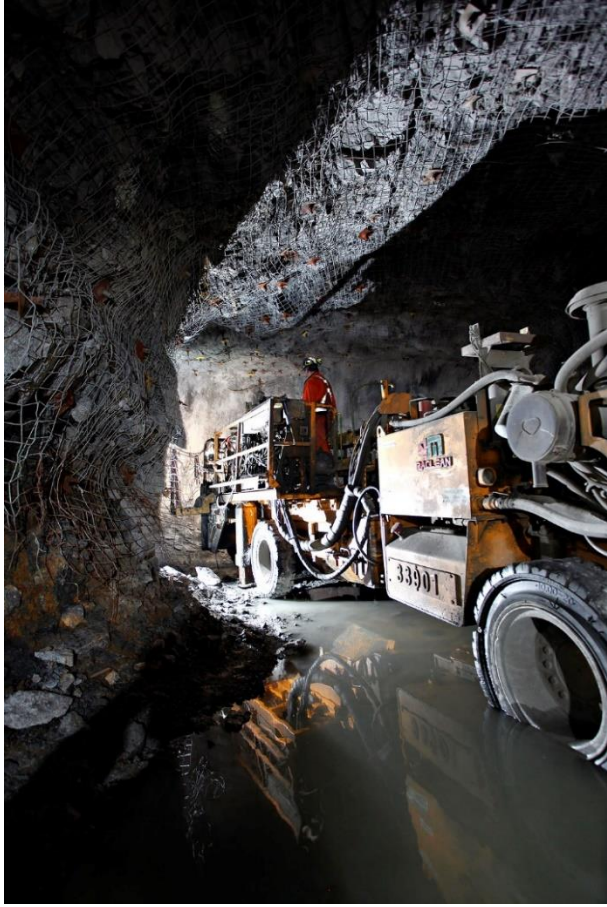


BATTERY ELECTRIC VEHICLES IN UNDERGROUND MINING
A CASE STUDY IN THEORY AND PRACTICAL TERMS

MacLean Engineering

Workplace Safety North – BEV Safety in Mines

Our purpose is to connect people with ideas to enhance life underground and above.
We are the people who power world class ideas.

MacLean

Performance. Reliability. Innovation.

- Founded in 1973 by Don MacLean
- Largest Canadian Mining Equipment Manufacturer
- Product Types:
  - Ground Support (Bolters, Shotcrete)
  - Utility Vehicles (Boom Truck, Scissor Truck, Cassette Truck, etc)
  - Ore Flow (Blockholer Drill, Water Cannon, Rock Breaker)
- Over 2000 rigs built to date
- Approaching 1000 employees globally

Introduction to MacLean BEVs

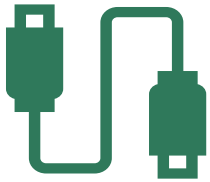
The MacLean BEV fleet by April 2020 totals 30+ vehicles (7 different application models) and will have amassed more than 50,000 hours of run time at 10 different mine sites

15 vehicles operate at Newmont Borden

13 vehicles operate at a combination of Glencore and Vale sites in Sudbury basin or Thompson

Application conditions range in ambient temperatures (+40C to -40C), depth (surface to 9800 ft), working at the face and tramming materials to and from locations

Results from both performance and environmental/safety benefits have been very encouraging



Our approach to BEVs is focused on the engineered integration of best available components to meet high performance and safety

NMC battery chemistry with liquid cooling for larger energy density, long cycle life, and fast charge/discharge rates

On board chargers to offer maximum flexibility

Temperature management system for cooling and heating (can operate in -40C to +40C ambient)

Full vehicle CAN network to monitor entire battery drive system (feeds into MacLean VMS)

Presentation Overview

With success also comes challenges…we face both together with the industry stakeholders

- Summarize our practical experiences with BEVs in underground mining
- Summarize a specific challenge we encountered and how we adapted to the conditions
- Share takeaways that should be of interest and general benefit to the entire BEV and mining industry

Battery Electric Vehicles
Taking Mines from Theory to Reality

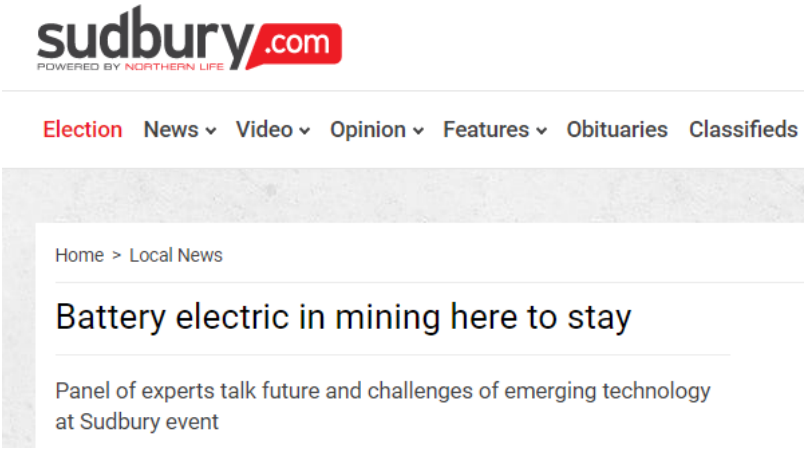
Feature

Goldcorp's Borden project to be first all-electric mine

A look at Goldcorp's Borden project, Canada's first totally electric underground mine.

Newmont Goldcorp's Borden Mine Achieves Commercial Production

10/01/2019



Onaping Depth: Collaborating with the EV industry to prepare for mining at depth

Author: Glencore | **Date:** 14/05/2019

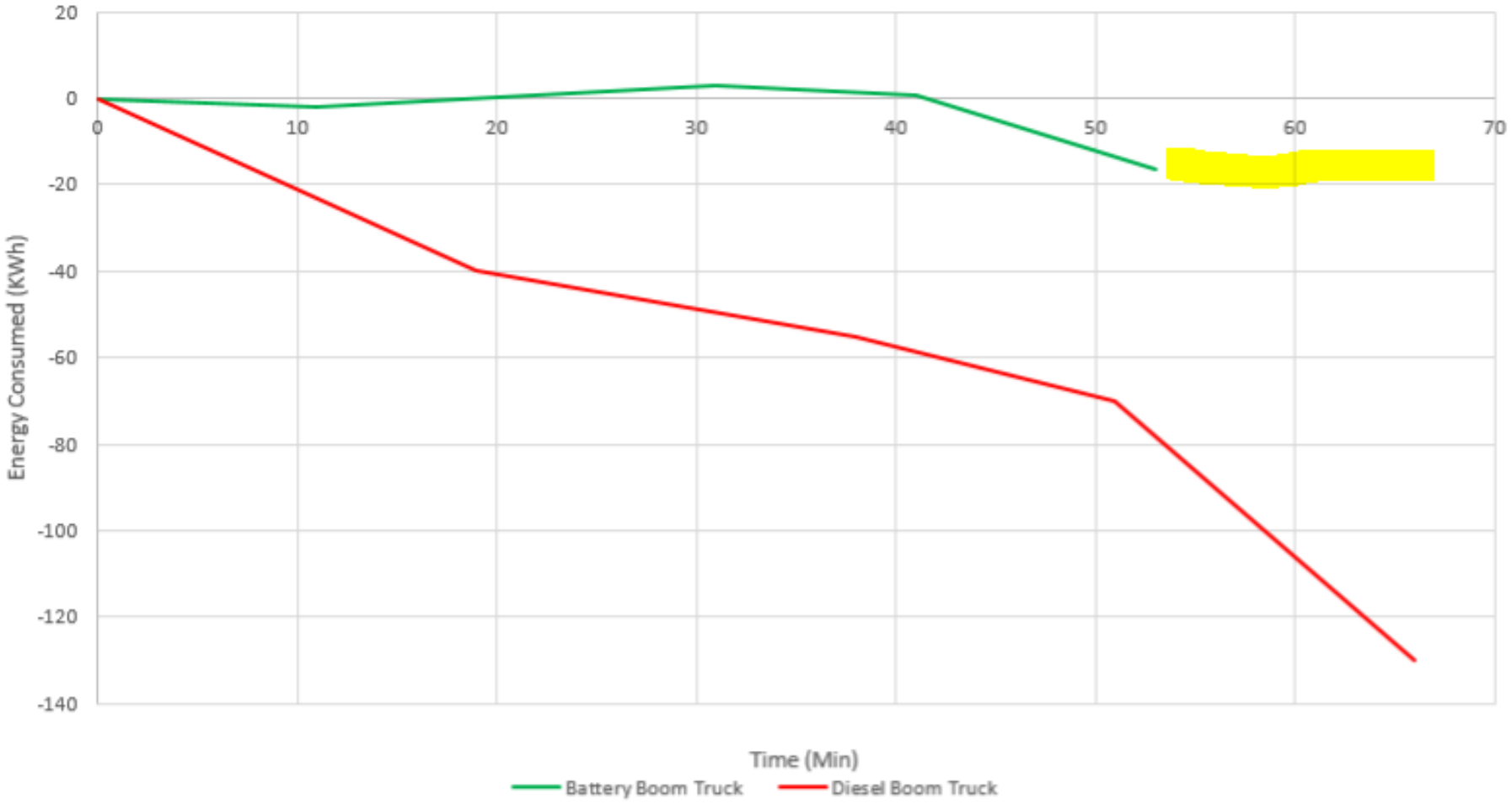
Our Sudbury Integrated Nickel Operations (INO) in Canada are looking to develop one of the world's first mines wholly operated by battery electric-powered vehicles (EVs). The Onaping Depth Project, currently under construction and expected to come on-stream in 2023/24, is collaborating with EV-producers to ensure all parties are fully prepared for an all-electric mining operation.

EV vs Diesel Head to Head Trial

Trial at Agnico Eagles Laronde Mine Using MacLean EV and Diesel Boom Trucks

- Compared diesel fuel consumed to battery energy consumed
- Both units transported 2 bundles of screen and 1 bundle of split sets from 278lvl to 320lvl storages
- Ramp distance was 2km each way
- Fuel tank was refilled at each point to measure how much was consumed from a 5gal pail
- Battery SOC was recorded from operators screen

Trial Results



Energy Consumption

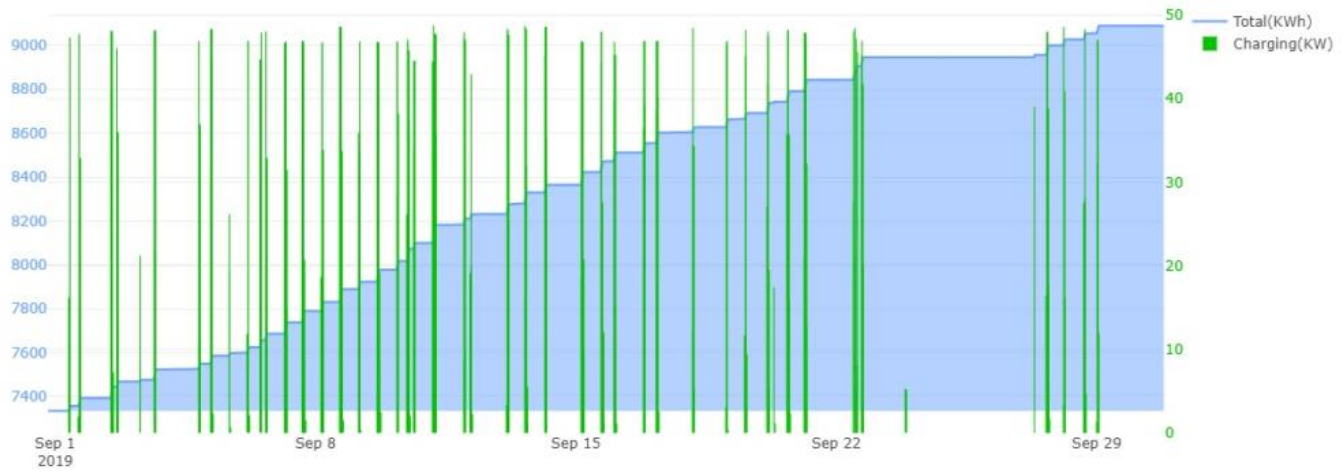
Machine Power Consumption: SL3191

Select View

- Overview
- Notification History
- Fault History
- Utilization Explorer
- Data Explorer
- Power Consumption

Beginning	Span (days)	End	Units	Step
August 31, 2019 3:30 PI	30.0	September 30, 2019 3:3	Days / Months	0.5

Total for Period	AVG Daily	AVG Monthly
1755.12 KWh	58.48 KWh	1754.51 KWh



Energy Consumption

Expanding the energy consumption across a full BEV fleet operating per year

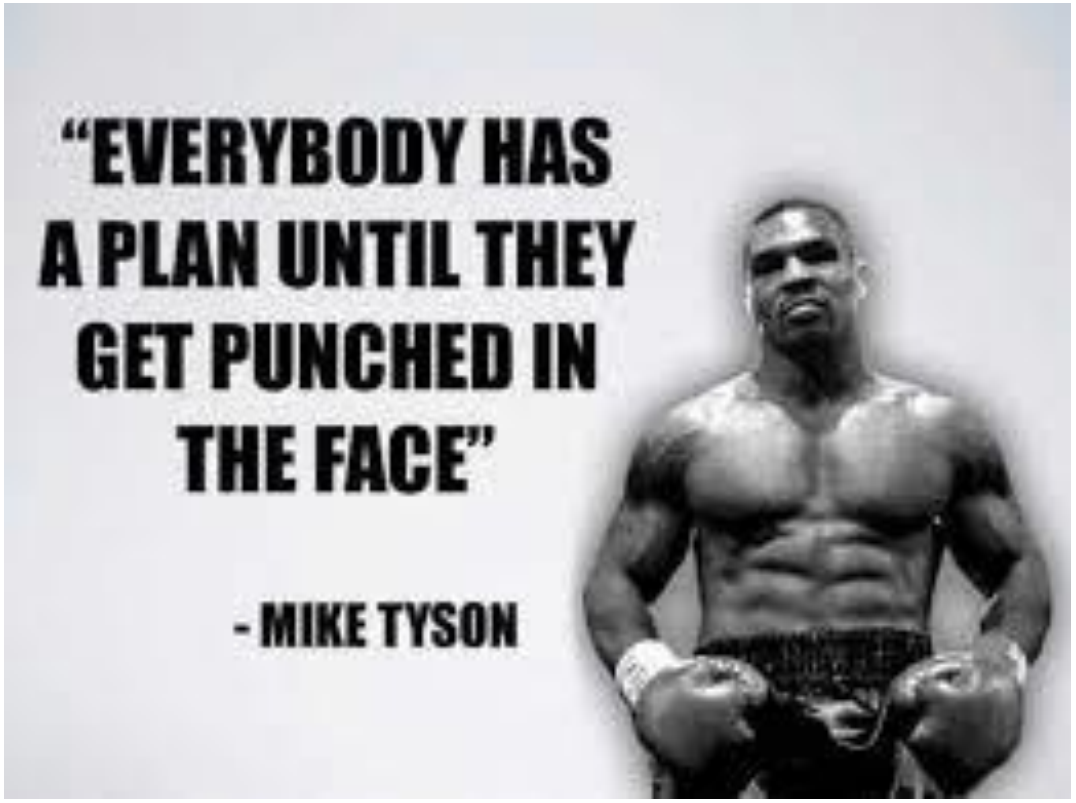
- Averaging 60 kWh of energy consumption per day per BEV (equivalent to 6L of diesel fuel)
- Across a fleet of 15 BEVs operating 310 days per year consumes 279,000 kWh (at $0.12 per kWh this brings a cost of $33,500)
- Equivalent diesel at 10 kWh per L and 33% efficiency would require 85,000 L per year for equivalent work (at $2/L this brings a cost of $170,000)

The Reality of BEVs is Impressive

Like all OEMs and early adopters we've seen the real benefits of BEVs

- BEVs operate efficiently and at higher performance potential vs diesel
- BEVs are quieter, emission free
- BEVs are able to operate in a variety of conditions and applications

The Plan is Working Right?



What Happens When Reality Bites Back?

Small Internal Coolant Leak Within a Module (48VDC Potential)

External Coolant Leak Within Tray (700VDC Potential)

- Battery in question had operated for 2 years
- Not physically damage
- Not overheated (25C)
- Total timeline is over period of ~ 10 days
- Battery software correctly detected isolation fault but not in early stages

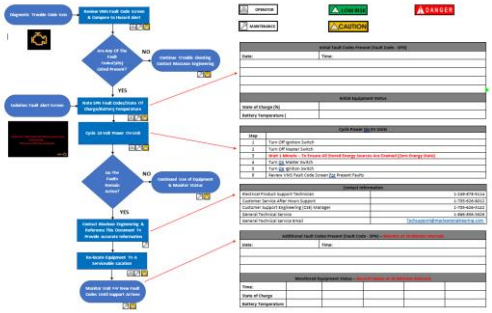
Arcing and Fire

What We Did To Mitigate?

Small Internal Coolant Leak Within a Module (48VDC Potential)

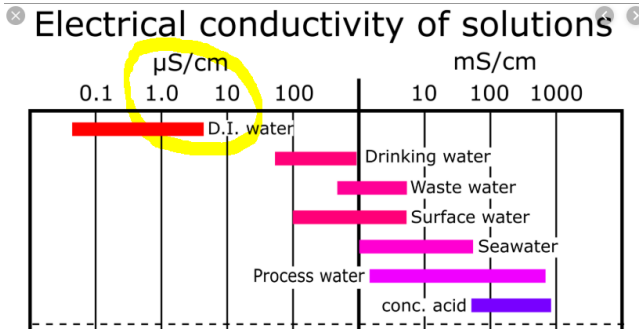
- Operators and Mechanics now have live monitoring of key parameters for battery health
- Detection of any conductive fluid (coolant, moisture, pressure washer) 20x earlier

External Coolant Leak Within Tray (700VDC Potential)



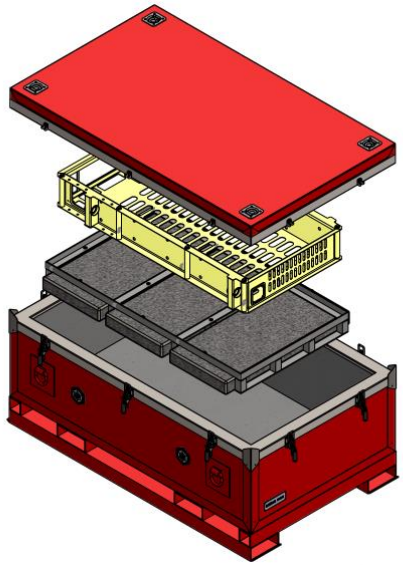
Arcing and Fire

Other Initiatives Needed by OEMs



Low Conductivity Coolant

Portable Battery Monitoring



Battery Fire Safety Containers

Other Initiatives Needed by Industry, National Standards, and Regulators

SUDBURY INTEGRATED NICKEL OPERATIONS
A GLENCORE COMPANY

VALE

Newmont

CSA

UL

Ontario
MINISTRY OF LABOUR

Electrical Safety Authority

Industry (Mines, Contractors, Mine Rescue)

Vehicle Specs
HDEM (EV) Techs
Mine Rescue Plans

National Standards (CSA, UL)

BEV Standards
1000V Standards
3rd Party Certification

Regulators (MOL, ESA)

BEV Regulations
Inspection of BEVs

Takeaways

- The adoption of BEVs is an expanding reality for underground mining and will continue
- The performance demands on BEVs will continue to drive innovation and adoption of more advanced chemistries and charging solutions
- Well designed battery systems are very capable of safely handling a wide range of predicted fault conditions but abnormal cases that could occur
- Allowance for any form of conductive liquid (coolant leak, condensation, pressure washing, etc) entering a high voltage energy source has to be prevented or controlled
- Risk assessments, active fault monitoring, emergency response plans, and safe battery transportation and storage solutions are important ingredients to a responsible BEV program
- Partnerships and transparency within the industry between OEMs and Customers are a key part of the BEV success

Thank You

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