Decarbonizing Mining: Diesel vs Electric Haul Trucks on Cost and Efficiency

Assessing Economic and Operational Trade-offs

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The mining industry is a major contributor to global greenhouse gas emissions. Making up about a quarter of the mining vehicle population, diesel-powered haul trucks are responsible for approximately 174 Mt of CO_2 equivalent emissions annually, highlighting the need for emissions reduction strategies. Transitioning to zero-emission electric haul trucks emerges as a crucial step for mining companies aiming to meet international net-zero targets while improving operational efficiency.

This analysis compares the Total Cost of Ownership and operational efficiency of 150 t diesel and electric haul trucks. Electric trucks, particularly those powered by lithium iron phosphate batteries, offer substantial benefits. These batteries are cost-effective; compared to other battery types they have a longer cycle life, and lower environmental impact, providing significant energy and maintenance cost savings, despite higher initial capital expenditure.

Operationally, electric haul trucks can reduce the cost per tonne of material moved by 65%, enhance operational efficiency through better torque and regenerative braking systems (which recover energy during braking and store it for reuse), and demonstrate superior performance metrics, including increased tonnes hauled and speed. Environmentally, electric trucks contribute to cleaner and quieter mining operations with significant reductions in energy costs and CO2 emissions.

Challenges such as battery technology, charging infrastructure, and productivity remain; however, advances in battery technology, rapid charging systems, and battery swapping are promising solutions to these issues. As these technologies evolve, electric haul trucks are expected to become increasingly viable, offering substantial financial and environmental benefits and transforming mining operations toward greater sustainability.

Introduction

Accounting for an estimated 7% of the world's total greenhouse gas (GHG) emissions, the global mining industry is a significant contributor, primarily stemming from energy consumption, blasting, material transport, and processing activities (World Bank, 2020). Diesel-powered machinery is a major source of GHG emissions and haul trucks are by far the largest and most emitting vehicles, making up almost a quarter of the global mining vehicle population.

Globally, haul trucks are responsible for approximately 174 Mt of CO2 equivalent (CO2e) emissions annually, constituting around 40-50% of the total GHG emissions from mining machinery (IDTechEx). This substantial contribution highlights the importance of focusing on this sector for emissions reduction.

As the global community intensifies its efforts to combat climate change, industries are increasingly pressured to reduce their carbon footprints. Mining companies, in particular, are under growing scrutiny to align with international net-zero targets. Many have pledged to achieve carbon neutrality by mid-century, necessitating a comprehensive overhaul of traditional operational practices.

Switching to zero-emission machinery, such as electric haul trucks, is not merely a regulatory compliance issue but a strategic necessity. Transitioning to electric-powered vehicles can significantly reduce GHG emissions, directly contributing to both global and company-specific net-zero goals. Additionally, the shift to electric haul trucks offers potential cost savings in fuel and maintenance, enhancing operational efficiency and sustainability.

In this context, analysing the total cost of ownership (TCO) and operational productivity of diesel versus electric haul trucks is crucial. It provides valuable insights into effectively managing this transition, ensuring mining companies can meet their environmental commitments without compromising productivity or profitability.

150 t Haul Trucks Cost Analysis: Diesel vs Electric

The growing interest from original equipment manufacturers (OEMs) in electric haul trucks reflects the rising demand from mining companies. Several of the world's largest miners have entered into agreements with retrofitters and OEMs to secure electric haul trucks as soon as the technology becomes commercially viable. These companies recognize that electric haul trucks offer significant environmental benefits and enhance safety conditions, while also delivering substantial savings in total cost of ownership.

This analysis evaluates the TCO for 150 t haul trucks, comparing diesel models with those powered by lithium iron phosphate (LFP) batteries. The decision to focus on LFP batteries is driven by several key factors that align well with the demands of heavy-duty mining equipment. Desktop research conducted by the authors found the LFP battery, with a capacity of 2200 kWh, supports operations for approximately 8 hours on a full charge.

LFP batteries are particularly cost-effective, making them a financially viable option for large-scale industrial use (BloombergNEF). This cost advantage is further enhanced by their extended cycle life, meaning they can endure more charge and discharge cycles before their performance declines. This longevity is crucial for haul trucks, which operate under rigorous conditions that demand consistent and reliable power.

Thermal stability is another significant LFP battery strength. In the challenging environments typical of mining operations, the risk of overheating and related safety hazards must be minimized, and LFP's robust thermal properties effectively address this concern. Additionally, LFP batteries have a lower environmental and supply chain impact compared to other chemistries like nickel-cobalt-aluminium (NCA) or nickel-manganese-cobalt (NMC). Unlike these alternatives, LFP does not rely on materials which are not only expensive but also raise ethical and environmental concerns due to their extraction processes.

In terms of environmental impact, LFP batteries have the lowest GHG emissions on a per kWh basis (Llamas-Orozco et al. 2023), making them particularly relevant in the context of decarbonizing mining operations, where the shift to electric haul trucks can significantly contribute to sustainability goals.

While LFP batteries do have a lower energy density compared to other battery types, storing less energy per unit of weight, this limitation is less critical for haul trucks. These vehicles are already designed to carry heavy loads, so the slightly reduced energy density of LFP batteries does not pose a significant disadvantage. Instead, the trade-off is justified by the battery's cost-effectiveness, safety, and environmental benefits, making LFP an optimal choice for powering 150 t haul trucks in mining operations.

Both truck types are assessed under identical operational conditions. Although electric haul trucks come with a higher initial capital expenditure, they present significant financial advantages over a 10-year horizon. The analysis, conducted by the authors, shows potential

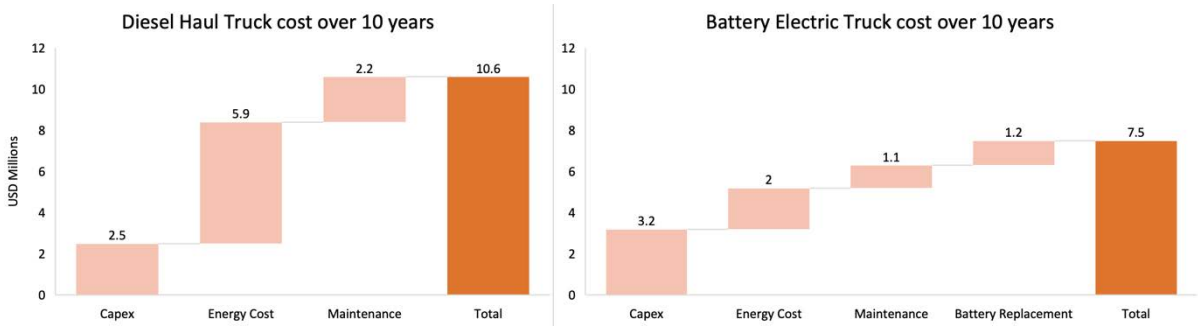
savings of around USD3 million, even after accounting for multiple battery replacements. These savings primarily stem from reduced energy and maintenance costs.

Electric haul trucks benefit from substantially lower energy costs: electricity is cheaper than diesel fuel. Furthermore, electric trucks require less maintenance due to their simpler mechanical design and lack of complex exhaust systems. One notable advantage of electric haul trucks is the absence of idling fuel consumption. While diesel trucks use fuel continuously, electric trucks do not draw energy when stationary, making 1 diesel truck hour roughly equivalent to 0.8 battery truck hours.

Additionally, regenerative braking technology allows electric haul trucks to recover and store energy during downhill operations, further enhancing efficiency. With rapid advancements in battery technology, charging times have improved significantly, with a full recharge from 0 to 100% now achievable within 1 to 1.5 hours (Fortescue Zero).

While the upfront investment in electric haul trucks is higher, the substantial long-term financial benefits, including major reductions in energy and maintenance costs, as well as efficiencies from regenerative braking and faster charging times, make them a compelling alternative to diesel trucks under identical operational conditions.

Crucially, the capital expenditure (CapEx) for electric haul trucks is recovered by the third year of operation, underscoring the swift return on investment through reduced operational and maintenance costs.



Operational Efficiency: Diesel vs. Electric Trucks

- **Cost Efficiency**: The 150 t diesel haul truck with a cycle time of 1 hour, consumes 100 litres of diesel per hour. With diesel priced at USD1 per litre, the energy cost to move 150 t of material amounts to USD100 per hour. In contrast, the electric truck consumes approximately 275 kWh of energy per hour, translating to an energy cost of around USD35, resulting in a 65% reduction in the cost to move 150 t of material.
- **Operational Efficiency**: Electric trucks offer significant improvements in operational efficiency due to higher torque at lower speeds and regenerative braking systems. For example:
    - **Boliden**: Reported a 15% reduction in cycle time with electric trucks.

    - **New Afton Gold Mine**: Experienced a 56% decrease in mucking cycle time compared to diesel equipment, using the Sandvik LH518B and Sandvik Z50 truck.
- **Performance**: Pretivm's Brucejack Gold Mine in British Columbia, Canada, using the Sandvik Z50 truck, reported:
    - More than 90% machine availability.
    - Speeds of 9.5 km/h on a 15% grade with a 42 t load.
    - Battery swap times of less than 10 minutes.
    - 42% increase in tonnes hauled compared to a diesel-equivalent machine and a 22% boost in speed.
- **Environmental Impact**: The Huolinhe coal mine in Inner Mongolia using an all-electric truck converted by Xiangtan Electric Manufacturing Co Ltd reported:
    - **Energy Savings**: Daily power consumption costs of USD263-298, compared to USD1,480-1,970 for a diesel truck.
    - **Reduced Emissions**: Benefitting from zero emissions, it is estimated annual CO2 emissions reduced by 1,500 t, contributing to a cleaner and quieter mining operation.

Challenges and Future Prospects

In conclusion, while electric haul trucks face several significant challenges, their potential to revolutionize mining operations is substantial.

Battery technology remains a key obstacle, with current advancements from suppliers like CATL, ABB, and Northvolt only recently meeting the high demands of haul trucks. The lack of a unified standard in battery designs and chemistries complicates the selection of the optimal solution for mining applications. Continued research and development in this area, however, is expected to yield more effective and affordable options.

Charging infrastructure presents another challenge, as electric trucks require high charging rates of 1 to 3C (where "C" refers to the charging rate relative to the battery's capacity; for example, a 1C rate means the battery will be fully charged in one hour, while a 2C rate charges it in half an hour) to maintain productivity which can impact battery life and necessitate frequent replacements. Nevertheless, emerging solutions, such as rapid charging technologies and battery swapping, offer promising ways to address these issues. For instance, Fortescue's 221 t haul truck, equipped with a 1.4 MWh battery that can be charged in 30 minutes, highlights the potential of fast-charging systems. Battery swapping allowing quick exchanges of depleted batteries could further reduce downtime and enhance operational efficiency.

Productivity concerns also contribute to the slow adoption of electric haul trucks. Currently, electric trucks cannot match the uptime of diesel trucks, which require only about 10 minutes of refuelling per day compared to the 1 to 2 hours battery charging. Despite this, electric trucks offer advantages such as higher torque and regenerative braking systems, which can lead to reduced cycle times and increased material handling capacity over time.

Overall, the commitment of OEMs and the mining industry's eagerness to adopt electric haul trucks underscore their potential. With significant financial and environmental benefits on the

horizon, ongoing advancements in battery technology, charging infrastructure, and operational efficiency are expected to address the current limitations. As these solutions continue to develop, electric haul trucks are poised to become a more viable and transformative option for the mining sector.