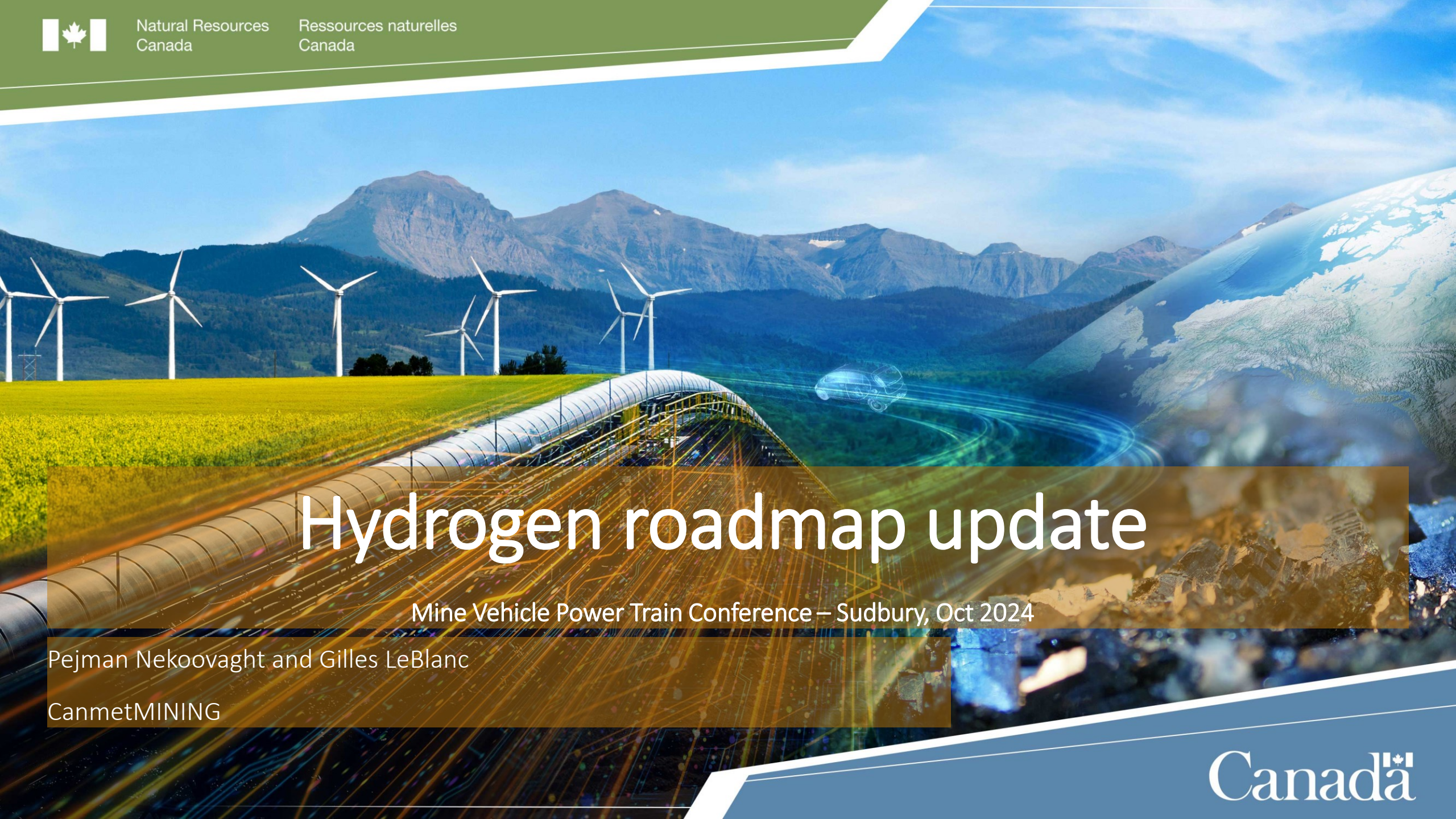


Hydrogen roadmap update

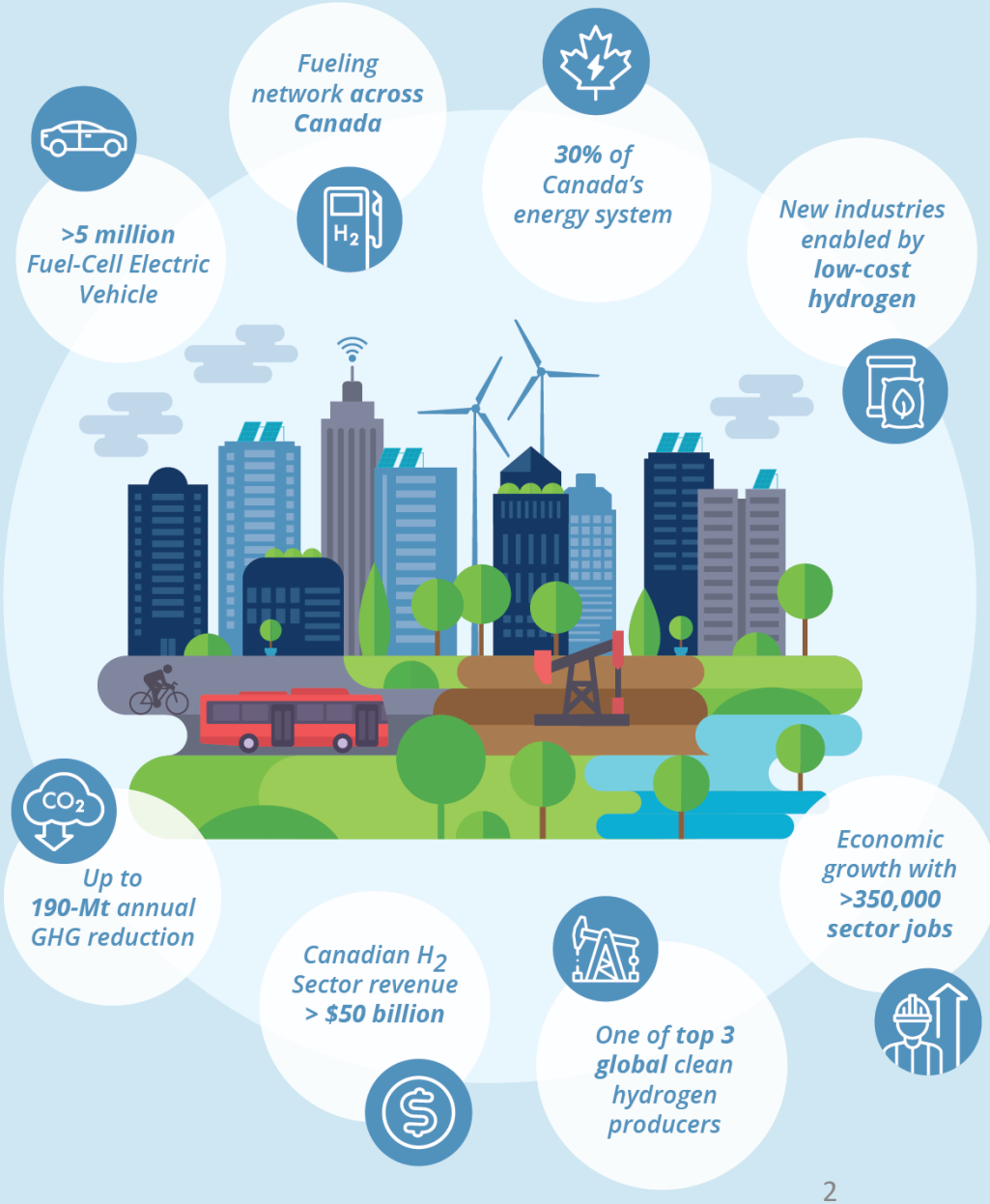
Mine Vehicle Power Train Conference – Sudbury, Oct 2024

Pejman Nekoovaght and Gilles LeBlanc

CanmetMINING

Outline

- Brief background overview
  - Hydrogen roadmap development
  - Project definition
- CSR gap analysis
- Hydrogen value chain and layouts on a mine site
- Risk analysis and mitigation measure identification



Progress overview

Priorization criteria

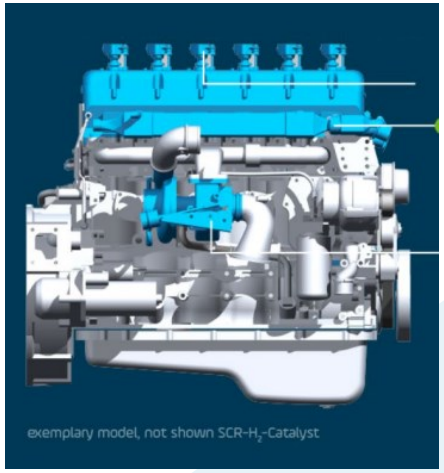
- Consulting the industry through the CHIM-AC meetings
  - Roadmap toward 2030
  - Utilization methodology and applications
- Support development of Codes, Standards, and Regulations

Progress overview

CMIN scientific involvement

Define and lead on new projects

- Hydrogen Internal Combustion Engine for heavy-duty mining mobile equipment
- Underground mine ventilation heating with a blend of 20% Hydrogen and 80% natural gas
- Infrastructure (production/storage, distribution and refueling) and safety
  - Develop appropriate guidelines to support development of Codes, Standards, Regulations
  - Risk register, analysis and mitigation measures
  - CSR gap analysis of hydrogen value chain



CSR Gap Analysis on H_2 Value chain in Mining

Hydrogen Dispenser

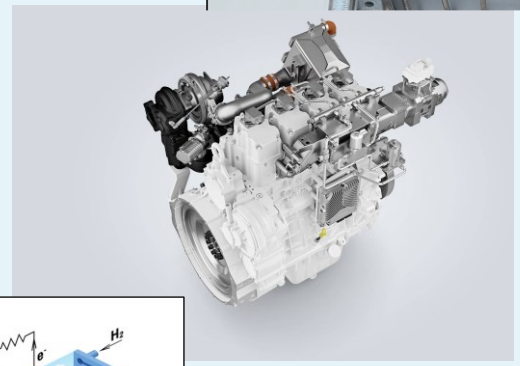
- High flow rate fueling dispensing system
- Integrated thermal management system
- Distribution piping system infrastructure

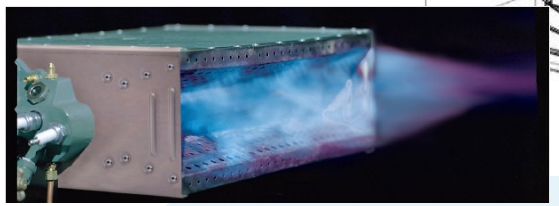
Mobile equipment (ICE or Fuel cell)

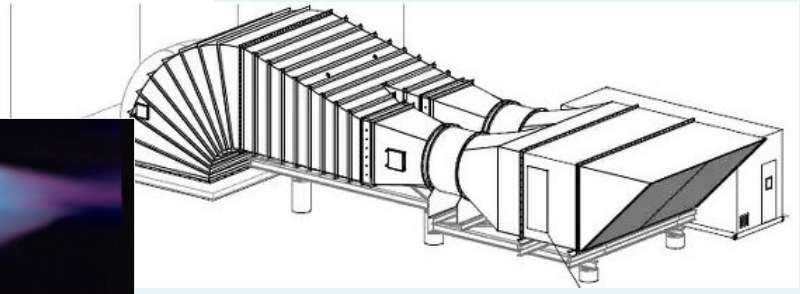
- Gaseous or Liquid hydrogen storge on-board
- Safety standards for underground application
- Emission certification

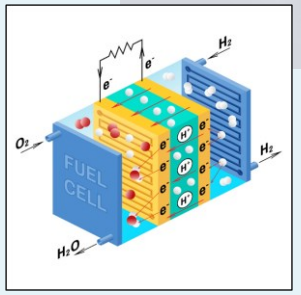
Underground mine ventilation heating with hythane

- Impact on existing infrastructure
- Energy assessment
- Air quality









Process sections of H_2 value chain on a mine site

Supply

- Production on site
  - Electrolysis
  - SMR-Transportable Nuclear Power Plant (TNPP)
- Truck delivery (gas/liquid)
- Pipeline network

Storage

- Back up storage
- High/low pressure reservoirs
- On-board vehicle storage

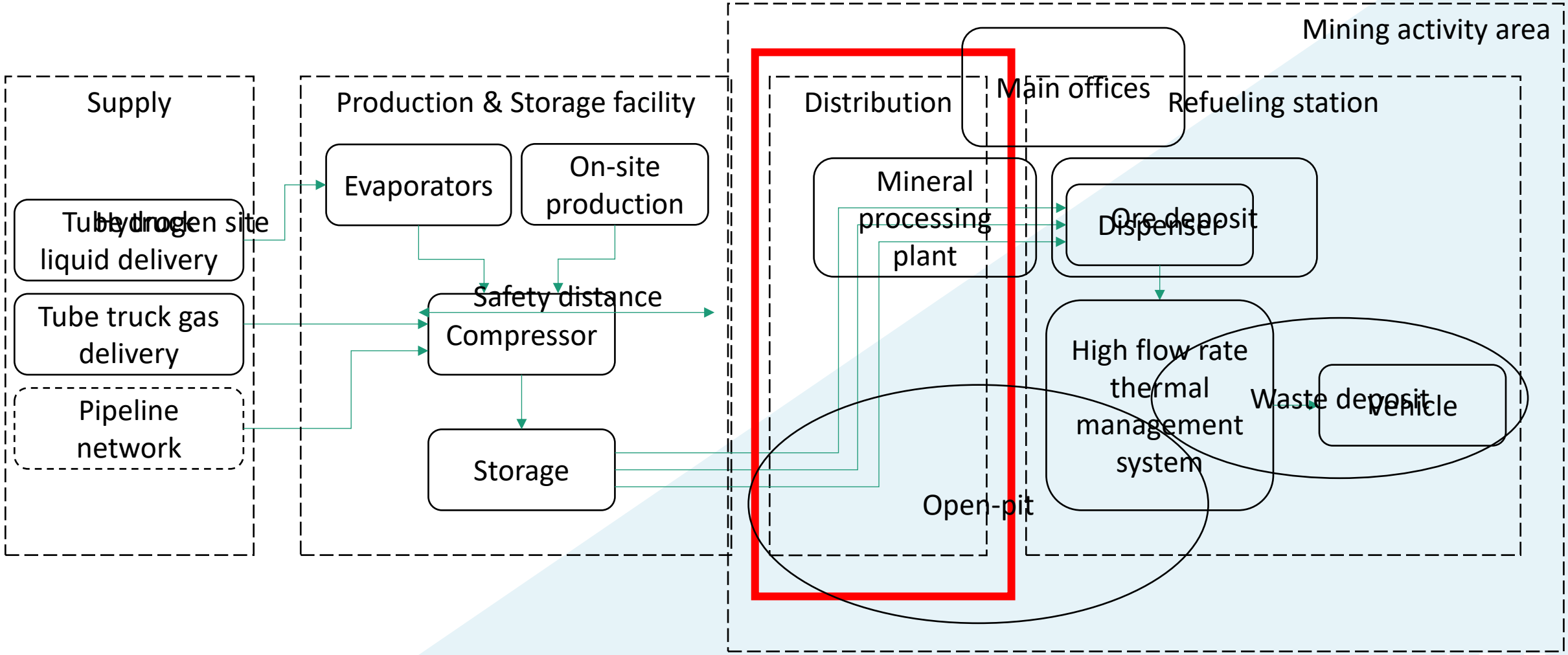
Distribution

- Refueling station
  - Surface/under ground
- Distribution system from surface to underground stations
  - Distribution of piping underground

Usage

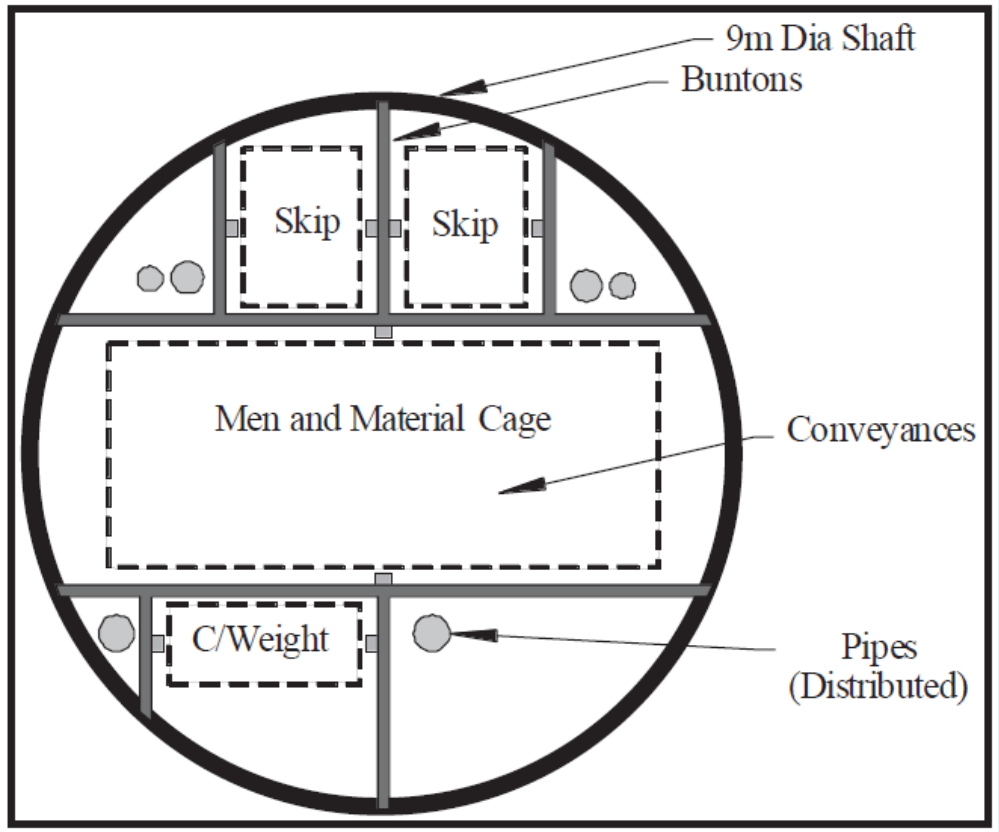
- Mobile equipment
- Electricity generators
- Heating applications
- Processing purposes

H_2 Process value chain on a mine site



Underground mining layout

- Mobile equipment,
  - Storage tank
  - Distribution pipes and valves
  - Power source (ICE, Fuel Cell)
- Dispensers at refueling station,
  - Dispenser components
  - Connecting hose
  - Compressor
  - Storage tank
- Piping system for gas distribution and delivery through,
  - Main shaft
  - Exhaust shaft/raise
  - Main galleries
  - Ramp
  - Ventilation raise
  - Dedicated boreholes
  - Tube trailer truck via main shaft or ramp
  - Swapping tanks by truck via main shaft or ramp

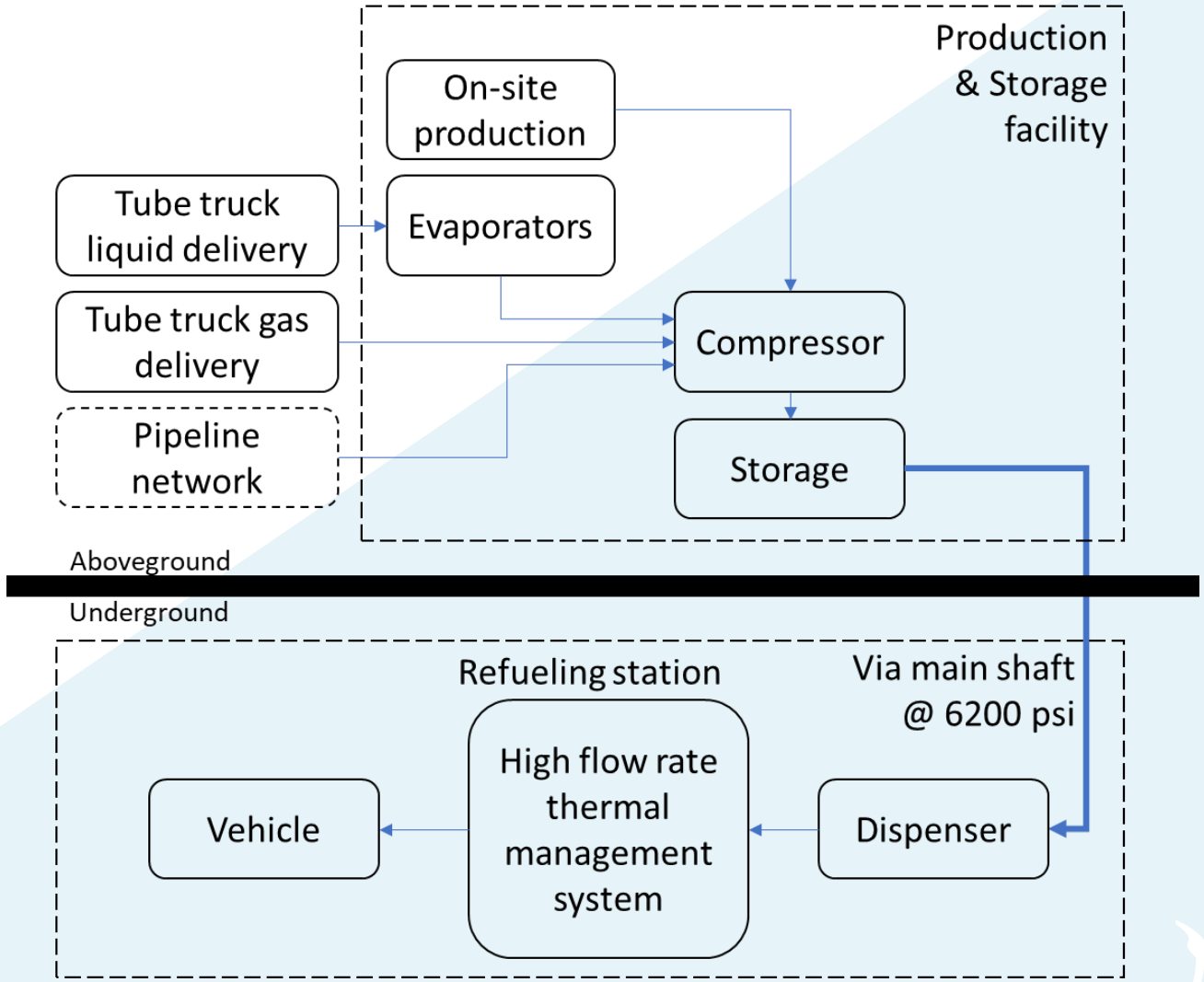


Example of distribution through the main shaft

Distributing high pressure gas from surface to underground

Risk register and analysis criteria:

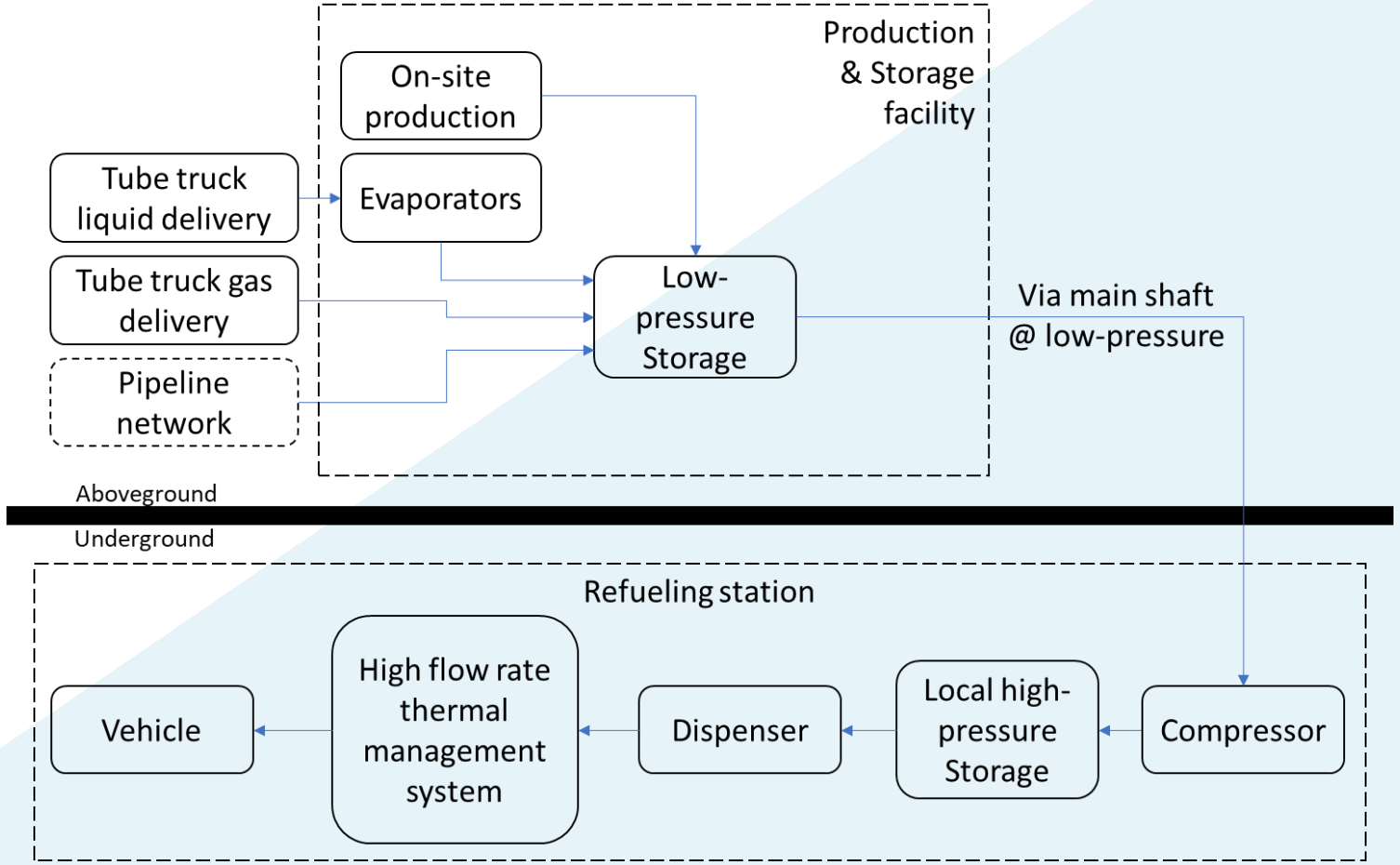
- Access point from surface to underground
  - Main shaft
  - Exhaust shaft/raise
  - Main galleries
  - Ramp
  - Ventilation raise
  - Dedicated boreholes
- High flow rate in the event of leakage
- Component level leakage risk



Distributing low pressure gas from surface to underground

Risk register and analysis criteria:

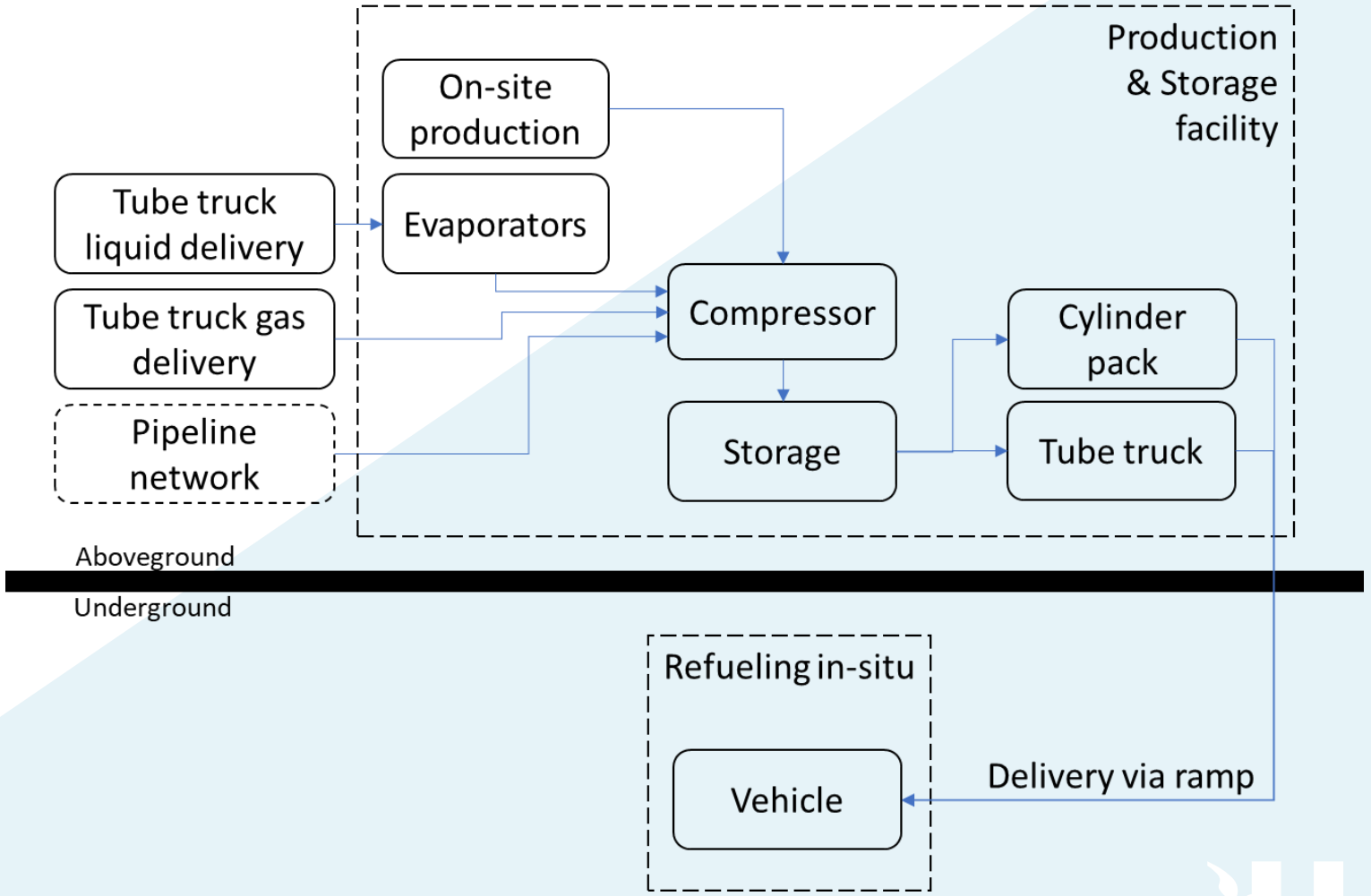
- Access point from surface to underground
  - Main shaft
  - Exhaust shaft/raise
  - Main galleries
  - Ramp
  - Ventilation raise
  - Dedicated boreholes
- Low flow rate in the event of leakage
- Component level leakage risk
- Intermediate, high pressure and stationary reservoir underground



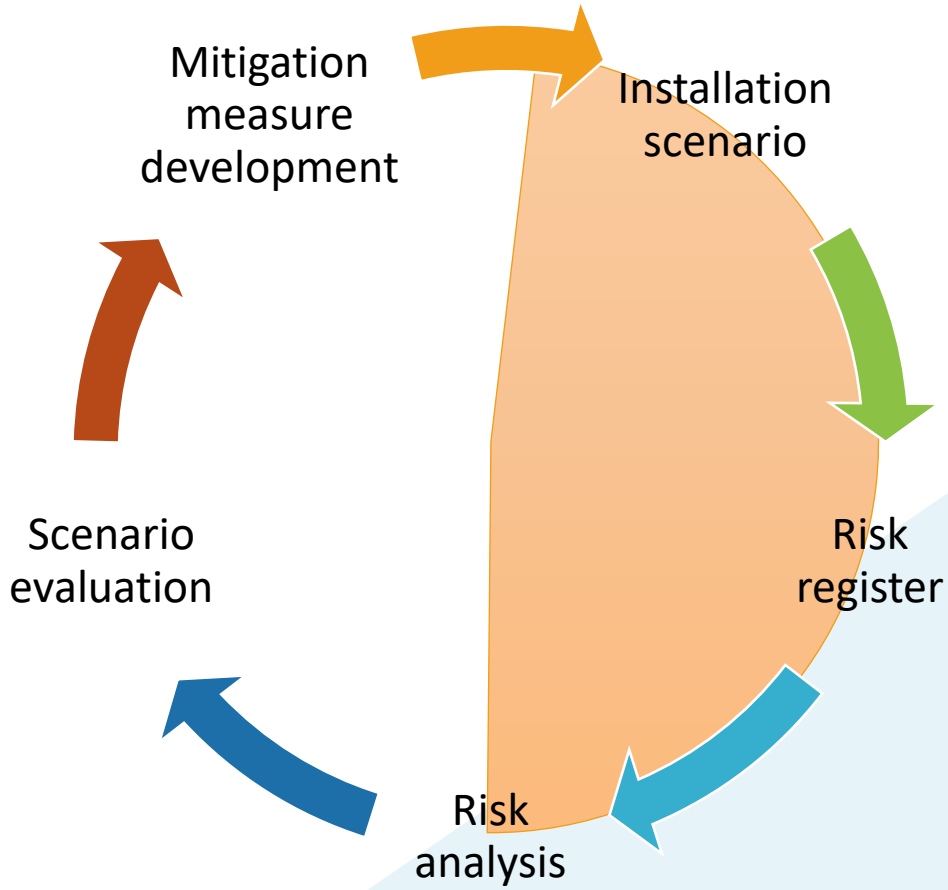
Truck delivering and in-situ refueling

Risk register and analysis criteria:

- Access point from surface to underground
  - Dedicated boreholes
  - Tube trailer truck via main shaft or ramp
  - Swapping tanks by truck via main shaft or ramp
- High flow rate in the event of accident/leakage
- Component level leakage risk
  - Delivery vehicle system design
  - Refueling system connection design



Risk analysis methodology and mitigation measure development



Assumption factors taken into account:

- Domino effect
- Based on available statistical database (non-mining related)

Methodology

Canadian Nuclear Laboratories

Severity levels

Level	Description	People	Environment	Material
0	NO DAMAGE	No injury, annoyance, disturbance	No environmental damage	No material damage
1	MINOR DAMAGE	Minor injury, annoyance, disturbance	Minor environmental damage	Minor material damage
2	DAMAGE	Medical treatment; Lost time injury	Local environmental damage of short duration < 1 month	Minor structural damage; minor production influence
3	MAJOR DAMAGE	Permanent disability Prolonged hospital treatment	Time for restitution of ecological resource < 2 years	Considerable structural damage; production interrupted for weeks
4	SEVERE/CATASTROPHIC	One to several fatalities	Time for restitution of ecological resource such as recreation areas, ground water >2 years	Loss of station and production interrupted for months

Frequency levels

Level	Description	Definition	Frequency
0	IMPROBABLE	Possible but may not be heard of or maybe experienced world wide	$\leq 10^{-4}$ per year
1	REMOTE	Unlikely to occur during lifetime/operation of one sub-system	10^{-3} - 10^{-2} per year
2	OCCASIONAL	Likely to occur during lifetime/operation of one sub-system	10^{-2} - 10^{-1} per year
3	PROBABLY	May occur several times in the sub-system	0.1 - 1 per year
4	FREQUENT	Will occur frequently at the sub-system	> 1 per year

Used standard methods to analyze the risk level based on existing incidental data base.

Consequence Severity	Frequency of occurrence (per year)				
	0-Improbable (<0.0001)	1-Remote (0.01-0.001)	2-Occasional (0.01-0.1)	3-Probably (0.1-1)	4-Frequent (>1)
0-No Impact	LOW	LOW	LOW	LOW	LOW
1-Minor damage	LOW	LOW	LOW	LOW	MEDIUM
2-Damage	LOW	LOW	LOW	MEDIUM	HIGH
3-Major Damage	LOW	LOW	MEDIUM	HIGH	HIGH
4-Severe/Catastrophic	LOW	MEDIUM	HIGH	HIGH	HIGH

Definition of Risk

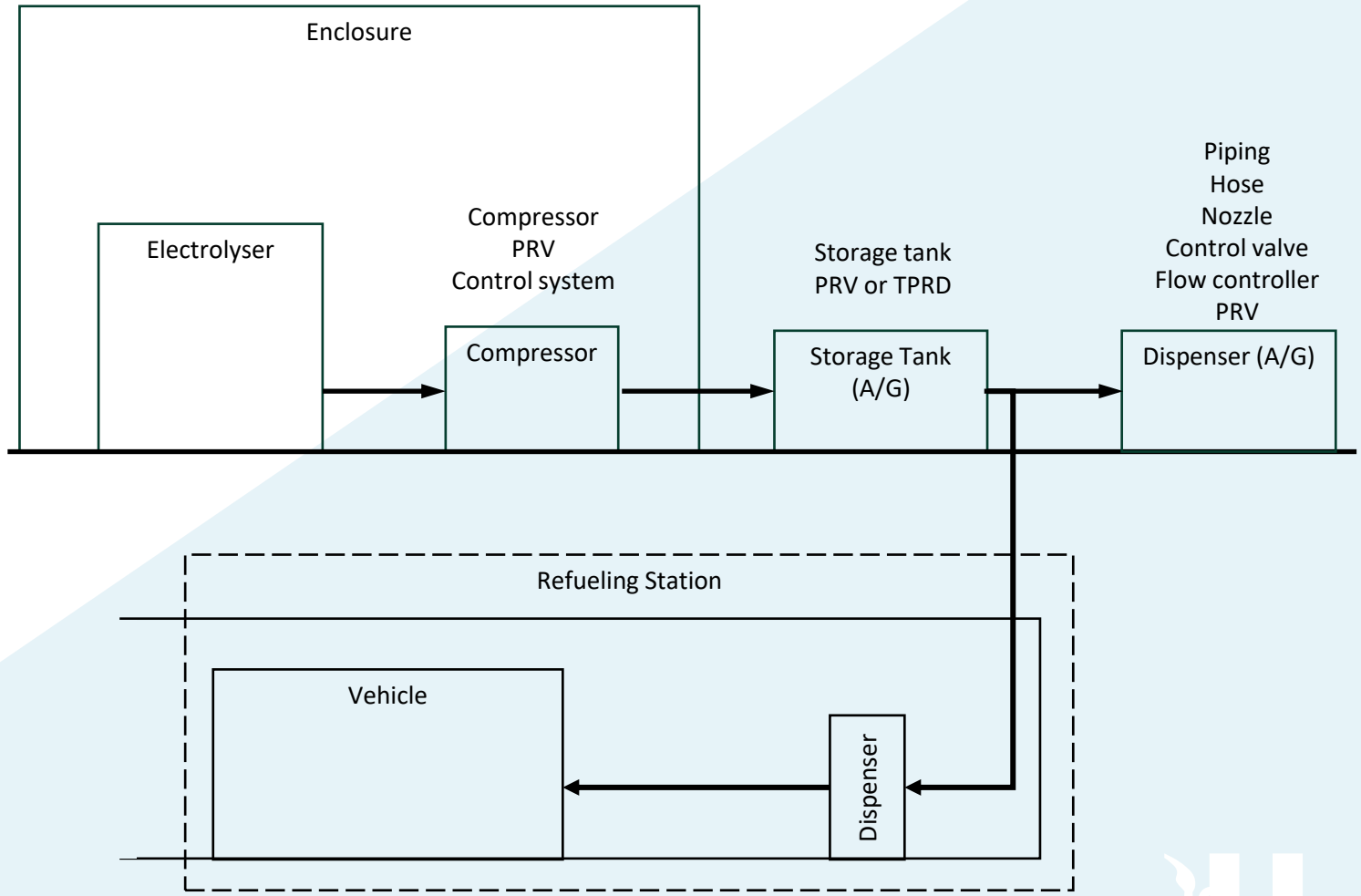
High (H)	Risk criticality is too high and not acceptable. Redesign or other changes should be introduced to reduce the criticality
Medium (M)	May be acceptable but redesign or other changes should be considered to ensure risk is as low as reasonably practicable (ALARP)
Low (L)	Risk criticality meets acceptance criteria and further risk reducing measures are not necessary

Ref: "Methodology for Rapid Risk Ranking of H_2 Refuelling Station concepts", European Integrated Hydrogen Project (Contract: ENK6-CT2000-00442), 2002

Risk register system definitions and assumptions

- System component above ground
- Distribution component from above ground to refueling station underground
- Refueling station component underground
- Mobile equipment component underground

System components for above/underground ground H_2 production, storage and dispensing



Conclusion

1. In general, the risk level of hydrogen utilization on a mine site is low, since all components involved are known technologies
2. Identified necessary simulation/experimental project to be studied and evaluated further for a mining application
3. The risk analysis activity demonstrates that the risk level for certain components can be lowered significantly by introducing some mitigation measures
   - On-board reservoirs safety
   - Managing and adapting operation
   - Safety devices for emergency shot down hydrogen circulation
   - Improve design of PTRV to adapt mining environment
   - Dedicated borehole for hydrogen distribution

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