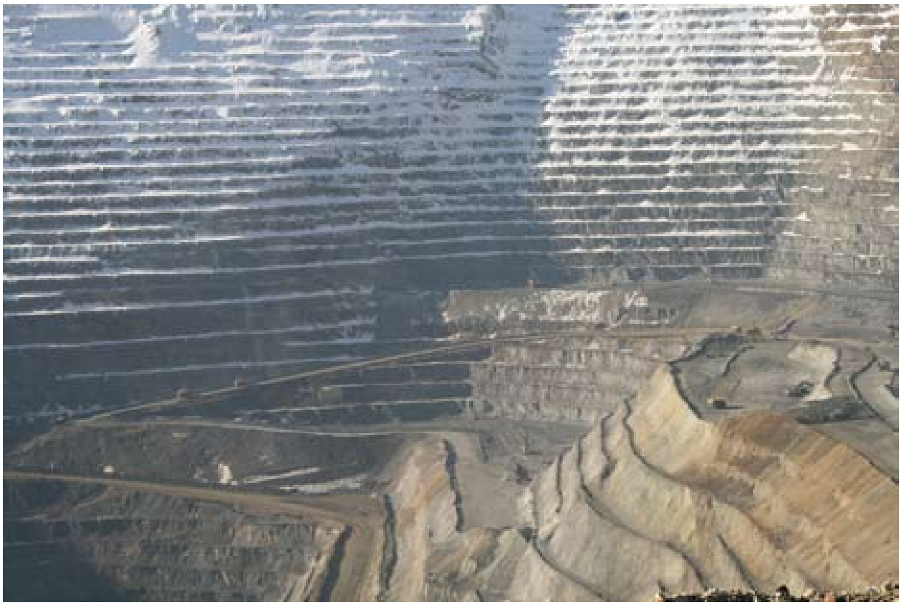
Carbon emissions from base metal mine sites

The threat of global warming and its prominent position in public discussion and political debate requires all industry to take stock of its contribution to rising atmospheric concentration of greenhouse gases. For the primary metals industry, the first step must be to identify the pattern and range of emissions at each step in the production chain. Only then can the industry assess the economic consequences of the penalties on emissions that will be imposed by governments and regulators and devise cost-effective plans to avoid or mitigate such penalties.

While some work has been done to estimate carbon dioxide (CO_2) emissions using Life Cycle Inventory analysis, this approach is less useful than site-by-site emissions estimates. It is the level of specific emissions at each site that will ultimately determine carbon taxation liabilities and participation in emissions trading schemes.

World Mine Cost Data Exchange Inc. studied CO_2 emissions from mines around the world, including the Bingham Canyon Mine in Utah, pictured here.



Most mining companies have moved with the times to issue sustainability reports for their operations. But in the absence of any standardized reporting format, it is difficult to make useful comparisons between even the best-reported producers on a like-with-like basis. For this reason, Minecost.com modeled the use of fuels and energy used in mining, milling, shipping and metallurgical treatment to cover “cradle-to-gate” emissions of greenhouse gases resulting from the production of the major base metals copper, zinc, lead and nickel.

Greenhouse gas emissions — overwhelmingly carbon dioxide — are associated with the consumption of energy at every step in the production chain, from exploration through mining to the production of refined metal. Producers of primary metal employ diverse technologies to mine, mill, smelt and refine several different types of ore. Every orebody has its own special characteristics. In addition, most base metals are produced in concentrate that must be transported to smelters, with consequent emissions consequences.

Many mines produce more than one metal. This raises the issue of how to allocate emissions among coproducts. In this study, emissions from common processes are allocated according to metal weight. However, emissions can also be allocated according to economic values.

Depending largely upon location, base metals mines, smelters and refineries consume energy in different proportions from the major primary energy sources. Electrical energy is generated from hydro, nuclear, natural gas, oil and coal, and needs to be identified for each production unit to correctly estimate its carbon emissions. Each generation source has a specific production rate of CO_2, ranging from about 340 kg/kWh (750 lb/kWh) generated from coal fired power stations to around 180 kg (397 lb) for natural gas. These emissions figures also need to be adjusted for power station thermal efficiencies — typically between 35 and 50 percent — and for transmission losses between the generator and the mine site.

Putting this together allows for a calculation of carbon emissions data based on Minecost.com’s model estimates of direct onsite fuel, power and explosives consumption for each mine, plus the indirect emissions associated with the identified electricity suppliers to each mine. For mine complexes that include a smelter, emissions estimates for metallurgical processing were included. The Minecost.com model uses engineering relationships to estimate fuel and power requirements for each mine, depending on mining method, ore characteristics, mine and mill layout and

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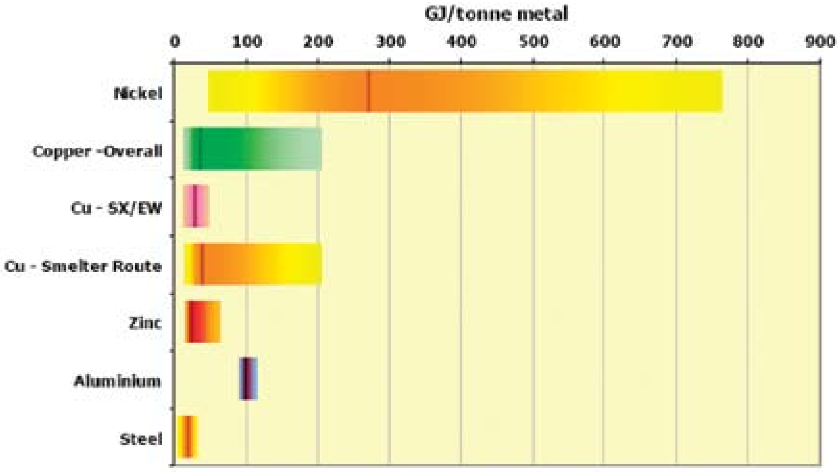
the mill flowsheet. All these models are available from the Minecost.com Web site (www.minecost.com).

Fuel and power consumption and carbon emissions data are shown in the form of emissions curves that rank mines by their carbon emissions consistent with each producer's sustainability reporting requirements. This allows each producer to be meaningfully compared with its competitors.

For regulatory and global comparisons, emissions data for concentrate shipping and metallurgical processing were also estimated to show all direct and indirect carbon emissions associated with the production of finished metal from each producer. The carbon emissions data can then be used to measure the impact of carbon penalties on the cash operating cost of each producer.

FIGURE 1

Final energy intensities of metals.



Energy consumption and carbon emissions

Primary metals production is a carbon-intensive business. Total CO$_2$ emitted by the sample of mines and metallurgical plants producing 90 percent or more of western world copper, lead, zinc and nickel in 2007 was some 92.3 Mt (102 million st) of CO$_2$. Of this total, 60.2 Mt (66 million st) was emitted at mine sites and 32.1Mt (35.4 million st) by concentrate shipping and metallurgical processing. Note that mine site emissions include some onsite metallurgical processing such as copper solvent extraction electrowinning (SK-EW), and several co-located smelters such as at the Garfield smelter at the Bingham Canyon copper mine in Utah.

In all, the base metals sample emissions are equivalent to about 33 percent of carbon emissions from the world steel industry. Base metals carbon intensity (the amount of CO$_2$ emitted per unit of metal) of 3.99 is higher than the IISI estimate of 1.7 for steel, including scrap recycling, or about 2.5 for steel made from primary iron ore. Another useful comparison carbon intensity statistic is 0.36 for the world cement industry.

Energy consumption for base metals primary production in 2007 ranged from 14.5 GJ/t for lead and 35.7 GJ/t for copper to 207.5 GJ/t for nickel, excluding byproduct nickel from platinum group element (PGM) producers. The corresponding mine site-only energy requirements were 6.6 to 6.8 GJ/t for lead and zinc, 23.1 GJ/t for copper and 29.5 GJ/t for nickel sulfide concentrate producers. Mine site nickel production including on site ferronickel smelters but not coproduct PGM production from South Africa was a much higher 139.9 GJ/t nickel.

Site CO$_2$ emissions from copper mining in 2007 averaged 2.45 t CO$_2$/t copper, above the 2.11 t CO$_2$/t nickel for nickel sulfides mine and well above the 0.81 t CO2/t lead and 0.58 t CO$_2$/t zinc. Relatively high copper mine site CO$_2$ emissions reflect the high proportion of large-scale low-grade openpit copper mines, compared with the higher ore grades at nickel, lead and zinc mines.

Large-scale bulk mining of copper also explains why the proportion of CO$_2$ emissions from electricity usage comprises almost four-fifths of copper mine site emissions, compared with closer to two-thirds for lead and zinc mines and about half for nickel mine site emissions. Grinding low-grade ores is a more energy intensive activity than moving ore, hence the high proportion of power usage at copper mines when measured in terms of metal produced.

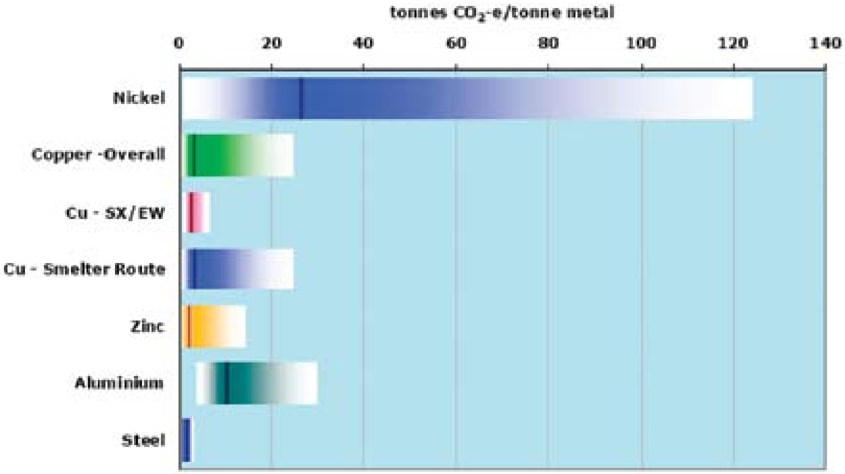
Copper concentrate shipping from mine to smelter produces 0.13 t CO$_2$/t copper contained, somewhat more than the 0.08 t CO$_2$/t lead for lead concentrates but well below the 0.27 t CO$_2$/t nickel for nickel in concentrate. These should come as no surprise since the CO$_2$ emissions figures should reflect the grade of metal in concentrate. Typical copper concentrate grades are between 28 and 34 percent, compared with nickel concentrate grades of 9 to 11 percent.

Carbon dioxide emissions from copper mining, shipping, smelting and refining averaged 3.33 t CO$_2$/t copper, compared with 2.28 t CO$_2$/t zinc and 19.53 t CO$_2$/t nickel for finished nickel production. These are consistent with the corresponding energy requirements of 35.7 GJ/t for refined copper production, 24.5 GJ/t for zinc and 207.5 GJ/t for nickel production.

Turning to specific operations, the Red Dog and Century zinc-lead mines in Alaska and Queensland, Australia, respectively, are examples of low energy intensive operations because they are bulk mining, openpit mines with relatively high ore grades. Above the middle of the distribution are the Escondida and Los Bronces copper mines in Chile, both of which have adjunct SX-EW copper production. Higher energy consumers are Teck Cominco's Highland Valley copper mine in British Columbia that is mining low-grade ore and normally relies on molybdenum byproduct to remain economic, and Rio Tinto's Bingham Canyon Mine in Utah, which has an on-site smelter. Freeport-McMoRan's Grasberg Mine in Indonesia is also a relatively high energy intensive mine as a significant

FIGURE 2

GHG intensities of metals.



proportion of production comes from underground.

The corresponding emissions data for these mines demonstrate the benefits of a low emissions source of electricity. Century's power comes from natural gas, while Red Dog uses self-generated electricity from diesel, however, the much higher zinc grades at Red Dog more than compensate for the higher consequent greenhouse gas emissions. Highland Valley looks much better from a CO_2 emissions point of view because of the availability of hydro-electricity in British Columbia, while the major Chilean mines remain above the middle of the emissions curve because their electric power comes from the largely fossil fuel generated SING system. Both Grasberg and Bingham Canyon use coal fired power that places them towards the top of the emissions curve.

The energy use data is illuminated by looking at energy use in terms of ore mined and milled. Most base metals mines in this study sample use less than 0.5 GJ/t of ore milled. Low energy users in ore terms tend to be the mine-for-leach copper SX-EW producers that do not grind ore, with energy consumption in the region of 0.1 GJ/t of ore treated. Then come large scale openpit operations with low waste to ore ratios such as Escondida and Chuquicamata, where energy consumption is about double at 0.2 GJ/t. Coming in at around 0.3 to 0.4 GJ/t of ore milled are the bigger underground mines such as Mt Isa (Queensland, Australia), Norilsk (Russia) and Cannington (Queensland, Australia), and then significantly higher again are mines with harder ore and finer grinding such as Red Dog and McArthur River (Northern Territory, Australia). Close to the top of the distribution at about 0.9 GJ/t is Century with very high stripping ratios and relatively finer grinding.

Mining companies must now pay as much attention to where they appear on the emissions curve as they do with cost curves. The rapidly increasing level of sustainability reporting by the mining industry, together with the almost universal adoption of standardized Global Reporting Indicators, means that emissions curves will soon be appearing in sustainability statements.

Carbon taxes

Regulatory action to curb greenhouse gas emissions will take the form of a tax on the carbon content of fuels, or cap-and-trade schemes as already established in the European Union. Carbon taxation is probably the simplest approach to discouraging greenhouse gas emissions. By raising the cost of using carbon-containing fuels, producers and consumers will be encouraged to adopt low-emissions fuels and processes. Cap-and-trade schemes involve the authorities setting a global limit to carbon emissions and allowing producers and consumers to trade emissions rights. With carbon taxes, there are no limits placed on the quantity of carbon emissions; carbon emitting behavior just becomes more expensive, thereby encouraging emitters to find ways to avoid or minimize their carbon tax liabilities. Cap-and-trade schemes limit the quantity of carbon emitted and allow market mechanisms to price the cost of emissions reduction. But whatever way the authorities choose to go, there will always be an explicit dollar cost attached to carbon emissions.

The impact of a carbon tax — or, alternatively, the cost of purchasing emission rights — will vary across the primary base metals industry. Once the specific carbon emissions are established for each producer, it becomes a relatively simple exercise to determine the impact on operating costs.

The following cost curves are drawn for 2007 cash costs for the copper, zinc, lead and nickel and include the cost of a $50/t ($45/st) carbon tax. In each case, the curves are for cash costs after credits, where mine products with values less than 20 percent of total mine value are credited against the principal metal product. Where a mine product is worth more than 20 percent of total mine production value, it is retained as a coproduct. It should be noted that the curves show total carbon penalties incurred along the production chain from mining to smelting to refined metal. The extent to which carbon penalties are shared between miners and smelters will depend on the state of concentrate markets, as for other metallurgical costs, hence the numbers given here should be considered as upper bounds of likely carbon penalties imposed on miners.

For copper, a $50 carbon tax would have raised costs after credits by an average of 8.7 percent in 2007. The greatest impact of a carbon tax would have been on the Palabora Mine in South Africa, where cash costs would have been 28 percent higher, largely because of the use of ESKOM coal-generated power. The reliance on electricity generated largely from coal also explains the 15 percent impact on Bingham Canyon cash costs. And while the current severe shortage of hydropower in Chile explains the 21 percent impact on Zaldiuvar cash costs and the 17 percent increase at Chuquicamata SX-EW. Chuquicamata copper in concentrate costs would have increased by 13 percent and Andina by almost 14 percent, again mainly because of the high fossil fuel origin of SING power in Chile.

Other copper mines facing high carbon tax penalties include Bingham Canyon with its associated coal-fired power station (23 percent) and Palabora in South Africa (19 percent) that relies on ESKOM coal-generated power. The other big South American openpit copper mines face carbon penalties of between 8 and 17 percent of 2007 cash costs, again a result of the shortage of hydropower. On the other hand, the availability of hydropower largely explains the low penalty mines such as Highland Valley in British Columbia (6 percent), all of the Zambian mines at less than 2 percent, Aitik in Sweden at 2.5 percent and Paupa New Guinea's Ok Tedi Mine at 4 percent. Large-scale underground mines tend to be at the lower end of the penalty range. El Teniente in Chile, at 9 percent carbon penalty, is well below the major Chilean openpit producers. Olympic Dam (5 percent) derives 75 percent of its power from natural gas so it would attract a much lower penalty than Australian openpit mines such as natural gas fired Ernest Henry (10 percent) and the New South Wales coal-power reliant Northparkes (13 percent), Ridgeway (12 percent) and Cadia openpit (13 percent).

But percentage changes in costs due to a carbon tax can be misleading due to their dependence on the effects of crediting. Thus Grasberg, which after crediting gold and silver had a cash cost of 12 cents/lb copper in 2007, would have seen costs increase by 102 percent to 24.2 cents/lb from a $50/t ($45/st) carbon tax. For this reason, carbon penalties in absolute cents/lb copper terms are a more reliable guide to the effect of carbon taxation on mine economics. Cadia (Australia) has the highest carbon tax penalty at 23 cents/lb, closely followed by Palabora (Australia) at 21 cents/lb, the restarted Morenci copper in concentrate mine in Arizona at 16 cents/lb, Zaldivar (Chile) 15 cents/lb, Batu Hijau (Indonesia) and Grasberg at 12 cents/lb, and Chuquicamata SX-EW 11 cents/lb. It is worth noting that these mines rely mostly or all on coal-fired electricity.

A $50/t ($45/st) carbon tax levied on zinc mines in 2007 would have raised average cash costs after credits by 9.5 percent . The highest penalty as a percentage of pre-penalty cash costs would have been incurred at El Porvenir in Peru (44 percent) but this is more a reflection of El Porvenir's very low cost after credits. The absolute penalty of 2.4 cents/lb zinc at El Porvenir is much the same as Kidd Creek, Zinkgruvan and Langlois and way below the absolute carbon penalties at Penoles' Francisco Madero Mine in Mexico at 18 cents/lb zinc, Montana Tunnels at 14 cents/lb and the new San Cristobal Mine in Bolivia at 13.5 cents/lb. Carbon penalties at the other Penoles zinc mines in Mexico range between 10 and 12 cents/lb, principally because electricity is supplied by Termoelectrica Penoles that burns petroleum coke.

Table 1

Cost increases with carbon tax of US$50/t CO_2-e.

Energy source	CO_2 content	Cost increase for carbon tax at US$50/t CO_2-e
Diesel	2.62 kg/l	13.1 c/l
Fuel oil	3.17 kg/l	15.9 c/l ($25/bbl)
Natural gas	51.4 kg/GJ	$2.75/GJ
Diesel-fired power	0.73 kg/kWh	3.7 c/kWh
Oil-fired power	0.79 kg/kWh	3.9 c/kWh
Gas-fired power	0.36 kg/kWh	1.8 c/kWh
Coal-fired power	0.87 kg/kWh	4.3 c/kWh

Cash costs at Rosh Pinah in Namibia would have been 21 percent higher, largely because of the high proportion of coal in Namibian and South African power generation, 18 percent at Rampura Aguch in India — a coal powered dependent producer — almost 15 percent at Antamina in Peru, 14 percent at Skorpion — another coal dependent producer — and 11 percent at Century where the advantage of natural gas was offset by accelerated stripping. Carbon penalties at the diesel-powered Red Dog Mine would have raised costs by 7 percent or almost 5 cents/lb zinc – about average for the industry. In Canada, the dominance of hydropower meant that most zinc producers cost penalties ranged between 2 to 6 percent, except for Brunswick, which would have incurred a 4.2 cents/lb penalty to raise costs by almost 14 percent. Among the low penalty producers at less than 2 cents/lb zinc were Hudbay's Flin Flon and Snow Lake mines in Manitoba, Pend Oreille in the United States and Rosebery in Australia. For all these mines, hydropower was an important part of the story.

Lead mines would have been less affected by a $50/t ($45/st) carbon tax last year, with an average cost increase of only 6.9 percent. At the top of the list is the Doe Run's Viburnam Trend mines, where a carbon penalty would have doubled cash costs after credits. This is because Missouri power is predominantly generated from coal and Doe Run costs were much lower than normal because of the high zinc and copper values from credits in 2007. More typical were Francisco Madero in Mexico and Atacocha in Peru with an 18 percent increase, and Doe Run's Sweetwater operation at 12 percent. Typical mines in the middle of the emissions curve are Mt Isa and Cannington, which both use natural gas fired electricity. Looking at absolute carbon penalties, the highest is 11 cents/lb lead at Francisco Madero and 9 cents/lb at Montana Tunnels, again because of the high CO_2 content of their respective power generation fuels. On an absolute basis, Doe Run would have attracted a more modest carbon penalty of 3.7 cents/lb, but still significantly higher than the 2 to 2.5 cents/lb at Red Dog, Cannington and Mt Isa. The least affected lead producers, like zinc, are the Boliden Swedish mines where a carbon impost would have raised costs by less than one cent.

Nickel costs would have increased on average by 12.4 percent for a $50 carbon tax. Again the average disguises the larger variances, since the average included by-product nickel production from high cost South African PGM mines and the ferronickel producers. The highest cost increase would have been 30 percent at Larco. It relies mainly on coal-generated power and uses lignite as a reductant at the smelter. A $50/t ($45/st) carbon tax at Larco translates to a $2.03/lb nickel increase in costs. Indeed, the next eight highest cost increases are at ferronickel smelters such as oil-dependent Falcondo where costs would be up by 25 percent or $1.56/lb nickel, followed by PT Inco with a 14-percent or 99-cents/lb nickel cost increase.

It comes as no surprise that the lowest cost impact nickel producers are in Canada, where hydropower again saves the day. Canadian costs would have increased by just 1 percent at Vale Inco's Manitoba division and by 2.1 percent at the Ontario division. In absolute terms, the Canadian cost increases are of the order of 4 to 8 cents/lb nickel. Contrast these with BHP Billiton's Nickel West Australian natural gas-fired producers where costs would have increased by 22 to 30 cents/lb nickel.

These estimates are based on cash costs after credits, where the underlying crediting assumptions will affect the apparent carbon tax effect, and that the burden of the cost increase will not necessarily be borne by the miners.

Overall, the impact of a carbon tax on the base metals industry may not look particularly onerous in an environment of record prices. But a $50/t ($45/st) carbon tax would probably turn out to be insufficient to reduce greenhouse emissions to the levels being targeted by Stern and others.

A carbon tax would also have a second round effect on world metals demand, that could end up squeezing producers between lower demand and prices and higher carbon tax induced costs.

Given the well-documented inelasticity of demand for fossil fuels, carbon taxes and emissions prices could come in higher than $50/t ($45/st).

This has already happened since the collapse in metals prices in late 2008 and the subsequent closures of many mines as prices fell below cash operating costs. So what looks like a relatively benign cost impact of a carbon tax on 2007 operating conditions will translate to a much tougher environment for the industry when carbon penalties become fact of life in the next couple of years. ■

TECHNOLOGY NEWS

Caterpillar introduces new ground-engaging tools

Caterpillar LM Series ground-engaging tools (GET) are designed specifically to promote safety, productivity and reduced costs on sites operating large mining machines, such as shovels, hydraulic excavators and draglines.

The new "hammerless" GET system features the Caterpillar CapSure tip-retention design, that allows tip installation and removal by using only a 19 mm (0.75 in.) ratchet.

The new CapSure retention system makes the pin and retainer integral with the tip. The service technician need only turn the side-mounted locking system 180 degrees, exerting minimal force 136 N/m (100 lbs/ft), to activate the CapSure system. Positioning access to the locking system on the side of the tip reduces wear and results in easier, faster tip replacement.

Caterpillar's LM series ground-engaging tools feature the CapSure tip retention design.

To further enhance the safety and simplicity of replacing LM Series GET, two lifting eyes on top of the tip assembly allow the technician to easily attach a small sling for use with a service crane. And once installed, the new tips, constructed of DH3 alloy, are designed to outlast tips constructed of other materials.

Caterpillar GET systems, available for mining and other industries, are available through Caterpillar dealers worldwide for all Cat equipment and for certain competitive machines. ■