WARM SPRINGS Consulting LLC

MATERIALS TRANSPORT:

RACING TO NET ZERO

Comparing Haulage Options for Reduced Greenhouse Gas Emissions and Costs

3.11.2022

ACLYMATE CLIMATE LEADER Plus

Certified B Corporation

This company meets the highest standards of social and environmental impact

Contact: Amber Bieg
Phone: 208-918-1707
217 S. 11th St., Boise, ID, 83704
amber@warmspringsconsulting.com
www.warmspringsconsulting.com

Material Transport: Racing to Net Zero

Comparing Haulage Options for Reduced Greenhouse Gas Emissions and Costs

Authors: Amber Bieg, M.B.A; Mitch Samson, M.B.A, B.S.M.E.; Zach Bell, B.A.; Jay Schuyler, B.A., and Austin Zinsser, M.S., P.G.

Keywords: Energy Transition | Electric Mining | Electricity Supply | Sustainability

As the world progresses toward the renewable energy transition, the demand for minerals increases exponentially. According to the International Energy Agency (IEA) 2021 Net Zero by 2050 Report, critical mineral production needs to grow six times in order to combat climate change. The need for raw materials used in solar, wind, and electric vehicle infrastructure will lead to massive growth in the mining sector over the next two decades. It's estimated that four to seven percent of global greenhouse gas (GHG) emissions come from the mining sector's Scope 1 and 2 (direct and indirect) emissions. Including Scope 3 (upstream, downstream, and embedded) emissions, the sector accounts for 28% of global GHG emissions.

> **"Half of global emissions come from 50 companies, 20 of which are mining companies."**
>
> **- S&P Global Platts**

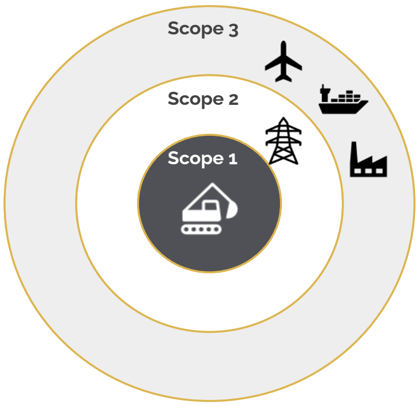
Purpose of This Study

The purpose of this study is to compare seven haulage options in terms of greenhouse gas emissions (GHG), using the methodology defined by the Greenhouse Gas Protocol Scopes 1, 2, and 3 (Category 2). Additionally, this analysis compares operating and capital costs associated with the seven haulage options (both emerging and proven technologies): 1) Diesel-Electric Haul Trucks, 2) Battery-Electric Haul Trucks, 3) Fuel Cell Haul Trucks, 4) Railveyor, 5) Diesel-Electric Heavy Rail, 6) Long Haul Diesel Trucks, and 7) Conveyor.

This analysis looks at both the emissions and costs associated with operating the equipment (fuel and electricity), the embedded emissions and costs associated with the construction and installation of the equipment itself, and the associated infrastructure (roads, powerlines, and rail). This study also compares these haulage systems in a hypothetical scenario as well as two real-world scenarios where mines have developed tradeoff studies specific to their sites.

While this analysis focuses on mining operations, the energy and emissions factors can be applied to haulage for other industries. The agricultural sector uses much of the same equipment and this study could inform ag sector haulage as well.

GHG Scopes



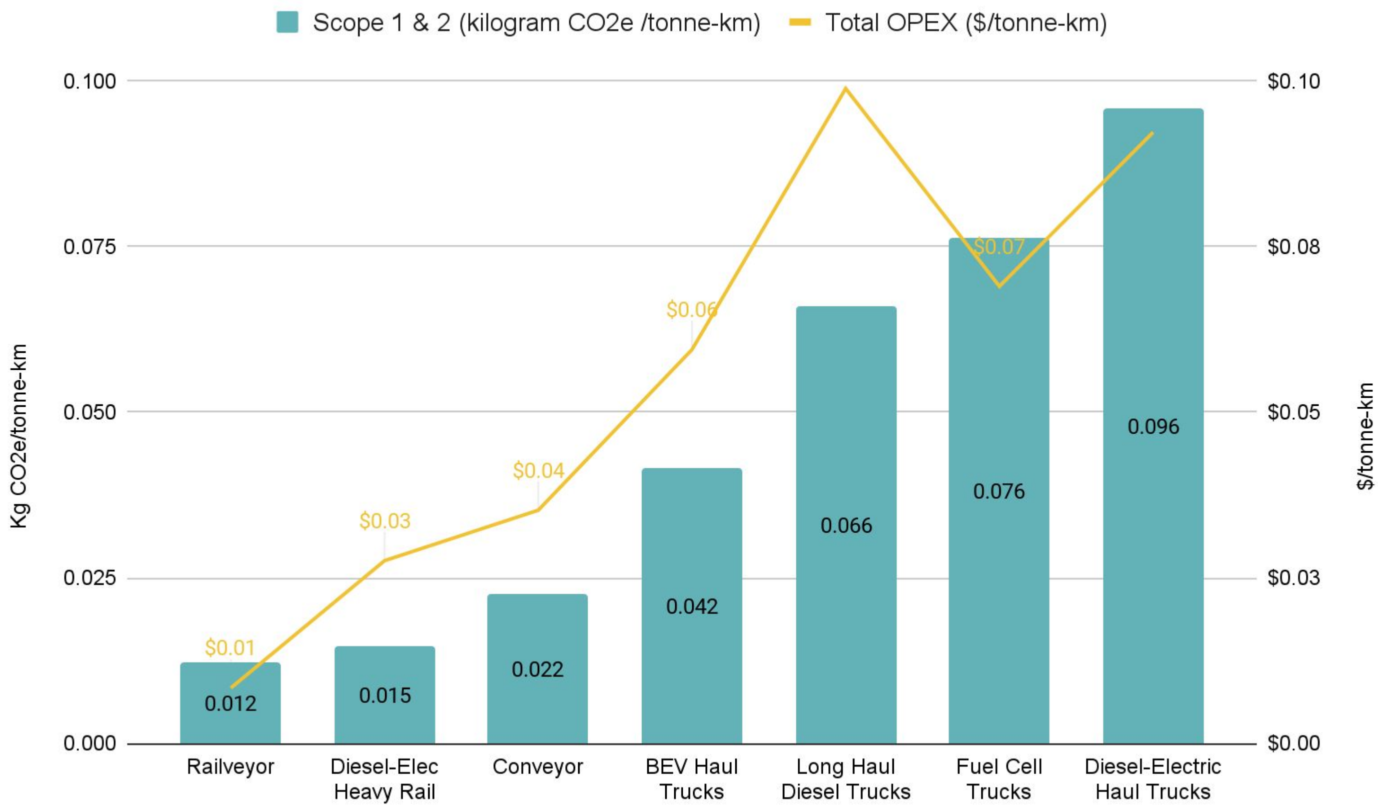
In a typical mining operation, diesel fuel is the biggest source of direct GHG emissions, and haulage is often the main source of diesel emissions. If a mine can electrify its hauling operations, it can significantly reduce GHG emissions and lower costs.

Large haul trucks have been the industry standard for over 50 years and offer flexibility, relatively low capital cost (especially with equipment lease options), and guaranteed technology with known maintenance.

The challenge will be to justify their continued use when there are more economical options that lead to significant reductions in GHG emissions.

Emissions & Costs

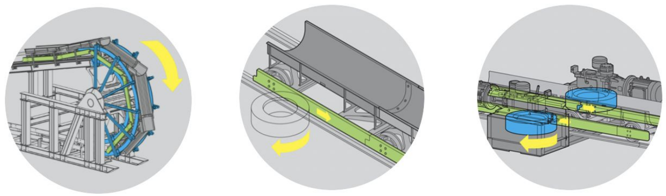
Diesel-electric haul trucks are estimated to have the highest GHG emissions of the specified hauling methods at 0.096 kilograms CO2e /tonne-km. This is directly related to the high emissions factor of diesel fuel and limited haul capacity per truck. The hauling method with the lowest emissions is the Railveyor system, with an estimated 0.012 kilograms CO2e /tonne-km.



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 $0.043 /tonne-km. Railveyor is estimated to have the lowest fuel operating cost at just $0.003 /tonne-km. The hauling method with the highest operating cost not including fuel cost is estimated to be long haul diesel trucks at $0.069 /tonne-km. The lowest non-fuel operating cost is estimated to be Railveyor at $0.005 /tonne-km. Section 2 (Haulage Analysis) of this report details the method of calculations and sources for the energy, costs and emissions factors.

Hitachi Truck with Trolley

Sandvik BEV Haul Truck

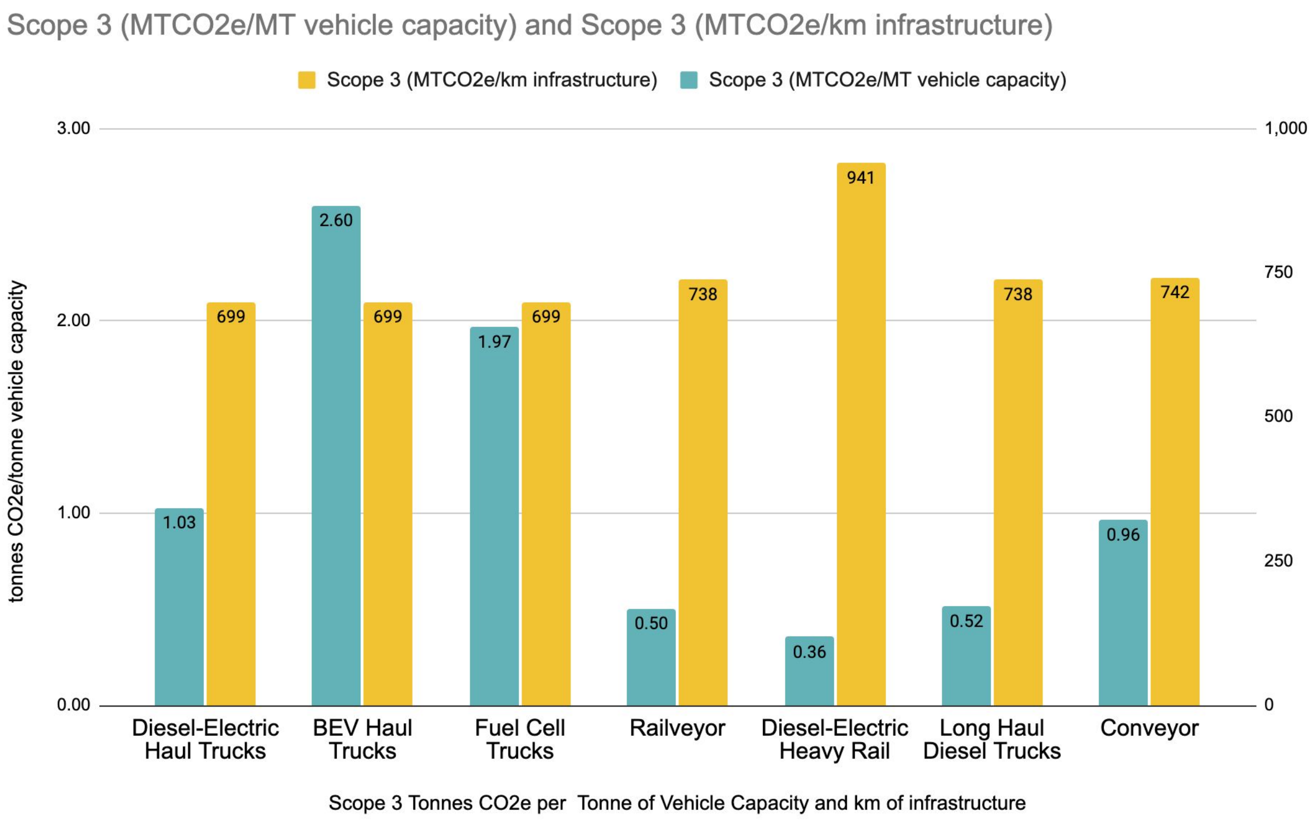


Railveyor System

Emissions & Costs

The hauling method with the highest embedded (Scope 3) emissions per tonne of vehicle capacity is estimated to be the battery electric vehicle (BEV) haul truck at 2.6 tonnes CO2e/tonne vehicle capacity. This is a result of emissions associated with the production of the battery used to power the vehicle. However, it is important to note that the Scope 2 emissions during the use phase of a BEV haul truck are half that of the diesel-electric haul truck.

The system with the lowest Scope 3 emissions per tonne of vehicle capacity is diesel heavy rail, estimated to be 0.36 tonnes CO2e/tonne vehicle capacity. This is a result of the material efficiency used in the rail cars, along with the high haul capacity of each vehicle. The embedded (Scope 3) emissions associated with the infrastructure required for each hauling method is the highest for Diesel-Heavy Rail, at 941 tonnes CO2e/km of infrastructure. This high emissions factor is heavily influenced by the amount of raw material and extensive installation operations required by rail infrastructure. The lowest emissions associated with infrastructure is estimated to be gravel haul roads, the infrastructure associated with diesel haul trucks, BEVs, and hydrogen fuel cell trucks at 699 tonnes CO2e/km of infrastructure.



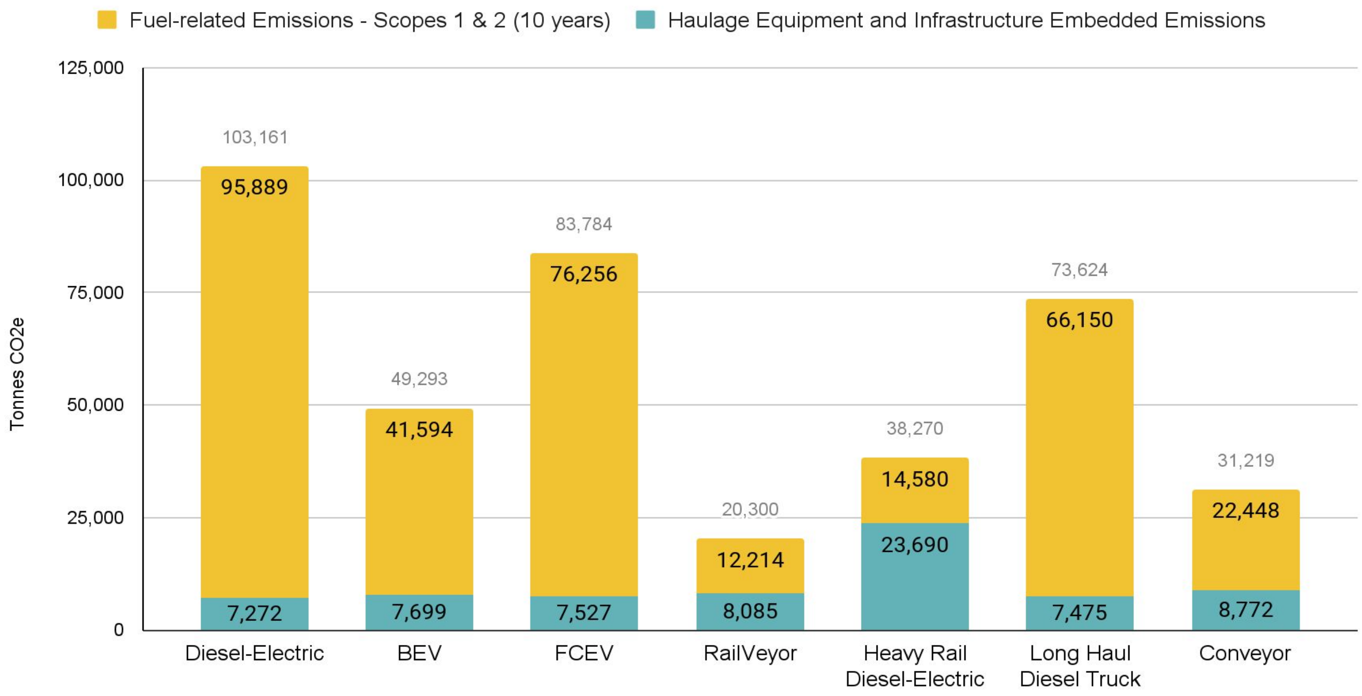
Diesel-Electric Heavy Rail

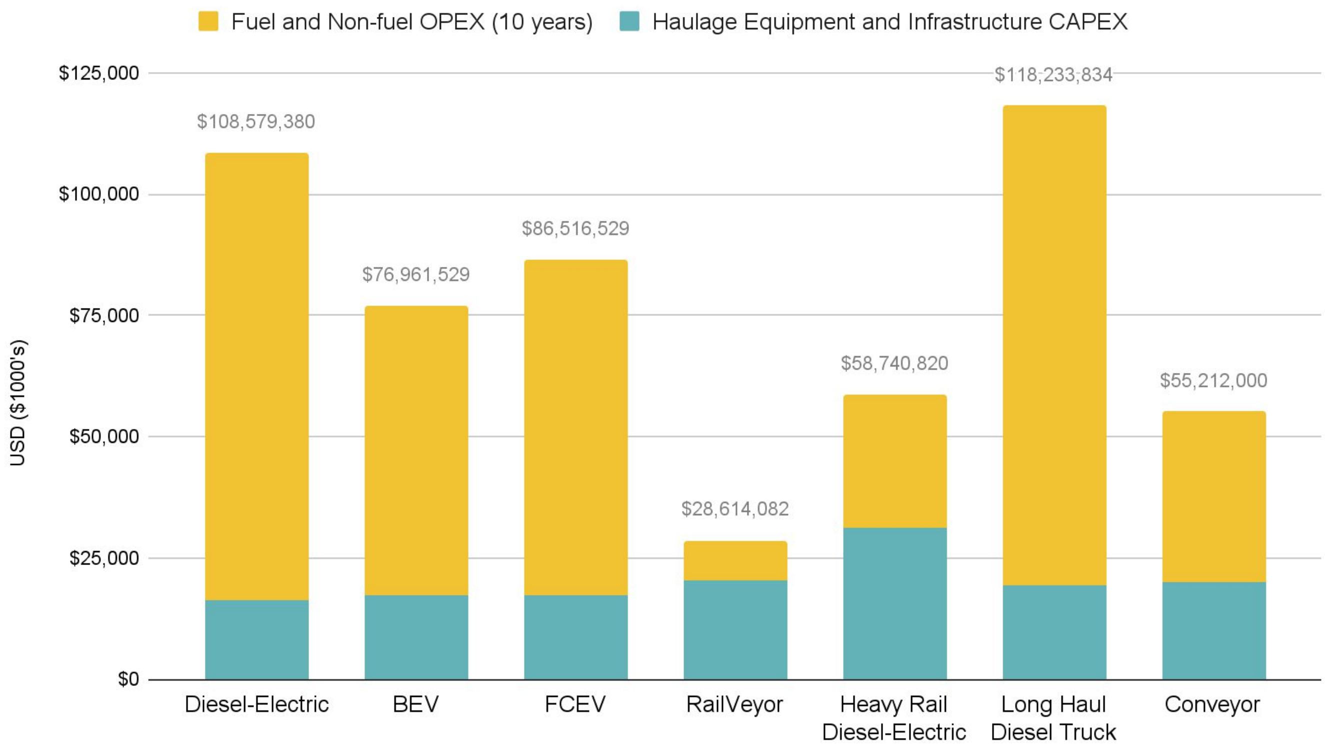
Long Haul Diesel Truck

Diesel-Electric Haul Truck

Apples to Apples Mine Scenario

While cost and emissions factors on a per tonne-km basis are valuable for comparative analysis, the comparison is easier to see in the context of an operation. The study team used a theoretical scenario of 10 million tonnes annually (~30k tonnes/day) and 10km. The chart below illustrates the overall ten year total emissions per haulage option.





About This Project

This project emerged from the work performed by the study team (Warm Springs Consulting's technical team) for the Integra DeLamar Prefeasibility Study. Over the 18 months of that project and various iterative analyses, it became evident that Railveyor had significantly lower fuel and non-fuel operating costs compared to diesel haul trucks - and perhaps other haulage systems. Over a series of conversations with Railveyor during the Integra DeLamar PFS, Railveyor inquired about developing a larger study to compare Railveyor to other haulage options. WSC's leadership saw a need for this type of study - as it would serve not only our work with other mining and agricultural clients, but it would provide valuable information to industries seeking pathways to net zero. This report is written for those who seek to reduce ghg emissions and costs in overland haulage systems.

The technical team at Warm Springs Consulting agreed to take on this project with some initial funding from Railveyor. Railveyor's sponsorship covered approximately one third of the total cost to develop this study. While Railveyor's team provided guidance, input and feedback, the company did not have editorial control over this study. The conclusions in this document are grounded in the data and calculations developed solely by Warm Springs Consulting's technical team.

Our goal in this endeavor is to provide valuable information around potential costs and emissions of various haulage systems to decision-makers in the mining sector. **The study team welcomes questions, revision suggestions and critique. If you would like to provide feedback and technical review for this study, please contact Aly Dritenbas** (aly@warmspringsconsulting.com), Business Manager and Research Coordinator at Warm Springs Consulting.

About The Study Team

The authors of this report are part of the technical team at Warm Springs Consulting, which mostly focuses on climate solutions for mining and large impact industries. As a team, we are all passionately committed to solving interesting problems - we see climate change as one of the most urgent and interesting problems of our time. We're engineers, economists, legal experts and philosophers that think about things in systems and take a holistic approach to our work. As both explorers and homebodies, we love to climb mountains and curl up with a good book. We have families of all shapes and sizes. On our wall, we hang degrees, certificates, kid drawings and a photo of our next adventure destination. We're introverts and extroverts, thinkers and feelers, and all the personalities that make up one amazing team.

Warm Springs Consulting (WSC) is an Idaho-based, internationally recognized, sustainability consulting firm that serves high-impact industries, businesses and governments by guiding clients in how to leverage sustainability as a strategic and profitable advantage. We support companies in significantly moving the needle on greenhouse gas (GHG) emissions reduction while achieving sustainable profits. Our diverse body of work covers sustainability strategy, economic feasibility studies, electrification analysis, GHG inventories, human-centered design solutions, climate resilience strategies, scenario planning, energy and waste planning, technology planning and deployment, communications, stakeholder engagement, and organizational training.

To learn more about the Warm Springs Consulting Team visit: www.warmspringsconsulting.com/team

Acknowledgements:

This report was made possible not just through the financial commitment of WSC and Railveyor, but also through the contributions of other individuals in the form of interviews, data, case studies, advice, review of calculations and content, and editing. The Warm Springs Consulting team would like to recognise and thank the following people for their support and contributions to this report:

Railveyor

Jim Fisk
James Hawkins
Matt Walton
Lisa Youngblood
Eric Zanetti

Integra Resources

Mark Stockton
Mike Spicher
Andree St. Germain

RESPEC

Tom Dyer

Mackay School of Earth Sciences and Engineering, University of Nevada, Reno

Ehsan Vahidi

WSC

John Gardner
Deborah LaSalle
Heather Colwell
Alaina Sisco

TABLE OF CONTENTS

1. Introduction and Context

As the world progresses toward the renewable energy transition, the demand for minerals increases exponentially. According to the International Energy Agency (IEA) 2021 Net Zero by 2050 Report, critical mineral production needs to grow four to six times in order to combat climate change.[1]

The need for raw materials used in solar, wind, and electric vehicle (EV) infrastructure is already causing an increase in mineral prices. Growth in market share of EVs and battery storage have caused a cascading surge in demand for lithium, nickel, and cobalt, as well as several other critical materials. At the same time there also is mounting pressure on the mining industry to commit to net-zero greenhouse gas (GHG) emissions, ensuring the minerals to support the clean energy economy are free of emissions.

The European Union (E.U.) is set to finalize a bill that will create a legally binding 2050 net-zero emissions target for companies operating in the E.U.[2] Climate legislation is advancing in North America (Canada and U.S.), and shareholders around the globe are demanding change. With the inevitable growth in the mining sector, coupled with the need to decarbonize, there is a race to net-zero.

1.1 What Is GHG Net-zero Mining?

Carbon or GHG net-zero mining is where all fuel and energy come from renewable sources, free of GHG emissions, and the upstream and downstream emissions associated with mining activities are mitigated. According to the Net Zero by 2050 report from the International Energy Agency (IEA), "The world has a viable pathway to building a global energy sector with net-zero emissions in 2050 . . . it requires a complete transformation of how we produce, transport and consume energy, with a large deployment of renewable energy and an end to sales of internal combustion engines by 2035."

GHG emissions are divided into three scopes, as shown in the image to the right and described in the table on the following page.

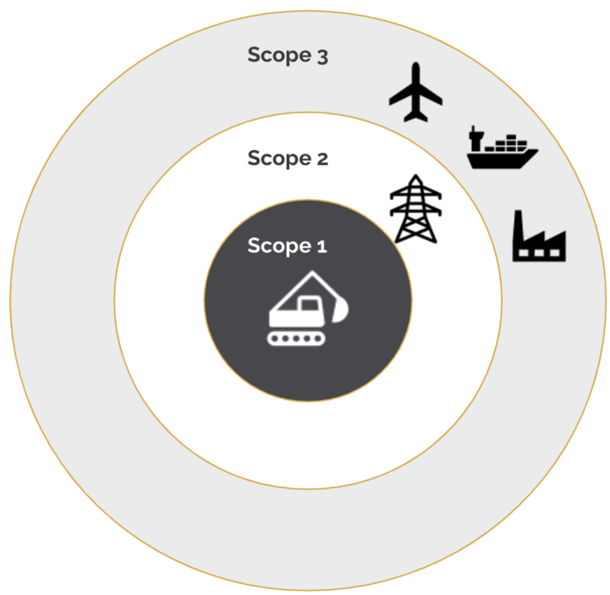


Image 1: GHG Emissions Scopes

[1] IEA. (2021, May). *Net Zero by 2050*.
[2] Fankhauser, Sam. *The Eu's New Climate Law Lays the Groundwork for Net Zero*. July 22, 2021.

Table 1: GHG Emissions Scope Definitions

Scope	Definition	Examples
Scope 1: Direct Emissions	Emissions from operations that are owned or controlled by the reporting company.	Emissions from direct operations, such as: • Equipment, vehicles, etc. and/or • Emissions from chemical production in owned or controlled process equipment
Scope 2: Indirect Emissions	Emissions from the generation of purchased or acquired electricity, steam, heating or cooling consumed by the reporting company.	Use of purchased electricity, steam, heating or cooling, often from a utility or energy service provider.
Scope 3: Indirect Emissions	All indirect emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.	Emissions from the transportation of purchased products or the use of sold products. In the mining sector this also includes emissions associated with the production of equipment, as well as with transportation and distribution of materials.

1.2 How Significant Are Emissions from Mining?

Emissions from the mining sector are significant in the context of global GHG emissions. "Mining is responsible for four to seven percent of global GHG emissions in terms of the sector's Scope 1 and Scope 2 emissions. Including Scope 3 emissions links, the sector contributes to around 28% of global emissions."[3] This scenario has created an increased demand for transparency, traceability, and lower emissions by mining customers, investors, and government entities. Given the ever-growing awareness around GHG emissions and climate change, mining companies and other GHG emitters likely will only face more scrutiny in the years to come. And, as always, money talks; while regulatory bodies may move slowly in their efforts to curb emissions, shareholders are not as patient. If a move toward more sustainable operations can help ease public pressure, build trust, reduce scrutiny and, in turn, improve the bottom line, shareholders will demand it. Investors are placing pressure on mining companies to take responsibility for Scopes 1, 2 and 3. Larry Fink, chief executive at BlackRock, the world's largest fund manager, said "climate risk is investment risk," and in 2020 published a letter stating the group would "place sustainability at the center of its investment approach."[4] Climate Action 100+, an investor-driven initiative, already has 450 signatories and

[3] Delevingne, L., Glazener, W., Grégoir, L., & Henderson, K. (2020, January 28). *Climate risk and decarbonization: What every mining CEO needs to know*. McKinsey Sustainability.
[4] Fink, L. (2020). *Larry Fink CEO letter*. BlackRock.

represents over $40 trillion in assets. The initiative is focused on getting high-emission companies to agree to net-zero targets. Allison Forest, responsible investment officer at Resource Capital Funds, and giving the keynote talk at the American Exploration & Mining Association (AEMA) Conference in Reno, Nevada, stated "if mining companies want to get capital from us and other institutions like us, climate disclosure is important."

1.3 Climate Change Risks to Mining Sector

The mining sector is particularly vulnerable to climate change and climate change mitigation is in the sector's best interest. "Trucost research, which analyzed mines owned by the top 20 miners by market capitalization, showed that on average, 11% of the mines' profits could be at risk by 2025 due to potential increases in carbon regulation costs and higher water costs due to changes in climate."[5] In 2019, 96 institutional investors representing $10.3 trillion in assets issued an open letter to 658 mining companies requesting public disclosure on 20 specific questions about climate risk related to tailings dams.[6]

Stakeholder trust and shareholder investment are strongly linked and at risk in the mining sector due to climate concerns. As the world wakes up to the impacts of climate change, stakeholders are demanding all companies across global value chains to take action. "Mining companies should recognize that there is a correlation between stakeholder sentiment and company valuation," said Henry Stoch, Partner and the Risk Advisory and National Sustainability and Climate Change Leader at Deloitte Canada.[7] "Companies that fail to commit to a decarbonization agenda could find their share prices affected, which strengthens the case for decarbonization."

1.4 Evolving Priorities of Mining Companies

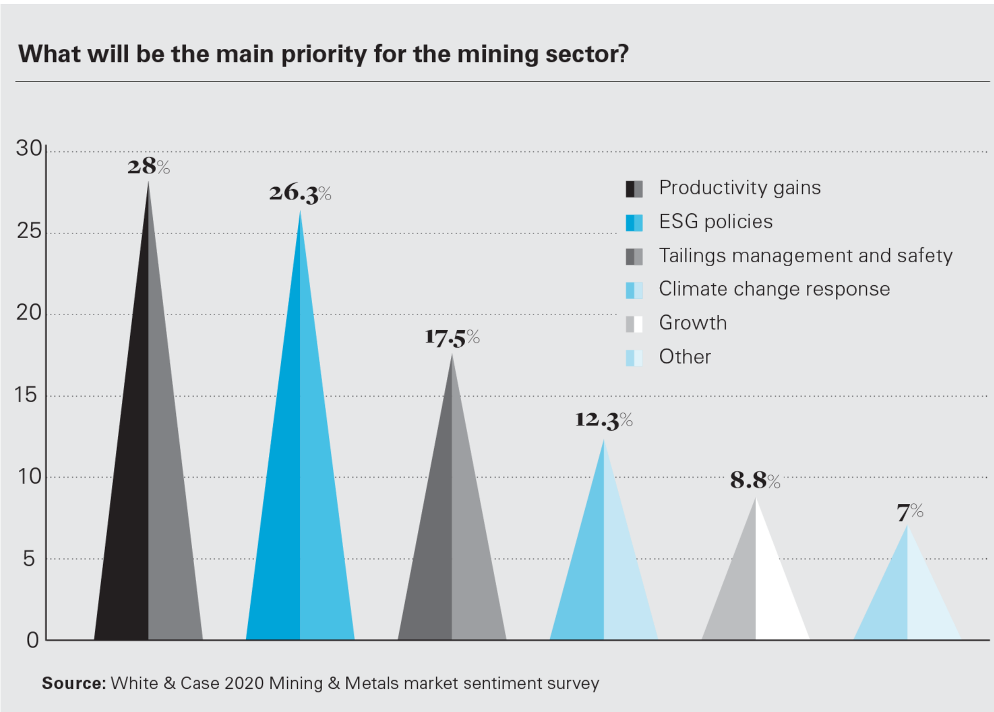
$2bn by 2030
Brazil's Vale SA commitment to reduce emissions

Mining companies are listening to stakeholder and shareholder demands for decarbonization. Along with a dozen top mining companies such as BHP, Vale SA, and others, Anglo American in Australia CEO Tyler Mitchelson committed the company to carbon neutral operations by 2040, with the aim to reduce Scope 3 emissions by 50% in the same timeframe.[8] In doing so, the company has taken on large initiatives, including the development of a 220 tonne hydrogen fuel cell haul truck in partnership with Engie, NPROXX, First Mode, Williams Advanced Engineering, Ballard, ABB, Nel, and Plug Power.[9] "Displacing our use of diesel is critical to eliminating emissions at our sites and along our value chain. We believe that our innovative hydrogen-led

[5] Kuykendall, T. (2020, July 28). *Path to net zero: Miners are starting to decarbonize as investor pressure mounts*. S&P Global Market Intelligence.
[6] Owen, J. R., Kemp, D., Lèbre, É., Svobodova, K., & Pérez Murillo, G. (2020). *Catastrophic tailings dam failures and disaster risk disclosure*. *International Journal of Disaster Risk Reduction, 42*.
[7] Deloitte. (2021). *Tracking the trends 2021: Closing the trust deficit*. Deloitte Insights.
[8] Iannucci, E. (2021, December 13). *Anglo American and Aurizon study hydrogen trains*. Mining Weekly.
[9] Preyser, J. (2021, December 21). *Miners experiment with hydrogen to power giant trucks*. BBC News.

technology provides a versatile solution, whether for trucks or trains, or other forms of heavy-duty transport," says Anglo American's Technical Director Tony O'Neill.

Chart 1: White & Case 2020 Survey of Mining & Metals Priorities



It's not just the largest mining companies that are taking action. According to a 2020 White & Case survey of mining sector companies, over 26% of respondents said Environmental, Social, and Governance (ESG) policies will be the main priority for the mining sector, and over 12% said climate change response would be the top priority.

When combined, ESG and climate change response emerge as the top priorities for mining companies. This makes sense given the mining sector's unique climate change vulnerability from both a financial standpoint, stakeholder concern, and physical infrastructure risk.

1.5 Why Haulage Matters in Reducing GHG Emissions

For most mines, Scope 1 and 2 emissions come from energy used in mining operations, either in the form of fuel or electricity. These are also among the top operational expenditures (OPEX). If a mine can reduce Scope 1 emissions or move emissions from Scope 1 (emissions from the burning of fossil fuels) to Scope 2 (emissions from the purchase of electricity), the pathway to net zero emissions opens up, often resulting in OPEX savings.

> **"Half of global emissions come from 50 companies, 20 of which are mining companies."**
>
> **- S&P Global Platts**

In the mining sector, diesel fuel is the biggest source of direct GHG emissions, and haulage often represents the largest source of diesel emissions. Where a mine can electrify its hauling operations, it can significantly reduce GHG emissions and lower costs. Large haul trucks have been the industry standard for over 50 years and offer flexibility, relatively low capital cost (especially with equipment lease options), and guaranteed technology with known maintenance. With the emergence of adaptable, affordable, and reliable electric hauling options that improve a mine's overall economic performance and lower emissions, the challenge will be to justify the continued use of diesel.

When fuel switching (from diesel to electric or hydrogen) to reduce GHG emissions, the new fuel source is likely cleaner and cheaper than burning diesel. In most places, electricity is both cheaper and cleaner than diesel. As the world continues to decarbonize the grid, renewables are becoming a larger share of the grid mix. In 2020, according to a report from the World Economic Forum, renewables (solar and wind) became the cheapest form of energy.[10]

In places where grid electricity is more expensive or unavailable, onsite renewables can be a cost-competitive option. The Integra DeLamar Mine published a feasibility study in March 2022, in which the WSC technical team compared a large line upgrade to a solar, battery and natural gas generator microgrid for a mine site in Southwest Idaho. The levelized cost of energy (LCOE) for the microgrid was 64% less than the LCOE for the line upgrade and energy purchase from the utility.

Section 2 of this paper analyzes the emissions and cost tradeoffs between seven haulage systems used in mines: 1) Diesel-Electric Haul Trucks, 2) Battery-Electric Haul Trucks, 3) Hydrogen Fuel Cell Haul Trucks, 4) Railveyor, 5) Diesel-Electric Heavy Rail, 6) Long Haul Diesel Trucks, and 7) Conveyor. This analysis looks at both the emissions and costs associated with operating the equipment (fuel and electricity), as well as the embedded emissions and costs associated with the construction and installation of the equipment itself, and the associated infrastructure (roads, powerlines, and rail). Section 3 presents two cases where mines have developed tradeoff studies specific to their sites and operations, looking at various haulage options. The conclusions and results are detailed in Section 3.

[10] Masterson, V. (2021, July 5). *Renewables were the world's cheapest energy source in 2020*. World Economic Forum.

2. Haulage Systems GHG Emissions Analysis

2.1 Objective and Scope

The objective of this analysis is to compare seven primary haulage options for the mining sector in terms of GHG, using the inventory methodology defined by the Greenhouse Gas Protocol Scopes 1 and 2, for direct and indirect emissions. This analysis also includes Scope 3 (Category 2) for embedded emissions in the manufacturing of the equipment and associated infrastructure. Additionally, this analysis compares operating and capital costs associated with the seven haulage options.

The scope of this analysis is limited to GHG emissions and operating costs related to fuel, maintenance, and operation of equipment, as well as the upfront capital costs associated with equipment purchase and installation. For GHG emissions, the boundaries are direct emissions from the burning of fuel (Scope 1), indirect emissions from the consumption of electricity (Scope 2), and upstream embedded emissions associated with the manufacturing of the equipment (Scope 3, Category 2), as well as the materials and construction of infrastructure such as roads, powerlines, and rail.

The calculated emissions factors published here can be used to estimate high-level emissions of a mining operation. A company's operations can have one or many haulage options to account for variation in distance, topography, geography, and other site conditions. The range of haulage methods analyzed are not all considered direct replacements of one another. Instead, the emissions factors specific to complementary long distance and short distance haul methods are meant to estimate different portions of the supply chain. The emissions factors in this study (GHG emissions per tonne-km) are designed as a comparative estimating tool and should not be the primary source for accounting or disclosure. It is also important to note that these emissions and operating cost factors are for a zero percent grade scenario, for simplicity in comparing apples-to-apples. For a full and complete analysis, grade, schedule, and power source are aspects that need to be considered. Special consideration should also be given to different haul lengths and how operating expenses like fuel, labor and maintenance would scale (which is not linear).

2.2 Methodology, Assumptions, and Frameworks for Comparing Haulage Systems

In evaluating GHG emissions associated with each haulage option, the study team used the internationally recognized Greenhouse Gas Protocol and ISO 14064 for Greenhouse Gas Inventories and Reporting for Scopes 1 and 2 and ISO 14044 for Life Cycle Assessments (LCAs) for the embedded GHG emissions associated with the equipment and infrastructure. All emissions factors were derived from peer-reviewed databases such as the U.S. EPA GHG Emission Factors, the Chalmers University LCA Database, and other published LCAs. All data and references are documented as footnotes. Some emissions factors such as infrastructure GHG emissions per kilometer are sourced from LCAs, whereas others such as direct, Scope 1, emissions for diesel haul trucks were calculated from the fuel economy values provided by the equipment manufacturer and EPA emissions factors to arrive at a kilogram of CO2e per tonne-km. The study team developed a complete cost and emissions factor calculator for each haulage option. The scenario variables are distance and tonnes/year. The calculator was used to develop the hypothetical scenario for comparing each system apples-to-apples.

The team used a limited set of variable cost assumptions (which are subject to market fluctuations) to develop cost calculations. The team used spot pricing for February 22, 2022, with diesel prices at $1.22/liter, and carbon at $50/tonne. Diesel emissions are converted from metric tonnes (equal to 1000 kg) of CO2e per gallon to metric tonnes of CO2e per liter, derived from the mobile combustion emissions for diesel EPA factors table.

The emissions factor for diesel used in this study is 0.0027 tonnes CO2e/liter. All Scope 2 emissions factors are calculated using an average energy grid emissions factor for the U.S., Canada and Mexico, at 0.33 kilograms CO2e per kWh. The study team used North American emissions factors for electricity, as many of the clients and projects the team works with are in North America. Appendix A contains a full list of key assumptions used in this study. All calculations are based on a kWh/tonne-km value, which could have any region's emission factor applied. The chart below shows the factors from each country and data sources for each emission factor.

Table 2. Emissions Factors for Diesel and Electricity

Emissions Factors	Value	Unit	Source
Diesel mobile combustion emissions factor	0.0102	mtco2e/gal	2020-EPA-CCL Emissions-Factors-GHG-Inventories | Table 4
Diesel emissions factor	0.0027	mtco2e/liter	Calculated from gallons to liters
Average U.S. Electricity Emissions Factor	0.00040	mt/kWh	EPA eGRID2019(DY 2019) (Feb 2021)
Average Canada Electricity Emissions Factor	0.00013	mt/kwh	2019 - National Inventory Report: 1990 - 2017 - Environment and Climate Change Canada | Table A13
Average Mexico Electricity Emissions Factor	0.00046	mt/kwh	https://www.climate-transparency.org/wp-content/uploads/2017/07/B2G2017-Mexico.pdf
Average North America Emissions Factor	0.00033	mt/kwh	Average of U.S., Canada and Mexico.

Scope 1 and 2 emissions factors have been presented in kilograms (kg) CO2e, as the metric tonne kilometer (tonne-km) is the international standard for evaluating various haulage systems. While GHG emissions are frequently presented in metric tonne (MT) of C02e, in this case the values (tonne of CO2e per tonne-km) are very small and therefore it is hard to discern relative differences, hence kilogram (kg) is used in lieu of tonnes.

Scope 3, Category 2 is being taken into account for embedded emissions in materials and infrastructure. Scope 3, Category 3, the emissions associated with the extraction and distribution of energy consumed, is not being taken into consideration. Scope 3, Category 3 data was not readily available, particularly for comparing the emissions associated with transporting hydrogen. However, the emissions associated with the production of hydrogen was assigned as a Scope 2 calculation, assuming that hydrogen would be produced onsite.

It is important to note that the embedded emissions associated with transportation infrastructure is being counted here in order to better compare these various haulage options. This is due to the fact that some haulage options, like conveyors, do not have separate equipment apart from the infrastructure. Some of the embedded emissions associated with roads, rail and conveyors can be counted either as a Scope 1 or 2, or Scope 3 for reporting, depending on who constructs and/or owns the infrastructure. In most scenarios, associated transportation infrastructure is not counted, unless calculated by the reporting company.

The following section summarizes the comparative emissions and cost calculations. It is number-heavy and intended for use in developing high-level estimates for costs and emissions in various haulage scenarios. While this analysis may be a tool for helping companies estimate GHG emissions and costs for various scenarios, it is not designed to be a tool for reporting.

Note: when referring to vehicle capacity, both imperial tons and metric tonnes are used, depending on which equipment is being referenced. The study team kept the haulage capacity definition in its original terms as a descriptor of the equipment, but converted any imperial tons to metric tonnes for calculating emissions, cost and energy consumption.

2.3 Haulage Systems GHG Emissions and Cost Comparison Summary

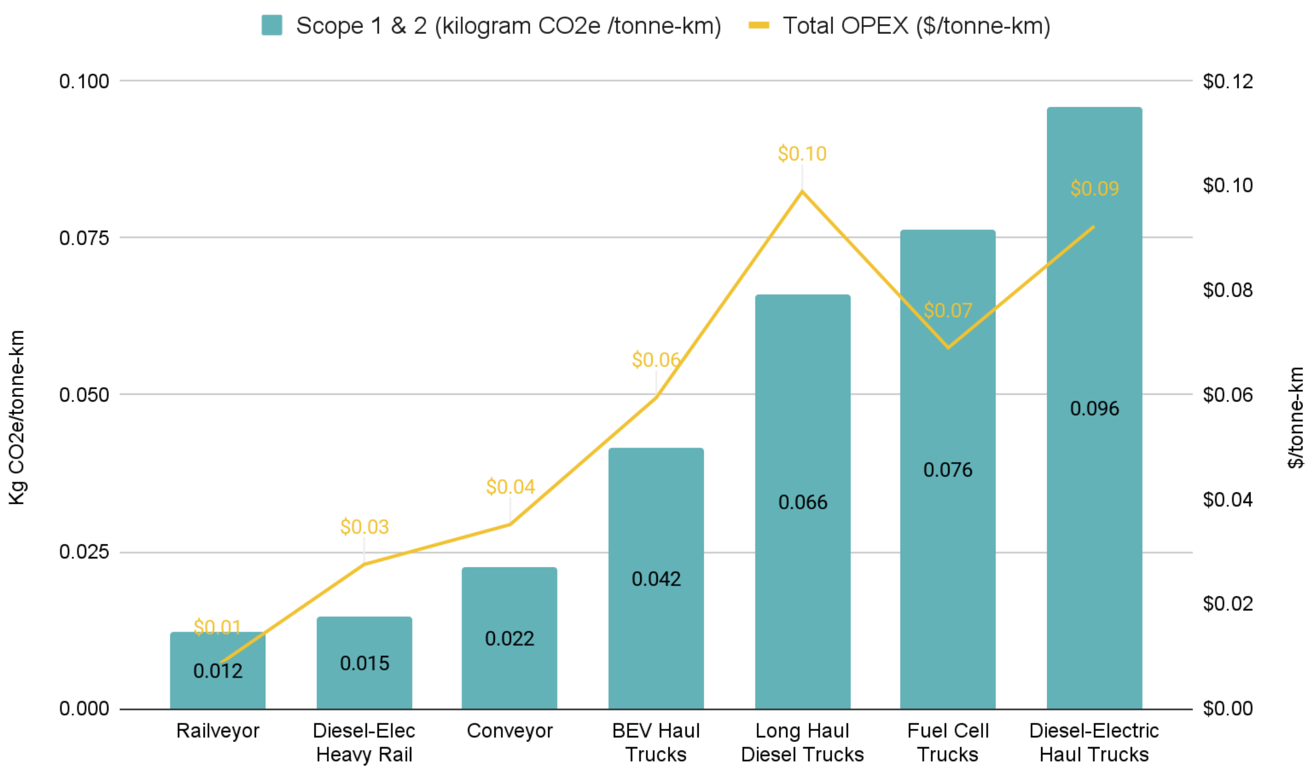
2.3.1 Scope 1 &2 Direct and Indirect Emissions and

Diesel-electric haul trucks are estimated to have the highest GHG emissions of the specified hauling methods at 0.096 kilograms CO_2e /tonne-km. This is directly related to the high emissions factor of diesel fuel and limited haul capacity per haul truck. The hauling method with the lowest emissions is the Railveyor system, with an estimated 0.012 kilograms CO_2e /tonne-km. Fuel switching from diesel to electricity along with scalable haul capacity allows Railveyor to surpass all other haul methods in terms of efficiency. All electricity-fueled vehicle emissions factors are site specific as the emissions from electricity generation depends on location.

2.3.2 Fuel and Non-fuel Operating Costs

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 $0.039 /tonne-km. Railveyor is estimated to have the lowest fuel operating cost at just $0.003 /tonne-km. The hauling method with the highest non-fuel operating cost is estimated to be long haul diesel trucks at $0.07/tonne-km. The lowest non-fuel operating cost is estimated to be Railveyor at less than $0.01/tonne-km, considerably lower than any other hauling method included in this analysis. This is due to autonomous operations and relatively low maintenance costs.

Chart 2: Haulage Systems GHG Emissions and OPEX Per Tonne-Km



2.3.3 Scope 3, Category 2 Embedded Emissions by Vehicle Capacity

The hauling method with the highest Scope 3 emissions per tonne of vehicle capacity is estimated to be the Battery-Electric Haul truck (BEV) at 2.6 tonnes CO2e/tonne vehicle capacity. This is a result of emissions associated with the production of the battery used to power the vehicle. However, it is important to note that the Scope 2 emissions during the use phase of a BEV Haul truck are half that of the Diesel-Electric Haul truck. The system with the lowest Scope 3 emissions per tonne of vehicle capacity is Diesel-Heavy Rail, estimated to be 0.36 tonnes CO2e/tonne vehicle capacity. This is a result of the material efficiency used in the rail cars, along with the high haul capacity of each vehicle.

2.3.4 Scope 3, Category 2 Infrastructure Embedded Emissions

The Scope 3 emissions associated with the infrastructure required for each hauling method is the highest for Diesel-Heavy Rail, at 941 tonnes CO2e/km of infrastructure. This high emissions factor is heavily influenced by the amount of raw material and extensive installation operations required by rail infrastructure. The lowest emissions associated with infrastructure is estimated to be gravel roads (typical of a mine haul road) at 699 tonnes CO2e/km.[11] This makes sense, as grading requires no steel or other materials and the emissions associated with the gravel road is largely due to direct emissions from grading equipment.

Chart 3: Comparison of Haulage Systems Vehicles and Infrastructure Scope 3 Embedded Emissions

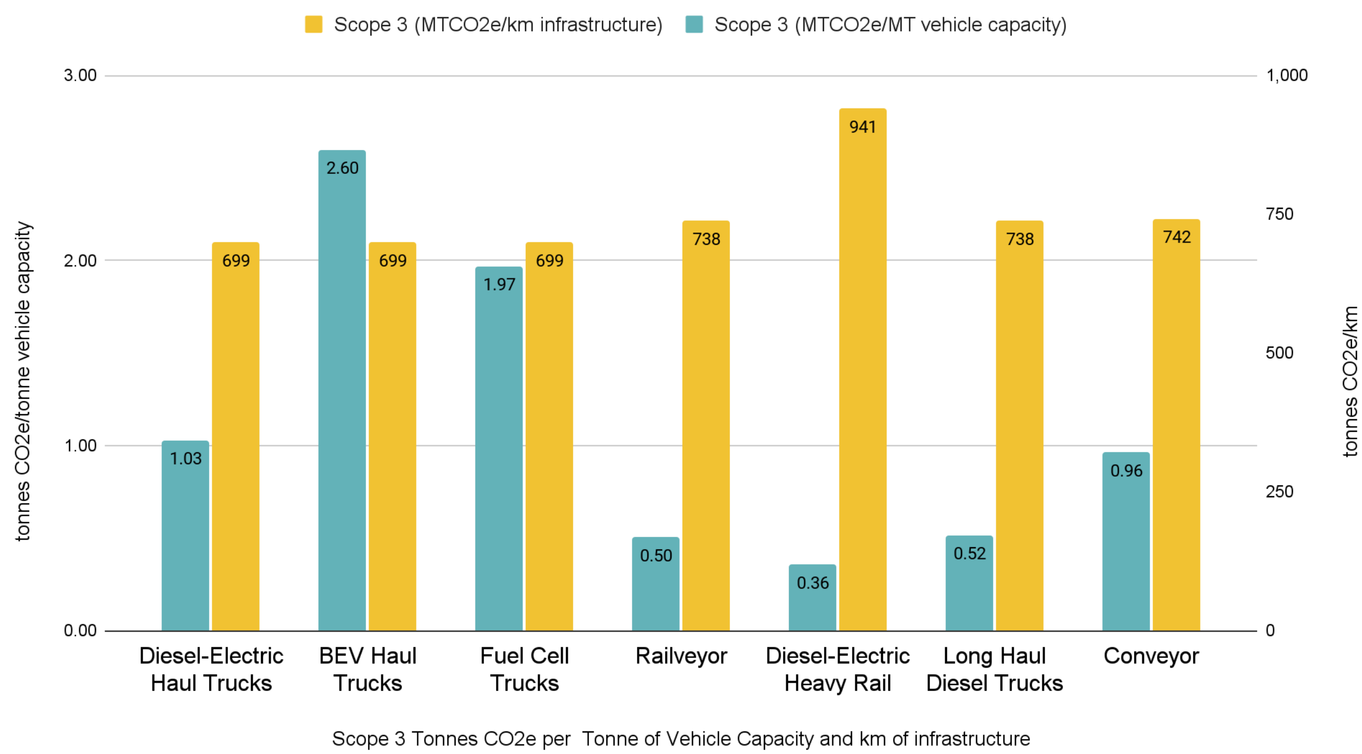


Table 3. Haul System GHG Emissions and Cost Comparison

	Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne -km

[11] Dillon Consulting. (2017). Manitoba infrastructure remote road operations: Greenhouse gas follow-up assessment.

Diesel-Electric Haul Trucks	0.096	$0.039	$0.053	1.03	699	$0.163
BEV Haul Trucks	0.042	$0.011	$0.048	2.60	699	$0.175
Hydrogen Fuel CellTrucks	0.076	$0.021	$0.048	1.97	699	$0.175
Railveyor	0.012	$0.003	$0.005	0.50	738	$0.202
Diesel-Electric Heavy Rail	0.015	$0.007	$0.021	0.36	941	$0.312
Long Haul Diesel Trucks	0.066	$0.030	$0.07	0.52	738	$0.193
Conveyor	0.022	$0.006	$0.029	0.96	742	$0.200

2.4 Haul Options Emissions Details

2.4.1 Diesel-Electric Haul Trucks

2.4.1.1 Diesel-Electric Haul Trucks Description

Diesel-electric haul trucks feature a diesel generator supplying power to an electric motor rather than a rigid drive train. This type of powertrain is an industry standard today because of its start/stop capability and motor efficiency. In addition, electric drive means fewer mechanical components and less maintenance, which can help improve truck availability and lower lifecycle cost.[12] Fuel efficiency for these vehicles is dependent on a number of factors such as grade resistance, traction, altitude, and more. Average fuel use estimates based on load factors can be calculated for these vehicles, but actual values will vary from site to site. Estimated fuel consumption for three payload capacity trucks are summarized in the table below, assuming a moderate consumption scenario.

Image 2. CAT Diesel Haul Truck

Table 4. Fuel Consumption by Capacity and Load Factor for Diesel Haul Trucks

Capacity (tons)	Hourly Fuel (L/hr)	Load Factor*
150	80-107	37%
200	106-142	37%
250	146-194	37%

**Load factor is "the ratio of the average load to total vehicle freight capacity, in tonnes or volume" (EEA, 2001), where the load is expressed as tonne-km (t-km) and capacity as vehicle-km (v-km).*

2.4.1.2 Diesel-Electric Haul Trucks Market Availability

Diesel-electric haul trucks, also known simply as diesel haul trucks have been available in all markets for many decades. Diesel-powered vehicles are currently the most widely used haulage system in mining. Haul trucks with payloads ranging from 20-400 tons are available from major manufacturers that include Sandvick, Epiroc, CAT, Komatsu, Belaz, Hitachi, and others.

[12] Komatsu. (n.d.). *730E-10 Electric Drive Mining Truck*. Retrieved February 1, 2022.

The estimated capital costs for these vehicles are based on direct conversations with manufacturers. Costs associated with the required infrastructure, capital costs per tonne-km, have been calculated from existing case studies.[13] Diesel-Electric Haul Trucks operating costs include fuel and non-fuels costs like maintenance and labor. Fuel cost is estimated from an assumed price of fuel and equipment manufacturer feedback on fuel consumption. Equipment operator and maintenance costs are derived from a case study.[14]

2.4.1.3 Diesel-Electric Haul Trucks Scope 1: Direct Emissions

Scope 1 emissions for diesel-electric vehicles were calculated using 2020 EPA emissions factor of 0.0027 $MTCO_2e$/liter for diesel fuel and the estimated fuel consumption (hourly fuel and percent load) per tonne-km.[15] These emissions assume a 150 ton haul capacity truck.

2.4.1.4 Diesel-Electric Haul Trucks Scope 2: Indirect Emissions

Diesel haul trucks consume no grid electricity, therefore have no Scope 2 emissions.

2.4.1.5 Diesel-Electric Haul Trucks Scope 3: Embedded Emissions in Equipment and Infrastructure

The embedded emissions associated with the production of large haulage vehicles has been studied by Swedish heavy-duty vehicle manufacturer Scania.[16] This study takes into consideration the extraction of raw materials, production of components, and the assembly of these vehicles. Based on the Scania study, the team calculated an emissions factor of 1.03 $MTCO_2e$/tonne of vehicle weight. This factor is used for the Scope 3 estimates of $MTCO_2e$/tonne vehicle capacity. The embedded emissions associated with the required road infrastructure were calculated based on a study in Manitoba, Canada, detailing the embedded emissions for an all-season gravel road. These emissions include the production of materials and use of equipment during the construction of the road.[17] The chart below details the emissions factors for diesel electric haul trucks.

Table 5. Emissions Factors and Fuel and non-Fuel Cost Factors for Diesel Haul Trucks

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne -km
0.096	$0.039	$0.053	1.03	699	$0.163

[13] Tetra Tech. (2013). [Canada Chrome Corporation rail v/s road tradeoff study]().
[14] Tetra Tech. (2013). [Canada Chrome Corporation rail v/s road tradeoff study]().
[15] U.S. Environmental Protection Agency. (2020). *Emissions factors for greenhouse gas inventories*. EPA Center for Corporate Climate Leadership.
[16] Burul, D., & Algesten, D. (2021). *Life cycle assessment of distribution vehicles: Battery electric vs diesel driven*. Scania.
[17] Dillon Consulting. (2017). *Manitoba infrastructure remote road operations: Greenhouse gas follow-up assessment*.

2.4.2 Battery-Electric Haul Trucks

2.4.2.1 Battery-Electric Haul Trucks Description

The use of BEVs significantly increases energy efficiency in mining operations by better utilizing energy stored in batteries rather than energy stored in fuel. BEVs more effectively convert stored energy to electrical motors which is why they are more operationally efficient than combustion engine vehicles, while eliminating tank-to-wheel emissions. According to operators that have used BEVs and in field tests by operating equipment manufacturers (OEMs), BEVs have shown to be significantly faster than their diesel counterparts. Sandvik presented a chart at the 2022 Electric Mine Conference in Stockholm that showed a speed comparison of BEVs to diesel haul trucks fully loaded at different grades.

Image 3. Hitachi Truck with Trolley Assist

According to Sandvik, the BEV truck (fully loaded) was able to climb an eight percent grade at nearly twice the speed of the diesel truck. At zero grade, the speed was 20% faster. While in the personal EV market, charging systems are a big conversation and charging times have been identified as a concern in technology transition. Most OEMs have found a solution in this space. Charging technology depends on the manufacturer. Some companies, like Sandvik, have implemented battery swapping technology whereas others, like Hitachi, have partnered with companies like ABB who produce electric trolley infrastructure for on-the-go charging.

Image 4. Sandvik BEV Articulated Haul Truck

2.4.2.2 Battery-Electric Haul Trucks Market Availability

In underground operations, BEVs are well-established with underground fleets deployed around the world. BEVs are safer than diesel equipment, especially in ventilation-constrained environments where carbon monoxide poisoning is a risk with diesel and gas emissions.[18] However, BEVs are still an emerging technology for open-pit mining operations. Multiple manufacturers are in various development stages for BEV haul trucks designed for open-pit operations. Current market availability is limited, however. Kuhn Gruppe offers a fully electric haul truck with a capacity of 65 tonnes and is working on a 100-tonne option.[19]

In March 2021, Hitachi and ABB signed an agreement to develop battery electric haul trucks.[20] CAT is in early development stages of a large capacity BEV truck for open-pit operations. To date, only lower-capacity BEV haul trucks have been developed due to vehicle weight limitations and battery size. Cummins points out that "long distances and heavy payloads require larger and heavier batteries, and larger and heavier batteries lead to diminishing performance and efficiency."[21] As battery technology becomes more energy dense (meaning the same amount of energy is stored in a smaller and lighter envelope) BEV haul trucks with a larger haul capacity will be developed. Until then, "maximum allowable axle weights constrain the number of battery packs that can be installed before compromising road weight limits and payload capacity."[22]

Because many of these vehicles are not yet commercially available, and based on conversations with manufacturers, a 20% higher per vehicle capital cost over Diesel-Electric Haul trucks is assumed in this study. The capital costs associated with the necessary infrastructure are based on the same information used for the Diesel-Electric Haul Truck option. The major difference in operating costs compared to Diesel-Electric Haul trucks is that the energy source is electricity which is less expensive than diesel fuel per energy unit and electric motors are much more efficient in their use of energy. A conventional combustion-based power plant typically generates electricity at efficiencies of 33-35%, while fuel cell systems can generate electricity at efficiencies up to 60% (and even higher with cogeneration).[23]

2.4.2.3 Battery-Electric Haul Trucks Scope 1: Direct Emissions

BEVs substitute the traditional diesel power plant with batteries containing stored electrical power. As there is no combustion associated with BEVs, direct, Scope 1 emissions are avoided entirely.

2.4.2.4 Battery-Electric Haul Trucks Scope 2: Indirect Emissions

Direct energy emissions during the use phase for BEVs are Scope 2, indirect emissions: the use of the electricity purchased to charge the BEV. This electricity is either generated by a utility and distributed through grid infrastructure or generated onsite. Scope 2 emissions will vary based on the carbon intensity

[18] Cummins Inc., Global Power Leader. (2020, May 14). *Batteries and Fuel Cells: Understanding differences and opportunities*. Cummins Inc.
[19] eMining Switzerland. (n.d.). *Development: 123-Tonne eDumper*.
[20] Brightmore, D. (2021, June 28). *Hitachi partners with ABB to develop electric dump truck*. Mining Global.
[21] Cummins Inc., Global Power Leader. (2020, May 14). *Batteries and Fuel Cells: Understanding differences and opportunities*. Cummins Inc.
[22] Linebarger, Tom. (2020, June). Cummins Webinar. The International Partnership for Hydrogen and Fuel Cells in the Economy.
[23] U.S. Department of Energy. (2006, October). *Hydrogen fuel cells fact sheet*.

of the electricity generation sources, and the mix of energy sources varies significantly around the world. The Scope 2 emissions are based on 150 ton haul capacity BEV trucks and an average electricity emissions factor for North America of 0.33 kg CO2e per kWh.[24,25,26] Within the energy generation mix, the higher the renewables factor, the lower the emissions intensity. Therefore, the Scope 2 emissions from powering BEVs could be eliminated if 100% renewable generation serves as the power source.

2.4.2.5 Battery-Electric Haul Trucks Scope 3: Embedded Emissions in Equipment and Infrastructure

The presence of batteries in a BEV haul truck adds nearly 0.595 MTCO2e per tonne vehicle weight to the emissions factor of the BEV haul truck. Life Cycle Assessments (LCAs) of heavy-duty vehicles used for long-haul transportation and distribution were used as base assumptions for the comparisons between diesel and battery powered vehicles that are used in mining operations. Scania, a heavy vehicles manufacturer based in Sweden, published an LCA showing that the emissions resulting from the production of a heavy BEV is 2.6 tonnes CO_2e/tonne of vehicle weight compared to 1.26 from the production of heavy diesel vehicles (using a European energy mix).[27] This was used to develop the emissions per vehicle capacity. The increase in emissions during the production phase of BEVs are a result of the manufacturing of the battery used in the vehicle. Scania concluded that while the production of BEVs results in higher emissions than that of diesel vehicles, there are major reductions in lifecycle emissions during BEVs use phase, providing a return on carbon. The source of electricity for BEVs also affects Scope 3 emissions. Emissions required to produce utility grid infrastructure or renewable and microgrid materials contribute to total Scope 3 emissions of BEVs. The emissions associated with the road infrastructure are assumed to be the same as the diesel-electric haul truck.

Table 6. Emissions Factors and Fuel and non-Fuel Cost Factors for Battery Electric Vehicle (BEV) Haul Trucks

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne-km
0.042	$0.011	$0.048	2.60	699	$0.175

[24] *Emissions & Generation Resource Integrated Database (eGRID).* (n.d.). EPA. Retrieved February 1, 2022. https://www.epa.gov/egrid
[25] *Canada's official greenhouse gas inventory.* (n.d.). Government of Canada. Retrieved February 1, 2022. https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
[26] *Mexico.* (n.d.) Climate Transparency. Retrieved February 1, 2022. https://www.climate-transparency.org/countries/americas/mexico
[27] Burul, Dora, and David Algesten, Sania Life cycle assessment of distribution vehicles Battery electric vs diesel driven. 2021.

2.4.3 Hydrogen Fuel Cell Haul Trucks

2.4.3.1 Hydrogen Fuel Cell Haul Trucks Description

Fuel cells can power electric motors in cars, buses, trains, and mining haul trucks by converting the chemical energy of hydrogen to electricity. The usage of diesel-electric technology in mining haul trucks opened the door for the replacement of the onboard diesel power plant. Substituting a Hydrogen Fuel Cellpower plant for a diesel power plant can deliver increased energy efficiency and shift emissions from GHGs to water.

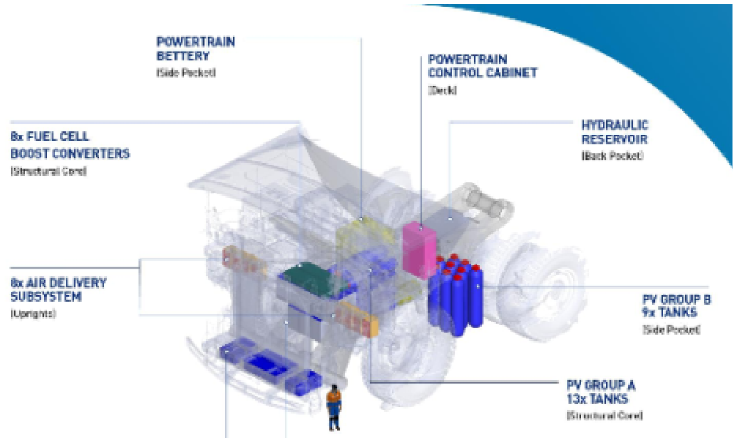


Image 5. First Model and Ballard Hydrogen Fuel Cell Design

Hydrogen is more energy dense than diesel, which allows for the equivalent amount of energy to be stored in less mass. Specifically, in electrical terms, the energy density of hydrogen is equal to 33.6 kWh of usable energy per kg, versus diesel which only holds about 12-14 kWh per kg.[28] Fuel cells alone provide a steady supply of electricity but do not handle demand changes well, such as those coming from truck acceleration. Improved vehicle performance comes from combining fuel cells with batteries. Hydrogen fuel cell systems enhance the performance of batteries by addressing distance and refueling time issues that have prohibited the adoption of BEVs for some applications. Because of hydrogen fuel cells' similarity in range and fueling time to diesel, hydrogen fuel cell haul trucks can be implemented without needing to drastically adapt current scheduling and routing, allowing for a more seamless transition to a more emissions efficient, and thus cost-effective, hauling system.

2.4.3.2 Hydrogen Fuel Cell Electric Haul Trucks Market Availability

Fuel cell technology in transportation extends as far back as the 1960s. Due to increased awareness of energy efficiency and alternative energy sources, by the end of the 1970s, many of the world's automakers had active demonstration fleets. Usage in heavy transport machinery has recently emerged due to wider adoption of onboard electric motors and initiatives towards decarbonization. Several manufacturers have entered partnerships to develop heavy duty haul vehicles designed for mining operations. In 2021, Komatsu formed a GHG Alliance with several of its customers aimed at developing the next generation of zero-emissions mining vehicles and infrastructure. The company's initial concept for a haulage vehicle that could run on a variety of power sources, part of the power-agnostic development, made its official debut at

[28] Molloy, P. (2019, October 2). *Run on less with hydrogen fuel cells*. RMI.

MINExpo 2021 on Sept. 13th in Las Vegas.[29] The types of power sources for this vehicle potentially include battery electric, trolly wired, and hydrogen fuel cells.

Anglo American, in partnership with Williams Advanced Engineering, Ballard Power Systems, and First Mode, has been developing a 290 ton haul truck powered by hydrogen fuel cells which, as of 2022, is being tested at the Mogalakewna mine in South Africa.[30] Anglo plans on producing on-site hydrogen from excess solar production. In this sense, hydrogen can simultaneously serve as a vehicle fuel source and energy storage method for mining operations. The electrolyser that will generate renewable hydrogen for the world's largest hydrogen fuel cell electric vehicle project has been delivered to site by Nel Hydrogen Electrolyser AS, as part of the joint partnership with ENGIE and Anglo American, announced last year.[31] The pipeline of green hydrogen electrolyser projects nearly tripled in the five months leading up to April 2020 to 8.2 gigawatts.[32]

The capital costs of Fuel Cell Haul Trucks were estimated using the same assumptions as the Battery-Electric Haul Trucks, a 20% premium compared to the Diesel-Electric Haul Trucks. The capital costs associated with the necessary infrastructure is assumed to be the same as the Diesel-Electric and BEV Haul Truck option. Fuel cost of Fuel Cell Haul Trucks factors in slightly lower energy efficiency than BEVs because of the need to convert hydrogen energy to electrical energy before powering the electric motors. Non-fuel operating costs for this haul method are assumed to be the same as those of the BEV.

2.4.3.3 Hydrogen Fuel Cell Electric Haul Trucks Scope 1: Direct Emissions

Hydrogen fuel cell haul trucks replace the traditional diesel power plant with fuel cells and batteries. As there is no combustion associated with fuel cell trucks, Scope 1 emissions are eliminated depending on how and where the hydrogen is produced, as detailed further below.

2.4.3.4 Hydrogen Fuel Cell Haul Trucks Scope 2: Indirect Emissions

Scope 2 emissions account for the emissions from the generation of electricity used in operations. Assuming hydrogen is produced on-site as part of mining operations, electricity is needed to perform electrolysis. This is the process of using energy to break water molecules into oxygen and hydrogen. 44 kilo-watt hours are required to produce one kilogram (kg) of hydrogen.[33] The efficiency at which fuel cells can convert hydrogen energy to electrical energy ranges from 40% to 60%.[34] The emissions associated

[29] Komatsu. (2021, August). *Komatsu announces collaborative customer alliance to advance zero-emission equipment solutions*.
[30] Moore, P. (2021, July 29). *Anglo American says fuel cell-battery hybrid mining truck project at Mogalakwena entering final phase with testing start Q4 2021*. International Mining.
[31] Creamer, M. (2020, November 25). *Anglo praised for blazing decarbonised mining trail with hydrogen truck project*. Mining Weekly.
[32] Deign, J. (2020, June 29). *So, what exactly is green hydrogen?* Wood Mackenzie.
[33] Christensen, A. (2020). *Assessment of hydrogen production costs from electrolysis: United States and Europe*. International Council on Clean Transportation.
[34] U.S. Department of Energy. (2015, November). *Fuel cells fact sheet*.

with this electrical energy depends on the type of power feeding the electrolysis system. The average North American grid emissions factor, the electrical energy required to produce hydrogen, the efficiency of fuel cells, and the power required by electric motors in a haul truck are used to calculate the $kgCO_2e$ per tonne-km for fuel cell electric haul trucks.

The larger the percentage of renewable energy used to power electrolysis, the lower this emissions factor will be. If a fuel cell haul truck were to run on green hydrogen (which is hydrogen produced from electrolysis that is powered by 100% renewable energy) such as solar, wind, nuclear or geothermal, the Scope 2 emissions factor would be zero.

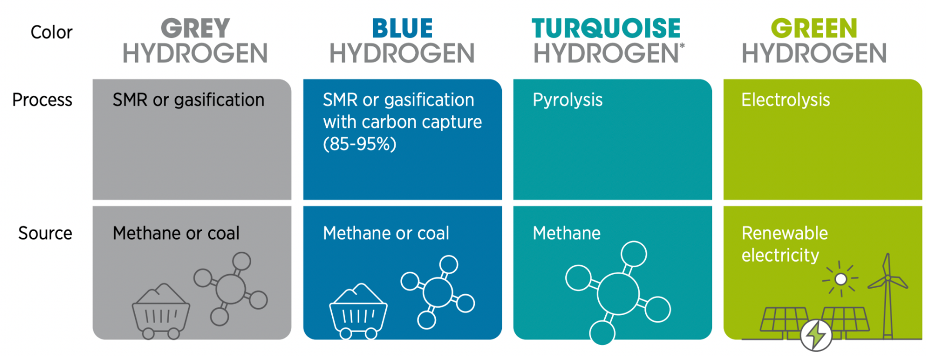
2.4.3.5 Hydrogen Fuel Cell Haul Trucks Scope 3: Embedded Emissions in Equipment and Infrastructure

The Scope 3 emissions of a hydrogen fuel cell haul truck are driven by the vehicle and the infrastructure it operates on. Emissions associated with the fuel cell electric vehicle include emissions from hydrogen fuel production, raw materials extraction and processing, vehicle assembly, distribution, and disposal.

LCA comparisons between internal combustion automobiles and 100% fuel cell automobiles show the emissions associated with the materials production, assembly of the vehicle, distribution and disposal are nearly identical.[35] Lacking manufacturers' materials lists, the study team assumed that for diesel-electric haul trucks and a 100% fuel cell-electric haul truck, the total embedded emissions would be similar. This is the case for the adapted Komatsu Haul Truck being tested by Anglo American that includes 800 kW of fuel cell power and 1.1 kWh of lithium ion batteries.

While not included in this analysis, it is important to note that another contributing factor to the emissions factor of fuel cell haul trucks is the carbon footprint of the hydrogen fuel. The emissions required for the extraction and processing of materials that go into electrolysis equipment would contribute a small amount to this Scope 3 emissions factor.

Also important to note: there are multiple and more common ways to produce hydrogen. Grey, blue and turquoise hydrogen requires processing fossil fuels. The contribution to the Scope 3 emissions factor would increase substantially if grey hydrogen is produced via the steam reforming of natural gas. In this process,



Note: SMR = steam methane reforming.
** Turquoise hydrogen is an emerging decarbonisation option.*

[35] Hussain, M., Dincer, I., & Li, X. (2007). A preliminary life cycle assessment of PEM fuel cell powered automobiles. *Applied Thermal Engineering*, 27(13), 2294–2299.

methane—the primary element in natural gas—is mixed with steam at a high temperature to yield hydrogen and carbon dioxide through a catalytic chemical reaction.[36] 9.3 kg of CO2 is produced per kg of grey hydrogen.[37]

Emissions associated with the road infrastructure are again estimated to be the same as the diesel and BEV truck options.

Table 7. Emissions Factors and Fuel and non-Fuel Cost Factors for Hydrogen Fuel Cell Haul Trucks

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne -km
0.076	$0.021	$0.048	1.97	699	$0.175

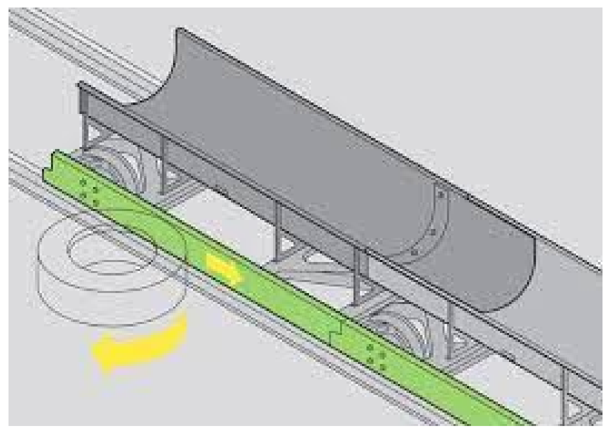
[36] Choksey, J. S. (2021, September 27). *What's the difference between gray, blue, and green hydrogen?* J.D. Power.
[37] Rapier, R. (2020, June 6). *Estimating the carbon footprint of hydrogen production*. Forbes.

2.4.4 Railveyor

2.4.4.1 Railveyor Description

Railveyor is an autonomous, electrically controlled and powered light-rail materials haulage system that utilizes a connected set of trough cars. The number of cars is dependent on haul capacity needs. Railveyor is powered by electric drive stations placed along a track throughout the length of the system. Trains utilize a clevis pin connection in conjunction with a spherical bearing between cars, enabling articulation through horizontal and vertical curves, and discharge loops to drop materials from the trough cars.

The cars are equipped with steel troughs for material transport, and a section of rubber sheeting to form a seal with the adjacent car. This prevents the spilling of material between cars and allows the cars to pivot during the unloading process. The cars are equipped with magnets with sensors at the drive stations that count cars, track train location, direction of travel, and clock speed.



Trains travel from loading points and can either travel along a haul road or overland on a dedicated track to a discharge loop, ultimately emptying contents into a repository (like a crusher).

Images 6 & 7. Railveyor Connected Trough Cars

Through the use of inverted tracks and switches, the trough cars complete a loop. Car positioning requires a metal rail fixed in place with gravel, which can change as the layout of a site develops. Loading and off-loading points are fixed until the entire system is repositioned.

2.4.4.2 Railveyor Market Availability

Railveyor systems have been in place for more than a decade with seven installations worldwide. Mining operations have utilized Railveyor as a singular haulage system or combined it with other haulage options. Haul trucks, shovels and conveyor belts can transfer materials into the trough cars or receive materials from Railveyor, at the start or at the end of the loop, to continue moving materials to stockpiles or processing facilities.

Total capital and operating costs estimated by Railveyor for Canada Chrome Corp drive the generalized per tonne-km cost estimates reported in this study.[38]

2.4.4.3 Railveyor Scope 1: Direct Emissions

Railveyor is an electrically driven and controlled haulage system. It contributes no Scope 1 emissions.

2.4.4.4 Railveyor Scope 2: Indirect Emissions

Scope 2 or indirect emissions are from the generation of electricity required for operations. Electricity is either generated by a utility and distributed through it's grid infrastructure or generated onsite. Scope 2 emissions vary based on the carbon intensity of the electricity generation sources and the mix of energy sources varies heavily around the world. Like all haul systems, the electricity required by a Railveyor system depends on the profile of the haul. For a flat surface haul profile, the average power demand is 10.5 megawatts to move 1,300 tonnes/hour a total of 310 meters at 4.5 meters per second. These performance metrics, along with the average North American grid mix emissions intensity of 0.33 kgCO2e per kWh, are used to calculate the Scope 2 emissions of kgCO2e/tonne-km for Railveyor. Within the energy generation mix, the higher the renewables factor, the lower the emissions intensity. Therefore, the Scope 2 emissions from powering Railveyor would be eliminated if 100% renewable generation serves as the power source.

2.4.4.5 Railveyor Scope 3: Embedded Emissions in Equipment and Infrastructure.

Materials and processes for Railveyor construction and installation contribute to Scope 3 emissions. This category of emissions can be broken down into upstream and downstream emissions of infrastructure construction, maintenance, and operations, as well as manufacturing, maintenance, and disposal of the haul cars moved along the rail. The infrastructure associated with Railveyor is the steel track, discharge and re-invert loops, and drive stations.

The embedded emissions associated with the trough cars were calculated using the quantity of steel used in each car. Cradle-to-gate emissions factors were used to calculate the emissions associated with the extraction of raw materials and the production of those materials into primary products.[39] This calculation does not include the manufacturing of these materials into secondary products, as there is limited data available. Cradle-to-gate emissions factors are used to estimate the emissions of tonnes CO_2e per tonne of vehicle capacity for a Railveyor train.

The embedded emissions associated with the infrastructure of the system was calculated based on the capital costs of the system and Scope 3 commodity emissions factors from the EPA.[40] The embedded emissions for the Railveyor system are estimated to be 738 tonnes CO_2e per km compared to the 941 tonnes CO_2e per km for the average heavy rail system. Railveyor's modular design and low downforce

[38] Railveyor. (2021, December). Rail-veyor Engineering and Design Services Report.
[39] World Steel Association. (2021, May). *Life cycle inventory (LCI) study 2020 data release*.
[40] Ingwersen, W., & Li, M. (2020). *Supply chain greenhouse gas emission factors for U.S. industries and commodities*. U.S. Environmental Protection Agency.

requirement allows it to be installed with small-scale equipment that includes mini-excavators and boom trucks or fork trucks. This, combined with a short installation period, limits the fuel consumed and emissions generated during construction.

Maintenance of infrastructure and trough cars requires periodic visual inspection which optimizes the system and supports minimal energy consumption (and emissions). Clearing debris from the track will increase energy usage and emissions and can be minimized with track placement as well as sufficient clearance and protection from falling debris.

Table 8. GHG Emissions for Railveyor

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne-km
0.012	0.003	0.005	0.503	738	$0.202

2.4.5 Diesel-Electric Heavy Rail

2.4.5.1 Diesel-Electric Heavy Rail Description

Diesel-electric rail freight allows for the movement of material in a fuel efficient and highly scalable system. Bogeys or train cars can be added to a locomotive in varying numbers to satisfy demand. Transportation of goods via rail amounts to seven percent worldwide.[41] While a sizable portion of global freight, rail freight emits very little–only one percent of transport emissions.[42]

Image 8. Diesel-Electric Heavy Rail

Large investments in capital are needed to kickstart rail freight operations but, once in place, a single locomotive can move significantly more freight over long distances than road hauling. Thus, rail freight often offers favorable returns. The downsides of rail are fixed routes and transloading, the need to couple rail with other forms of transport. This keeps rail from being a cost-effective means of transportation for limited quantity, short distances, and time sensitive items. Rail freight works best when moving a large quantity of material, frequently, over a long period of time to a single destination on a rail line.

[41] Milman, O. (2021, September 16). 'Dramatically more powerful': World's first battery-electric freight train unveiled. *The Guardian*.
[42] Ritchie, H. (2020, October 6). Cars, planes, trains: Where do CO2 emissions from transport come from? Our World in Data.

2.4.5.2 Diesel-Electric Heavy Rail Market Availability

Diesel-electric heavy rail freight has been commercially available and in-use since the 1920's. The largest portion of global market share is held by the Asia Pacific region and it is expected to hold this position as population growth and urbanization continues. Europe and North America are projected to see steady growth and demand in their rail sectors from having rail component manufacturing companies, well developed rail networks and favorable changes in public policy relating to fuel efficient transportation.[43]

Total capital and operating costs estimated by Tetra Tech for Canada Chrome Corp drive the generalized per tonne-km cost estimates reported in this study.[44]

2.4.5.3 Diesel-Electric Heavy Rail Scope 1: Direct Emissions

Direct emissions from rail freight occur from the combustion of diesel fuel. U.S. freight railroads, on average, move one ton (0.9 tonnes) of freight more than 480 miles per gallon (204 km/L) of fuel.[45] This average U.S. fuel consumption along with the EPA diesel emissions factor was used to calculate the Scope 1 emissions. Regional route differences in topography, length, and frequency of stops are contributing factors to average regional fuel consumption. For example, the average Scope 1 emissions for rail freight in the E.U. is lower than the calculated emissions in this paper.[46] No matter the market, Scope 1 emissions intensity has decreased over the years because of more fuel efficient locomotives, more capacity per car and more cars per train. Improved rail car design, specialized rail cars and other factors have helped increase the amount of freight railroads carry, with an average train in 2020 (the average freight train carrying 3,817 tons) up from 2,923 tons in 2000.[47] These rail technology improvements have decreased the environmental footprint of rail over the past two decades. In 2020 alone, U.S. freight railroads consumed 675 million fewer gallons of fuel and emitted 7.6 million fewer tons of carbon dioxide than they would have if their fuel efficiency had remained constant since 2000. [48]

2.4.5.4 Diesel- Electric Heavy Rail Scope 2: Indirect Emissions

Diesel powered Heavy Rail Locomotives consume no grid electricity and therefore have no Scope 2 emissions.

---

[43] Fortune Business Insights. (n.d.). *Locomotive market size, share & COVID-19 impact analysis, by technology type (IGBT Module, GTO Thyristor, and SiC Module), by propulsion type (diesel and electric), and regional forecasts, 2021–2028*.
[44] Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
[45] Association of American Railroads. (2021, April). *AAR sustainability fact sheet*.
[46] European Chemical Transport Association. (2011, March). *Guidelines for measuring and managing CO2 emission from freight transport operations*.
[47] Association of American Railroads. (2021, April). *AAR sustainability fact sheet*.
[48] Association of American Railroads. (2021, April). *AAR sustainability fact sheet*.

2.4.5.5 Diesel-Electric Heavy Rail Scope 3: Embedded Emissions in Equipment and Infrastructure

Materials and processes that allow for heavy rail transportation have embedded emissions. These can and should be broken into upstream and downstream emissions of raw materials, construction, maintenance, and disposal of the infrastructure and the rail equipment, like locomotives and railcars. Two separate Scope 3 emission factors need to be utilized when analyzing the full footprint of a rail project because of the fixed nature of the infrastructure and the variability of equipment used on that infrastructure.

Heavy rail infrastructure requires steel rail supported by timbers or concrete sleepers on top of crushed ballast. Sub-ballast and non-frost-susceptible fill are required below the ballast. The raw material extraction and manufacturing of these materials contributes Scope 3 emissions. Similarly, operations to cut and fill material along the rail path and install rail components contribute to the overall Scope 3 emissions. Literature review has determined scope 3 emissions per kilometer of infrastructure.[49] This emissions factor increases substantially as the amount of tunnels and bridges increases.[50]

The extraction and production of the raw materials that go into railcars and locomotives contributes 12% to total embedded emissions.[51] After factoring out emissions from operations, Scope 3 emissions associated with the materials, manufacturing, maintenance and disposal of equipment becomes 15% of Scope 3 emissions. Railcars are almost completely steel, and when a conventional train of 100 cars with a carrying capacity of 12,000 tonnes is paired with one or two locomotives, an insignificant amount of all the materials of the train are not steel.[52] Because of this, the estimated Scope 3 emissions per vehicle capacity is based on an emissions factor from the World Steel Association's 2020 Life Cycle Inventory study.[53]

Table 9. Fuel Consumption by Capacity and Load Factor for Diesel Electric Heavy Rail

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne -km
0.015	0.007	0.021	0.357	941	$0.312

[49]Olugbenga, O., Kalyviotis, N. & Saxe, S. (2019). Embodied emissions in rail infrastructure: a critical literature review.
[50] International Union of Railways. (2016, June). Carbon footprint of railway infrastructure.
[51] Merchan, A., Belboom, S., & Léonard, A. (2017). Life cycle assessment of freight transport in Belgium.
[52] Barkan, C. (2012). Introduction to rail transportation.
[53] World Steel Association. (2021, May). Life cycle inventory (LCI) study 2020 data release.

2.4.6 Long Haul Diesel Truck

2.4.6.1 Long Haul Diesel Truck Description

In the context of this paper, long haul trucks differ from the diesel, BEV, and hydrogen fuel cell trucks earlier referenced. Long haul trucks describe a tractor trailer style combination of semi truck and 53 foot trailers. These trucks will have a smaller hauling capacity compared to the other truck options, but are more efficient for hauling materials greater distances.

2.4.6.2 Long Haul Diesel Truck Market Availability

Long haul trucks are widely available across the world through a number of manufacturers.

Image 9. Long Haul Diesel Truck

In North America, Freightliner, International, PACCAR, and Volvo represent the most popular tractor trailer trucks in the industry. Due to increasing freight demands and challenges within supply chains, truck and trailer inventories are shrinking while prices are rising.[54]

Total capital and operating costs estimated by Tetra Tech for Canada Chrome Corp drive the generalized per tonne-km cost estimates reported in this study.[55]

2.4.6.3 Long Haul Diesel Truck Scope 1: Direct Emissions

The same EPA diesel emissions factor for Diesel-Electric haul trucks was used to calculate the Scope 1 emissions for Long haul trucks. The estimated Scope 1 emissions for long haul trucks are lower than that of the other diesel truck option. The difference observed between Diesel-Electric Haul trucks and Long Haul Diesel Truck emissions factors comes from the improved efficiency from the lower capacity long haul trucks, resulting in a lower fuel consumption. The fuel consumption per tonne-km is lower for Long Haul Diesel Trucks compared to that of the larger Diesel-Electric haul trucks. The fuel efficiency is derived from multiple sources, including the earlier mentioned Scania LCA and EPA fuel efficiency data.

2.4.6.4 Long Haul Diesel Truck Scope 2: Indirect Emissions

As these vehicles require no grid electricity, there are no Scope 2 emissions from the result of operating these vehicles.

[54] Fisher, J. (2021, August 17). *Freight market demand grows as truck and trailer inventory shrinks: ACT*. FleetOwner.
[55] Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.

2.4.6.5 Long Haul Diesel TruckScope 3: Embedded Emissions in Equipment and Infrastructure

The emissions factor calculated by Scania for the embedded emissions of a diesel haul truck, 1.26 tonnes CO2e/tonne vehicle weight, was used to estimate the emissions associated with the production of a long haul truck.[56] The embedded emissions in the road infrastructure show an increase due to the inclusion of asphalt. The added emissions associated with the production and use of this material in the infrastructure leads to a greater estimated emissions per km of infrastructure compared to the gravel roads assumed for the heavier haul truck options. It's important to note that while the truck has a relatively low emissions per vehicle, more vehicles are required to make up for less capacity, leading to more overall Scope 3 emissions.

Table 10. Fuel Consumption by Capacity and Load Factor for Long Haul Diesel Trucks

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne-km
0.066	$0.030	$0.07	0.52	738	$0.193

56 https://www.scania.com/content/dam/group/press-and-media/press-releases/documents/Scania-Life-cycle-assessment-of-distribution-vehicles.pdf

2.4.7 Conveyor

2.4.7.1 Conveyor Description

Conveyors have been present since the earliest days of mining. Today, a system can be adapted with multiple types of configurations, including buckets, pipes, and open trough belts. The systems typically consist of a composite belt that is connected to a tail and head pulley which is supported by a metal frame. The system is driven by electric motors.

Image 10. Conveyor System

2.4.7.2 Conveyor Market Availability

Large conveyor systems are widely available through a number of manufacturers including ABB, Beumer Group, TCI, and others. Important considerations include topography, length, and power requirements.

Capital costs are dependent on a number of factors, as is the case with other haul methods. However, with an average cost between $1,100 - $3,400 per meter, the initial investment for an overland conveyor system is relatively high.[57] The midpoint of this cost range was used to estimate capital cost per tonne-km rates for this study.

Despite the high capital costs, conveyors do result in low operating cost relative to other haulage methods. Utilizing electric drives, and the advantage of harnessing regenerative power when transporting material downhill are factors that contribute positively to conveyor's energy efficiency. The energy required to move a tonne-km via conveyor reported by Deloitte and the assumed energy rate leads to the estimated conveyor fuel operating cost in this study. Non-fuel operating costs are sourced from a Beumer Group white paper. [58]

2.4.7.3 Conveyor Scope 1: Direct Emissions

Scope 1 emissions are emissions from fuel. A conveyor is an electrically driven and controlled system, therefore it contributes no Scope 1 emissions.

[57] BEUMER Group. (2020, April 21). *Belt conveyor as an economical alternative to trucks: Does it pay off?*
[58] BEUMER Group. (2019, March). *Advances in Conveyor Technology*.

2.4.7.4 Conveyor Scope 2: Indirect Emissions

Scope 2 emissions are from the generation of electricity required for operations. This electricity is either generated by a utility and distributed through it's grid infrastructure or generated onsite. Scope 2 emissions will vary based on the carbon intensity of the electricity generation sources and the mix of energy sources varies significantly. The electricity required by a conveyor system depends on the profile of the haul. For a flat surface haul profile, a conveyor moving 1,550 tonne/hour a total of 100 km would have an average power demand of 10.5 megawatts. These performance metrics along with the average North American grid mix emissions intensity are used to calculate the Scope 2 emissions of kgCO2e/tonne-km for a conveyor system. Within the energy generation mix, the higher the renewables factor, the lower the emissions intensity. Therefore, the Scope 2 emissions from powering the conveyor would be eliminated if 100% renewable generation serves as the power source.

2.4.7.4 Conveyor Scope 3: Embedded Emissions

The embedded emissions associated with the conveyor system were calculated using cradle-to-gate emissions factors for the materials used in the conveyor belt system, the majority being steel and rubber. The estimated emissions were calculated using an assumption that the system is roughly 75% steel and 25% rubber, with rubber having an emissions factor nearly four times that of steel.[59] The embedded emissions associated with the infrastructure of the system were calculated based on the estimated capital expenditure for a conveyor system and Scope 3 commodity emissions factors from the EPA.[60] The estimated capital costs are based on a statement made by Beumer Group, citing estimated costs between 1,000 and 3,000 euros per meter.[61]

Table 11. Fuel Consumption by Capacity and Load Factor for Conveyors

Scope 1 & 2 (kilogram CO2e /tonne-km)	Fuel OPEX ($/tonne-km)	Non-Fuel Operating Expense ($/tonne-km)	Scope 3 (MTCO2e/MT vehicle capacity)	Scope 3 (MTCO2e/km infrastructure)	Est. Capital Expense/tonne-km
0.022	$0.006	$0.029	0.96	742	$0.200

[59] Circular Ecology. (2020, October 8). Embodied carbon footprint database.
[60] Ingwersen, W., & Li, M. (2020). Supply chain greenhouse gas emission factors for U.S. industries and commodities. U.S. Environmental Protection Agency.
[61] Gleeson, D. (2020, April 21). BEUMER Group makes the economic case for ore transport by conveyor. International Mining.

2.5 Hypothetical Apples to Apples Scenario

In order to compare these haulage scenarios apples to apples, the study team designed a very basic hypothetical scenario. It is important to note that variance in an operation, site, production schedule, ore body, and local infrastructure will limit which haulage options make sense for a site. In many operations, multiple haulage technologies will be employed to transport across different parts of a site.

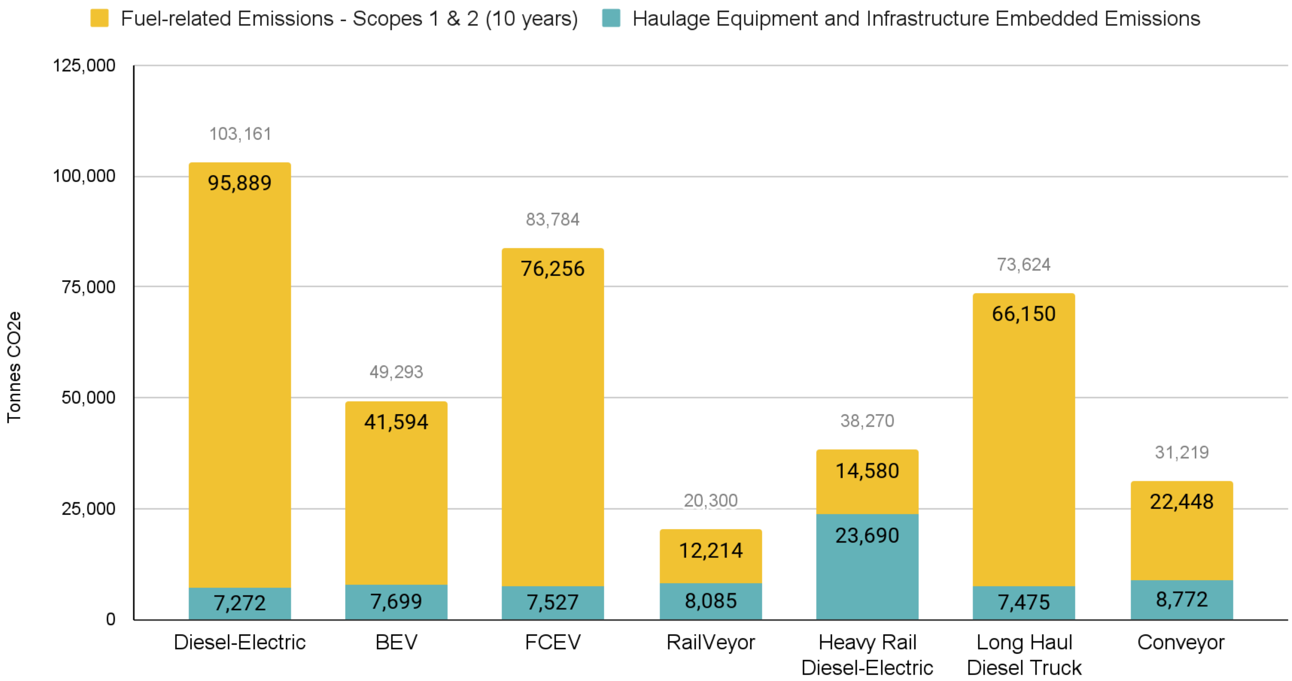
Moreover, there are certain grade-based nuances that are not captured in this analysis. For example, a fully loaded electric truck is able to climb an eight percent grade at nearly twice the speed of its diesel counterpart. At zero grade, the speed is estimated to be 20% faster, improving production.[62] Also, based on conversations with operators who have deployed electric haulage systems and the OEMs that have extensive field tests, in nearly every setting, electric equipment outperforms diesel equipment on speed, efficiency and lower maintenance costs. Where the study team was able to verify data, it was incorporated in this analysis.

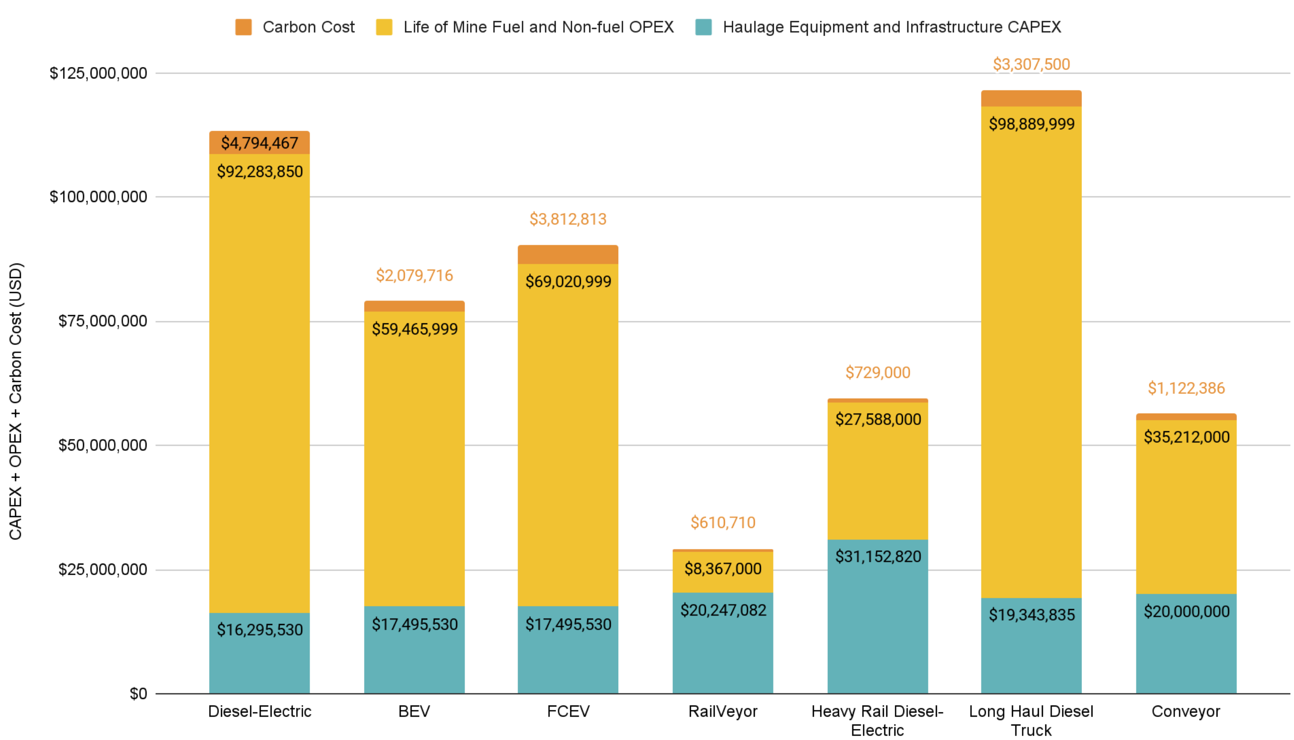
In this Hypothetical Apples to Apples Scenario, the seven different haulage technologies are compared using the same annual tonnage hauled (10,000,000 tonnes/yr), hauling distance (10 km), and haulage route grade (0%).

Table 12. Hypothetical Haulage Scenarios CAPEX, OPEX, Emissions and Total Life of Mine Net Present Cost

Haulage Type	Haulage Equipment and Infrastructure CAPEX	Haulage Equipment and Infrastructure Embedded Emissions - Scope 3 (MTCO2e)	Life of Mine Fuel and Non-fuel OPEX	Life of Mine Fuel-related Emissions - Scopes 1 & 2 (MTCO2e)	Total Life of Mine Emissions (Scopes 1, 2 & 3) MTCO2e
Diesel-Electric	$16,295,530	7,272	$92,283,850	95,889	103,161
BEV	$17,495,530	7,699	$59,465,999	41,594	49,293
FCEV	$17,495,530	7,527	$69,020,999	76,256	83,784
RailVeyor	$20,247,082	8,085	$8,367,000	12,214	20,300
Diesel-Electric Heavy Rail	$31,152,820	23,690	$27,588,000	14,580	38,270
Long Haul Diesel Truck	$19,343,835	7,475	$98,889,999	66,150	73,624
Conveyor	$20,000,000	8,772	$35,212,000	22,448	31,219

[62] Sandvik Coromant. Presentation *Electric Mine Conference in Stockholm*, 2022.


Fuel-related Emissions - Scopes 1 & 2 (10 years)
Haulage Equipment and Infrastructure Embedded Emissions
Tonnes CO2e
125,000
100,000
75,000
50,000
25,000
0
103,161
95,889
7,272
49,293
41,594
7,699
83,784
76,256
7,527
20,300
12,214
8,085
38,270
14,580
23,690
73,624
66,150
7,475
31,219
22,448
8,772
Diesel-Electric
BEV
FCEV
RailVeyor
Heavy Rail Diesel-Electric
Long Haul Diesel Truck
Conveyor


Carbon Cost
Life of Mine Fuel and Non-fuel OPEX
Haulage Equipment and Infrastructure CAPEX
CAPEX + OPEX + Carbon Cost (USD)
$125,000,000
$100,000,000
$75,000,000
$50,000,000
$25,000,000
$0
$4,794,467
$92,283,850
$16,295,530
$2,079,716
$59,465,999
$17,495,530
$3,812,813
$69,020,999
$17,495,530
$610,710
$8,367,000
$20,247,082
$729,000
$27,588,000
$31,152,820
$3,307,500
$98,889,999
$19,343,835
$1,122,386
$35,212,000
$20,000,000
Diesel-Electric
BEV
FCEV
RailVeyor
Heavy Rail Diesel-Electric
Long Haul Diesel Truck
Conveyor

As seen in the graphs above, the combined Scopes 1 & 2 emissions vary greatly. This is entirely due to each respective technology's energy source, electricity or fossil fuel. Scope 3 emissions, from the upstream cradle-to-gate for each technology and infrastructure, are relatively similar with the exception of Diesel-Electric Heavy Rail. This is particularly interesting in light of the recent common misconception that electric vehicles are more emissions intensive than combustion powered vehicles due to the life-cycle cost (LCC) related emissions (often associated with batteries). Emissions from the extraction of raw materials for batteries, like nickel, cobalt and lithium, and battery manufacturing are thought to be so high that it takes years of product usage to break even with combustion alternatives. While any manufacturing process produces waste and emissions, the LCC emissions of BEVs are no worse than that of extracting, refining and transporting fossil fuels. This same emissions intensity relationship was determined in a Yale University study. The transition to electric vehicles, including production, demonstrates a net decrease in overall emissions.[63]

[63] Wolfram, P., Weber, S., Gillingham, K. et al. Pricing indirect emissions accelerates low—carbon transition of US light vehicle sector. Nat Commun 12, 7121 (2021). *https://doi.org/10.1038/s41467-021-27247-y*

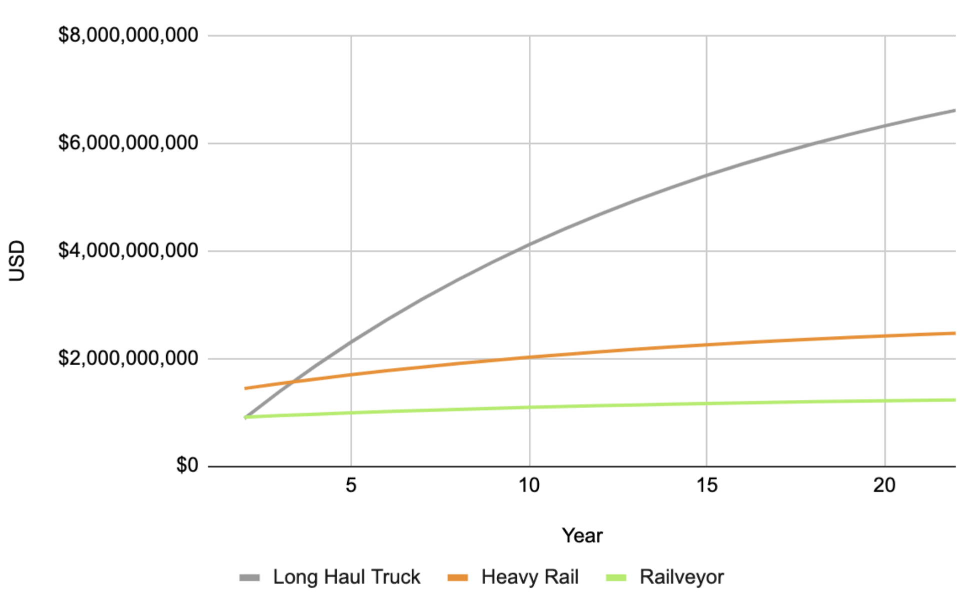
3. Haulage Systems Case Studies

3.1 Case Study: Comparing Railveyor to Trucks and Rail - Ring of Fire, Ontario, Canada

Canada Chrome Corp has a series of land claims in Northern Ontario that, if developed into a transportation corridor, can connect "Ring of Fire" mining opportunities to Nakina, Ontario, Canada. Because this region is remote with limited access, a significant investment in material hauling is necessary to move supplies and mined materials between the market and the mine. This transportation system would span 330 km from the Nakina Railway Line to the location of mining operations.

A mine that this corridor services could vary drastically in mine life. Annual production volumes determine the eventual mine life and means of transporting materials from the mine affects the production capacity. Production rates between 1.5 and 5 million tons per year (MTPA) would result in a mine life between 44 and 146 years.[64] The feasibility and financial performance of developing heavy rail, long haul trucking, and Railveyor have been evaluated in this corridor. These three methods of transportation require significantly different amounts of initial capital and recurring costs. These different expense types along with total embedded emissions can be compared to determine the best financial and most sustainable investment opportunity.

Chart 8: Comparison of Discounted Total Haulage Cost



Utilizing Railveyor to satisfy ten MTPA over 22 years, when considering a seven percent discount rate, will reduce the total cost of haulage operations by 81% when compared to road haulage and 50% when compared to heavy rail haulage.

[64] Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.

3.1.1 Haulage Capacity

A trade-off analysis between road and rail considered 3 MTPA production while a Railveyor engineering and design services report planned for 10 MTPA. An accurate comparison of these haul methods can only be conducted if the production and haul capacity are equal. The Railveyor report is the most recent, therefore, the infrastructure, equipment and services required by road haulage and rail haulage options have been analyzed and scaled, when necessary, from 3 MTPA to 10 MTPA. For both of these options, the fixed infrastructure required would be consistent for any amount of haulage. Operating expenses, however, will scale according to the amount of equipment and support systems required to meet haulage requirements.

3.1.2 Capital Costs

Developing the 330 km corridor requires a significant amount of materials staging, earthworks, and construction regardless of the selection of rail, road, or Railveyor. All of these factor into the total upfront capital required for each haulage option. Taking total capital costs at face value directly from the trade-off analysis and Railveyor engineering report, a haul road would require less capital cost than heavy rail and Railveyor, which also requires electrical infrastructure.

Table 13. Capital Costs directly from reports

Road	Rail	Railveyor + Electrical
$1,015,748,608	$ 1,560,685,236	$ 1,063,420,000

3.1.2.1 Electrical Infrastructure

The only haulage option that incorporates the cost of electrical infrastructure is Railveyor. The capacity of the transmission and distribution infrastructure for Railveyor is enough to provide power to a mine. A mine would eventually need to install this same infrastructure so for a better comparison we can look at the capital cost of road, rail and Railveyor without the cost of electrical infrastructure. When it is removed from the total Railveyor capital cost, Railveyor is the haulage option with the lowest upfront capital required.

Table 14. Railveyor and Electrical Infrastructure Capital Cost

Railveyor	$656,699,000
Electrical Infrastructure	$406,721,000
Total	$1,063,420,000

Table 15. Capital Cost of Haulage Options without Electrical Capital Cost

Road	Rail	Railveyor
$1,015,748,608	$ 1,560,685,236	$ 656,699,000

3.1.2.2 Bridges

Another difference between the analysis of road and rail versus Railveyor is the cost of bridges. Capital cost estimates for road and rail include major and minor bridge construction projects. The size, scope and cost of bridges required for Railveyor would be significantly less than that of road or rail due to the reduced downforce from Railveyor track and loaded trough cars. Preliminary plans for bridges for Railveyor include temporary bridging solutions like launched bridges used in military applications. Assuming bridge infrastructure to be the same cost for Railveyor as for heavy rail ($250M), the capital cost of Railveyor amounts to less than the road and heavy rail options.

Table 16. Capital Cost of Haulage Options with Bridges

Road	Rail	Railveyor
$1,015,748,608	$ 1,560,685,236	$908,214,255

3.1.2.3 Service Road

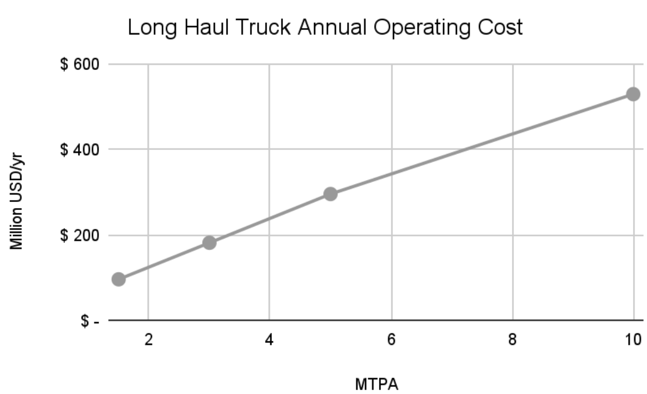
The cost of installing a service or access road along the corridor, and before the rest of the infrastructure, is included in the road and rail trade-off study. The Railveyor engineering report considers an access road (to be used by installation crews) would already be in place from electrical infrastructure installation. While it is a reasonable assumption that electrical infrastructure would be installed in the corridor regardless of the haulage method selected, the order of operations is not known.

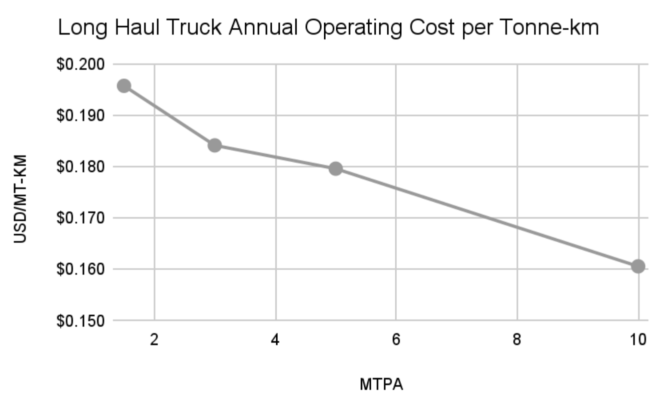
Table 17. Capital Cost of Haulage Options with Bridges and without a Service Road

Road	Rail	Railveyor
$883,748,608	$ 1,440,685,236	$908,214,255

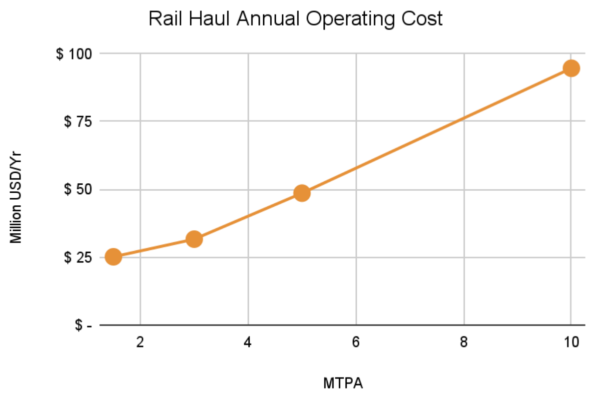
3.1.3 Operating Cost

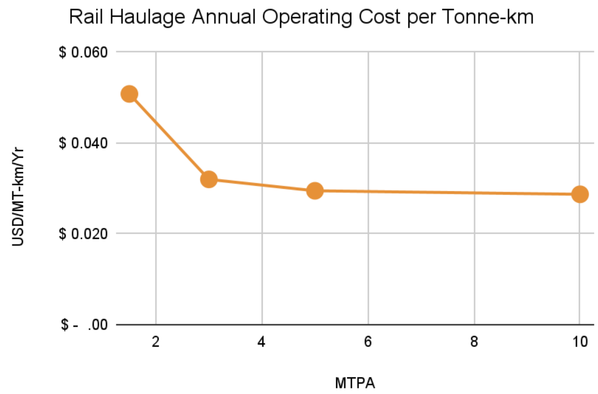
A sensitivity analysis within the road and rail trade-off study made it clear that operating expenses for long distance haul trucks scale linearly with increasing or decreasing haul capacity. As expected, more trucks, fuel, operators and equipment maintenance are needed for increased haul capacities.





Rail operating costs scale at a slower rate than road haulage operating costs. The operating cost per tonne of material remains lower than that of trucking due to economies of scale from higher capacity trains.





After normalizing operating costs for haulage capacity, Railveyor offers the lowest annual operating cost per tonne of material hauled. The main driver of Railveyor's low operating cost is that it is a system managed through programmable logic controllers (PLCs) and powered by electricity. This leads to lower fuel and labor expenses than road and rail.

Table 18. Annual Operating Costs for Road, Rail and Railveyor

Item	Units	Road	Rail	Railveyor
Haulage	MTPA	10	10	10
Distance	km	330	330	330
Equipment Cost	USD/yr	$ 164,430,336	$ 3,000,000	
Labor Cost (Operator/Driver)	USD/yr	$ 135,681,721	$ 26,520,000	
Energy Cost	USD/yr	$ 98,658,200	$ 19,462,980	$ 11,115,629
Transloading at Nakina	USD/yr	$ 17,439,580		
Maintenance	USD/yr	$ 25,780,061	$ 28,931,250	$ 17,682,962
Indirect and Overhead Cost	USD/yr	$ 18,879,667	$ 4,400,000	
Direct Operating Cost	USD/yr	$ 460,869,565	$ 82,314,230	
Profit (15%)	USD/yr	$ 69,130,435	$ 12,347,135	
Total Operating Cost	USD/yr	$ 530,000,000	$ 94,661,365	$ 28,798,591
Cost per tonne	USD/T	$ 53	$9.47	$ 2.88
Cost per tonne-km	**USD/T-km**	**$ 0.16**	**$0.03**	**$ 0.01**

3.1.4 Emissions

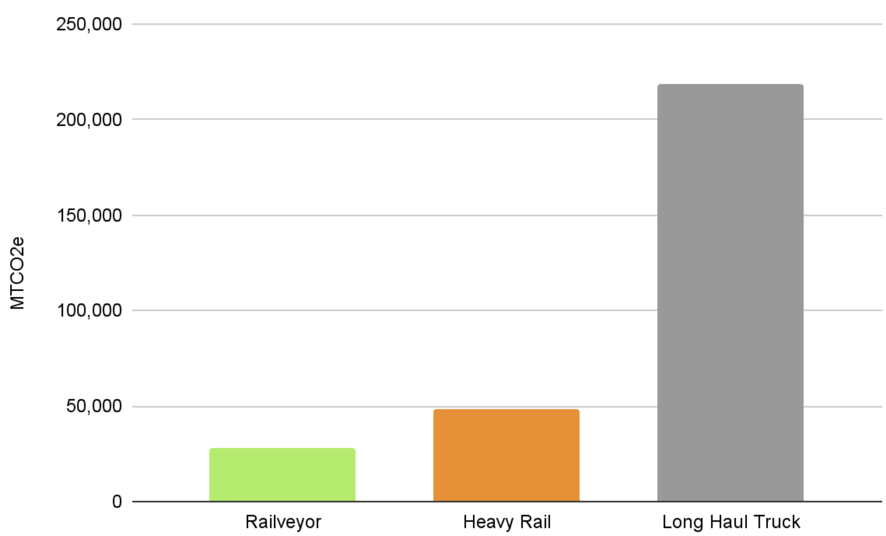
Expectations for the mining industry to reduce its carbon footprint are becoming stronger. Public opinion and investor demand are for low carbon operations that minimize waste and achieve higher operational efficiency.

3.1.4.1 Scope 1 and 2

Scope 1 emissions are emissions associated with fuel used in day to day operations. Scope 2 emissions are the emissions from the generation of electricity used in day to day operations. Operating cost projections from the trade-off analysis for road and rail haulage include fuel line items. Diesel fuel is the energy source for these haul methods. The diesel emissions factor, annual haulage weight and distance allows for the estimation of total yearly emissions from hauling via road and rail.

As already mentioned, Railveyor is an electrically controlled and powered haul system. The electrical infrastructure planned to power Railveyor will tie into existing grid infrastructure. The emissions intensity of grid power generation in the province of Ontario is found to be 40g CO2/kWh. Railveyor annual usage leads to energy generation by regional power providers, which emits carbon dioxide according to the grid factor.

Chart 9: Annual Scope 1 & 2 Emissions



Using the calculated emissions factors from section 2, haul capacity of 10 MTPA and a haul length of 330 km, Railveyor and Heavy Rail are estimated to contribute significantly less Scope 1 and 2 emissions than long haul trucks.

In reality, Railveyor annual Scope 1 and 2 emissions would be less than currently estimated, using the emissions factors from section 2, because the grid emissions factor for the province of Ontario is less than the North American average used to calculate the generalized Railveyor Scope 1 and 2 emissions factor.

This difference in Scope 1 and 2 emissions for each haul method stems from the significant difference in energy efficiency of the haul methods and emissions intensity of fuel sources. Heavy rail freight and Railveyor achieves economies of scale and benefits from reduced friction when moving the required annual haulage over rail infrastructure. Between three or four locomotives are needed to achieve 10 MPTA on heavy rail versus 78 long haul trucks. Railveyor achieves lower Scope 1 & 2 emissions than heavy rail by substituting electrically powered fixed drive stations that propel loaded train cars autonomously for diesel fueled locomotives. These drive stations utilize the energy provided by the electric infrastructure more efficiently than diesel engines. In addition, as stated previously, the emissions factor of grid electricity is lower than combusted diesel so not only is Railveyor moving materials with more energy efficiency, but it's using a less emissions intense fuel source to do so.

3.1.4.2 Carbon Cost

Applying an expected cost of carbon to Scope 1 and 2 emissions translates the environmental effects of emissions into financial implications. By applying $50 per tonne CO2, as was agreed upon as an international target by the Paris Climate Accords, the effect of each hauling method on yearly operating cost can be estimated and risk of potential carbon taxes avoided when deciding on a haul method.

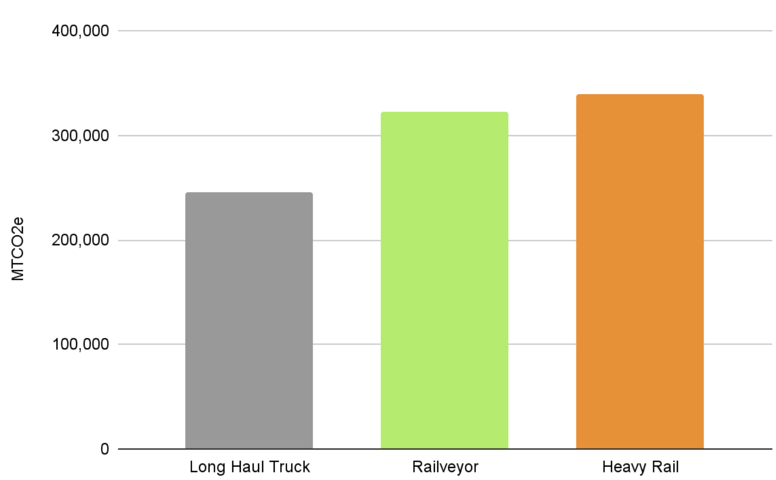
Table 19. Carbon Cost Implication of Haulage Methods - 10 MPTA Scenario

	Units	Long Haul Truck	Heavy Rail	Railveyor
Annual Scope 1 & 2 Emissions	MTCO2e	218,342	48,145	28,324
Annual Carbon Cost from Scope 1&2 Emissions	USD ($50/MT)	$10,917,096	$2,407,237	$1,416,188

3.1.4.3 Scope 3

It is important to separate Scope 1 and 2 emissions from Scope 3 emissions for potential carbon cost calculations and because Scope 3 communicates the amount of embedded emissions within the infrastructure and equipment required by a haul method. This can be looked at in a similar way to upfront capital of a project.

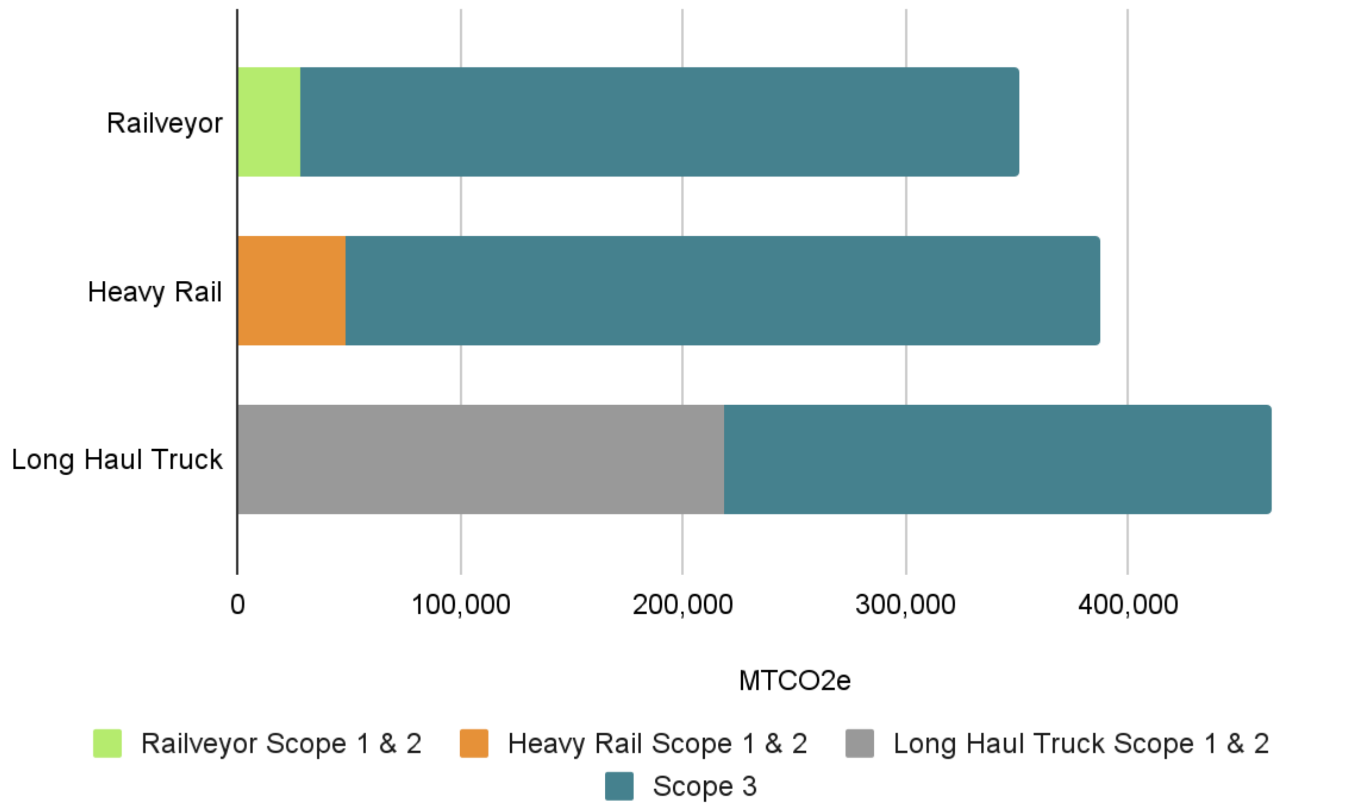
Chart 10: Total Scope 3 Embedded Emissions



Return on Carbon

It is important to note the difference in emissions generated by the haulage of 10 MPTA and the embedded emissions for the infrastructure required to do this by truck, rail and Railveyor. By looking at the Scope 1, 2 and 3 emissions after one year of haulage, the return on carbon that comes from investing in a haul method with high Scope 3 emissions but low Scope 1 and 2 emissions, like Railveyor or heavy rail, becomes evident.

Chart 11: Return on Carbon: Scope 1, 2 and 3 Emissions after Year 1 of 10 MTPA Haulage



Soil Carbon Disturbance

An embedded emissions source that has not been factored into the Scope 3 emissions of each haul project is carbon released from the removal of peat land within the corridor. The road and rail trade-off study determined that most of the ground features one to five meters, and possibly more, of compressible peat overlying clayey/silty lake sediments. This peat has to be dug up and moved off site because it is not appropriate for the foundation of a road or rail. There is currently heavy focus on peatlands as a solution and potential contributor to carbon emissions. Peatlands feature large amounts of stored carbon due to decayed organic matter. Preservation of these soils and keeping large amounts of stored carbon in place is important for efforts to curb climate change and achieve sustainable development goals.[65] Rail requires removing over five million cubic meters of material in order to lay an appropriate foundation. Similarly, a road requires over three million cubic meters. Railveyor offers the chance to minimize soil disturbance.

[65] International Union for Conservation of Nature. (2021, November). *Peatlands and climate change*. IUCN.

3.1.4.4 Infrastructure Development for Indigenous Communities

Incorporating electrical and fiber optic infrastructure for indigenous communities along the corridor helps Canada Chrome Corp earn a social license. Railveyor runs on electricity and requires signal processing through fiber optic cables. Requiring this infrastructure along the corridor presents Canada Chrome Corp the opportunity to create offshoots from the main transmission and distribution line to the nearby Marten Falls, Eabametoong (Fort Hope), Neskantaga (Lansdowne House), Nibinamik (Summer Beaver) and Webequie Indigenous communities that currently run off diesel generator power. Supplying grid connected power from a heavy hydropower region will drastically reduce the emissions intensity of the power consumed by these communities, but more importantly, it will eliminate harmful emissions coming from diesel generators located within the communities. Furthermore, adding grid power to an already functioning diesel generator system adds resiliency to the power supply of these local communities.

3.1.5 Ring of Fire Case Study Summary

Road haulage and Railveyor require significantly less capital cost than rail haulage. As production commences, however, 10 MTPA leads to massive annual operating costs for long haul trucking. Truck and labor costs contribute the highest portion of trucking annual operating costs. Rail haulage and Railveyor provide energy efficient haul methods that minimize operating costs. Rail usage shifts the majority of operating costs to labor and maintenance instead of fuel by incorporating high vehicle haul capacity and requiring only a few sets of equipment. Railveyor drastically reduces energy and labor costs by utilizing autonomous controls and electricity as a fuel source. Fuel switching and haulage efficiency leads to GHG emissions efficiency. Railveyor infrastructure includes more embedded emissions, but the emissions efficiency of the operating system quickly breaks even with the emissions intensity of road and rail options. Ultimately, Railveyor presents Canada Chrome Corporation with an opportunity to minimize annual operating expenses, achieve a short payback period and achieve the lowest total emissions.

3.2 Case Study Comparing Railveyor to Haul Trucks - Integra DeLamar, Idaho, U.S.

The Integra Resources Corp. (Integra) is actively developing the DeLamar gold-silver mining project in Southwestern Idaho that would entail mining of two open pits with on-site heap leach and milling operations. The Integra PFS[66], published February 2022, envisions a 16 year mine life with a phased development approach entailing initial 35k tonnes/day heap leaching operations and construction of a 6k tonnes/day mill in phase two. Average gold and silver production is estimated at 163k ounces/year (gold equivalent). In support of the PFS, Integra conducted a tradeoff study that evaluated 150-ton diesel haul trucks vs Railveyor for the 8 km haul from the mine pit to the mill. Railveyor was found to improve project economics and lower operating expenditures through reduced haul truck requirements, fuel consumption and offer additional ancillary benefits, such as a reduction in fugitive dust.

Incorporating Railveyor will replace approximately 25% of the project's haul trucks (four to five trucks), reducing fuel consumption from haulage by approximately 20% with an overall reduction of diesel consumption by 13%. Haul trucks would still be utilized to transport ore from the working face to the Railveyor loading station. Fuel and labor savings provide significant reductions in operating expenditures but carry increased capital costs. The overall project NPV is better with Railveyor.

3.2.1 Capital Costs

As outlined in the 2022 PFS, there will be two (2) Railveyor systems in operation at the DeLamar project to service two (2) open pits. The Florida Mountain system will be in operation during years 1-6. The second system will come online in year 4 for development of the DeLamar Pit. The systems would consist of multi-train loops with approximately 19 km of rail total. Ten trains in each pit-loop would be capable of transporting 2100 to 2700 tons per hr and would consist of approximately 150 individual cars with a total train length of 340-380m.

Capital costs for the Railveyor system are presented for each system separately as the DeLamar system would be purchased and constructed mid-way into the project to coincide with initiation of mining of the DeLamar pit. Total CAPEX for the system is estimated at $36.2M (Table Reference).

[66] Integra Resources Corp. (2022, February 9). *Integra completes Pre-Feasibility study for Delamar project with average annual production of 163,000 Oz AuEq for the first 8 yrs, and demonstrates project optionality with phased development approach*. Integra Resources.

Table 20. Summary of Capital Expenditures for the DeLamar Project Railveyor Systems

	Florida Mountain		DeLamar		Total
Equipment Description	Qty.	CAPEX $USD	QTY	CAPEX $USD	CAPEX $USD
Train Cars	1413	$9,804,271	0	$0	$9,804,271
Drive Stations Complete: Mechanical Components and Electrical Control Cabinets	71	$11,290,861	55	$8,746,442	$20,037,303
Track/Structure Components:	1 Lot	$2,147,053	1 Lot	$1,209,992	$3,357,045
Control System Components: Communication Cable, PLCs, HMI, PLC Programming	1 Lot	$307,967	1 Lot	$122,738	$430,705
Services: Engineering, Installation, Commissioning, Training	1 Lot	$311,915	1 Lot	$223,457	$535,372
Feeders (MMD quote)	1	$1,012,549	1	$1,012,549	$2,025,098
Rail-Veyor Equipment Supply Total		$24,874,616		$11,315,178	$36,189,794

Capital expenditures for the Railveyor system are partially offset by a reduction in the number of haul trucks. Because Railveyor will be used to transport ore from the pit rim to the mill, haul trucks will still be required but the fleet is reduced by approximately four haul trucks over the life of mine. Under a direct equipment purchase assumption, this would result in savings of approximately $11.6M - $14.5M, however, Integra anticipates leveraging equipment manufacturer financing options for the DeLamar mining fleet.

3.2.2 Operating Cost

Principal operating expenditures for the Railveyor system include electricity and maintenance. Maintenance costs are relatively consistent for the Florida Mountain and DeLamar systems but electricity consumption is dependent on elevation changes along the haulage routes. The Florida Mountain route is a downhill haul from the loading area to the mill and Railveyor's regenerative braking technology results in a net surplus of electricity generated within this system of approximately 2.3M kWh/year during peak production from the pit. The DeLamar system, which is not a downhill haul, is estimated to require approximately 3.2M kWh/year for operation on average over the life of mine (referenced in the table below).

Table 21. Railveyor Operating Expenditures - Florida Mountain System

Florida Mountain OPEX							
Year	Y1	Y2	Y3	Y4	Y5	Y6	Average
Average Operating Power kW	26	-411	-425	-423	-528	-184	-324
Total kWh/year	302,411	-2,299,704	-2,382,794	-2,370,963	-2,996,424	-944,986	-1782077
Energy Cost per year USD	$19,054	-$144,881	-$150,116	-$149,371	-$188,775	-$59,534	-112271
Annual Maintenance USD	$591,039	$654,637	$450,241	$636,391	$387,748	$334,678	509122
Annual OPEX USD	$610,093	$509,756	$300,125	$487,020	$198,973	$275,144	$396,852

Table 22. Railveyor Operating Expenditures - DeLamar System

DeLamar OPEX													
Year	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Average
Average Operating Power kW	432	1,142	1,011	682	254	178	222	204	203	202	208	156	40	169
Total kWh/year	2,960,260	6,923,993	6,143,258	4,179,071	1,626,959	1,176,753	1,439,373	13,330,146	1,328,246	1,322,073	1,353,416	1,292,629	601,649	3,204,693
Energy Cost/year USD	$169,486	$436,212	$387,025	$263,281	$102,498	$74,135	$90,680	$93,799	$83,680	$83,291	$85,265	$81,436	$37,904	$77,563
Annual Maintenance USD	$614,851	$758,208	$893,221	$585,278	$424,495	$396,132	$412,677	$405,795	$592,925	$405,287	$487,376	$403,432	$359,900	$442,453
Annual OPEX USD	$784,337	$1,194,420	$1,280,246	$848,559	$526,993	$470,267	$503,357	$499,594	$676,605	$488,578	$572,641	$484,868	$397,804	$520,015

The autonomous Railveyor system would reduce personnel requirements for the mine, including truck operators and mechanics. The 25% reduction in haul trucks and commiserate reduction in labor costs is estimated at $30M over the life of the mine.

3.2.3 Direct and Indirect (Scope 1 and Scope 2) Emissions

Adoption of the Railveyor system has a number of environmental benefits over haulage with typical diesel powered trucks. The system will reduce noise and dust along the haul route and less water will be required for dust suppression. Use of the electrically powered Railveyor system and reduction in the number of diesel haul trucks is estimated to reduce Scope 1 emissions by approximately 160k tonnesCO2 over the life of the mine, or 12.1%. Particulate emissions from diesel exhaust are also reduced.

3.2.4 Carbon Cost

Under potential carbon pricing scenarios, the Railveyor system could significantly reduce costs associated with CO2 emissions. Assuming a $50/tonne CO2, as targeted in the Paris Climate Accords, the Scope 1 emissions reductions realized through incorporation of Railveyor would translate to monetary savings of $8.0M over life of mine by reducing total carbon costs from $64M to $56M, or $0.47M/year. Presentation of emissions as a financial information illustrates the environmental and business advantages of Railveyor for the DeLamar Project.

3.2.5 Summary

In summary, by leveraging the Railveyor system, the DeLamar mine has a unique opportunity to realize cost savings compared to typical truck haulage, while reducing its overall carbon footprint and automating many essential functions that typically would require onsite personnel. The 25% reduction in haul trucks and commiserate reduction in labor costs offers significant operational cost savings, reduced emissions and additional environmental benefits for the project.

Glossary

Key Acronyms

AEMA - American Exploration & Mining Association
BEV - battery-electric haul truck
CAPEX - capital expenses
EPA - Environmental Protection Agency
ESG - environmental, social, governance
E.U. - European Union
EV - electric vehicle
GHG - greenhouse gas
IEA -International Energy Agency
kWh - kilowatt hour (1,000 watt-hours)
LCA - life cycle assessment
LCOE - levelized cost of energy
MT, tonne - metric tonne
MTCO2e - Metric tonne of carbon dioxide equivalent
MTPA - million (mega) tonnes per annum
MWh - megawatt hour (1,000,000 watt-hours)
NPV - net present value
OEM - Operating equipment manufacturers
OPEX - operational expenses
PFS - pre-feasibility study
WSC - Warm Springs Consulting

Definitions

Blue hydrogen - Blue hydrogen is hydrogen produced from natural gas with a process of steam methane reforming, where natural gas is mixed with very hot steam and a catalyst; chemical reaction occurs creating hydrogen and carbon monoxide

Clevis pin connection - Clevis pins are used as a quick and secure fastener in place of bolts and rivets; designed with both a flat or domed head on one end and crosshole at the other, a clevis pin is inserted through the holes at the pronged ends of a clevis and is kept in place by a cotter pin

Composite belt - a rubber conveyor belt that is flexible, resistant, smooth and seamless that also doesn't have any holes or openings; to increase strength, many belt materials contain additives, including fabric, steel, polyester or fiberglass

Cradle-to-gate emissions - These emissions refer to the carbon impact of a product from the moment it's produced to the moment it enters the stores; some companies prefer to measure cradle-to-gate because they've designed a product that can be easily recycled or composted, avoiding the landfill altogether

Decarbonization - the reduction of carbon dioxide emissions through the use of low carbon power sources, achieving a lower output of greenhouse gasses into the atmosphere

Embedded emissions - These carbon emissions carbon consist of all the GHG emissions associated with building construction and infrastructure, including those that arise from extracting, transporting, manufacturing, and installing building materials on site, as well as the operational and end-of-life emissions associated with those materials

Electric drive station - These fixed devices are placed in a series along the train route to provide forward motion; they consist of drive motors, gear reducers and horizontal flexible drive tires located on either side of the track which can be adjusted to provide sufficient friction to drive plates on the sides of the train to transform rotational tire motion to horizontal thrust of the entire train

Electrolyzer - An electrolyzer is a system that uses electricity to break water into hydrogen and oxygen in a process called electrolysis

Fuel efficiency - the capacity of an engine, especially that of a vehicle, to obtain energy from fuel

Fugitive dust - an environmental air quality term for very small particles suspended in the air, primarily mineral dust that is sourced from the Earth's soil; the particles are mainly minerals common to soil, including silicon oxides, aluminum oxides, calcium carbonates and iron oxides

Grade resistance - the gravitational force acting on the vehicle; this force may not be exactly perpendicular to the roadway surface, especially in situations when a grade is present

Green hydrogen - hydrogen produced from electrolysis that is powered by 100% renewable energy

Grey hydrogen - hydrogen produced via the steam reforming of natural gas; methane is mixed with steam at a high temperature to yield hydrogen and carbon dioxide through a catalytic chemical reaction

Haulage - the commercial transport of goods or materials

Heap leaching operation - this process is used to recover minerals from low-grade ore, involving the use of a solution that dissolves the minerals; it involves laying down an impermeable leach pad, heaping ore on the pad, and then using a drip system to spread a- leach solution over the ore

Life-cycle cost (LCC) - an accounting ownership approach that assesses the total cost of an asset over its life cycle including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life

Load factor - the ratio of the average load to total vehicle freight capacity, in tonnes or volume where the load is expressed as tonne-km (tkm) and capacity as vehicle-km (vkm)

NetZero - a goal to negate the amount of greenhouse gasses produced by human activity, achieved by reducing emissions and implementing methods of absorbing carbon dioxide from the atmosphere

Payload - the part of a vehicle's load, especially an aircraft's, from which revenue is derived

Regenerative power - the power that returns to an Inverter when a motor decelerates or a load descends; power produced by a motor for a generator

Scope 1 Emissions - GHG emissions from operations that are owned or controlled by the reporting company, such as equipment, vehicles and/or emissions from chemical production in owned or controlled process equipment

Scope 2 Emissions - GHG emissions from the generation of purchased or acquired electricity, steam, heating or cooling consumed by the reporting company, such as the use of purchased electricity, steam, heating or cooling, often from a utility or energy service provider

Scope 3 Emissions - all indirect GHG emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions. For example, emissions from the transportation of purchased products or the use of sold products. In the mining sector, this also includes emissions associated with the production of equipment, as well as transportation and distribution materials

Tailings dams - typically an earth-fill embankment dam used to store byproducts of mining operations after separating the ore from the gangue; tailings can be liquid, solid, or a slurry of fine particles, and are usually highly toxic and potentially radioactive

Tank-to-wheel efficiency (TTW) - TTW efficiency is defined as the ratio between energy output from the wheels and the energy content of the fuel in the tank

Tank-to-wheel emissions (TTW) – TTW emissions are defined as the emissions related to a particular engine type as work is performed from storage (tank, battery, etc.) to output

Turquoise hydrogen - Turquoise hydrogen is made using a process called methane pyrolysis to produce hydrogen and solid carbon. In the future, turquoise hydrogen may be valued as a low-emission hydrogen, dependent on the thermal process being powered with renewable energy and the carbon being permanently stored or used

References

Alicke, K., Gupta, R., & Trautwein, V. (2021, July 21). *Resetting supply chains for the next normal*. McKinsey & Company.
Association of American Railroads. (2021, April). *AAR sustainability fact sheet*.
Barkan, C. (2012). *Introduction to rail transportation*.
BEUMER Group. (2020, April 21). *Belt conveyor as an economical alternative to trucks: Does it pay off?*
BEUMER Group. (2019, March). *Advances in Conveyor Technology*.
Brightmore, D. (2021, June 28). *Hitachi partners with ABB to develop electric dump truck*. Mining Global.
Briginshaw, D. (2019, June 3). *Europe leads the charge to replace diesel traction*. International Railway Journal.
Burul, D., & Algesten, D. (2021). *Life cycle assessment of distribution vehicles. Battery electric vs diesel driven*. Scania.
Choksey, J. S. (2021, September 27). *What's the difference between gray, blue, and green hydrogen?* J.D. Power.
Christensen, A. (2020). *Assessment of hydrogen production costs from electrolysis: United States and Europe*. International Council on Clean Transportation.
Circular Ecology. (2020, October 8). *Embodied carbon footprint database*.
Climate Transparency. (n.d.). *Mexico*.
Creamer, M. (2020, November 25). *Anglo praised for blazing decarbonised mining trail with hydrogen truck project*. Mining Weekly.
Cummins Inc., Global Power Leader. (2020, May 14). *Batteries and Fuel Cells: Understanding differences and opportunities*. Cummins Inc.
Deign, J. (2020, June 29). *So, what exactly is green hydrogen?* Wood Mackenzie.
Delevingne, L., Glazener, W., Grégoir, L., & Henderson, K. (2020, January 28). *Climate risk and decarbonization: What every mining CEO needs to know*. McKinsey Sustainability.
Deloitte. (2021). *Tracking the trends 2021: Closing the trust deficit*. Deloitte Insights.
Dillon Consulting. (2017). *Manitoba infrastructure remote road operations: Greenhouse gas follow-up assessment*.
eMining Switzerland. (n.d.). *Development: 123-Tonne eDumper*.
European Chemical Transport Association. (2011, March). *Guidelines for measuring and managing CO2 emission from freight transport operations*.
Fink, L. (2020). *Larry Fink CEO letter*. BlackRock.
Fisher, J. (2021, August 17). *Freight market demand grows as truck and trailer inventory shrinks: ACT*. FleetOwner.
Fortune Business Insights. (n.d.). *Locomotive market size, share & COVID-19 impact analysis, by technology type (IGBT Module, GTO Thyristor, and SiC Module), by propulsion type (diesel and electric), and regional forecasts, 2021–2028*.

Gleeson, D. (2020, April 21). *BEUMER Group makes the economic case for ore transport by conveyor*. International Mining.
Görner, S., Kudar, G., Mori, L., Reiter, S., & Samek, R. (2020, October 5). *The mine-to-market value chain: A hidden gem*. McKinsey & Company.
Government of Canada. (n.d.). *Canada's official greenhouse gas inventory*.
Hussain, M., Dincer, I., & Li, X. (2007). A preliminary life cycle assessment of PEM fuel cell powered automobiles. *Applied Thermal Engineering*, 27(13), 2294–2299.
Iannucci, E. (2021, December 13). *Anglo American and Aurizon study hydrogen trains*. Mining Weekly.
IEA. (2021, May). *Net Zero by 2050*.
Ingwersen, W., & Li, M. (2020). *Supply chain greenhouse gas emission factors for U.S. industries and commodities*. U.S. Environmental Protection Agency.
Integra Resources Corp. (2022, February 9). *Integra completes Pre-Feasibility study for Delamar project with average annual production of 163,000 Oz AuEq for the first 8 yrs, and demonstrates project optionality with phased development approach*. Integra Resources.
International Union for Conservation of Nature. (2021, November). *Peatlands and climate change*. IUCN.
International Union of Railways. (2016, June). *Carbon footprint of railway infrastructure*.
Joiner, S. (2010, February 11). *Is bigger better? "Monster" trains vs freight trains*. Popular Mechanics.
Komatsu. (n.d.). *730E-10 Electric Drive Mining Truck*. Retrieved February 1, 2022.
Komatsu. (2021, August). *Komatsu announces collaborative customer alliance to advance zero-emission equipment solutions*.
Kuykendall, T. (2020, July 28). *Path to net zero: Miners are starting to decarbonize as investor pressure mounts*. S&P Global Market Intelligence.
Masterson, V. (2021, July 5). *Renewables were the world's cheapest energy source in 2020*. World Economic Forum.
Merchan, A., Belboom, S., & Léonard, A. (2017). *Life cycle assessment of freight transport in Belgium*.
Milman, O. (2021, September 16). *'Dramatically more powerful': World's first battery-electric freight train unveiled*. *The Guardian*.
Molloy, P. (2019, October 2). *Run on less with hydrogen fuel cells*. RMI.
Moore, P. (2021, July 29). *Anglo American says fuel cell-battery hybrid mining truck project at Mogalakwena entering final phase with testing start Q4 2021*. International Mining.
Nunno, R. (2018, May 30). *Electrification of U.S. railways: Pie in the sky, or realistic goal?* Environmental and Energy Study Institute.
Owen, J. R., Kemp, D., Lèbre, É., Svobodova, K., & Pérez Murillo, G. (2020). *Catastrophic tailings dam failures and disaster risk disclosure*. *International Journal of Disaster Risk Reduction, 42*.
Olugbenga, O., Kalyviotis, N. & Saxe, S. (2019). *Embodied emissions in rail infrastructure: a critical literature review*.
Preyser, J. (2021, December 21). *Miners experiment with hydrogen to power giant trucks*. BBC News.
Railveyor. (2021, December). *Rail-Veyor engineering and design services report*.
Rapier, R. (2020, June 6). *Estimating the carbon footprint of hydrogen production*. Forbes.

Reuters. (2021, December 12). *Australia's Aurizon teams up with Anglo American for hydrogen-powered freight rail*.

Ritchie, H. (2020, October 6). *Cars, planes, trains: Where do CO2 emissions from transport come from?* Our World in Data.

Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.

U.S. Department of Energy. (2006, October). *Hydrogen fuel cells fact sheet*.

U.S. Department of Energy. (2015, November). *Fuel cells fact sheet*.

U.S. Environmental Protection Agency. (2020). *Emissions factors for greenhouse gas inventories*. EPA Center for Corporate Climate Leadership.

U.S. Environmental Protection Agency. (2022, January 27). *Emissions & Generation Resource Integrated Database (eGRID)*.

World Steel Association. (2021, May). *Life cycle inventory (LCI) study 2020 data release*.

Appendix

Appendix A: Key Assumptions and Inputs for Calculations

Conversions		
Item	**Unit**	**Source**
Ton to Tonne	ton/MT	*Metric conversion charts and calculators*. (2020). *Metric Conversions*.
Mile to km	mile/km	*Metric conversion charts and calculators*. (2020). *Metric Conversions*.
MT to g	g/MT	*Metric conversion charts and calculators*. (2020). *Metric Conversions*.
gal to liters	liter/gal	*Metric conversion charts and calculators*. (2020). *Metric Conversions*.
Diesel to kWh energy	kWh/liter	Cambridge Regional College. (2012, April). *What is energy and how much do you use? Sustainability Exchange*.

Variable Inputs		
Haul Scenario	**Unit**	**Source**
Daily Tonnes Hauled	tonnes	WSC assumption for technologies comparison
Haul Distance	km	WSC assumption for technologies comparison
Annual Days of operation	days/year	WSC assumption for technologies comparison
Annual Hours of operation	hrs/year	WSC assumption for technologies comparison
Grade	%	WSC assumption for technologies comparison

Variable Assumptions		
Item	**Unit**	**Source**
Price of diesel	USD/liter	Spot pricing 02/22/22
Road Maintenance per km	USD/km	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
Price of electricity	USD/kWh	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
Labor rate hourly (operators)	per hr	Interviews with mine operators
Carbon Pricing	USD/MTCO 2e	Market estimate

Emissions Factors		
Item	**Unit**	**Source**
Diesel emissions factor	mtco2e/gal	U.S. Environmental Protection Agency. (2020). *Emissions factors for greenhouse gas inventories*. EPA Center for Corporate Climate Leadership.
Diesel emissions factor	mtco2e/liter	U.S. Environmental Protection Agency. (2020). *Emissions factors for greenhouse gas inventories*. EPA Center for Corporate Climate Leadership.
Diesel emissions factor	mtco2e/gal	U.S. Department of Energy. (n.d.). *Alternative fuels data center: Maps and data*. Alternative Fuels Data Center.
Average US electricity EF	mt/kWh	U.S. Environmental Protection Agency. (2019, February). *eGRID2019 summary tables*.
Average Canada EF	mt/kWh	2019 - National Inventory Report: 1990 - 2017 - Environment and Climate Change Canada | Table A13
Average Mexico EF	mt/kWh	Climate Transparency. (2017). *BROWN TO GREEN: THE G20 TRANSITION TO A LOW-CARBON ECONOMY*.
Average combined EF	mt/kWh	U.S. Environmental Protection Agency. (2019, February). *eGRID2019 summary tables*.
Steel product emissions factor	mtco2e/tonne	World Steel Association. (2021, May). *Life cycle inventory (LCI) study 2020 data release*.

Rubber emissions factor	mtco2e/tonne	Circular Ecology. (2020, October 8). *Embodied carbon footprint database*.
Other transport and support activities	kgco2e/USD	Scope 3 Cat 1 Commodity Table EPA Emissions Factors

Diesel-Electric Truck Key Calculation Assumptions		
Item	**Unit**	**Source**
Cost per vehicle	USD	Interviews with mine operators
Top speed	km/h	from interviews with Caterpillar
Hourly fuel consumption	L/h	from interviews with Caterpillar
Liters per kilometer	L/km	from interviews with Caterpillar
Mt CO2e per kilometer	MTCO2e/km	from interviews with Caterpillar
Haul capacity	MT	from interviews with Caterpillar
Mt CO2e per tonne-km	MTCO2e/tonne-km	from interviews with Caterpillar
Haul capacity	MT	Burul, D., & Algesten, D. (2021). *Life cycle assessment of distribution vehicles. Battery electric vs diesel driven*. Scania.
Vehicle empty weight	MT	Komatsu. (n.d.). *HD785-8 mechanical haul truck*.

Diesel Heavy Rail Key Calculation Assumptions		
Item	**Unit**	**Source**
Fuel gal diesel per ton mile	gal/ton-mile	Association of American Railroads. (2022, February). *Freight rail facts & figures*.
Fuel liter diesel per ton mile	liter/ton-mile	Association of American Railroads. (2022, February). *Freight rail facts & figures*.
Liters per tonne mile	liter/tonne-mile	Association of American Railroads. (2022, February). *Freight rail facts & figures*.
Liters per tonne km	liter/tonne-km	Association of American Railroads. (2022, February). *Freight rail facts & figures*.
Haul capacity	MT	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.

Vehicle empty weight	MT	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.

Railveyor Key Calculation Assumptions		
Item	**Unit**	**Source**
Fuel OPEX/Tonne	USD/tonne	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
Fuel OPEX/Tonne/km	USD/tonne-km	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
Non-fuel OPEX/tonne	USD/tonne	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
Non-fuel OPEX/tonne-km	USD/tonne-km	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
kWh/tonne-km	kWh/tonne-km	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.
kWh/tonne-km	kWh/tonne-km	Tetra Tech. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*.

Conveyor Key Assumptions Calcs		
Item	**Unit**	**Source**
Capacity	Mtph	BEUMER Group. (2020, April 21). *Belt conveyor as an economical alternative to trucks: Does it pay off?*
Power	kW	BEUMER Group. (2020, April 21). *Belt conveyor as an economical alternative to trucks: Does it pay off?*
Haul capacity	MT	BEUMER Group. (2020, April 21). *Belt conveyor as an economical alternative to trucks: Does it pay off?*
Vehicle empty weight	MT	assumed similar to RailVeyor
Install cost	USD/km	BEUMER Group. (2020, April 21). *Belt conveyor as an economical alternative to trucks: Does it pay off?*
Steel	%	WSC estimate
Rubber	%	WSC estimate

Emissions estimate per MT	MTCO2e/MT	World Steel Association. (2021, May). *Life cycle inventory (LCI) study 2020 data release*. Circular Ecology. (2020, October 8). *Embodied carbon footprint database*.
kWh/tonne-km (conveyor)	kWh/tonne-km	Canada Chrome Corporation. (2013). *Canada Chrome Corporation rail v/s road tradeoff study*. Tetra Tech.

BEV Key Calculation Assumptions

Item	Unit	Source
Diesel truck fuel efficiency	mpg	Environmental Defense Fund. (2020, October). *Electric combination short-haul trucks*.
Electric truck fuel efficiency equivalent	mpg diesel e	Environmental Defense Fund. (2020, October). *Electric combination short-haul trucks*.
EV fuel efficiency comparison to Diesel	%	Environmental Defense Fund. (2020, October). *Electric combination short-haul trucks*.
BEV fuel use per tonne-km	liters diesel/tonne-km	Environmental Defense Fund. (2020, October). *Electric combination short-haul trucks*.
BEV electricity use per tonne-km	kWh/tonne-km	Environmental Defense Fund. (2020, October). *Electric combination short-haul trucks*.
% Less indirect & overhead costs of diesel-electric	%	Cunanan, C., Tran, M. K., Lee, Y., Kwok, S., Leung, V., & Fowler, M. (2021). A review of Heavy-Duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles. *Clean Technologies, 3*(2), 474–489.

FCEV Key Calculation Assumptions

Item	Unit	Source
% Less indirect & overhead costs of diesel-electric	%	Cunanan, C., Tran, M. K., Lee, Y., Kwok, S., Leung, V., & Fowler, M. (2021). *A review of Heavy-Duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles*. *Clean Technologies, 3*(2), 474–489.

Haul capacity	MT	Moore, P. (2021, July 26). *XEMC's retrofitted 120 t all battery electric truck gets to work at Huolinhe coal mine*. International Mining.
Vehicle empty weight (haul trucks)	MT	assumed same as BEV
Annual BEV energy requirement	kWh	Molloy, P. (2019, October 2). *Run on less with hydrogen fuel cells*. RMI.
Energy loss %	%	Molloy, P. (2019, October 2). *Run on less with hydrogen fuel cells*. RMI.
kWh hydrogen requirement	kWh	Christensen, A. (2020). *Assessment of hydrogen production costs from electrolysis: United States and Europe*. International Council on Clean Transportation.
% Less indirect & overhead costs of diesel-electric	%	Cunanan, C., Tran, M. K., Lee, Y., Kwok, S., Leung, V., & Fowler, M. (2021). *A review of Heavy-Duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles*. *Clean Technologies, 3*(2), 474–489.

Long Haul Diesel Truck Key Calculation Assumptions		
Item	**Unit**	**Source**
Top speed	km/h	from interviews with CAT, Sandvik
Hourly fuel consumption	L/h	from interviews with CAT
Liters per kilometer	L/km	from interviews with CAT
MTCO2e per kilometer	MTCO2e/km	from interviews with CAT
Haul capacity	MT	from interviews with CAT