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This issue of ***Copper Studies*** is published to coincide with CESCO Week and CRU's 10th World Copper Conference held in Santiago, Chile.

Three CRU-sponsored CESCO scholars have each written an article on a chosen subject relevant to the Chilean and Peruvian copper industries.

Feasibility of incorporating solar energy as a power source for the Chilean mining industry

Introduction

This article analyses the energy challenges faced by the copper mining industry in Chile and evaluates the key factors that determine the feasibility of incorporating solar energy as an alternative source of energy.

The growth of the copper mining industry has resulted in significant challenges, including shortages of equipment, skilled labour, water supply, and a reliable supply of energy at competitive prices. This latter challenge also needs to take into account the strategic need to diversify Chile's energy sources with non-conventional renewable energy (NCRE) accounting for a larger share of the total energy supply. The growing international experience in adopting these technologies and Chile's advantage of having some of the best conditions in the north of the country for the exploitation of solar energy, are key aspects favouring the inclusion of such technologies.

There are, however, many concerns over whether solar energy will be able to meet the demanding requirements of copper mining. Some of the main concerns are discussed in this article, which also evaluates aspects such as the potential impact of the use of solar technology, legal issues, and challenges facing the copper mining industry in terms of energy constraints and the likely rise in future costs.

The current situation

The importance of the mining sector in the Chilean economy

Copper mining is essential for the Chilean economy. In 2009 the mining sector as a whole accounted for 15.5% of GDP, with copper mining alone accounting for 13.6%. In 2009, Chile produced 5,38Mt of contained copper and copper cathode. In the same year, copper accounted for 90% of total Chilean mining exports, which in turn accounted for 56% of total Chilean exports (total Chilean exports reached US$53,735M in 2009). Chilean copper exports accounted for 37.3% of global exports in 2009.[1]

Installed electrical capacity in Chile

In 2008, Chile was ranked 42nd in the world in terms of electricity production, generating 55.2TWh. Chile has 16,143MW of installed capacity divided into four separate grid systems, with SING and SIC providing 99.1% of total energy requirements:

- **Northern Interconnected System (SING – Sistema Interconectado del Norte Grande)**. This system supplies the north of the country, from Arica in the north to the town of Coloso in the south. Thermal generation is mainly oriented to the mining industry (90% of demand is for copper mining). Represents 23.4% of total capacity, with 3,772MW.
- **Central Interconnected System (SIC – Sistema Interconectado Central)**. This system supplies the region from the central area of Chile to the island of Chiloé in the south. The distance between the two locations is about 2,100km. Serves 90% of the population. Represents 75.7% of total installed capacity, with 12,221 MW.
- **Aysen Electric System**. Consists of five medium-sized systems located in the south of the country: Palena, Hornopirén, Career, Cochamó, and Aysen. Represents 0.6% of total capacity (99 MW).
- **Magallanes Electrical**. Consists of four sub-systems: Punta Arenas, Puerto Natales, Porvenir and Puerto Williams, which supply the cities of the same names. Represents 0.3% of total capacity (50 MW).[2]

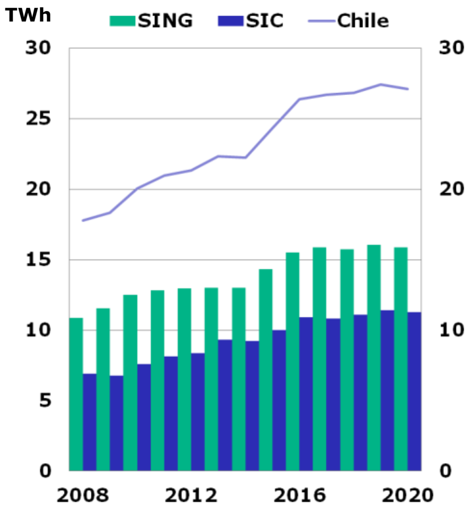
Chilean and mining energy demand

In 2008, Chile was ranked 44th in the world in terms of per capita consumption of electricity, at 3,336kWh per capita. Demand for electricity in Chile has increased on average by 5% pre year over the past five years. It is important to note that during 2008, consumption of electricity in the SIC showed zero growth compared to 2007. This trend in part reflected plans for energy saving and improved energy efficiency promoted by the government, in order to avoid power rationing following both the cessation of the natural gas supply from Argentina to many of the combined cycle power plants and a drought at the beginning of the year that affected hydroelectric power plants.

The mining industry is the largest consuming sector of electricity in the Chilean economy. Consumption was 20,973,000MWh in 2008, corresponding to 37% of the national total. The copper mining industry consumed 17,790,000MWh in the same year. Region II (Antofagasta) has the highest consumption – 9,677,000MWh in 2008, representing 46% of the total consumed by the mining sector. Total consumption in Chile's other regions is equivalent to less than a quarter of that in Antofagasta.[3]

Since 2004 there has been steady growth in the consumption of electrical energy in mining. One reason for the increase is the general decline in the copper grade of deposits. In general, mining companies will initially target high grade zones, where possible delaying mining of lower grade areas. In addition, in recent years no high grade-large tonnage deposits have been discovered. As grades decline, greater tonnages of rock must be processed to recover the same quantity of metal, resulting in a higher energy requirement per processing unit.

Forecast consumption of electricity by the Chilean copper industry



	2008 (TWh)	2020 (TWh)	% Change
SING	10.9	15.9	+46%
SIC	6.9	11.3	+63%
Chile	17.8	27.1	+53%

CRU | ANALYSIS Source: Cochilco 2010

The projected increase in copper production will lead to a proportional increase in electricity demand. It is estimated that by 2020, demand will be about 27,120,000MWh, an increase of 52.5% over consumption in 2008.

Motivation for the use of solar energy

Solar conditions in northern Chile

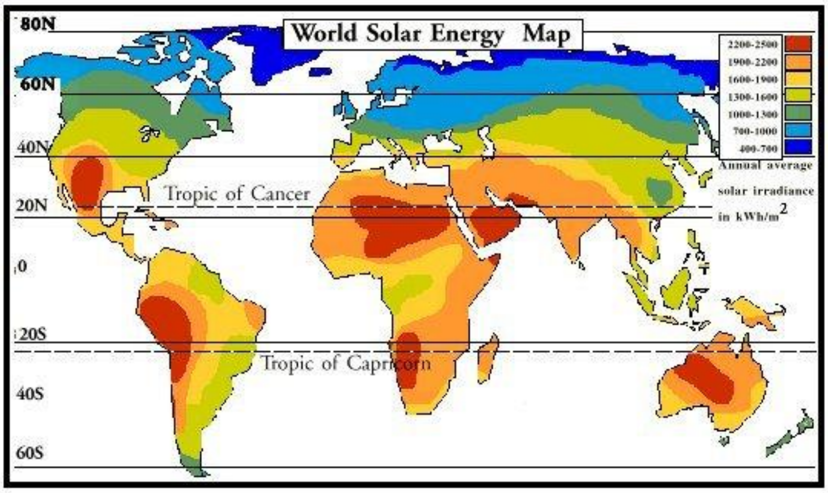
The key factor in solar technology is a high solar irradiation (incident power at a given time per unit area). In the case of thermal power stations with solar concentrators, which also require high direct solar radiation, the presence of clear skies for most of the year is essential. Parts of Chile have optimal conditions for the installation of solar power – both solar thermal and large photovoltaic plants. Solar irradiation in the Atacama Desert is around 2,900kWh/m^2, compared to 2,700kWh/m^2 in the Mojave Desert in the USA and the Sahara Desert in Africa.[4]

Even more favourable, the main mining operations are located in the zones – Tarapaca and Antofogasta regions – which have these optimal levels of sunlight and incident radiation. In Calama City, for example, the annual average irradiation on the surface (horizontal) is about 64kWh/m^2 a day.[5]

Not only is the available solar resource in the northern zone of Chile more than 30% higher than in southern Europe, where there are several solar plants, but there are also optimal dry conditions, average rainfall of 15mm/y, clear skies for most of the year, a greater number of hours of sunlight, and less fluctuation in sunlight hours between summer and winter.

World Solar Energy Map

Illustrating the global solar resource available to PV applications



CRU | ANALYSIS Source: http://www.rise.org.au/info/Applic/Array/index.html

Reduction of pollutant emissions

Chile signed the Kyoto Protocol (1997) and ratified it in 2002. The protocol primarily aims to reduce emissions of greenhouse gases, and to gradually increase the use of NCRE in the energy matrix. It is an initiative to reverse climate change, caused largely by fossil fuel consumption and therefore CO_2 emissions. NCRE contributes to this goal by considerably reducing the CO_2 emissions compared to conventional energy sources.[6]

One reason why governments are pushing more strongly for the introduction of non-conventional renewable energy (NCRE) is the pollution generated in the process of energy production. Use of solar energy could reduce the emission of pollutants as follows. Each kWh produced by photovoltaic solar energy prevents the emission into the atmosphere of about 1kg CO_2/kWh generated by coal and 0.41kg CO_2/per kWh generated by natural gas. An installed capacity of 5kW can therefore avoid 1.9t/y of CO_2 emissions for each kWh generated by a natural gas combined cycle plant. A 10MW plant can avoid 6,500t/y of CO_2 emissions.[7]

Fiscal policies and government incentives

The Chilean government has made recent efforts to improve the regulatory framework of electricity markets, in order to incorporate the NCRE in the energy matrix. This started in March 2004, when Law 19940 (Ley Corta I) was enacted, changing the General Law of Electricity Services (LGSE). This new law allowed, amongst others things, access to distribution networks for power generators providing less than 9 MW. It marked a milestone, as it established for the first time in Chile a framework that gave a preference for non-conventional renewable energies. With Law 20018, enacted in May 2005 (Ley Corta II), investment in generation was encouraged by establishing a competitive bidding system to ensure a set price over a given time.

In April 2008, Law 20.257 (also called the Law on NCRE) was enacted. It amends the General Law on Electric Utilities regarding the generation of electric power with NCRE sources. The following types of energy were defined as NCRE:

- small hydro (less than 20 MW peak power); and
- projects harnessing energy from biomass, geothermal, solar and wind sources, amongst others.

The law states that from the year 2010, 5% of the energy withdrawn from electrical systems with an installed capacity exceeding 200 MW, must come from NCRE, be it from self-generated sources or contracted from external sources. The 5% level is valid for the years 2010 to 2014, before increasing by 0.5% annually from 2015 until reaching 10% in 2024.

This law was imposed on companies that withdraw electrical energy directly from grid systems for trading to distributors or end-customers. It makes no direct reference to energy generated by mining companies, however. These companies would have to sell their energy production to utility companies that buy and sell energy from the grid systems. Any utility company that exceeds the designated percentage for annual NCRE injections (self-generated or contract), may agree to transfer their surplus to another utility company, which may take place even between companies in different grid systems.

Generators that do not meet this requirement must pay a fine of about US$31/MWh for the period 2010 to 2013. The fine increases to about US$47/MWh for the period 2014 to 2020 if they fail to comply within three consecutive years.

The introduction of direct support instruments for NCRE investment projects has been less developed, although there have been some government initiatives. The introduction of Law 20365, for example, established a tax exemption in relation to solar thermal systems. This has resulted in growth of the solar thermal power industry in Chile. The surface area of panels installed has increased to about 7,000m^2 in four years. The market is divided between the residential sector: 33%, swimming pools: 20%, companies and institutions: 20%, the industrial sector: 19% and others 8%.[8]

Strategic aspects

The energy supply in Chile comes mainly from conventional coal-fired plants, combined cycle plants, diesel engines, turbines, gas/oil and large hydroelectric plants. In 2007, conventional power plants accounted for 97% of total electricity production, with the remaining 3% produced by non-conventional renewable power sources.

The SING grid supplies power to copper mines that produce 3.4Mt/y of contained copper and EW cathodes. This represents 63% of Chilean copper supply, and 21% of global supply. The grid is based predominantly on bituminous coal (50%), natural gas (30%) and diesel (20%). This situation provides a significant risk to the mining industry, not only because much of the production is based on non-renewable fuels, but also because Chile imports most of its energy (96% of coal, 98% of diesel and 75% of natural gas). The lack of autonomy leaves the country vulnerable to volatility in international markets and to supply interruptions and delays.

The SIC grid is based on hydroelectric (52.3%), thermal (46%) and wind (1.7%). It supplies power to copper mines that produce 2Mt/y contained copper and EW cathodes. This represents some 37% of 2011 Chilean supply, and 12% of global supply. A substantial amount of Chilean copper production is therefore dependent on hydroelectric power and subject to the high risk of drought.[9]

Solar energy technology

Photovoltaic solar energy

Photovoltaic (PV) cells are based on direct conversion; they convert the photon energy directly into electrical energy. The most important factor is that the area has a horizontal total incident radiation (which diffuses radiation more directly); it makes no major difference for the cell how this is received. This conversion shows efficiencies between 13% and 30% depending on the technology used. The development of this technology is advanced but still has growth potential.

Thermal solar energy

Thermal conversion, whereby solar radiation is converted into heat, can be used in a wide range of applications, from warm fluids (water, air) to power generation. The flat plate solar collectors and the compound parabolic concentrator are the most well-known and widely-used technologies for heat generation. They are able to operate from ambient temperature up to over 50°C.

In the case of power generation by concentration, the critical factor is the amount of direct radiation incident on the field concentrator, optimised when there are clear skies for most of the year. There are three basic types of conversion technologies:

- **Parabolic trough collectors**. These follow the sun in one axis (cylinder) and focus on it through their parabolic shape. They can operate from ambient temperature to 300°C. Have a high cost but high efficiency. The level of development of this technology is high, nearly reaching its potential limits. Widely-used throughout the world.
- **Central tower system**. These systems are used in the indirect generation of electricity, generating steam that drives a turbine. Can easily reach temperatures above 1,000°C. Achieve efficiencies from 30% to 35%. Today this area is under rapid development.
- **Paraboloid collectors**. These have large parabolic dishes to concentrate sunlight onto a small focus. They can work from 400º to 800°C above ambient temperature. Technology is less well-known and not developed at an industrial level. Costs are uncertain because the technology is still under development.

Accumulation solar systems

- **Photovoltaic accumulation through batteries**. The battery is a device to store electricity generated by the PV panel and then deliver it to the equipment as needed. As the energy demand cycle usually does not coincide with the availability of energy generated by the PV panel, the accumulated energy needs to be stored in batteries. One advantage of a battery is that it provides a constant voltage source between the panel and the load, and the panel operates more efficiently because it is working closer to the points of maximum power.
- **Thermal energy storage**. Thermal solar technology has a number of challenges to meet before it becomes established as a viable alternative for the industry. One is the continuity of supply. In this area, the use of molten salt for thermal energy storage represents an interesting option. The Thermal Energy Storage plant (TES-PS10), located in Seville, Spain, is leading the world in thermal accumulation, with a thermal capacity of 8.1MWh (i.e. 4 hours of accumulated energy). In simple terms, the heat transfer fluid from the parabolic trough passes through two tanks containing molten salts (a mixture of 60% sodium nitrate and 40% potassium nitrate, both sourced from Chile). This system exchanges heat through one cold salt tank and one hot salt

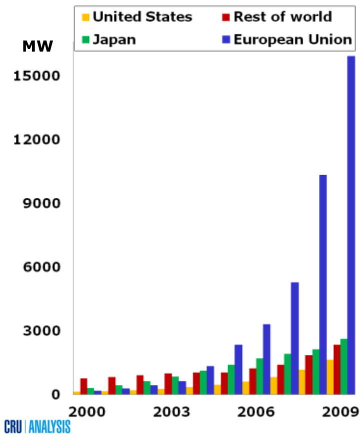
tank. The large reserves of high quality salt available in Chile, and the stability of the domestic industry, create favourable conditions for the study and development of the generation and storage of thermal energy. There are solar power plants operating today using thermal accumulation that have capacity utilisations of above 50%. The same technologies operating in northern Chile would reach capacity utilisations above 65%.

International market

In the last decade, solar energy has positioned itself as the option with the greatest development potential for power generation. Between 2000 and 2009, this market grew by 1,500%, and global installed capacity for photovoltaic energy reached 23,000MW, producing around 25TWh/y of electricity.

The common factor in the development of NRCE in the leading countries has been the implementation of market intervention measures such as price regulation of NCRE, introduction of standards, tax and credit incentives, quality labels and emission taxes, and the promotion of research and development.

Main Installed PV capacity worldwide



Country	2000 (MW)	2009 (MW)	% Change
United States	139	1650	+1087%
Rest of world	763	2347	+208%
Japan	318	2633	+728%
European Union	189	15943	+8335%
Total	1428	22878	+1502%

In Spain, for example, installed capacity rose by 560MW to 2,605MW between 2007 and 2008 due to the introduction of government legislation that lowered barriers to entry for new competitors, and today capacity is 3,523MW. Germany doubled its market share between 2008 and 2009 from 1,800MW to about 3,800 MW. By 2009, Italy had installed capacity of 711MW, the Czech Republic 411MW, Belgium 292MW and France 185MW. These countries have implemented various incentive programmes, all based on the feed-in-tariff.[10] Until 2008, China was almost absent in the global photovoltaic market, but in 2009 it approved large scale projects for about 12GW.

In 2009, solar collectors with a capacity of 22.13M thermal kW and covering an area of 3,160 hectares (ha) were installed for heat generation. The countries with the largest numbers installed were Germany with 1,270ha, Greece 400ha, Austria 350ha, Italy 200ha, France 195ha and Spain 180ha.[11]

Considering the concentration of solar thermal plants, only Spain has ten installed, with 382MW capacity. It has 18 plants under construction which will add more than 1,757MW and has announced the construction of an additional 20 plants with an installed capacity of 1,080MW.

Regarding large capacity plants, the USA is building the world's largest solar plant, called Solana, in Phoenix, Arizona. The plant will generate 250MW using parabolic trough technology and will be capable of storing the energy generated via molten salt thermal storage. It will also avoid emissions of 475,000t/y of carbon dioxide compared to a natural gas-burning power plant. Assuming the plant operates at a capacity utilisation of only 50%, it would generate 1,095,000MWh/y power.

Chile currently has no participation in solar energy

Currently, Chile has practically no participation in the worldwide solar energy market. There is, however, particular interest from the mining industry in the evaluation of this alternative renewable energy source. The mining company Dona Ines de Collahuasi, in conjunction with the University of Chile, has implemented the first isolated microgrid power generation scheme, which supplies the village of Huatacondo. Codelco is also planning the construction of a 1MW PV plant to generate electricity in mining camps, which will begin operating in November 2011. Two projects have also been approved by the Environmental Impact Assessment System (SEIA) for the construction of PV plants in northern Chile: Calama PV Solar Plant 1 and 2, both in Atacama region, with a capacity of 40MW each and with a total joint investment of US$80M.

Feasibility of solar energy

Technical feasibility

- **Power consumption**. The power consumption of an average copper mine producing 180,000t/y of copper, is about 450GWh/y. In the case of a copper concentrates (sulphide) mine without smelting and electrorefining processes, it is about 320GWh/y. Considering the solar power projects previously discussed, generation of this amount of energy is feasible using solar power technology. A few years ago, Germany developed installed solar power capacity similar in size to the SING grid, using PV technology.
- **Maturity of technology**. This factor is key to ensuring the reliability of supply, and is determined by the number of existing projects, their installed capacity and the period of commercial operation of each technology (lifetime). Different technologies for solar power generation have different degrees of maturity. The parabolic trough technology has a high level of development and some plants have been operating for over 25 years. The PV technology has the widest global presence and has proven to be a reliable and secure technology; it is also constantly being improved due to various investigations to develop new materials and improve the efficiency of the cells. The other solar technologies have a few hundred MW capacity and a low degree of maturity. It is important to say, however, that international development and global installed capacity do not guarantee the technical feasibility for conditions in northern Chile, and these have to be evaluated in each case.
- **Requirements to enter the electric grid system**. A solar power generation system that does not accumulate energy is inherently non-uniform; it only generates energy during the day and is less efficient on cloudy days. This feature should be considered in cases of delivering energy directly to a mining operation, or injecting power into the grid system. Stable consumption of electricity provided by the grid (SING or SIC) must be maintained in order to avoid any destabilisation of the system. To avoid destabilisation, the General Law of Electricity Services (LGSE), through the Technical Standard of Security and Quality of Service (NTSCS) requires all mining operations (due to their high level of consumption) to comply with standards and requirements ensuring there are no frequency or voltage changes in the system.[12] In addition, to ensure the operational safety of the overall electrical system, the operation of any individual system and its consumption should be coordinated with the Centre for Economic Load Dispatch (CDEC).[13] As a result, it is important to consider accumulation in the design of a solar power generation system. Currently the maximum storage time for the most advanced technology (CSP) is 12 hours.
- **Environmental impact**. In Chile, the main tool to prevent damage to the environment is the Environmental Impact Assessment System (SEIA), created under Law 19,300 and its Regulations. Similar to any other energy project, a solar power plant with capacity greater than

3MW should be evaluated for potential environmental impacts, in terms of the quantity and quality of renewable natural resources that could have an impact.[14]

- **Greenhouse gas emissions**. In Chile, there is no legal framework for carbon dioxide emitters to take responsibility for their emissions. Nevertheless, the environmental impact of a solar generating plant, compared with traditional power plants, is low. For instance, a coal thermal power plant emits approximately 6,500t/y CO_2 per MW of installed capacity.
- **Light pollution**. The skies of northern Chile are recognised as the purest and most transparent in the world. These allow perfect astronomical observation, with about 340 nights a year of clear skies. The mirror reflection coefficients of solar plants are extremely high, and light pollution could be caused at night if artificial light was shed on the skies. This component should be analysed in the evaluation of a solar project.[15]
- **The landscape.** Impact on the landscape is a key aspect for solar plants, especially if the solar fields are installed away from the cities and in places of natural special value. PV panels are difficult to integrate into an environment without having an impact. The light reflections of these structures also make them visible from great distances. In the case of concentration technology, about 1 to 9 hectares are required for each MW installed power rating.[16]
- **Flora and fauna.** A study must be conducted to assess the use of land for energy production in order to avoid locating the solar installations in areas of interest. A preliminary study of the flora and fauna of the chosen site and the alternatives under consideration is essential, as the presence of endemic and endangered species is a limiting factor for the construction of solar plants. Northern Chile, due to its climate, does not have an abundance of flora. The unique characteristics of the soils, however, do give rise to several species that deserve to be preserved in their natural environment.
- **Land availability**. This is an important factor when selecting the location for the installation of a plant, because a solar plant requires a large area in proportion to its installed capacity. Land is scarce and mining companies are constantly looking for new deposits.
- **Water availability**. The northern region of Chile is extremely arid and both surface water and groundwater supplies are scarce. As a result, water is a strategic resource and has a high cost. It should be ensured that the availability of the water resource is sufficient and is managed as efficiently as possible. Thermal solar power plants generally require a constant supply of fresh water for the condensing tower and for cooling. Dry cooling towers or hybrids have been developed, which require less water, but they may have higher capital costs and lower efficiency. An alternative is to evaluate the use of sea water. In the mining industry, Antofagasta Minerals' new Esperanza mine, located in the Atacama Desert 180 km from Antofagasta, uses sea water pumped 145km from the coast to the mine-site via a pipeline.
- **Human capital**. Currently the development of human capital is one of the most important challenges for Chile and its copper mining industry. The case of solar technology is no exception, because both technical and professional expertise in the solar area are virtually nil.[17]
- **Sociocultural aspects**. The lack of information about the consequences of the pollution levels generated by conventional energy sources that currently make up the Chilean energy sector, and the need for security and autonomy, increase the uncertainty of NCRE projects. Chile does not have a research and development culture, or at least not at the level seen in developed countries, which hampers investment in new technologies and adoption of new power generation alternatives. The reluctance to change, in particular to accept innovative solutions, also makes it difficult to implement substantial improvements in energy issues.
- **Cultural heritage and community impact**. Important archaeological discoveries of pre-Columbian cultures have been made in northern Chile. Depending on the location of the solar plant, a study would be needed to ensure that these discoveries are not likely to be affected. It is

also important to consider the potential conflict over land use due to the existence of protected populations in the areas to be occupied.

Economic feasibility

- **Carbon bonds benefits**. Chile as a signatory to the Kyoto Protocol can access the Clean Development Mechanism (CDM), which is an instrument that allows developing countries access to clean technology transfer in order to mitigate and adapt to climate change. Chilean companies can trade Certified Emission Reductions (CERs), which represent some decrease in emissions in Chile. A CDM project could therefore be financed through the sale of carbon credits, if otherwise the project would not be profitable for the company, or if the project risk was too high, for example by using existing conventional technologies.[18]
- **Investment required**. Solar power technologies require higher capital investment per unit of installed capacity compared to conventional technologies. This is mainly due to the implementation costs, which will be reduced when the adoption of the technology increases, and also to the higher cost associated with a higher risk because of the lack of specific experience.[19] Aiming to recover the investment and generate profit in the short term could reduce the chances of developing projects that require a higher initial investment. On the other hand, there are significant benefits from use of NCRE for society as a whole, and including these benefits in the economic feasibility analysis would be a motivation to invest in these technologies. Other aspects that have to be included in the feasibility analysis, and which could make the projects viable, are the carbon credits mentioned above, and the impact of possible fines imposed if the generating companies do not inject enough NCRE into the system. This “cost” would be passed on and paid for by the customer, in this case the copper mining companies.

Conclusion

With the technologies currently available and growing successful international experience, it is feasible to develop large scale solar power plants that could have a significant impact on the supply of energy to copper mining companies. Construction of solar power plants would not only expand and diversify the supply of energy to meet growing demand, but also would have an important impact on reducing the carbon footprint associated with mining and processing of copper.

In order to apply this international experience to the copper mining industry, the specific factors associated with each case must be evaluated. Given the high standards and requirements of the mining sector, a secure energy supply must be ensured, with no possibility of failure. A sensible strategy therefore would be to develop the use of solar power gradually, starting with pilot plants, to ensure the success of future large scale projects.

Regarding economic feasibility, a key factor to be considered in the analysis is the cost of penalty fines which may be applied if the generators do not meet legal requirements. In future such costs would be transferred to copper mining companies, which are the main direct customers negotiating energy prices with the utility companies.

Any project must also take trade in carbon credits into account in the feasibility analysis, which in this case could have a significant impact on future cash flows of the project, thereby directly influencing potential feasibility.

From a government viewpoint, the social impact of NCRE projects should be considered, not only in terms of the direct benefit of diversification of the Chilean power industry, but also in terms of the advantages to be gained from the use of clean and renewable energy sources. The government should also consider the impact this would have in reducing the country’s reliance on coal and other conventional fuel imports.

The main challenges to be overcome to enable the development of large scale solar technology are the development of both the human capital needed for implementation and operation, and of storage system technologies. This will enable the production of both more energy and a more uniform energy supply, which would considerably enhance the efficiency of solar power systems.

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Overview of port infrastructure for the copper mining industry in Chile

Introduction

Chile is a long and narrow country, with over 4,000km of coastline from north to south on the edge of the Pacific Ocean. The country is, however, only 200km wide. This geography provides a good scenario for international maritime trade. According to the Chilean Maritime and Port Chamber, growth in maritime international trade was almost 50% between 1999 and 2009.

For the Chilean copper industry, maritime transportation is fundamental, as the large quantities of materials produced can only be transported by sea. Chile's total copper production, both concentrates and cathodes, is around 5.4Mt/y. Of this total, 2.1Mt/y is in the form of copper cathodes, which are mostly exported. The balance of 3.3Mt/y is copper contained in copper concentrates, which are also exported. Different types of ships are used to handle these two types of material. Container vessels are used to transport copper cathodes, while concentrates are transported in bulk carriers. As a result, the port facilities handling these two types of vessels and materials are very different.

Over the past three decades, port facilities have been growing in line with growth in the copper mining industry. Given the country's unique geography, port facilities are generally located near to mining operations, increasing the competitiveness of the Chilean mining industry. This article, however, shows that maritime conditions for the construction of new port facilities are limited.

Several expansions and new projects are currently in the pipeline for the copper mining industry. The Escondida V Expansion and Esperanza project, to name a couple, will each require maritime transportation facilities. The recent accident suffered at the Collahuasi mine port (Puerto Patache) has highlighted the issue of whether port capacity and infrastructure will be sufficient to cope with the expected increase in copper mine production.

This article provides an overview of the port situation for the copper mining industry in Chile and provides guidelines for future developments in the sector.

Port facilities in Chile

Until the 1990s, Chilean ports were state-owned and operated through a company called Empresa Portuaria de Chile (Emporchi according to its Spanish acronym). Emporchi's function was to administer the ten public ports in operation at that time. In 1997, the government launched a new law (19.542) called "Modernization of the State-Owned Port Sector". It reorganised the port system and converted the ten state-owned port companies into independent companies. This allowed the private sector to start investing in ports through concessions, which means that although public ports are state-owned, they are privately operated. Following this development, public ports in Chile have shown significant improvements in terms of efficiency. They have decreased their tariffs, which has contributed to Chile's competitiveness in international trade.

Chile's port system comprises 33 ports divided into three categories:

- state-owned (with private concessions)
- ports open for public service (with private administration)
- privately-owned

Of the public ports, Valparaiso and San Antonio Ports, both located in the central part of Chile, are the most important and handle over 70% of Chile's imports and exports. In terms of the copper mining industry, Antofagasta Port, located in the northern part of Chile, is very important. This port is operated by the state-owned autonomous company, Empresa Portuaria Antofagasta and handles cargo such as copper concentrate and cathode, zinc concentrate and non metallic products, among others. In 2010, Antofagasta Port handled almost 1Mt of copper concentrates and cathodes exports.

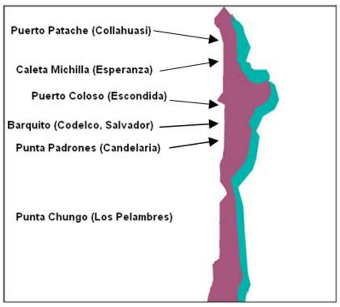
Mejillones Port is another important port for the copper mining industry. It was built to support Antofagasta Port and is located 65km north of Antofagasta. Mejillones Port is dedicated to the mining industry and handled some 1.3Mt of copper cathode exports in 2010.

The non privately-owned ports are important providers of port facilities and services to both major and small miners. All miners export copper cathodes through these ports. The majority of copper concentrates, however, are shipped from private ports, with only small quantities shipped from non privately-owned ports. Antofagasta Port is a public port handling different types of cargo. It has facilities to ship copper concentrates and even has a special temporary warehouse for this purpose. It also has conveyor belts to load concentrates in a clean and environmentally-friendly manner. Mejillones Port is mainly oriented to copper cathodes and most of the region's cathode exports are handled by this port.

The non privately-owned ports contribute to the flexibility of the industry, which can be seen by the support Antofagasta Port has provided to Collahuasi in recent months. This mining operation suffered an accident in its Puerto Patache port facilities at the end of last year and has not been able to ship materials through its port since then. Collahuasi is currently repairing the damage but in the meantime, it has had to turn to other alternatives and Antofagasta Port has been able to assist.

Two maps are presented below: the map on the left indicates the privately-owned mining ports and the one on the right shows all the public use ports. Ports used by copper mining operations are highlighted in red.

Chilean private and public ports



Private ports owned by mining companies

Public ports

Source: Sistema Portuario de Chile 2005, Direccion de Obras Portuarias, Gobierno de Chile

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Ports used for copper cathodes

Copper cathodes can be shipped from any public port that has handling facilities for different types of cargo. Cathodes are transported in containers, which makes them more flexible in terms of port facilities. Public ports handling copper products in Chile have multi-type cargo facilities. As a result, a mine that produces both copper concentrate and cathode will ship its materials from two different ports. The chart above shows Escondida ships its copper concentrates from Puerto Coloso and its copper cathodes from Antofagasta Port.

Ports used for copper concentrates

Major mining companies usually prefer to build their own ports to handle copper concentrates. This has the advantages that they have priority in shipping their materials, better freight tariffs and storage facilities for copper concentrate located near the port area. Some mining companies transport concentrate slurry to the port and operate dewatering and filtering plants at the port.

These ports are built by private engineering companies but are owned and operated by the mining companies. Mining ports are built to high quality standards in order to meet internal regulations and environmental regulations.

The main privately-owned ports handling copper concentrates in Chile belong to:

Escondida	Puerto Coloso
Collahuasi	Puerto Patache
Candelaria	Punta Padrones
Los Pelambres	Punta Chungo

All these ports have state-of-the-art technology and comply with both national and company regulations. Most recently, operations have begun at the new Esperanza mining project, which included the building and use of a private port located in Caleta Michilla. This port will only be used to ship copper concentrates.

The size of vessels used by ports handling copper concentrate varies in terms of draft and length, depending on the port's capacity. The usual capacity of the vessels is around 40,000dwt to 50,000dwt. According to published information on export statistics, average monthly capacity of these ports in 2010 was 100,000t of copper concentrate. The number of vessels loading material depends on the mine's capacity, but is usually four to five vessels a month.

The following charts indicate the ports that transport copper cathodes and copper concentrate.

Copper cathodes

Company	Port Used	Port Ownership Type	Quantity handled (tonnes) 2009	2010
Codelco	Valparaiso/ Antofagasta	State owned/State owned	1,487,097	1,484,214
Escondida	Antofagasta	State owned	304,431	289,389
Enami	Valparaiso/San Antonio	State owned	183,852	161,302
Spence	Antofagasta/ Mejillones	State owned/Private open for public	162,498	168,532
El Abra	Antofagasta	State owned	157,398	151,290
El Indio	Antofagasta	State owned	142,590	145,602
Mantos Blancos	Antofagasta/ Iquique	State owned/State owned	116,291	116,290
Cerro Colorado	Antofagasta/ Iquique	State owned/State owned	92,605	87,783
Quebrada Blanca	Iquique	State owned	87,953	86,430
El Tesoro	Antofagasta	State owned	84,712	97,970

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Copper concentrates

Name	Port Used	Port Ownership Type	Quantity handled (tonnes)	
			2009	2010
Escondida	Puerto Coloso	Privately owned	2,163,576	2,029,498
Collahuasi	Puerto Patache	Privately owned	1,311,905	1,244,237
Los Pelambres	Punta Chungo	Privately owned	1,065,395	1,230,226
Candelaria	Punta Padrones	Privately owned	390,463	440,937
Codelco	Ventanas	Private open for public	547,990	433,609
Mantos Blancos	Antofagasta/ Mejillones	State owned/Private open for public	114,450	319,509
Cormin	Antofagasta/ Ventanas	State owned/Private (open for public)	85,820	140,206
Anglo American	Ventanas	Private (open for public)	230,638	131,374
Andacollo	Coquimbo	State owned	-	120,286
Minerales del Sur	Ventanas	Private open for public	-	48,610

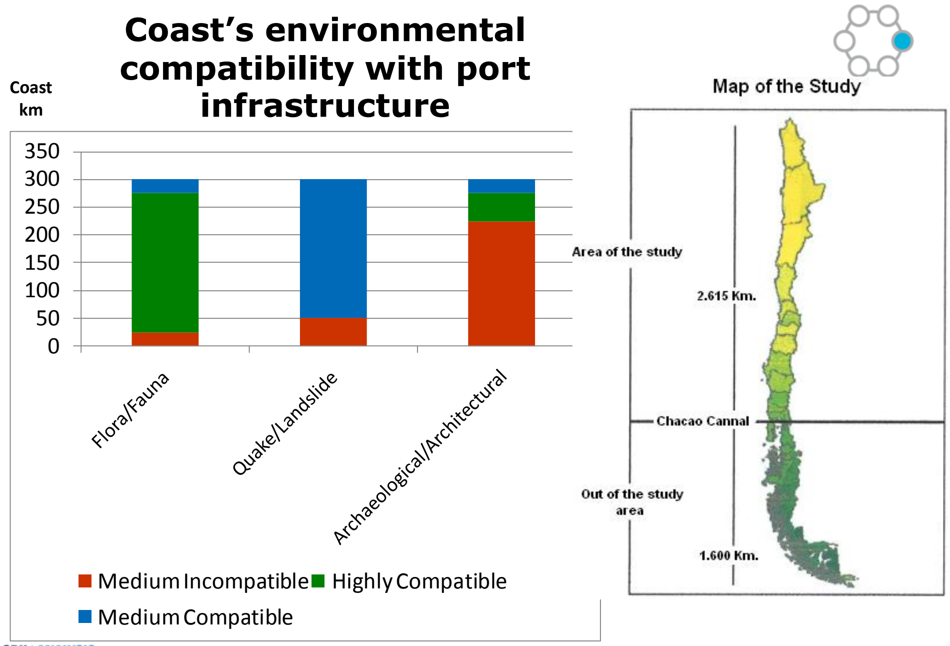
CRU | ANALYSIS Source: www.bbs.cl

Not so easy to build new ports

Several factors need to be considered for the construction of new ports. As contrary as it may seem, Chile, with its long coastline, does not have many available and suitable locations with the natural conditions necessary to accommodate ports. The construction and operation of a new port in Chile requires the presence of calm, sheltered water conditions, which can usually only be found in naturally protected bays, canals and fjord areas. If no natural sheltered areas are available, they have to be produced artificially, which entails higher capital costs. In addition, most of the suitable areas for the building of ports are already occupied by other ports and also by cities and towns, which provides a challenge for new projects.

According to a study conducted by the Chilean government in 1998, Chile has 4,000km of coastline. Of this, 1,600km can be discounted because of the complex landscapes in the more southern regions and also the small population inhabiting those areas. Out of the remaining 2,400km of coastline, 226km (12 bays) have the minimum natural conditions needed to accommodate ports. Of this, 82km of coastline could be used to build container cargo ports but only 22km could be used for non-container cargo ports (i.e. ports for copper concentrate). This study only evaluated bays with very sheltered natural conditions, however. It ruled out many locations not in sheltered areas but which would nevertheless be suitable for the building of ports. There are therefore more than 226km of coastline that could be potentially used for port facilities. New ports have already been built in areas not included in the government study – Punta Chungo (Minera Los Pelambres) and the recently-completed Caleta Michilla (Esperanza). The location for the construction of new ports can therefore be flexible as long as projects are evaluated on a case-by-case basis, taking factors such as environmental regulations, maritime concessions and the existence of sheltered areas, into account when conducting a project's economic evaluation.

From an environmental viewpoint, no area of the above-mentioned coastline is completely incompatible with the construction of new ports, although some areas are more compatible than others. The chart below illustrates the compatibility of the area studied by the government.



CRU | ANALYSIS **Source:** Analisis y Definicion de Areas Costeras Reservadas para Uso Portuario, Mideplan, 1998

The regulation of ports in Chile is organised on a geographical basis. Some regions are developing port regulations, others are still at the drafting stage, while there are some areas that have no regulations whatsoever. New port projects have to comply with the regulations, which are often very complex.

The cost of building a new port will vary from one case to another. As an example, the initial investment can start at US$50 million and the additional operational costs can be some US$5 million. The construction of this project would take around 50 months.

It is worth mentioning that some mining companies in Argentina export their materials through Chilean ports. The main reason is that for projects located near the Andes Mountain Range, the Chilean Pacific Coast is closer than the Argentinean Atlantic Coast.

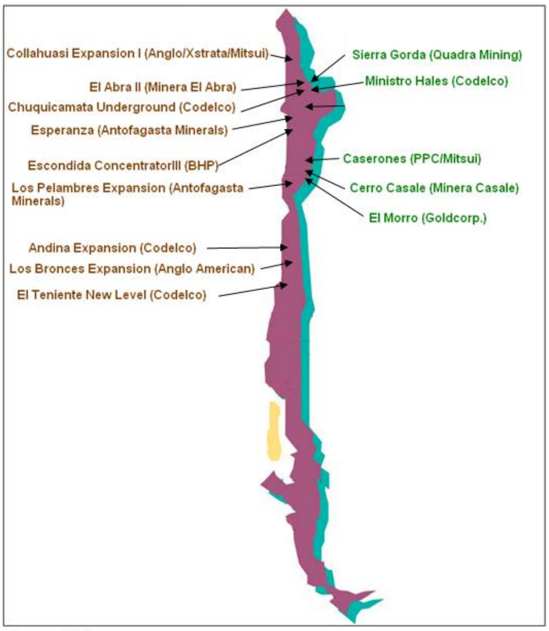
Mine expansions and projects

According to CRU's summary of copper projects, brownfield and greenfield projects planned to go on-stream in Chile in the next ten years have the potential to raise copper production by around 4.3Mt/y. A major limitation for bringing these projects to commercial production is the lack of infrastructure, and port capacity is increasingly becoming a more important issue.

As explained above, private ports are only used to move copper concentrate, while copper cathodes are transported through public ports. As mining port infrastructure grows in line with the mining industry, it can be presumed that copper concentrate ports will undergo expansion or modification to cope with the increase in copper capacity in the coming years. This will require more investment and higher capital costs.

The public ports that are oriented to the mining industry, mainly Antofagasta Port, will also require further expansion and refurbishment, in addition to support from Mejillones Port. These ports in particular are very important to the mining industry because of their location close to most of the large mining operations, such as Escondida and Codelco Norte, thus enhancing both copper concentrate and copper cathode operations by junior and major mining companies.

In order to identify the copper projects that will require mining port infrastructure in the future, the projects have been divided into four categories: brownfield copper cathode and concentrate projects and greenfield copper cathode and concentrate projects.



Map of brownfield/ greenfield projects over next 10 years

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Source: CRU Analysis

Mining companies whose main product is copper concentrate are more vulnerable to a shortfall in port infrastructure since these operations use/need a privately-owned port with specific logistics and facilities to handle concentrates.

In the case of **brownfield** projects, investment is often aimed at extending the life of the mine through upgrading existing equipment. This is the case in the Escondida Phase V project where the current concentrator plant will be replaced by a new one that will enable it to continue operations. This type of investment usually does not require large modifications to existing port facilities, instead equipment changes are needed. Reflecting the growth of Escondida, Coloso Port will also undergo modernisation, with the installation of new equipment at its port facilities. On the other hand, brownfield projects aimed at expanding capacity, such as the Collahuasi expansion, will probably need a matching expansion of port facilities.

In the case of **greenfield** copper concentrate projects, especially large-scale ones, construction of a port facility is frequently undertaken. It is indicated above that all the large copper concentrate mining operations have their own port facilities, including Esperanza, the latest project to come on-stream. This is not always the case for medium/small mines, however, with the decision depending on the company's comparison between capital costs and operating costs. Lumina Copper, for example, will not build a private port for its Caserones operation. It will transport all its products – copper concentrate, copper cathodes and molybdenum concentrate – by truck to the nearest port, probably Antofagasta or Mejillones given the location of the project. This is not the only copper concentrate project/operation to follow this strategy for transport and shipping of materials produced.

There are several factors to consider when analysing infrastructure requirements for a new project. For instance, in the long term it may be more economical to build a pipeline to transport copper concentrate to the port facilities rather than transporting the materials by truck, although initial costs are higher and it increases the initial investment in the project. Building a new port also increases the initial investment in a mine project. On the other hand, transporting materials by truck has more risks of road accidents and can be an issue with the local communities through which the material would have to travel. The cost of using a public port or another company's port facilities seems to be a cheaper and easier option than the company having its own facilities. This aspect of a project will depend on each company's strategy and will be studied on a case-by-case basis.

Considering public ports, in the case of Antofagasta Port, the port serves different purposes by being a multi-type cargo port and also a public port. As a result, it often undergoes capacity expansions, given its location near to most of the large mining operations. Investment has been made in increasing equipment capacity and in new facilities, and recently, a set of cranes has been acquired which will increase loading speed and thus capacity. In addition, Mejillones Port serves as support to Antofagasta Port.

Copper greenfield projects

Name	Owner/Operator	Type	Production Capacity (000 t/y)	Materials Contained
Sierra Gorda	Quadra Mining	Concs	139	Cu, Mo, Au
Ministro Hales	Codelco	Concs	170	Cu , Mo, Ag
Caserones	PPC/Mitsui	Conc	150	Cu, Mo
Caserones	PPC/Mitsui	SXEW	30	Cu
Cerro Casale	Minera Casale	Concs	102	Au, Cu, Ag
El Morro	Goldcorp	Concs	150	Cu, Au

Source: www.bbs.cl

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Copper brownfield projects

Name	Owner/Operator	Type	Production Capacity (000 t/y)	Materials Contained
Collahuasi Expansion	Anglo/Xstrata/ Mitsui	Concs	320	Cu, Mo
El Abra	Minera El Abra	SXEW	160	Cu
Chuquicamata Underground	Codelco	Concs	340	Cu, Mo
Esperanza	Antofagasta Minerals	Concs	191	Cu, Au, Mo, Ag
Escondida Concentrator	BHP Billiton	Concs	300	Cu
Los Pelambres Expansion	Antofagasta Minerals	Concs	90	Cu, Mo
Andina Expansion	Codelco	Concs	393	Cu, Mo
Los Bronces Expansion	Anglo American	Concs	173	Cu, Mo
El Teniente New Level	Codelco	Concs	430	Cu, Mo

CRU | ANALYSIS Source: www.bbs.cl

An example of an expansion of a privately-owned port is Ventanas Port. In a joint venture with the Los Bronces operation; a new storage shed will be built next to the existing one with capacity of 60,000dmt of copper concentrates. This will triple Anglo American's current capacity at the port. This initiative was taken in line with Los Bronces' expansion project that will need more capacity at the port facilities. The increase in port storage capacity will be able to cope with the rise in production at Los Bronces from the current 600,000t/y of copper concentrates to over 1Mt/y, which is expected to start-up in the fourth quarter of 2011. Another example in the privately-owned ports sector is Escondida, which will need to expand its port facilities (Puerto Coloso) by installing new radial loaders to accommodate the expansion which is expected to come on-stream in 2015.

The port facilities required also depend on the quality and type of copper products produced as some mines have different treatment processes for their copper concentrates. As a result, some materials require further treatment in the final stage of the production chain which is often carried out at the port. The new Esperanza mine, for example, uses seawater in its processes which necessitates washing the concentrate at the port to remove the seawater. Another example is Collahuasi, which transports bulk copper-molybdenum concentrate from the mine-site to the port. A molybdenum plant at the port recovers copper and molybdenum concentrates, which are also filtered and dried at the port prior to shipment. Finally, all copper concentrate mining ports require storage facilities.

Conclusion

This article has shown that despite the challenges posed by the current port infrastructure and lack of suitable coastal areas to build new ports, the mining industry in Chile has managed to build and maintain port facilities to support its operations. All the indications are that it will be able to continue to provide sufficient port facilities to match the needs of future projects with the help and support of both governmental and private institutions.

This article has highlighted, however, that the issue of port infrastructure is not to be considered lightly and it will have to be taken more into account in order to ensure that port capacity is able to cope with copper concentrate and cathode exports in future. Port facilities are a strategic part of a mining operation. Considering the large tonnages of capacity coming on-stream, port infrastructure, both public and private, is expected to continue to grow in line with the industry. Port facilities for each project will, however, have to be studied and evaluated in more detail as building a new port or expanding an existing one is not as easy a matter as one might have been expected to be.

Author: *This article was written by* ***Andrea Francisca Zambrano Mora****, a CRU-sponsored CESCO scholar. Andrea studied English-Spanish translation at Universidad Tecnologica de Chile and holds a Diploma on Negotiation and Foreign affairs from Universidad de Chile. She has been working in the mining industry since 2007 as a commercial assistant for Mitsui Chile.*

Information used in this article comes from public sources. The opinions expressed are the sole responsibility of the author and do not represent those of Mitsui, CRU or CESCO.

Junior mining companies in Peru – Source of new mining developments and indicator for mining resource valuation

Introduction

Peru is the world's second-largest copper producer and one of the countries expected to contribute the most to future growth in copper supply, driven by both greenfield and brownfield projects. Today, Peru produces 1.2Mt/y of copper and production is expected to reach levels of over 3.5Mt/y in the second half of this decade.

In this context, exploration plays an essential role and most exploration activity in Peru and Latin America is carried out by junior mining companies. Peruvian exploration accounts for 20-25% of exploration expenditure in Latin America, and together with Mexico, it is the main exploration destination in the region. Junior mining companies are focused on the exploration and development of mining properties (scope, prefeasibility and feasibility studies) in order to reduce risks and later sell these projects to a major mining company (a larger company with greater access to financial resources). This pattern is typical of junior mining companies engaged in copper projects, given that such investments usually amount to hundreds or thousands of million dollars. At present, open pit copper projects require a capital expenditure of around US$12,340/t/y Cu, on a worldwide basis.

Junior mining companies play an important role as they explore and provide projects for major mining companies. Junior mining activity is therefore expected to increase copper supply in Peru and Latin America.

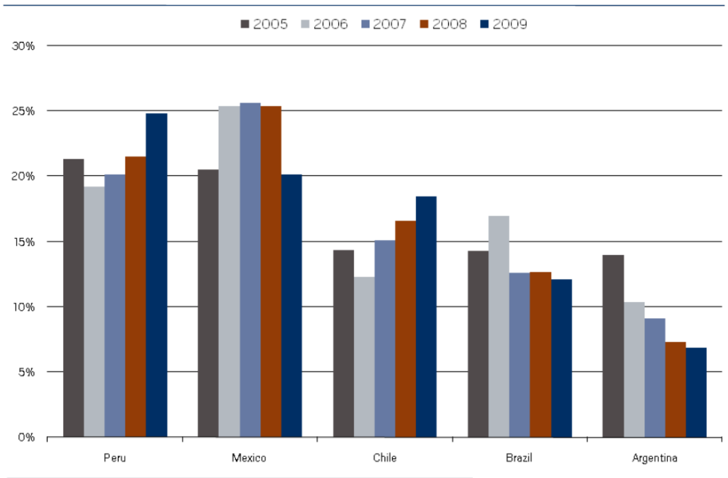
In addition, the valuation of junior mining companies indirectly provides an indicator of the value assigned by the market to in situ mining resources. Firstly, many junior mining companies sell their projects to major mining companies, thus providing a indicator of the value of mining resources. Secondly, most exploration companies are financed by resources obtained from stock markets (IPOs and successive capital increases), and their market capitalisation is therefore a reflection of what investors are willing to pay for mining resources at a certain level of development.

Junior mining companies and new mining developments

A large number of mining projects in Peru and Latin America are being, or have been, developed by junior mining companies at some stage. A prime example of this was the discovery of Escondida copper mine in the north of Chile in 1981 by Minera Utah de Chile and Getty Mining, two companies that later transferred the mine to the current owners, including BHP Billiton (57.5%) and Rio Tinto (30%). Escondida started operations in 1991, ten years after its discovery, and in 2010 produced approximately 1.1Mt of copper-in-concentrates and copper cathode.

Over the next ten years, Peruvian copper production is expected to increase from a current 1.2Mt/y to 3.5-3.9Mt/y by 2020, similar to growth in Chilean production during the 1990s. In Chile, copper output grew from 1.6Mt to 4.6Mt between 1990 and 2000.

Exploration expenditure in Latin America by country, 2005-2009



Source: Metals Economic Group

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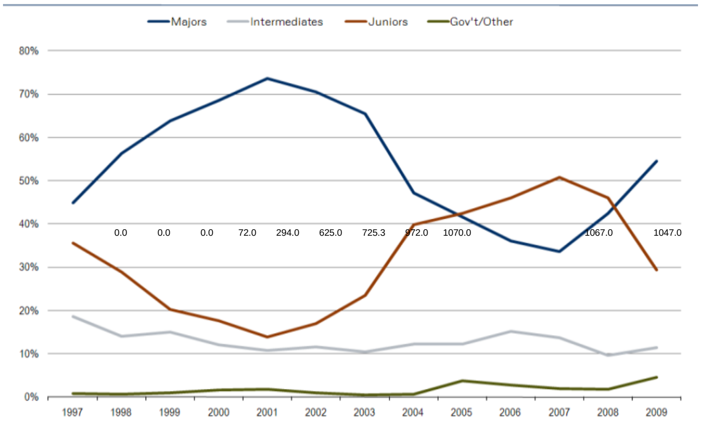
Exploration expenditure in Latin America by type of company, 1997-2009



In 2009, junior exploration fell in response to a lack of funds during the financial crisis. In 2010 junior exploration was expected to have recovered.
Source: Metals Economic Group

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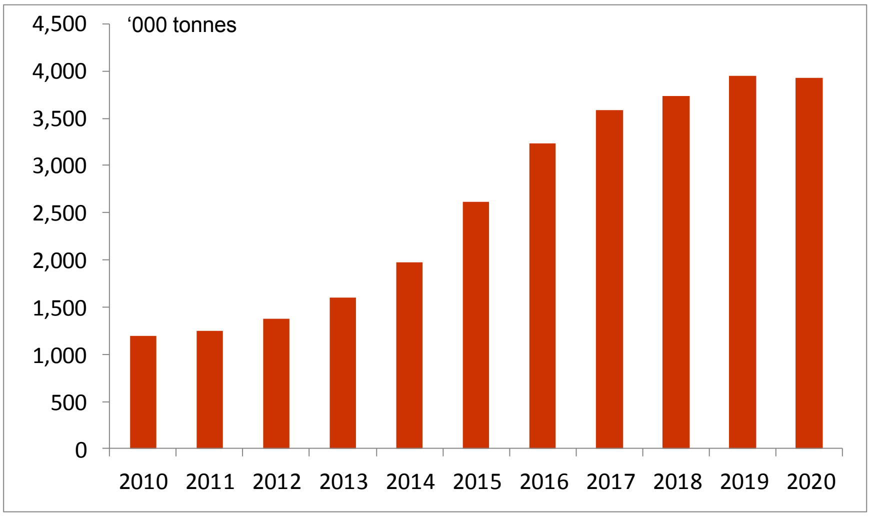
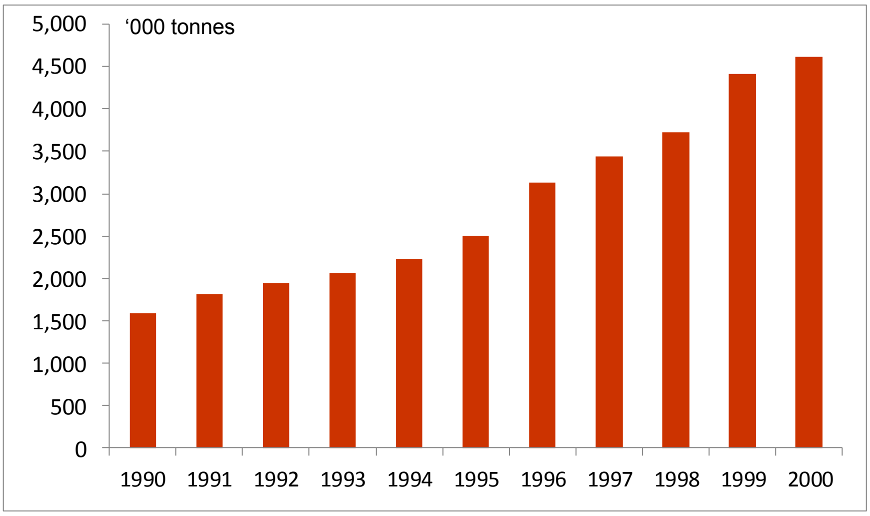
Forecast Peruvian copper production, 2010-2020 (‘000 tonnes)



Source: CRU and mining companies

Chilean copper production, 1990-2000 (‘000 tonnes)



Source: CRU and mining companies

An important part of the growth in Peru’s copper supply between 2011 and 2020 will come from projects that were developed at an early stage by junior mining companies. The first projects acquired by major mining companies from junior companies were Toromocho, El Galeno and Mina Justa.

Toromocho was acquired by the Chinese company Chinalco from junior mining company Peru Copper for US$860M in 2007, and the project has mining resources of 1.98Bt grading 0.62% Cu equivalent (27Blb Cu). At present the project has approved environmental permits and Chinalco expects to start construction during the first half of 2011. The estimated capital investment for the project is US$2.2B.

El Galeno was acquired by a Chinese consortium (China Minmetals and Jiangxi Copper) in December 2007 from junior company Northern Copper Mining for about US$455M. El Galeno, located in Cajamarca region, has indicated resources of 1.03Bt grading 0.58% Cu and the estimated capital investment for the project is US$2B. The project is currently at the feasibility study stage. Both Toromocho and El Galeno are expected to produce around 200,000t/y of copper – Toromocho 250,000t/y and El Galeno 200,000t/y in the first five years.

Mina Justa, the smallest project (114,000t/y combined copper concentrates and copper cathode), was acquired in March 2010 from junior mining company Chariot Resources by Chinese company CST Mining Group for US$250M.

These three projects are expected to start operations between 2013 and 2015. By 2015, they are estimated to account for about 24% of Peru's copper production, which is forecast to reach 2.5Mt. Towards 2020, with the start-up of projects such as Constancia, Cañariaco, Haquira and Zafranal, the share of total production held by projects initially developed by junior mining companies may reach 27%, out of total Peruvian production of around 3.9Mt.

It should be noted that in some cases, a partnership with a local company would be useful in the development of a project. The Constancia project, for example, was recently acquired by Canadian miner HudBay Minerals, and a partnership between HudBay and a local mining company could be important for the progress of the project, considering the skills of local companies in terms of access to human resources and knowledge of regulations, among other issues.

Growth in Peruvian copper production will also be driven by greenfield projects developed by major companies with no junior involvement (Tia Maria and Las Bambas among others), and by some brownfield projects (expansions such as those at Cerro Verde and Toquepala).

Peruvian greenfield projects, 2011-2020

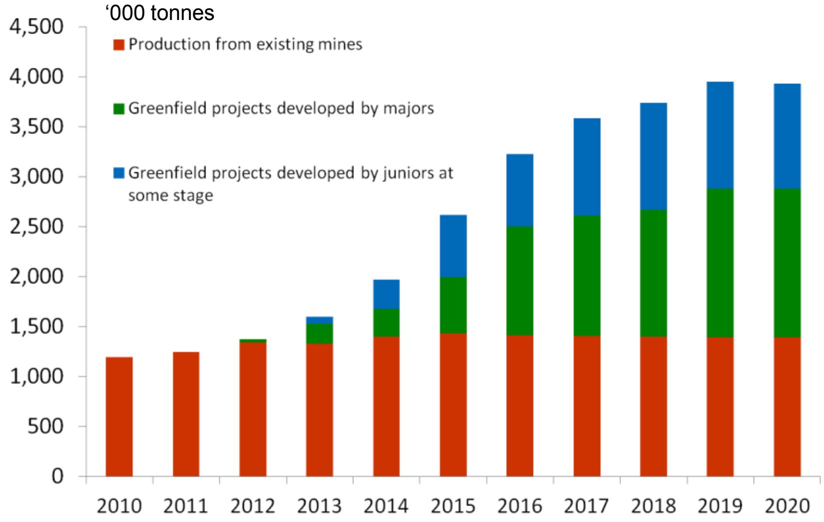
Company	Project	Stage	Capex (US$M)	Annual Cu Prod. ('000 tonnes)	Start-up year
Projects developed by juniors at some stage					
Chinalco	Toromocho	Approved EIA	2200	250	2013
CST Mining	Mina Justa	Approved EIA	745	114	2014
HudBay	Constancia	Approved EIA	850	102 (first five years)	2014-2015
Minmetals/Jiangxi	El Galeno	FS	2000	200 (first five years)	2015
First Quantum Minerals	Haquira	PEA completed	2030	200-230	2016-2017
Candente Copper	Cañariaco Norte	PFS completed	1450	120	2017
AQM Copper	Zafranal	Advanced Exploration	1000-1200	90-100	2017-2018
Projects developed by majors					
Southern Copper Corp	Tia Maria	Environmental permits	940	120	2012-2013
Xstrata Copper	Antapaccay	Construction	1470	160	2013
Pan Pacific Copper	Quechua	FS	850	76	2015
Xstrata Copper	Las Bambas	FS completed	4200	400	2015-2016
Anglo American	Quellaveco	FS	3000	225	2015-2016
Newmont / Buenaventura	Minas Conga	Approved EIA	3000	70	2015
Southern Copper Corp	Los Chancas	FS	1200	80	2017
Anglo American	Michiquillay	Advanced Exploration	2580	155	2018-2019
Rio Tinto	La Granja	PFS	3100	300	2019

Notes: FS = Feasibility Study; PFS = Prefeasibility Study; PEA = Preliminary Economic Assessment

Source: CRU Analysis and mining companies

In summary, projects developed by junior mining companies will play an important role in growth in Peru's copper supply. To some extent this trend is also likely to be seen in other countries in the region – Argentina, Mexico and Chile – where there are a large number of junior mining companies.

Forecast Peruvian copper production by type, 2010-2020 ('000 tonnes)



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Note: In addition to projects recently acquired, Cañariaco (Candente Copper) and Zafranal (Apoquindo Minerals) have been included in our calculations.
Source: CRU and mining companies

Valuation of mining resources

In addition to their role in mining exploration, junior mining companies constitute a key parameter in the valuation of mining resources, for two reasons:

- Most junior mining companies explore and prepare studies on projects that are later sold to a major mining company with more financial resources to invest in the project's construction and start-up. These sales become a point of reference for the price at which in situ mining resources are traded.
- Most junior mining companies finance exploration activities with funds obtained on the stock market (IPO and successive capital increases), and their market capitalisation is therefore a reflection of what investors are willing to pay for mining resources at a certain level of development.

Although each project has its own individual features, the most recent project acquisitions in Peru provide a benchmark for the value of mining resources in the country. The recent acquisition of Norsemont Mining (Constancia project) by Canada's HudBay Minerals has provided the most recent benchmark. The Constancia project is located in southern Peru, adjacent to other copper projects (Antapaccay, Las Bambas, Haquira, Los Chancas), and the operating Tintaya copper mine. The acquisition price is likely to have been strongly influenced by this factor. In terms of mining potential, Constancia has reported measured and indicated resources of 315Mt grading 0.597% Cu (4.15Blb contained copper). Based on these parameters, the acquisition value would have amounted to US$0.12-13/lb Cu (US$520M in total, assuming an exchange rate of Can$1.0/US$1). It should be noted, however, that the completed feasibility study on Constancia project reported mineral reserves of 277Mt grading 0.56% Cu. Considering the project's reserves alone, the acquisition multiple would be US$0.15/lb. In addition, Constancia has an approved Environmental Impact Assessment, which should also be taken into account.

Canadian-based First Quantum Minerals has recently acquired Antares Minerals, whose principal asset is the Haquira project in southern Peru, relatively near the Constancia project and adjacent to Xstrata Copper's Las Bambas project. Haquira only has mineral resource estimations (under Canadian National Instrument 43-101) and some economic studies, but no prefeasibility or feasibility studies have been undertaken, and no minerals have been categorised as reserves. The multiple paid for the Haquira project was US$0.056/lb Cu, based on measured and indicated resources.

Other projects acquired in Peru in recent years are: Mina Justa (March 2010 – multiple: US$0.06/lb); El Galeno (December 2007 – multiple: US$0.034/lb); and Toromocho (June 2007 – multiple: US$0.032/lb). In all these cases calculations are based on measured and indicated resources.

Some junior explorers continue to develop their copper projects in Peru and to date have not been acquired by a large mining company. Two examples are Candente Copper (Cañariaco Norte project) and AQM (Zafranal project). Candente has already developed a prefeasibility study and has reported measured and indicated resources of 8.3Blb Cu equivalent. Based on its market capitalisation of US$220M, Candente is therefore trading at US$0.027/lb Cu.

It is reasonable that the multiple assigned by the market to Candente should be lower than that assigned to Norsemont, given that the former is at an earlier stage of development (prefeasibility versus feasibility), and also taking into account that Candente is located in an area that is less developed in terms of copper mining. AQM's Zafranal project is at a preliminary stage compared to Cañariaco Norte. It has no prefeasibility study, but has recently released its resource estimation (measured and indicated resources) of 200Mt grading 0.57% Cu and 9g/t Au (0.623% Cu equivalent), taking into account a cut-off grade of 0.3% Cu. Based on AQM's market capitalisation of US$87M, its resources and its 50% share in the Zafranal project, the company would be trading at US$0.06/lb. It is important to mention that according to AQM, the main zones of its deposit remain open in several directions and at depth, and in this context there is an upside potential in the size of resources.

Valuation metrics for recent acquisitions and Junior companies on the market

Junior Company	Project	Purchaser	Acquisition	Acq. Value / Market Cap. (US$M)	Cu Eqv Resources (M+I) (Blb)	Multiple (US$/lb)
Recent Acquisitions						
Peru Copper	Toromocho	Chinalco	Jun-07	860	26.8	0.032
Northern Peru Copper	El Galeno	Minmetals/Jiangxi	Dec-07	455	13.2	0.034
Chariot Resources (1)	Mina Justa	CST Mining	Mar-10	250	4.2	0.060
Antares	Haquira	First Quantum Minerals	Oct-10	452	8.1	0.056
Norsemont Mining	Constancia	HudBay	Jan-11	520	4.1	0.126
Average						**0.062**
Junior Companies on the Market						
Candente Copper	Cañariaco Norte	-	-	222	8.3	0.027
AQM(2)	Zafranal	-	-	87	1.4	0.063

Notes: (1) Chariot Resources has a 70% interest in Mina Justa and 4.2Blb is equivalent to this percentage.

(2) AQM has a 50% interest in Zafranal and 1.4Blb is equivalent to this percentage.

Source: CRU Analysis and mining companies

In summary, recent acquisitions point to average values of US$0.06-0.07/lb Cu for in situ mining resources in Peru, which may also be taken as a benchmark for other projects in Latin America. In general, the more advanced the project, the higher the value paid due to the substantially reduced risk for the acquiring company. In addition, factors such as copper grades (important at the time of calculating costs); access to infrastructure, water sources and energy; and location (in terms of proximity to other projects and mining operations), among others, also influence the multiple to be paid.

Finally, it is important to note that the value of mineral resources is closely related to copper prices, because new buyers emerge in a context of high prices (in historical terms). In the case of Peru, the number of bidders for copper projects has increased due to the entry of several Chinese companies into the market, partly replacing traditional buyers, with a consequent impact on prices.

Conclusion

Junior mining companies will contribute significantly to future growth in copper production in Peru, due to their intensive exploration work and their role in mitigating project risks. Regarding the last point, junior mining companies try to increase mineral resources in copper projects and they conduct prefeasibility and feasibility studies (including environmental approvals) with the objective of selling the asset after de-risking the project through reducing uncertainty.

These companies are also an important parameter for the valuation of mining resources as they are a benchmark of the value assigned by the market or major mining companies to in situ mining resources, particularly when selling the project, launching an IPO or requesting a capital increase. This value is also closely related to the copper price, which in turn generates the emergence of new potential buyers beyond traditional mining companies.

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Information used in this article comes from public sources. The opinions expressed are the sole responsibility of the author and do not represent those of Larrain Vial, CRU or CESCO.

CRU and CESCO

The CRU-sponsored CESCO scholarship scheme is now in its fourth year. Since 2007, CRU has sponsored two or three CESCO Scholars each year to visit London and spend some time with CRU's Copper Team.

During the visit the scholars learn how CRU's Copper and other teams work. They also visit the London Metal Exchange and head offices of major mining companies in London. Atlantic Copper also sponsors a visit to its head office in Madrid and to its smelter-refinery complex at Huelva.

Prior and during their visit to CRU, the scholars also research and write articles for ***Copper Studies***.

About CESCO

The Center for Copper and Mining Studies, CESCO, is an independent, non-profit organisation created in Santiago in 1984. The members of CESCO work as executives or consultant for national and foreign mining companies, others as professors in local or foreign universities. Throughout its history, CESCO has positioned itself as a meeting place for diverse sectors interested in mining --business, academia, policymakers and professionals-- to promote ideas and discuss criteria about public policies related to economic and mining activities.

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April 4-6th, Santiago, Chile

- Cesco Week will start of Monday, April 4th, with CESCO International Conference on Mining Exploration at Sheraton Hotel, Santiago.
- CRU's 10th Worldwide Copper Conference will be held during CESCO Week on April 4-6th at Grand Hyatt Hotel, Santiago.
- CESCO Week will end on the evening of Wednesday, April 6th with the CESCO XV Annual Dinner at Club Hípico, Santiago.

CESCO Week gathers the most important worldwide leaders of mining companies, metal manufacturing companies, investment banks, metal traders, engineering companies and shipping companies among others. CESCO has organised this event since 1997 becoming the main meeting point for Latin American mining companies and one of the most important events of international mining industry.

Copper Studies

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