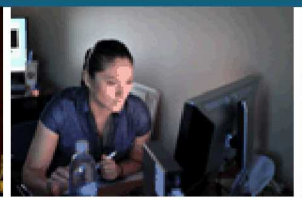
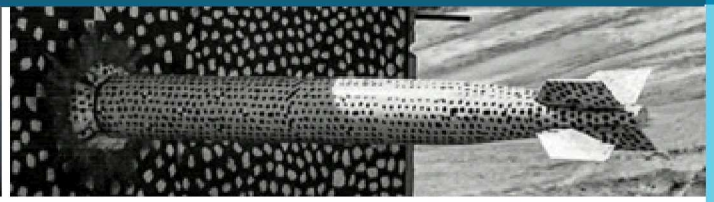
SAND2018-12341PE

Risk Analysis and Modeling to Improve Hydrogen Fuel Cell Vehicle Repair Garage Codes and Standards





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Risk Analysis

Hazard and Operability Study (HAZOP)

- Full HAZOP will be in future full report
- Scenarios ranked by severity of consequence and frequency of occurrence

Selected high-risk scenarios:

Event Description	Comments	Comments
External fire causes TPRD release of H_2 cylinders	Worst consequence: 2 tanks, high pressure, jet fire	Only occurs when external fire heats H_2 storage
Accidental operation by operator of defueling valve	1 tank, high pressure	Valve protected by resin and procedure; would require multiple failures to occur
Small release in low-pressure system	Most likely: <1 tank, low pressure	Mitigated by detection; the event below bounds this scenario
Premature disconnect of venting tool	1 or 2 tanks, low pressure	**Modeled and discussed in presentation**
Premature disconnect of high pressure defueling tool	1 tank, high pressure	High-P defueling already rare, failure while defueling more so

Modeling Scenario

Vehicle is defueling using vent hose to an external exhaust outlet and the vent hose is cut

4 key scenarios in this summary
- Scenario F: No ventilation
- Scenario J: Regular ventilation near the vehicle
- Scenario K: Regular ventilation away from the vehicle
- Scenario G: Higher ventilation directed at the vehicle
- Additional scenarios will be included in upcoming report

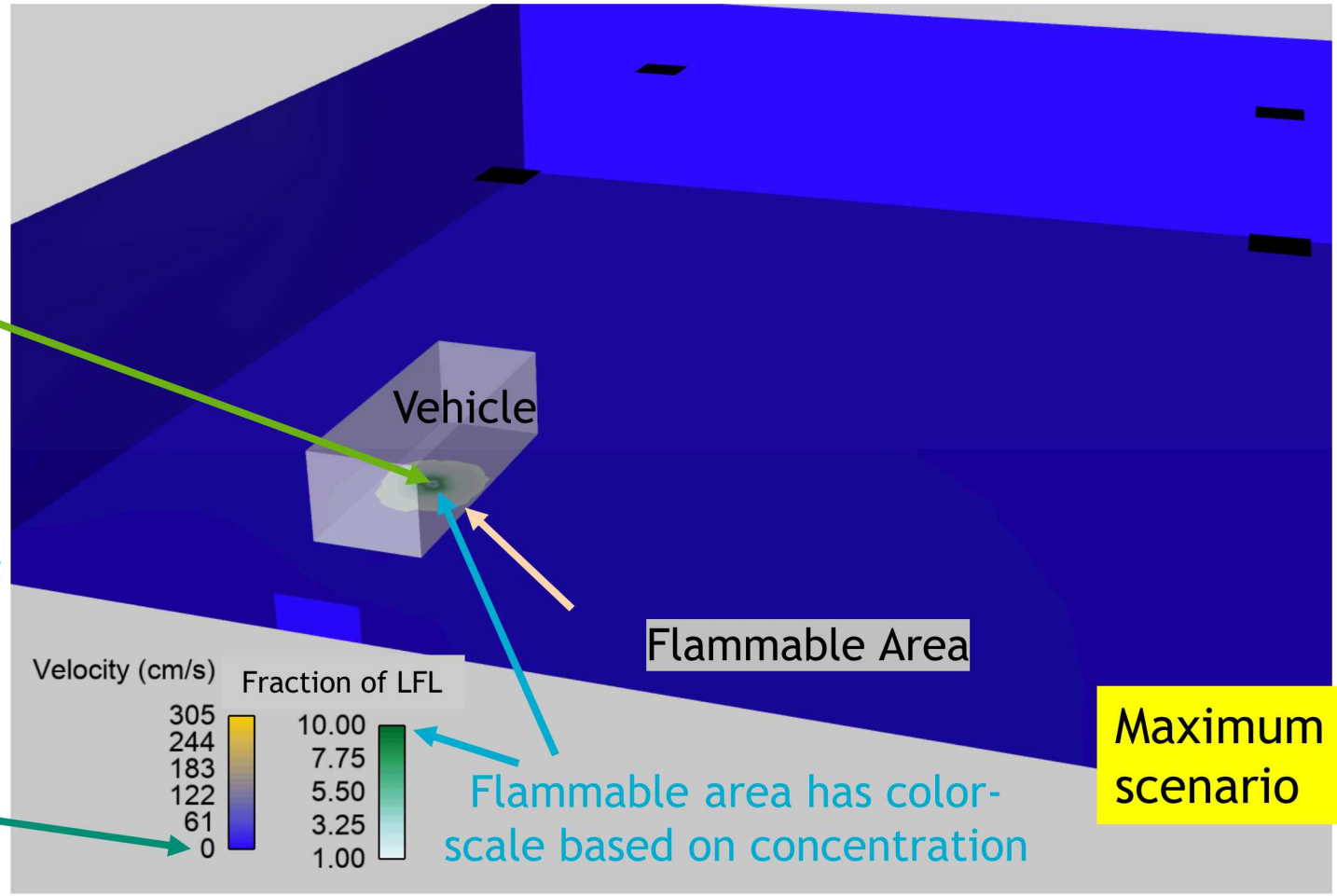
Typical 12-bay garage
- Each bay 14' x 27' x 16'
- Center aisle 6' x 84' x 16'

Leak:
- 2.5 kg of H_2 released
  - Most hydrogen vehicles have 2 tanks which store approximately 2.5 kg of hydrogen each
  - Energy equivalent to 2.5 gallons of gasoline
- Release from mid-pressure port: 1.5 MPa (217.6 psi)

Computer modeling simulates the leak and shows:
- Direction of ventilation and released gas
- Any areas of flammable mixture (LFL = 4 mol%)

Scenario F: No Ventilation

Leak comes from center of bottom of vehicle

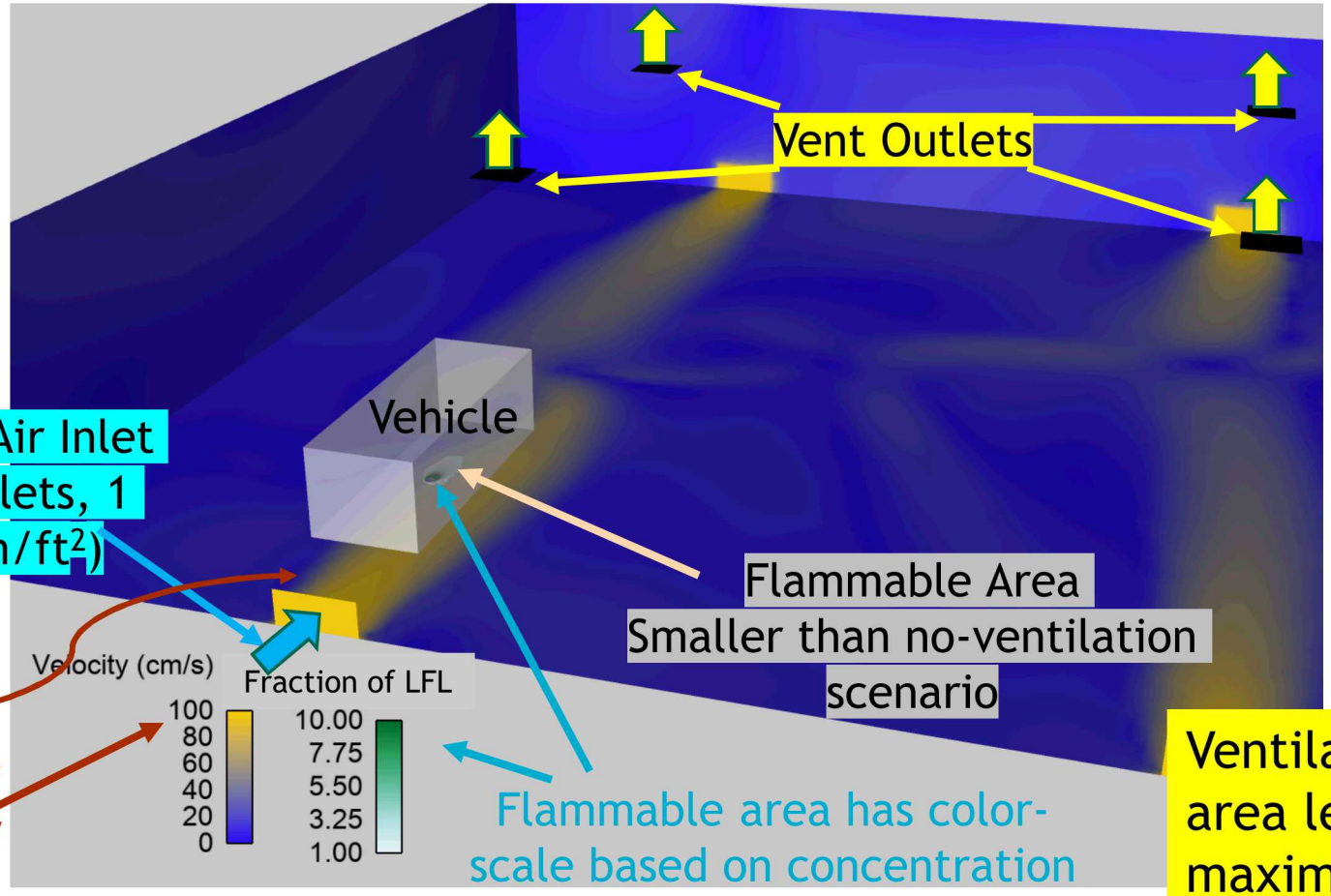


Blue walls and floor mean 0 cm/s velocity Showing no air movement for no-ventilation scenario

Flammable area has color-scale based on concentration

Maximum flammable mass scenario

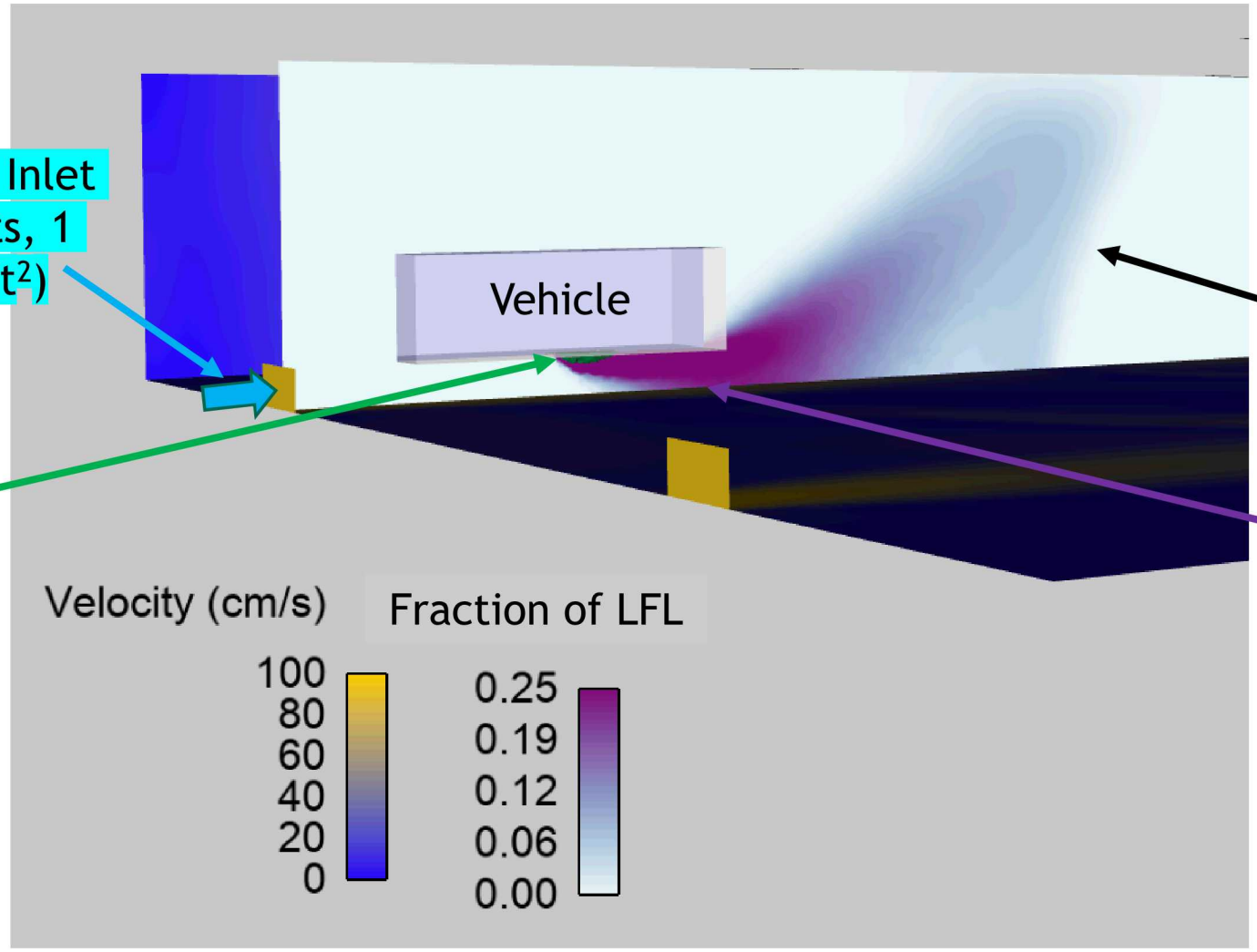
Scenario J: Ventilation Near Leak



Ventilation directed at leak area leads to a decrease in maximum flammable mass

Scenario J: Ventilation Near Leak – Dissipation

Side view of leak scenario



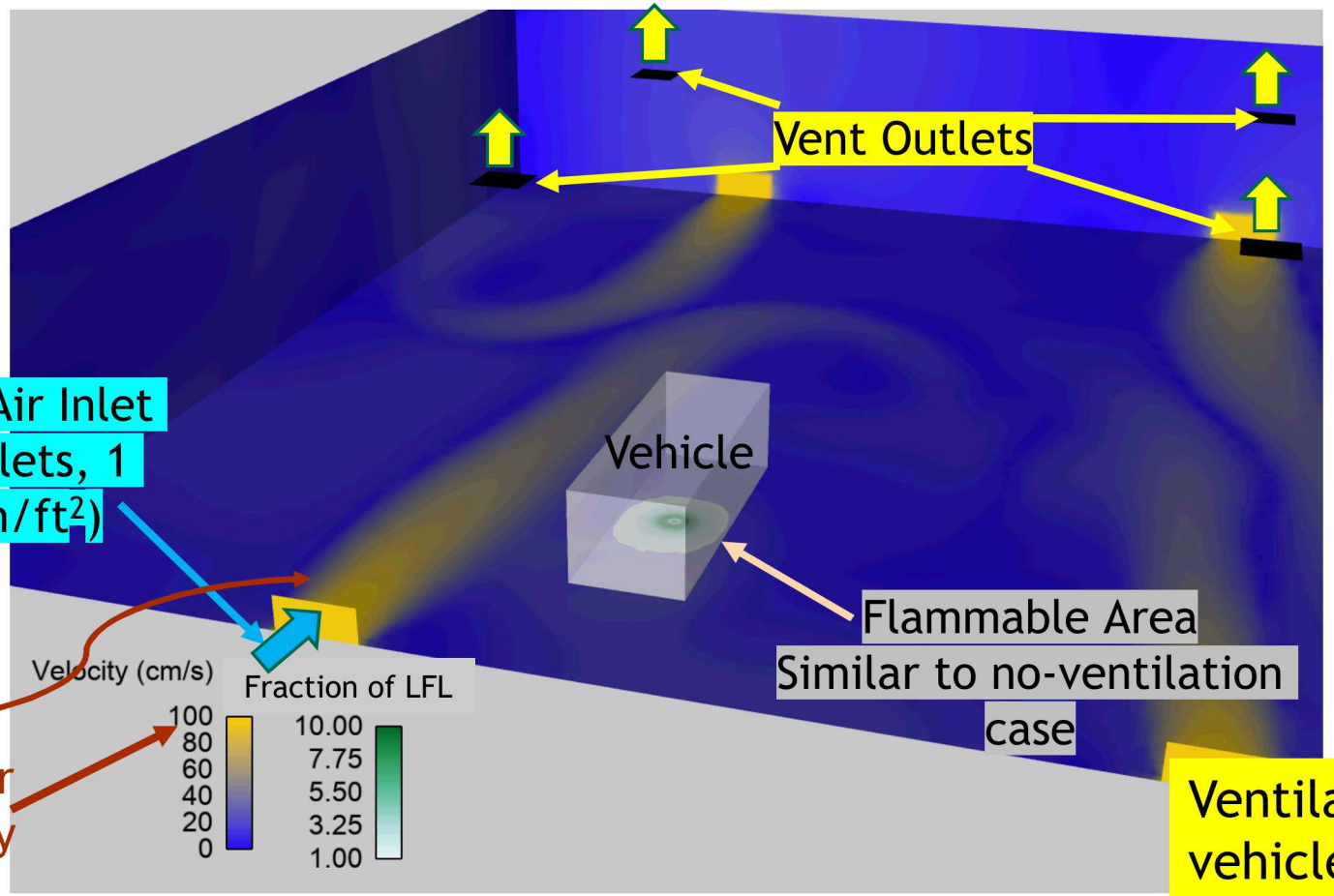
Vent Air Inlet (4 inlets, 1 cfm/ft^2)

Green is flammable area near leak point

Hydrogen mixes with air (diluting) and going towards ceiling vent outlets

Purple is hydrogen concentration below LFL

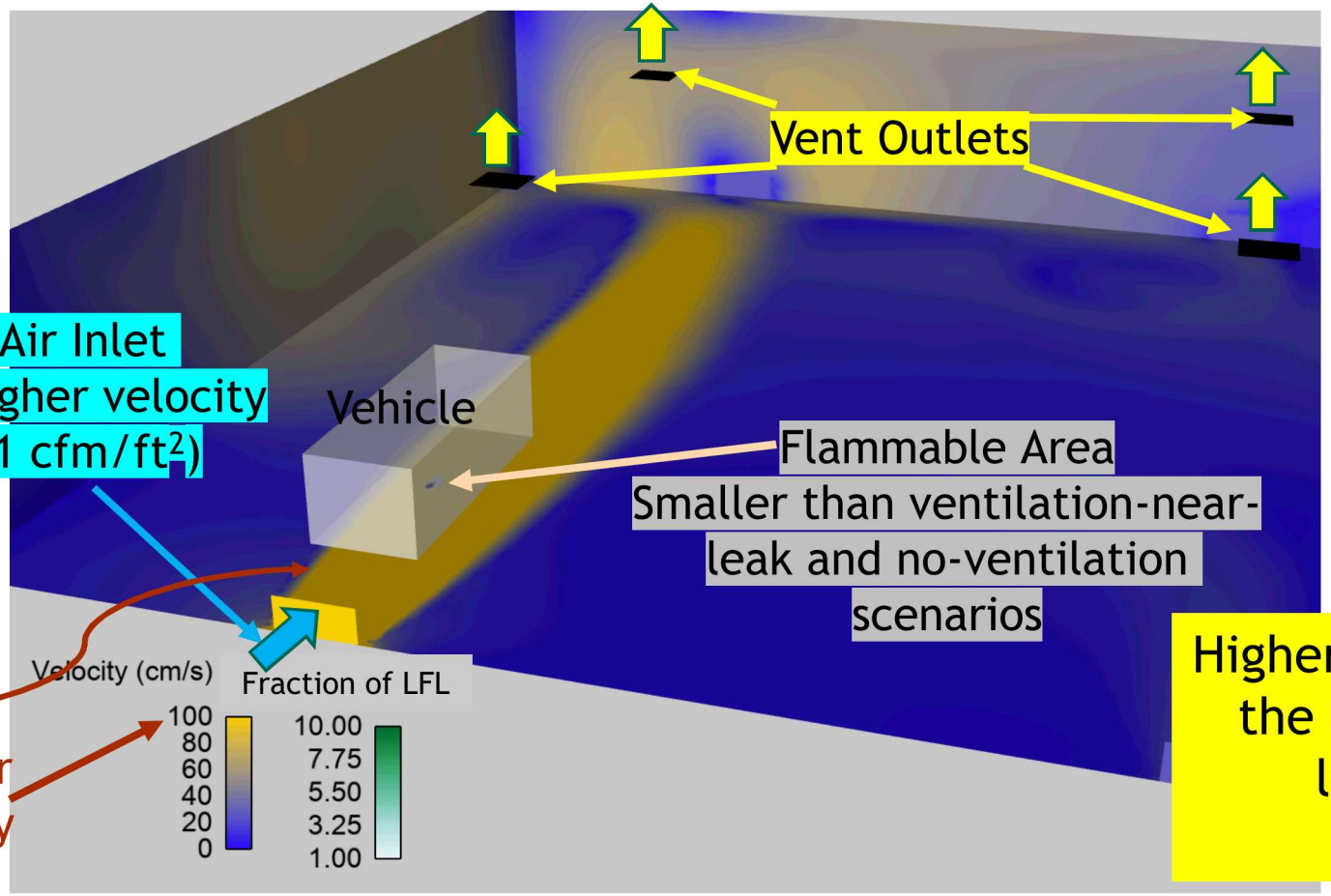
Scenario K: Ventilation Away From Vehicle



Yellow on walls and floor mean ~100 cm/s velocity Showing air movement from ventilation

Ventilation away from the vehicle has little affect on maximum flammable mass

Scenario G: Higher ventilation directed at vehicle



Yellow on walls and floor mean >100 cm/s velocity
Showing air movement from ventilation

Higher ventilation directed at the leak area leads to the largest decrease of flammable mass

Hazard Quantification

Flammable mass

- Total flammable mass of hydrogen in garage based on wherever the local hydrogen concentration is >LFL
- Cut-off: >4 mol% H_2 (LFL)

No-ventilation case (F) has low amount of flammable mass relative to mass released (2.5 kg)

- Due to dispersion of hydrogen in large area
- Also due to slow (low pressure) release

Ventilation directed at leak area leads to large decrease in maximum flammable mass (G & J)

Ventilation not directed at leak has little effect on maximum flammable mass (K)

Scenario	Ventilation	Maximum Flammable Mass (kg)*
F	No Ventilation	0.002
J	4 inlets: 1 cfm/ft^2 (42 cm/s) away from leak	0.0004
K	4 inlets: 1 cfm/ft^2 (42 cm/s) near leak	0.002
G	Box Fan: 300 cm/s Other 3 inlets adjusted to achieve 1 cfm/ft^2	0.00006

*1 kg of hydrogen ≈ 1 gallon of gasoline