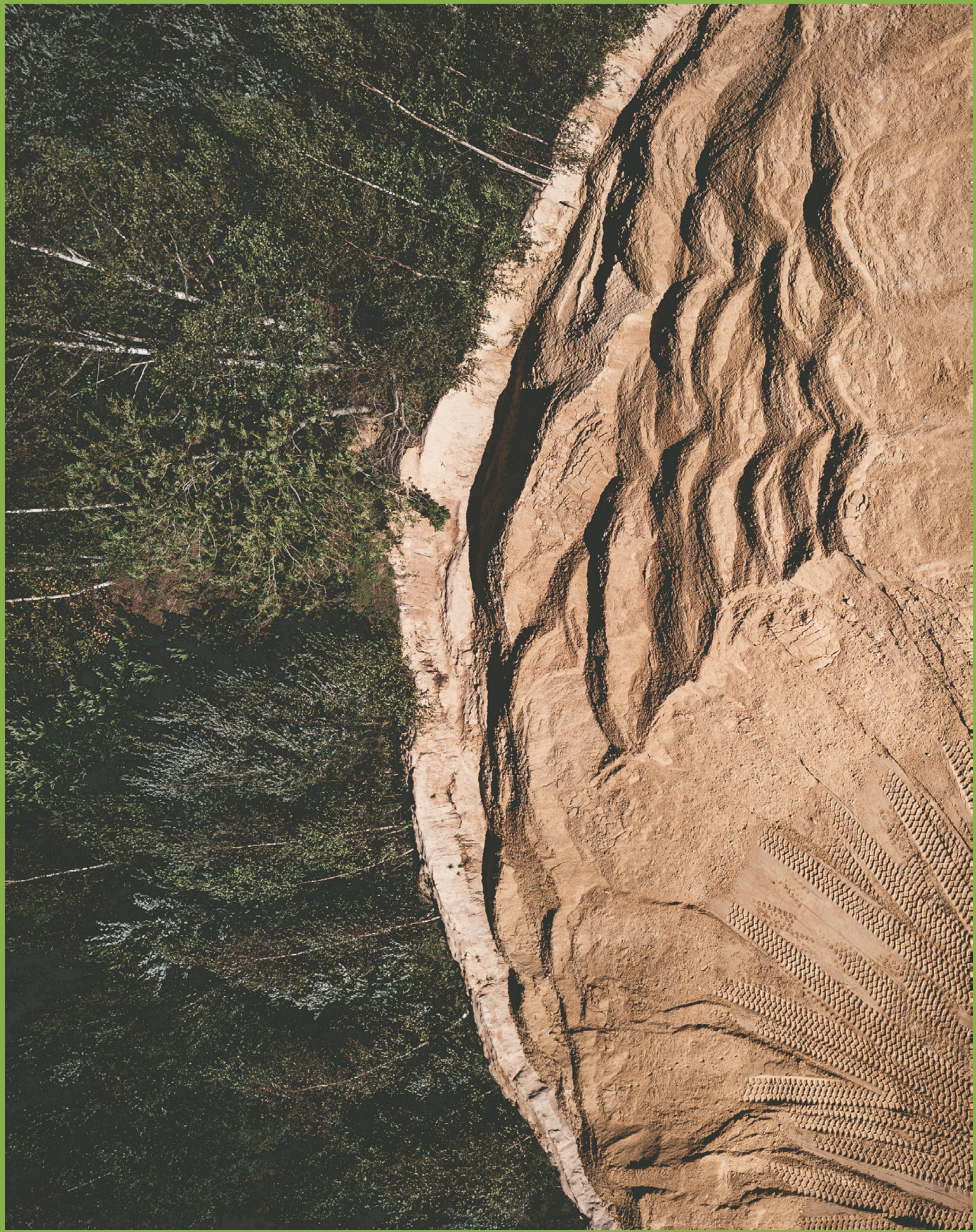
Commissioned by

MINING ENERGY CONSUMPTION 2021

A high-level study into mining energy use for the key mineral commodities of the future.



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EXECUTIVE SUMMARY

The mining industry plays a critical role at the heart of modern global economy, extracting and processing a wide range of minerals that are essential for economic development and human progress.

As a primary industry producing essential resources, mining supports some of the biggest structural trends in our world from population growth to urbanisation through to decarbonisation. Metals such as copper, nickel, steel, and lithium are core components of electricity transmission and storage, electric vehicles and renewable energy infrastructure. The industry therefore has a crucial role in supporting the transition to net zero emissions that is required to limit global temperatures in line with the Paris Agreement.

Mining faces a challenge however: how to provide the essential resources the world needs while reducing its own environmental impact? In essence, mining needs to become more sustainable and efficient. This report seeks to support a more comprehensive understanding of the scale of that challenge by focusing on where energy is consumed in mining and minerals processing. It identifies opportunities for innovation and improvement that will in turn make a significant contribution to the world's carbon transition. Figure 1 shows a high level energy flow on a copper mine, as determined in this study. Although 60% of total energy is estimated to be consumed in mining equipment, this category covers a very wide variety of different equipment, as indicated in the figure. Comminution, consuming close to 40% of total energy contains a single piece of equipment—the grinding mill—that is typically the largest single consumer in a mining operation.

Noting that the comminution area also includes crushing, pumps and other equipment—the grinding mill(s) are normally the largest single energy consumer.

This report quantifies energy use in five commodities: copper, gold, iron ore, nickel and lithium. Bringing together mine energy use data from more than 40 published studies (each of which references dozens more studies and hundreds of mining operations) from 2007 to 2020 into a single narrative, the report aims to build a more comprehensive understanding of energy use in the mining industry.

In order to obtain an understanding of the impact of energy use in the mining industry, a literature survey has been completed exploring energy usage in some key commodities. Information has been collected that examines total final energy consumption in copper, gold, nickel, lithium and iron ore. The study has focussed on minerals processing that involves comminution and either concentration through flotation or leaching. Pyrometallurgical processes such as smelting have been excluded from this study as the energy profiles of those industries are very different to the processes in this study. Both mining operations and processing have been explored with calculations that show the split of final energy consumption in mining vs. processing. These broad areas were then further split into energy used in mobile equipment and ventilation for mining, and into comminution and other processes for process plants.

Across the commodities in the study, an average energy intensity per commodity was calculated. As these were calculated in differing units (i.e. GJ/tonne of ore, GJ/t of product etc.), all intensities were converted to tonnes of copper equivalent. This metric is commonly used in the industry to provide a common measurement across different minerals. Tonnes of copper equivalent is determined from the ratio of market prices for each of the commodities.

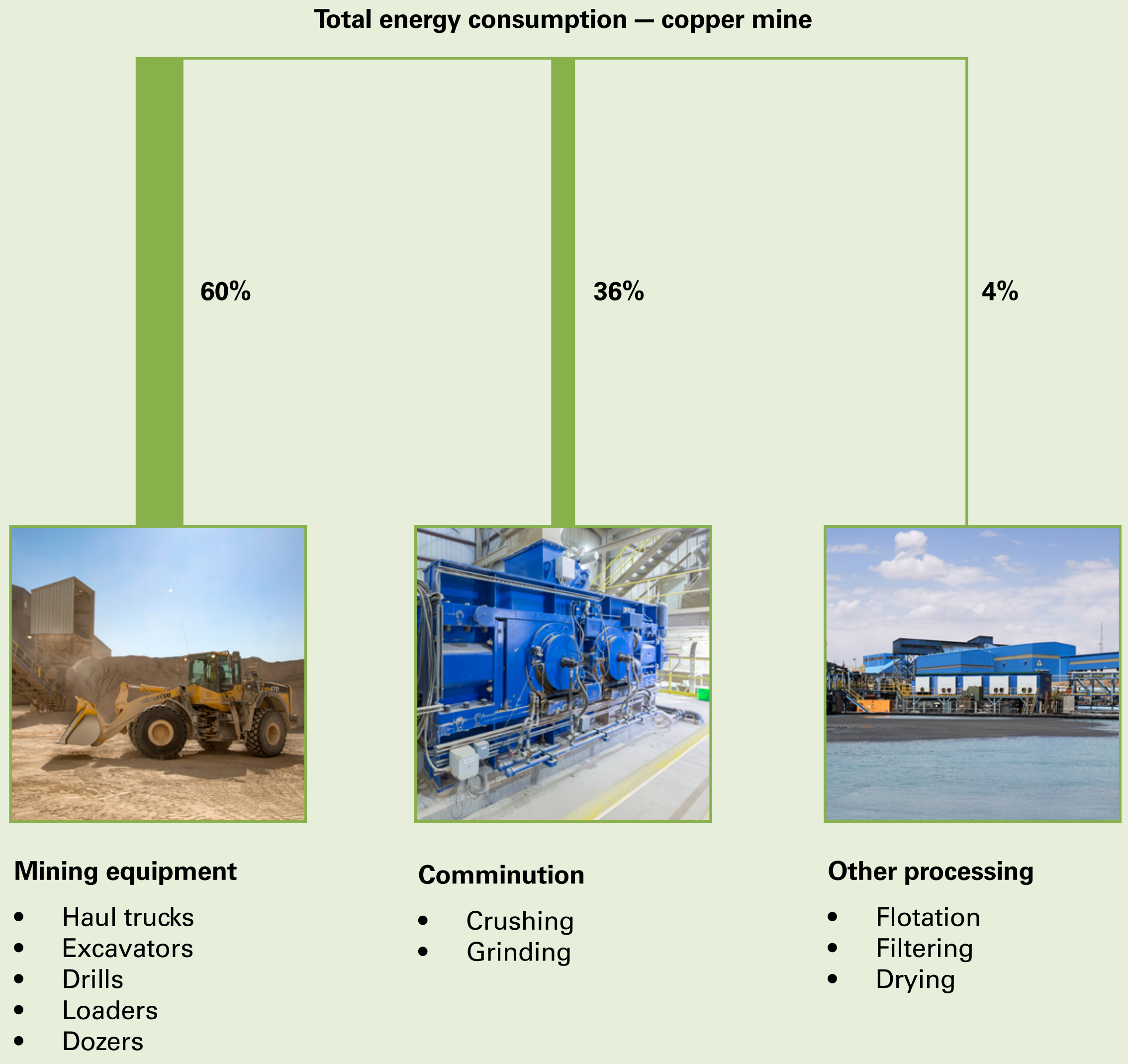


Figure 1 — High level energy consumption: copper mine

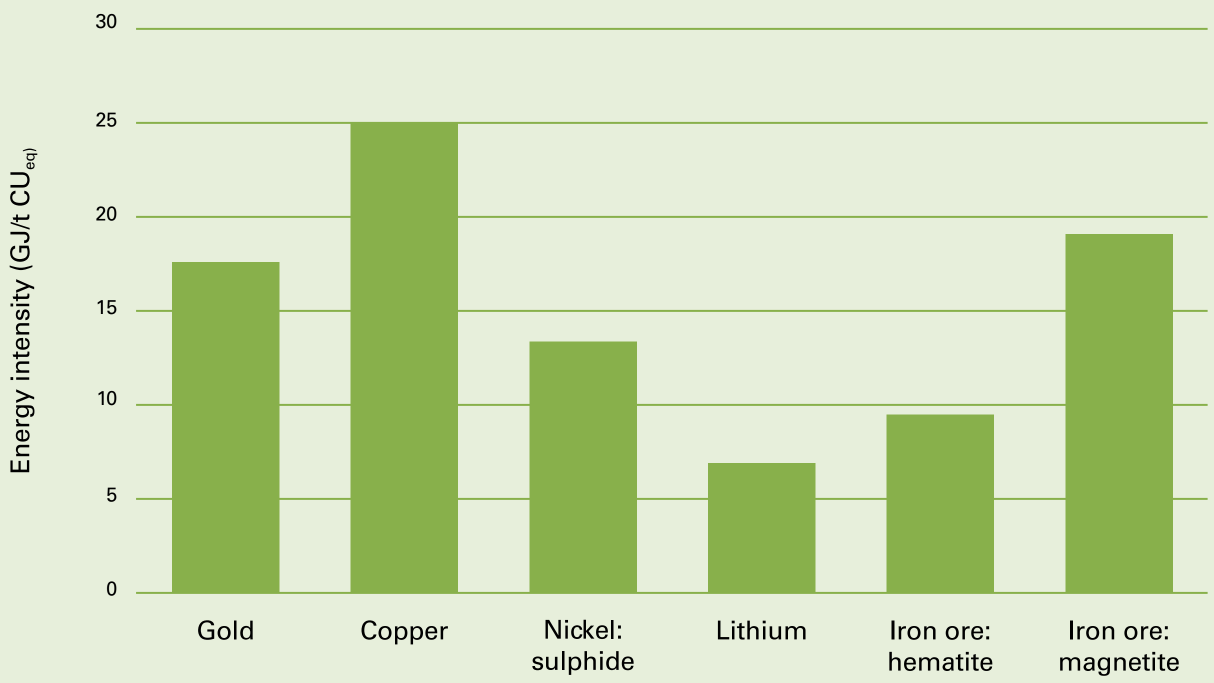


Figure 2 — Energy intensities of different commodities

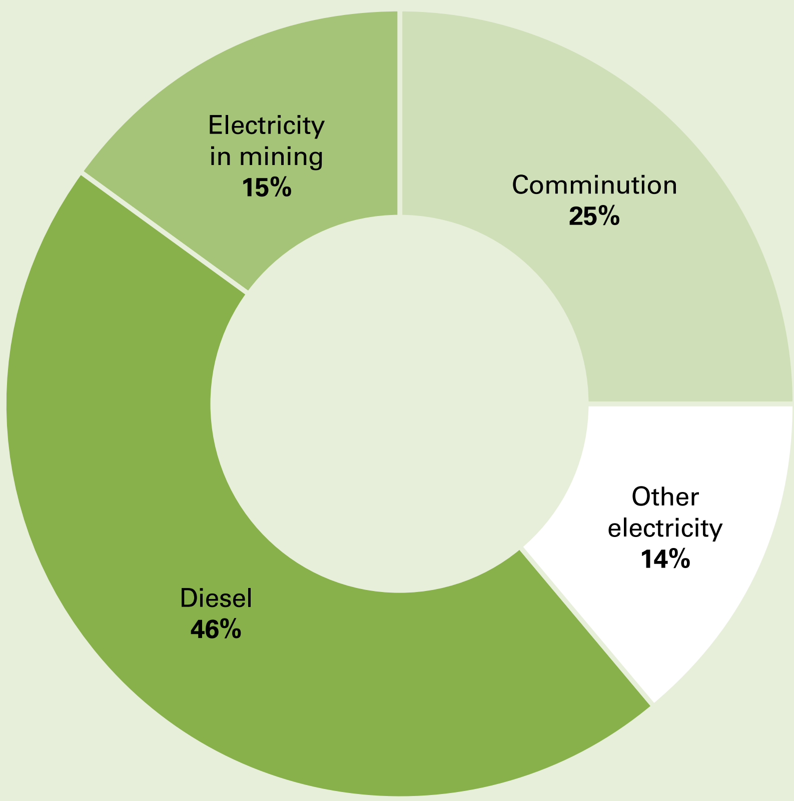


Figure 3 — Split of energy consumption across the mining industry

From the breakdown of energy consumption, it was found that comminution accounts for 25% of final energy consumption of an "average" mine site. Diesel in mobile equipment accounts for 46%, electricity in mining (ventilation) 15% and other electricity 14%. These are averages based on the different splits of energy consumption that were calculated for each of the commodities and the total energy per commodity. That is, the absolute energy consumption in each area for each commodity was calculated and the percentage splits in the chart below were derived from that. Comminution is typically the single biggest user of energy in a mine site as diesel in mining operations is split across multiple different equipment types and comminution is only a small number of unit operations—this makes comminution a natural target for identification of energy savings opportunities able to have the largest impact.

Using the current production rates of the commodities in question, and the energy intensities for each of the commodities, a total of 1,68 EJ/a (1,680,000,000,000,000,000 joules per year) has been calculated. This is approximately 0.5% of total final energy consumption globally. Published information indicates that the entire mining industry consumes approximately 12 EJ per year—or 3.5% of total final energy consumption globally. Using the energy splits from the above chart, the process of comminution may use up to 1% of total final energy consumption globally—equivalent to the power consumed by 221 million typical UK homes[1].

As comminution circuits have been shown to be largest single consumer of final energy for hard rock mining operations, using one quarter of the total final energy in mining, small improvements in comminution technologies can lead to relatively large savings in both energy consumption and GHG emissions. For example, a 5% incremental improvement in energy efficiency across comminution could result in greenhouse gas emissions reductions of more than 30M tonnes of CO_2-e[2].

Primary energy, that is—energy that is combusted directly to drive mobile equipment or generate electricity—was also explored in this study by analysing different ways in which mine sites may generate or purchase electricity. Using a typical power generation efficiency of 35%, comminution may use up to 3% of primary energy globally.

[1] Based on average electricity consumption of 3,769 kWh/a for households in the UK in 2018 (statista.com)

[2] Based on diesel combustion to produce electricity with an efficiency of 35% - actual emissions reductions vary depending on electricity source

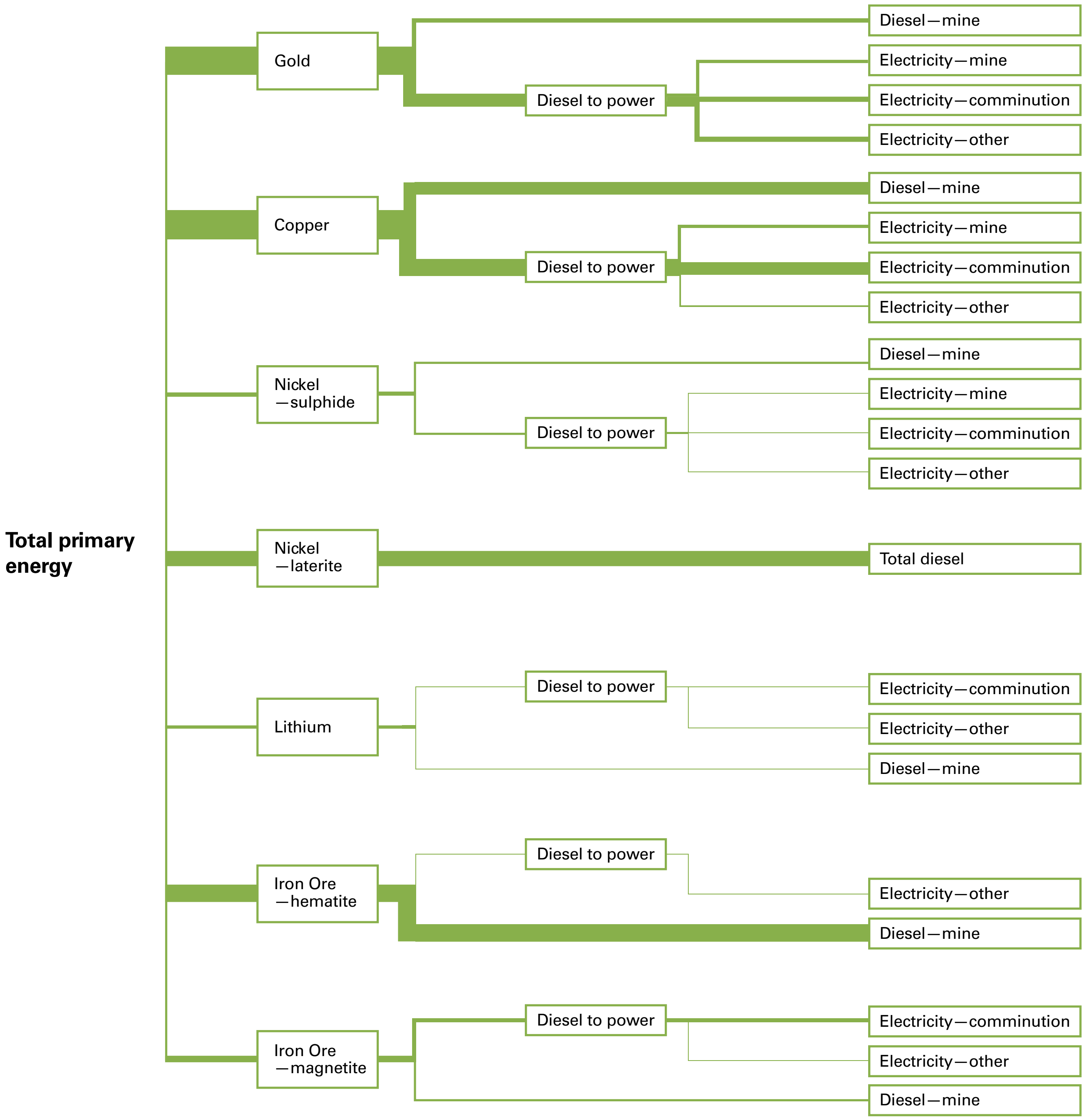


Figure 4— Sankey diagram showing energy flows in mining

The Sankey diagram shown above provides an indication of energy flows in the industry for the commodities under investigation and shows primary energy and final energy.

This study has shown that the mining industry is a significant user of energy overall. To meet the challenge of decarbonisation it is clear the industry needs to evolve, and that this will require a transition from legacy systems and processes to new more efficient and sustainable technologies.

There are a number of significant opportunities available to the minerals industry to reduce its energy consumption. These involve optimisation, big data and artificial intelligence, replacement of traditional comminution equipment with new technology, pre-concentration and others. In addition, if zero emissions energy sources are deployed for mobile and stationary equipment—e.g. renewable energy, energy storage and alternative fuels—then the mining industry may well be able to achieve zero emissions, or close to it. Leaving a relatively small role for offsets and carbon credits to play. Opportunities that are focused on comminution circuits, as the single biggest user of energy in a mining operation, are considered to be high priority as small improvements can have a large impact on overall site energy and emissions. Also of note are any opportunities that reduce or eliminate grinding media—the import of which into a mining operation carries with it embodied emissions to manufacture the steel balls. Although these are indirect emissions for a mining operation, they are important in terms of overall impact of the industry and increasingly the subject of study.

Against a background of robust demand fundamentals, the mining industry remains central to future economic development globally, with some critical minerals enabling the low-carbon transition required in the rest of the economy. But the environment in which it will operate in future will be very different from the past, requiring change and investment to preserve its licence to operate.

This report illustrates the globally significant scale of energy use across the industry and the potential for it to use new technologies to make improvements to its own environmental impact and the global effort to reduce carbon emissions.

1

INTRODUCTION & CONTEXT

The mining industry is a key part of the global economy, from the point of view of both providing jobs and broad economic benefits as well as providing the raw materials for many of the products that are used today. At the same time, countries and other actors such as states, cities and companies are increasingly setting targets to reduce overall impacts on the environment. This includes many parties setting targets to achieve net-zero greenhouse gas (GHG) emissions in the middle of the century. Currently 29 countries have indicated or set a target of net zero emissions—with indications that this number will grow in coming months.

These emissions reduction targets—supporting the Paris Agreement, which sets an overall goal of limiting temperature increase to well below 2°C by the year 2100—will require an economy wide transformation involving mass electrification, decarbonisation of the electricity system, use of low/zero carbon energy such as hydrogen, and a transformation to a circular economy. The global mining industry has a key part to play to enable these changes.

The move to a decarbonised economy is expected to result in increases in the consumption of critical outputs of the mining and mineral processing industry—especially commodities such as copper for transmission of electricity, lithium, nickel, graphite and cobalt for electric vehicle and grid support batteries, aluminium for lightweighting of electric vehicles, rare earths for construction of renewable energy plants such as wind turbines and iron ore/steel to support both the megatrend of urbanisation and also to construct infrastructure required for the future decarbonised economy. Some of this will be supplied by improving recovery and recycling of valuable materials at product end of life, taking a circular economy approach, but the expected demand is likely to outstrip the supply available from these avenues. Mining and mineral processing will be a vital part of the economy for the foreseeable future.

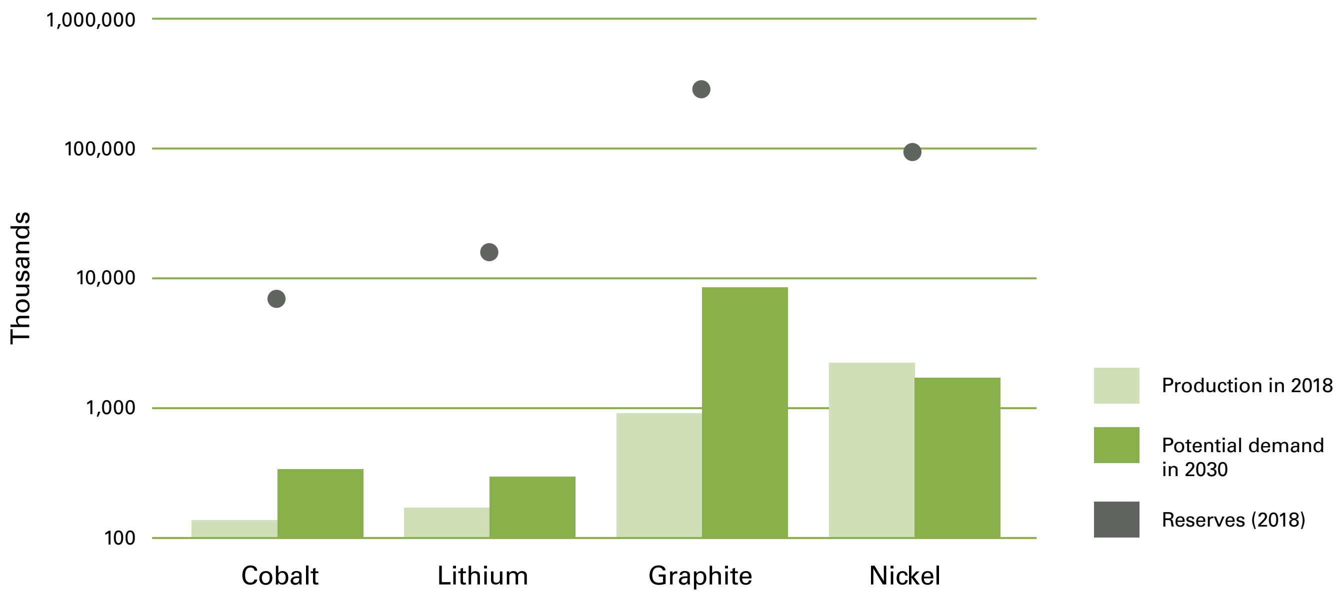


Figure 5 — Critical mineral demand for electric vehicles in tonnes of minerals

Figure 5 shows one example of future demand for the outputs of the mining industry with some critical minerals. Taken from the US Geological Survey and the International Energy Agency's Global Electric Vehicle Outlook (2019), potential demand for cobalt, lithium, graphite and nickel has been explored using a basis of 250M electric vehicles on the road in 2030—this represents less than 20% of all vehicles. To meet this potential demand (shown in the dark green columns), production will need to be scaled up from 2018 levels (shown in the light green columns) significantly. There are certainly enough reserves to meet this demand but production currently lags the expected demand—noting that the current production of nickel is used primarily for other purposes such as steelmaking, and the expected demand just for electric vehicle batteries is close to current production rates. Since developing this chart, demand for some of these minerals has changed—in particular changes in battery chemistry may see a reduced volume of cobalt required compared to this data. The 2020 IEA Global Electric Vehicle Outlook continues to show a potential demand of 250M electric vehicles on the road in 2030 to enable the world to limit global temperature rise to well below 2°C.

The electric vehicle battery use case is just one example of where critical minerals will be required in ever increasing quantities. As a result, the mining industry remains critical to global economic transformation. However, the mining industry also has a requirement to operate as sustainably as possible and needs to also play its role in decarbonisation. The industry must also find a way to decarbonise its own operations—minimising its exposure to climate change risk and supporting targets for decarbonisation. While offsetting of emissions is currently a reasonable opportunity for reducing emissions, there should be a program of first reducing emissions via abatement projects prior to offsetting those that are difficult or costly to reduce. It is likely that the carbon offset market will tighten in coming years as more companies utilise them as a decarbonisation mechanism increasing the price and making abatement options more attractive.

Current projections show that the current rate of decarbonisation globally is far below what is required to meet the goals of the Paris Agreement. A sustained decarbonisation rate of up to 7% per year[3], year on year should be sufficient to achieve the goal of a temperature increase of well below 2°C by 2100. For the mining industry, there are multiple ways to achieve decarbonisation including energy efficiency and fuel/energy switching. Many of these opportunities are starting to be explored by both the mining companies and the mining services providers, who see decarbonisation and energy reduction as a key way to reduce exposure to the risks of climate change.

[3] Taken from the Intergovernmental Panel on Climate Change Special Report—Global Warming of 1.5°C (2018)

Figure 6 — Risks of climate change to businesses

Policy — Policies are implemented at a national level, to support international goals. These could increase costs of operations, increase costs of input material and reduce demand for products.

Legal — There is a risk of litigation being brought upon companies who are not responding to and disclosing exposure to climate change risk. Some markets consider this a breach of fiduciary duty.

Social license — The company's actions, or inaction, could be viewed unfavourably by stakeholders which could result in an erosion of social license and impact sales/income.

Finance and insurance — Companies could see a reduction in their ability to access credit or equity as banks and investors review their investment portfolios and move to xero carbon portfolios.

Market — The product or service sold by the company could lose market share compared to competitor products if it is higher emissions intensity.

Technology — Disruptive technological improvements as climate related opportunities are pursued by others may render the products and services of a company obsolete.

Physical (acute) — Acute physical risks are those associated with short-term extreme events, which are higher probability with climate change. This includes fire, flood, storms, storm surge, etc.

Physical (chronic) — Chronic physical risks are those associated with long-term climatic trends. This includes the impact of increasing temperature and humidity on performance and rising sea levels.

Specifically, moves towards decarbonisation and energy efficiency will help to minimise exposure to policy risks, social license risk, availability of debt and equity and market risk — as well as reducing legal risk that a company may be exposed to.

While the industry does have a role to play with regard to its own decarbonisation, it is also true that the energy intensity of mining is predicted to increase over time. A number of factors contribute to this trend including a trend of overall decreasing minesite productivity over time, new deposits being lower grade and potentially more difficult to extract/located in deeper deposits. This does underscore the need to rethink the way in which mining is done so that impacts can be minimised overall.

The purpose of this document is to describe the key energy users in the mining and mineral processing industry from an equipment point of view and quantify the impact the industry has in terms of energy consumption and emissions. Key commodities in the hard rock mining space have been explored and an estimation of energy consumption generated for these commodities. The document then outlines some energy and emissions reduction opportunities that could be implemented to support the industry in future years. A thorough literature survey has been completed to collect information on the industry and "typical" energy consumption on an industry wide basis.

The focus has been final energy use (i.e. electricity consumption and liquid fuel consumption) but some scenarios have been developed with regard to primary energy use (i.e. fuel used to generate electricity) as decarbonisation of energy supply systems is a key lever for overall industry decarbonisation in the short to medium term.

In the mining industry, the final energy use is distributed across the operations in both mobile equipment (generally liquid fuels) and stationary equipment (generally electricity). There are potentially some other energy users such as LPG in some flowsheets but these are normally fairly small compared to the large final energy users. Open pit mining operations are almost exclusively diesel, potentially with a small amount of electricity in some applications like in-pit crushing, pumping and maybe even conveyors. Underground mining operations consume diesel in mobile equipment but also significant electricity in ventilation, pumping and other equipment. Ventilation is generally the largest consumer of electricity however. On the processing plant side, downstream of the run-of-mine (ROM) pad, electricity is the main final energy source. Where crushing and grinding operations exist, this equipment is often the largest single consumer of electricity. The remainder of the process plant will include slurry pumps, agitators and blowers on flotation tanks and other smaller equipment.

Figure 7 shows a general flowchart of a mining operation, with the main final energy users shown. Electricity as final energy does need to be generated from an energy source; electricity being an energy carrier rather than an energy source. In the diagram, electricity is shown as either coming from purchased electricity (from an electricity grid or a specific supplier) or being self-generated. The source of electricity, and whether it is purchased or self-generated, has an impact on overall GHG emissions for a minesite and may also change the split between Scope 1 (direct) and Scope 2 (indirect from purchased energy) emissions.

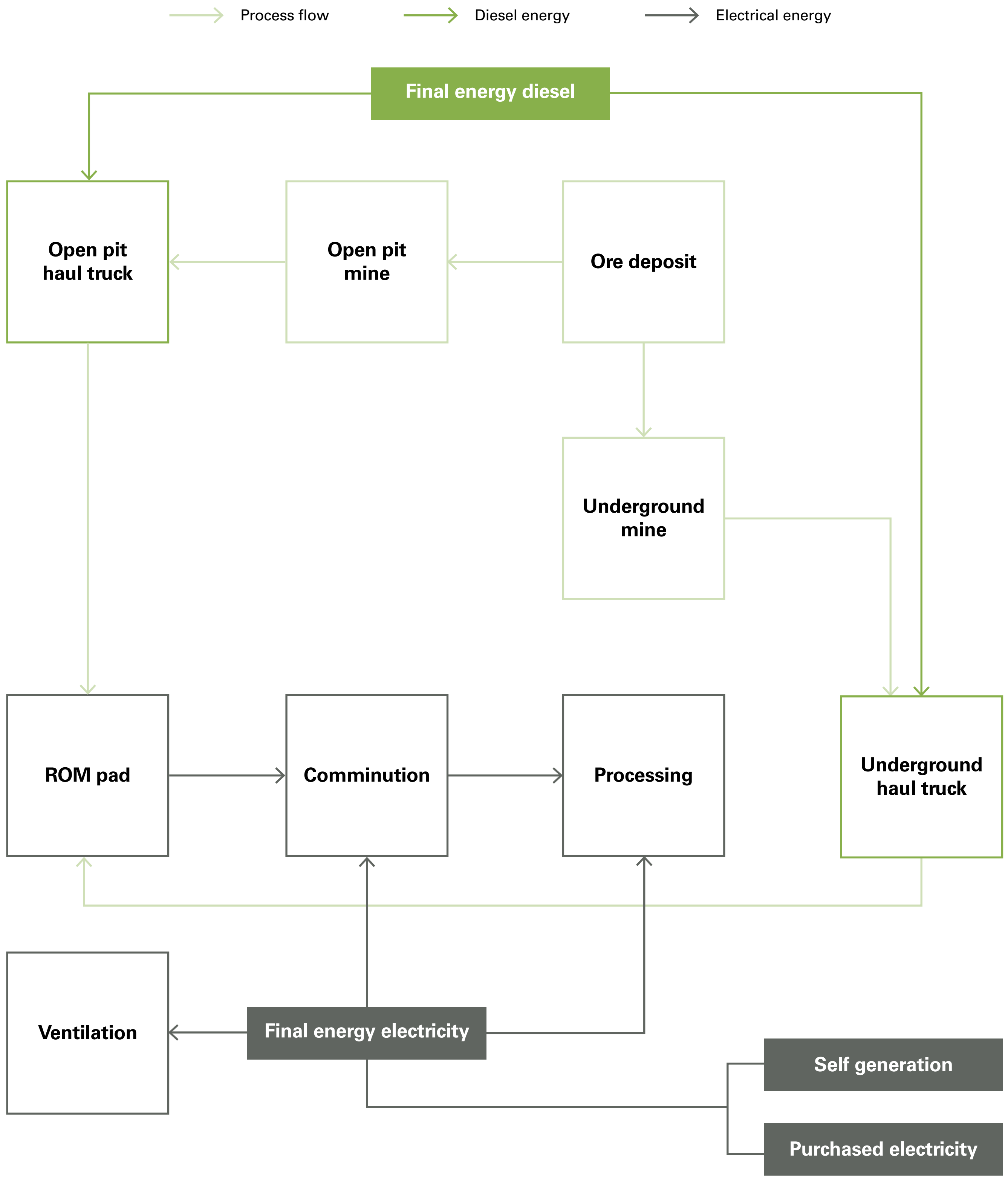


Figure 7 — General flowchart of a mining operation showing key energy users

2

COMMODITIES UNDER INVESTIGATION

To provide a boundary for analysis, operations in hard rock mining with extractive metallurgy were explored in detail. Specific commodities were chosen with consideration given to how important they will be in the future. In terms of commodities under investigation, information was gathered in:

- Gold
- Copper
- Nickel
- Lithium
- Iron ore

From the above list, clearly iron ore is a bulk commodity currently, rather than a hard rock mining operation with extractive metallurgy. However, there may be an increase in magnetite processing in future, to supplement current hematite operations. There is also a trend towards beneficiation plants in the iron ore industry as the high iron content deposits continue to be depleted. Lower iron content deposits will likely require some form of processing to boost iron content in final products, compared to the high grade deposits that are mined today that generally just require crushing and transport.

Data was collected from a thorough literature survey to obtain information on the amount of energy typically used in mining operations vs. processing. In addition, where information was available, mining was classified into energy consumption in open pit vs. underground. Processing operations were classified into comminution vs. other processes—given that comminution is generally the highest single energy consumer in a typical processing plant. When analysing information, pyrometallurgical processes such as smelting and furnaces were excluded—to align with the view that comminution, concentrators and aqueous based processes were of most interest.

The level of detail and available information does vary between the commodities. In general, a large dataset is available for gold and copper and relatively good information was able to be developed for these commodities. Nickel had less information available but still enough to derive a useful dataset. Lithium, being an emerging mineral has had fewer papers published discussing energy consumption.

3

KEY RESULTS

The results presented in the charts and datasets below represent final energy consumption. That is direct combustion of fuels in mobile equipment and consumption of electricity in electrically driven equipment. From an emissions and energy point of view however, primary energy—that is, the energy used to provide electricity—is also very important. To determine primary energy and potential emissions from that, scenarios have been developed that explore different energy supply systems that minesites may employ. This ranges from self-generation using diesel or natural gas through to importing electricity from the grid.

For fuel consumption in mobile equipment, it is assumed that diesel is the energy source.

3.1 Copper

Significant information was available on energy consumption in the copper industry from individual site energy assessments and from global studies and life cycle assessments that study typical copper operations. The dataset uncovered in the literature survey was the most extensive of all the commodities studied.

To set the boundaries of the analysis, and to avoid skewing of the information with particularly high intensity processes, pyrometallurgical operations were excluded from the study. The information collected covers mining operations and then either flotation plants/copper concentrators, or leach and solvent extraction and electrowinning (SX/EW). There are more potential processing routes compared to gold processing and some data was found describing the relative energy intensity of each of these types of operation. The type of processing route chosen is predominantly a function of the ore type in the deposit.

Overall, copper processing from the data analysed showed an average energy intensity of 24 GJ/t of copper produced. When exploring the different types of copper processing plant, it was seen that leach and SX/EW is a similar energy intensity to a concentrator. This is primarily a result of comminution being common to both processes and that step being the most energy intensive of the processing steps in the plant. The data shows that open pit mining operations are more energy intensive than underground operations. This reflects the fact that open pit operations are generally lower grade so more material is moved for the same production of copper. The majority of information analysed is in energy units per tonne of copper produced. Where data was only available in energy per tonne of ore, a copper grade of 0.5% has been assumed—reflecting a typical deposit grade for newer copper deposits and the trend of declining grade over time. The open pit and processing plant configuration has an average energy intensity of 26 GJ/t of copper produced. Underground mines with processing plants were found to have an overall energy intensity of 16 GJ/t of copper produced from the dataset studied. The overall average energy intensity of 24 GJ/t of copper is closer to the open pit value because the majority of operations in the study are open pit operations.

A database of over 400 copper minesites was reviewed with respect to average energy intensity across the entire operation. This database of energy consumption in these sites indicated an average energy intensity of approximately 25 GJ/t of copper produced so aligns well with the analysed data from the literature survey.

The life-cycle assessment work by Norgate and Haque (2010) provides insight into the split of energy consumption for a typical underground operation with a concentrator. This study indicates that just over 50% of total site energy is in the mining operations (~55%), with the remainder of energy consumption occurring in the processing plant. Energy use in the mining operations is 40% electricity (primarily ventilation) and 60% diesel (for loading and hauling). In the processing plant, the majority of energy consumption occurs in grinding (90%) with the remaining energy consumption in this study being attributed to flotation. A similar study by Koppelaar and Koppelaar (2016) has a very similar outcome with 87% of processing plant energy in a concentrator attributable to comminution and the remainder to flotation. A leach plant with solvent extraction and electrowinning has approximately 70% of processing plant energy in the comminution area with the remainder in leach and SX/EW.

Open pit operations utilise mainly diesel as the energy source for extraction and transport of material to the processing plant. The percentage splits of total site energy consumption are similar with close to 60% of total site energy being consumed in mining operations and the remaining 40% being consumed in the processing plant.

What is clear from the following diagrams is that comminution consumes between 30% and 40% of total energy in copper mining, regardless of the configuration. This aligns with the work completed by Ballantyne and Powell (2014) that concluded that the average percentage of total site energy usage in copper and gold mines that is consumed by comminution is 35%.

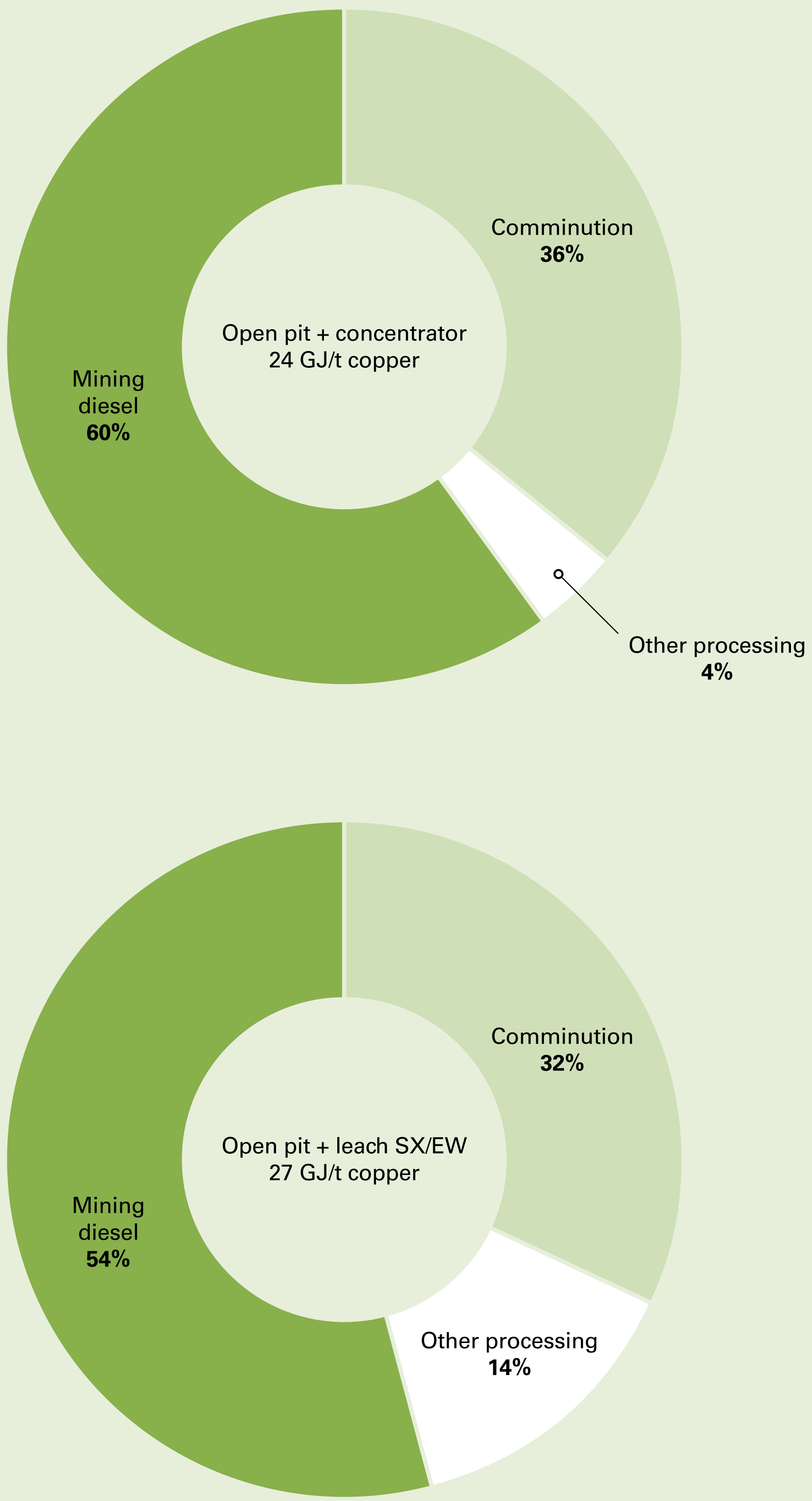
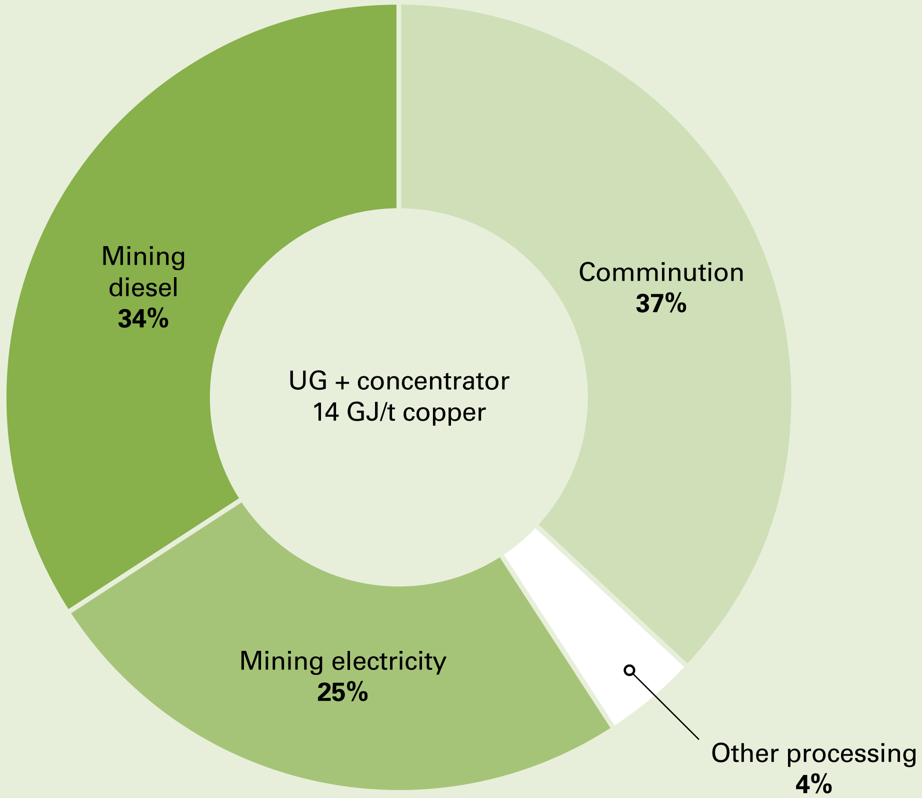


Figure 8—Split of energy consumption in copper open pit operations



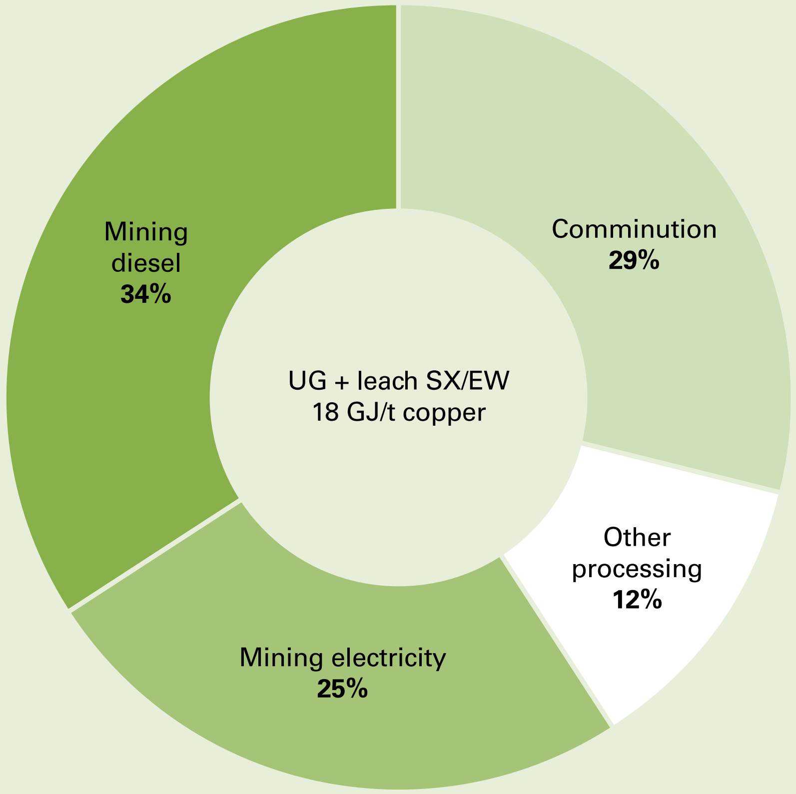


Figure 9—Split of energy consumption in copper underground operations

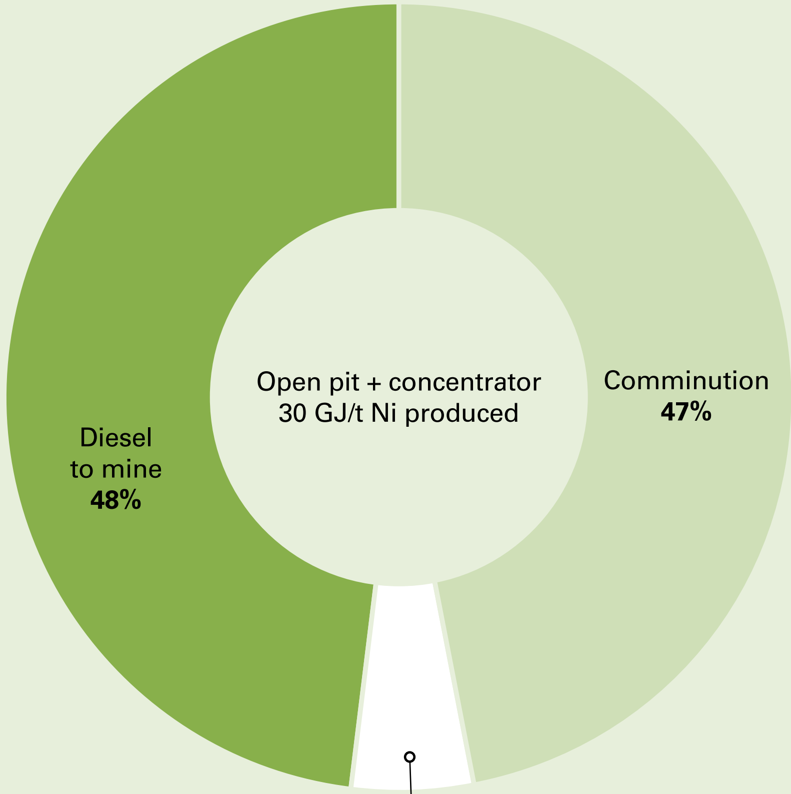
3.2 Nickel

Information availability on the nickel industry energy consumption is slightly more difficult to come by as it appears fewer papers have been published on the energy consumption in these operations. Typically, processing plants fall into two main categories, based on the ore type. Nickel sulphide deposits are generally milled and concentrated—with the flotation concentrate being filtered and shipped to smelters and refineries. Nickel laterite operations generally undergo a relatively energy intensive process of acid leaching followed by a solvent extraction process and electrowinning or briquette production. Laterite deposits are generally located close to surface and are low grade—this means that an open pit mining method is normally used. The majority of nickel deposits globally are laterite deposits (over 70%) but traditionally, these have been less exploited than sulphide deposits—mainly because nickel concentrators are lower cost and lower energy. Nickel laterites are expected to be the dominant source of nickel in the future however as the sulphide deposits continue to be depleted. Approximately 60% of global nickel supplies currently come from sulphide deposits.

As the energy profiles of sulphides vs. laterites are so different, they have been looked at separately in terms of energy consumption.

Norgate and Jahanshahi (2011) completed a study on life cycle assessment of nickel laterite processing, using data from a large set of nickel laterite operations using different leach processes—from heap leach through to high pressure acid leach. The study builds on previous work by Norgate et. al. (2007) that explored a life cycle assessment of a number of different minerals including nickel sulphide and nickel laterite processing. The energy intensity of nickel laterite processing is relatively high at over 200 GJ/t of nickel on average. High pressure acid leach is the most energy intensive form of laterite processing consuming 272 GJ/t nickel. Enhanced pressure acid leach is 250 GJ/t while heap leach is 211 GJ/t. The average energy consumption across these three processing routes is 244 GJ/t of nickel. With laterite processing expected to increase in coming years, to meet increased nickel demand, then overall energy consumption in this industry is expected to increase. There is general agreement in this energy intensity data with Eckelman (2009) though this paper does point out that there is a great deal of variability in the energy consumption from nickel laterite processing facilities—particularly as some of the pyrometallurgical processes are included. Comminution in laterite processing is generally minimal and only contributes a small amount to overall energy intensity. Typically, ore is crushed but then undergoes a wet scrubbing process rather than grinding in a SAG or ball mill configuration—as is appropriate for ores with high clay content.

Barkas (2009) reports a much lower energy intensity of nickel sulphide processing, as expected from the different processing routes. Including the energy intensity of smelting and refining using the Sherritt-Gordon process, nickel sulphide processing averages less than 200 GJ/t of nickel. Eckelman (2010) provides some guidance as to the energy intensity of mining and milling processes in sulphide concentrators. This paper, which reviewed of a large dataset of nickel operations from a number of other published sources, estimates an energy intensity of approximately 15 GJ/t for comminution processes in nickel sulphide projects. A similar energy intensity is estimated for mining operations—both underground and open pit are similar though the underground mines have a high proportion of electricity consumption for ventilation. Nickel concentrators are very similar to copper concentrators so it is reasonable to assume that 90% of processing plant energy is attributable to comminution, with the balance being flotation, regrind and tails. An extensive study by Yanjia and Chandler (2010) on nickel sulphide processing in China using actual operator data yielded very similar results with regard to the split between mining and milling for nickel concentrators in the country—albeit at a slightly higher energy intensity than the global average used by Eckelman.



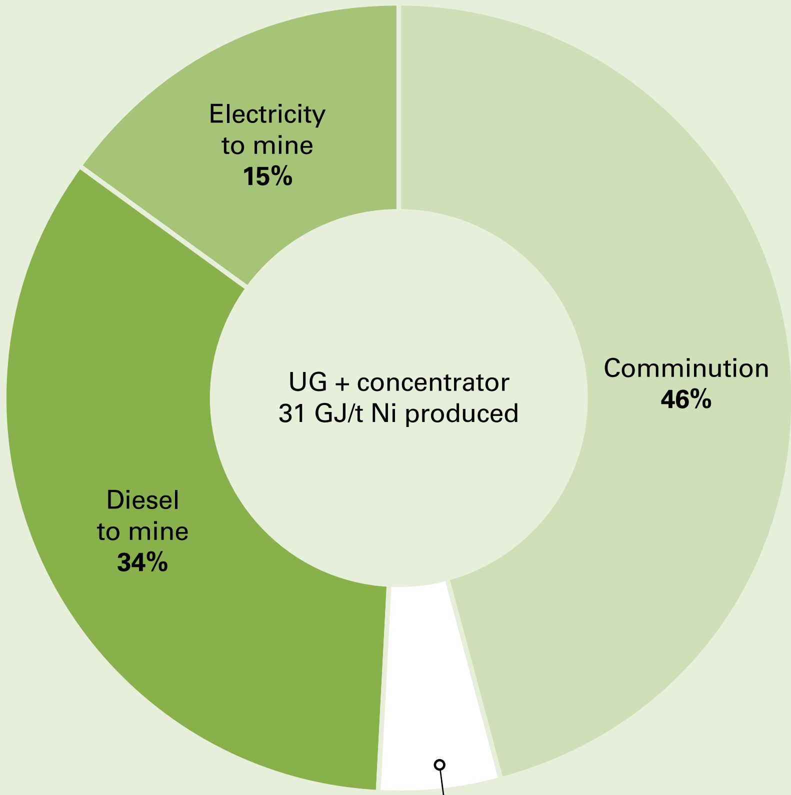


Figure 10 — Split of energy consumption for nickel sulphide concentrators

Applying the collected data and the percentage splits of energy consumption yields an average energy intensity for nickel sulphide concentrators of 31 GJ/t of nickel produced. Of this, the split between mining and processing is approximately 50:50—with then 90% of the processing plant energy consumption being used in comminution. Given the overall nickel sulphide energy intensity of ~200 GJ/t of nickel, the concentrators are only a relatively small portion of overall energy footprint. To remain consistent with the other commodity analysis, the energy results will be presented for concentrators only.

From the data analysed, comminution in nickel sulphide operations does consume a higher percentage of overall site energy use than copper or gold—reflecting the approximately 50:50 split of total site energy consumption between mining and processing.

3.3 Lithium

Lithium is a critical metal for future decarbonisation efforts, particularly in its use case in electric vehicle batteries. Lithium and nickel will be used extensively in battery chemistry for the foreseeable future and demand is expected to grow significantly in coming years. During the 1990s, recovery of lithium moved from traditional hard rock mining methods to recovery from brine pools as this is a far cheaper processing route. Hard rock mining of lithium is poised to be the dominant source of lithium in the future however as the world moves towards low/no cobalt batteries, which tend to use lithium hydroxide rather than lithium carbonate. Lithium hydroxide is more readily recovered from hard rock mining than from brines.

With regard to processing infrastructure for lithium, concentrators are often used to upgrade lithium content prior to downstream processing to lithium carbonate or lithium hydroxide. The concentrators are closer to mineral sands operations than copper or nickel concentrators. A typical flowsheet will include crushing of mined rock, dense media separation, magnetic separation and flotation of spodumene. The flotation circuit may have a small regrind facility in it to increase recovery.

Published information on energy consumption in lithium concentrators has been difficult to come by with much of the available information found in design documents for upcoming facilities. This includes information published as part of NI-43-101 reports by companies listed on the Toronto Stock Exchange.

Best available estimates, from a small dataset, indicate that energy requirements for a lithium concentrator are approximately 15 GJ/t lithium produced. Of this, approximately 60% of energy consumption is electricity in the concentrator with the remaining 40% in the mining operations. In the processing plant, the largest portion of energy consumption is estimated to be in the crushing area, followed by dense media separation. Crushing accounts for about 20% of site energy consumption, with a further 7% in the regrind mill. This data has been derived from published information from lithium producers—mostly for forthcoming projects and, as mentioned, is a relatively small dataset.

There is an expectation that the availability of data, and studies into life cycle assessment of batteries will increase in coming years as the extraction and processing of lithium increases.

3.4 Gold

In the gold sector, a typical operation is made up of mining and processing, with production of unrefined gold bars (gold doré) generally the final product. Mining operations will either be categorised as open pit or underground operations, with the energy profile being different between those two. Open pit mining operations consume mostly diesel in large quantities to move large volumes of material. Underground vehicles are smaller so diesel consumption in absolute terms is lower but they also move less material resulting in a similar, but slightly higher energy intensity per tonne of ore. Underground mines also consume fairly large quantities of electricity that is used for mine ventilation.

For processing of gold ores, data has been collected for plants consisting of comminution (crushing and grinding), cyanide leaching, carbon loading, electrowinning and tailings management. In the gold industry, sustainable alternatives to cyanide leaching are also part of the overall sustainability journey for companies; as this study focuses on energy however, this was not reviewed in detail.

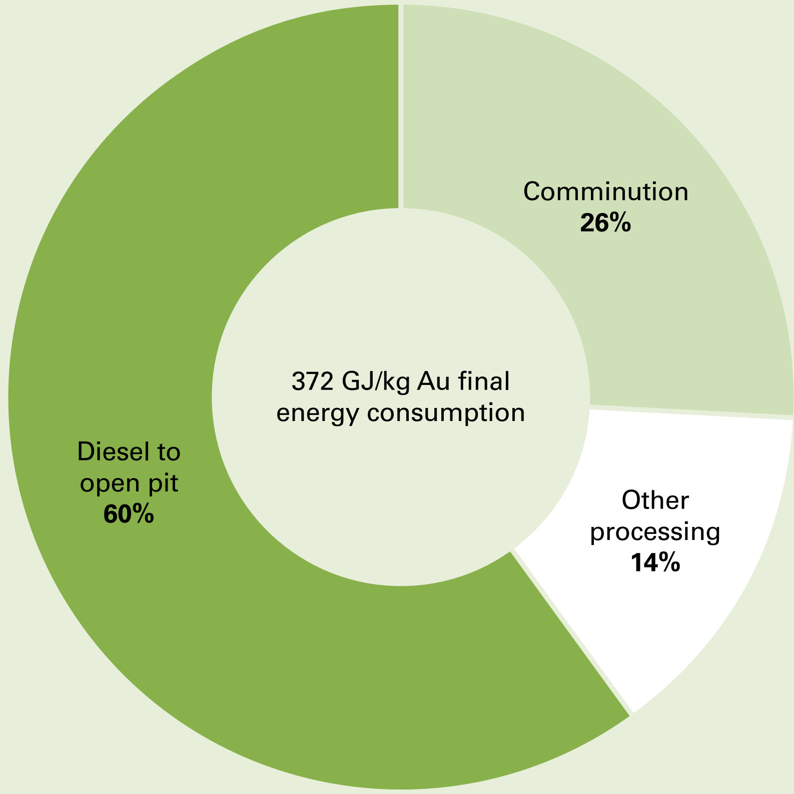
Based on the literature survey and reviewed data, average overall energy consumption for the mines was found to be approximately 130 GJ/kg of gold production. This is the final energy consumption in gigajoules—and includes both diesel and electricity. Of this total energy consumption, up to 30% is attributable directly to comminution processes—the single largest electricity user in a typical gold mine. The study by Katta et. al. (2020) indicates that 48% of energy consumption in a mine site is attributable to mining operations (underground mining), with the remaining 52% being attributed to the processing plant. Further breaking down energy consumption in the mining operations yields 60% of the energy as diesel and the remaining 40% as electricity. Katta et. al. uses a value of 22% of total final energy use for comminution.

The study by Norgate and Haque (2012)—which is a life cycle assessment of the gold mining process yields similar results but assumes an open pit mine rather than an underground operation. In this case, approximately 60% of total site energy is attributed to mining activities—and this is all diesel consumption. The remaining 40% is attributed to the processing plant. Comminution processes in this study also represent 22% of site final energy consumption.

Finally, the study by Ballantyne and Powell (2014) explored the energy intensity of a large dataset of gold and copper mines. This study concluded that, across copper and gold, comminution consumes over 35% of mine energy. Specifically for gold, an average comminution energy intensity of 0.14 GJ/t of ore is calculated from the data in this paper[4]. This translates to 30% of site energy use being consumed in comminution.

A number of different papers were reviewed, in addition to the ones summarised above. The majority of these papers refer to overall site energy consumption. Many of these papers provide estimates of either global gold mining energy consumption or use large datasets to estimate the energy consumption. Typically, there is very good agreement between the presented data, yielding the overall average energy consumption of approximately 134 GJ/kg of gold for underground mines and an average energy consumption of 372 GJ/kg of gold for open pit operations. The key difference in this case comes from grade—with underground operations tending to be higher grade compared to open pit operations. This is then reflected in significantly more material moved and higher comminution energy as a result, from milling more ore overall. The splits of energy consumption by user are shown in the charts on the following page.

[4] A gold grade of 3.5 g Au per tonne of ore has been assumed for the calculation.



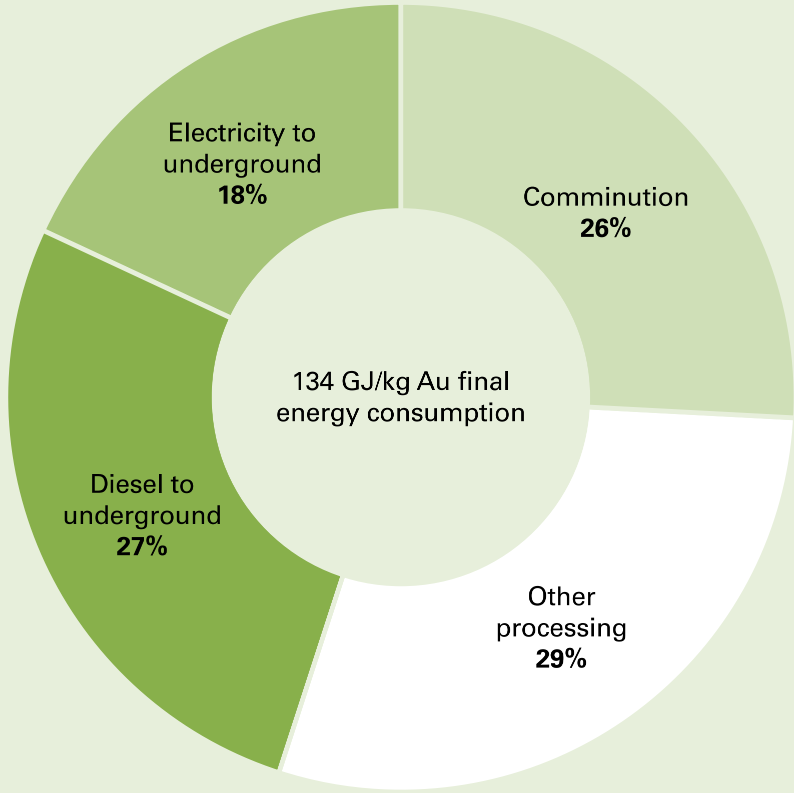


Figure 11 — Split of energy consumption for gold operations (open pit: top, underground: bottom)

3.5 Iron Ore

Iron ore mining currently is predominantly a bulk commodity process. That is high grade hematite is mined, crushed and transported to steel smelters. The energy intensity of these types of operations is typically very low and dominated by diesel combustion in mobile equipment. Hematite processing and direct shipped ore are normally very low cost, which gives it an advantage over more complicated processing plants such as magnetite. Magnetite occurs at much lower grades in-situ so requires additional processing and concentration at the minesite, generally involving comminution operations followed by magnetic separation to generate a high concentration magnetite product that can be shipped to steel smelters. Despite the additional energy of magnetite concentration processes, there is a view that magnetite has a lower energy intensity across the entire steel making lifecycle. Magnetite, compared to hematite, has both higher iron and oxygen content (Fe_3O_4 vs. Fe_2O_3) so uses less energy and generates fewer emissions in the blast furnace process to make carbon steel.

Mining processes in both magnetite and hematite operations are generally similar. Large open pit operations utilising very large haul trucks to transport mined ore to the processing plant. For hematite operations, data was obtained from the public reports of large iron ore miners such as BHP, Rio Tinto, FMG and Vale. This was used to generate an intensity value across their total operations for both diesel consumption in the mine and electricity production for processing plants. In these operations, energy intensity averages less than 0.15 GJ/t of iron ore. This data is reflected in other studies that are exploring life cycle assessments of the steel industry. Approximately 90% of this energy consumption is diesel consumption in mobile equipment. The remaining energy consumption is electricity in processing plants—mostly crushing and conveyors. The split is slightly different between FMG and the other iron ore producers as FMG processing plants feature more beneficiation due to their lower grade. In this case, approximately 85% of site energy is diesel with the remainder power in processing plants.

Magnetite operations are much more energy intensive. A study by McNab et. al. indicates that the grinding circuit in a magnetite operation has an energy intensity of approximately 33 kWh/t of ore processed. This data is confirmed by Katta et. al. (2020) and De La Torre (2011)—which both study life cycle assessment of magnetite processing. Including the additional separation and concentration equipment yields a total energy intensity for magnetite processing of 0.23 GJ/t of shipped ore. Mining operations add up to an additional 0.16 GJ/t of shipped ore giving a total site energy intensity of 0.3 GJ/t of shipped ore.

Figure 12 — Split of energy for iron ore processing

4

ANALYSIS OF RESULTS

To analyse the collected data, the commodities in question were converted to a consistent basis that would enable comparison of results against each other. This would provide an indication as to which commodities were more energy intensive than others. To do this, it is common practice in the mining industry to convert commodities to tonnes of copper equivalent. This is done using the ratio of commodity prices for different metals. 2019 average prices in US dollars were used to generate these ratios.

Commodity Pricing

Commodity	2019 Price (USD/Tonne)	Copper Equivalent
Gold	$44,773,000	7,500
Copper	$6,000	1
Nickel	$13,900	2.3
Lithium	$13,000	2.2
Iron Ore	$94	0.02

Table 1 — Commodity pricing: 2019 USD

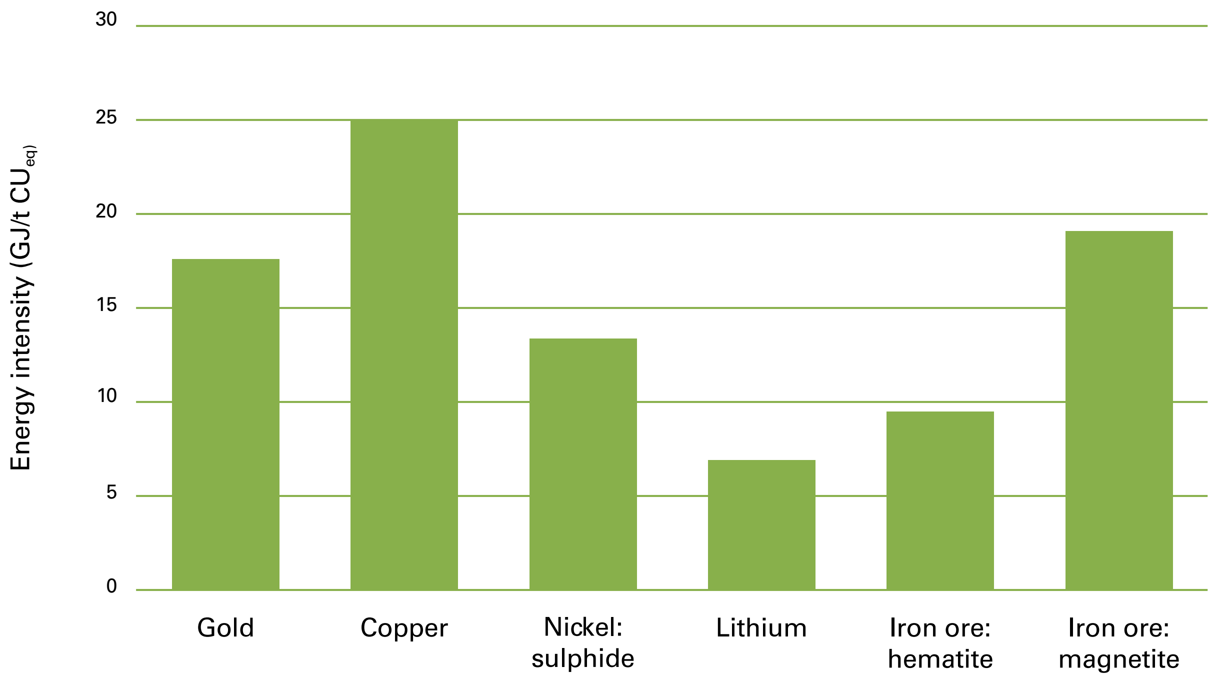


Figure 13 — Energy intensities of different commodities

The energy intensity numbers that were calculated in the data analysis and literature survey were used to determine an energy intensity for each of the commodities in GJ/t Cu_{eq}. The analysis showed that copper is the most energy intensive of the metals in the study given 2019 metal price ratios. This is followed by magnetite, gold, nickel sulphide, hematite and then lithium. It is noted however that the data set for lithium is very small. The relatively high energy intensity of copper and gold reflects the fact that, compared to nickel and lithium, more processing is completed on site and the final product is often a finished metal product—either gold doré or copper cathode. Nickel and lithium processing for the purposes of this study are limited to delivery of concentrate. Copper concentrators do have lower energy intensity that copper projects with SX/EW processes. Magnetite is also a high intensity operation when measured in GJ/t Cu_{eq} as the milling energy is relatively high and the value of iron ore is comparatively low.

Nickel laterites are not shown on the chart as the energy intensity of that process is not immediately comparable to the others. Nickel laterite processing has an energy intensity of 105 GJ/t Cu_{eq}—much higher than the other processes. This reflects the additional processing required to provide the high heat and high pressure required for leaching—and the fact that nickel laterite processes also tend to ship pure metal from the operation, adding to the energy intensity. Similar values would be achieved through including smelting operations for copper and nickel concentrate.

The energy intensity data for each individual commodity was then applied to the production of each of those commodities. This could be used to calculate the absolute energy consumption across the different processes. This simple calculation yields a final energy consumption across the commodities of interest of approximately 1.68 EJ[5]. This converts to approximately 4 million tonnes of oil equivalent, or 0.5% of total final energy consumption globally[6]. A paper by Holmberg et. al. (2017) estimates that the entire global mining and mineral processing industry consumes approximately 12 EJ of energy annually. Based on this, the estimation of 1.68 EJ across the five commodities in question does not seem unreasonable.

[5] 1 exajoule is 1,000,000,000 GJ
[6] Based on 9,900 Mtoe final energy consumption in 2018 as calculated by the International Energy Agency

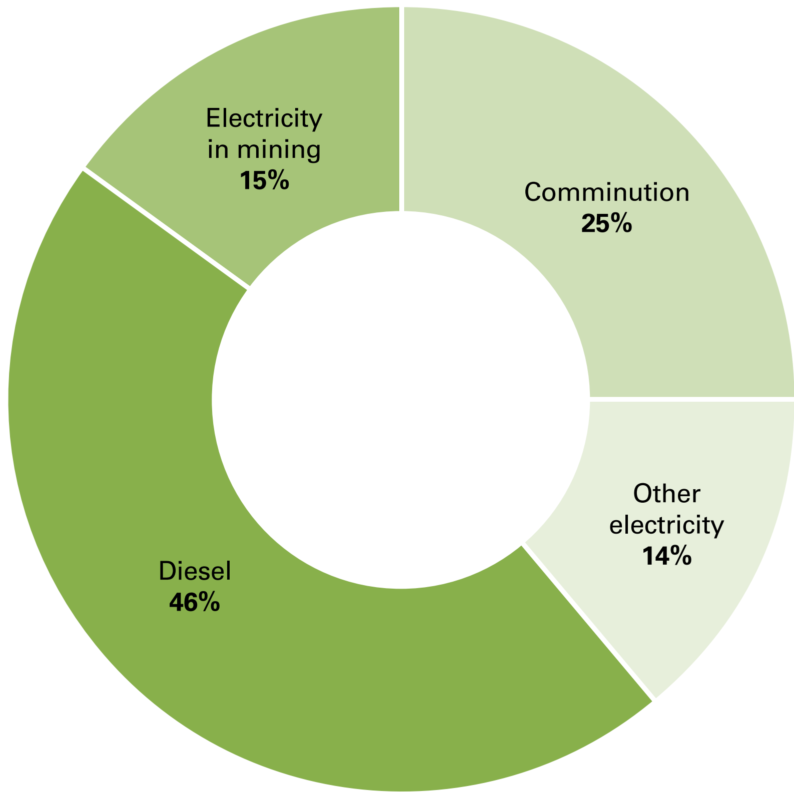


Figure 14 — Breakdown of total final energy consumption

Applying the splits of energy consumption identified during the data analysis portion of this study, shows that approximately 45% of the final energy use in mining for these commodities is from diesel combustion. The remaining 55% is electricity consumption. Of the total final energy consumption in these commodities, 25% is attributable to comminution activities (comminution is 63% of processing plant electricity consumption and 45% of total electricity consumption).

Comminution is typically the single largest energy consumer in the minerals industry and remains an area of interest as the industry moves towards decarbonisation. Whilst diesel is a large contributor to overall energy consumption, it is spread across multiple individual pieces of equipment and multiple equipment types. Comminution is only a small number of equipment types and large unit operations with high energy consumption in a single unit.

The paper by Holmberg et. al. estimates 30% of final energy use in mining as being attributable to comminution so there is relative agreement with this data. Holmberg et. al also estimate 9% energy use in ventilation and 40% in diesel combustion in mining so again, reasonably good agreement with this data—given the inherent uncertainties associated with this sort of analysis.

Also of interest, particularly for the purposes of decarbonisation opportunities is primary energy. In many cases, mining operations self-generate electricity on site using diesel or gas fired power generation. To estimate the primary energy consumption typical efficiencies of diesel and gas fired generation were used. In this case, diesel engines were assumed to have an electrical efficiency of 36%. Gas turbines were assumed to have an efficiency of 28% (open cycle gas turbines). Gas engines would have a higher efficiency, as would combined cycle turbines but the electrical load is generally not high enough to justify combined cycle power plants. This primary energy consumption was then used to calculate potential greenhouse gas emissions.

A Sankey diagram has been created showing the total breakdown of energy across the commodities in the study and where the key energy users are. This Sankey diagram, for ease of calculations, is based on all primary energy being supplied by diesel.

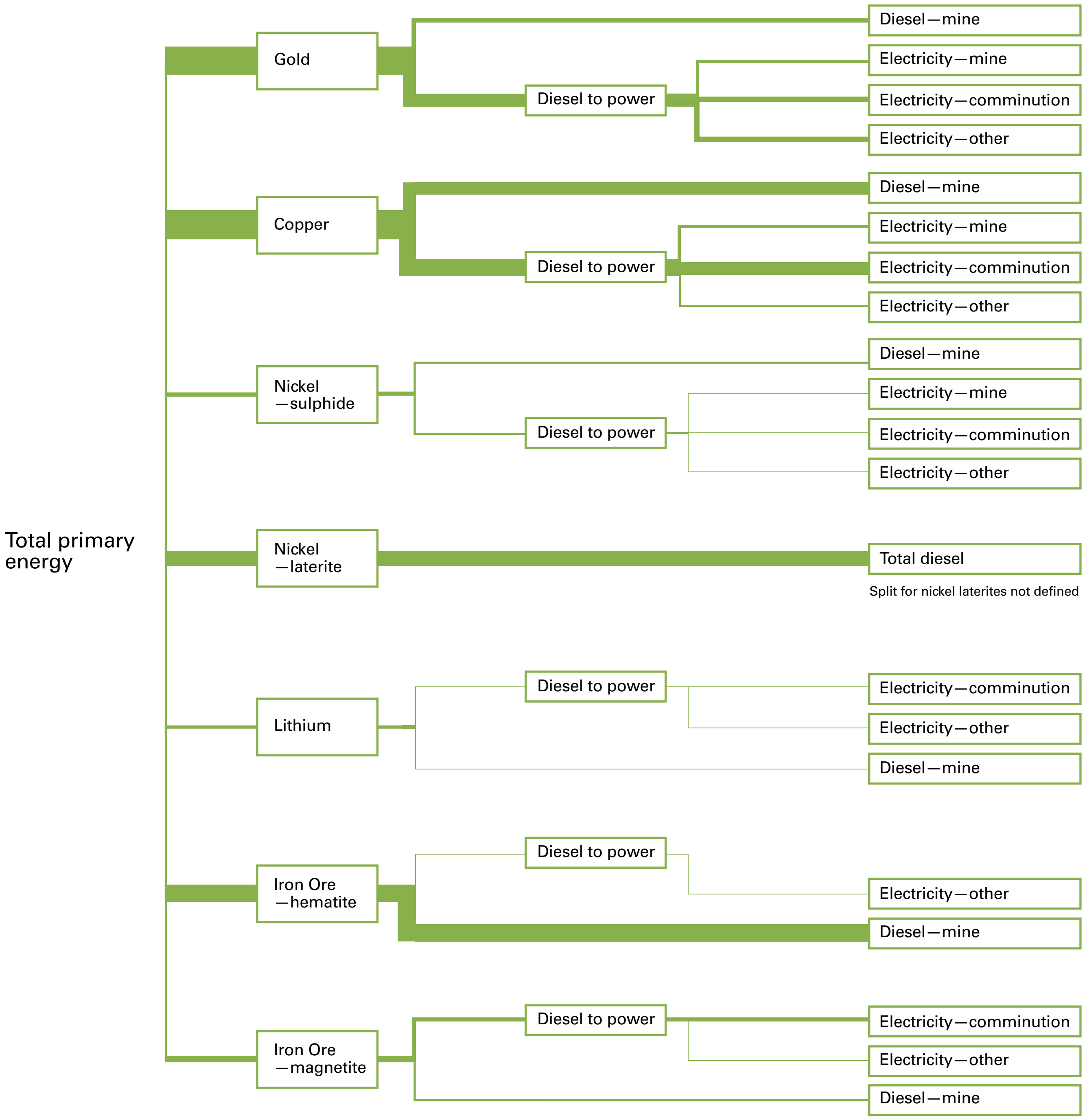


Figure 15—Sankey diagram showing energy consumption across commodities

Potential Scope 2 Emissions		
Country	Emissions Factor	Potential Emissions
Australia	0.8 t CO_2e/MWh	172 Mt CO_2e
Brazil	0.54 t CO_2e/MWh	116 Mt CO_2e
Canada	0.14 t CO_2e/MWh	30 Mt CO_2e
China	0.92 t CO_2e/MWh	197 Mt CO_2e
South Africa	1.02 t CO_2e/MWh	218 Mt CO_2e
USA	0.45 t CO_2e/MWh	97 Mt CO_2e

Table 2—Potential emissions if facilities are grid connected

Based on the calculated final energy supplied by electricity (772 PJ), a potential primary energy consumption of 2,145 PJ from diesel and 2,758 PJ from natural gas has been calculated. Applying the emissions factors from the IPCC[7] 2006 Guidelines for National Greenhouse Gas Inventories yields a potential emissions footprint of:

- Diesel combusted in mining operations—48 Mt CO_2-e
- Diesel combusted for power generation—159 Mt CO_2-e
- Natural gas combusted in turbines for power generation—155 Mt CO_2-e
- Natural gas combusted in engines for power generation—124 Mt CO_2-e

If the operations in this study were grid connected, the grid emissions intensity is used to determine the indirect emissions from electricity generation (referred to as Scope 2 emissions) attributable to the facility. These grid emissions factors vary significantly between countries and even on a sub-national level. To determine the potential emissions if the final electricity demand were supplied by a grid, average grid emissions factors in countries with large mining industries have been used to compare potential emissions impact.

Clearly the emissions factor that applies to a grid has a huge influence on the potential emissions for grid connected power. Countries with relatively emissions intensive grids that have significant coal fired power such as Australia, China and South Africa will result in emissions footprints that will be smaller if onsite generation is used. Countries with low and zero carbon power in the generation mix such as Canada with hydro power and the US with nuclear and gas will benefit from overall emissions if facilities are grid connected rather than self-generating.

[7] Intergovernmental Panel on Climate Change

5

MINING VALUE CHAIN EMISSIONS

This study has focussed on direct energy use and emissions from minesites and, in particular, identified that comminution processes are a key target for identification of energy and emissions reductions — being the single largest energy user on a typical minesite. There are some areas that contribute to indirect emissions for a minesite — i.e. emissions in the mining value chain that occur as a result of the minesite's inputs and outputs.

One area that may be overlooked in studies relating to emissions reduction in comminution are indirect emissions in the mining value chain that occur from the manufacture and use of steel grinding media in comminution circuits. Steel manufacture is inherently emissions intensive with emissions occurring along the entire production cycle from mining of iron ore to manufacture of steel in a blast furnace and finally manufacture of finished products like the steel balls used as grinding media. Although not specifically studied as part of this report, some studies estimate embodied emissions from steel production up to 2.5–3 tonnes of CO_2-e per tonne of steel—not including transport—with the actual embodied emissions dependent on the type of steel being used. This does mean that any opportunity to reduce grinding media usage will have an impact not only on costs but also on value chain emissions for the site.

Another area of interest with value chain emissions may be in the minimisation of water consumption on site—particularly in arid regions where desalination may need to be utilised to generate water for the site. Creating water via desalination is quite energy intensive, consuming up to 5 kWh for every m^3 of desalinated water produced (Jia et. al. 2018). Depending on the source of electricity, this could be up to 5.1 kg CO_2-e for every m^3 of desalinated water[8]. This means that opportunities to reduce water consumption could have a reasonable impact on value chain emissions in the same way that reducing steel consumption in grinding circuits could have an impact. Where the ore type allows, there are opportunities for dry grinding and dry classification—which will reduce the amount of water use for the site.

[8] Assuming grid emissions intensity of 1.02 t/MWh—e.g. South Africa

6

ENERGY & EMISSIONS REDUCTION OPPORTUNITIES

It is important that mining operations decarbonise over time. Although the mining industry will continue to be important in the coming years, the risks of climate change and societal expectations will require the industry to change the way in which mining and mineral processing occurs. A number of potential energy and emissions reduction opportunities are outlined below.

Comminution optimisation

Comminution circuits have been shown to be largest single consumers of final energy for hard rock mining operations consuming one quarter of the total final energy in mining. This does mean that small improvements in comminution circuits can lead to relatively large savings in both energy consumption and GHG emissions. Optimisation opportunities in existing crushing and grinding circuits can include grinding surveys and analysis to ensure optimum grind size is being maintained, ball charge is optimised and recirculation is minimised. This generally involves sampling and analysis of slurry at various points in the comminution circuit and applying simulation techniques and potentially laboratory analysis to ensure the grinding circuit and downstream processing like flotation or leaching are optimised. Replacing the existing crushers and (traditional) mills with highly effective comminution equipment can mitigate or reduces the grinding media requirement which will reduce the CO_2 emissions significantly. In turn, whilst consuming less, or diminishing the grinding media, the downstream mineral extraction process will experience less contamination and will therefore be more efficient.

Another opportunity in comminution optimisation is with the use of advanced process control for grinding circuits. Process control algorithms can be set to maximise automated control of process plant and maintain operations within specific envelopes. This sort of control will minimise operator intervention and keep critical parameters in grinding circuits within optimum ranges. Advances in sensor technology, and reduction in the costs of sensors, means that the business case for advanced process control is more attractive now than in prior years.

Redesign of grinding circuits for new operations

Optimisation of grinding circuits as detailed above applies predominantly to existing grinding circuits. If designing a grinding circuit for a greenfields site, there are very large opportunities available when rethinking how the circuits are designed to take advantage of new technology. Advancements in high pressure grinding rolls, high intensity grinding and stirred mills/vertical mills mean that traditional semi-autogenous grinding/ball mill applications could be replaced and the same outcomes achieved—subject of course to the amenability of the particular ore type and processing requirements to these comminution circuits. New grinding technology can, in some instances, be significantly more energy efficient than traditional comminution circuits. SAG and ball mills do require a lot of energy to turn the mill itself—and they are relatively large pieces of equipment—and to lift the grinding media. Particularly SAG mills aren't efficient in processing competent rocks, and both mills do consume grinding media of which the embodied energy drastically influences overall CO_2 emissions.

The business case around replacing grinding circuits with newer technology that is more energy efficient is stronger when considering a greenfields site or an expansion as a brownfields site has already spent the Capex on the grinding circuit. However, there are instances on brownfields sites where energy limitations, and availability of grinding energy becomes a bottleneck on throughput for the whole site. Additional throughput in grinding circuits as a result of energy savings unlocking additional energy capacity should form part of business cases when exploring the potential of equipment and circuit changes.

Ideally, consideration should be given to alternative comminution processes when exploring the design for new facilities. This applies to entire process circuits and mining operations, not just comminution. The greatest ability to influence energy consumption comes during the design phase. Best practice is to have a dedicated energy management process at each stage of project design and development and explore all avenues to reduce energy consumption, GHG emissions and ultimately operating costs.

[8] Assuming grid emissions intensity of 1.02 t/MWh—e.g. South Africa

Geometallurgy and AI/big data

Geometallurgy is focussed on greater transfer of information between geology, mining and processing. Conceptually it links the geological model and extractive metallurgy. Recent advances in computing technology and data manipulation capability mean that high fidelity block models can be created and maintained showing mineral concentration and composition throughout the mining areas. If these are combined with mine plans and computers used to track actual flows and locations of mined materials, the processing plant can have greater certainty of the material that is being delivered to the run of mine ore pad (ROM pad) and where it is at any point in time. A potential outcome is that blending operations can be automated providing the optimum feed to the plant ensuring it can operate at its best operating point and recovery is maximised.

The geological block model can be linked to the mine plan and ultimately a real time model of the processing plant—which can then be imported to an advanced control system and used to set the control parameters and set points for the plant. All of this can be set within the confines of a site-wide (or enterprise-wide) objective function, potentially taking into account external factors such as markets, and the operation as a whole can be optimised to achieve a set of objectives. AI and machine learning can be deployed to enable decision making, or at least decision suggestions, to be made automatically. Computer technology has the potential to process vast volumes of data quickly which has unlocked huge opportunities.

In addition to the macro level optimisation that AI and machine learning unlock, advancements in sensors and connectivity of those mean that instrumentation can be deployed across entire operations relatively cheaply. Newer innovations in sensor technology have provided process plant operators with insights into ball charge and mill liner wear rates—meaning that crash stops to conduct internal checks on mills may not be required as frequently and duration between liner replacement can be extended—maximising productivity.

Energy efficiency of plant

In general, there are energy efficiency savings that can be achieved on minesites in a number of areas. What is required to enable this is a structure energy management process where energy consumption is regularly reviewed and opportunities to save energy are identified. Energy efficiency opportunities that result in incremental improvements in energy consumption exist in every site and the structured process helps with identification and implementation of them.

Optimisation of drill and blast

Drill and blasting operations and increasing fragmentation of rock prior to delivery to the ROM pad has the potential to reduce energy consumption in the comminution circuit. Normally, the energy consumption in drill and blasting operations is much lower than that in comminution so decreasing distance between blast holes and maximising the work done by explosives will result in energy savings overall. The smaller rock is transferred to the ROM pad, the less energy will be required to break that rock down to the required product size. There is a trade off in increased explosive costs and detailed business cases need to be completed but there will be an optimum point that can be achieved to minimise comminution energy requirements.

Programs such as a Mine to Mill approach and the optimisation of those energy flows and processes can be implemented to ensure energy efficiency is maximised.

Pre-concentration

Pre-concentration of ores refers to the process of diverting waste material from the ore stream prior to comminution. Conceptually, pre-concentration has been used for some time but concerns around energy consumption/GHG emissions, water use and tailings volumes has renewed interest in this area. Processes such as gravity separation, dense media separation, fluidised bed flotation and x-ray ore sorting are used to lift the grade of valuable material in the plant feed and reject waste material early. This has the potential for large energy savings as energy is not wasted crushing and grinding rock that doesn't contain much valuable material. Coarser waste material is also much less risky to dispose of that the fine particles that make up a normal tails stream in a processing plant.

Alternative energy for open pit vehicles

Decarbonisation of the mining industry will require new ways to power mobile equipment. Currently, diesel is used almost exclusively for large mining equipment. Alternative fuels for the very large equipment used in open pit mining operations are possible but it may not be something like battery electric power. The scale of the vehicles is so large that battery systems may not be optimal. The battery systems required will be large to ensure the require energy density to move these haul trucks for extended periods. In addition, there may be limitations around the time required to recharge. To have high overall minesite productivity, haul trucks should maximise their operational time—particularly as autonomous haul trucks become the norm for mining operations. Taking vehicles offline to charge batteries may not be ideal—and battery swap systems or having an extra fleet of vehicles to operate during recharging will increase costs. In the long term, there is a role for hydrogen powered vehicles using fuel cells to provide the electricity to drive the motors from hydrogen stored in special tanks on the vehicle. Hydrogen costs are currently too high to be competitive but these are widely expected to reduce in coming years.

In the short to medium term, open pit haul trucks may use liquefied or compressed natural gas as fuel. Natural gas does emit fewer emissions when combusted but the efficiency of the engines and the energy density of the fuel is lower. Emissions savings should be possible however. Another alternative fuel that could be deployed is the use of trolley assist systems for haul trucks. This system uses overhead cables and extendable pantographs on the vehicles—like a tram. The trolley assist is used on the uphill portions of the haulage route allowing the engine to be idled and the truck to go up the incline using electricity directly. These systems have been successfully deployed at minesites globally and can be used to reduce fuel costs and fuel emissions.

An area of interest that could be further explored is the potential for changing the scale of the trucks that are in use. Fleets of smaller trucks with modern control capability (AI and automation) may unlock opportunities with battery electric vehicles and improve energy efficiency.

Alternative energy for underground vehicles

Underground vehicles are much smaller than open pit vehicles so there is a possibility of using battery electric vehicles. Some types of underground vehicles (e.g. jumbos, boggers and other vehicles that don't move around so much in a shift) may be able to be powered with cables connected to mains power and onboard batteries. Battery electric underground vehicles are already on the market and some mines are in the process of switching their entire fleet to battery electric.

The use of electric vehicles underground has an additional advantage in that ventilation can be reduced. One of the key functions of ventilation systems is to sweep diesel particulates from the air underground and minimise the risk to mine workers from this pollution. Having no diesel powered vehicles underground will allow changes to be made to ventilation rates thus saving additional electrical energy.

Organisations such as the International Council on Mining and Metals (ICMM) have already started to consider this. Their Innovation for Cleaner Safer Vehicles (ICSV) initiative aims to address key industry issues including climate change, health and safety by accelerating the development of a new generation of mining vehicles and improving existing ones.

Off-grid renewables and hybrid systems

The costs of renewable energy have reduced significantly in recent years and continue to reduce. Renewable energy from solar PV or wind power is increasingly a cost effective option to power a mine site and is being deployed in many sites worldwide. The most important aspect of power supply to a mine site however is security of energy supply. Mining is a 24x7 operation and generally has a fairly constant electrical load. Supplying 100% of an operation's power needs with renewable energy and storage is an expensive option currently but may be able to be achieved in future as energy storage technology becomes cheaper. The system being deployed currently in off-grid situations is a hybrid power system. That is, renewable energy is installed but supplemented by traditional diesel or gas fired power generation. A smaller battery is installed also to allow switching between power generation sources.

To be 100% renewable powered, energy storage is a must—for the times in which the renewable power source is unavailable. In addition, the renewable energy plant must be designed such that power can be generated above the maximum peak load of the plant, to allow for the energy storage to be recharged. For long term storage of energy and discharge over hours while renewable energy sources are unavailable, technologies such as pumped hydro, hydrogen, compressed or cryogenic air and potentially redox flow batteries are ideal.

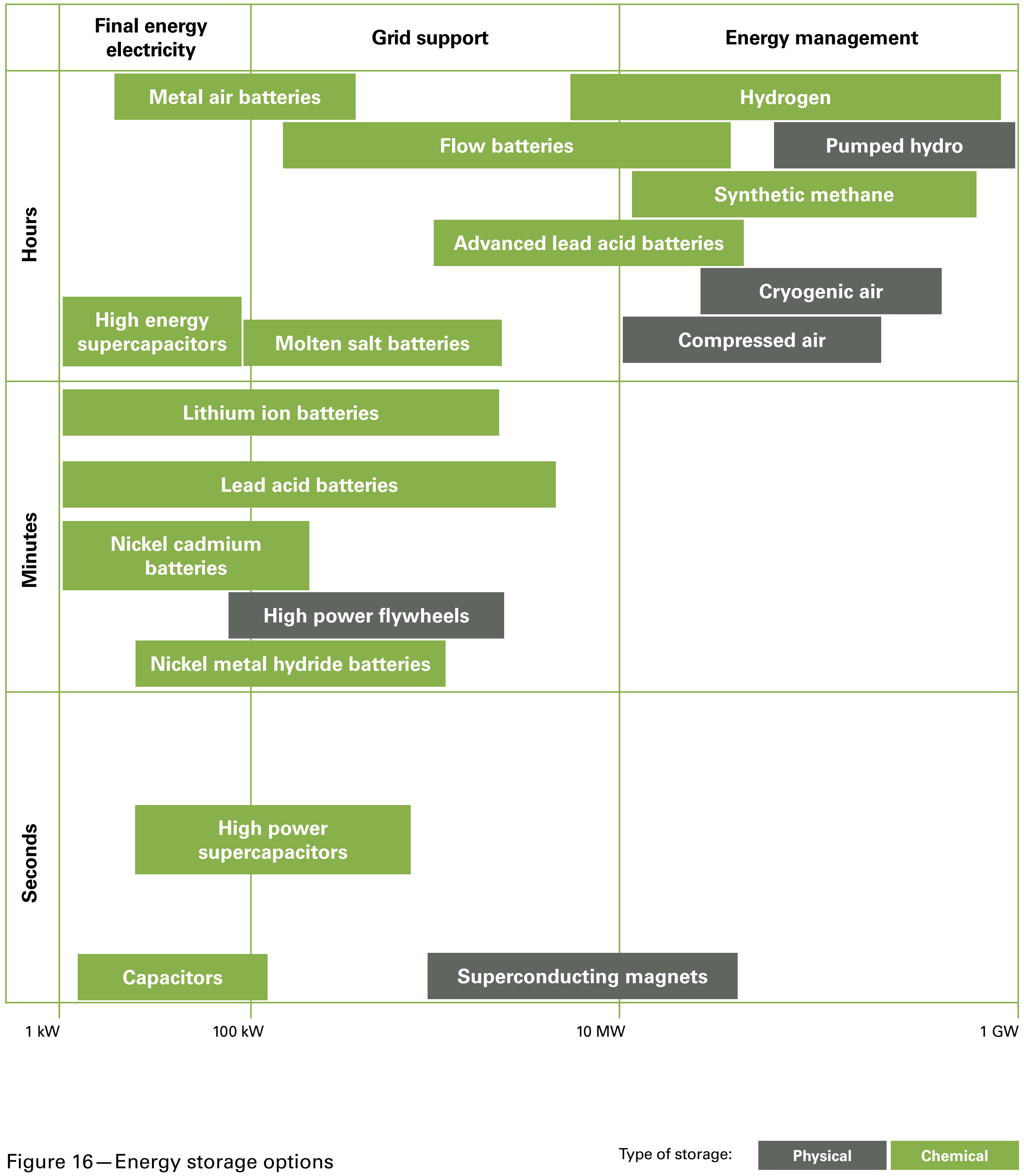


Figure 16 — Energy storage options

The figure above shows the size (on the horizontal) and the discharge time (on the vertical) that is ideal for different energy storage technologies. Pumped hydro could show some promise for mining operations as the height difference between the bottom and top of a pit, between two pits or using a mine shaft could potentially be utilised to store energy.

There may also be an opportunity to investigate how a minesite may be able to operate with a variable power supply. That is, adapt the industry so that it no longer needs to be a 24x7 operation but can potentially be paired with intermittent energy and energy storage more effectively. This could involve demand side management and programs to operate large energy consumers when the energy is available with stockpile management or similar. This will involve a major change to traditional thinking with respect to minesite operations.

Utilisation of carbon offsets

Finally, once all abatement options are exhausted, the mine of the future will need to turn to offsets to neutralise the remaining emissions impact of the facility. Offsets represent an emissions abatement that occurs outside of the facility boundaries. This may include forestry projects such as reforestation or avoided deforestation, grid connected renewable energy, fuel switching, refrigerant management, land based activities, soil carbon sequestration and a host of other potential project types. Companies may choose to purchase offsets on the open market, enter into contracts with other companies that are developing abatement projects or even be a project proponent of an abatement project outside of the facility boundaries.

When using offsets, companies should be mindful of environmental integrity of the offsets themselves and that the offset provider has the procedures in place to ensure that the offset projects are verified and the offsets being generated are fungible.

Note—not to scale, illustrative only

7

CONCLUSIONS

The mining and mineral processing industry remains critical to future economic development globally with some critical minerals enabling the low-carbon transition required in the rest of the economy. With that said however, the mining industry itself also needs to decarbonise and play a role in meeting the overall aims with regard to decarbonisation. This study has shown that the industry is a significant user of energy overall. For the commodities studied in this piece, approximately 1.7 EJ of final energy consumption is estimated, representing 0.5% of total final energy consumed globally. Across the entire industry, it is estimated that 12 EJ of final energy is consumed or 3.5% of total final energy globally.

Within the operations studied, it is estimated that 45% of this final energy consumption is diesel consumption, with the remaining 55% coming from electricity consumption. Comminution activities represent 25% of the total final energy consumption in the areas studied—a number that compares favourably with other published data in literature (generally estimating ~30% of final energy consumption). This makes comminution a key area in which energy savings efforts can be focussed in the short to medium term.

There are a number of opportunities available to reduce energy consumption in the mining and mineral process industry. Opportunities involving optimisation, big data and artificial intelligence, replacement of traditional comminution equipment with new, efficient technologies which consume less energy and reduce or mitigate grinding media, pre-concentration and others. In addition, if zero emissions energy sources are deployed for mobile and stationary equipment—e.g. renewable energy, energy storage and alternative fuels—then the mining industry may well be able to achieve zero emissions, or close to it. Leaving a relatively small role for offsets and carbon credits to play.

8

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