Chilean Copper Commission
Research and Policy Planning Department

ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS IN THE CHILEAN COPPER MINING INDUSTRY

Events of 2008

DE/07/09

Glossary

CDEC: Economic Load Dispatch Center

CNE: National Energy Commission

CUE: Unit emission load

DUE: Unit energy demand

EWC: Electrowon cathode (hydrometallurgy)

ER: Electrorefined cathode (pyrometallurgy)

EW: Electrowinning

GHG: Greenhouse gas

GJ: Gigajoule = 10^9 joules

GWh: Gigawatt/hour = 106 kilowatt-hour= 3.6 joules

IPCC: Intergovernmental Panel on Climate Change

KWh: Kilowatt-hour = 3.6 x 10^6 joules

LX: Leaching

MJ: Megajoule = 10^6 joules

SIC: Central Power Grid

SING: Power Grid of the Greater North

SX: Solvent Extraction

TJ: Terajoule = 10^{12} joules

MTF: Metric ton refined copper

Executive Summary

This is the 2008 update to ongoing Cochilco studies on energy consumption and greenhouse gas (GHG) emissions in the Chilean copper mining industry. Past editions are available from the Cochilco web site.[1][2][3][4][5]

Unlike previous studies, this review of energy, fuel and electricity use and GHG emissions in the copper mining industry spans only from 2004 to 2008, a period when most mining operations coming on stream in the mid-nineties were fully operational. This makes for a more representative analysis.

Starting this year this study will be updated on an annual basis. The intent is to conduct an ongoing assessment of the impact of the natural gas crisis and power supply restrictions on the copper mining industry and sector GHG emissions. In consequence, the data series reviewed in this study will be carried in the Cochilco Yearbook of Copper and Other Mineral Statistics on a regular basis.

This study tracks changes in energy use arising from technological change, commercial product portfolio shifts and other relevant factors, based on mining company reports.[6]

The information in this study is also used by Cochilco to forecast electricity demand in the copper mining industry.

As in previous years, the methodology involves identifying copper production areas, stages and processes resulting in specific material flows whose volume decreases as product purity increases. These definitions are then used to survey leading producers and refiners.

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[1] Coeficientes Unitarios de Consumo de Energía de la Minería del Cobre 1995-2004 *(Energy consumption unit ratios in the Copper Mining Industry 1995-2004)*. Chilean Copper Commission. www.cochilco.cl/productos/politica_estudios_2006.asp

[2] Coeficientes Unitarios de Consumo de Energía de la Minería del Cobre 1995-2006 (Energy consumption unit ratios in the Copper Mining Industry 1995-2006). Chilean Copper Commission. www.cochilco.cl/productos/politica_estudios_2007.asp

[3] Coeficientes Unitarios de Consumo de Energía de la Minería del Cobre 2001-2007 *(Energy consumption unit ratios in the Copper Mining Industry 2001-2007*). Chilean Copper Commission. www.cochilco.cl/productos/politica_estudios_2008.asp

[4] Emisiones de Gases de Efecto Invernadero de la Minería del Cobre de Chile 2006 *(Greenhouse Gas Emissions in the Chilean Copper Mining Industry 2006*). Chilean Copper Commission. www.cochilco.cl/productos/politica_estudios_2007.asp

[5] Emisiones de Gases de Efecto Invernadero de la Minería del Cobre 2001-2007 *(Greenhouse Gas Emissions in the Copper Mining Industry 2001-2007)*. Chilean Copper Commission. www.cochilco.cl/productos/politica_estudios_2008.asp

[6] Annex 1: Mining operations in this study.

Companies accounting for 99 percent of Chilean copper production in 2008 submitted reports on fuel and electricity consumption. These reports were used to calculate Specific Unit Ratios on a per-area and -operation basis for fuel and electricity use per unit of ore treated, material produced and refined copper content in treated material. Next, a weighted Global Unit Ratio average was determined for each area.

The study reviews direct[7] and indirect[8] greenhouse gas emissions associated with the copper concentrate, anode and cathode life cycle. The focus is on compiling GHG emission information per commercial copper product (i.e., concentrate, ER cathodes, EW cathodes, anodes) and process area (mines, concentrating plants, smelters, refineries, leaching-solvent extraction & electrowinning, and services) in order to gauge the impact of the energy mix on product and process emissions.

[7] In-place emissions from fossil fuel combustion.

[8]Emissions from consumption of electricity, most of which is generated through fossil fuel combustion. Includes emissions from production of fuels used in the copper mining industry, which contribute about 1 percent of the total.

Key Findings

1. Unit and Total Energy Consumption

Although production fell in 2008, total energy consumption in the copper industry actually increased. Total energy consumption unit ratios[9] rose 9 percent to an average of 22,869 MJ/MTF.

Taking as base year the onset of natural gas supply cuts in 2004, the study found that total energy consumption unit ratios in the Chilean copper mining industry rose 23 percent through 2008.

In fact, while total copper production fell 2 percent in the period, total estimated energy consumption rose 21 percent (from 100,341 TJ in 2004 to 121,897 TJ in 2008). In 2004-2008, fuel and electricity use rose 36 and 11 percent, respectively. Global fuel consumption unit ratios increased 38 percent (12 percent in 2008) while electricity increased 13 percent (6 percent in 2008).

Significantly, while in 1995-2004 global fuel consumption unit ratios tended to decrease (29%), they rebounded in 2005 (34%), resulting in a 3 percent reduction for the period. In addition, while electricity consumption unit ratios varied they mostly tended to increase, rising 22 percent. The global unit energy consumption in the copper mining industry rose 9 percent.

In the second half of this decade, a range of factors -lower grades, greater haulage distances, a shifting commercial product portfolio, technological change- have made copper mining significantly more energy-intensive.

[9] Unit consumption: energy required to produce a unit of a product (1 ton refined copper content).

2. Greenhouse Gas Emissions

2.1 GHG Emissions in Power Grids

The study found that electricity demand for copper production in the SIC power grid rose 10.6 percent, from 23,235 TJ in 2004 to 25,701 TJ in 2008 (17 percent of net grid generation). Significantly, demand fell 0.7 percent in 2008. In the same period, demand in the SING grid grew 13.6 percent, from 34,470 to 39,148 TJ (78 percent of net grid generation).

The study also found that in 2004 the SIC and SING grids emitted 248.3 tons and 696.0 tons CO_2 equivalent/GWh, respectively. In other words, SING GHG emissions per GWh were 2.8 times greater. In 2008 the ratio rose to 2.9 times (324.9 and 952.5 tons, respectively).

These developments were due to changes in the energy mix of both grids. The SING power grid uses practically 100 percent thermal sources. In 2004, fully 61.2 percent of SING energy came from natural gas, which has a lower unit GHG emission footprint. In 2008, however, 58.8 percent of SING electricity was generated from coal or a combination of coal and petcoke. In the SIC power grid, thermal source use increased and hydroelectric generation decreased. In addition, natural gas was replaced with diesel and coal, intensifying GHG emissions.

2.2 GHG Emissions From Copper Production

In 2004-2008, GHG emissions from copper production rose 48 percent, from 11.5 to 17 million tons CO_2 equivalent. These increases were mostly due to natural gas cuts and rising fuel and electricity consumption.

GHG emissions in copper mining operations served by the SING power grid grew faster (50%) than energy consumption (23.5%), mostly due to a 37 percent increase in unit emissions from fuel source changes. In the SIC, GHG emissions also grew significantly faster (40%) than energy consumption (14.7%) as unit grid emissions increased 31 percent in the period.

While unit SING and SIC emissions in 2001-2008 rose 50 and 59 percent, respectively, predominance of thermal generation made the former much more significant.

Energy consumption unit ratios associated with nationwide copper production rose 23 percent in 2004-2008. GHG emission unit ratios also tended to increase, especially starting in 2005, rising a total of 52 percent in the period.

The above was caused by increased unit GHG emissions in both grids as coal and diesel (with a much higher unit GHG emission footprint) replaced natural gas and SIC thermal generation rose to offset hydroelectric generation declines.

Increased fuel use as a share of total energy use in operations served by both grids is mainly due to rising consumption unit ratios in open-pit mines as grades decline and haulage distance increases.

Increased fuel use caused electricity use as a share of sector energy consumption to drop for the fourth straight year from its peak in 2004. Energy used in 2008 was 53 percent electricity and 47 percent fuel.

Emissions, both direct (fossil fuels) and indirect (electricity consumption), rose 35 and 52 percent, respectively. In 2008, indirect emissions accounted for 76 percent of the total.

3. Energy Consumption and Emissions by Process Area

3.1 Energy Consumption

A per-process[10] review of total energy consumption shows mining operations as the top energy consumers (38%), followed by concentrating plants (24%). While energy used in mining facilities is 87 percent fuels, concentrating plants use 97 percent electricity. In 2004-2008, fuel use in mining operations rose 52 percent while electricity use in concentrating plants increased 5 percent.

Mining operations increased their share of industry-wide fuel consumption from 38 percent in 1995 to 71 percent in 2008. Most mines coming on stream in the period are open-pit. As mining proceeds, slopes rise and ore and waste rock haulage distances increase, driving up fuel consumption.

The study shows that sulfide ore concentration accounts for almost half of sector electricity requirements, although shares dropped from 49 percent in 1995 to 43 percent in 2008.

In 2004-2008, energy,[11] fuel and electricity unit ratios rose practically across the board, save for electrolytic refining and services.

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[10] Open pit and underground mines, concentrating plants, smelters, electrolytic refineries, leachable ore treatment and services.

[11] See Annex II.

Fuel Consumption Unit Ratios

(Refined ton in final product)

	2004	2005	2006	2007	2008
Open Pit (MJ/MTF ore)	4,442.4	4,196.4	4,465.0	5,119.6	5,634.4
Underground (MJ/MTF ore)	1,000.6	1,333.1	1,563.9	1,808.5	1,297.6
Mina (1) (MJ/MTF ore)	3,932.9	3,799.9	4,084.6	4,702.9	5,186.4
Concentrating Plant (MJ/MTF concentrate)	176.2	215.8	185.4	188.6	233.4
Smelter (MJ/MTF anodes)	4,699.8	4,965.3	4,827.9	4,964.9	5,170.3
Refinery (MJ/MTF EW cathodes)	1,475.2	1,751.7	1,603.7	1,504.0	1,195.1
LX-SX-EW (MJ/MTF SX-EW cathodes)	2,669.1	2,905.5	2,893.8	3,094.6	3,080.1
Services (MJ/MTF total production)	318.6	278.3	280.0	266.1	256.7

(1) Weighted average of open pit and underground mining unit ratios.
Source: *Cochilco, based on company reports.*

Electricity Consumption Unit Ratios

(Refined ton in final product)

	2004	2005	2006	2007	2008
Open Pit (MJ/MTF ore)	585.6	639.7	614.3	619.9	654.8
Underground (MJ/MTF ore)	1,257.9	1,558.5	1,693.5	1,692.3	2,099.4
Mina (1) (MJ/MTF ore)	689.1	770.0	758.5	757.3	808.2
Concentrating Plant (MJ/MTF concentrate)	6,942.7	7,240.9	7,424.6	7,862.7	8,208.5
Smelter (MJ/MTF anodes)	3,836.2	3,771.7	3,778.7	3,887.1	3,692.1
Refinery (MJ/MTF EW cathodes)	1,276.8	1,269.9	1,233.4	1,221.2	1,285.1
LX-SX-EW (MJ/MTF SX-EW cathodes)	10,429.0	10,082.3	10,128.7	10,479.6	10,702.3
Services (MJ/MTF total production)	515.9	576.1	502.5	443.2	558.0

(1) Weighted average of open pit and underground mining unit ratios.
Source: *Cochilco, based on company reports.*

3.2 GHG Emissions

In 2004-2008 total GHG emissions rose across all industry process areas.

A review of GHG emissions by process area in 2008 shows that leachable ore treatment (30 percent of direct and indirect sector emissions) surpassed concentrating plants (29%) as a source of emissions, followed by open pit mines (21%) and smelters (10%).

The table below shows unit emission loads by process area in 2004-2008.

Unit Emission Loads by Process Area

	Unit	2004	2005	2006	2007	2008
Open Pit	MT CO2 eq. /MTF ore	0.38	0.42	0.44	0.47	0.55
Underground	MT CO2 eq. /MTF ore	0.17	0.20	0.22	0.31	0.28
Concentrating Plant	MT CO2 eq. /MTF concentrate	0.92	0.92	1.04	1.40	1.50
Smelter	MT CO2 eq. /MTF anodes	0.84	0.81	0.86	1.08	1.10
Refinery	MT CO2 eq. /MTF ER cathodes	0.24	0.25	0.22	0.30	0.30
LX-SX-EW	MT CO2 eq. /MTF EW cathodes	2.06	1.92	2.21	2.67	2.81
Services	MT CO2 eq. /MTF total production	0.10	0.10	0.10	0.11	0.17

Source: *Cochilco, based on company reports.*

4. Unit Energy Demand and Unit Emission Loads by Product

Energy consumption and GHG emissions associated with copper production (concentrate, anodes, ER cathodes, EW cathodes) were estimated on a per-grid basis.

While the amount of energy required to produce a ton of refined concentrate was relatively similar across grids (SING: 16.7 GJ/MTF; SIC: 16.2 GJ/MTF in 2008), unit emission loads differed substantially. SING loads were 1.7 to 2.2 times greater than SIC loads. As noted, this is due to high concentrating plant electricity consumption and greater reliance on thermal sources in the SING power grid.

In 2008, 37 percent of Chilean copper was shipped in concentrate form. The balance shipped as refined copper, including 0.99 million MTF ER cathodes and 1.97 million MTF EW cathodes. The study also found that while 8 percent more energy was required in 2008 to produce ER than EW cathodes (30.9 vs. 28.4 GJ), they emitted 5 percent fewer GHG (4.1 vs. 4.3 tons CO_2 equivalent).

This shows that while ER cathodes required more energy, in unit terms EW cathodes emitted larger GHG amounts. This is a function of the energy supply from the SING power grid, which, as noted, has a larger GHG emission footprint.

As to the carbon footprint of Chile's leading commercial copper products, country weighted averages in 2008 were as follows:

Product	**MT CO_2 Equivalent/MTF**
Concentrate	2.28
ER Cathodes	4.09
EW Cathodes	4.31

Source: *Cochilco, based on company reports.*

In Conclusion

The most salient point in these results is reversion, starting in 2007 and mounting in 2008, of the trend observed since 1995 whereby energy consumption and emissions would trail increases in copper production.

Increased total and unit energy use through 2008 stem from a host of factors -declining grades, greater haulage distances, changes in the commercial product portfolio, and technological change- that have made copper mining noticeably more energy-intensive in the past four years.

Copper mining energy consumption patterns underwent significant changes in 1995-2005, especially a rise in the relative weight of electricity consumption. While electricity accounted for 58 percent of total energy use in 2005, the trend reverted in 2006 and fell to 53 percent in 2008, with a wide range of fuels accounting for the remaining 47 percent.

Fuels used directly by the copper mining industry in 2008 included diesel (79.6%), Enap 6 fuel oil (16.7%) and natural gas (1.7%). Other fuels (i.e., coal, kerosene, liquefied gas and gasoline) accounted for marginal amounts. Significantly, supply cuts slashed the natural gas share of direct sector consumption from 13.3 percent in 2004 to 1.7 percent in 2008 and increased diesel use from 69.1 to 79.6 percent. Most natural gas was used by copper smelters.

As such, it appears that while natural gas cuts since 2004 have not directly impacted copper mining dynamism, they have driven up electricity costs as generation companies turn to costlier fuel options.

In addition to higher unit energy costs, both unit and absolute fuel and electricity demand per ton of refined copper have also seen increases in recent years.

Natural gas cuts are reflected in increased sector emissions, especially over the past five years. Total unit GHG emissions rose 50 percent, to 3.19 MT CO_2 equivalent/MTF in 2008. This stems from both declines in hydroelectric generation, especially in the SIC power grid, and natural gas cuts forcing widespread use of fuel options (coal, diesel) with much higher unit emission footprints.

The increase in total unit emissions has been mostly driven by rising indirect emissions, which grew 52 percent in the period as a result of the significant increase in unit emission ratios across both grids. In addition, the share of indirect emissions (from electricity use) in total sector emissions rose from 74 percent to 76 percent in 2008.

As regards GHG emissions, the most significant conclusion is the growing impact of the grid emissions profile on emissions from various process areas, and ultimately, the unit product. In 2008, electricity accounted for 53 percent of sector energy use. As such, it is clear that future GHG emission reductions in the copper mining industry will, to a large extent, hinge on GHG-efficient grid policies.

Just as clear is the direct challenge the role of GHG emissions in global warming poses to the mining sector -a mainstay of the Chilean economy- especially at a time when energy use in the industry is mounting.

As such, Chilean mining is in a position to move gradually by anticipating and even contributing to development of suitable GHG emission regulations.

The results of this study should help miners identify areas exhibiting energy efficiency and GHG emission reduction potential, including new emission reduction opportunities under the Clean Development Mechanism (i.e., tradable offsets) and electricity generation from non-conventional renewable energy sources.

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