KOMATSU

Digging beyond the buzz word

Electrification of hydraulic mining excavators

White Paper

Disclaimer

This white paper was developed and is intended for general information purposes only. The findings, interpretations and conclusions presented in this white paper are the result of a collaborative process driven by Komatsu Germany GmbH and our valuable business partners, who supported with the practical use case. The contents reflect the state of knowledge and opinion at the time of publication. Although the information has been compiled with the greatest possible care, there is no guarantee that it is factually correct, complete and/or up to date; in particular, this publication cannot take into account the specific circumstances of individual cases. Any liability is excluded.

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We like to extend our sincere gratitude to Barrick Gold Corporation and BIA Group for their exceptional support in developing this white paper. Their invaluable contributions, especially in providing firsthand operational insights into electric-driven hydraulic mining excavators, play a crucial role in highlighting the potential of this technology as a fundamental component of sustainable and cost-efficient open-pit mining methods.

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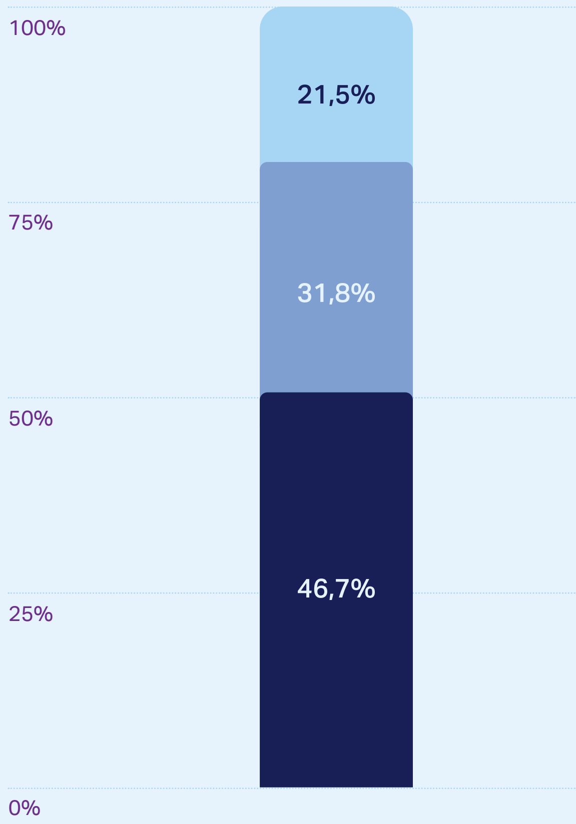
Introduction

In recent years, climate change has become a focal point within the mining industry, prompting discussions on the industry's necessary responses.

Globally, the transition towards a clean and renewable energy future is underway: solar panels, wind turbines, battery technology, hydropower – all these innovations will have to scale to meet the climate goals of the Paris Agreement, by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. And with it, the demand for metals and minerals will increase.

Emissions in open-pit Mining

Emission by Scope



Scope

1 2 3

Example: iron ore, open-pit mine, Australia [McKinsey & Company 2023]

The mining industry must cut emissions drastically, while increasing production to meet the global demand. This balancing act is challenging and there is no doubt about the future destination: all signs point to decarbonization as the end goal. Even though there is no "right" way to get there, electrification plays a vital role. The availability of more and more low-cost renewable energy as well as rapid technological improvements such as battery and storage possibilities enable a wider field of application for electrification.

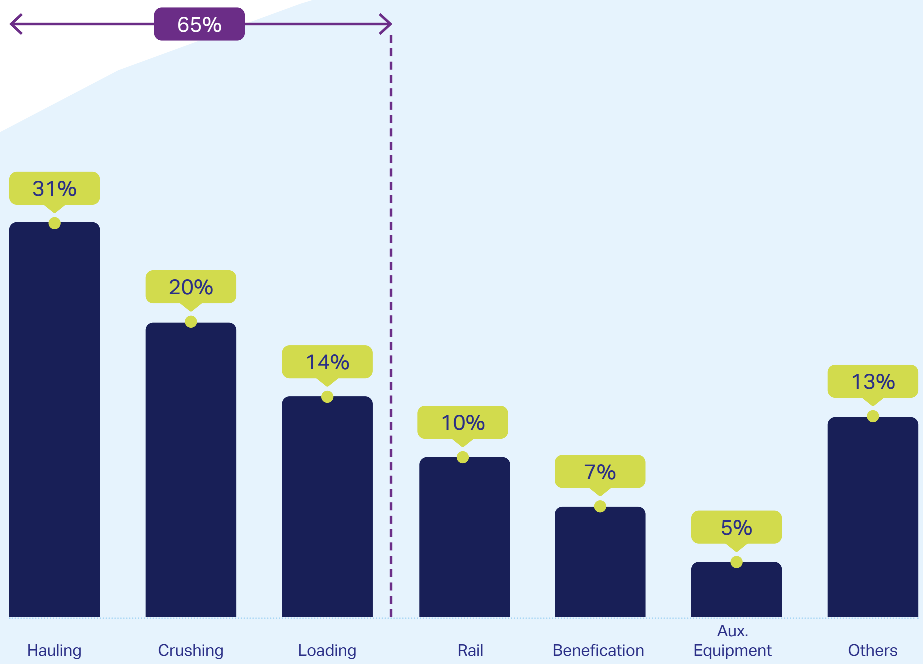
Already today, greenfield projects are mandated to minimize or even eliminate the utilization of conventional fossil fuel-based energy sources. The general viability of projects therefore is highly dependent on the choice of energy sources as a key criterion – beyond traditional considerations such as mine design, mine planning, ore extraction and material movement strategies.

Recent studies in open-pit mining indicate that two thirds of all mining emissions result from three major processes within the mine: hauling, crushing, and loading – all processes mostly contributing to scope1 emissions.

The current decade is decisive: mining companies need to adapt and decarbonize to achieve their corporate greenhouse gas reduction targets towards net zero, specifically with a distinct focus on their load and haul equipment.

Emissions in open-pit Mining

Emission by Process Step



Example: iron ore, open-pit mine, Australia [McKinsey & Company 2023]

02 EV adoption in hydraulic mining excavators

History of electrification in hydraulic mining excavators

Even though the discussions on electrification are recently in-creasing on a global scale, it is not a new topic for the OEMs. In fact, electrified hydraulic mining excavators have been in the mining market since the 1980s. DEMAG, the forerunner com-pany of Komatsu Germany's Mining Division, pioneered with an all-electric-driven hydraulic mining excavator in the early 1980s.

The H241, a 300-tons backhoe mining excavator, was the first hydraulic mining excavator without a diesel engine. The ma-chine was powered by a 1,500kW electric motor delivering the same operational performance and productivity compared to its conventional diesel-driven counterparts.

In a tethered configuration with a large cable, the machine's switch cabinet was directly connected to a substation and the mine grid. These first fully electric-driven hydraulic mining excavators were delivered with global focus on coal mines in the United States, South Africa and Thailand using their own

History of electrification: H241, first electric-driven hydraulic mining excavator globally mined thermal coal within nearby power plants, supported to reduce the operating costs tremendously and enable the playground for further developments in the field of electric-driven hydraulic mining excavators.

Throughout the 1980s, DEMAG continued to expand its electric-driven product offerings within its whole loading equipment portfolio. The largest hydraulic mining excavator of its time, the H485 with 700-tons and the predecessor of the Komatsu PC8000, was electrified and delivered to the first customer in 1989. Powered by two 1,600kW squirrel-cage electric motors, the machine was operating in a copper mine in northern Europe and demonstrating the capabilities of this technology also in an arctic environment.

The technology acceptance grew over time: higher availabilities and equivalent productivity compared to the diesel machines as well as lower operating costs facilitated further applications in various commodities from coal mining and oil sands, limestone and uranium to hard rock applications in gold, copper, and iron ore. By the end of the 1990s, DEMAG and Komatsu introduced more than 50 electric-driven hydraulic mining excavators to the mining market of which eight were equipped with a backhoe attachment.

History of electrification: H485, the largest hydraulic mining excavator of its time powered by an electric motor

more than
260
delivered machines

over
40
years of experience with electric-driven hydraulic mining excavators

exceeding
12.7 m.
operating hours with electric motors

To keep the mobility of the hydraulic mining excavators in electric configuration, DEMAG introduced a cable drum in 1984. First it was mounted on a trailer next to the machine, one year later directly fixed on the undercarriage frame on the hydraulic mining excavator itself, giving the machine an operational travel radius of more than 150 meters.

Today, latest technologies are incorporated into Komatsu's electrically powered hydraulic mining excavators. The simplified electric schematic with a CAN-bus system enabling a lean and maintenance-friendly environment, as well as the fully automated cable drum offered for the whole range of equipment, assist to maximize productivity while maintaining a low cost per ton.

In 2024, Komatsu Germany is celebrating over 40 years of electric-driven hydraulic mining excavators with more than 260 delivered machines beyond 200-tons of operating weight and an experience of more than 12.7 million operating hours with electric drives.

Advantages and limitations of electrically powered hydraulic mining excavators

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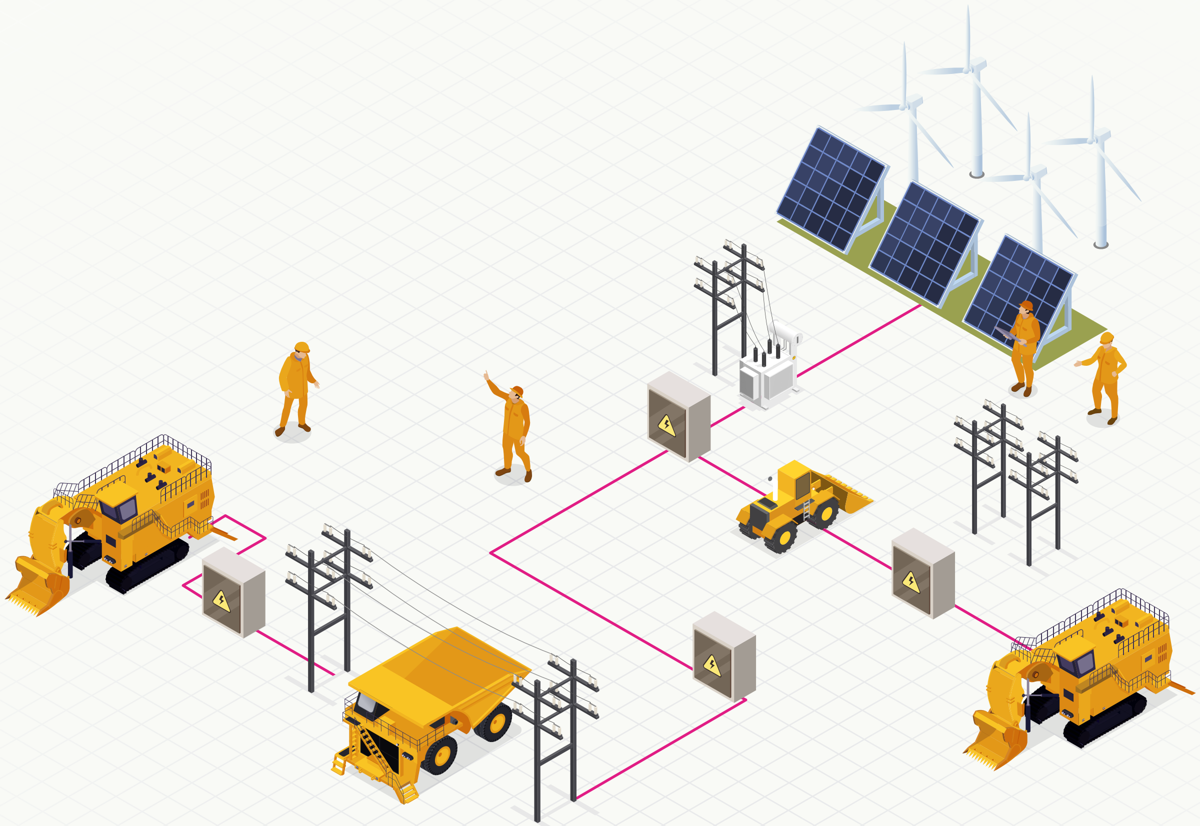
Utilizing electric drive technology in hydraulic mining excavators offers a multitude of advantages, with one of the most prominent being the elimination of CO_2 emissions during operation. Komatsu's electric drive hydraulic mining excavators are engineered to operate without emitting harmful exhaust gases, thereby mitigating environmental impact and safeguarding personnel within mining environments. When paired with renewable energy sources, this emission-free operation can significantly reduce the overall carbon footprint along the entire well-to-wheel emission chain, thereby bolstering miners' efforts in CO_2 reduction, while maintaining equivalent productivity levels when compared to their diesel-driven counterparts.

Moreover, electrically driven hydraulic mining excavators facilitate substantial reductions in operating costs. The streamlined design of a squirrel-caged electric motor, in contrast to the complexities of the latest diesel engine technology with exhaust gas after-treatment, results in lower equipment maintenance costs per hour of operation. This reduced maintenance requirement also translates to decreased reliance on service personnel, a crucial benefit given the scarcity of qualified technicians, particularly in remote mining regions.

In summary, the adoption of electric drive systems in hydraulic mining excavators not only addresses environmental concerns by eliminating emissions, but also delivers tangible economic benefits through reduced operating costs and alleviated pressure on maintenance personnel, thus positioning mining operations for greater efficiency and sustainability.



Schematic visualization of electric infrastructure inside the mine

It is also important to acknowledge certain limitations inherent with the utilization of electric loading equipment in general. Firstly, implementing electric infrastructure within the mine site necessitates at least four key components: the mine grid, a substation, cable towers, and a junction box to connect the machinery. In remote areas, a thorough assessment is imperative to determine the feasibility of accessing an available power grid. Alternatively, micro-grid solutions such as local solar power installations or external fuel cells are to be considered based on local conditions.

Secondly, in comparison to conventional diesel-driven hydraulic mining excavators, the mobility of electrically powered models is constrained by the length of the cable between the machine and the junction box. When relocating the equipment, miners must also relocate the junction box or substation using auxiliary equipment like wheel loaders. Yet the use of a factory-fitted automated cable drum mitigates operational disadvantage and enables a working radius of up to more than 250 meters, enabling mobility and flexibility in daily operation.

In summary, the benefits derived from electrically driven hydraulic mining excavators, coupled with strategies to address mobility limitations and enhance mine site electrification, highlight that electric drive technology is a crucial alternative for the present and foreseeable future.

03 Business Case

The preceding sections have demonstrated that electric vehicle (EV) adoption in hydraulic mining excavators is more than just a buzz word. Beyond the 40 years of application, the world demand for electric-driven hydraulic mining excavators above 200-tons of operating weight is increasing and reached approximately 15% between 2018 and 2023.

Alongside the significant contribution to the decarbonisation, electric equipment presents considerable upside potential and is economically favourable compared to conventional diesel-driven hydraulic mining excavators.

The forthcoming sections delve into detailed field data to substantiate the business case for transitioning from conventional diesel-driven to electric-driven equipment, focusing on the 700-ton class, namely the PC7000-11 hydraulic mining excavator.

> *Up to 95% of CO_2 emissions and more than 40% of a machine's TCO can be reduced with electric-driven hydraulic mining excavators*

The carbon footprint perspective

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In a study conducted by McKinsey and Company, it was found that over 85% of the CO_2 footprint in the lifecycle of a diesel-driven hydraulic mining excavator is generated during its operation at the mine site. This emission of CO_2 from burning diesel fuel directly impacts the scope 1 emissions of mining companies.

To illustrate the carbon footprint comparison, we selected a highly fuel-efficient Tier4-certified diesel machine. The entire CO_2 emission cycle, spanning from raw oil production to refining, transportation, and consumption in the diesel-driven hydraulic mining excavator, is referred to as well-to-wheel emissions. This cycle results in an accumulation of 3.31 kilograms of CO_2 per liter of diesel burned, with 80% of these emissions directly attributed to fuel combustion within the engine, and the remaining 20% associated with the production, refining, and transportation processes.

Determining the well-to-wheel emissions for electric energy is a more intricate process due to its reliance on various power sources for energy generation. However, these emissions can be estimated based on the average energy mix in a particular country and the associated emissions of the energy sources used.

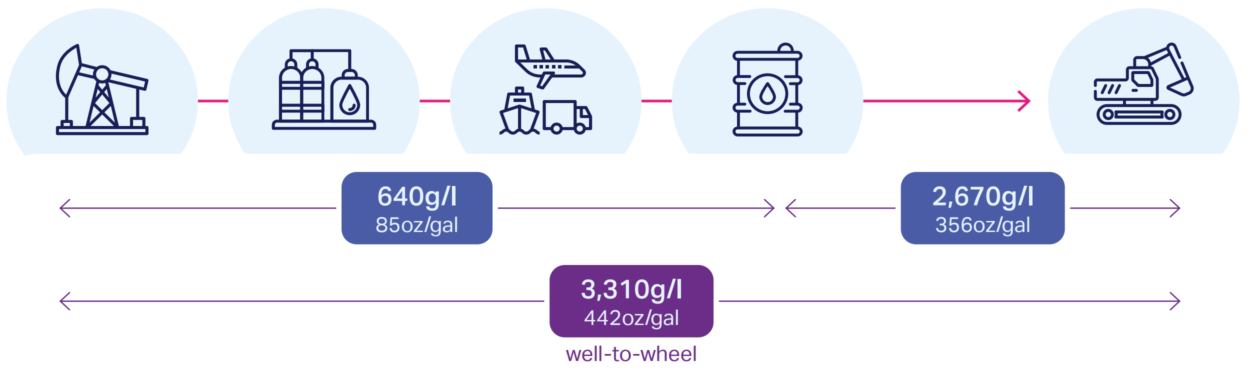
The illustration on the next page depicts four examples, ranging from countries with predominantly fossil fuel-based energy generation such as Australia resulting in 606g CO_2 per kWh and the United States with 399g CO_2 per kWh, moving towards Canada, where most energy is generated from hydro and tidal sources, emissions decrease to 164g CO_2 per kWh. Lastly, countries like Sweden, heavily invested in hydro and nuclear energy, boast the lowest emissions at just 42g of CO_2 per kWh[1].

[1] ourworldindata.org, data as of 2021

PC7000-11: well-to-wheel emissions comparing diesel & electric drive

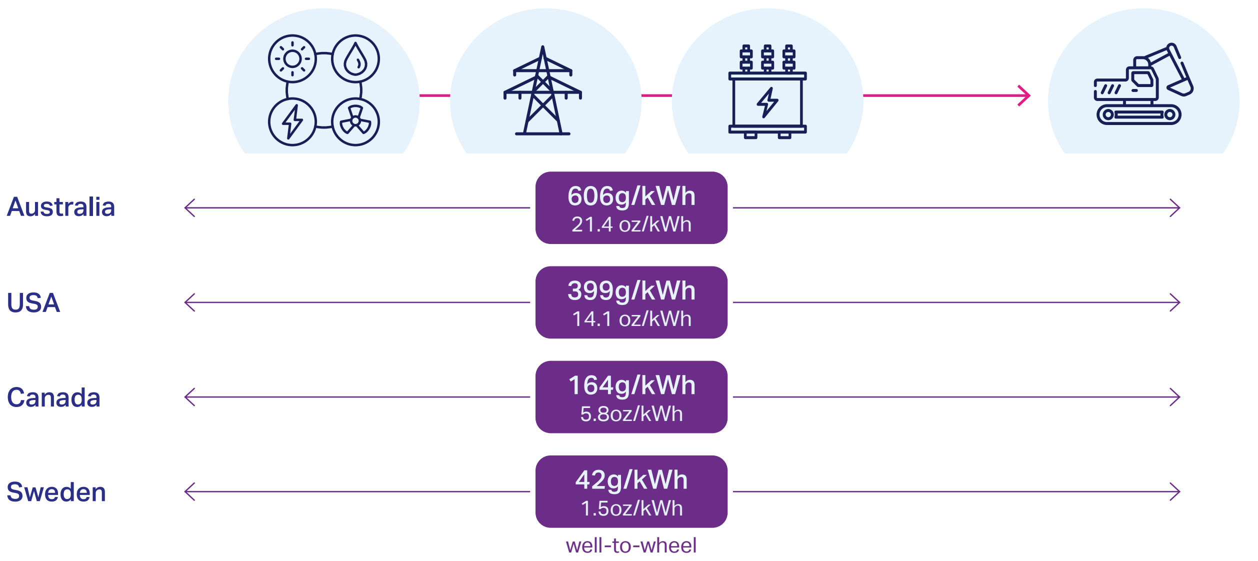
Diesel (emission per liter)

Innovation Orgins, 2020



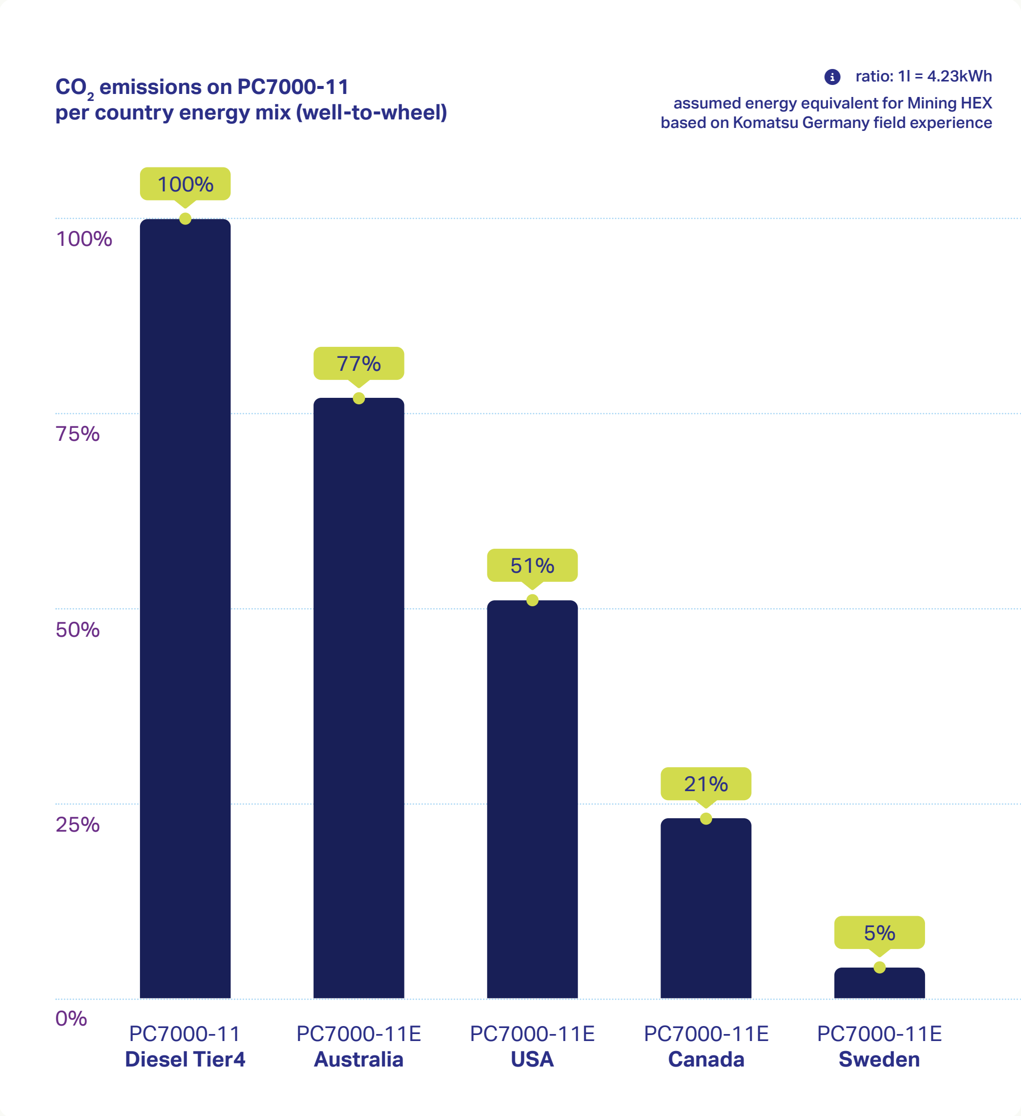
Electric (emission per kWh)

ourworldindata.org, data from 2021



Despite the significant variance between these countries, each example demonstrates a substantial reduction in CO_2 emissions compared to the latest technology Tier4 engine. Even in the case of Australia's brown energy mix, there is a notable emission reduction by 23% during the operation of an electrically driven hydraulic excavator compared to the Tier4 diesel engine. Furthermore, in scenarios such as the Swedish energy mix, this reduction can be maximized so that a reduction in emissions of up to 95% can be achieved on a well-to-wheel basis.

PC7000-11: well-to-wheel emissions comparing diesel & electric drive



This business case clearly demonstrates the emission reduction potential of electrically driven hydraulic mining excavators in today's condition. With a notable transition towards a higher proportion of renewable energy sources throughout the typical lifecycle of a hydraulic mining excavator, which spans more than 10 years, miners can anticipate even greater contributions to their efforts aimed at reducing CO_2 emissions[1].

[1] The highlighted CO2 emission savings potentials are derived from literature values from the cited sources and are associated with an assumed hourly consumption rate of Komatsu Germany's hydraulic mining excavators. A detailed, site-specific analysis is necessary for each mine to accurately determine the exact CO2 and CO2-equivalent emission savings potentials

The TCO perspective

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Looking beyond the carbon footprint implications, the adoption of an electric drive train also brings about cost reductions in terms of TCO. Komatsu Germany conducted a thorough analysis, drawing from over 40 years of experience and data from 260 units of electrically driven hydraulic mining excavators. The study focused on comparing the potential savings over a 90,000-hour lifespan of a PC7000-11 when transitioning from diesel drive to electric power.

When examining a conventional Tier4 engine-powered hydraulic mining excavator like the PC7000-11, roughly 90% of the total primary costs are divided into three main categories: power consumption accounting for approximately 44% of the total costs, spare parts consumption around 32% and initial capital expenditure constituting 13% of the total costs when amortized over 90,000 operating hours.

PC7000-11: cost per hour comparing diesel & electric drive

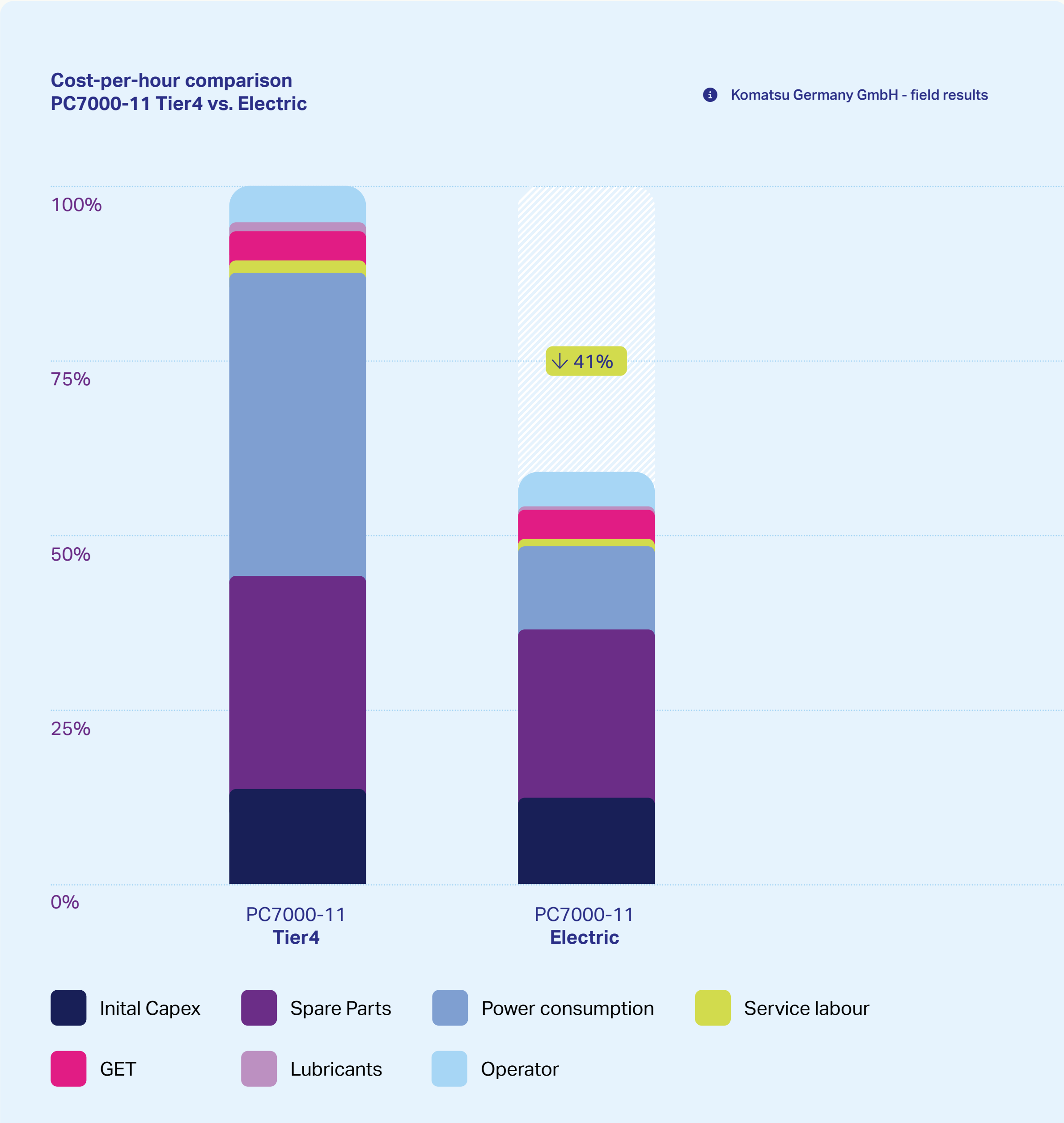
	PC7000-11 Tier4		PC7000-11 Electric
CAPEX (depreciated over 60,000 hrs)	100%	↓ 5%	95%
Spare Parts	100%	↓ 29%	71%
Service labour	100%	↓ 7%	93%
Lubricants	100%	↓ 31%	69%
Power consumption (Diesel = 1.2$/l, E = 0.08 $/kWh)	100%	↓ 73%	27%

Due to the lower complexity of the electric drive train configuration, the initial capital expenditure for an electrically driven PC7000-11 is approximately 5% lower than its diesel-powered counterpart with Tier4 certification. During operation, the electrically driven machine also boasts a further 29% reduction in spare parts costs, attributed to decreased service and maintenance requirements for the drive train and fuel system, consequently reducing the need for on-site service labour. This results in a crucial advantage given the scarcity of skilled workers in remote mining regions.

However, the most significant savings stem from reduced power consumption costs. For instance, at an existing and known mine site in Canada, diesel is priced at $1.20 per litre, while electricity can be purchased for 8 cents per kWh. This translates to a potential 73% saving when comparing electric drive energy consumption per hour to fuel consumption over the same timeframe.

PC7000-11: cost-per-hour comparing diesel & electric drive

Overall, in this specific mine configuration, the total potential savings on a per-hour basis amount to 41% when transitioning to electric power. While actual savings may vary depending on fluctuating fuel and energy prices globally, it can be generally concluded that the savings potential typically falls within the range of 20% to 50%.



04 Use Case Barrick Lumwana Second Life going electric

The feasibility of adopting electrically powered hydraulic mi-ning excavators is influenced by specific mine designs and infrastructural frameworks. The transition from diesel to elec-trically powered equipment represents a significant shift, prompting several mine sites to initiate their electrification efforts by converting existing diesel-driven hydraulic mining excavators in their fleet to electric drive.

This approach is not merely a theoretical business case but is substantiated by practical examples. One such case involves three Komatsu PC8000 face shovel machines at the Barrick Lumwana copper mine in Zambia's Copperbelt – a mine pro-ducing 118,000 tonnes of copper[1] at a cost of sales of $2,81 per pound[2]. These three Komatsu machines were initially diesel driven and operated at the high-altitude Pascua Lama gold mine in Chile, situated over 5,000 meters above sea level. In a significant project, these PC8000 diesel machines were dismantled, transported to Zambia, and reassembled as electric units at the Lumwana mine in 2019. The modular design principle of the PC8000 machines facilitated the reuse of most components across all three units, except for the assemblies directly related to the conversion to electric drive.

Reused parts	**New parts fitted during conversion**
Complete undercarriage	Machine house with 2x electric motors
Complete attachment incl. cylinders	High voltage cabinet for electric supply
42m³ face shovel buckets	Cab-base with electric supply
Superstructure / main frame	New cabin (non-mandatory)
Hydraulic tank & cooler	Cable drum
Lubrication system	
Counterweight	

Reused / New parts on the conversion of 3x Komatsu PC8000 to electric at Barrick Lumwana

[1] Barrick 2023 performance report
[2] Barrick website

The conversion from diesel to electric drive represents a project of the scale comparable to assembling a new hydraulic mining excavator. At the Barrick Lumwana mine, each machine underwent a meticulous reassembly process spanning between 45 to 75 days per unit onsite. Collaboration between Barrick as the customer and Komatsu as the distributor and OEM proved essential in tailoring the required new parts & assembly groups to optimize the utilization of existing components. This approach, customized for each machine rebuild, aims to minimize both time and resources required for the conversion while ensuring top-tier quality and productivity of the machine. Notably, particular attention was paid to considerations when reusing assembly groups such as the lubrication and hydraulic oil coolers, requiring adjustments to cable harnesses, connectors, and machine software settings to align with the newly fitted electric drive.

Until today, the three converted PC8000 hydraulic mining excavators have collectively exceeded 85,000 hours of operating at the Lumwana mine following their conversion and subsequent commissioning in 2019. Notably, one of these units has achieved over 31,000 operating hours under the tethered electric drive configuration. The chronological progression of the rebuild activities is detailed in below illustration.

Disassembly & Shipping
3xPC8000 Diesel
Pascua Lama, Chile

Conversion 3xPC8000
Diesel → Electric
(45 - 75 days for assembly)
Lumwana, Zambia

Operating hours since rework
PC8000 #1: 31,002 hrs
PC8000 #2: 30,275 hrs
PC8000 #3: 24,617 hrs

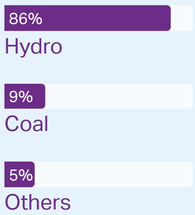
2018-2019

May 2024

Second Life going electric - 3x PC8000-6 at Barrick Lumwana mine converted to electric in 2019

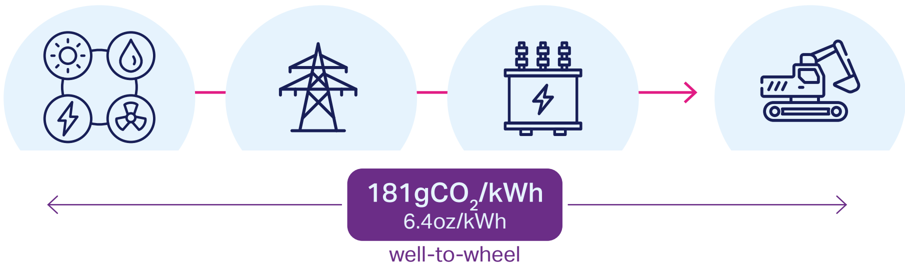
Barrick Lumwana CO_2 footprint reduction going electric with hydraulic mining excavators

Energy sources



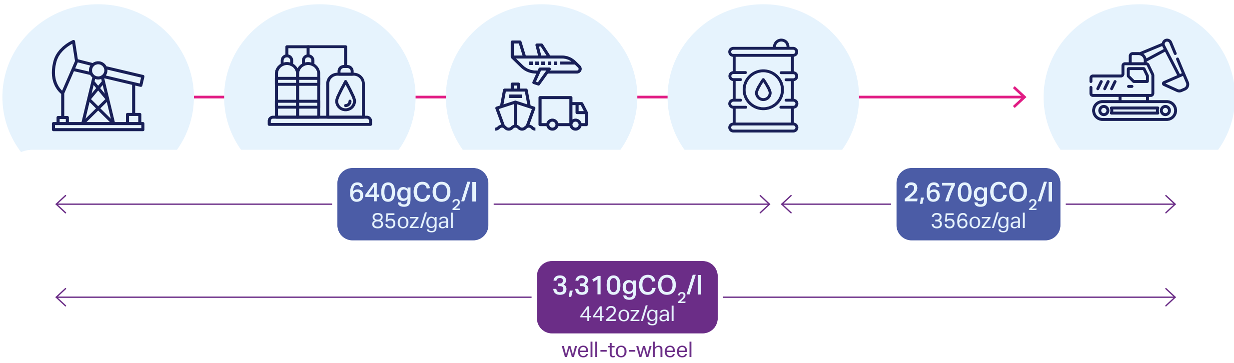
ZESCO / Barrick Gold Corporation

Electric (emission per kWh)



Diesel (emission per liter)

Innovation Orgins, 2020



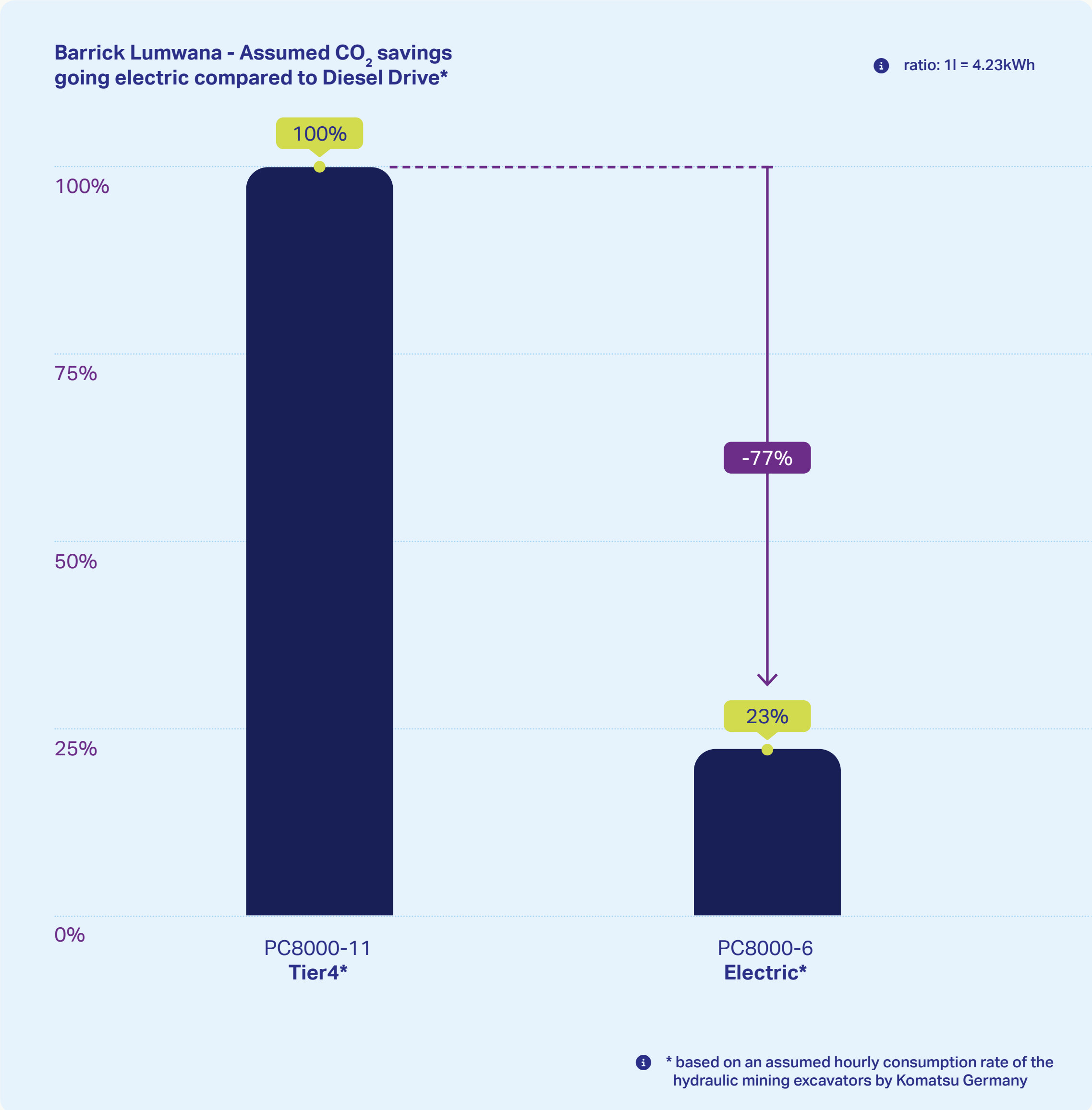
While operating with a tethered electric drive with an automated cable drum, the Lumwana mine infrastructure utilizes electricity from the ZESCO grid, Zambia's largest electricity provider. Approximately 86% of the country's electricity is generated with hydro power from the six extensive rainfall catchment areas. Further 9% of the electricity is sourced from coal-fired plants, with the remaining 5% from various sources predominantly derived from solar power.

When considering the equivalent CO_2 emissions per kWh from these sources, the total amounts to 181g of CO_2 per kWh on a well-to-wheel basis. Operating an electric-driven hydraulic mining excavator with these energy sources, as opposed to its conventional diesel-driven counterpart, achieves a significant reduction in CO_2 emissions by 77% on a well-to-wheel base[1].

[1] The CO_2 emission savings result is based on the assumptions and literature values from the cited sources. These numbers are not directly comparable to Barrick Gold Corporation disclosures as they are based on an assumed hourly consumption rate of the hydraulic mining excavators by Komatsu Germany.

In addition to the significantly reduced environmental footprint, the conversion of the three PC8000 to electric drive technology at Barrick's Lumwana mine site in Zambia showcases compelling economic advantages. Field experience after five years of operation confirm that there is no discernible variance in performance or productivity between diesel and electric-driven hydraulic mining excavators.

Furthermore, internal analysis conducted by Barrick Corporation reveals that electric-driven hydraulic mining excavators exhibit a 47% improvement in cost-effiectiveness when considering the total cost of ownership (TCO) model in comparison to their diesel counterparts. This reduction is primarily attributed to savings realized from the transition to electric power supply and decreased demand for spare parts.



BARRICK

To conclude, the conversion has attributed to Barrick's overall strategy. As part of the organisational sustainability goal, Barrick has set an medium term Greenhouse Gas Scope 1 & 2 emissions reduction target of 30% by 2030 against a 2018 baseline from its operations. While the long-term target is to achieve net-zero emissions by 2050, primarily through greenhouse gas reduction initiatives and offsets for some hard-to-abate emissions.

The Lumwana operation emitted 267 ktCO_2e in 2022 against the organization's 6.705 ktCO_2e. Lumwana is implementiong a REDD+ Project in collaboration with communities surrounding the mine, and in partnership with government authorities. The Project aims to tackle deforestation and its effects on climate change and biodiversity, while providing local communities with socio-economic opportunities and alternative sources of income. The Project will also generate carbon credits that will be used as an offset for hard to abate emissions.

In terms of technology the increased use in high efficiency electric motors in the PC8000 hydraulic mining excavators at Lumwana has directly contributed to the reduction in GHG emissions. The conversion to electric shovels is helping drive GHG emissions savings over the life of the mine.

On a global perspective it can be stated that conversions to electric are not just a recent trend. Back in 2009, Komatsu pioneered the initial retrofit project by transforming two H485S front shovel units in Colombia.

These units, having accrued over 60,000 operating hours with twin diesel engines, were upgraded to PC8000-1 twin electric motor specifications. This conversion extended their lifespan by an additional 60,000 hours whilst boosting their performance by 15% due to the new specifications. Presently, the mine site operates more than a dozen PC8000 units equipped with electric drive.

PC8000 at Barrick Lumwana Mine

05 Conclusion

In this white paper we have traced the evolution and current status of electric-driven hydraulic mining excavators. We have demonstrated through specific business cases and a practical use case, that electric drivetrains represent a vital and effective alternative for achieving carbon emission reduction goals while remaining economically viable.

Perceived operational challenges associated with tethered electric machines such as the limited mobility and flexibility can be effectively addressed with thorough mine planning and mitigated by utilizing existing and automated cable drum technologies during operations. Other limitations, such as the need for specialized electric infrastructure at the mine sites, are offset by substantial reductions in operating costs – up to 50% savings on total costs of ownership (TCO). The value of these savings increases further with the broader deployment of bigger loading fleets and other electrifiable equipment throughout the entire value chain of the mine site, from surveying to crushing and beyond.

Highlighting the advantages and potential of EV technology for hydraulic mining excavators and other equipment in open-pit mining is essential to increase awareness and adoption. We are confident that the industries uptake of electric-driven hydraulic mining excavators will continue to accelerate further, enhancing economic efficiency and productivity while fostering sustainable practices in open-pit mining.

Are you considering transitioning to electric vehicles for your loading operations, or do you have any questions? Reach out to Komatsu Germany today.

Let's create value together.

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