

Metals and Mining Practice

Creating the zero-carbon mine

Despite a daunting timeline, zero-carbon mines are within reach if the right solutions are implemented.

by Henry Legge, Clemens Müller-Falcke, Tomas Naclér, and Erik Östgren



The mining industry is at a tipping point where sustainability and decarbonization are top items on CEOs' agendas. To achieve a 1.5°C climate-change target by 2050, the mining industry will need to reduce direct CO₂ emissions to zero. Encouragingly, our analysis shows that solutions to decarbonize the majority of emissions will become economic within this decade, addressing both Scope 1 and Scope 2 emissions.¹

The mining industry contributes 2 to 3 percent of global CO₂ emissions and has a large role to play in emissions reduction. Within the industry, much of the focus to date has been on portfolio shifts (that is, divestment of coal assets); however, the industry is facing increasing pressure from regulators, investors, and customers to decarbonize operations. The sustainability of miners is increasingly a focus for the capital markets, with access to capital now more frequently dependent on sustainability. The cost of capital can be 20 to 25 percent higher for those miners with the lowest ESG scores.² Simultaneously, customers are exerting increasing pressure. For example, most of the largest automotive OEMs have set ambitions for material decarbonization. This has led to substantial initiatives, such as the launch of H2 Green Steel in Sweden—the world's first zero-carbon steel producer. It will demand zero- or low-carbon iron ore to feed into production.

Many of the largest miners in the world have been taking action by setting increasingly ambitious targets for their CO₂ emissions. For example, since 2020, BHP and Vale have been targeting a 30 percent reduction in Scope 1 and 2 emissions by 2030; Rio Tinto is targeting 15 percent. While these are a big step change for the industry, the targets for net-zero carbon emissions are much further out (2050 for most players).

We believe now is the right time for miners to take action and accelerate their efforts to decarbonize, using this as a differentiator toward customers. Given this growing ambition for decarbonization, we set out to explore the current state of the industry, to build a robust fact base on what it would take to decarbonize aggressively so as to achieve the 1.5°C climate-change goal,³ and to understand related costs and the investments required. The following analysis is focused on the mining of metals (copper, gold, iron ore, and so on) and excludes coal and fugitive methane.

Breakdown of current mining emissions

Emissions within mining can be broken down into three broad types: Scope 1 (emissions from diesel), Scope 2 (emissions from electricity generation), and Scope 3 (emissions from the supply chain and transport). Today 40 to 50 percent of CO₂ emissions come from diesel used in mobile equipment, with another 30 to 35 percent from nonrenewable electricity. However, the emissions intensity varies widely across mines: for example, within copper and iron ore, we see a twentyfold spread among the emissions intensity of mines (Exhibit 1).

To understand this variation, we have created a comprehensive mine-decarbonization model. This breaks down mining emissions at an equipment level and assesses more than 20 decarbonization options (Exhibit 2). We have used an iron ore mine in Australia as an example to see what the world's first zero-carbon mine could look like.

In this particular example, haulage trucks are the single biggest source of emissions from the mine (accounting for 20 to 25 percent of the total), followed by comminution or crushing equipment

¹ Scope 1 includes all direct emissions from the activities of an organization or those under their control (for example, fuel combustion from vehicles), while Scope 2 includes indirect emissions from electricity purchased and used by the organization.

² Environment, social, and governance scores.

³ The United Nations Framework Convention on Climate Change or Paris Agreement requires signatories to pursue efforts to limit the global average temperature increase to 1.5°C above preindustrial levels.

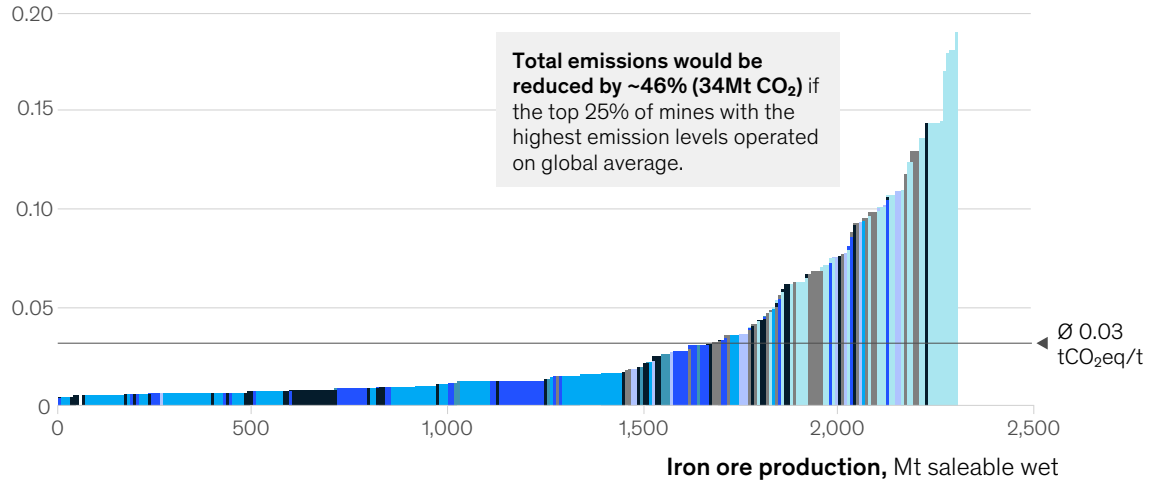
Exhibit 1

Miners could substantially reduce carbon emissions by targeting mines with the highest emissions.

Iron ore mine level, greenhouse gas intensity curve 2019¹

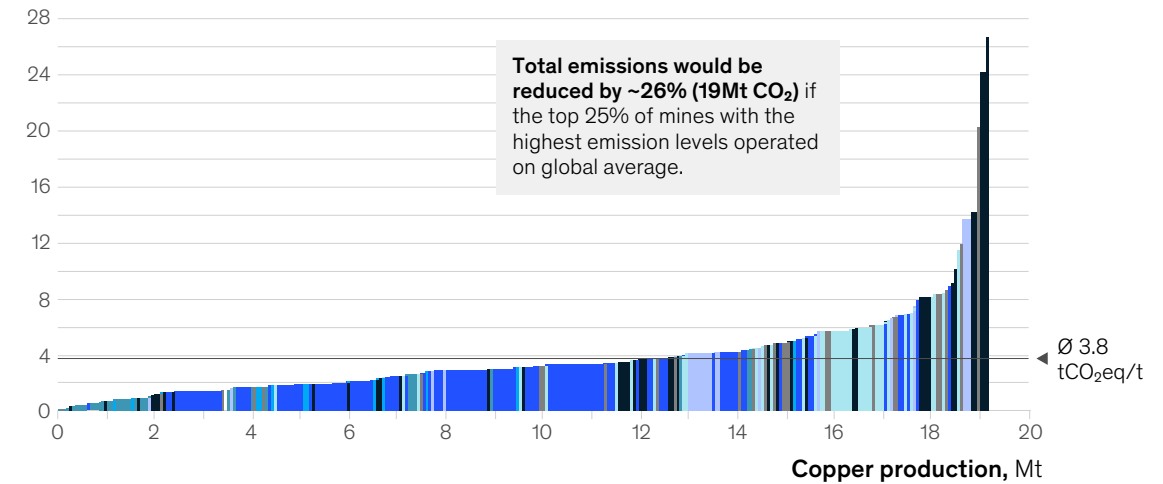
tCO₂eq/t,² iron ore

- Rest of world
- Sub-Saharan Africa
- Oceania
- China
- North America
- Latin America
- Commonwealth of Independent States



Copper mine level, greenhouse gas intensity curve 2019¹

tCO₂eq/t,² copper

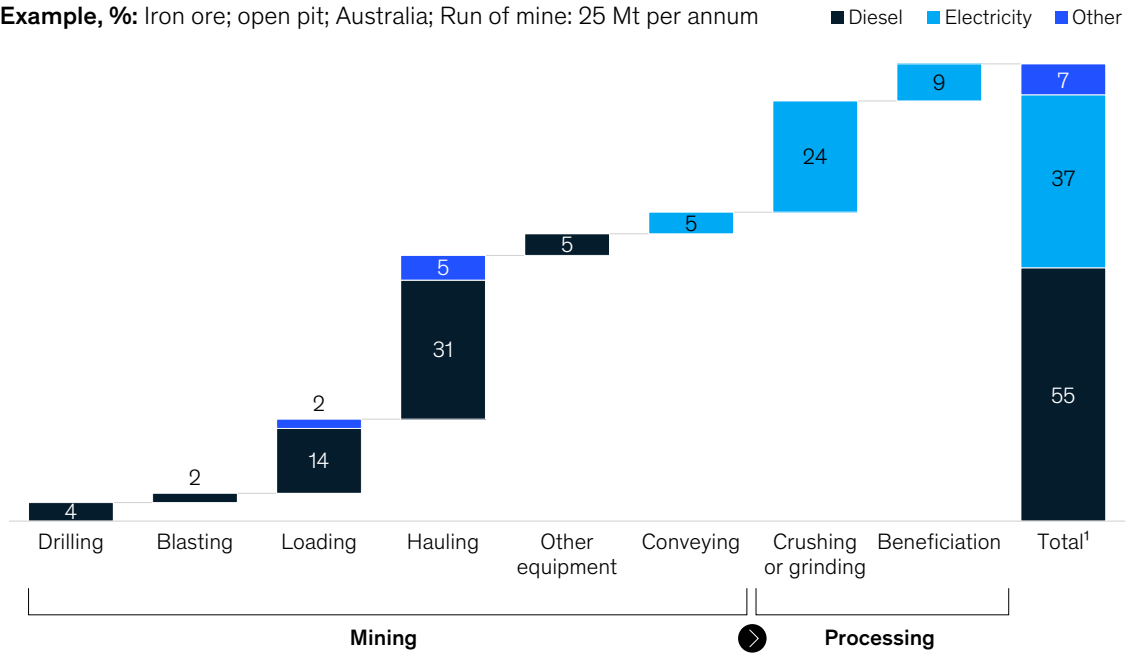


¹Considers Scope 1 and 2 emissions.
²Total CO₂ equivalent per metric ton.

Exhibit 2

Addressing emissions from multiple sources is key to the decarbonization of mining.

Example, %: Iron ore; open pit; Australia; Run of mine: 25 Mt per annum



¹Figures may not sum to 100%, because of rounding.
Source: McKinsey Mine Decarbonization Model

(approximately 20 percent of emissions), bulldozers (7 percent), and excavators (5 percent). Addressing carbon emissions from these four types of equipment offers a substantial opportunity to make a step change in reducing overall mining emissions.

Decarbonization options

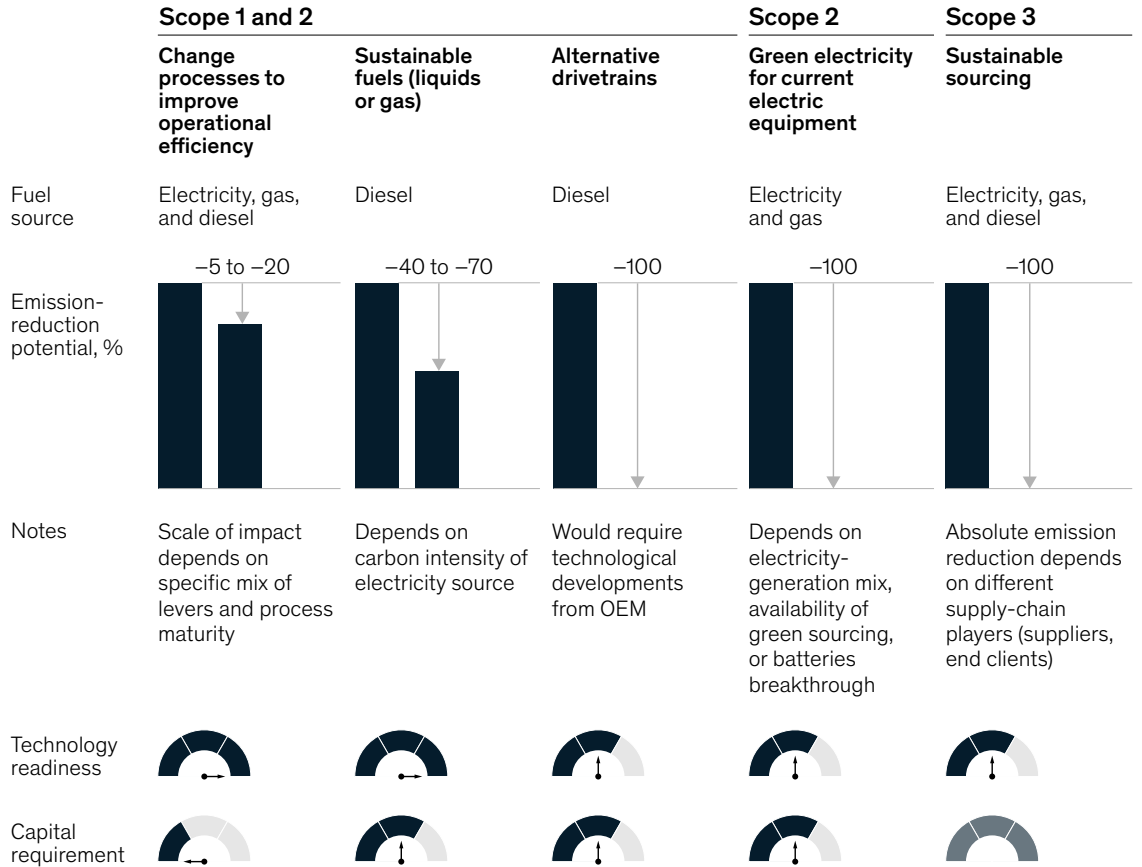
Multiple efforts will be required to address the principal sources of emissions and to decarbonize. Such actions include a move toward sustainable sourcing, fuels, and drivetrains, as well as a switch to green electricity. The following options are at varying states of technological readiness; several are already cost-positive today or will be by 2030 (Exhibit 3).

- *Scope 1 and 2: improve operational efficiency.* Modest investment in upgrading operational efficiency from average to top-quartile or benchmark levels via improved process and performance can generate cash flow to invest in alternative drivetrains or operations modifications.
- *Scope 1 and 2: sustainable fuels.* Several options exist for the mobile equipment used on the mine. For example, switching to liquid sustainable fuels (biofuels or synfuels⁴) has the potential to decrease carbon emissions by more than 70 percent, even using existing equipment and infrastructure. However, this will come at a small cost, increasing total cost of ownership (TCO) by 10 to 15 percent today and approximately 5 percent by 2040.

⁴ Synfuels, or synthetic fuels, are liquid—sometimes gaseous—fuels obtained from syngas, a mixture of carbon dioxide and hydrogen. Synthetic fuels require carbon capture from the environment to be zero-carbon (that is to say, use of CO₂ captured from existing fossil fuel power plants to create synfuels is still carbon-emitting).

Numerous options at varying states of readiness exist for decarbonization efforts.

Decarbonization levers



Note: Highly dependent on project. Can be financed 100% off-balance sheet through outside investors.
 Source: McKinsey Mine Decarbonization Model

- *Scope 1 and 2: sustainable drivetrains.* To go fully carbon neutral, a shift in drivetrains is required, with both hydrogen fuel cells and battery electric vehicles (BEVs) being possible long-term options. Different players are actively looking into this: Boliden has already set up a pantograph-charged hybrid at Aitik; Anglo American is developing a 300-metric-ton fuel cell electric vehicle (FCEV) haulage truck; and Newmont Goldcorp has set up the world’s first fully electric mine at Borden.
- *Scope 2: green electricity.* Switching to a green source of electricity addresses between 30 and 50 percent of current emissions output and is a must if electrifying processes is the chosen path to decarbonization. Several alternatives at different levels of complexity are available, from purchasing green electricity to installing and saving renewable energy (for instance, using photovoltaic solar panels). Several large-scale initiatives are already under way to shift mines to fully renewable electricity. For example, Rio

Tinto's Gudai-Darri mine will have 65 percent of its total electricity consumption supplied by a combination of solar farms and battery storage.

- *Scope 3: sustainable sourcing.* Moving entire supply chains toward greener operations is a challenge that the industry needs to tackle, and this will happen sooner rather than later as OEMs pressure for decarbonization. Key consumables included in this category are cement, steel, and lime.

One opportunity—the decarbonization of haulage trucks—could reduce a mine's emissions by up to 25 percent. As such, this is one of the most critical actions to take. In the short term, the most significant approach will be the use of sustainable fuels (such as biofuels); however, substantial scale-up of biofuel production will be required to meet industry demand. Long-term switching from today's diesel-powered trucks to either pantograph-charged BEV trucks or hydrogen fuel cell trucks will be the most favorable options from a cost and adoption perspective (Exhibit 4). We estimate that by 2030, TCO for a BEV or FCEV haulage truck will be approximately 20 percent, and 10 percent lower than existing diesel trucks thanks to 20 to 30 percent lower maintenance costs and 40 to 60 percent lower fuel costs, as compared with diesel despite higher upfront vehicle and infrastructure costs. Such a move will likely require changes to the design of existing mines, as well as commercialization of these types of vehicle (which today are only at the pilot stage). Nevertheless, if this approach is implemented in greenfield sites, there is a significant opportunity for substantial reductions in both carbon emissions and cost.

Looking across all of these potential decarbonization opportunities, we found that solutions to decarbonize the majority of emissions will be economic within this decade (Exhibit 5). That said, much of the opportunity is limited by technology availability and other operational

considerations that need to be refined on a case-by-case basis. In practice, there is a huge opportunity for miners both to decarbonize and to reduce costs once these barriers are overcome.

Possible pathways toward the zero-carbon mine

There are several potential routes to achieving zero-carbon mines sometime between 2030 and 2040, including BEV and hydrogen pathways. These will require significant mine-level investments—typically \$100 million to \$130 million for a 25 million metric ton run-of-mine (ROM) facility—as well as an accelerated technology push and commercialization of the technology. There are short-, mid-, and long-term opportunities for decarbonization.

Short-term decarbonization actions

Focus on cost-positive alternatives with technology available today to ensure no-regret moves. Improve and take your operations to top-quartile levels; search for green energy alternatives and purchase them if available, or invest in renewable capacity; and switch to existing drop-in sustainable fuels. During this first stage, up to 60 percent of emissions can be reduced over the next three to five years.

Mid- and long-term opportunities for achieving zero carbon

These all need technological development not yet commercially available. The following three options all offer routes to sustainable mining, though the precise selection depends on operational characteristics and some forthcoming industry developments:

- *BEV pathway.* Move to a fully electric mobile equipment fleet, with haulage trucks charged on pantograph and others charged using a battery-swap approach.
- *Hydrogen pathway.* Use an FCEV mobile fleet, combined with a buildup of green hydrogen capacity derived from wind or solar.

Exhibit 4

Battery electric is a front-runner in zero-emissions trucking options.

Example: 400t haulage truck

■ Worse than other fuel alternatives
■ Average
■ Better than other fuel alternatives

No change over time

2020 2030 2040

Category

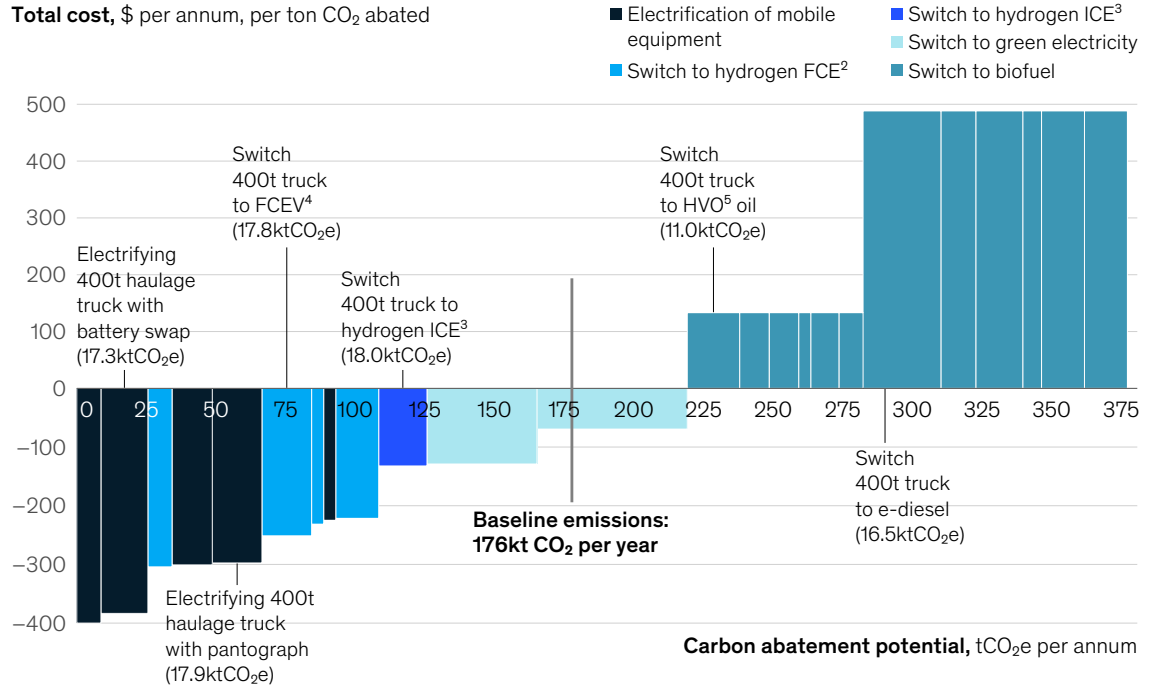
Potential fuels	ESG	Economics	Complexity or adoption of risk	Availability and scalability
	High sustainability criteria	Decarbonization potential TCO, ³ % difference vs diesel		
Renewable diesel*	Hydrotreated vegetable oil (HVO) E-diesel or Power-to-X Other advanced diesels	 55–85% vs diesel		Low High
Low-blend biofuels*	Biodiesel (fatty acid methyl ester [FAME]), bioethanol	<30% (limitations on blending and sustainability issues)	10–50% increase	Med High
Potential alternatives*	Dimethyl ether (DME), ammonia	 >70% vs diesel		High High Med Low Low Med
Gaseous sustainable hydrocarbons	Liquified or compressed biomethane (LBM or CBM) Other advanced syngas or biogas	 >70% vs diesel	~10–50% increase	Med Med
Hydrogen FCEV¹	Blue hydrogen (from natural gas) Green hydrogen (from renewable energy sources)	 >70% vs diesel (green H ₂ only)		High Med Med Low Med Med
Hydrogen ICE²	Blue hydrogen (from natural gas) Green hydrogen (from renewable energy sources)	 >70% vs diesel (green H ₂ only)		High Med Low Low Med High
Battery electric (including hybrids)	Green electricity (from renewable energy sources: eg, solar, wind)	 >70% vs diesel		High Med Low Med Med High

*Liquid sustainable fuels.
¹Fuel cell electric vehicle.
²Internal combustion engine.
³Total cost of ownership.
⁴HVO.
⁵Pantograph-charged BEV.
 Source: McKinsey Mine Decarbonization Model

Within this decade, solutions for the majority of emissions will become economic.

Extraction and processing all levers for open-pit iron ore in Australia,¹ 2030

Total cost, \$ per annum, per ton CO₂ abated



Note: ktCO₂e = kilotons of carbon dioxide equivalent.
¹Mine size: Run of mine of 25 million tons. Baseline emissions: approximately 176kt of CO₂ per year.
²Fuel cell energy.
³Internal combustion engine.
⁴Fuel cell electric vehicle.
⁵Hydrotreated vegetable oil.
 Source: McKinsey Mine Decarbonization Model

- *Synthetic fuel pathway.* Keep existing equipment, but use drop-in synthetic fuels created from green hydrogen and carbon capture, utilization, and storage (CCUS). This to happen at scale across the industry, multiple stakeholders (including mining houses, OEMs, suppliers, oil and gas players, commodity customers, and others) need to work together to develop the potentially cost-positive abatement approaches that are currently unavailable.

Decarbonization presents a significant opportunity for ambitious players to differentiate themselves and lead the way toward zero-carbon mining. For

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