ANNUAL MDEC CONFERENCE

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Hydrogen Mine Introduction Initiative – Study of Hydrogen Behaviour in Underground Mine Conditions

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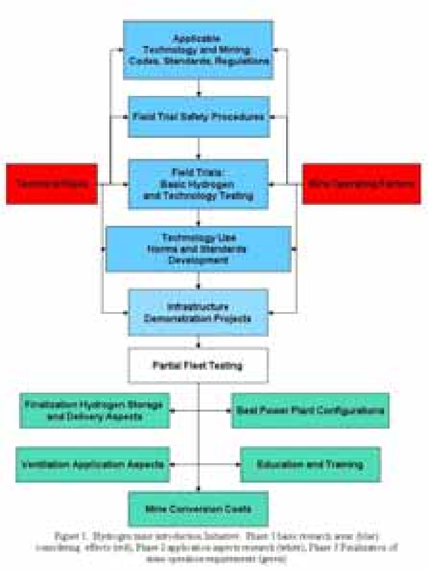
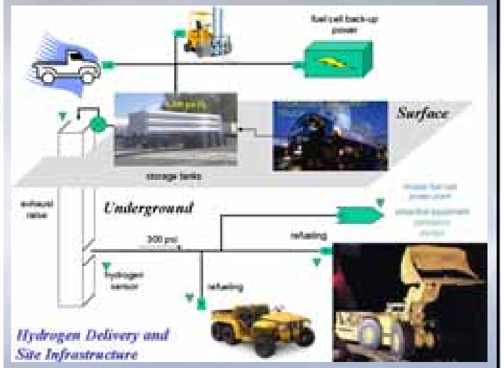
Background / Rationale for HMII

Green Mining Vehicles, Green Energy Impacts

- ❑ **Reduce production costs for Canadian mine operators**
- ❑ **Valuable Canadian alternate energy technology investment opportunity**
- ❑ **Clear green mining leadership image for Canada in a global industry**
- ❑ **Advancement of S&T for mining industry to position itself as a green industry**
- ❑ **Significant clean air benefits**

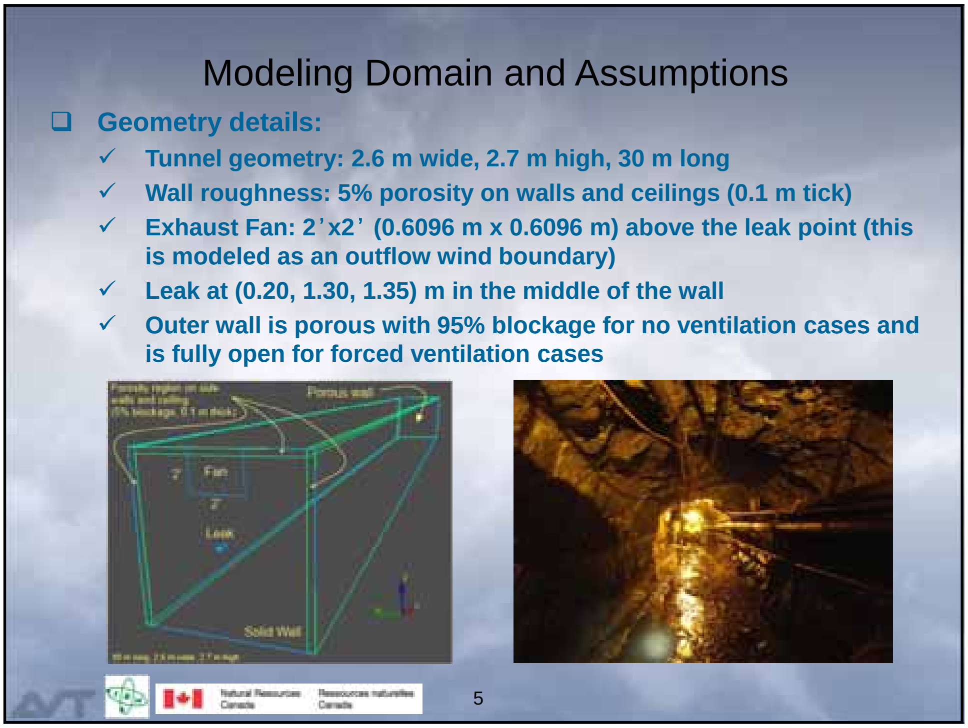
HMII Outline





Objectives, Assumptions and Scenarios

- ❑ **Key objectives for Project 2 modeling:**
  - ✓ **Obtain a spectrum of results of H2 behaviour necessary to perform risk analysis for development of safety procedures**
  - ✓ **Identify potential gaps in data for risk evaluation**
- ❑ **Key objectives for Project 3:**
  - ✓ **Validate CFD model predictions via dispersion and ignition tests inside a surface test chamber at Val d'Or experimental mine.**
- ❑ **Scenarios:**
  - ✓ **Dispersion and ignition simulations in Val d'Or and Norcat real geometry:**
    - ➢ **Leak opening: d = 8.48 mm – expected pipe size (via 100% and 50% ID); Horizontal release; Standard H_2 piping distribution system; Leak time: 1 and 3 sec – flow to be stopped by excess flow valve**
    - ➢ **Ventilation: no ventilation, pull and push at 0.5 m/s average velocity**
    - ➢ **Ignitions events (with and without ventilation)**
    - ➢ **Modeling results sensitivity checked for ceiling cavities, wall roughness and leak orifices location at the ground level**
    - ➢ **Total performed 81 dispersion and 48 ignition simulations**



Modeling Domain and Assumptions

- ❑ **Geometry details:**
  - ✓ **Tunnel geometry: 2.6 m wide, 2.7 m high, 30 m long**
  - ✓ **Wall roughness: 5% porosity on walls and ceilings (0.1 m tick)**
  - ✓ **Exhaust Fan: 2’x2’ (0.6096 m x 0.6096 m) above the leak point (this is modeled as an outflow wind boundary)**
  - ✓ **Leak at (0.20, 1.30, 1.35) m in the middle of the wall**
  - ✓ **Outer wall is porous with 95% blockage for no ventilation cases and is fully open for forced ventilation cases**

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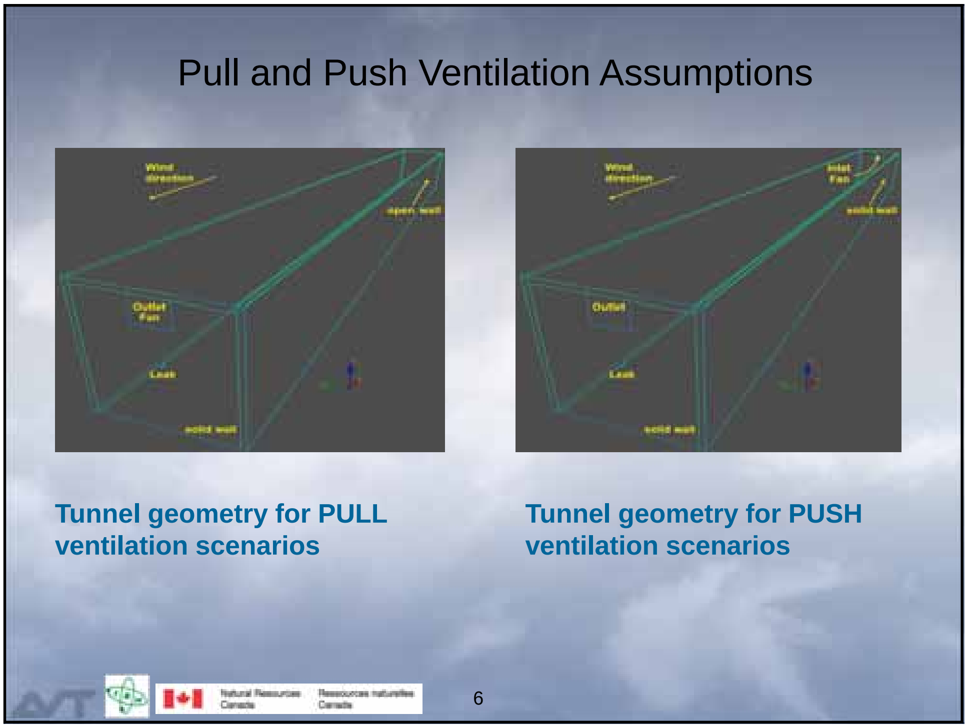

Pull and Push Ventilation Assumptions

Tunnel geometry for PULL ventilation scenarios

Tunnel geometry for PUSH ventilation scenarios

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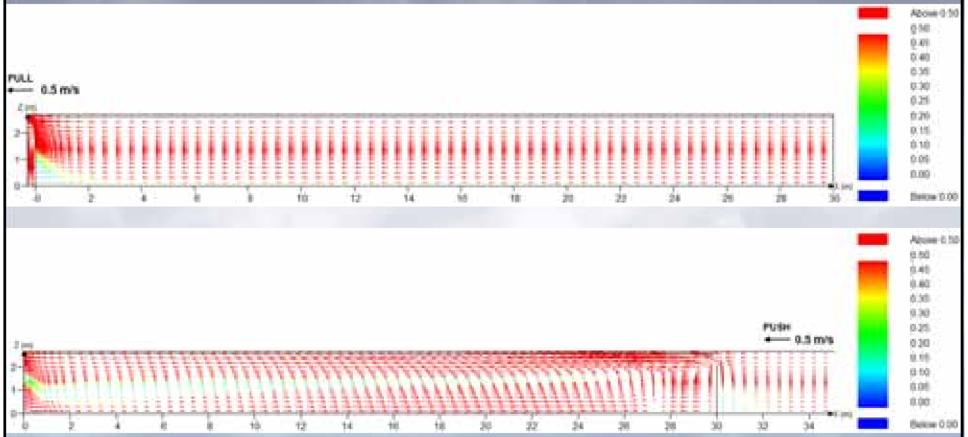
Pull and Push Ventilation Velocities Profiles

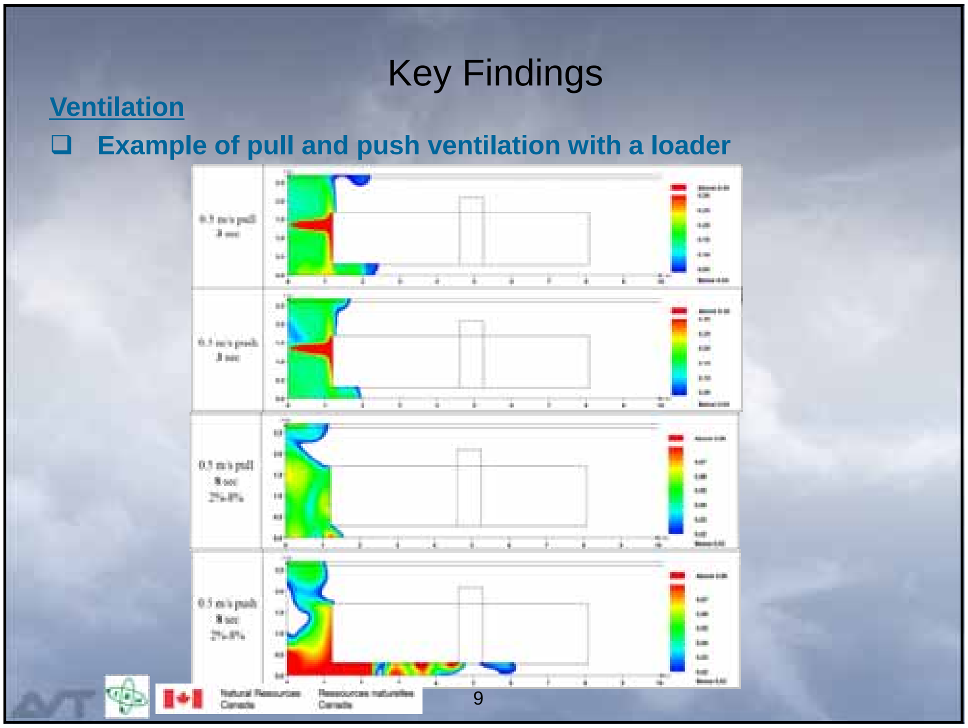


0.5 m/s PULL and PUSH ventilation velocity fields on the plane in the center of the domain (y = 1.3 m)

Key Findings

Ventilation

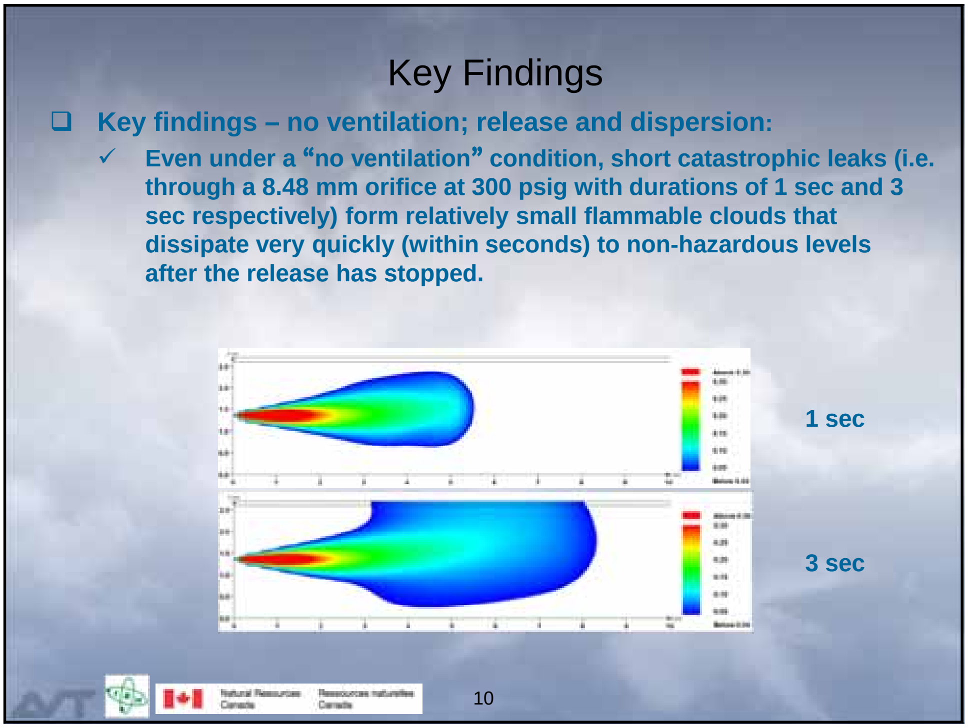
- ❑ **Push and pull differ in mechanism:**
  - ✓ **Push ventilation appears to be more effective for short releases, likely due to enhanced dispersion within the test chamber.**
  - ✓ **Pull ventilation gets more effective with time due to better evacuation from the test chamber.**
- ❑ **Example with loader present:**
  - ✓ **At 3 sec mark (end of the release), push ventilation results in a smaller flammable cloud but with time it drags flammable hydrogen cloud underneath the loader.**
  - ✓ **At 8 sec mark pull ventilation achieved significantly smaller H2 flammable cloud with no drag of flammable hydrogen cloud under the loader.**



Key Findings

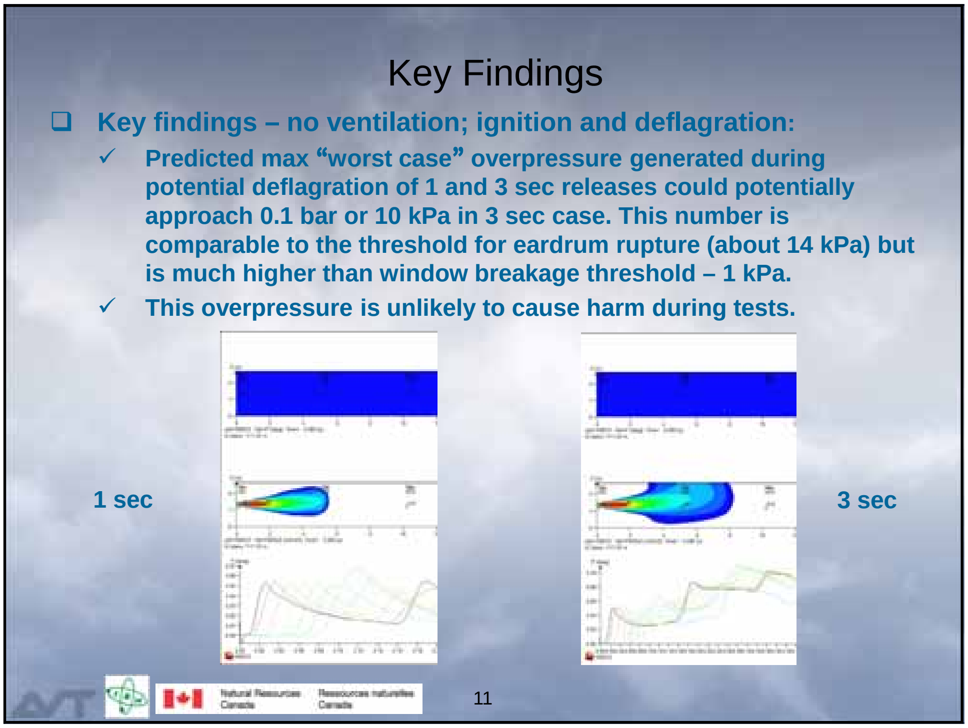
Ventilation

- ❑ Example of pull and push ventilation with a loader



Key Findings

- ❑ Key findings – no ventilation; release and dispersion:
  - ✓ Even under a “no ventilation” condition, short catastrophic leaks (i.e. through a 8.48 mm orifice at 300 psig with durations of 1 sec and 3 sec respectively) form relatively small flammable clouds that dissipate very quickly (within seconds) to non-hazardous levels after the release has stopped.

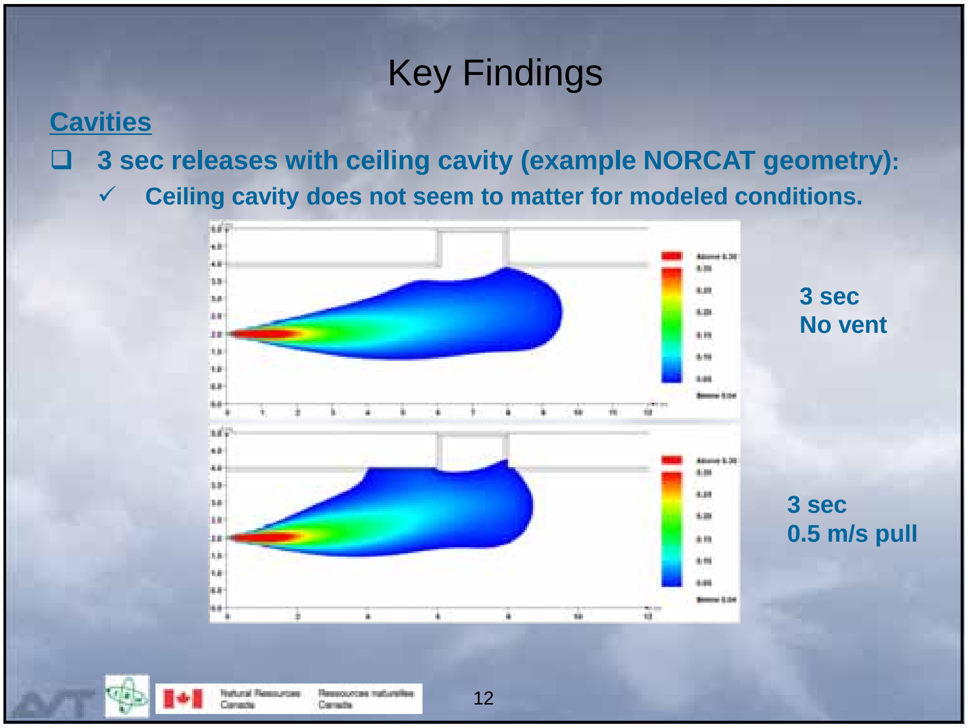


Key Findings

- ❑ **Key findings – no ventilation; ignition and deflagration:**
  - ✓ **Predicted max “worst case” overpressure generated during potential deflagration of 1 and 3 sec releases could potentially approach 0.1 bar or 10 kPa in 3 sec case. This number is comparable to the threshold for eardrum rupture (about 14 kPa) but is much higher than window breakage threshold – 1 kPa.**
  - ✓ **This overpressure is unlikely to cause harm during tests.**

1 sec

3 sec



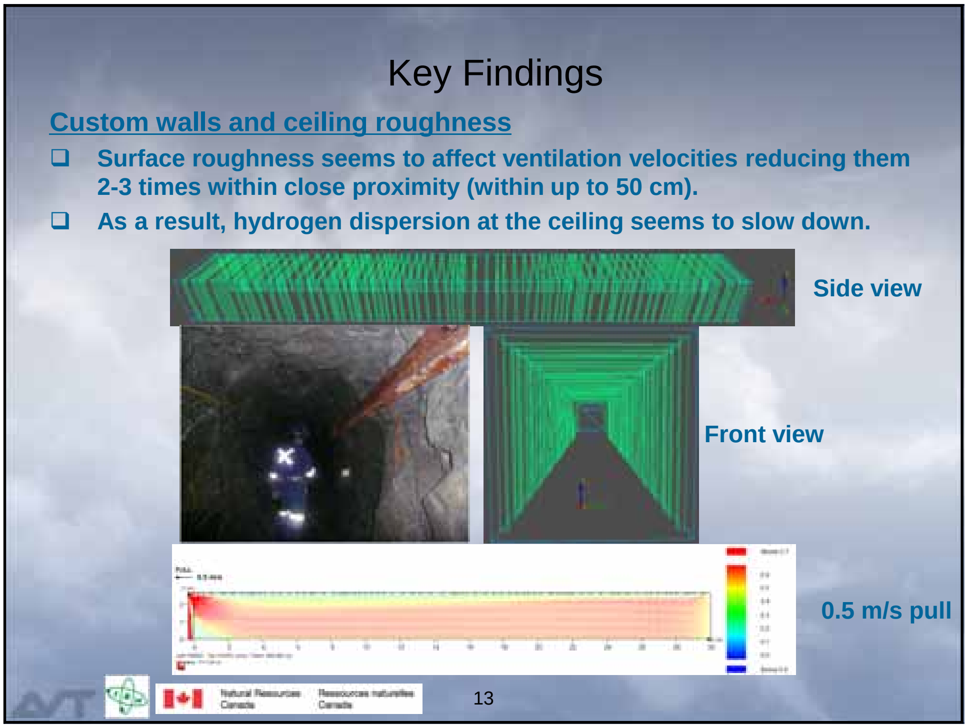
Key Findings

Cavities

- ❑ **3 sec releases with ceiling cavity (example NORCAT geometry):**
  - ✓ **Ceiling cavity does not seem to matter for modeled conditions.**

3 sec
No vent

3 sec
0.5 m/s pull



Key Findings

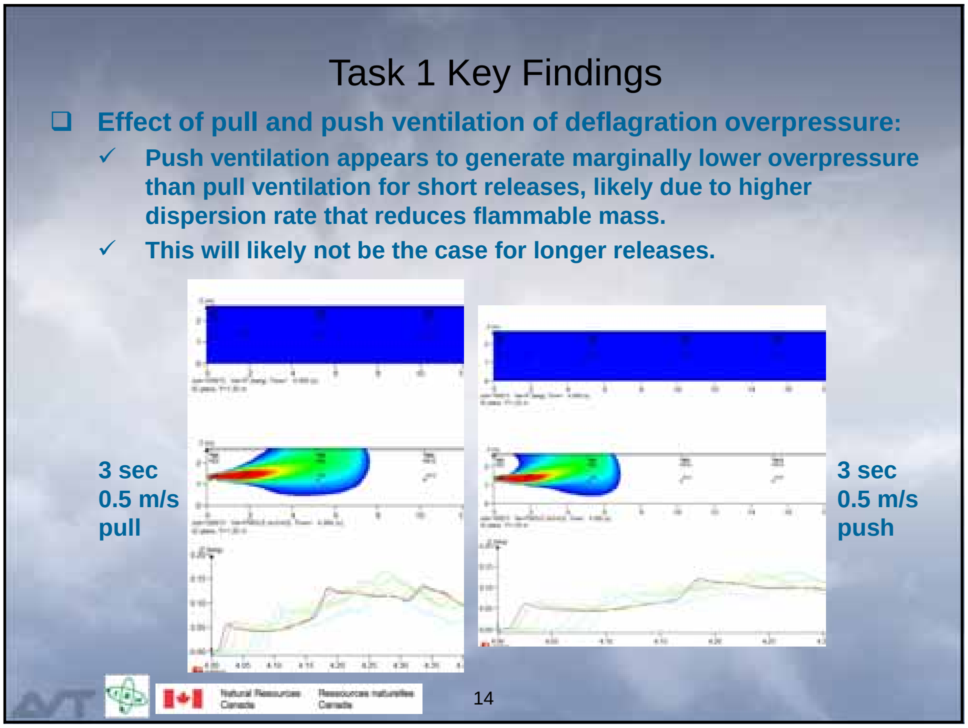
Custom walls and ceiling roughness

- ❑ Surface roughness seems to affect ventilation velocities reducing them 2-3 times within close proximity (within up to 50 cm).
- ❑ As a result, hydrogen dispersion at the ceiling seems to slow down.

Side view

Front view

0.5 m/s pull

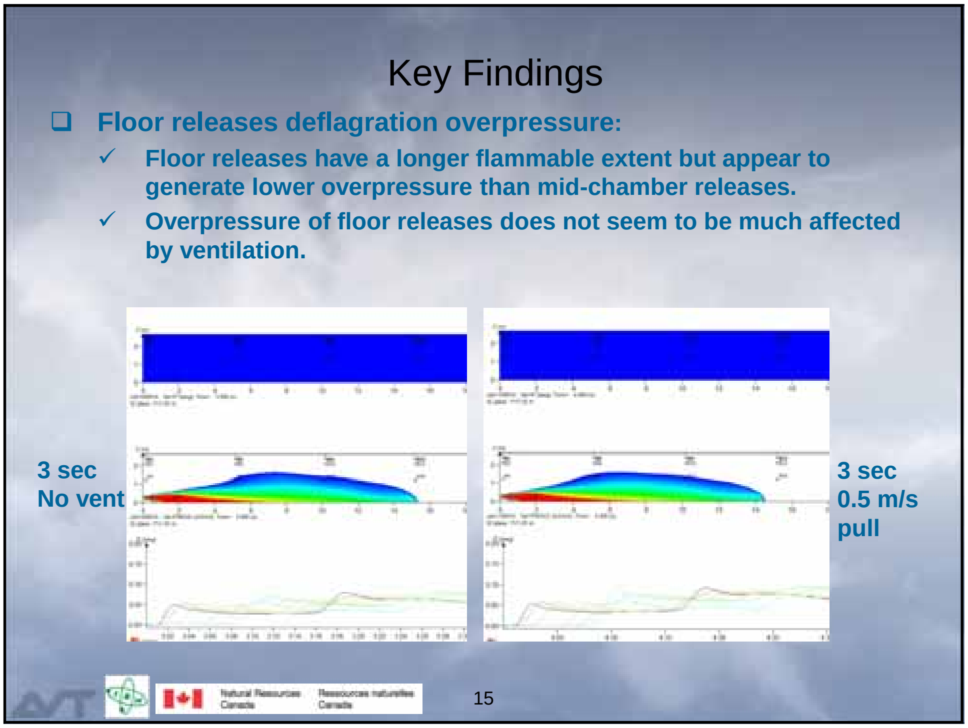


Task 1 Key Findings

- ❑ Effect of pull and push ventilation of deflagration overpressure:
  - ✓ Push ventilation appears to generate marginally lower overpressure than pull ventilation for short releases, likely due to higher dispersion rate that reduces flammable mass.
  - ✓ This will likely not be the case for longer releases.

3 sec
0.5 m/s
pull

3 sec
0.5 m/s
push



Key Findings

- ☐ **Floor releases deflagration overpressure:**
  - ✓ **Floor releases have a longer flammable extent but appear to generate lower overpressure than mid-chamber releases.**
  - ✓ **Overpressure of floor releases does not seem to be much affected by ventilation.**

3 sec
No vent

3 sec
0.5 m/s
pull

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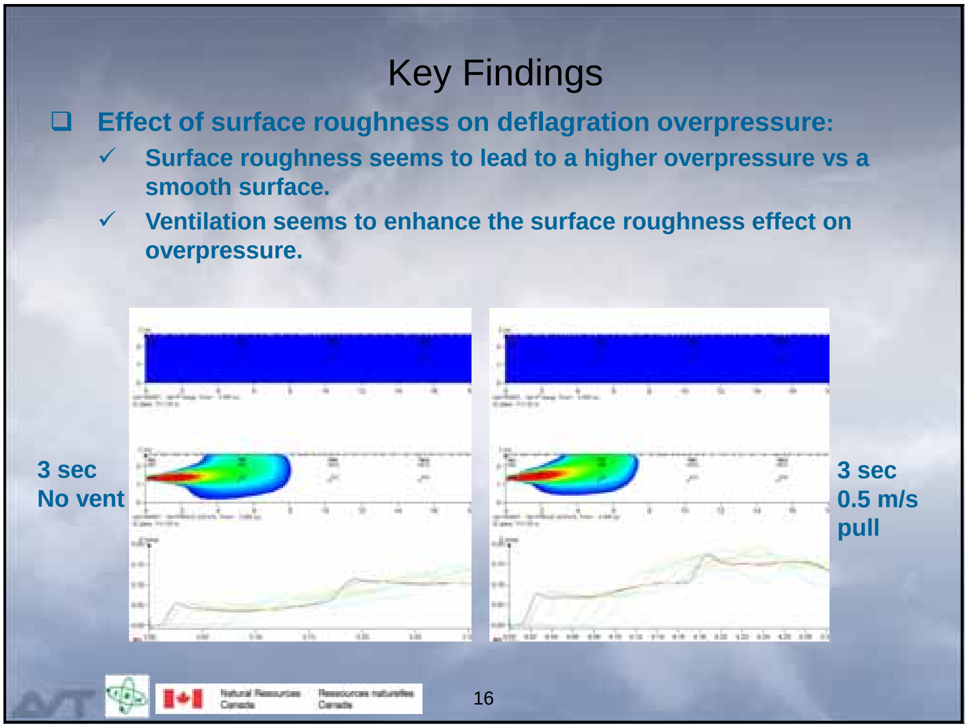

Key Findings

- ☐ **Effect of surface roughness on deflagration overpressure:**
  - ✓ **Surface roughness seems to lead to a higher overpressure vs a smooth surface.**
  - ✓ **Ventilation seems to enhance the surface roughness effect on overpressure.**

3 sec
No vent

3 sec
0.5 m/s
pull

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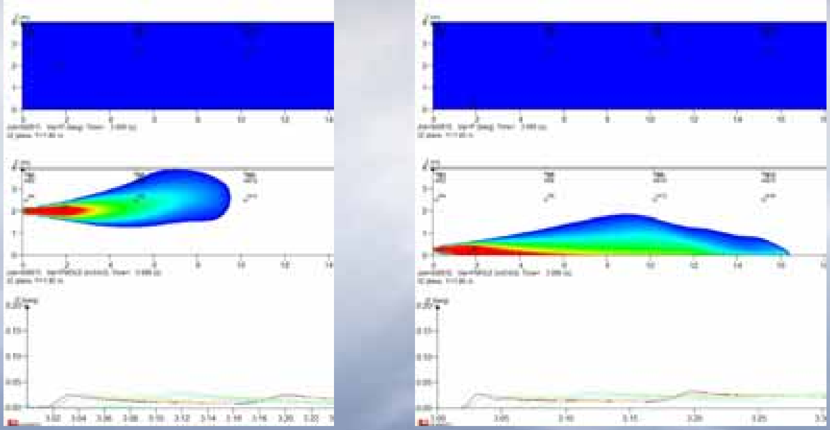
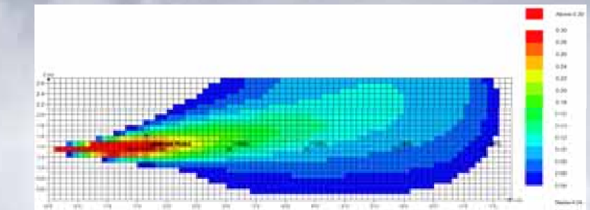
Key Findings

- **Norcat geometry – ignition and combustion:**
  - ✓ **3 s, no ventilation, regular and floor releases.**
  - ✓ **Overpressures are significantly lower than in Val d'Or geometry.**



Key Findings

- **Sensitivity study of ignition and deflagration:**
  - ✓ **Sensitivity trials showed that jet ignition and its pressure effects are sensitive to both time and location of ignition:**



Ignition time (sec)	Max OP domain (barg)	Difference
3.000	0.178	0%
3.025	0.168	-6%
3.050	0.159	-10%
3.075	0.153	-14%
3.100	0.147	-17%
3.125	0.127	-29%
3.300	Ignition was not possible at that position and time	

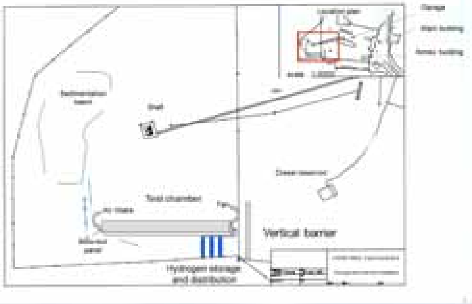
Variation of ignition position (1.65, 1.3, 1.35)		**Ignition position (m)**			**Mole fraction (m^3/m^3)**	**Max OP domain (barg)**	**Difference**
Along Axis	Delta (m)	X	Y	Z			
X, Y, Z	0.0	1.65	1.3	1.35	30%	0.178	0%
X	-0.3	1.35	1.3	1.35	37%	0.168	-6%
	+0.3	1.95	1.3	1.35	26%	0.183	3%
	+1.4	3.05	1.3	1.35	18%	0.165	-7%
	+2.7	4.35	1.3	1.35	12%	0.127	-28%
Y	-0.1	1.65	1.2	1.35	25%	0.178	0%
	-0.2	1.65	1.1	1.35	15%	0.175	-2%
	-0.3	1.65	1.0	1.35	6%	0.000	-100%
Z	+0.3	1.65	1.3	1.65	16%	0.174	-2%
	-0.3	1.65	1.3	1.05	5%	0.000	-100%

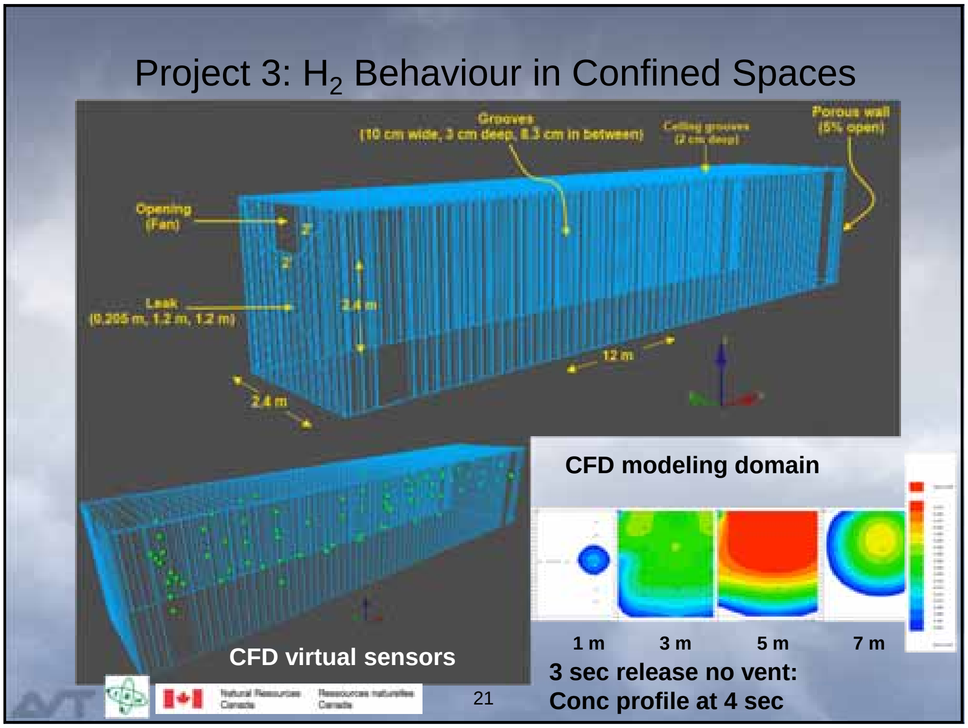
Conclusions from Project 2

- ❑ **Push and pull ventilation:**
  - ✓ **Main mechanism: push – dispersion within, pull – evacuation from.**
  - ✓ **More modeling is needed on selected geometry and set up of test chamber to find optimum solution.**
  - ✓ **For short releases ignition with no obstacles, ventilation enhances turbulence which may lead to a higher overpressure. In cases with obstacles, ventilation significantly reduces overpressure**
- ❑ **Sensitivity:**
  - ✓ **Low: ceiling cavities; floor leaks location; ignition probability vs X dimension (along the leak).**
  - ✓ **High: surface roughness; chamber dimensions; obstacles (e.g. loader); ignition probabilities vs timing of ignition and Y and Z dimensions (perpendicular to the leak).**
- ❑ **Leak from Metal Hydride Bed:**
  - ✓ **5 cm wide, 62.8 cm long hole on the side of the cylinder generates a max leak rate of 1 g/s that is easily handled by pull ventilation (0.5 m/s).**

Project 3: H_2 Behaviour in Confined Spaces

Test chamber location, CanmetMINING Experimental Mine



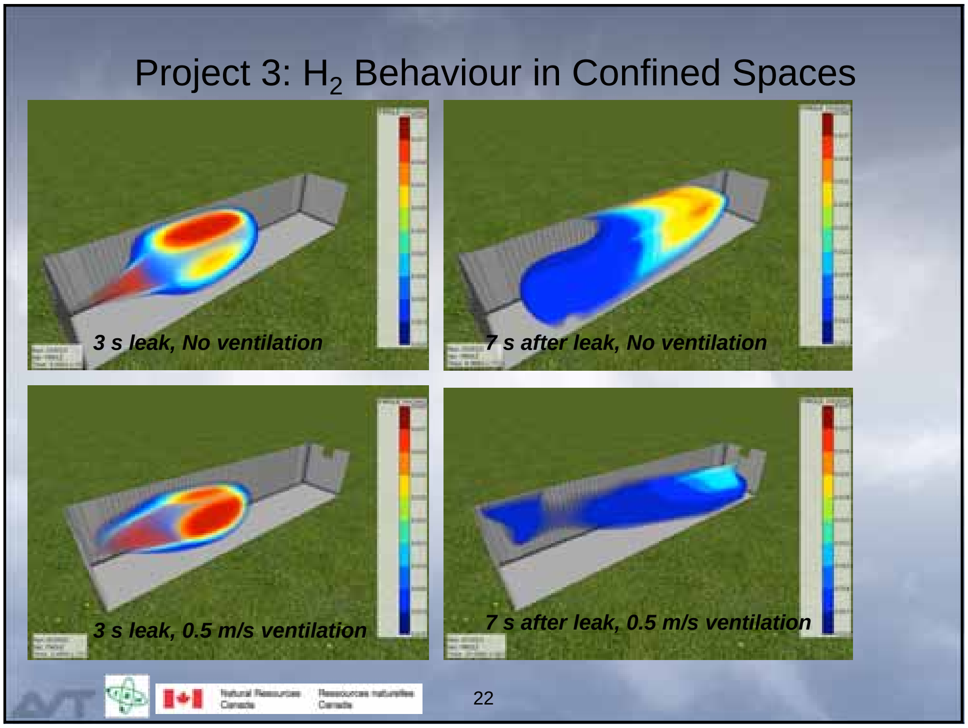


Project 3: H_2 Behaviour in Confined Spaces

CFD modeling domain

CFD virtual sensors

**3 sec release no vent:
Conc profile at 4 sec**



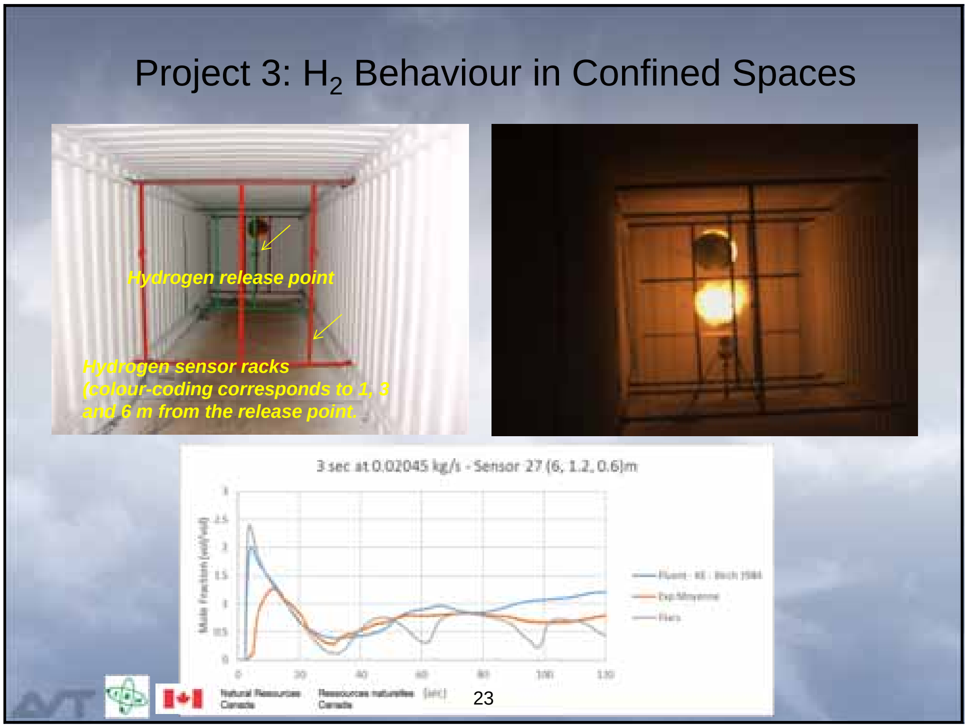
Project 3: H_2 Behaviour in Confined Spaces

3 s leak, No ventilation

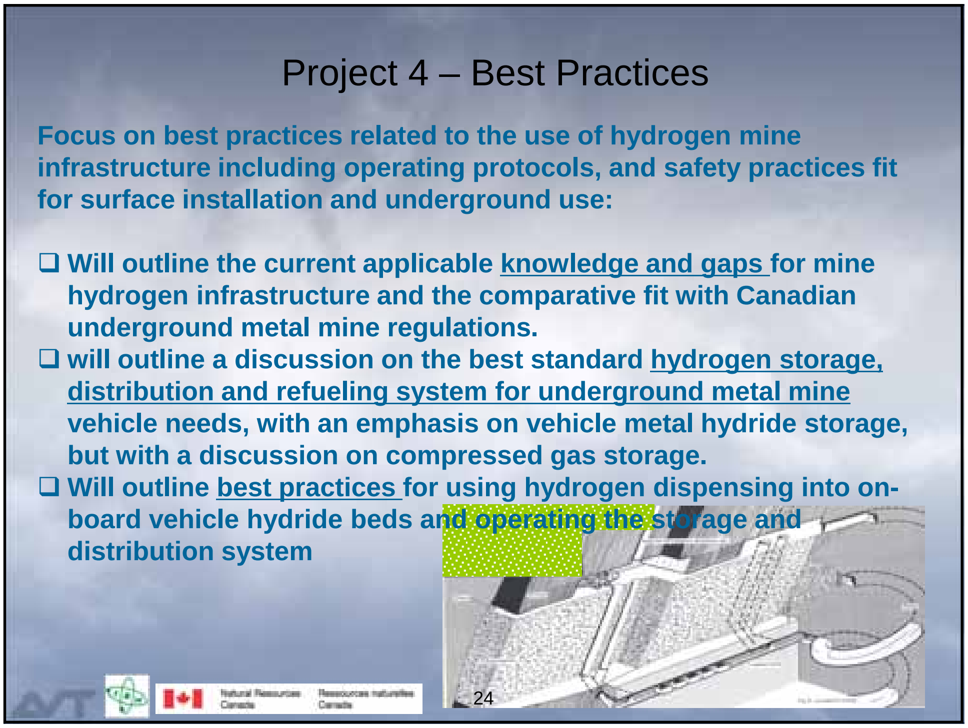
7 s after leak, No ventilation

3 s leak, 0.5 m/s ventilation

7 s after leak, 0.5 m/s ventilation



Project 3: H_2 Behaviour in Confined Spaces



Project 4 – Best Practices

Focus on best practices related to the use of hydrogen mine infrastructure including operating protocols, and safety practices fit for surface installation and underground use:

- ❑ **Will outline the current applicable <u>knowledge and gaps</u> for mine hydrogen infrastructure and the comparative fit with Canadian underground metal mine regulations.**
- ❑ **will outline a discussion on the best standard <u>hydrogen storage, distribution and refueling system for underground metal mine</u> vehicle needs, with an emphasis on vehicle metal hydride storage, but with a discussion on compressed gas storage.**
- ❑ **Will outline <u>best practices</u> for using hydrogen dispensing into on-board vehicle hydride beds and operating the storage and distribution system**

Conclusions / Recommendations

- ❑ CanmetMINING has tested hydrogen power in underground mines, e.g. the Campbell Mine in Northwestern Ontario, in a production locomotive from R.A. Warren Equipment North Bay as well as the Caterpillar loader R1300 on surface, with great success and no safety issues.
- ❑ CanmetMINING has been carrying out tests to quantify hydrogen leak behaviour and ignition potential in an underground-like test chamber setting with various regimes of ventilation.
- ❑ Under the industry consortium Hydrogen Mine Introduction Initiative, hydrogen and mine regulations experts confirmed that hydrogen fuel cells could safely be used with no mine regulations against it for underground use.
  - ✓ It is the surface and underground hydrogen delivery infrastructure that must be regulated, given potential leaks, handling, and other issues.
  - ✓ CanmetMINING has written a draft version of the mining infrastructure portion in the update to the Canadian Hydrogen Installation Code
  - ✓ While hydrogen power is available for application, the work carried out will be placed into context of the broader aspects of readiness to indicate when fully regulated and safe hydrogen power can be introduced into mining vehicles

Questions?

THANK YOU FOR YOUR ATTENTION!