

Chile's Mining and Chemicals Industries

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With abundant mineral resources, Chile's chemicals industries are dominated by mining, with many of its operations among the world's most productive and important.

Chile's chemicals industries consist of 300 companies and some 400 products, with sales representing 4% of the nation's gross domestic product (GDP) and about 25% of all industrial contributions to the GDP (1). Chile's major chemical exports include methanol, inorganic compounds (nitrates, iodine, lithium products, sodium chloride), combustibles (gasoline, diesel, fuel oil), algae derivatives, and plastic resins (polypropylene, low-density polyethylene). However, the mining industry — consisting of 100 large and medium-sized companies and more than 1,600 mining operations (2) — dominates Chile's chemical-industry landscape. These companies' primary products include molybdenum, rhenium, iron, lithium, silver, gold, and — most important — copper.

This article presents a historical overview of Chile's chemicals and mining industries, with a focus on the mining sector. The map in Figure 1 identifies the country's geographic regions, key locations, and products.

Chile's resources in review

The first records of mining activity date back more than 10,000 years to an iron oxide mine in the Antofagasta region. Over the centuries, continuous exploitation of coal in Chile's northern regions, silver in Chañarcillo, and saltpeter (nitrates) in the Tarapaca and Antofagasta regions led to the first mining boom in the 19th century.

Chile has long ranked as the world's leading copper

producer. Chilean mining continues to reach unprecedented levels — not only the mining of copper, but particularly of nonmetallic ores. Recent growth has been supported by favorable economic policies and incentives for foreign investors that were intended to overcome the lack of domestic investment after Chile's return to democracy in the 1990s.

Chile's main metallic and nonmetallic ore deposits are located in the country's northern regions, which are rich in copper, gold, silver, and iron deposits, as well as salt lake mineral byproducts such as nitrates, boron, iodine, lithium, and potassium. Chile's abundance of mineral resources is remarkable: Its reserves constitute 6.7% of the world's gold, 12.1% of the molybdenum, 13.3% of the silver, 27.7% of the copper, 53% of the rhenium, 57.9% of the lithium carbonate, 60.8% of the iodine, and 100% of the natural nitrates (3).

In addition to its abundant resources and attractiveness to investors, Chile's mining industry is boosted by several other natural, technological, and administrative advantages:

- Chile's geography places mineral deposits in the vicinity of many seaports.
- The desert setting surrounding the large deposits facilitates land claiming, exploration, and exploitation.
- Large deposits enable the use of massive mining and low-cost modern technologies, such as open-pit extraction.
- Chile has an abundance of well-trained workers.
- The country's economic and political stability create a favorable environment for developing mining activities.

Mining as an economic force

Mining activity has been present in Chile since ancient time; for example, Chuquicamata was a center of copper metallurgy as early as the 6th century (4). Mines rich in silver were exploited using the mercury amalgamation method beginning in 1760, and because of its value as international currency, silver remained Chile's primary metallic ore until 1840. Silver mining declined in 1870 due to devaluation that occurred when the United States switched to the gold monetary standard.

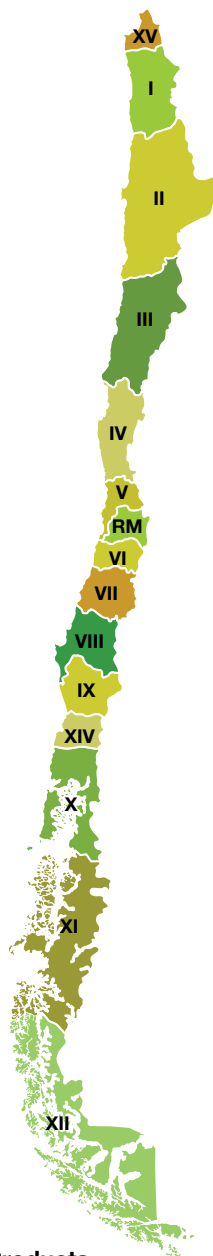
Although by 1810 Chile was producing 19,000 m.t./yr of copper from oxidized ores, copper mining did not dominate until 1840, when reverberatory furnace technology was introduced to process sulfurous ores. At that point, Chile became the largest copper producer worldwide, producing a total of more than 2 million m.t. of copper over the course of the 19th century.

The 1800s also saw the birth of an important new industry: saltpeter. Chile began producing nitrates (or saltpeter) from the caliche located on the sedimentary rock strata at Pampa Calichera, an area corresponding to old salt lakes from which water had long ago evaporated. From 1860 to 1925, saltpeter was Chile's main export, due to its demand for military and agricultural uses (5). When new ways to obtain nitrogen for explosives were invented during World War I, nitrate consumption progressively decreased. With the arrival of the Great Depression, the saltpeter market collapsed; the value of saltpeter fell by 90%, and more than 200 saltpeter operations closed, most of them located in the Atacama Desert.

The Chilean government faced this mining industry crisis by promoting the exploitation of gold at gold-panning sites. Chile increased its gold production from 1.4 m.t./yr to 5.0 m.t./yr during the 1930s.

Copper began its own new wave of production with the exploitation of the El Teniente mine by the U.S.-based Braden Copper Co. in 1905, and the Chuquicamata mine by the Guggenheim group, another U.S. company, in 1910. During World War II, these American mining companies set the price for copper, cutting into the profits previously received by the Chilean government and arousing strong feelings in the population against the foreign companies that managed the large-scale copper mining operations.

In 1971, the administration of President Salvador Allende nationalized the Andina, Chuquicamata, El Teniente, and Salvador copper mines. After Allende was overthrown in 1973, Chile was ruled by a military dictatorship under General Augusto Pinochet until 1990. Under Pinochet, the military government began to privatize state-owned companies, including some mining properties. In the 1970s and 1980s, several mines were privatized, including Soquimich (SQM) and Carolina de



Regions and Locations

XV. Arica y Parinacota: Surire Salt Lake

I. Tarapaca: Pampa Calichera, Salinas Punta de Lobos, Salar Grande

II. Antofagasta: Ascotán, Atacama Salt Lake (Salar de Atacama), Chuquicamata, Escondida, Esperanza, Gabriela Mistral, Lomas Bayas, Ministro Hales, Pampa Calichera, Radomiro Tomic, Spence

III. Atacama: Atacama Desert, Candelaria, Cerro Casele, Chañarcillo, Collahuasi, El Moro, Lobo Marte, Pascua Lama, Salvador

IV. Coquimbo: Los Pelambres

V. Valparaiso: Andina, Concón, Los Bronces

RM. Metropolitana de Santiago

VI. O'Higgins: El Teniente

VII. Maule

VIII. Biobío: Pemuco, Talcahuano

IX. La Araucania

XIV. Los Ríos

X. Los Lagos

XI. Aysén

XII. Magallanes: Cabo Negro, Mina Invierno, Punta Arenas, Riesco Island

Products

XV: Borax, Boric Acid

I: Copper, Iodine, Salt, Saltpeter

II: Boric Acid, Copper, Gold, Iodine, Lithium, Molybdenum, Potassium, Saltpeter, Silver, Sulfuric Acid

III: Copper, Gold, Iron, Molybdenum, Silver, Sulfuric Acid

IV: Copper, Gold, Iron, Silver

V: Copper, Gold, Liquefied Natural Gas, Molybdenum, Petrochemicals, Silver, Sulfuric Acid

RM: Gold, Silver

VI: Copper, Gold, Molybdenum, Silver, Sulfuric Acid

VIII: Coal, Petrochemicals, Solvents

XI: Gold, Silver

XII: Coal, Natural Gas, Oil

▲ **Figure 1.** Chile's northern geography is marked by desert salt flats, the source of abundant natural and mineral resources. The southernmost Magallanes region has a subpolar climate, and contains Chile's only known petroleum reserves.

Table 1. Chile's top chemical exports in 2010 (1).

Product	Volume, m.t.	Sales, U.S.\$ millions
Iodine	15,401	404.1
Potassium Chloride	1,087,335	319.0
Methyl Alcohol	764,651	211.5
Potassium Nitrate	303,512	194.3
Molybdenum Trioxide	6,076	147.8
Sea Salt	6,539,296	112.6
Diesel Oil	88,473	64.1
Ammonium Nitrate	163,326	63.9
Boric Acid	104,831	62.7
Sodium Nitrate and Potassium Nitrate	133,941	57.1
Agar-Agar	2,170	36.6
Potassium Sulfate	65,060	31.4

Michilla (now owned by Antofagasta Minerals), as well as other state-controlled properties through Chile's economic development agency (Corfo) and its national mining company, Empresa Nacional de Minería (ENAMI).

Excluded from these privatization policies was The Corporación Nacional del Cobre (Codelco). Founded in 1976, the state-owned Codelco has become the world's largest copper producer, controlling about 10% of the global copper reserves and generating significant income for Chile.

The mining boom of the 1990s was kicked off by the 1988 implementation of the Escondida copper project. That initiative was developed using foreign investment stimulated by the favorable regulations and contractual guarantees under Chile's Decree Law 600, which facilitated the participation of overseas investors. By March 2008, copper prices reached a record \$4.03/lb — only to fall to \$1.30/lb by December 2008 due to the ensuing worldwide financial crisis. However, thanks in part to the opening of Codelco's Gabriela Mistral mine — the first state-owned mining project in decades — copper prices recovered to an average of \$3.42/lb in 2010.

Investments in the copper industry have helped increase production from approximately 3.5 million m.t./yr in the 1990s to 5.5 million m.t./yr in 2012. Chile's production of gold is expected to double by 2015 with the launch of new mining projects. Recent decades have also seen significant increases in the production of nonmetallic products, including nitrates, iodine, sulfuric acid, lithium carbonate, calcium carbonate, sodium chloride, and boric acid.

Some of Chile's main exports are listed in Table 1.

One sector that has not kept pace with this recent expansion in mining has been the coal industry. The high costs associated with this sector, as well as competition from inex-

pensive coal imported from Colombia, have forced numerous Chilean coal mines to close. However, the changing world energy situation is generating a new wave of coal initiatives, including a recently constructed mine and new seaport at Riesco Island in Chile's southernmost Magallanes region.

In fact, Chile has a large portfolio of mining projects in development, with record investments of \$104.3 billion expected by 2025. Twenty-nine new copper mining projects will launch by then, to supplement the inevitable depletion of currently active deposits. In the next decade, copper mining projects will come online at Caserones, Ministro Hales, Sierra Gorda, Antucoya, Radomiro Tomic, El Espino, Lomas Bayas, and Pascua Lama, increasing Chile's copper production to 9.5 million m.t./yr by 2023.

Iron mining began in Chile in the late 19th century, driven by Chile's Sociedad de Fomento Fabril (Society for Industrial Development), although the ore was not significantly exploited until the arrival of U.S.-based Bethlehem Steel. Bethlehem Chile Iron Mines, the company's Chilean subsidiary, exploited the El Tofo deposit located in the Coquimbo province from 1917 until the mine was nationalized and transferred to the Compañía de Aceros del Pacífico (CAP) in 1971. Today, the top Chilean iron producers include CAP, Compañía Minera Huasco, and Minera Santa Fe.

The 1970s also witnessed the reemergence of the salt-peter industry, when the state-owned nitrate company was privatized and became Sociedad Química y Minera de Chile (formerly Soquimich; now SQM). This entity rebuilt the devastated industry — making it profitable, promoting new products, and opening it to new markets, particularly abroad.

Also in this era, lithium carbonate production began in 1984 with the 5,000 m.t. of product generated by the Lithium Chilean Society (Chemetall) at the Salar de Atacama salt flat. SQM completed its first shipment of lithium carbonate in 1996 and exploited the same salt lake to produce potassium, lithium, and boron.

Copper and copper byproducts

Copper is Chile's most important export, accounting for more than half of the country's export income and reaching a sales value of \$47 billion in 2012. During 2012, Chile produced 5.43 million m.t. of fine (*i.e.*, metallic) copper, representing 32% of the worldwide production. Table 2 lists some of the country's major copper mines and companies.

Chile's copper reserves exceed 190 million m.t. of metallic copper, 28% of the world's total (6). Codelco Chile is the largest copper mining company, producing 11% of world's copper and controlling approximately 15% of the world's proven and inferred copper reserves. At the current production rate of about 1,760 m.t./yr, Codelco's deposits should remain productive for more than 70 years. The most important of Codelco's reserves are in the Andina, El Teniente,

Table 2. Some of Chile's key copper mines in 2012.

Mine	Companies	Production, m.t.
Escondida	BHP Billiton; Rio Tinto	1,075,800
Radomiro Tomic	Codelco	427,800
El Teniente	Codelco	417,200
Los Pelambres	Antofagasta Minerals	403,700
Anglo American Sur	Anglo American	373,800
Chuquicamata	Codelco	356,000
Collahuasi	Anglo American; Mitsui; Xstrata Copper	282,100
Andina	Codelco	249,900
Spence	BHP Billiton	166,700

Radomiro Tomic, Chuquicamata, El Salvador and Ministro Hales deposits.

Exploration by Codelco and foreign investors using modern technology and satellite assistance has yielded a substantial increase in known copper reserves over the last decade. Meanwhile, the reserves currently exploited by medium- and small-scale mining operations have remained largely unquantified, due to limited capital for exploration and measurement.

Despite an increase in copper production via hydro-metallurgical processes, concentrate production by flotation remains the most popular method because most of Chile's copper reserves are sulfide ores.

Molybdenum is Chile's second-most-important mineral export, with a value of \$11.50/lb in 2012. Chile's sales of molybdenum concentrate totaled \$1.25 billion that year, making Chile the world's third-largest molybdenum producer, after China and the U.S. In Chile, molybdenum is obtained exclusively as a copper byproduct.

The history of molybdenum in Chile, unlike that of copper, is relatively short. In the 1990s, when the industrial exploitation of copper was nearly a century old, Codelco had just begun recovering molybdenum. In the 2000s, producers such as Minera Los Pelambres and Sur Andes (currently Anglo American Sur) followed suit.

Rhenium, a byproduct of molybdenum production, is one of the most valuable elements in the world, with a price of \$3,000/kg in 2014. Currently the world leader in rhenium production, Chile produced almost 30 m.t. of this metal, accounting for half of the world's total, in 2012.

Sulfuric acid, another copper byproduct, is essential for the production and recovery of copper via hydrometallurgical leaching. Sulfuric acid is an abundant byproduct at the copper smelters, where it is recovered by abating the sulfur contained in the gases emitted during the process. Approximately three tons of sulfuric acid are produced for each ton of casted copper.

Gold, silver, and iron

Although gold mining is not as prominent as some other mining sectors, Chilean companies produced approximately 45 m.t. in 2012, or 2% of the worldwide total. The Ministry of Mining forecasts that Chile could increase its gold production to nearly 120 m.t./yr by 2015 with the launch of new projects at Pascua Lama (Barrick), Lobo Marte (Kinross), El Moro (Goldcorp), and others.

Chile produced approximately 1,130 m.t. of silver in 2012, making it the world's eighth-largest silver producer. When Barrick's gold and silver project at Pascua Lama begins operations, the domestic production of silver is expected to increase by approximately 1,000 m.t./yr.

Iron mining in Chile is primarily concentrated in the Cordillera de la Costa (coastal mountain range) in the Atacama and Coquimbo regions — known as the Chilean Iron-Bearing Strip. Iron is present in magmatic rocks, which have metallic contents above 50%.

In 2012, Chile's iron production reached 9.4 million m.t., generating \$1.19 billion. Most of Chile's iron is destined for the steel industry, and mostly for international markets. World production of raw steel reached a record 1.55 billion m.t. in 2012, and China was responsible for 46% of that. As the primary market for Chilean iron exports, China receives 73% of the total volume exported.

Coal, crude oil, and natural gas

Although Chile holds only 5.5% of South America's coal reserves, current restrictions on imported natural gas from Argentina and a need for affordable fuel alternatives have created an increasing demand for coal. This demand comes mainly from the power sector, which generates approximately 2,490 MW (16%) of Chile's electricity from coal. Domestic coal production is led by the state-owned company Empresa Nacional del Carbón (ENACAR).

Domestic coal production had been declining, from a high of 2.1 million m.t. in 1992 to a low of 238,370 m.t. in 2004. However, with renewed demand, production capacity has recovered somewhat, reaching 711,714 m.t. in 2012. Since 1998, the main domestic coal producer has been Catamutún, which, after its purchase of Pecket Mine in the Magallanes region in 1997, shifted its emphasis from open-pit mining to underground operations. The company also produces coal in the Biobío, Los Ríos, and Los Lagos regions.

One of the most important coal deposits is on Riesco Island in the Magallanes region — an area with sub-bituminous coal reserves (lignite) estimated at 3.2 billion m.t. In 2008, the Chilean company Copec and Canada's Ultramar formed the Minera Isla Riesco company to exploit the island's coal mining leases. This \$530-million initiative included construction of a new seaport and the Mina Invierno open-pit coal mine. Online since 2013, it is Chile's largest

coal mining operation, with an annual production capacity of 4–5 million m.t. The site has already begun shipping coal to customers in India and Europe.

After the discovery of oil in the Magallanes region in 1945, the government created Chile's national oil company, Empresa Nacional del Petróleo (ENAP). Today, ENAP is the only Chilean company producing and refining fuel. It supplies two-thirds of the oil-derived fuels used in Chile, and sells fuels under the Primax brand. ENAP's holdings are organized under two subsidiaries: ENAP Sipetrol is devoted to hydrocarbon (oil and natural gas) and geothermic exploration in Chile and abroad, while ENAP Refinerías is in charge of fuel and other petrochemicals, and manages the logistics, transportation, and storage of those products.

ENAP's exploration and production activities remain concentrated in the Magallanes region, the only area in Chile where exploitable hydrocarbon deposits have been discovered. ENAP Refinerías has a total capacity of 229,000 bbl/day, and has plants in Concón, Talcahuano, and in Magallanes. In collaboration with British Gas (United Kingdom), Metrogas (Argentina), and Endesa (Spain), ENAP built the Americas' first storage facility for liquefied natural gas (LNG) and LNG-regasification plant. Located at Pemuco in the Biobío region, it has a 10-billion m³/day regasification capacity. ENAP exports some of its products to Peru, Ecuador, and Argentina.

Additionally, a petrochemical complex in Biobío hosts such international firms as Occidental Chemical, Eka Chemicals, Petroquim, and Petroquímica Dow (1).

Since 1998, Methanex (Canada) has invested more than \$1.3 billion in its Chilean production facilities located in the Atlantic-coast port city of Cabo Negro in Chile's southern petroleum- and gas-producing region. Methanex's Chilean plants have a methanol capacity of 3.8 million m.t./yr. However, due to a currently limited gas supply, the site is operating at a reduced production rate of 1.8 million m.t./yr, which is sufficient to supply its export customers (8).

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Chemicals from saline deposits

The saline deposits and brines in northern Chile are the most important source of many nonmetallic mineral compounds, including (9):

- iodine and its derivative salts (iodides and iodates)
- saltpeter (potassium nitrate and sodium nitrate)
- potassium salts (chloride and sulfate)
- sodium chloride
- lithium salts (carbonate, hydroxide, and chloride)
- borates (unexcited boric acid and refined borax).

In 2012, these nonmetallic mining exports, as well as mineral and chemical fertilizers, accounted for more than \$1.5 billion in sales.

Iodine and its derivatives — primarily used in healthcare products — are the most valuable chemical products obtained from Chile's nonmetallic mining operations. Iodine is not abundant on Earth's surface, but commonly found as the highly water-soluble iodide ion that concentrates in oceans and brine pools. After the year 2000, Chile's iodine production increased due to the expansion of the SQM company and the creation of new iodine recovery plants (ACF Minera and Compañía Salitre y Yodo de Chile) that extract iodine from the waste cakes generated by old saltpeter operations. These activities boosted iodine production capacity to approximately 17,000 m.t./yr within a decade. In 2012, Chilean exports of iodine and its derivatives had a value of \$955 million.

Nitrates (saltpeter) and iodine come from the caliche strata — a Paleolithic sea sediment present in the Atacama Salt Desert. In 2012, nitrate production reached 822,584 m.t., generating potassium nitrate exports worth \$363 million (10). Common salt and ulexite are minerals typical of the evaporites found in the northern Chile salt deserts, where lithium and potassium salts, as well as boric acid, are obtained from the Atacama Desert brine (Figure 2).

Elemental potassium does not occur in nature (it reacts violently with water). The majority of the world's potassium reserves are located in stratified saline deposits, while the rest are obtained from surface brine evaporation that occurs in salt deserts and lakes. The most important potassium compounds mined in Chile are potassium chloride and potassium sulfate, both of which are obtained by treating the chlorinated brines from the Atacama salt deposits. The Atacama Salt Lake supplies 250,000 m.t./yr of potassium chloride.

SQM, Chile's largest potassium producer, began obtaining potassium chloride from the Atacama Salt Lake brine in 1995. The company uses its potassium chloride in a variety of plant nutrition and agricultural products. The second-largest potassium producer is Sociedad Chilena del Litio, an affiliate of the U.S. company Rockwell Holdings, whose original mining operations at Atacama Salt Lake focused on obtaining lithium carbonate and lithium chloride. In 2012, Chilean potassium chloride production overall reached

900,000 m.t., with potassium compound exports generating about \$564 million (10).

Sodium chloride reserves at Salar Grande and other salt deserts in the Arica-Parinacota, Tarapacá, and Antofagasta regions are huge and of high purity (exceeding 99%). Nearly all production is carried out by the Salinas Punta de Lobos company, which processes the material in its Patillos plant. Thanks to

an increasing foreign demand for sodium chloride — 88% of Chile's NaCl is exported — shipments of NaCl reached 8.8 million m.t., valued at \$150.2 million, in 2012.

Lithium, an alkaline metal, is obtained from two primary sources: brine and hard rock mining. Historically, lithium's applications were limited to pharmaceutical products, glass, ceramics, aluminum, and lubricant production processes. In recent years, however, the growing market for lithium-based rechargeable batteries has changed the landscape. (See CEP's energy supplement on Li-ion batteries, Oct. 2013, pp. 33–64). Over the past decade, world demand for lithium has risen an average of 7% per year, and its price has tripled (11).

Chile holds more than half of the world's lithium reserves, and in 2012 ranked first (tied with Australia) in lithium production, producing 13,000 m.t. Chile's lithium oxide and lithium hydroxide production reached 5,300 m.t. in 2012. Two Chilean companies — SQM and Sociedad Chilena del Litio — dominate the global lithium market, extracting brines from the Salar de Atacama in the Antofagasta region. Because Chile considers lithium a substance of strategic importance, and because of its potential use in nuclear power generation,



▲ **Figure 2.** Salar de Atacama is Chile's largest salt flat, and the world's largest source of lithium. Image courtesy of Martchan.

lithium extraction is regulated by the Chilean Council of Nuclear Energy and other governmental authorities.

Boron reserves are found in the Andean salt deserts in the Arica-Parinacota (Surire) and Antofagasta (Ascotán) regions. Minerals of commercial interest include borax, kernite, colemania, and ulexites. Until the 1930s, Chile was the world's primary boron source, generating

50,000 m.t./yr of ulexite-based boron compounds. Production later decreased due to the marketing of boron compounds based on borax, which is water-soluble and thus has a lower production cost. Since the 1980s, the Arica-Parinacota region has reemerged as a leading boron producer (7).

Closing

The chemicals industry in Chile is dominated by mining. Indeed, Chile has long been a world leader in the production of copper, molybdenum, rhenium, silver, gold, iodine, lithium, nitrates, and sodium chloride.

The energy needs of these mining operations underscore a major challenge for Chile and its industries: Chile's domestic production of oil, natural gas, and coal has decreased over the past two decades, while its consumption has considerably increased. The installation of new LNG plants and the promotion of renewable energy such as solar power are steps that Chilean industries have undertaken to help fulfill energy needs. In addition, the use of seawater at mining operations is another measure by which Chile's mining companies have addressed resource challenges. **CEP**

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