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Hydrogen Risk Assessment Models 2.0: An open source quantitative risk assessment framework

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

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Authorities look to NFPA 2 for standards on how to site hydrogen fueling stations

Can follow prescribed separation distances:

- Different distances for different exposures
- Some distances able to be reduced with mitigations (barrier wall, insulation, etc.)
- Justification for some (gaseous) separation distances provided in annex
  - ✓ Separation distance reductions in NFPA 2 2011 and again in 2020 enabled by Sandia-led scientific analyses

Or alternative means and measures (AM&M):

- Demonstrate acceptable protections and risk for non-compliance to prescribed separation distance(s) to authority having jurisdiction (AHJ)

Or full performance-based design:

- Simulate all required design scenarios in NFPA 2 Chapter 5

2–42 HYDROGEN TECHNOLOGIES CODE

Table 7.3.2.3.1.1(a) Minimum Distance (D) from Outdoor [GH_2] Systems to Exposures — Typical Maximum Pipe Size

Pressure	>15 to ≤250 psig		>250 to ≤3000 psig		>3000 to ≤7500 psig		>7500 to ≤15000 psig	
Internal Pipe Diameter (ID) d_{mm}	>103.4 to ≤1724 kPa $d=52.5_{mm}$		>1724 to ≤20,684 kPa $d=18.97_{mm}$		>20,684 to ≤51,711 kPa $d=7.31_{mm}$		>51,711 to ≤103,421 kPa $d=7.16_{mm}$	
Group 1 Exposures	m	ft	m	ft	m	ft	m	ft
(a) Lot lines (b) Air intakes (HVAC, compressors, other) (c) Operable openings in buildings and structures (d) Ignition sources such as open flames and welding	12	40	14	46	9	29	10	34
Group 2 Exposures	m	ft	m	ft	m	ft	m	ft
(a) Exposed persons other than those servicing the system (b) Parked cars	6	20	7	24	4	13	5	16
Group 3 Exposures	m	ft	m	ft	m	ft	m	ft
(a) Buildings of noncombustible non-fire-rated construction (b) Buildings of combustible construction	5	17	6	19	4	12	4	14

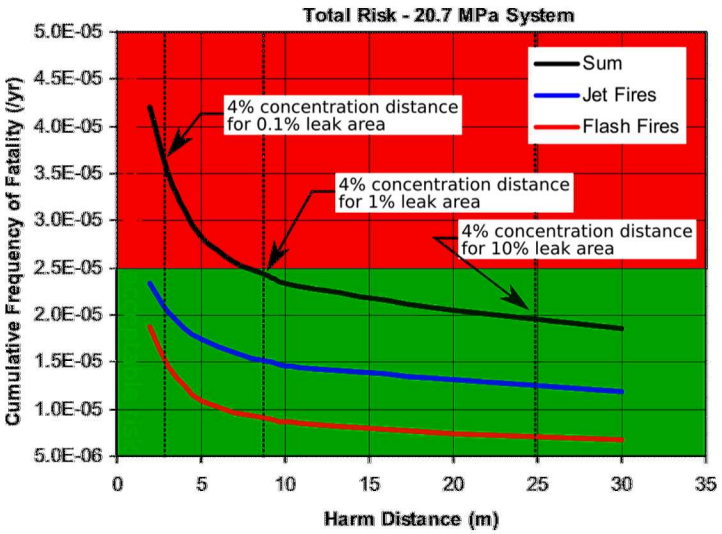
2–58 HYDROGEN TECHNOLOGIES CODE

Table 8.3.2.3.1.6(A) Minimum Distance from Bulk Liquefied Hydrogen [LH_2] Systems to Exposures

	Total Bulk Liquefied Hydrogen [LH_2] Storage					
	39.7 gal to 3500 gal	150 L to 13,250 L	3501 gal to 15,000 gal	13,251 L to 56,781 L	15,001 gal to 75,000 gal	56,782 L to 283,906 L
Type of Exposure	ft	m	ft	m	ft	m
Group 1						
1. Lot lines	25	7.6	50	15	75	23
2. Air intakes [heating, ventilating, or air conditioning equipment (HVAC, compressors, other]	75	23	75	23	75	23
3. Wall openings Operable openings in buildings and structures	75	23	75	23	75	23
4. Ignition sources such as open flames and welding	50	15	50	15	50	15
Group 2						
5. Places of public assembly	75	23	75	23	75	23
6. Parked cars (distance shall be measured from the container fill connection)	25	7.6	25	7.6	25	7.6
Group 3						
7. Building or structure (a) Buildings constructed of noncombustible or limited-combustible materials (1) Sprinklered building or structure or nonsprinklered building or structure having	5[a]	1.5	5[a]	1.5	5[a]	1.5

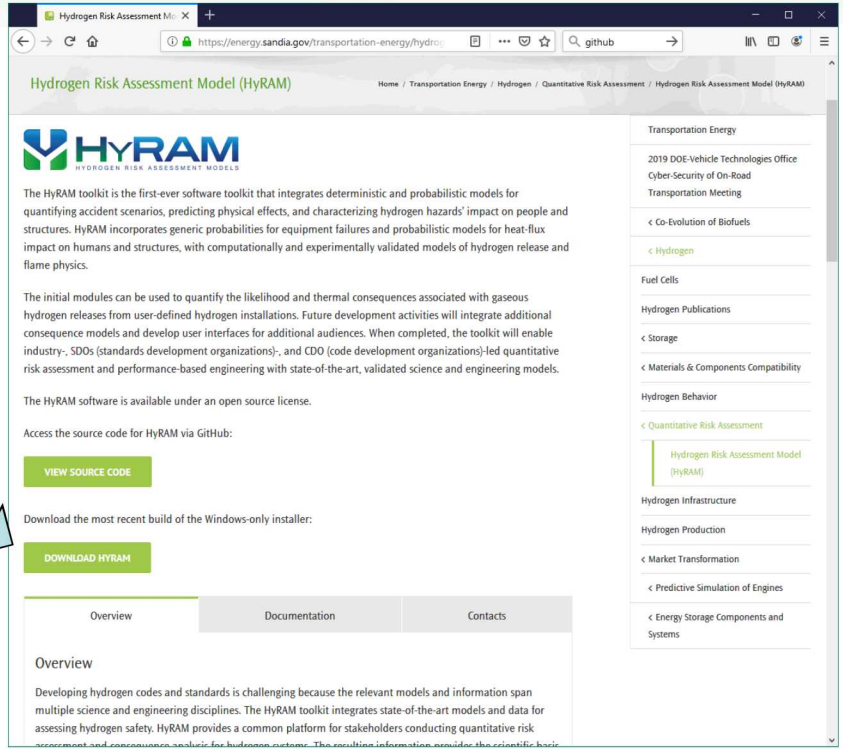
Risk can be used to inform siting decisions (AM&M) and/or separation distances

- Quantitative risk assessment (QRA) requires
  - Data on frequency and size of leaks
  - Models for consequences of leaks
  - Calculation of harm due to exposure
- QRA can inform decisions based on acceptable risk for a specific or typical system
  - 2×10^{-5}/yr selected by NFPA separation distance working group (average frequency of fatalities at US gasoline stations)
  - Typical (gaseous H_2 storage) system modeled using HyRAM models

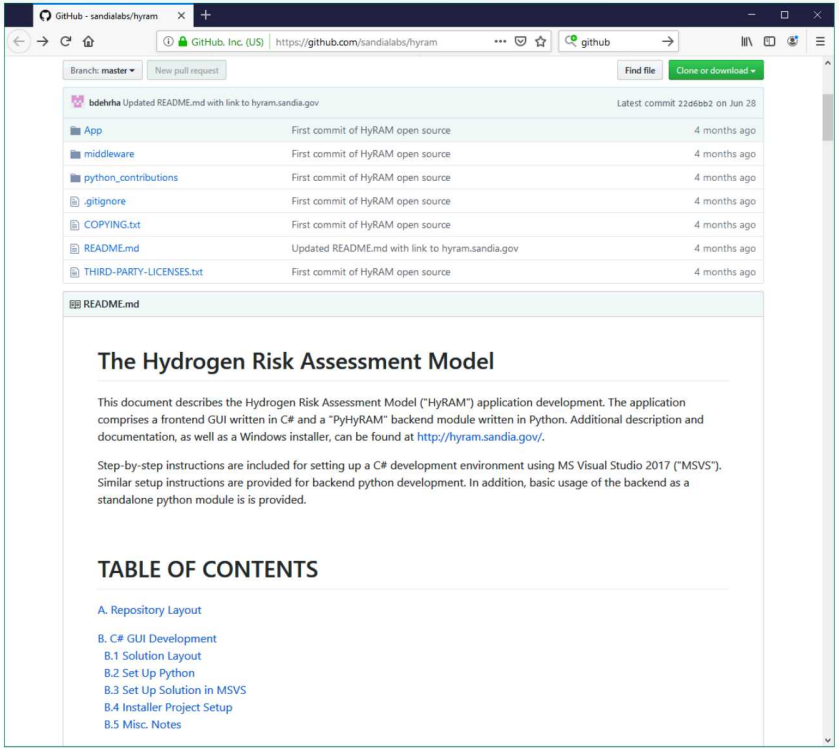


Modified version of plot from SAND2009-0874

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



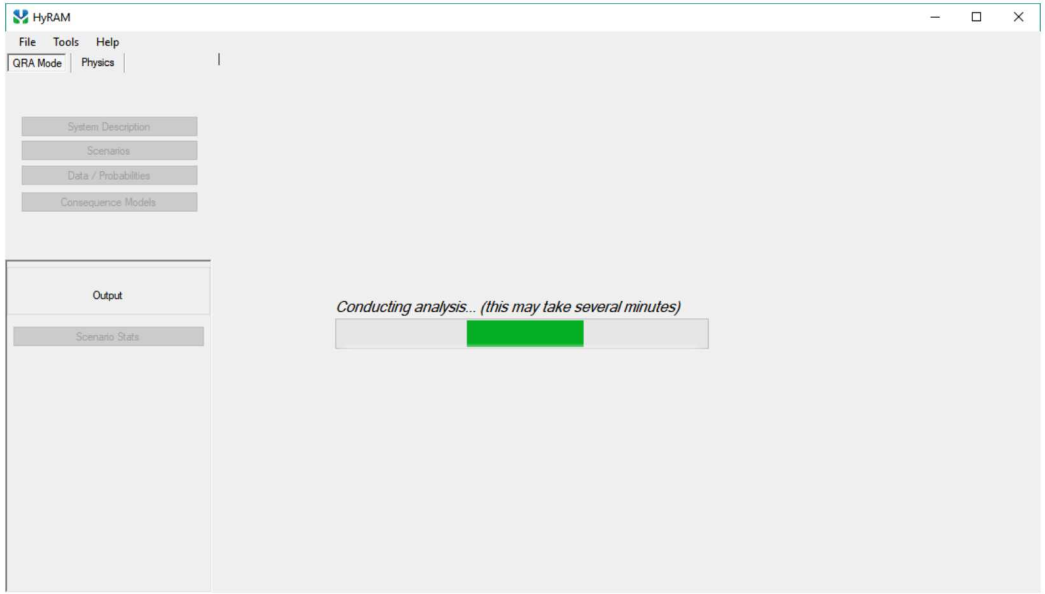
hyram.sandia.gov



github.com/sandialabs/hyram

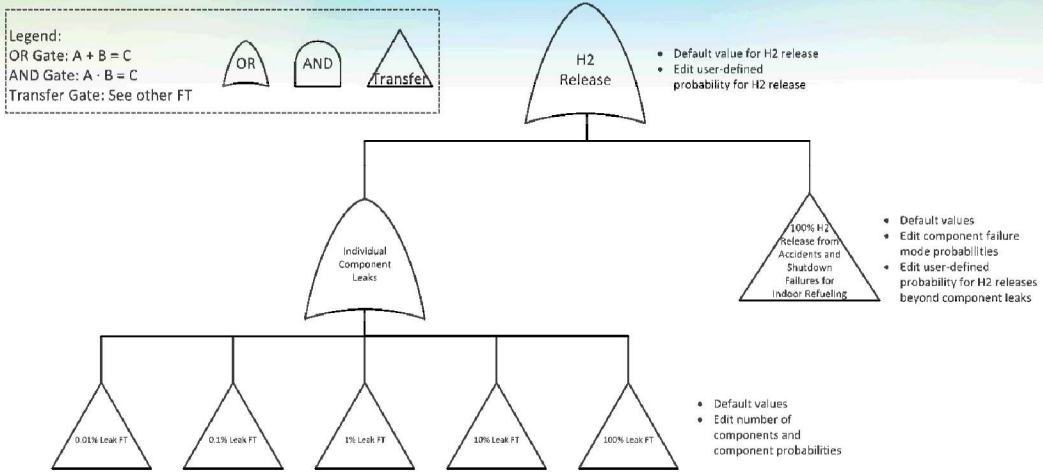
HyRAM 2.0 enables consistent, traceable and rigorous QRA for specific systems

- ✓ User inputs system description
  - ✓ Number of components
  - ✓ Pressure
  - ✓ Nominal pipe size
- ✓ Generic data for scenarios and probabilities an be updated if data is available
- ✓ Consequence models can be selected
- ➢ Risk metrics calculated
- ➢ Scenarios can be saved



Model flexibility enables QRA beyond hydrogen refueling stations

- Users able to edit the parameters of the existing fault tree (FT) or substitute their user-defined FT results from external FT software
- Updated HyRAM methodology enables users to alter the risk analysis for different applications



Data/Probabilities

Probability data quantifying the events contained in the scenario models (ESDs and FTs)

Component Leaks | Component Failures | Ignition Probabilities | Distributions

Compressors | Cylinders | Filters | Flanges | Hoses | Joints | Pipes | Valves | Instruments | Extra Component #1 | Extra Component #2

Leak Size	Mu	Sigma	Mean	Variance
0.01%	-1.7198	0.2143	1.83E-001	1.58E-003
0.10%	-3.9185	0.4841	2.23E-002	1.32E-004
1%	-5.1394	0.7898	8.01E-003	5.55E-005
10%	-8.8408	0.8381	2.06E-004	4.31E-008
100%	-11.3365	1.3689	3.04E-005	5.11E-009

Data/Probabilities

Probability data quantifying the events contained in the scenario models (ESDs and FTs)

Component Leaks | Component Failures | Ignition Probabilities | Distributions

Accident and shutdown failure parameters included in 100% leak release calculation

Component Failures

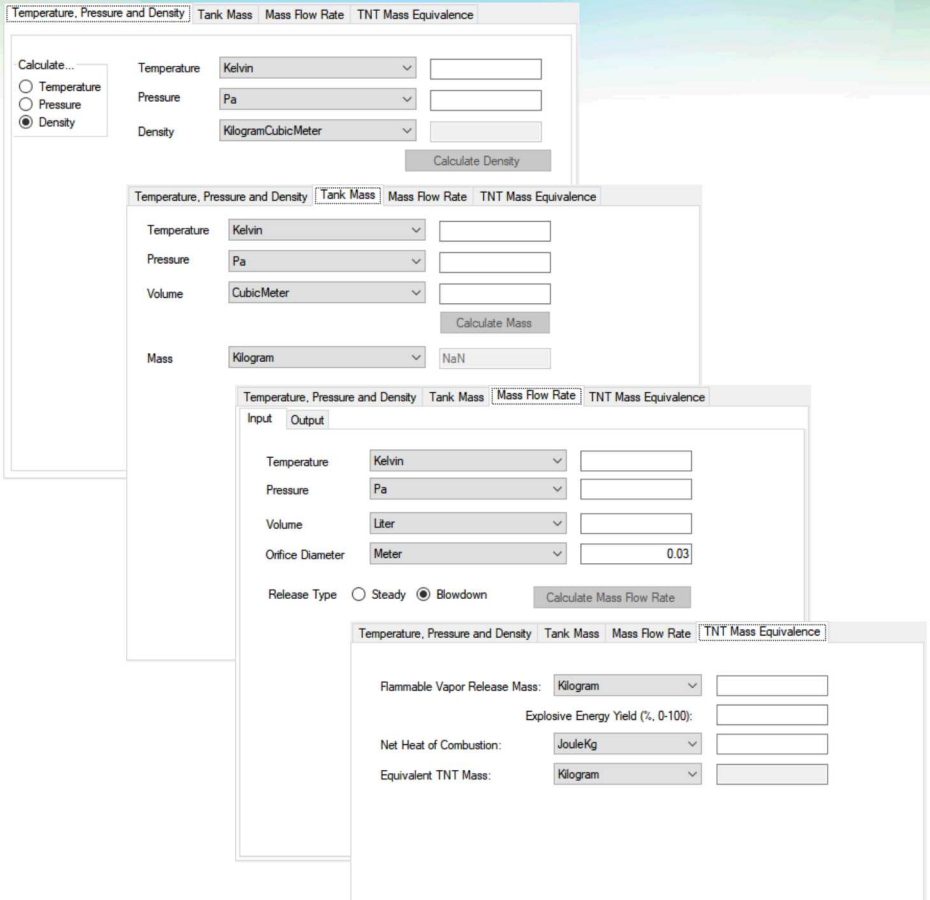
Component	Failure Mode	Distribution Type	Parameter A	Parameter B
Nozzle	Pop-off	Beta	0.5	610415.5
Nozzle	Failure to close	ExpectedValue	0.002	
Manual valve	Failure to close	ExpectedValue	0.001	
Solenoid valve	Failure to close	ExpectedValue	0.002	
Solenoid valve	Common-cause failure	ExpectedValue	0.00012766	

Accidents

Component	Failure Mode	Distribution Type	Parameter A	Parameter B
Overpressure during f...	Accident	Beta	3.5	310289.5
Pressure relief valve	Failure to open	LogNormal	-11.7359368859313	0.667849415603714
Driveoff	Accident	Beta	31.5	610384.5
Breakaway coupling	Failure to close	Beta	0.5	5031

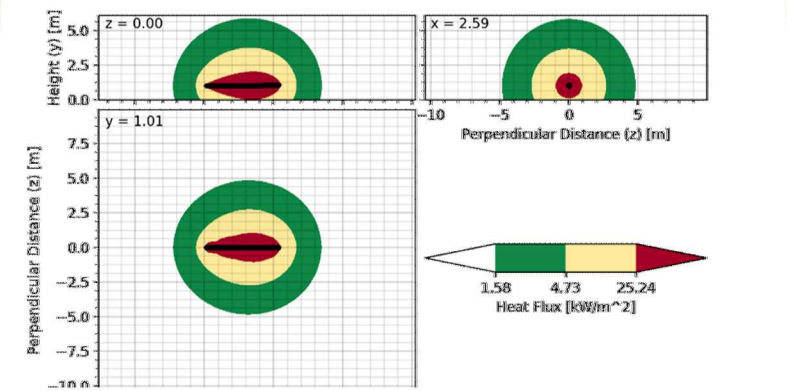
The HyRAM GUI also contains an Engineering Toolkit for some common calculations

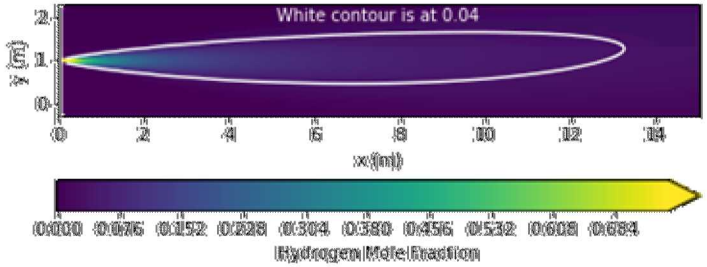
- Equation of state
- Tank mass
- Mass flow rate
- TNT mass equivalence
- Valid for high pressures (soon to be updated for cryogenic temperatures)

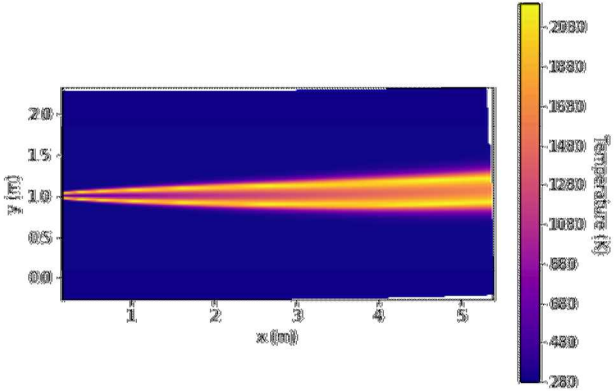


A variety of validated physical models are used in HyRAM, which can be used independently from QRA

- Unignited dispersion
  - Distance to certain concentration
- Flame model
  - Temperature field
  - Heat flux field
- Overpressure for delayed







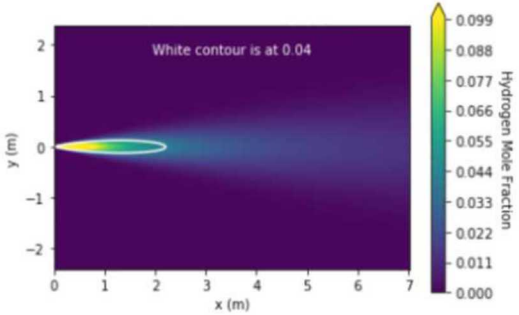
The underlying Python modules can be inspected, updated, and/or used independently

- Physics modules based on intuitive object oriented structure
- Implemented as a python package
- Additional details of simulations can be explored
- First access to upcoming module releases (e.g. ColdPLUME - before implementation in Windows GUI)
- Incorporation of user-preferred physics models possible

In [1]:
```
from altRAM import phys
```

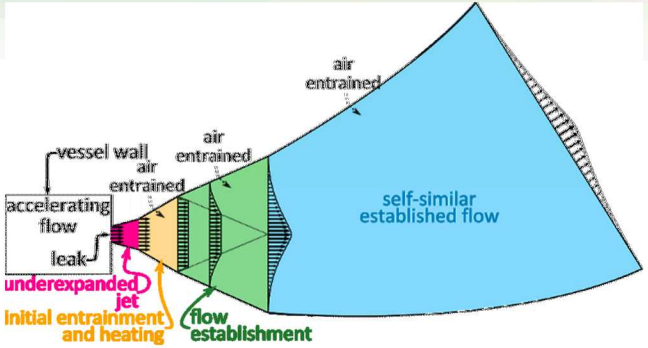
In [2]:
```
H2 = phys.Gas(T = 40, P = 5e5);
air = phys.Gas(T = 295, P = 101325, species =
['air']);
orifice = phys.Orifice(d = 0.001);
release = phys.Jet(H2, orifice, air);
release.solve(Ymin = .001);
release.plot_moleFrac_Contour();
```

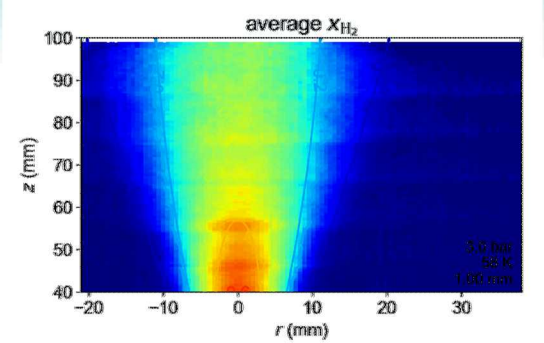
```
solving for the plume... done.
```



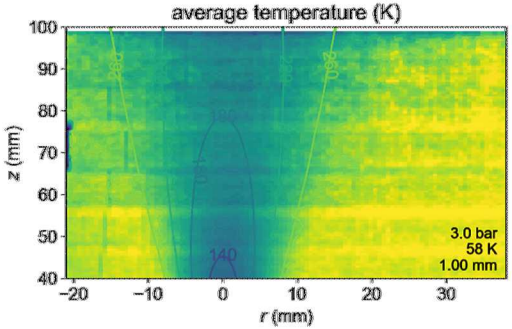
➢ Code organization, ease of use and documentation critical for outside development and use

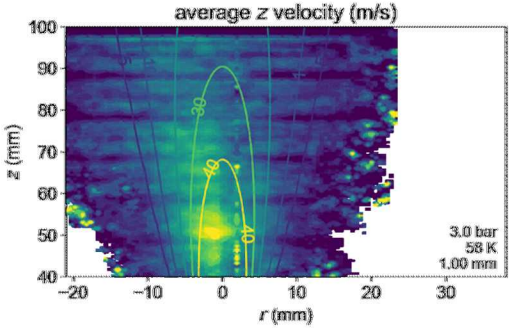
The ColdPLUME model has been validated with laboratory data





- Experimental results shown by shading and thick, dashed lines
- ColdPLUME model results are thin, solid lines





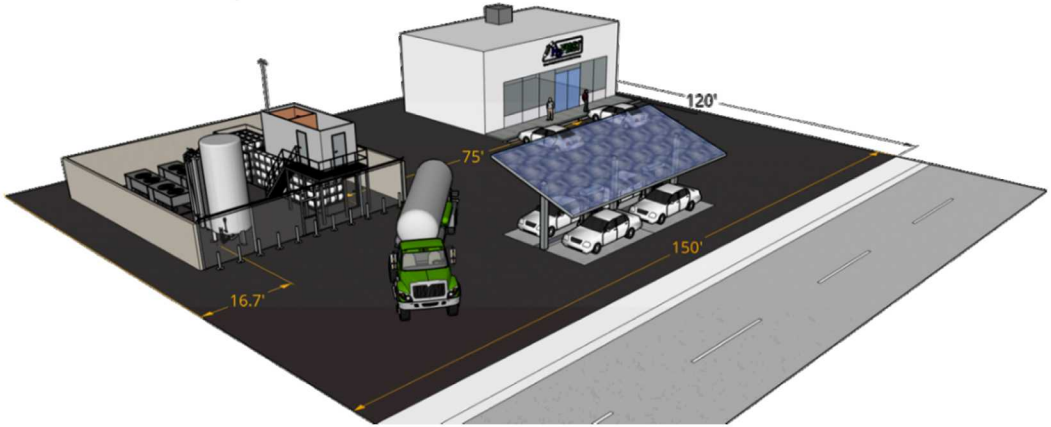
➢ Model accurately simulates mole fraction, temperature, and velocity -- can be used as a predictive tool

Upcoming additions to HyRAM

- Incorporate validated physics models for hydrogen behaviors
  - liquid/cryogenic release behavior
  - deflagration (unconfined) and detonation models
  - flow/flame surface interactions
  - pooling and vaporization
  - barrier walls
  - ignition
- Include additional data/probabilities
  - liquid hydrogen system component failures and leak frequencies
  - effectiveness of detection
- Quantify risk reduction from hydrogen system mitigation features
- Extension to other fuels (e.g., CNG, LNG)

Summary

- HyRAM 2.0 is an open-source toolkit for QRA or physics simulations of hydrogen systems
- QRA and physics simulations can be used to inform siting decisions or separation distances
- Underlying source code can be used to explore the details of the calculations
- The team at SNL is working to expand and enhance the toolkit
- External use, feedback and development is welcomed and encouraged



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Thank you!

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