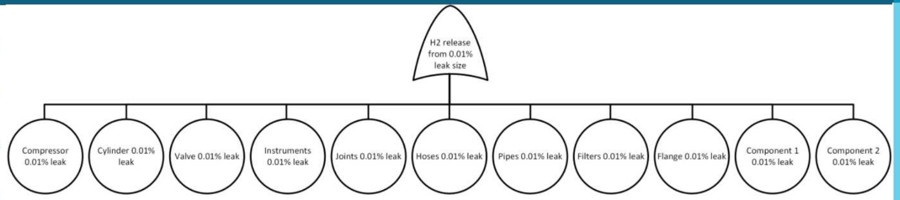
SAND2020-3300PE

Estimation of Liquid Hydrogen Component Leak Frequencies using Liquefied Natural Gas as Proxy







Presented by:

Brian Ehrhart, Dusty Brooks

NFPA 2 Storage Task Group – March 17, 2020

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SAND2020-XXXX PE

Background: LaChance et al. and Gaseous Hydrogen

Options for determination of setback distances
- Consequence-based – "worst case scenario"
- Risk-based – "meet this risk metric"
- Risk-informed – "setbacks based on scenario identified from risk analysis"

Steps of risk-informed process
- Assume a "representative" system
- Analysis risk of entire system
  - Quantitative risk assessment (QRA)
  - Lots of individual choices for Task Group feedback
- Identify scenario(s) of highest risk
  - Combination of likelihood and consequence

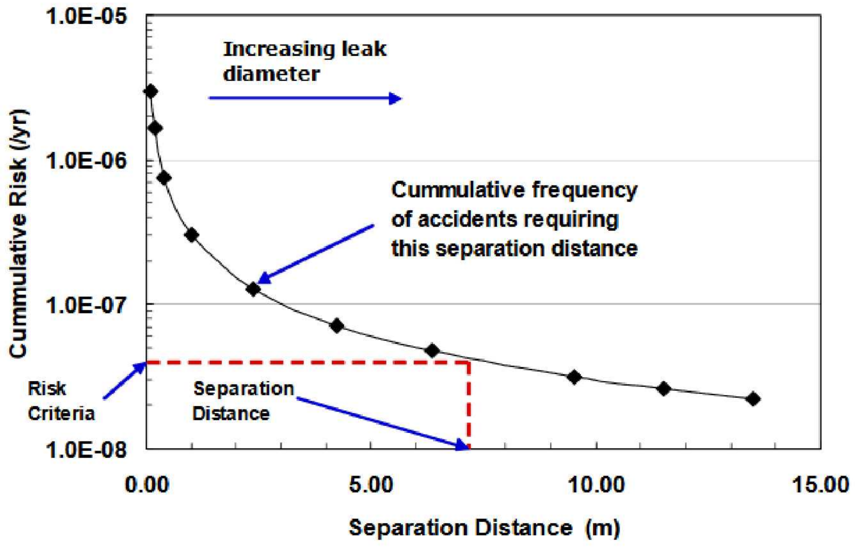


Figure 2-7. Risk-informed approach for establishing safety distances.

Ultimately, NFPA 2 Storage Task Group and Technical Committee will decide on acceptability and scenario choice

LaChance et al. Sandia National Laboratories Report SAND2009-0874, March 2009

Task Group Prior Work: HAZOP and Identified Scenarios

Described in Appendix Section I.8 of NFPA 2 2020 Edition

Assumed a representative system from CGA P-28
- OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Systems

Task group analyzed **102 node deviations** from HAZOP and made a risk-ranking
- Likelihood classification of level 1 (expected to occur 1/yr) to level 6 (less than 1/10,000yrs)
- Hazard severity classification of level 1 (public fatality) to 4 (no injury or system damage)

Based on "**expert elicitation**" and discussion within task group

Resulted in **9 identified scenarios** of concern

Stated next steps are to use Sandia COLDPLUME and NETFLOW to model consequences

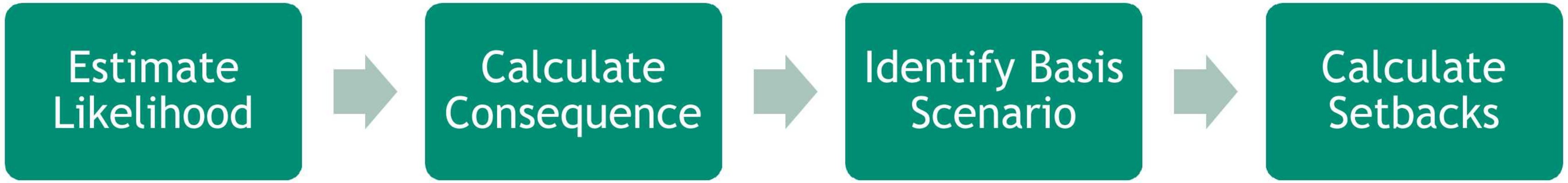
Plan: Quantitative Risk-Informed Scenario Identification

Estimate likelihood of scenarios of concern
- Estimate leak frequencies for liquid hydrogen system components
- Combine component leak frequencies to determine frequency of scenario

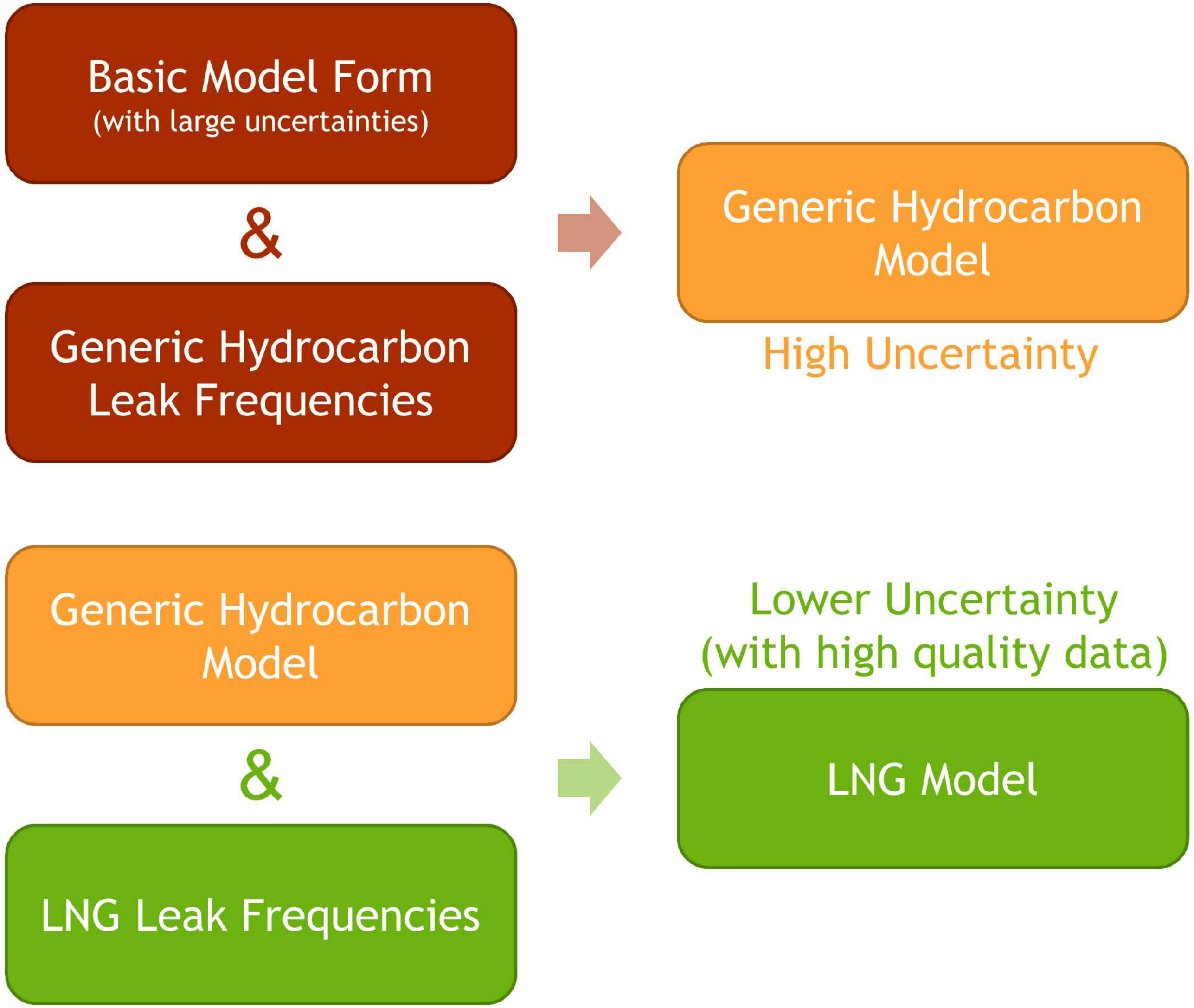
Estimate consequence severity of scenarios of concern
- Estimate gas concentration dispersion and jet flame using ColdPlume
- Estimate liquid pooling using CFD
- Estimate harm/fatality using models in HyRAM

Task Group selects specific scenarios of concern

Use physics models to determine setback distance based on harm from that release scenario



Leak Frequency Estimation Methodology



Model update using Bayesian methods

- Start with high uncertainty
- Use generic hydrocarbon leak frequencies to refine the uncertainty (i.e. improve the model)
- Use LNG-specific leak frequencies to further refine the uncertainty

Final model informed by generic and LNG data

- If data is sparse, the model will predict a wide range of leak frequencies
- If data is numerous and of high quality, the model will predict a narrower range of leak frequencies

LNG Leak Frequency Data Sources

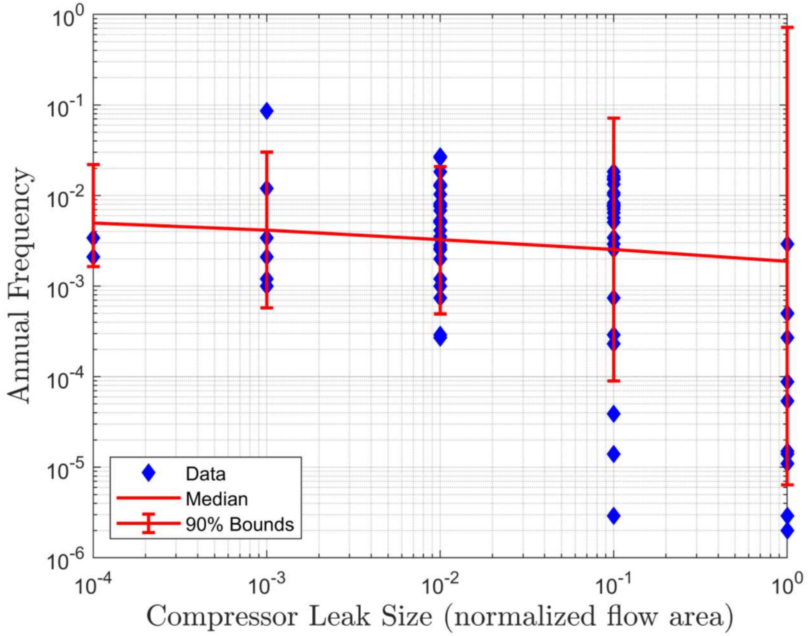
Generic Data Set	Components
HSE (UK) Offshore Data (1992-2015)	Compressors, Condensers, Cylinders, Filters, Flanges, Hoses, Pipes, Pumps, Valves
COVO Study (Netherlands, 1982) from Spouge (2005)	Pipes
HSE (UK) Failure Rate and Event Data for Use Within Risk Assessments (2017)[1]	Compressors, Pipes
OGP Risk Assessment Data Directory – Process Release Frequencies[2]	Compressors, Cylinders, Flanges, Pipes, Valves

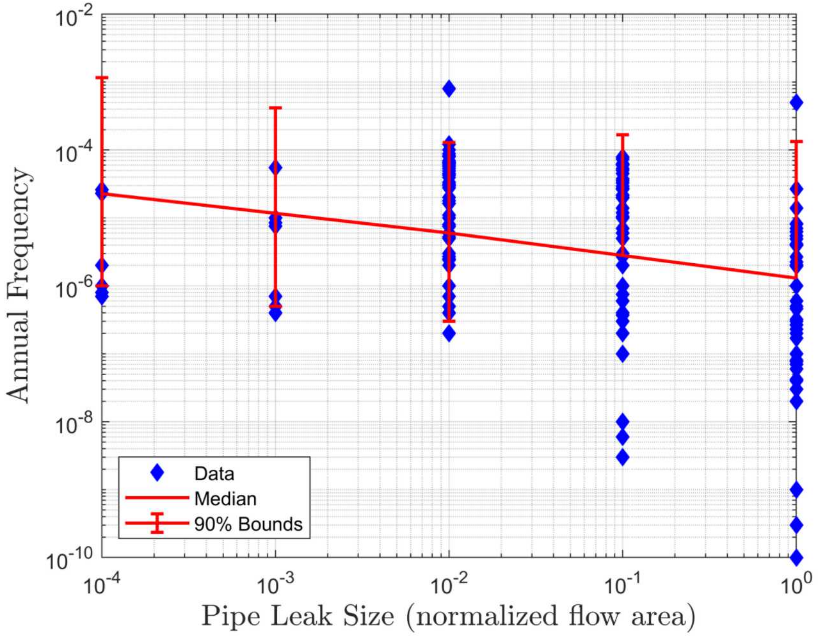
[1] Based on chlorine pipework, augmented with other sources
[2] May have duplication of HSE offshore data

Specific Data Set	Components
DOT/PHMSA – Statistical Review and Gap Analysis of LNG Failure Rate Table	Condensers, Cylinders, Flanges, Hoses, Joints, Pipes, Valves
FERC/OGP as duplicated in Hongjun (2017)[1]	Hoses, Pipes, Valves

[1] May include duplication of OGP generic hydrocarbon data

Preliminary LNG Leak Frequency Results





Leak Size	5th	Median	95th
0.0001	1.6E-03	5.0E-03	2.2E-02
0.001	5.7E-04	4.1E-03	3.0E-02
0.01	4.9E-04	3.3E-01	2.1E-02
0.1	9.0E-05	2.5E-03	7.2E-02
1	6.4E-06	1.9E-03	7.2E-01

Leak Size	5th	Median	95th
0.0001	1.0E-06	2.3E-05	1.2E-03
0.001	5.0E-07	1.2E-05	4.2E-04
0.01	3.0E-07	6.0E-06	1.3E-04
0.1	0.0	2.8E-06	1.7E-04
1	0.0	1.3E-06	1.3E-04

Underlying model is log-linear

Uncertainty is high

The median is the best measure of central tendency

Generic hydrocarbon data is over-represented

Use of both generic and LNG data may result in more spread

- If sufficient LNG data existed, the generic hydrocarbon data would not be used

Leak Frequency Estimation Next Steps

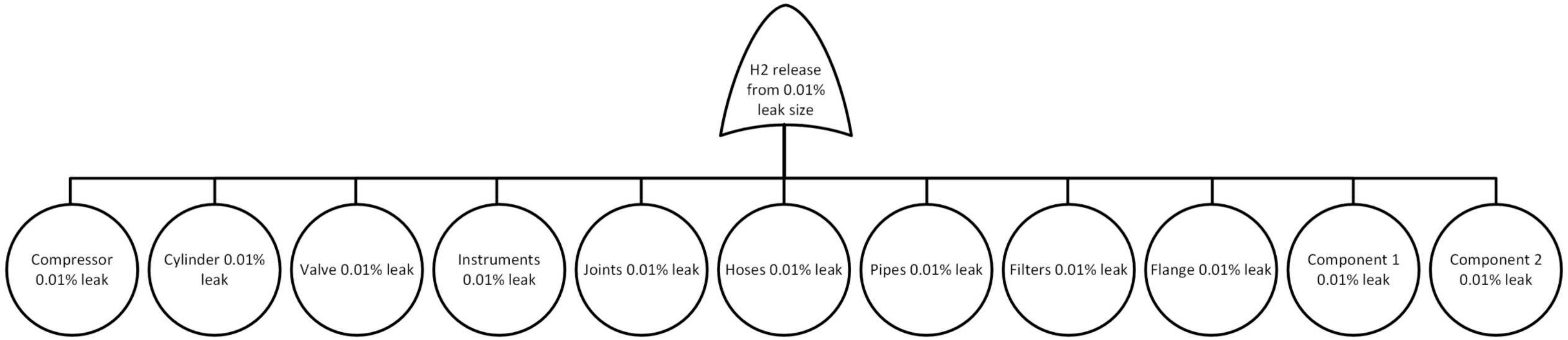
Refine LNG data selection
- Remove non-LNG-specific data
- Add additional sources if available

Refine data weighting and leak size assumptions

Compare LNG-based leak frequencies to CNG and GH2

Incorporate LH2 data
- **Need input!** See next slide…

Determine scenario leak frequencies by combining component leak frequencies



Examples of LH2 Data That Could be Used

Leak count data for each component

Leak Size (% flow area)	Count	Time (component-years)
0.01%	7	77595
0.1%	3	77595
1%	2	77595
10%	1	77595
100%	1	77595

Event Record	Component Diameter	Leak Diameter	Time (component-years)
1	100 mm	0.5 mm	1
2	100 mm	1 mm	0.75
3	100 mm	5 mm	2
⋮	⋮	⋮	⋮

Can be estimated from mass flow, pressure drop, leak/flame extent, …

Leak frequency data

Leak Size (% flow area)	Annual Frequency
0.01%	7.3E-03
0.1%	1.8E-03
1%	1.2E-03
10%	4.3E-04
100%	8.3E-04

The best data will be LH2-specific and:

- have frequencies or counts for all five leak sizes or identify how your leak size bins should be mapped to our leak size bins,
- include estimates for the very small leaks,
- be estimated over a large number of component-years, and
- include descriptions of the components and identification of any atypical components

Consequence Modeling – Cryogenic Vapor with ColdPlume

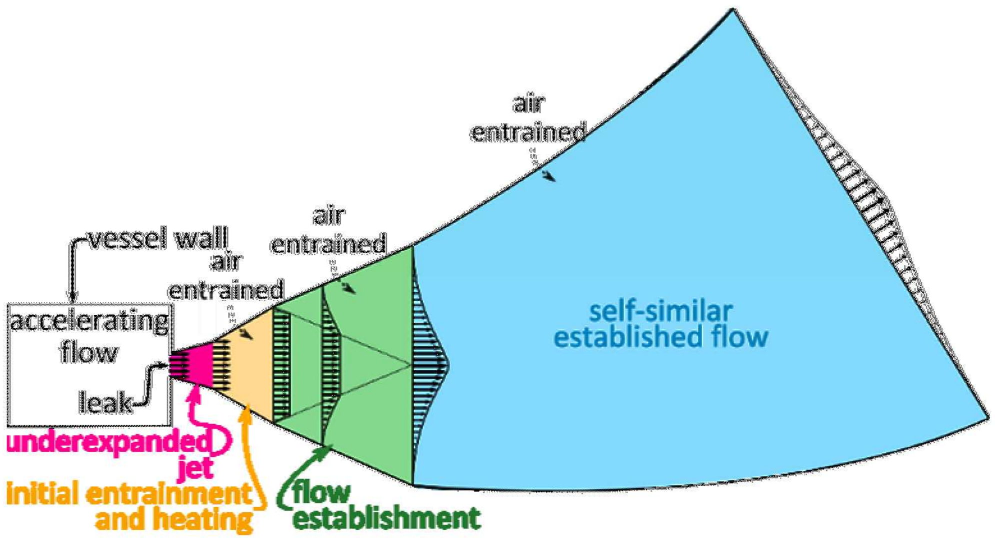
Used for scenarios like vent stack or other releases where cold gaseous hydrogen is released

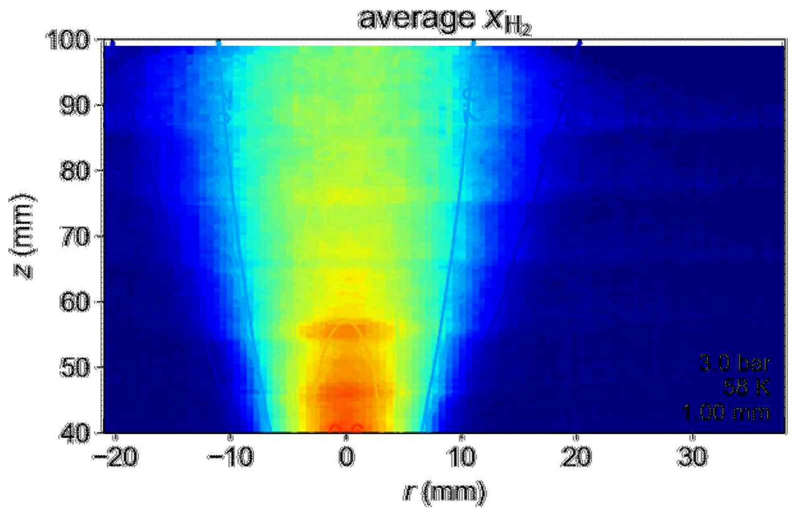
Validated for small (lab-scale) releases

- Currently being validated for larger outdoor releases

Easy to run on normal computer (reduced-order model, not CFD)

- **Many different scenarios and sensitivity analyses can be run**





Consequence Modeling – Liquid Pooling with CFD

Computational fluid dynamics model under development for liquid hydrogen pooling

- Takes both liquid and gaseous hydrogen into account

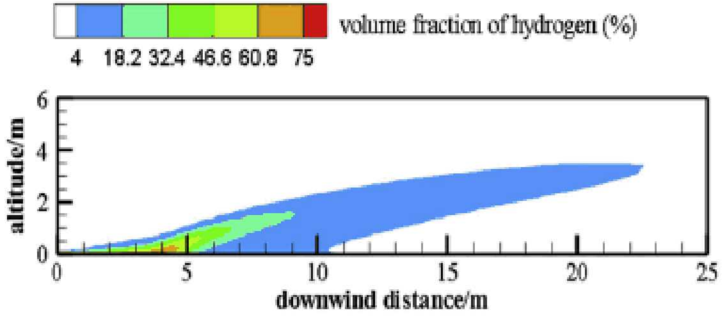
Used for scenarios like liquid transfer line break where actual liquid hydrogen is released

Computationally expensive

- New scenarios could take weeks to complete

Compare ColdPlume results to CFD results

- If ColdPlume inputs can be set to ensure conservatism, could use ColdPlume for pooling scenarios also



Pu et al. IJHE 44 (2019) 22368-22379

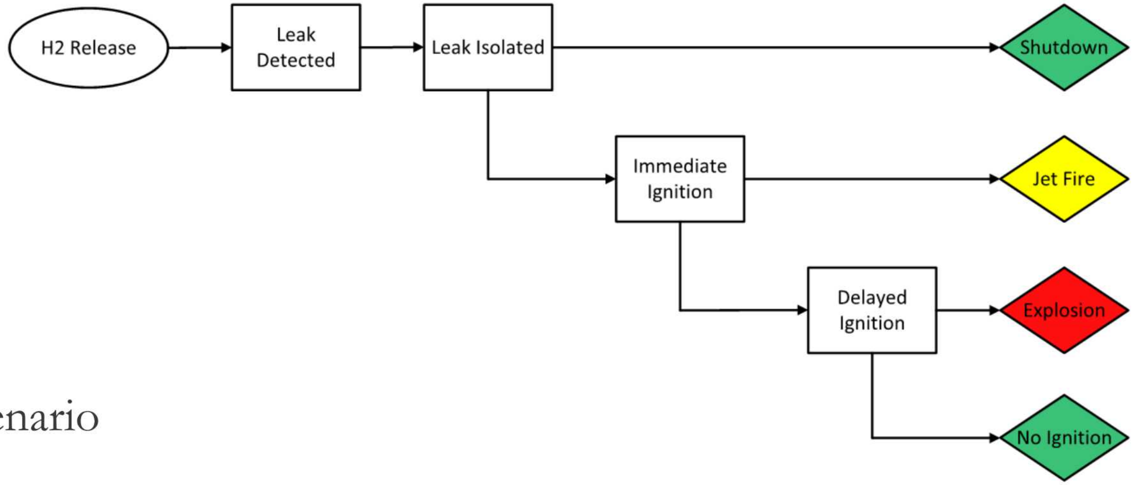
Other Risk Inputs

Detection/Isolation Credit
- Should any be assumed?

Ignition Probability
- Method from Tchouvelev

Harm Criteria/Fatality Probit
- Many possibilities available
- Different levels of conservatism, may vary based on scenario

Do be discussed later…



A. V. Tchouvelev, International Energy Agency Hydrogen Implementing Agreement Task 19, 2006

Summary

Liquid Setback Calculation Plan

- Estimate leak frequencies
  - Need LH2 data
- Calculate release consequences
  - ColdPlume, CFD, harm
- Identify basis scenario
  - Based on results of risk analysis
- Calculate LH2 setback distances

Ultimately Task Group and Technical Committee decide on code requirements

Leak frequency estimation in progress

- Leak frequencies using LNG under refinement
- Need LH2 data

Consequence modeling in progress

- ColdPlume analysis started
- CFD analysis begun, but takes longer
  - Looking into whether ColdPlume can be used

Questions?

Thank you!

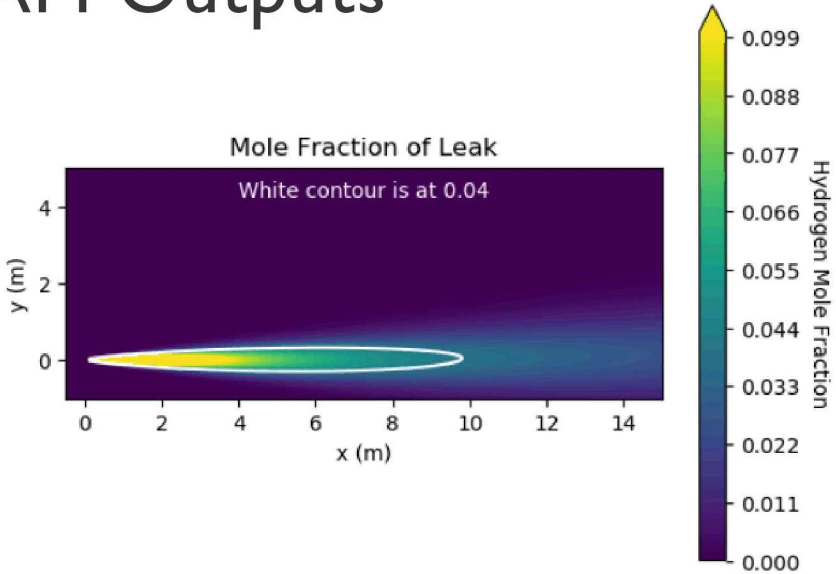
Back Up Slides

HAZOP Scenarios and Modeling Notes

NFPA 2 2020 Table I.8(c)

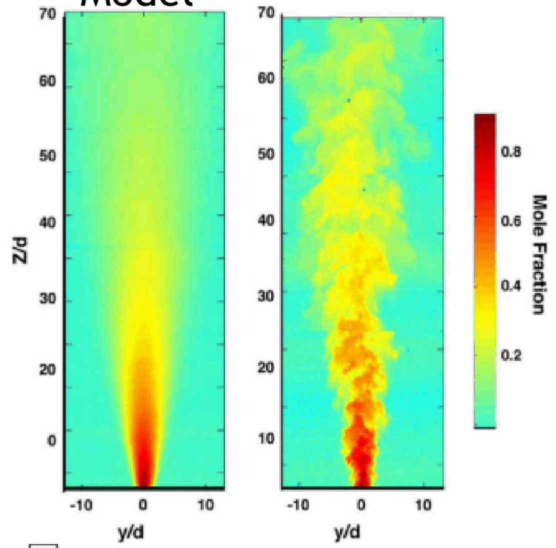
	HAZOP Number and Description		Modeling notes	Separation Distance Driver
Release scenarios during liquid transfer to bulk storage tank	1.18	High flow gaseous hydrogen from trailer vent stack due to venting excess pressure after LH2 transfer	Estimate of up to 50 kg cold gaseous hydrogen released	Modeling results will be used to calculate separation distance from Air intakes and Overhead Utilities because this is highest frequency release and release point is closest proximity to these exposures
	1.19	Normal flow from trailer vent stack due to venting excess pressure after LH2 transfer	Estimate of up to 50 kg cold gaseous hydrogen released	
	1.6	High flow-Line rupture valve or component failure during transfer process	Assumption is that it will dump onto the ground. Do not currently have a model for pooling or evaporation from pools. Need liquid pool and evaporation model.	
	1.4	High temperature caused by external fire will cause high flow venting through tank vent stack	Worst case venting scenario. Ambient temperature will be hot, PRD will blowdown longer with more hydrogen. PRDs designed to vent for external fire.	
	1.8	Reverse Flow during transfer process caused by human error and pressure mismanagement	Assumption is that it will dump onto the ground. Do not currently have a model for pooling or evaporation from pools. Need liquid pool and evaporation model.	
	1.16	Loss of containment- External impacts, consider all causes	Vehicle crash into the tanker while it's transferring. Uncontrolled leak outside transfer hose with a fire.	
Release scenarios during normal system operation	4.15	Loss of containment- release from pipe leading from tank to vaporizer or vaproizer itself caused by thermal cycles or ice falling from vaporizers	Cold plume model could handle this scenario. Could be liquid pooling and could be impingement.	Modeling results of hydrogen concentration plume and heat flux from a subsequent fire will be used for all other separation distance exposures because this is the highest risk priority
	6.15	Misdirected flow caused by operator error resulting in large low level release of cold gaseous hydrogen through bottom drain valve of vent stack during normal tank venting process	Need to characterize ground level behavior and the extent of flammable concentration.	
	2.1	High pressure- leak in inner vessel allowing hydrogen into the vacuum area	Need to model flow out of the casing vent (a big hole instead of a pipe orifice). Netflow and cold plume could model this.	

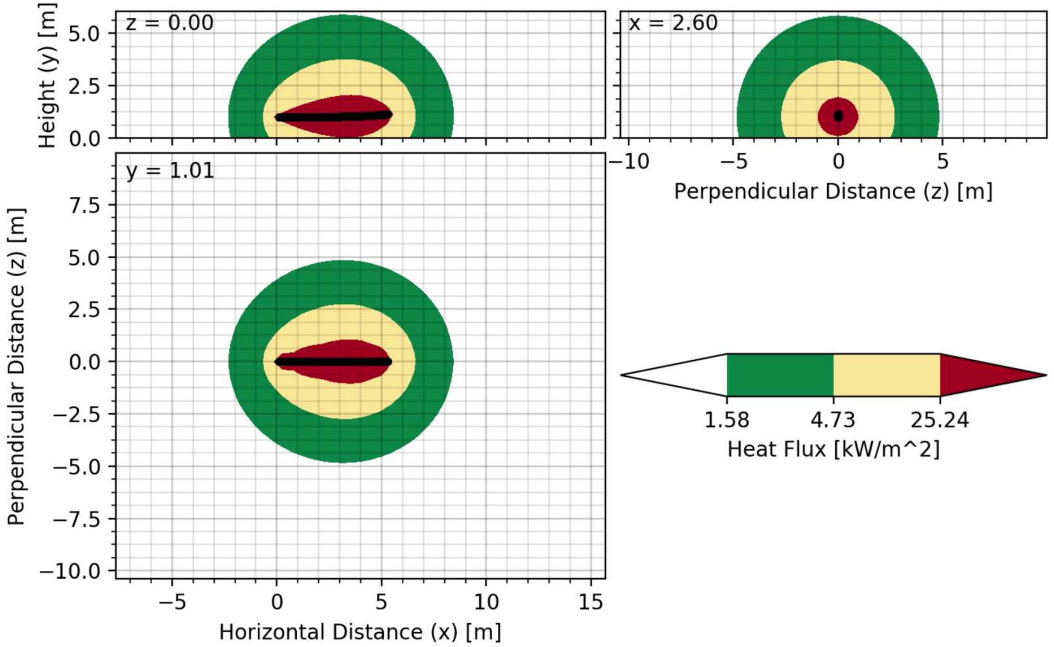
Example HyRAM Outputs

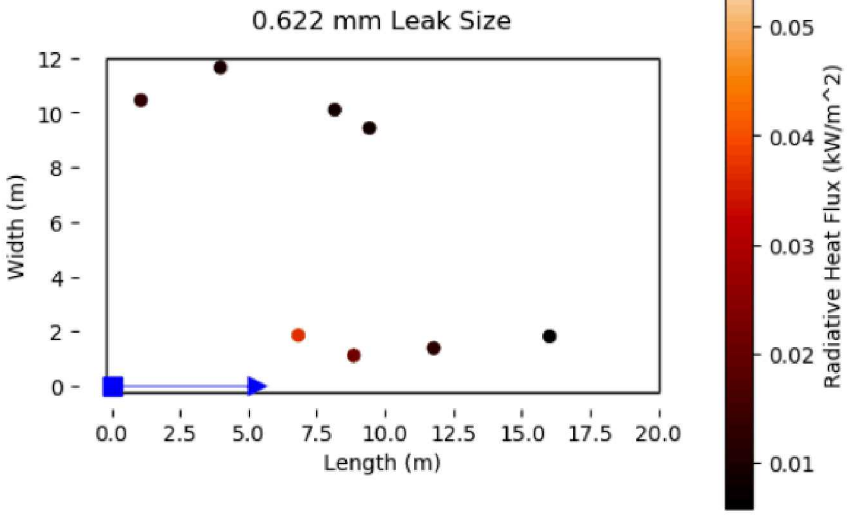


Reduced-Order Model

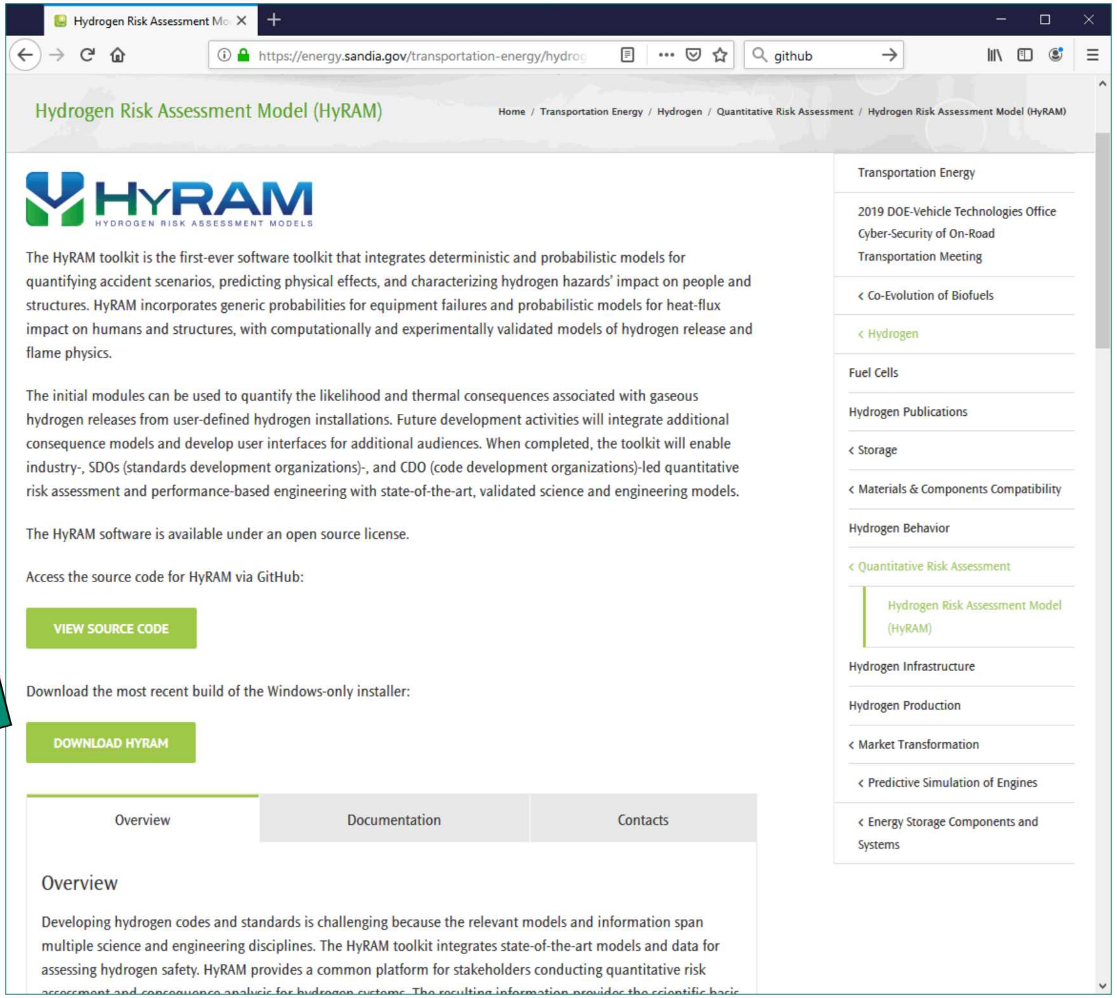
Real System



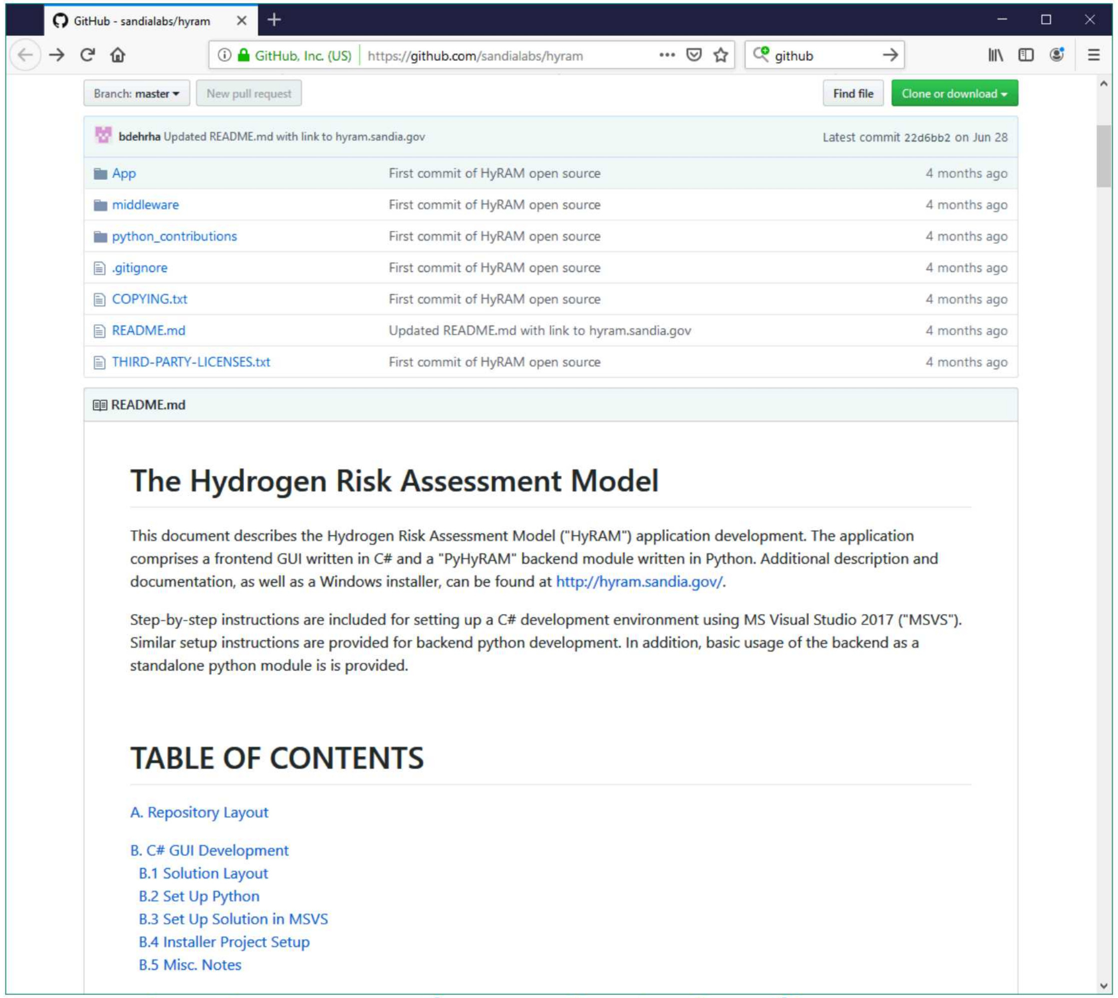




HyRAM 2.0 can be installed as a Windows executable and as an open-source software, users have access to the source code



hyram.sandia.gov



github.com/sandialabs/hyram