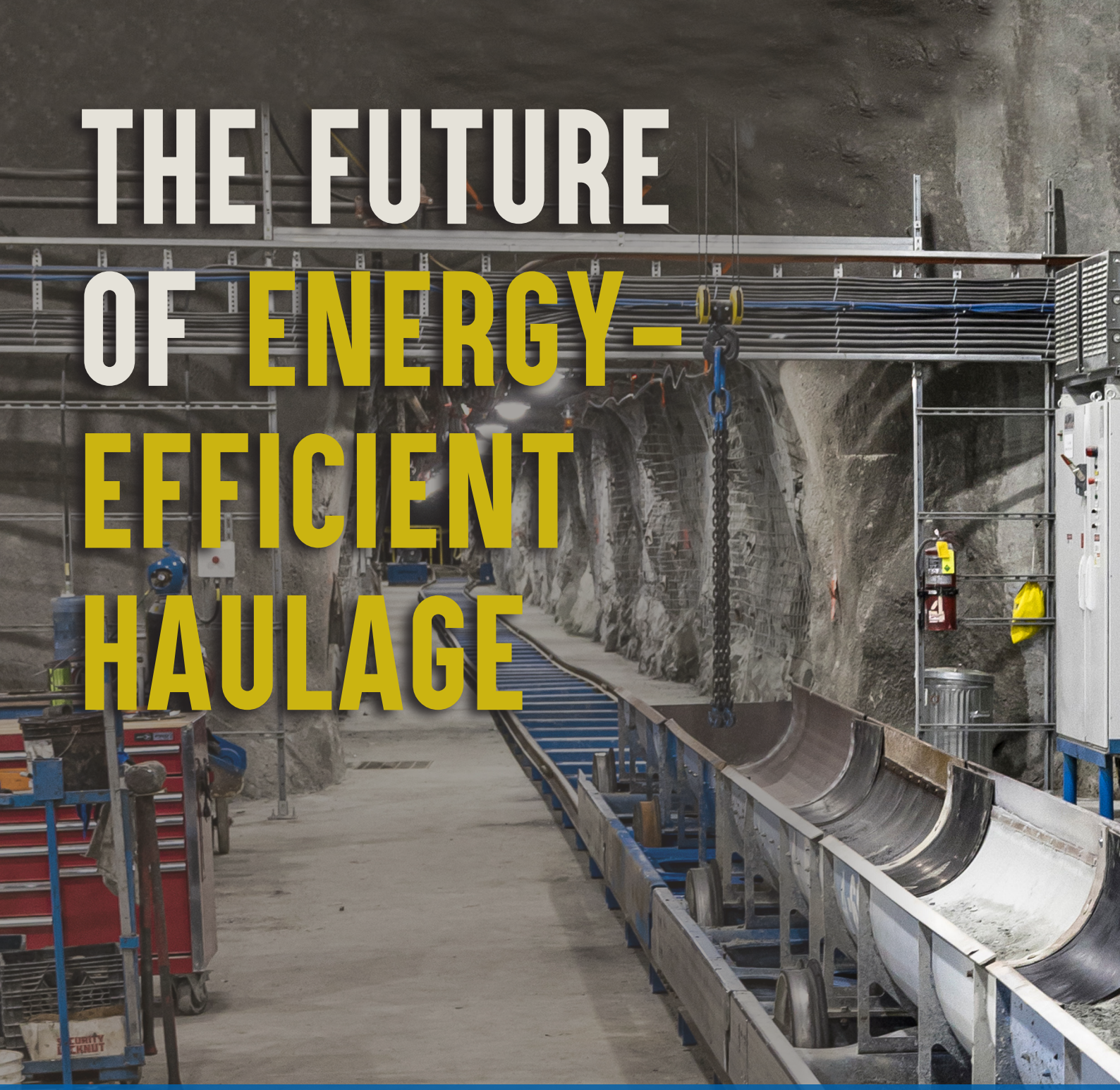


THE FUTURE OF ENERGY-EFFICIENT HAULAGE

In today's mining industry, companies face increased pressures: lower ore grades, deeper mines, increased labour and material costs, and the call to decarbonise operations, among others. Prioritising these concerns is a complex undertaking. Companies choosing a direction can look for activities and technologies that address multiple objectives.

The single greatest target for decarbonising mining operations is material haulage. A recent report by McKinsey estimates that traditional material haulage accounts for 36% of the emissions generated by a typical mine – the most significant emissions-generating activity.

In order for mining companies to achieve stated decarbonisation targets, OEMs are racing to develop material haulage solutions that reduce emissions. One alternative to truck haulage that is currently installed in applications around the globe is the Railveyor autonomous, fully electric material haulage solution. The real-world performance of the Railveyor system has now been validated at Agnico Eagle's Goldex mine by CanmetMINING, providing a useful comparison to existing diesel haulage and potential BEV fleet systems.

The understudied complexity in swapping diesel for batteries

Every deposit and mine plan is unique – and there are many valid material transport strategies, each with their own ideal use case. Replacing diesel truck haulage with battery electric vehicles (BEVs) is an increasingly attractive solution to miners. However, replacing fleets with BEVs places additional burdens on operations that are becoming more commonly known. On the user level, designing and implementing battery charging, storage, and disposal strategies is a novel and complex project. On a societal scale, economically sourcing the raw materials for

Nik Gresshoff and Matt Youngblood, Railveyor, Canada, review how operators can cut costs and emissions by implementing an electric haulage system.

Figure 1. The Railveyor autonomous material haulage system at Agnico Eagle's Goldex mine has been evaluated for real world energy consumption by CanmetMINING.

a transition to electric vehicles for material haulage in mining – in addition to serving the massive projected demand for similar batteries in personal and commercial transportation – presents serious challenges.

The existing power generation and electrical grid infrastructure would also need to be substantially upgraded in order to handle the projected demand from BEVs. In a report from April 2023 titled 'Electrifying mines could double their electricity demand', McKinsey modelled the increased electricity demand created by simply swapping diesel trucks for their battery-powered counterparts. McKinsey claims that electrifying just the existing global iron ore industry would require the generation of additional electricity equivalent to 10 –15% of Australia's current consumption.[1]

The increased demand caused by electrification, including charging infrastructure for BEVs, may also be massive at the level of a single mine. In estimates calculated in 2023 by Warm Springs Consulting and released at the Electric Mine Conference in Tucson, Arizona, a theorised large open-cut mine in Australia might need 56 MW of electricity to support the charging infrastructure for a fleet of BEV trucks with trolley assist and dynamic charging. Even at a less productive mine, operators must ask if they can account for an extra 10 – 20 MW of power for a BEV haulage electrification project.

With those figures in mind, the mining industry must seek ways to not only electrify haulage, but also to make haulage intrinsically more energy-efficient. Increasing energy efficiency may reduce costs (in lower fuel/electricity expenses) and aid in decarbonisation (by lowering greenhouse gas emissions), cutting across multiple issues. Forward-thinking mining companies are smart to explore

BEV-based haulage solutions, and they are wise to investigate other innovations in the material haulage space as well.

Not just electric but more energy-efficient

Railveyor is an intelligent material haulage solution that integrates with existing control infrastructure and allows operations with just a single worker to monitor the system from a mine control room. Composed of trains with steel wheels riding on light steel rails and driven by stationary electric drive stations, Railveyor achieves high energy efficiency by reducing rolling resistance, increasing the payload-to-vehicle-weight ratio, and utilising innovative electric motors.

In a study comparing the economics and energy efficiency of competing haulage systems, Warm Springs Consulting reported:

"Diesel-electric haul trucks are estimated to have the highest GHG emissions of the specified hauling methods at 0.096 kg CO_2e/tkm. This is directly related to the high emissions factor of diesel fuel and limited haul capacity per truck. The hauling method with the lowest emissions is the Railveyor system, with an estimated 0.012 kg CO_2e/tkm.

"Based on average diesel and electricity prices, the hauling method with the highest fuel operating cost is estimated to be diesel-electric haul trucks at US$0.043/tkm. Railveyor is estimated to have the lowest fuel operating cost at just US$0.003/tkm. The hauling method with the highest operating cost not including fuel cost is estimated to be long haul diesel trucks at US$0.069/tkm. The lowest non-fuel operating cost is estimated to be Railveyor at US$0.005/tkm."[2]

Railveyor's customer, Agnico Eagle Mines, saw the potential value of the system's low OPEX and emissions when they selected Railveyor as the material haulage system at the Goldex mine in 2017. In 2023, the findings of a study of power consumption by the AEM Goldex Railveyor system have been published by CanmetMINING, an agency under the umbrella of Natural Resources Canada. As part of the 360 Electric Mine research project, CanmetMINING aims to help accelerate the mining industry's transition from fossil fuels to the use of electric energy and reduce the amount of greenhouse gases produced in the sector.

Within the study of the Goldex Railveyor system, CanmetMINING measured daily electricity usage, ore hauled, and Railveyor train trips taken. The conclusions confirm that the Railveyor system at Goldex is operating within 6% of estimated energy usage levels, requiring 0.989 kWh to move one tonne of ore one kilometre. Taking the average electricity price in Quebec, this equates to a cost of US$0.07/tkm.

"Since 2018, the implementation of the Railveyor system at Goldex has had a positive impact on our operations. It allowed us to raise the bar on our production," stated Christian Lessard, Maintenance Superintendent of Agnico Eagle's Goldex mine, "As a leader in sustainable mining, we were pleased to facilitate CanmetMINING's study of Railveyor's electricity consumption. We believe that the projected and measured electricity consumption figures

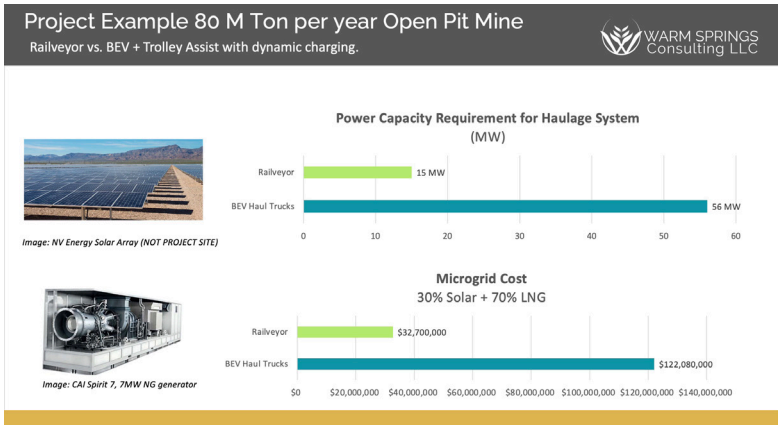
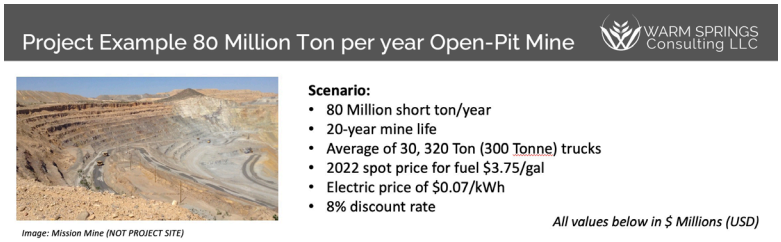


Figure 2. Chart from Warm Springs Consulting contrasting the power capacity requirement and microgrid cost between Railveyor and BEV fleet haulage solutions.



Scenario	Description/Assumptions	Total Capex	Total OPEX	Net Present Value
Diesel Trucks	100% diesel trucks, 2022 spot price fuel	$185	$1,328	**(861)**
BEV Haul Trucks + Trolley Hybrid	BEV cost 30% more, includes trolley, charging other infrastructure	$300	$1,318	**(965)**
Railveyor	90% of haul handled by RV system. 10% truck. Includes in-pit crush, feeders, loaders, etc.	$451	$955	**(855)**

Figure 3. Theoretical scenario presenting the estimated NPV in an opencast mine between diesel trucks, BEVs with trolley assist, and Railveyor.

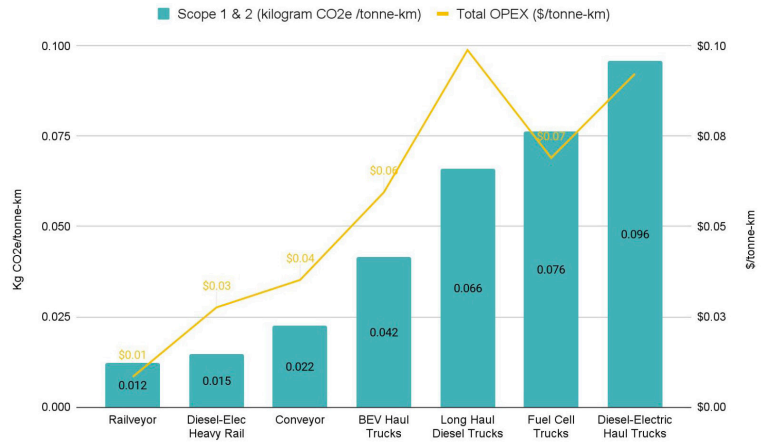


Figure 4. Chart from Warm Springs Consulting showing Railveyor as the estimated lowest cost per tonne-kilometre (tkm) and lowest Scope 1 and 2 GHG emitting solution between a variety of systems.

compare favourably and validate our decision to select Railveyor as our material haulage method at Goldex."

"Oftentimes, when new customers first encounter the energy efficiency offered by Railveyor, they find it hard to believe," added Railveyor Executive Vice President of Sales & Marketing, Nik Gresshoff. "We are proud to see that the CanmetMINING study of Railveyor's energy use validates our claims. We are even more pleased to be able to deliver that value to Agnico Eagle at Goldex."

Looking ahead to the future of energy-efficient haulage

In coordination with Agnico Eagle Mines and Railveyor, CanmetMINING presented a summary of the study at the Mining Diesel Emissions Council's (MDEC) 1st Annual Mining Vehicle Powertrain Conference (MVPC) held in early October 2023 in Toronto. Readers may view the presentation at mdec.ca/2023, under the title 'Mine Electrification Research: Goldex Railveyor Study'.

Throughout the next year, CanmetMINING may continue to expand on the conclusions of the study by conducting comparative analysis of competing haulage methods for presentation at major mining industry conferences.

Concurrently, Railveyor aims to make electrical demand estimates even more precise by incorporating learnings from the Canmet study into their engineering process. Next-gen Railveyor systems may deliver increased efficiency, due to the greater availability and more economic price point of drives supporting regenerative braking – a feature not selected for incorporation into the system at Goldex.

Railveyor is a solution that cuts across multiple issues for the modern miner. In addition to aiding decarbonisation, increased physical efficiency saves on energy cost. Railveyor's fully automated material haulage system allows for a mine to maintain or improve productivity in volatile and demanding labour markets. Moreover, removing workers from potentially hazardous material haulage areas diminishes risk and enhances safety.

"With the worrying context of climate change, it becomes important for the mining industry to reduce their production of greenhouse gases", says the report from CanmetMINING, "The use of the 'TrulyAutonomous' system is a concrete example of a system making it possible to achieve this target for mines that have access to a low-intensity GHG-emitting electricity grid. This technology has proven itself at Goldex mine." GMR

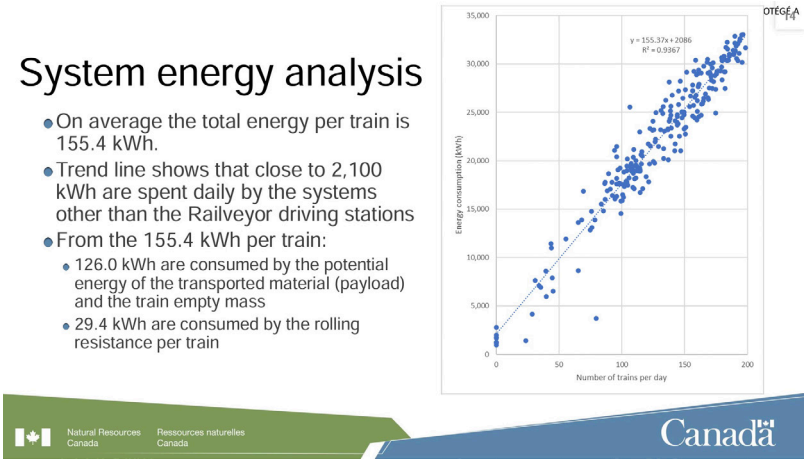


Figure 5. Chart from CanmetMINING presentation at MDEC showing a measured energy use trend line in the Railveyor system.

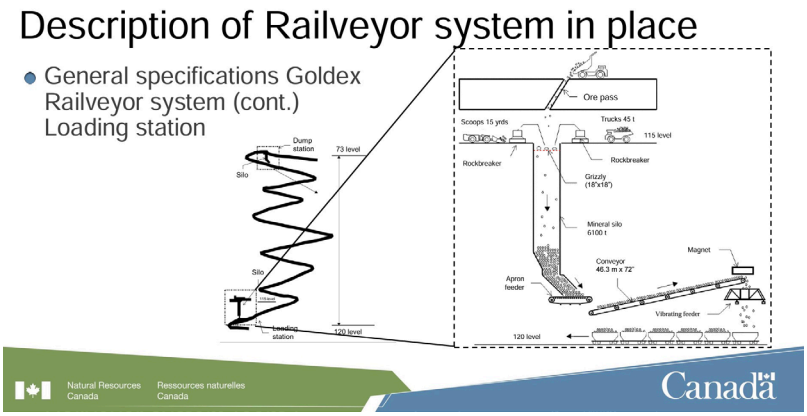


Figure 6. General overview of Railveyor material haulage system at AEM's Goldex mine.

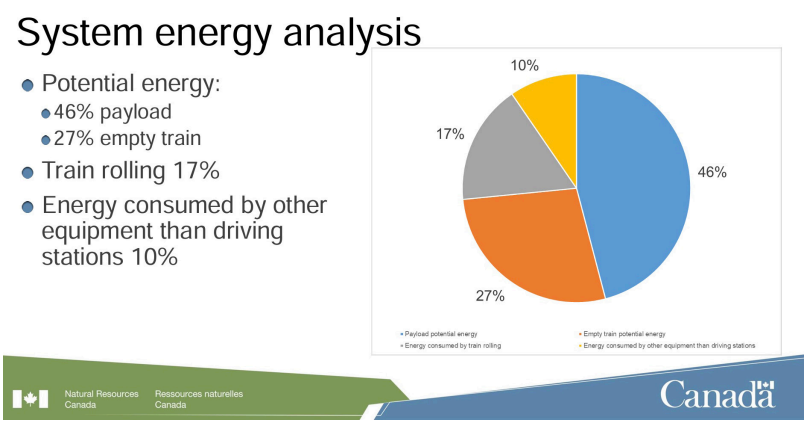


Figure 7. Railveyor system measured energy usage broken down by energy use category.

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