Fuelcell Versus Diesel Loader Operation: *Mine Ventilation Cost-Benefit Study*

by

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Mine Ventilation – Cost Issues

- Power α Airflow^3 – Primary System
- Reductions in the mine's intake airflow can generate significant operating cost savings
- For example: 10% airflow reduction can generate 30% savings in operating cost

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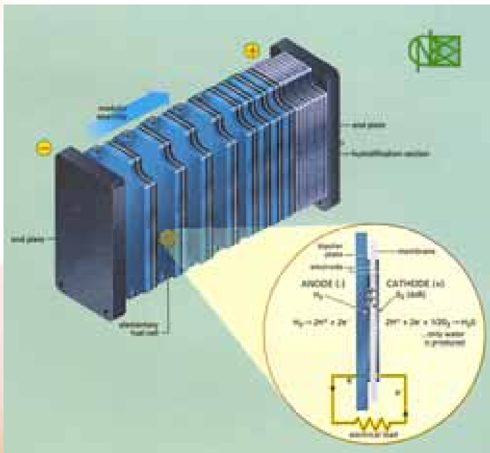
What are fuelcells?



- A fuelcell is an electrochemical energy conversion device that converts H_2 and O_2 into H_2O producing electricity and heat
- The Proton Exchange Membrane Fuelcell (PEM) is one of the most promising technologies
- This type of fuelcell is used to power the mining equipment

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Fuelcell Technology – Mine Ventilation Benefits

- Zero toxic emissions ⇒ replace diesel exhaust design criteria
- Fuelcells mechanically more efficient than diesels ⇒ less heat rejected into the U/G environment
- Reduced airflow requirements ⇒ reduced power consumption
- Reduced power and energy usage ⇒ reduced GHG emissions

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Ventilation Cost-Benefit Study

Analysis comprised 3 parts:

1. Classification of Canadian underground metal mines (with respect to production rate, mining method, depth, ventilation)
2. Detailed analysis selected metal mines (operational survey, ventilation modelling)
3. Summary report of the potential benefits (airflow/operating cost reductions, qualifiers that can limit ventilation savings)

Ventilation Benefit Analysis Fuelcells vs. Diesels

The approach:

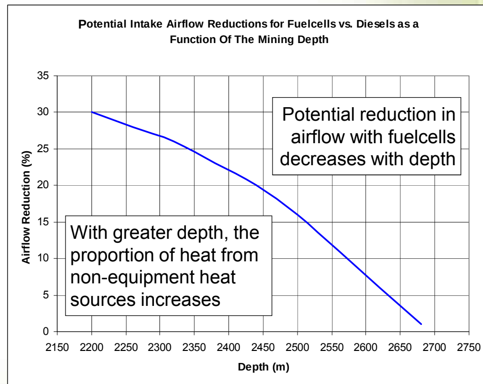
- Six Canadian mines selected - ranging from a large deep base-metal mine to a small precious metal
- Assumption made ⇒ to replace production diesels with fuelcell powered equipment
- Their current and future ventilation system assessed, typically trough models using ventilation simulators
- Determination of potential cost and environmental benefits

Ventilation Requirements in Canada

Mines employing diesels:

- Diesel exhaust design criteria: 0.063 $m^3/s/kW$ or 100 cfm/bhp (in Ontario, Northwest & Nunavut and Yukon Territories)
- CSA Standards based on a quality criterion ⇒ airflow prescribed for a certified engine (other provinces)
- Heat management criteria, when working temperatures become the overriding design element

If mines employ fuelcells:



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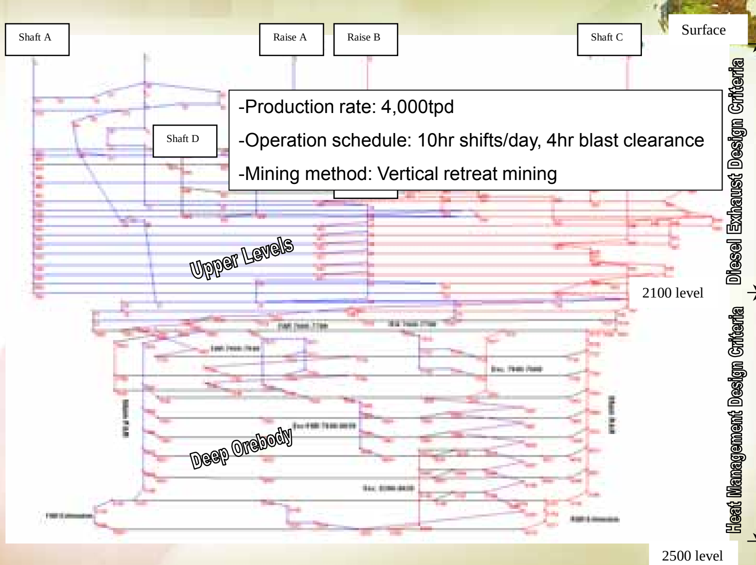
Deep and Large-Sized Base Metal Mine



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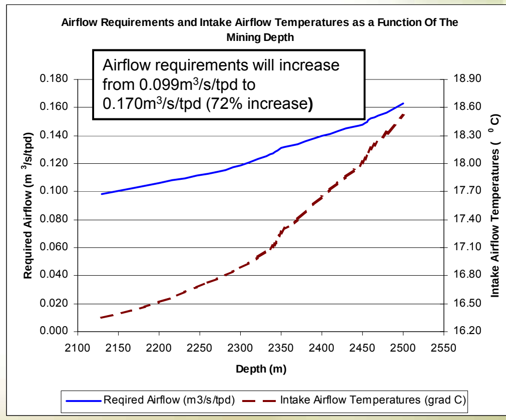
Ventilation Design Criteria – Employing Diesel Equipment

Upper area of the mine:

- Controlling criteria is diesel exhaust
- Design Airflow - 0.079m^3/s (125cfm) per kW of diesel power
- This is 25% higher than the requirements in Ontario

Deep orebody:



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Ventilation Operating Cost - Diesels vs. Fuelcells with Production from the Upper Area

Mine employing diesels:

- Mine total intake airflow: 608m^3/s
- Primary ventilation system operating cost: $3.4M/year
- Secondary ventilation system operating cost: $1.5M/year
- Combined ventilation system operating cost: $4.9M/year

Mine employing fuelcells:

- Mine total intake airflow: 459m^3/s (24% reduction)
- Primary ventilation system operating cost: $1.77M/year (48% reduction)
- Secondary system operating cost: $1.27M/year (15% reduction)
- Combined ventilation operating cost: $3.04M/year (38% reduction)

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Ventilation Operating Cost - Diesels vs. Fuelcells with Production from the Deep Orebody

Mine employing diesels:

- Mine total intake airflow: 652m^3/s
- Primary ventilation system operating cost: $4.2M/year
- Secondary ventilation system operating cost: $1.8M/year
- Combined ventilation system operating cost: $6.0M/year

Mine employing fuelcells:

- Mine total intake airflow: 592m^3/s (9% reduction)
- Primary ventilation system operating cost: $3.3M/year (23% reduction)
- Secondary system operating cost: $1.6M/year (12% reduction)
- Combined ventilation operating cost: $4.9M/year (19% reduction)

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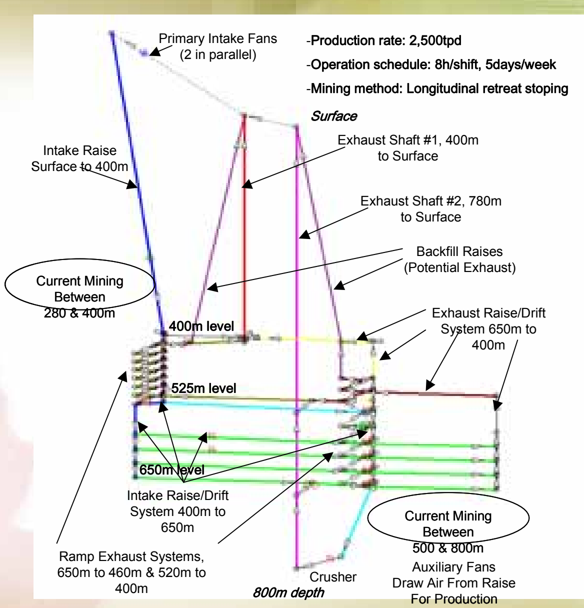
Medium-Sized Precious Metal Mine



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Ventilation Operating Cost - Diesels vs. Fuelcells with a continuous 24hr/7day operation

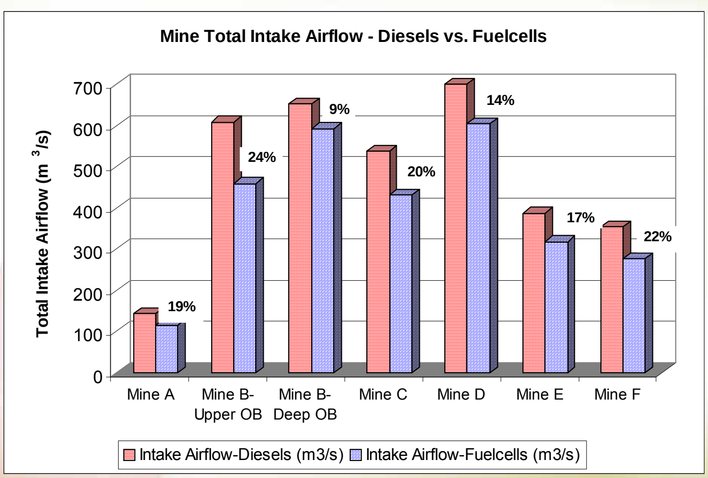
Mine employing diesels:

- Mine total intake airflow: 180m^3/s
- Primary ventilation system operating cost: $318k/year
- Secondary ventilation system operating cost: $322k/year
- Intake air heating cost (propane) during winter: 725k/year
- Combined ventilation system operating cost: $1.365M/year

Mine employing fuelcells:

- Mine total intake airflow: 132.5m^3/s (26% reduction)
- Primary ventilation system operating cost: $129k/year (60% reduction)
- Secondary system operating cost: $283k/year (12% reduction)
- Intake air heating cost: 536k/year (26% reduction)
- Combined ventilation operating cost: $948k/year (31% reduction)

Summary of Canadian Mine Case Studies – Mine Intake Airflow



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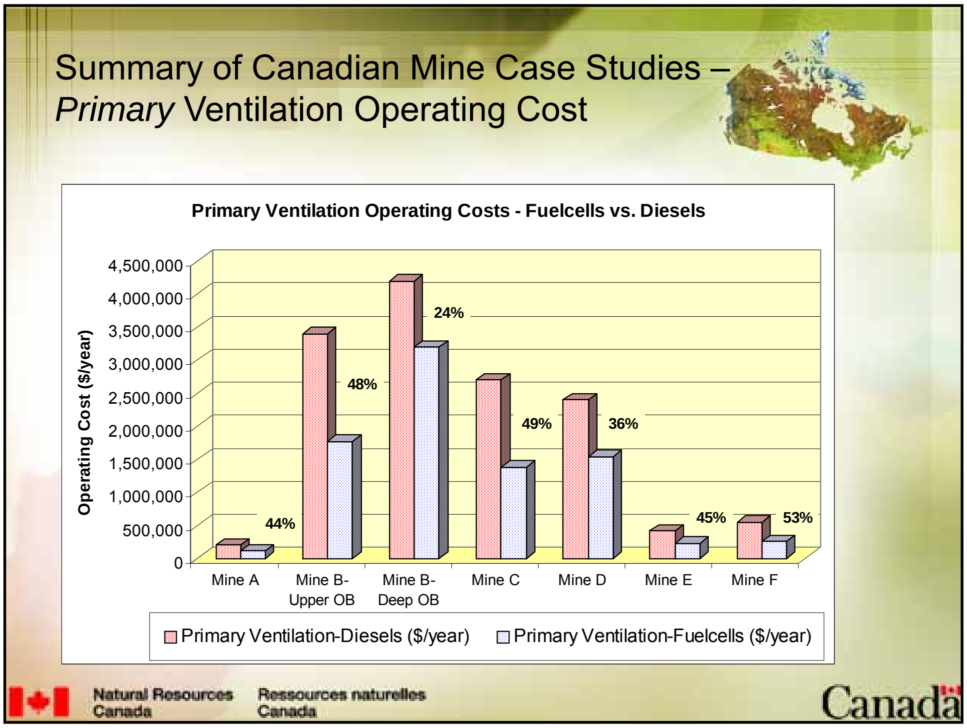
Summary of Canadian Mine Case Studies –
Primary Ventilation Operating Cost
Primary Ventilation Operating Costs - Fuelcells vs. Diesels
Operating Cost ($/year)
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
44%
48%
24%
49%
36%
45%
53%
Mine A
Mine B-Upper OB
Mine B-Deep OB
Mine C
Mine D
Mine E
Mine F
Primary Ventilation-Diesels ($/year)
Primary Ventilation-Fuelcells ($/year)
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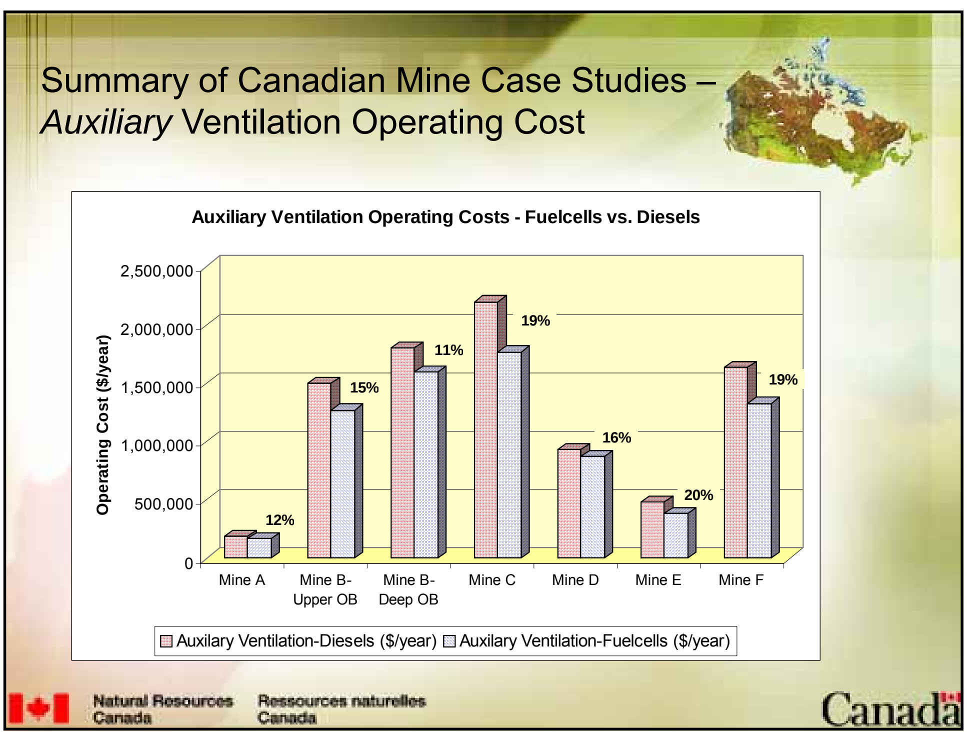
Summary of Canadian Mine Case Studies –
Auxiliary Ventilation Operating Cost
Auxiliary Ventilation Operating Costs - Fuelcells vs. Diesels
Operating Cost ($/year)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
12%
15%
11%
19%
16%
20%
19%
Mine A
Mine B-Upper OB
Mine B-Deep OB
Mine C
Mine D
Mine E
Mine F
Auxilary Ventilation-Diesels ($/year)
Auxilary Ventilation-Fuelcells ($/year)
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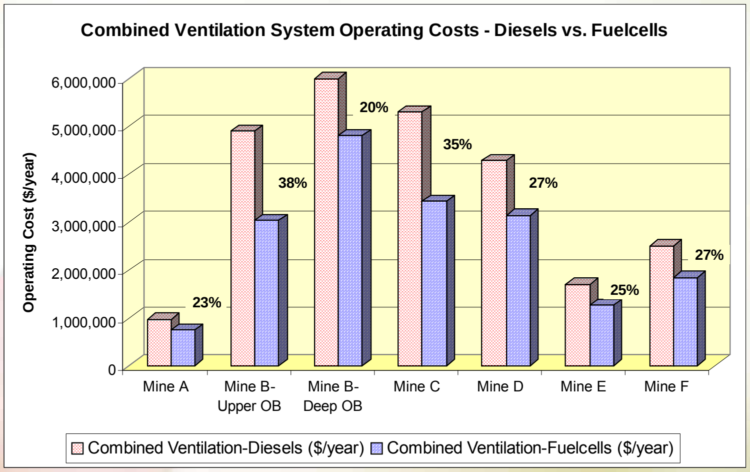
Summary of Canadian Mine Case Studies – *Combined* Ventilation Operating Cost



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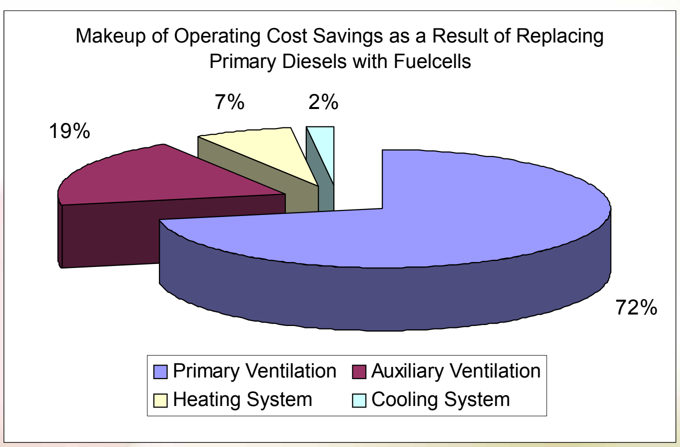
Makeup in Operating Cost Savings – Fuelcells vs. Diesels



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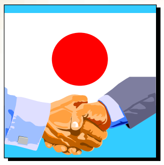
Global Environmental Concerns – Kyoto Accord



Kyoto, 1997

2010GHGs = 1990GHGs – 6%

2015GHGs = 1990GHGs – 8%

- Kyoto accord requires GHG emissions to 6% below 1990 levels by 2010 ⇒ significant reductions in energy usage
- Mine ventilation accounts for ≈ 40% of underground energy consumption (compressed air systems account for another 40%)
- If refrigeration employed ventilation would account for significantly more power consumption

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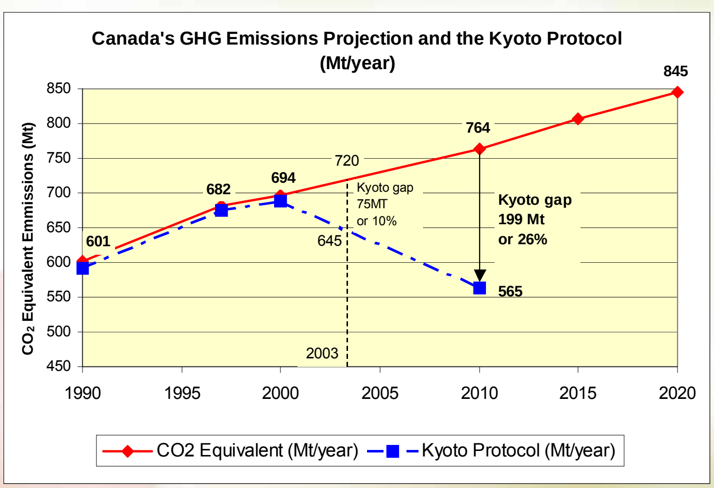
Greenhouse Gas Emissions – Canada's Energy Outlook



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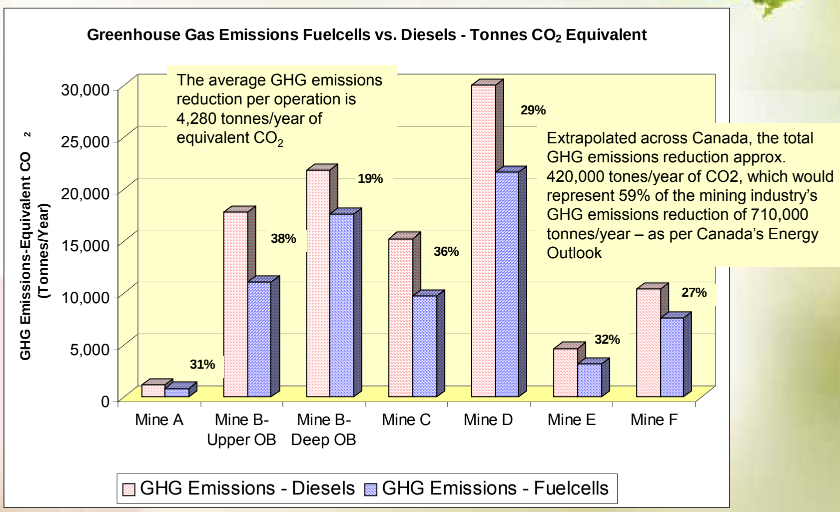
GHG Emissions and Their Potential Reduction (%) – Fuelcells vs. Diesels



Greenhouse Gas Emissions – Diesels vs. Fuelcells

GHG emissions for both diesels and fuelcells were determined using the following conversion factors (from Canada's Outlook Energy):

- 200 tonnes of equivalent CO_2 per 1 GWh consumed electricity (specific to Canada's electrical generation),
- 1.90 tonnes of equivalent CO_2 per one million litre of consumed natural gas, and
- 2.78 tonnes of equivalent CO_2 per one million litre of consumed diesel fuel

Ventilation Benefit Limiting Qualifiers

- Heat: with increasing depth - heat from non-machinery sources increases
- For "cut-and-fill" mining methods – high air volume needed to clear blast fumes
- Drift velocities in the inactive areas of the mine limited to >0.5m/s
- Airflow reductions $\Rightarrow$ airflow velocities in exhaust shafts between 7-12m/s
- Reductions in intake airflow $\Rightarrow$ reduce airflow velocities across the burners
- Airflow reductions $\Rightarrow$ silica dust concentrations can increase >0.1mg/m^3
- Added moisture to the airflow $\Rightarrow$ fogging along access ramps

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Conclusions

- Fuelcells - extremely beneficial in mines where production is continuous and heat is not an issue
- Most beneficial in reducing the power consumption in the primary ventilation system
- Beneficial in reducing the heating costs of the mine's intake air – linearly related to airflow reduction
- Least beneficial under deep mining conditions and in reducing auxiliary fan power
- By removing diesel contaminates - beneficial to the *health of U/G workforce* even in mines with small cost savings
- Fuelcells can also facilitate reductions in a mine's GHG emissions – this depends to how hydrogen is generated

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