



Hybrid & Battery/Electric Vehicles for Underground Mines



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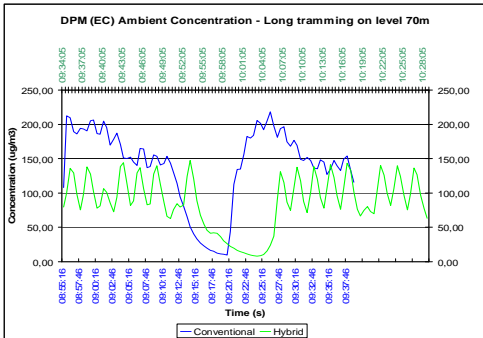
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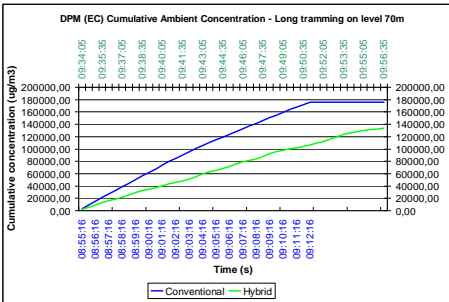
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HLT-270 Hybrid Loader Results: DPM and Air Quality

- Significant impact of hybrid cycle on emissions



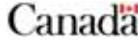


- Hybrid emissions are lower than conventional



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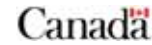
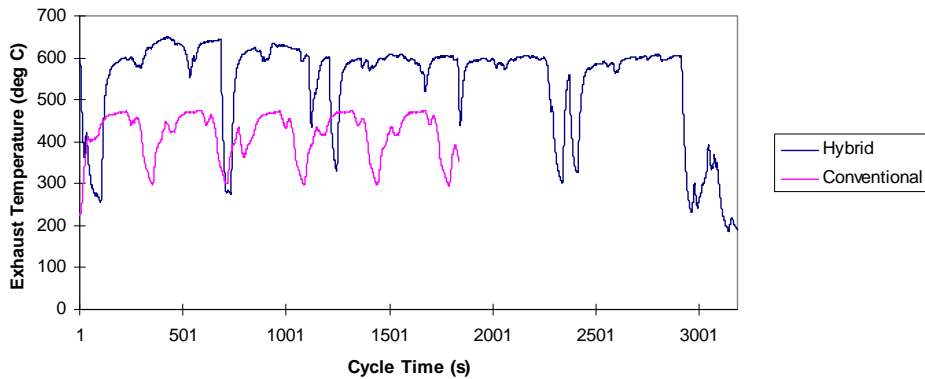
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HLT-270 Hybrid Loader Results: Exhaust Gas Temperature

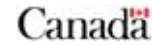
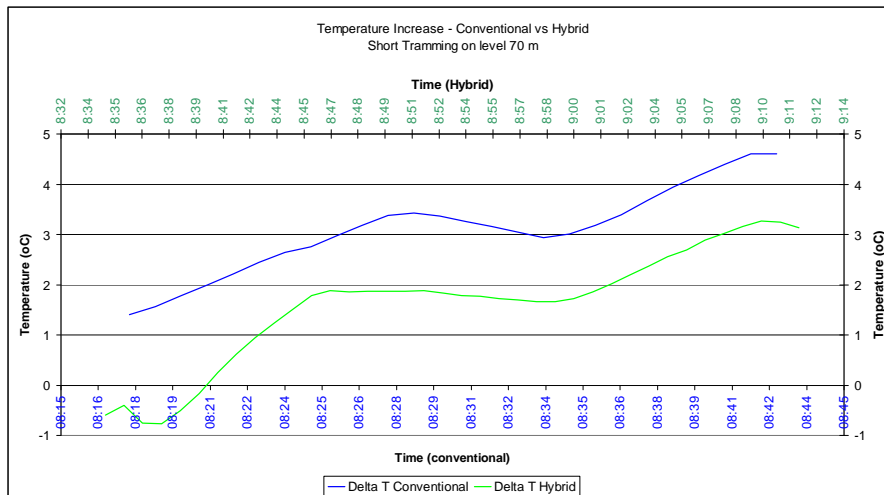
- Higher temperature that permit usage of regenerative diesel particulate filter

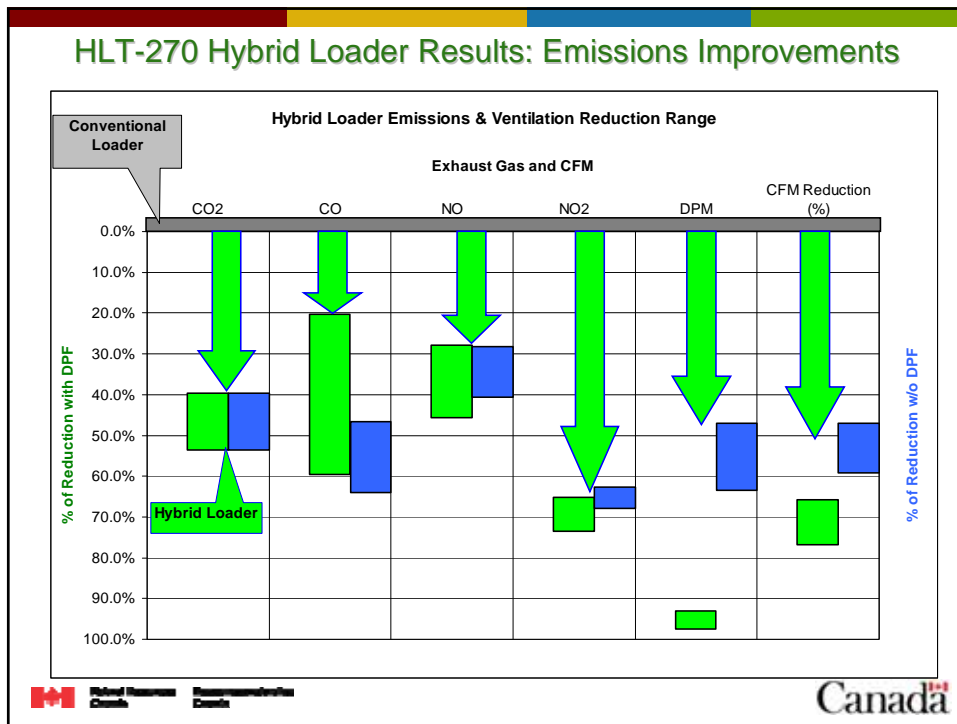
Exhaust Temperature, Ramp Cycle, Hybrid vs Conventional



HLT-270 Hybrid Loader Results: Less Heat Generation

- Because exhaust gas flow is 67% lower, the rejected heat is lower
- Ambient air increase is between 1 and 2 deg C less for hybrid loader



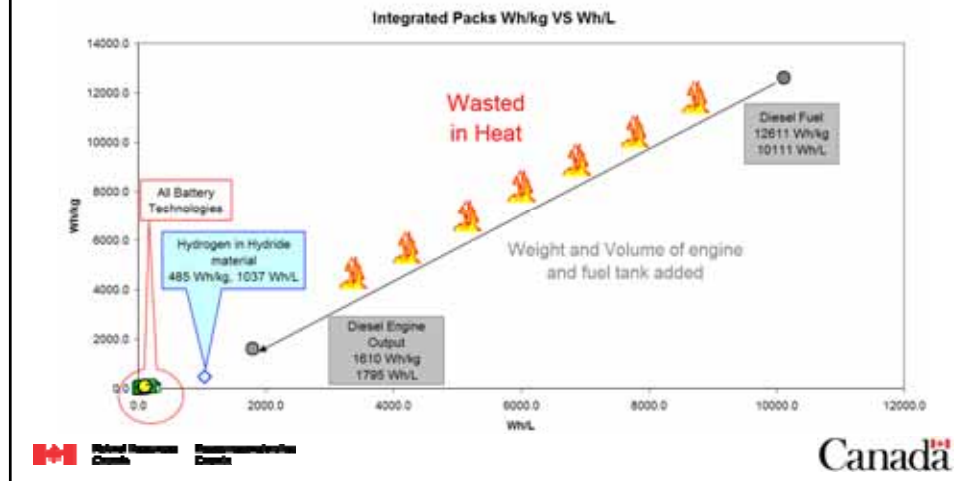


HLT-270 Hybrid Loader Conclusions

- Diesel particulate filter significantly reduces particle emissions, NO & NO₂
- Hybrid duty cycle well suited to DPF
- Possible NO_x control with exhaust gas recirculation, but NO_x is reasonable
- Decoupling hydraulics will reduce transients

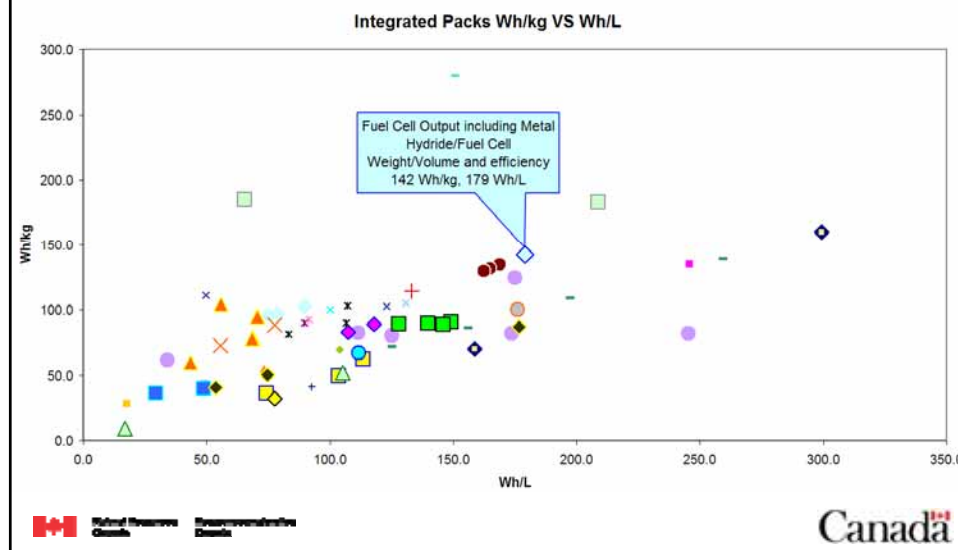
Possibilities to use battery operated mining vehicles

- Diesel engines are still offering a lot more power and energy per weight and volume than any battery pack technologies
- Internal combustion engine generates a lot of heat due to inefficiencies
- Add to this the wasted heat from Torque Converter



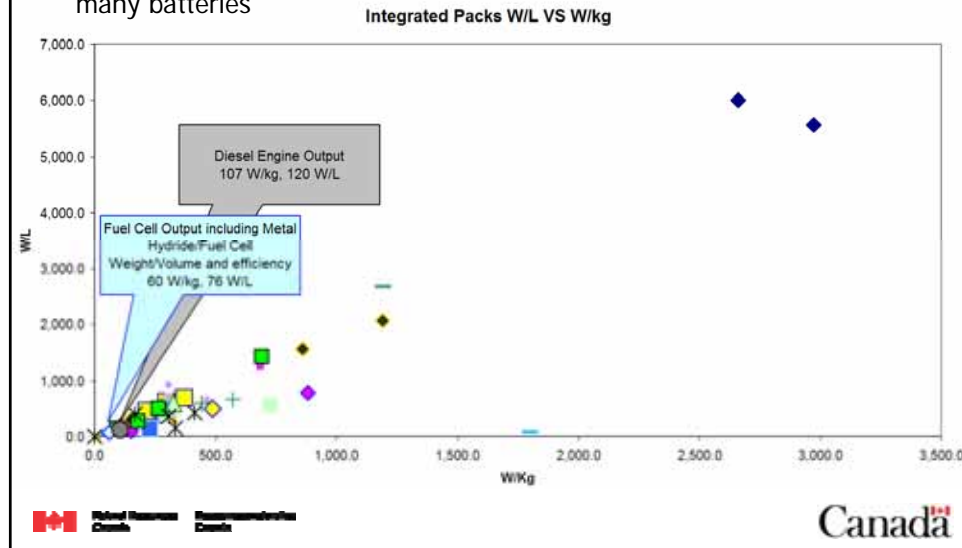
Specific Energy & Energy Density comparison

- Depending on storage, Hydrogen could offer more energy than battery packs but less power per volume and weight



Specific Power & Power Density comparison

- Fuel cells are below the average batteries in terms of power
- Even Diesel engines can deliver less power per volume and weight than many batteries



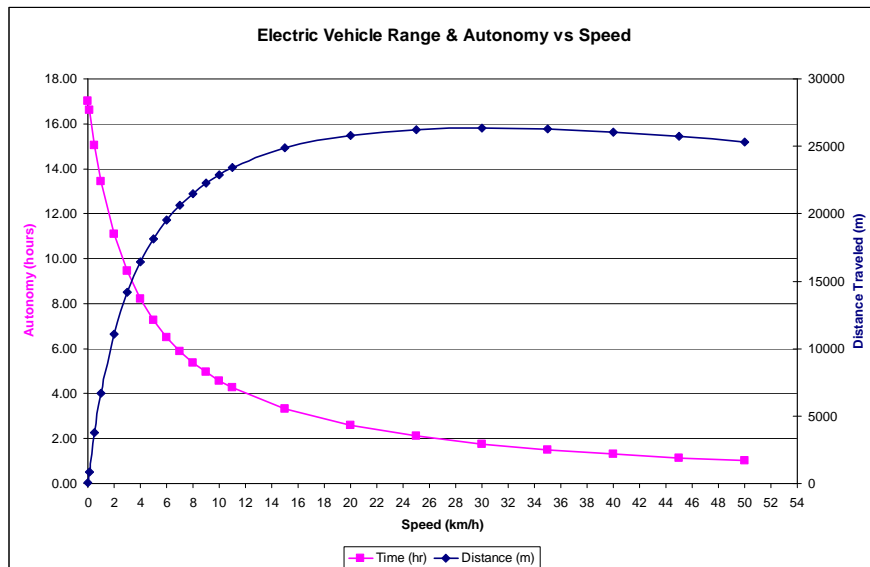
Battery chemistry comparison

- Some battery chemistries offer large amount of energy that could offer good autonomy
- Most of the time, these chemistries need long time for the recharge process
- Most of them will not tolerate 100% Depth of Discharge (DOD), can't use all the stored energy
- Life cycles is higher if DoD is low and discharge current is low (600 to 3000 cycles)
- Battery life would be less than 1000 days
- Could offer 3 to 6 hours of operation depending on vehicle type, duty cycle and space available

Battery chemistry comparison

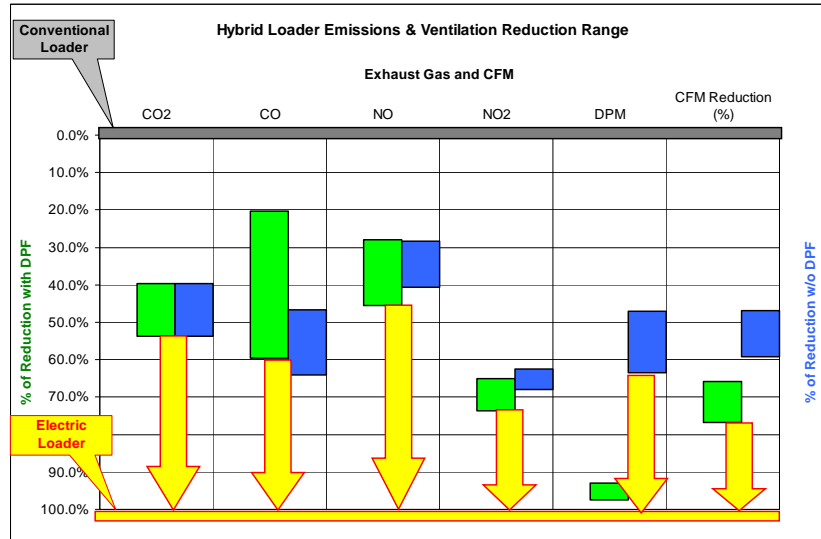
- Some other battery chemistries offer less amount of energy but high power capacity
- These chemistries can be charged from 0 to 90% in 6 minutes, 100% in less than 10 minutes
- Will tolerate 100% Depth of Discharge (DOD)
- Life cycles related to battery temperature more than discharge current (16000+ cycles)
- Battery life would be more than 2000 days
- Could offer 1 to 3 hours of operation depending on vehicle type, duty cycle and space available but could be recharged during brake and lunch time

Compromise between Range and Autonomy vs speed



Battery operated vehicle would produce no emissions

- Would also reject less heat since batteries are 95% efficient



Conclusions

- If vehicle is designed to save every Wh of energy, batteries operated vehicles could be a good solution to lower ventilation requirements and improve air quality
- Not all battery are created equal
- Even batteries with good Specific Power/Energy and Power/Energy Density can have lacks (internal resistance that creates heat, ratings given at very low current...)
- For almost all lithium-ion batteries, over temperature is the enemy
- Having a trolley line in the ramp with battery operated vehicle on drift could be a good compromise