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MINING DIESEL mdec EMISSIONS COUNCIL

360 Electric Mine Assessment

Kovatera BEV vs Diesel Utility Vehicles Field Test

John Le, P.Eng. (CanmetMINING),

1st Annual Conference "Mining Vehicle Powertrain", October 3-5,2023

KOVATERA

CMIN-2023-197-PP

NRCan - CanmetMINING

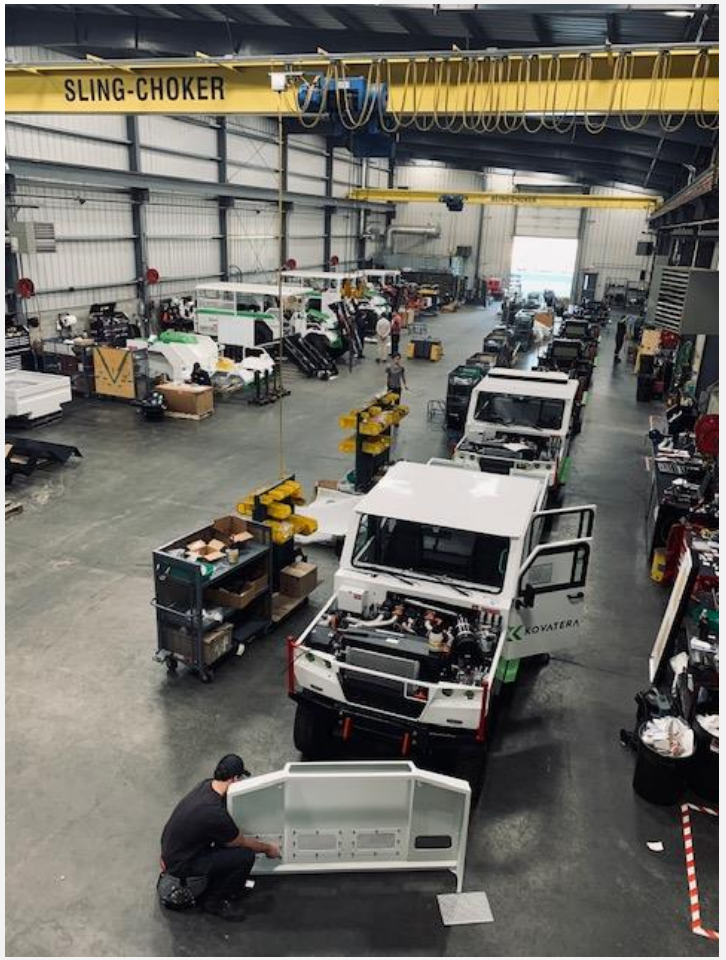
- Branch of Natural Resources of Canada (NRCan)

CanmetMINING R&D focused under three key priorities:

Critical Minerals R&D	▪ The building blocks for the low-carbon transition
Efficient Mining Practices	▪ New mining technologies & best practices
Climate Resilient Mining	▪ Adaptable & carbon neutral

Kovatera

- Founded in 2000, privately owned Canadian Company
- 72 full-time employees
- OEM of specialized, purpose engineered, non-articulated, small footprint, underground utility vehicles
- Completely designed internally and manufactured in Sudbury
- Global dealership: USA, Mexico, Norway, Indonesia, Türkiye, and Australia
- Over 900 units sold globally



** Source: Kovatera*

Kovatera

May 2015
1st unit delivered to Glencore

2021:
88kWh version available

May 2022
Kovatera wins 14 BEV order for Glencore Onaping Depth

2023:
KM200e

October 2022
KIC – Kovatera Innovation Centre opens

Today:
KT300e prototype

* *Source: Kovatera*

Overview of Mobile Equipment Underground

	Advantages	Drawbacks
Diesel Vehicle	Has a higher energy density fuel and fast refuel time Widely adopted and understood	Emissions can cause health effects Has poor efficiency, releases a large amount of heat and emissions
Battery Electric Vehicle	Has high efficiency, zero-emissions locally Rejects less heat, potentially requires less ventilation air	New technology requires training for operation and maintenance Limited driving range and requires a long time to charge the battery

Diesel to BEV Transition in Underground mines

BEV has been considered as a revolutionary technology to replace diesel vehicles underground.

Equipment manufacturers accelerating development, testing, and production of BEVs

Mine operators purchasing all classes of BEVs in recent years.

Diesel to BEV Transition in Underground mines

Can BEVs match diesel vehicle's performance in day-to-day operation?

How much electrical energy is required to replace diesel fuel for the entire mobile equipment fleet?

Mobile Equipment Classes

Light Duty Utility (4-7.5 tonnes)

Kovatera: Diesel UT99

Kovatera: KT200e

Heavy Duty Utility (20-30 tonnes)

MacLean: Diesel Cassette

MacLean: BEV Cassette

Production (40-50 tonnes)

Epiroc: Diesel MT42

Epiroc: BEV MT42

* *Source: Kovatera, MacLean Engineering, Epiroc*

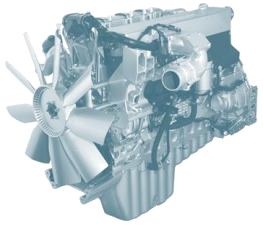
KOVATERA

Kovatera Diesel Utility Vehicle Configurations

* *Source: Kovatera*

Kovatera Diesel Utility Vehicle: Powertrain system

88 L diesel tank



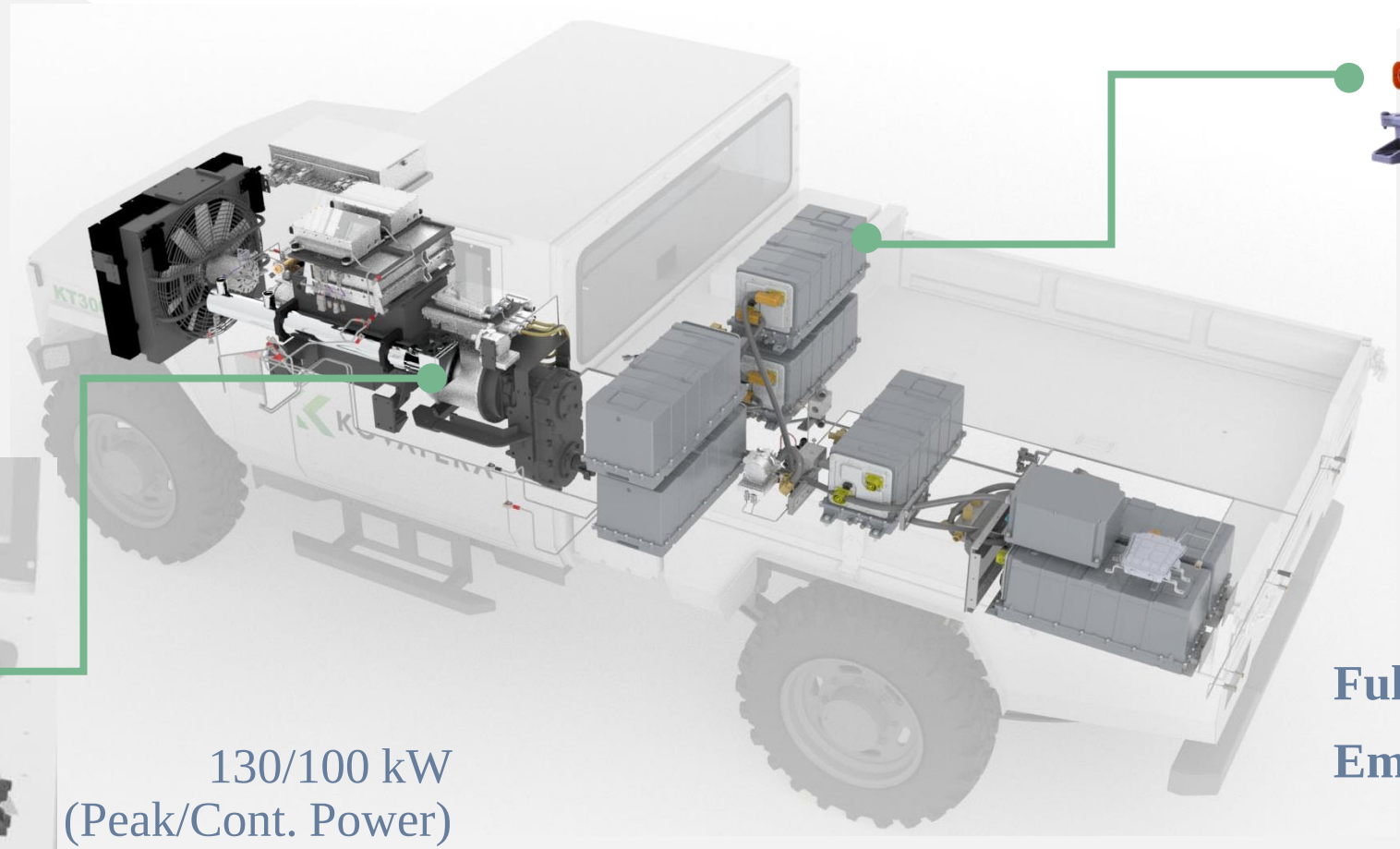
74 kW diesel engine

Full load: 5.29 tonnes

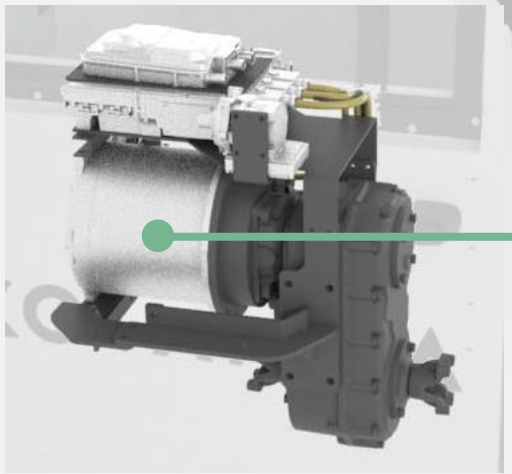
Empty load: 4.36 tonnes

** Source: Kovatera*

Kovatera Battery Utility Vehicle: Powertrain system



battery package
88.8/71 kWh
(nominal/usable energy)



130/100 kW
(Peak/Cont. Power)

Full load: 5.29 tonnes

Empty load: 4.92 tonnes

* *Source: Kovatera*

Estimate ownership cost of Kovatera Utility Vehicle

Items	Diesel Tier 3 ($/hr)	BEV ($/hr)
Ownership	$22*	$33
Maintenance	$25	$15
Consumables	$10**	$1.5
Total Hourly Cost	**$57**	**$54.5**

Cost of ownership is over 10 years, based on 1200 operating hours

** Diesel ownership includes a powertrain rebuild*

*** Diesel consumables include fuel, filters, fluids.*

Additionally, the cost of ventilation is greatly reduced, but the savings are not calculable

** Source: Kovatera*

Test Route – Surface Operation

Vale's North mine surface ramp test area

- Full-load "same gross weight" with two target speeds (5 and 15 km/h)
- Vehicles traveled from 'Start' to 'end' then returned to 'Start' for a full **lap**
- 2.5 km route (1.25 km per direction)
- Separated into 10 **sections** with different distances and grades (0, 5, 10, and 20%)
- Repeat again with empty-load with its own net weight with two target speeds
- Captured 10 data points/sec with J1939

Fuel and Energy Used During Operation

Diesel Vehicle

+ Diesel consumed flat, uphill (L)

+ Diesel consumed downhill (L)

Total diesel used (L)

Diesel fuel is consumed on all terrain grades

BEV

+ Energy consumed flat, uphill (kWh)

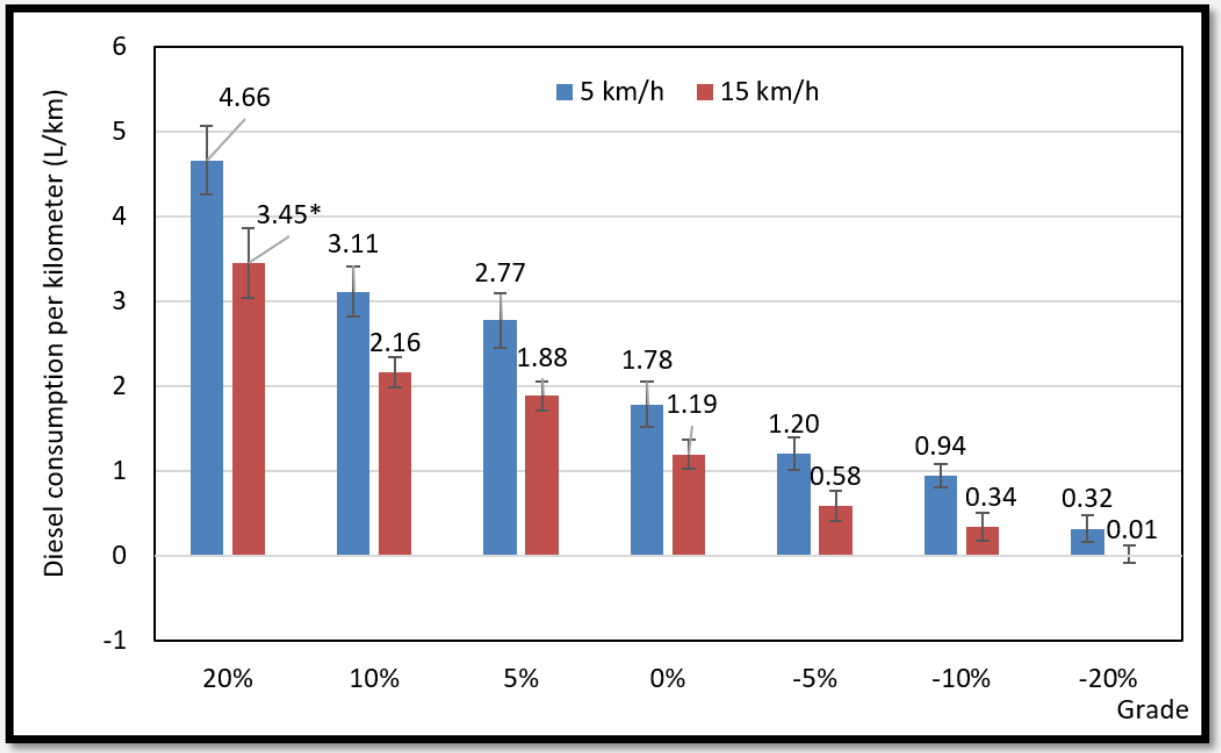
- Energy captured downhill (kWh)

Net energy used (kWh)

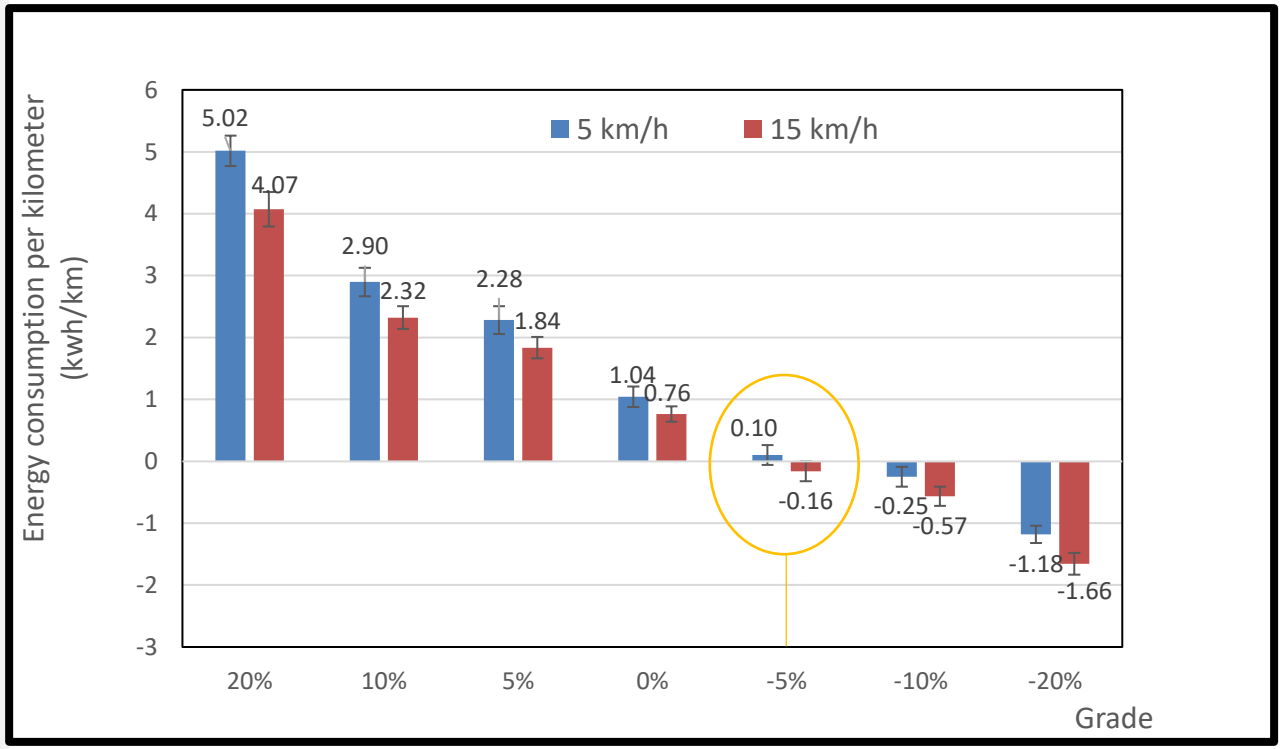
Energy is consumed on flat, uphill and shallow grades

Fuel/energy Results – Sections by Grade

Diesel UT99 – Full load



BEV KT200e – Full load



* Diesel vehicle did not reach target speed (15 km/h); average speed was 10.9 km/h

Battery Charging Methods for BEVs

Rokion: off-board charger Level 1, 2

Kovatera: Onboard charger

CAT: Off-board fast charger

Epiroc: battery swap & off-board charger

Sandvik: battery swap with onboard hydraulic device

Source: PMI, Kovatera, Caterpillar, Epiroc, Sandvik.

Kovatera BEV Charging Options

Description	Rated Power	Typical Efficiency	Estimate Output Power*	SoC Level**	Estimate charge Time*
Onboard - Single charger	13.2 kW	92%	12.1 kW	0 to 93.5%	5.5 hrs
Onboard - Double charger	26.4 kW	92%	24.3 kW	0 to 93.5%	2.7 hrs
Offboard - CCS1 or 2 charger	90 kW	95%	85.5 kW	0 to 93.5%	0.78 hrs

* The maximum estimate output power may be lower due to operating conditions that can result longer charging time

** The energy received by the battery is lower beyond 93.5% SoC of usable capacity

* *Source: Kovatera*

Discussion – Fuel and Energy Consumption, Charging

Steeper uphill terrain grade = increased fuel/electricity consumption

Less fuel/energy consumption at high speed

BEV captured more energy with increased downhill grade, speed and load

Discussion – Fuel and Energy Consumption, Charging

Fuel/energy used and energy captured values varies based on terrain grade, speed and load

The battery charges faster at lower SoC levels, programmed to reduce charging rate at higher SoC level.

Fuel/energy used or energy captured values presented herein are specific to Kovatera vehicles and should not be used for other vehicles

Hypothetical Duty Cycle for Planning Purposes

- On average, a Kovatera vehicle is utilized cumulatively for a total of 4-6 hrs during a 12 hr shift in underground mines with the following conditions:
  - average speed of 15 km/h
  - operate on various terrain grade
  - operate at two loads (empty and fully loaded)

- Using test results to evaluate how much fuel consumption, energy consumption and energy is captured in a duty cycle

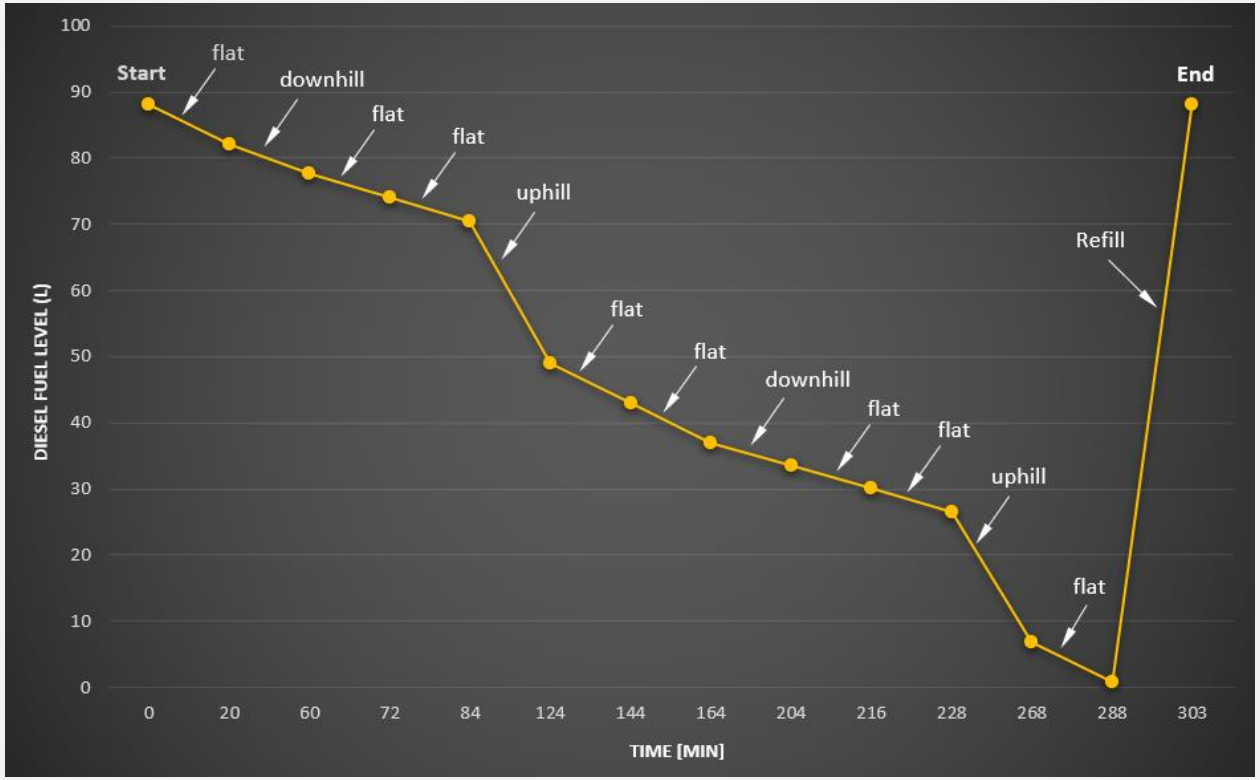
- Assess how battery charging time will affect BEV utilization

Hypothetical Duty Cycle – Using Test Results

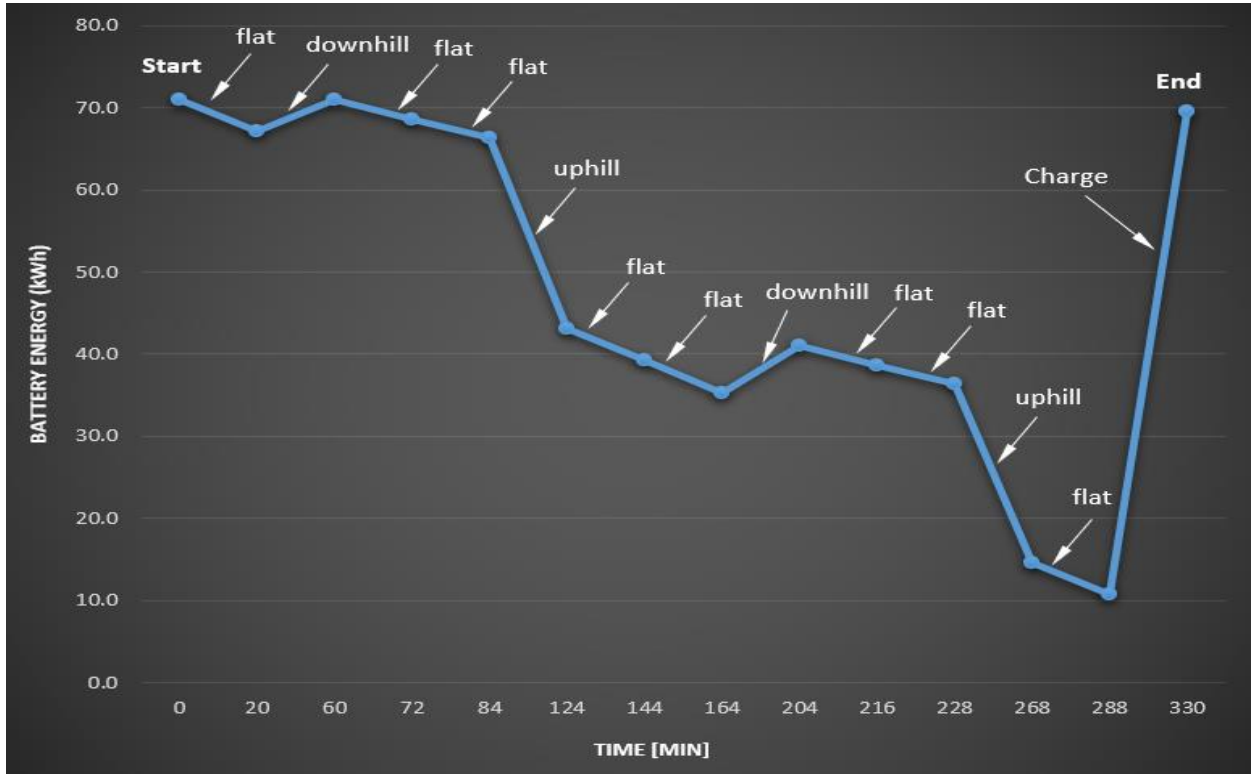
Load/ speed	Distance (km)	Grade (%)	Fuel rate (L/km)	Fuel (L)	Gauge (%)	Energy rate (kWh/km)	Energy (kWh)	SoC (%)	Time (hr)
Empty (15 km/h)	5	0	1.2	6.0	93%	0.8	3.9	95%	0.3
	10	-10	0.4	4.4	88%	-0.5	-5.4	100%	1.0
	3	0	1.2	3.6	84%	0.8	2.3	97%	1.2
Full (15 km/h)	3	0	1.2	3.6	80%	0.8	2.3	93%	1.4
	10	10	2.2	21.6	56%	2.3	23.2	61%	2.1
	5	0	1.2	6.0	49%	0.8	3.9	55%	2.4
Full (15 km/h)	5	0	1.2	6.0	42%	0.8	3.9	50%	2.7
	10	-10	0.3	3.4	38%	-0.6	-5.7	58%	3.4
	3	0	1.2	3.6	34%	0.8	2.3	54%	3.6
Empty (15 km/h)	3	0	1.2	3.6	30%	0.8	2.3	51%	3.8
	10	10	2.0	19.7	8%	2.2	21.7	21%	4.5
	5	0	1.2	6.0	→ 1%	0.8	3.9	→ 15%	4.8

Hypothetical Duty Cycle – Fuel / energy used over time

Diesel Vehicle



Battery Electric Vehicle



Hypothetical Duty Cycle - Discussion

Typical use for Kovatera utility vehicle in underground mines = 4-6 / 12 hr shift

Diesel

- Consumed 87.2 L of 88 L tank, 1% fuel remaining, covered 72 km
- Continuous operation (4.8 hrs) + fuel tank refill (0.25 hr) = 5.05 hrs

BEV

- Net energy 47.7 kWh (consumed 58.8 kWh – regen 11.1 kWh) of 71 kWh battery pack, 15% SoC remaining, covered 72 km
- Usable 71 kWh energy with 85.5 kW charging rate – offboard option
- Continuous operation (4.8 hrs) + charging (0.7 hr) = 5.5 hrs

- Both vehicles are capable of meeting demand for this duty cycle, even when including charging time
- Fuel / energy consumption varies based on conditions (speed, grade,…), performance should be assessed on a case by case basis

Discussion – Vehicle Availability

For planning purposes, specific duty cycles using test data should be assessed to avoid over or under-estimating fuel/energy consumption

One BEV may need to be charged sooner than another depending on battery size and other factors

Continuous operation with a large battery pack.

Depending on vehicle design and expected application, BEV could potentially replace diesel vehicles without impact on productivity

Future Work

- Test data can be used to select the proper BEV options
- More test results from other vehicles will be published in collaboration with stakeholders
- Mathematical models can be developed using the test data to estimate fuel/energy consumption at different loads, grades, and speeds
- More field tests should be done on other classes of vehicles

Transition from Diesel Fuel to Clean Technology Mine

Mobile Equipment Energy
(BEV, Trolley, Rail-veyor,…)

Case Studies
&
Publications

Smart Charging Strategies
&
Grid Demand

Transition from
Diesel Fuel

Environmental conditions
(heat, dust,…)

Life Cycle
Assessment

We would like to acknowledge

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- Vale for providing the resources and test site to complete this work
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- CanmetENERGY: Hajo Ribberink, Ahmad Mohsenimanesh

“Your contribution is greatly appreciated”

THANK YOU!

- **John Le, P.Eng. (CanmetMINING), john.le@nrcan-rncan.gc.ca**
- **Dave Schmidt (Kovatera), dschmidt@kovatera.com**

KOVATERA

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