Gustavo Lagos
THE LITHIUM INDUSTRY AND CHILE'S ROLE
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Gustavo Lagos

The Lithium Industry and Chile's Role

EDITEC
GRUPO EDITORIAL

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PROLOGUE

I came upon lithium quite by chance. When I completed my Ph.D. in England in 1978 I applied for several jobs and chose the one I found most interesting, the development of lithium battery cathode materials, in London. Four years later I returned to Chile and settled down as a professor at the Universidad de Chile, creating a laboratory of lithium battery materials.

Two years later, after a talk I gave on lithium batteries at the Mining Engineers' Institute, a friend said to me: "Gustavo, what you spoke about was as if you were in Mars, it has nothing to do with this country, nobody understood anything." Well, it's true that at the time we were just recovering from the sequels of the 1982 crisis and no one was interested in the lithium ion battery.

Throughout the 1980s I continued to be involved in lithium, although not exclusively. Shortly after arriving in Chile, a group of friends invited me to be part of the newly created Center for Copper and Mining Studies (Centro de Estudios del Cobre y la Minería, Cesco). As of then I began to lean toward copper and its economic issues and mining strategies, and from 1990 onward I devoted myself completely to copper and mining. In 1993 I went to the Universidad Católica (UC) to create the Mining Center and shortly afterward the Mineral Economics Program. In 2010 I returned to lithium again, prompted by the ongoing political debate at the time. Thirty-three years after Chile began to produce lithium there is still a considerable lack of awareness regarding this metal and its potentialities in the country.

The information regarding this metal that circulates most liberally is, of course, the most colorful and enticing. That lithium will be the new copper, that it is white gold, that it is increasingly becoming a precious metal, that the lithium triangle in South America will replace Saudi Arabian oil, that its price will go up and up, that Chile is the leader in lithium, and many other things.

Unfortunately for us, these assertions are far removed from reality, because if they were true we would only need to sit on our doorsteps and watch the piles of money roll by to make our country rich.

In Chile we're whizzes at discovering ideas but very bad at implementing them. Half way along something else pops up and everything is forgotten. This is what happened to lithium. We lived in hope for fifteen years, between 1978 and 1993, and then lapsed into twenty years of oblivion. The two companies in the Atacama Salt Lake managed to produce nearly half the lithium in the world. But for more than 10 years now Chile has been reducing its market share

due to its inaction. This will continue to occur notwithstanding the increased production agreement that Corfo and Albemarle signed in 2016.

This book is about lithium, both in Chile and worldwide.

It analyzes the history of lithium in Chile, since its discovery in 1962 up till 2017. It examines the institutionality of this metal in Chile and the intense debate it has generated in the élites of the country, although not among the Chilean people.

A review is made of the lithium industry at a global level, its brief history, the uses of the metal, its productive processes, global reserves and resources, supply and demand, its historic price and how it was structured, its production costs, the value added it can generate, the worldwide debates that have arisen in the past, as well as the current debate regarding its future supply and demand.

Even though it seems very difficult that lithium will ever replace what has historically been the copper industry in Chile, it is nonetheless important to continue to pursue this debate.

We have still not discovered the key factors that so many are seeking in order not to reduce lithium in Chile solely to production but also to contribute to the development of technological advances.

The purpose of the book is to discuss the main aspects of the lithium market from the viewpoint of mineral economics and history, providing arguments that will make it possible to size up our options.

It is a worthwhile debate and it is also essential to arrive at a common perspective and concrete actions soon. There is a sense of urgency to this, because the world continues to progress and every moment that passes without our managing to solve our problems will make us drop farther and farther behind.

The author
Santiago, August 2017

1. INTRODUCTION

During the government of Jorge Alessandri Rodríguez, in 1962 the U.S. mining company Anaconda that worked the Chuquicamata mine, explored the Salar de Atacama salt lake in search of water, but instead found salt water. A chemical analysis of the water content provided the first indications of the presence of high concentrations of lithium, potassium, magnesium and boron in the salt lake.[1] Many years later the conclusion would be reached that this salt lake is the most important lithium deposit in the world. Salar de Uyuni in Bolivia, located only two hundred and fifty kilometers away, is much larger in extension and its lithium resources more substantial than those of Salar de Atacama, but they are also more expensive to extract.

Salar de Atacama, ellipsoidal in shape, approximately 85 kilometers long in a north-south direction and 50 kilometers wide, is located in the Region of Antofagasta, to the south-west of San Pedro de Atacama, at a height of 2,300 meters above sea level, 80 kilometers distant from Chuquicamata and around 200 kilometers from the city of Antofagasta. The Salar forms a gigantic plain containing a white crust made up of crystallized salts, mainly common salt, in the southern half (saline nucleus) extending over approximately 1,400 km^2. This hard, resistant crust, with serrated edges and highly fractured, with an average microrelief 0.7 m high, which is difficult to walk on, overlays a porous saline mass that occludes the brines. These, located at a minimum phreatic level of 0.5 m, are saturated in sodium chloride, containing also other elements such as magnesium, lithium, potassium and boron. The water from the San Pedro river and other surface and underground water sources, dragged dissolved salts from the Andes range, which started accumulating and crystallizing by evaporation as a result of the intense desert sun and since geological times, giving rise to evaporites (chlorides and sulfates) together with clastic sediments in this tectonic and enclosed basin. The depth of the saline body exceeds 400 meters, but the greatest porosity is found in the first 30 to 40 meters, declining exponentially at the deeper levels. In the course of the exploration for water, Anaconda perforated the crust of the salt lake and found what looked like water. When observing the extracted liquid, however, it was found to be dense and to contain dissolved salts. These are called brines. Thus began the history

1 When water contains high concentrations of salts of different elements it is called brine.

of lithium in Chile, triggered by a superficial search for something else, as has occurred with many of the mining discoveries in the past. Without ruling out that this could happen again, recent history suggests that such findings will be increasingly infrequent, because a majority of the ore deposits close to the surface have already been discovered.[2]

The industry began its first global commercial applications in 1923. The lithium discovered in Chile in 1962 would wait 22 years for the country to start up mine production.

This book examines the lithium industry at a global level, its brief history, the uses of the metal, its productive processes, global reserves and resources, supply and demand, its historic price and how it was structured, its production costs, the value added it can generate, the worldwide debates that have arisen in the past, as well as the current debate regarding its future supply and demand. The book analyzes the history of lithium in Chile, from its discovery in 1962 up to 2017. It analyzes the institutionality of this metal and the debate it has generated in the country. The book concludes with reflections on the global and domestic debate that has arisen with regard to lithium production and demand.

2 Personal communication provided by geologist Francisco Camus.

2. THE DISCOVERY OF LITHIUM

The discovery of lithium is attributed to Swedish chemist Johan August Arfwedson in 1817, when he was analyzing ores brought to him by Brazilian scientist José Bonifácio de Andrada e Silva[3] (1763-1838), who had found a mineral called Petalite[4],[5] on the island of Utö in Sweden in 1800 (Wikipedia). Arfwedson could only account for 90% of the composition of the mineral, leading him to posit the existence of a new element, the third lightest in the periodic table and the lightest metal found in nature. It was called "Lithos" from the Greek, which means stone. In its pure form, lithium is a silvery white, soft substance, the surface of which, when in contact with the oxygen in the air rapidly oxidizes into a brown oxide. Its high reactivity to oxygen, even when in pure form, makes it necessary for the metal to be handled in dry chambers with argon and no oxygen. In 1818, British chemists Sir Humphry Davy and W.T. Brande obtained metallic lithium by means of electrolysis. Due to its reactivity, pure lithium is not found in nature, but only in the form of minerals and brine.

In 1876 Albert Edward Foote had created the Foote Mineral Company to produce rare minerals, but lithium mining and processing did not begin until 1950.

The production of lithium using lithium chloride electrolysis, discovered by Robert Bunsen and Augustus Matthiessen in 1855, took until 1923 to become a commercial venture undertaken by the German company Metallgesellschaft AG (Wikipedia) founded in 1881.

Even 100 years after the discovery of lithium, its uses were scant. Up to the beginning of World War II the so-called "Western World", excluding USSR, China and the Warsaw Pact countries, used less than 300 tons of lithium contained in different salts (Kunasz, 1986).

The first uses of lithium were in the form of lithium urate to treat gout and kidney stones at the end of the 19th century. It was also used as a substitute for table salt in patients with heart conditions, but health problems soon arose and its use became increasingly limited (Martínez, 1990). Also in the 19th century it was accidentally discovered that in high doses lithium has lethal effects, like

3 http://www.chemistryexplained.com/elements/L-P/Lithium.html.

4 According to Wikipedia the name derives from the Greek petalon, which means leaf.

5 Petalite in solid form is made up by an aluminum silicate and lithium, formula $LiAlSi_4O_{10}$

many other substances and elements.

In 1901 the Stewart mine located in the County of San Diego, California, was the first to produce lithium in the United States (Kunasz, 1986). At this deposit a form of lithium called lepidolite[6] was mined. During the First World War lithium was used for the first time in the manufacturing of alkaline batteries (Kunasz, 1986).

The first major use of lithium was as a lubricant in high-temperature greases for airplane engines during World War II. Lithium hydride was also used to inflate rescue devices (Kunasz, 1976).

The use of lithium in lubricant greases and oils improves the retention of their lubricant properties in a wide range of temperatures, maintaining viscosity, resistance to water, rust and handling, and providing good grease stability and pumping, thus making these products optimal for use in bearings and high-speed friction applications.

These uses were supplied by small mining operations in the United States. Kunasz estimated the greatest use of lithium in this country during World War II at around 700 tons between 1940 and 1945, which was equivalent to less than 3% of annual production in 2008 but in 1940 represented over double the world production[7]. Lithium-producing companies in the U.S. were able to provide the lithium required to support the military needs of their country. As indicated by Kunasz (1976), when the need arises, "resources become reserves practically overnight." The concept of reserve depends on price. When prices are high, reserves increase because it is financially viable to extract ores and brines with a lower grade or percentage of metal in them. In addition, in wartime conditions, the prices to be paid for essential products were secondary aspects.

In 1949 Australian psychiatrist John F. Cade discovered the effect of lithium salts in the treatment of bipolar disorder[8]. Although this application of the metal is still in use, it represents a very small fraction[9] of world demand for the metal. As of 1955 demand for lithium grew due to the construction of thermonuclear bombs, which require the use of lithium isotope 6 (lithium-6), among others (Kunasz, 1986). For this reason, the U.S. declared it to be a strategic element after World War II and stocked up on inventories for decades. Lithium-6, as well as lubricant greases, were produced on the basis of lithium hydroxide and this constituted the greatest incentive to develop more sophisticated production methods.

The U.S. Atomic Energy Commission (USAEC), subsequently known as the Energy Research and Development Administration (ERDA), bought substantial amounts of lithium to build nuclear fusion bombs, known as thermonuclear bombs. (Roskill, 84).

6 A silicate that contains variable quantities of potassium, lithium and aluminum hydroxide, and can be associated with the spodumene ore present in pegmatites.

7 This estimate was made on the basis of lithium production in the U.S. in 1940, which was 223 tons of contained lithium (Kunasz 1976), and considering that U.S. production represented 70% of global production (Wood 1976).

8 Wikipedia.

9 One pill for bipolar patients contains less than half a gram of lithium.

Many years later, in 1976, ERDA reported that it had 36,297 tons of lithium hydroxide monohydrate in stock (Wood, 1976). This policy was abandoned in the 1980s, but even in 1994 the U.S. Department of Energy (DOE) tried sell part of its inventories of 36,000 tons of lithium hydroxide monohydrate but did not manage to do so that year. The DOE had already tried to sell stock in 1989 but it had delayed this action until an environmental impact assessment was conducted. It was only in 1993, once the assessment had concluded, that part of the stock was sold (USGS, 1994). The U.S. stock amounted to 10,587 tons of metallic lithium and, according to the USGS, global production in 1994 was 9,439 tons. The Union of Soviet Socialist Republics, USSR, also sold off inventories it had accumulated since it conducted its thermonuclear program. The lithium sales of those programs are frequently characterized by an isotope lithium-6 deficiency in the products. For this reason the sales of inventories, both those of the U.S. and Russia, were key at the time of estimating worldwide production.

Up to World War II lithium production was carried out in small mines, for example in New Mexico and South Dakota, where pegmatites and petalites were extracted (Kunasz, 1986). The method used was low-tech, separating the pegmatites with a richer lithium content manually. This method continued to be used in small deposits up to the 1970s.

The methods used in the 1940s and 50s to extract lithium from pegmatites[10] were applied in the following decades by Foote and ALC (also known as Lithco), and by companies in Canada, Zaire, Zimbabwe, Namibia, Brazil, Argentina and Australia. The pegmatite mine in Bikita, Glen Cove, Zimbabwe – then Southern Rhodesia – belonged to Bikita Minerals, and achieved the largest production outside the U.S.[11] It began production in 1953 and constituted one of the richest lithium deposits, certainly with the highest ore grade. Up till 1959 this mine produced lepidolite, which was shipped to the lithium hydroxide plant of the American Potash Corporation in San Antonio, Texas, to meet the demand of the U.S. atomic program. When this demand fell off in 1959, lepidolite was used in the ceramics industry.

During the 1950s Lithco manufactured lithium compounds at plants in St Louis, Minnesota and Bessemer City, North Carolina, buying ore from Foote and Quebec Lithium Corporation in Canada (Roskill, 1984).

The need to have greater amounts of lithium available for military purposes led the Federal Geological Survey (now U.S. Geological Survey) to carry out a massive exploration program during World War II. As a result of these explorations, lithium resources and reserves increased from less than 100,000 tons prior to 1950 to close to 1 million tons in 1955, of which around 20% were reserves and the rest were resources. These were pegmatites and were located mainly in the United States (64%) and in the Yellowknife area in Canada (35%),

10 Pegmatite is an igneous rock the size of a granule of close to 20 mm. Most pegmatites are made up of granite, which contains quartz, feldspar and mica.

11 Does not include deposits in the USSR as no information covering that period is available.

with the rest in Zimbabwe and Australia[12] (Kunasz, 1986). At that same time China revealed its lithium reserves and operations. The technology to extract greater quantities of lithium from pegmatites was just being developed and the reserves and resources found were sufficient to meet the recently created demand.

Prior to 1980 there was no reliable information available regarding resources and reserves in the USSR, in the People's Republic of China or in the Warsaw Pact countries. Mineral statistics corresponded to the so-called "Western World", which, incidentally, included the figures of countries such as Japan, South Korea and other Asian states.

The U.S. Atomic Energy Commission Program generated a rise in investment in lithium mining between 1950 and 1959. The American Potash and Chemical Corporation had begun to produce lithium carbonate from lithium phosphates present in Searles Lake, California, in 1938. The Foote company became the largest lithium producer when in 1950 it acquired the rights to work a spodumene[13] deposit in Kings Mountain, North Carolina. This deposit was known since 1938 (Roskill, 1984). It also began to produce lithium hydroxide on the basis of pegmatites in Sunbright, Virginia. During that same time ALC built a lithium hydroxide plant in Bessemer City, North Carolina, and American Lithium Chemicals built another similar one in San Antonio, Texas, which processed lepidolite[14] originating from Southern Rhodesia[15] (Kunasz, 1986). Once the U.S. nuclear program came to an end during the 1960s, three of the five lithium-producing companies had to close down their operations due to lack of demand for lithium. The industry was left with an overcapacity of 500% and with only two companies still operating, Foote and ALC (Lithco). This situation would remain the same until 1997, when a third large lithium producer, SQM, entered the scene.

During the 1960s, the reserve status changed dramatically with the discovery of large brine deposits in two salt lakes in the United States – Searles Lake in California and Silver Peak in Nevada – leading to an increase in reserves that was far greater than the market required. The discovery of these brines and their much cheaper extraction methods to produce lithium made the discovery of applications in which lithium could add value to new products become an attractive proposition.

According to Kunasz (1986) this discovery was also crucial because it enabled the "reintroduction of lithium into an array of applications such as ceramics manufacturing and aluminum electrolysis."

And in South America, as of the 1960s the so-called "lithium triangle", including the Salar de Atacama in Chile, the Salar de Uyuni in Bolivia and the Salar de Hombre Muerto in the province of Salta in Argentina, came into

12 Reserves discovered by the Greenbushes company.

13 Mineral in solid form, made up of a lithium aluminum silicate, general formula LiAl(-SiO3)2.

14 Lepidolite is a silicate made up of potassium, lithium and aluminum, in which the potassium can be substituted by other elements.

15 Currently Zimbabwe.

being. According to Meridian International Research, 2008, the sides of the lithium triangle are 360, 280 and 560 kilometers, and contain within it 70% of the known lithium resources of the world. This concept led the director of the National Agency for Scientific and Technological Development of the Ministry of Science of Argentina, Rodolfo Tecchi, to posit (Clarín, 2011) the creation of a lithium "OPEC" between Bolivia, Argentina and Chile. By then numerous other Andean salt lakes were known to contain lithium. These were Salar de Rincón, also located in the Salta province in Argentina; Salar de Olaroz, located in the province of Jujuy only 100 km away from Salar de Rincón; the Cauchari and Centenario salt lakes, both in Salta, Argentina; Salar de Lagunas Pastos Grandes in the south of Bolivia; the Pedernales and Maricunga salt lakes in Chile, both located in the Region of Atacama, south of Salar de Atacama.

Lithium was used in the manufacturing of glass and ceramics because its low coefficient of thermal expansion enabled the glass and ceramics to withstand physical and thermal shocks. Moreover, the addition of lithium improved their mechanical properties. This application was first developed for missile warhead manufacturing in the 1950s and was later used to manufacture crockery, pots and pans, and glass for a wide array of domestic and industrial applications. Furthermore, the addition of lithium made it possible to reduce manufacturing temperatures, avoid bubble formation and provide better finish to the glass.

Another advantage of introducing lithium into these applications was, and continues to be, that it became unnecessary to refine the pegmatites and other minerals such as petalite or spodumene in order to achieve metallic lithium, it simply required adding the minerals themselves in concentrated form to the glass and ceramics. Finally, the price of lithium contained in ores was and continues to be considerably lower than the price of lithium contained in lithium carbonate, which in subsequent years would constitute the major part of the market.

The use of lithium in aluminum production[16] made it possible to reduce the melting point and increase the ionic conductivity of the molten salts in the electrolysis of the aluminum oxides – the final stage of the manufacturing of this metal – reducing the substantial costs of the process. The use of lithium also managed to increase electrolytic speed and reduce gaseous fluorine emissions, which have a high oxidizing strength and are extremely damaging to the health.

16 Aluminum electrolysis is carried out using the Hall Heroult process and consists of dissolving the alumina (aluminum oxide) in a molten bath (400 to 450°C) of cryolite (sodium aluminum fluoride). Aluminum is the most highly-used metal in the world and requires one of the greatest amounts of energy in its manufacture, second only to titanium.

3. FROM ORE TO END USE

Unlike other minerals[17], the lithium market is highly segmented, because the production of lithium ore can be used directly in some applications without having to go through the production of lithium carbonate, hydroxide, chloride or metallic lithium. For this reason, and again unlike other metals, there is a close relationship between the types of deposits and the end use.

Throughout the brief history of this industry, lithium carbonate constituted the most important product in terms of volume, with pegmatites in second place, hydroxide third and chloride fourth. From the beginning of the industry, metallic lithium represented up to 1% of total production. It did not make sense to obtain metallic lithium to produce the greater part of the materials required by the industry. Therefore, the price of metallic lithium was always extremely high because its uses were very few, but even so it decreased from over 400 dollars (2010 currency) per kg in 1945 (Roskill, 1984) to a little over 60 dollars (2010 currency) per kg in 2008 (Roskill, 2009). In 2017 the price of metallic lithium remained at the same level, between 65 and 68 US$/kg in 2017 currency (https://www.alibaba.com), although it can run higher for some applications

Prior to 1966, when the Silver Peak salt lake in Clayton Valley, Nevada, started production, practically all lithium production came from pegmatite deposits[18]. This changed radically with the entry into production of the salt lakes in Chile and Argentina, and in 2000, 78% of production issued from salt lakes. In 2008 (Roskill, 2009) two-thirds of production in the form of lithium chemicals originated from only four salt lakes[19], and the rest, in the form of

17 When speaking of the lithium industry in Chile, it is referred to in government institutions, the press and even in some academic media, as a nonmetallic industry. This is mistaken because lithium is an excellent conductor of electricity, which by definition makes it a metal.

18 The exception was the small amount of lithium products that were produced several decades before at the Searles Lake salt lake in California.

19 Atacama (Chile), Hombre Muerto (Argentina), Silver Peak (USA), and one or several salt lakes in China.

mineral concentrates, mainly spodumene, came from pegmatite deposits, notably Greenbushes in Western Australia, owned by Talison Lithium. The rest are quite small and are distributed in many countries (Canada, China, Portugal, Brazil, Zimbabwe and Uzbekistan, among others). The situation had changed dramatically in 2011 due to the entry, in 2006, of Talison Lithium in Australia, which prompted a strong increase in production capacity of the concentrate. In and after 2014 came the great surge of electric vehicles powered by lithium ion batteries, which completely changed the lithium industry.

In the future, a major part of lithium production may issue from clays, geothermal and oil-bearing brines, and jadarites. The clay minerals containing lithium are hectorites and jadarites (Evans 2008). The pegmatite minerals are spodumene, petalite, lithium and aluminum silicates, lepidolite and amblygonite. These minerals are used fundamentally in glass manufacturing, as long as they contain low quantities of iron. In China they are also used to manufacture lithium chemical products (Evans, 2008). Lithium minerals are also used in the direct production of lithium hydroxide, which is used to manufacture lubricant greases, batteries and inorganic derivatives. Lithium hydroxide is also produced on the basis of lithium carbonate issuing from brines.

Brines constituted the main raw material to produce lithium carbonate in different degrees of purity, which is used to manufacture batteries, pharmaceutical products, alloys and ceramics and glass. This was the case up till a few years ago, when affordable processes were developed to transform pegmatites into carbonate. Lithium chloride can be produced directly from brine, as occurs at the Salar de Hombre Muerto and Salar de Atacama plants. According to Roskill (2009), although chloride represented only 1% of the industry market at a global level, it was the basis for manufacturing dehumidification systems from metallic lithium and butyllithium, so that its primary market should continue. Butyllithium is used to manufacture synthetic rubber, polymers and organic derivatives. Finally, metallic lithium is used to manufacture non-rechargeable primary batteries and lithium aluminum alloys for the space or aeronautics industry.

Although technical grade (98.5% pure) or battery grade (99.5% pure) lithium carbonate, as well as the corresponding lithium hydroxides can be considered commodities, the extensive variety of forms of lithium presence in the earth's crust, as well as the production methods to extract lithium and its uses, establishes a strong market segmentation for this metal, as previously mentioned.

4. CHILE IN THE LITHIUM INDUSTRY

As a result of the Anaconda company's discovery in 1962, the Ministry of Mining[20] in 1969 commissioned the then Instituto de Investigaciones Geológicas (Geological Research Institute) to conduct a study on the Salar de Atacama (Pavlovic,1990). The study was carried out by A. Moraga, G. Chong, M.A. Fortt and H. Henríquez and was published in 1974 in the Bulletin of the Instituto de Investigaciones Geológicas (Moraga et al, 1974), and was possibly the cornerstone to establishing the lithium extracting potential of the salt lake. As of 1970, many additional studies were initiated by the Production Development Corporation, (Corporación de Fomento de la Producción, Corfo), including studies of the geology, hydrology, climatology and mineralogy of the salt lake, and confirming the excellent conditions of Salar de Atacama to produce lithium at a lower cost than the brine deposits in the United States (Pavlovic, 1990). In 1974 the government established the Mixed Salts Program (Programa de Sales Mixtas) at Corfo, which latterly became the Mixed Salts Committee (Comité de Sales Mixtas).

Foote Minerals Company, which had become aware of this new deposit, came to Chile and confirmed the high lithium concentrations on the basis of its own measurements.

In 1975 a first base agreement was established with the Government of Chile, whereby Foote was allowed not to pay the 6.8% royalty on the price of lithium that was subsequently required of SQM. Foote had the experience of working the salt lake in Clayton Valley, Silver Peak, Nevada, but the makeup of the brines of that salt lake[21] was very different to those of Salar de Atacama[22], because the latter could be crystallized by means of less costly evaporation processes. The technology used by Foote in Silver Peak to extract lithium carbonate from the brines had been developed by Foote, and in part by American Potash Corporation (APC), in Searles Lake, California, as of 1938 (Kunasz, 1986). Moreover, Foote conducted numerous research studies that led it to become the leading company in brine extraction and in the manufacture of different lithium compounds because it had the cheapest production methods. The lithium extracted from Searles Lake was not significant, but it prompted Foote's search for lithium in the Silver Peak salt lake. Upon arrival in Chile,

20 Minister Eduardo Simian

21 Low lithium content, 200 to 300 parts per million (ppm).

22 Average content of 1500 ppm.

Foote consolidated its leadership in lithium extraction from brines.

The Mixed Salts Committee (CSM – Comité de Sales Mixtas), which would only remain in existence for 10 years (1977-1987), played a fundamental role in the early development of lithium in Chile.

The discovery generated enthusiasm among Chilean technicians and engineers. Thus, toward the end of the 1960s several professionals who would be key players in the development of lithium started working at Corfo. Pedro Pavlovic, Civil Chemical Engineer from Universidad Técnica del Estado 1968, M.Sc. from Loughborough University, England, 1973, arrived at Corfo in 1968. The following year came Felipe Vergara, Civil Chemical Engineer from Universidad de Chile. The Chemical Engineering departments of those universities studied the crystallization of salts through solar evaporation and other techniques, used in the recovery of lithium and other metals from the salt lake. In 1976 Eduardo Morales, also a Civil Chemical Engineer from Universidad Técnica del Estado, joined the team; he would remain at CSM until 1983 when he went to work at the Chilean Lithium Society (SCL – Sociedad Chilena del Litio), eventually becoming its General Manager. Martin Laborde, Civil Chemical Engineer from Universidad Federico Santa María, directed Corfo's Mixed Salts Program (PSM – Programa de Sales Mixtas) from its beginnings in 1974, which became CSM in 1977. During the 1980s Laborde emigrated to other industries. Nancy Parada, Civil Chemical Engineer from Universidad de Chile, process specialist, joined CSM in the 1970s and remained there until its demise, after which she transferred to other areas in Corfo. The group was also joined by Fernando Ide, Civil Mining Engineer from Universidad de Chile. In the course of the 1990s other professionals also started working in the field and are now part of the select group of experts of this industry. Patricio de Solminihac, General Manager of SQM, is one of them. I have named seven of the most prominent senior engineers who participated in the beginnings of the lithium industry in Chile, at risk of omitting other distinguished professionals.

Unlike the copper industry, which required several thousand professionals at the time of its nationalization, the small lithium industry in Chile got started with the expert support of not more than 20 Chileans, in addition to engineers and geologists from the two U.S. companies, Foote and Amax.

In 2012 some of these professionals continued to be active in the field of lithium. New and valuable professionals have joined the industry in these past years, working mainly at the two lithium-producing companies in Chile. What has remained constant is that the group of expert professionals in lithium in Chile continues to be a small group of not more than 100 persons in 2017. On 22 October 1979 Decree Law 2,886 was enacted, which stated that lithium was a State resource[23] due to its potential use in nuclear fusion reactors and the interest of world powers in building thermonuclear bombs. Thus, Chile followed in the footsteps of the U.S. policy regarding lithium established after World War II. This decree was the culmination of a process that had begun in 1965 with the creation of the Chilean Nuclear Energy Commission (CChEN

23 Article 5 indicated: "Because it is a matter of national interest, as of the date of enactment of this decree law, lithium is reserved for the State."

– Comisión Chilena de Energía Nuclear) whose law (No. 16,319) established that the exploration and development of natural atomic material, or material that could be used to produce nuclear energy "could not be subject to any type of legal acts except when executed by or occurring within, in conjunction with or with the prior authorization of the CChEN." In 1975 regulations concerning "Nuclear Terms" were published, indicating that lithium was a material of nuclear interest even though it was not reserved for the State but was subject to "free right of claim" (Aserta Consultores, 2010). In 1976 Decree Law 1,557 modified the CChEN law, indicating, among other things, that the CChEN could expropriate for its own use any materials of nuclear interest once extracted.

Decree Law No. 2,886 indicated[24] "The granting of mining concessions in relation to calcium carbonate, phosphate and potassium salts remains subject to the general rules of the Mining Code, reserves lithium for the benefit of the State, and interprets and modifies the laws referring thereto". Article 5 of this law establishes that: "Because it is a matter of national interest, as of the date of enactment of this decree law, lithium is reserved for the State. The sole exception to the foregoing is: a) The lithium existing in previously granted lots, whether in respect of lithium or any of the substances named in paragraph one of article 3 of the Mining Code, and which, on the date of publication of this decree law in the Official Journal, have already registered their survey record, such record is in force, and whose statement of discovery, in turn, has been registered prior to 1st January 1979."

According to Aserta Consultores (2010), the strategic dimension of the use of lithium gained a greater stronghold during the military regime, in the midst of a global arms race, in which thermonuclear bombs represented the "state of the art" and nuclear fusion reactors were considered to be on a viable horizon (Chilenskas et al, 1976).

¿How would these regulations be translated in the Constitution of 1980 and in the Mining Code of 1983?

According to José Piñera (Piñera, 1981) "up till 1971 the country had an established legal system in this regard, which was as stated in the Mining Code of 1932. However, the Constitutional Reform of 1971, in addition to nationalizing the Large-Scale Copper Mining Sector, seriously weakened mining property rights. The Constitution of 1980 maintained the proposition introduced in 1971 that the State had absolute, exclusive, inalienable and imprescriptible title to all mines, but added that the precise nature of the mining concession would be subject to a constitutional organic law, a legal form that was unprecedented in our legal framework".

Further on Piñera indicated "Well, yesterday 1st December, the Honorable Government Junta has approved the Constitutional Organic Law on Mining Concessions[25] after the Constitutional Tribunal had unanimously responded to two key queries in this regard. Within the framework of the Constitution,

24 Revoking article number 8 of Law 16,319 (1965) created by the Chilean Nuclear Energy Commission

25 Law 15,242 known as the Mining Code, voted by the Government Junta on 1st December 1981 and published in the Official Journal of 16 February 1982.

the legislator has approved a vigorous right of concession that has been called full concession. This puts an end to a decade of uncertainty regarding mining rights."

According to the reasoning of José Piñera (Piñera 1981), the Lithium Law of 1979 complied with the Constitution of 1980 in the sense that the granting of concessions was subject to several exceptions. One of them was as established in the constitutional reform regarding the nationalization of copper, the second was the acquisition of a concession by the State, a third was to place a constraint on concessions, and a fourth due to the declaration stating the importance of lithium for national security. Lithium was considered to be within categories three and four.

At the same time, many legal scholars contested this interpretation, but it ultimately prevailed and has been applied in Chile ever since.

By 1977 Corfo, involved in lithium through the Geological Research Institute (Instituto de Investigaciones Geológicas) had requested and obtained 59,820 mining lots in Salar de Atacama. It subsequently relinquished 27,052 of them, remaining with the 32,768 it has to this day (Aserta Consultores, 2010). Also in 1977 Codelco had obtained the Ana María lot in the Salar de Pedernales and others in the Salar de Maricunga, both located in the region of Atacama. Of the 15 salt lakes where there are known lithium resources in Chile, Salar de Atacama is the largest, almost 10 times the size of the second largest, Pedernales, and 20 times that of Maricunga, which is the fourth largest. Moreover, Salar de Atacama has a greater concentration of lithium than the rest of the salt lakes in Chile and it is at a lower altitude, thus favoring the solar evaporation process through which the lithium salts are concentrated. The rest of the 15 salt lakes are: in the region of Atacama, La Isla, Aguilar and Las Parinas. In the region of Antofagasta are Punta Negra, Aguas Calientes 2, Aguas Calientes 1 and Aguas Calientes 4, Pajonales, Quisquiro or Loyoques, Tara, Pujsa, and Capur.

4.1- From Foote to Albemarle

In 1979 the possibility of producing lithium carbonate economically in Salar de Atacama was confirmed, upon which, on 13 August 1980, Colonel Rolando Ramos, Executive Vice President of Corfo, and William Walsh, Chairman of the Board of Foote, established the Chilean Lithium Society (SCL – Sociedad Chilena del Litio) with Corfo holding a 45% share and Foote 55% (Corfo, 1982). At the same time these two corporations entered into a Basic Agreement.

In 1988 Corfo sold 25% of its share to Foote, and in 1989 the remaining 20%, leaving Foote with 100% of the SCL ownership. At that time the Chilean State did not have fresh resources to place in SCL, so Corfo placed the fraction of Salar de Atacama[26] it assigned to SCL as payment for 45% of the shares. This consisted of 3,343 lots out of 32,768 it held in the salt lake. In this way Foote obtained a favorable deal for working the lithium in the salt lake in exchange for installing the technology it had developed and owned exclusively at that time.

26 16,720 hectares located in the southern part of the Salar.

The creation of SCL contained the Basic Agreement that established the conditions for carrying out lithium operations. Corfo assigned to SCL a maximum production quota of 200,000 tons of contained lithium or lithium equivalent in the form of lithium metal products[27], for a period of 30 years, renewable for five-year periods, to develop that amount of lithium, and granted it exclusive rights to produce lithium in Salar de Atacama for a period of eight years (CSM Corfo, 1980). The Chilean Nuclear Energy Commission, CChEN, authorized SCL to sell various products, except those that could be used to produce energy through nuclear fusion (Cochilco, 2009).

By the end of 2016, SCL had extracted 93,000 of the assigned 200,000 tons, but with the planned production increase to 13,000 tons per year of contained lithium that would take place after 2011, the term of the original contract would extend until 2021 (Morales, 2011).

The commissioning of SCL's first plant involved an investment on the order of 54 million dollars (Pavlovic, 1990) and immediately placed Chile on the map in the world lithium industry. The production process consisted of a system of solar evaporation ponds, located in the Salar de Atacama itself, and a chemical plant in La Negra, located 15 km south-east of Antofagasta, to process the brines and produce lithium carbonate.

In 1998 the Cyprus company purchased Foote Mineral Co., creating Cyprus Foote. That same year Chemetall bought Cyprus Foote, creating Chemetall-Foote. In 2004 the U.S. based Rockwood Holding company bought Chemetall, creating Rockwood Litio Limitada (RLL), which replaced SCL in the mining of the Salar. In 2015 Albemarle, another U.S. company, bought Rockwood and the name of the company working the salt lake was changed to Albemarle Limited. At the end of 2016 Corfo and Albemarle modified the basic agreement signed in 1980.

27 The brine-based products that were in greater demand in the market at the time were lithium carbonate, lithium chloride and lithium hydroxide.

Figure 1 shows the institutional and productive history of lithium in Chile.

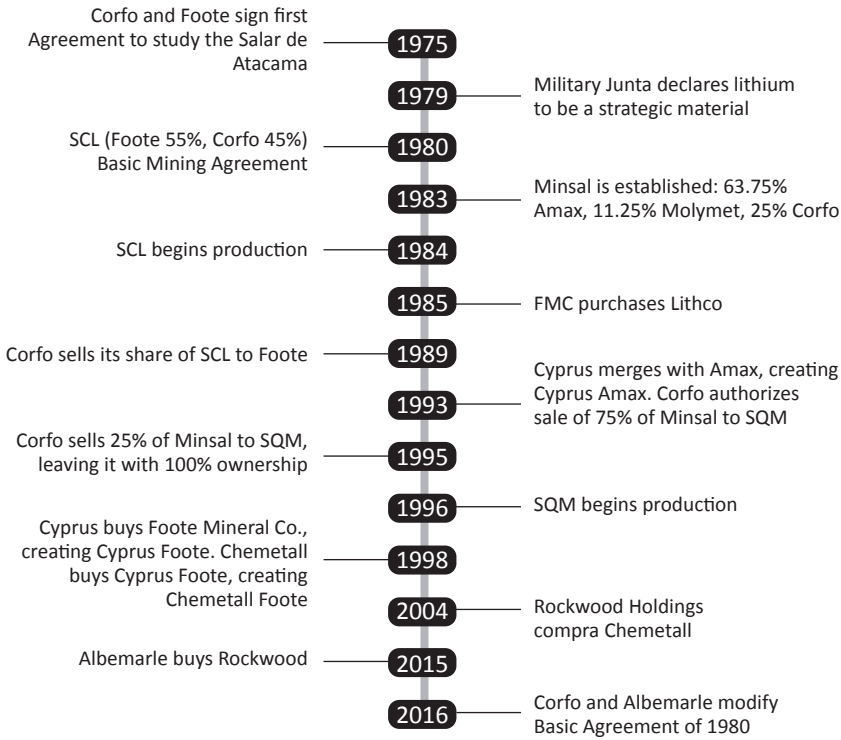

Figure 1: Evolution of ownership of companies working lithium and other salts in Salar de Atacama

4.2- Minsal and SQM

Ever since 1975 Corfo had been conducting studies aimed at analyzing the viability of working other resources of the Salar, potassium and boron, which gave rise to the idea of carrying out a second lithium mining project, but this time including the development of these other elements. The Saline Processors Inc. company provided guidance in these studies and was pivotal at the time of defining the most appropriate technologies. As a result, in 1983 Corfo made a call for bids for an international project to produce potassium salts, boric acid and lithium (Pavlovic, 1990). These salts can be considered to be by-products of lithium production, and lithium can be considered a co-product of the production of those salts.[28]

28 The process of producing lithium on the basis of brines consists in evaporating, by natural means, the brines deposited in large ponds. During each stage of evaporation certain salts and lithium begin to concentrate, resulting in potassium salts and other compounds until a brine concentrated in lithium, boron and magnesium is obtained, which is used to feed the chemical plants producing carbonates, hydroxides and chlorides.

The 1983 bidding terms and conditions established in clause 5.5.6, Research regarding uses of lithium: "Whenever the successful bidder produces lithium salts, it shall pay Corfo 0.8% on the gross sales value of such salts to contribute toward the funding of lithium research in the country".

In a personal communication with Pedro Pavlovic in June 2012, he indicated that: "Via Agreement No. 969 of 1984, the Chilean Nuclear Energy Commission recommended that, with the aim of increasing the value added of lithium extracted from Salar de Atacama, the corporation to be established between Corfo, Amax and Molymet will undertake to make yearly contributions toward the funding of a Lithium Research Center. Accepting this recommendation, the Base Agreement that gave rise to Sociedad Minera Salar de Atacama, Minsal, in 1986, stipulated in Clause Sixteen, point V, "Special rules regarding lithium", that the contribution of the corporation to the funding of lithium research plans will be included within the sum of royalties (6.8%) that will be paid to Corfo for the sale of lithium products, as established in the Lease Agreement."

"The same recommendation and undertaking indicated in CChEN Agreement No. 969 were maintained in the Agreement for the Salar de Atacama Project (Clause Fourteen) signed on 12 November 1993 between Corfo and SQM" (Pavlovic personal communication, 2012).

"As a result of Minsal Ltda. changing from a limited company into a closely held corporation in 1994, with Corfo (18.18%) and SQM Potasio SA (81.82%) as partners, the CChEN ratified several authorizations that had been granted to the corporation for the production of lithium salts through Agreement No. 1576 of 1995. In number 9 of this agreement, the Commission recommended that, in order to increase the value added of lithium extracted from Salar de Atacama, Sociedad Minsal, through Corfo, would undertake to make yearly contributions toward the funding of a Lithium Research Center, devoted to conducting studies regarding both nuclear and conventional industrial applications of lithium" (Pavlovic personal communication, 2012).

Up to 2017 Corfo had failed to recognize this agreement, to the detriment of the development of lithium research in Chile.

The U.S. company Amax had already come to Chile in 1980 in search of potash[29], a mineral containing potassium, and when it realized that the exclusive rights granted to SCL to produce lithium were only for eight years, it became interested in working other parts of the Salar de Atacama. Amax and FMC (ex Lithco) participated in the bidding process tendered by Corfo in 1983 and the former was awarded the bid together with Molymet. Thus, in 1986 the company Minsal Minera Salar de Atacama was established, made up by Amax Inc. 63.75%, Corfo 25%, and Molymet 11.25%. Corfo contributed 14,814 mining lots on lease to Minsal. In 1989 Minsal completed the feasibility study of the project, which required an investment of 360 million dollars, to produce potassium chloride, potassium sulfate, boric acid, lithium carbonate and lithium hydroxide. At the time Minsal S.A. was established, Corfo had authorized the mining of up to 180,100 tons of metallic lithium, meeting a schedule that had

29 Common name assigned to several water-soluble salts that contain potassium and are extracted or manufactured.

been pre-approved by Corfo itself and starting in 1992 with 2,800 tons. Due to the mining of several products in this new sector of the Salar, the working costs of lithium were much lower than those of other lithium operations in the world. Minsal produced lithium, but at the time of estimating extraction costs, the revenue obtained through the sale of potassium salts and boric acid was discounted. The contract with Minsal established that the CChEN had a preferential option to buy lithium 6. Unlike SCL, which had been granted the mining ownership, the contract with Minsal was on a rental basis.

Ultimately, Minsal started to produce lithium in 1996, four years later than planned, due to an increase in project costs. Amax was not convinced about making the investment. Thus on 12 November 1993 SQM, which had been privatized in 1985, acquired 75% of Minsal, a transaction that was approved by Corfo and the CChEN. FMC showed interest in this transaction, but Corfo gave preference to a Chilean company, granting it an additional period up to 2030 and increasing the mining lots under lease to 16,384, undertaking not to work the 11,670 lots it still had left in the Salar[30]. In December 1995 Corfo sold SQM the additional 18.18%[31], so that the company was left with 100% ownership of Minsal. The new company changed its name to SQM Salar SA.

After losing the bidding award to Amax, FMC (ex Lithco) turned to examining the Salar de Uyuni in Bolivia but failed to reach an agreement with the government of that country. FMC had also shown interest in the Salar de Hombre Muerto in Argentina and there it managed to negotiate the right to mine that deposit with the Argentine government (Evans, 2008). This salt lake is located just 220 km to the south-east of Salar de Atacama, crossing the Andes range. Although its reserves were much smaller than those of Uyuni and Atacama, its advantage was that the brines were very "clean" and could produce a cleaner lithium chloride than in any other part of the world. Operating costs to work the lithium in this salt lake turned out to be higher than anticipated, and so the startup of production was delayed for many years. FMC began to operate Salar de Hombre Muerto in 1997-1998, a year after Minsal in Salar de Atacama. Shortly thereafter it was seen that the evaporation was not as efficient as had been foreseen, among other reasons because it rained in that area. The process to extract carbonate required introducing bio ionic exchange resins.

By December 2016 SQM had produced 92,000 tons of lithium out of the assigned total.

4.3- The debate in Chile

The debate on lithium in Chile began in 2007 with a comprehensive project presented by Senator Alejandro Navarro[32], which declared radioactive substances or substances that could be used to generate nuclear energy, among them lithium, to be non-eligible for concession or special operations contracts

30 Personal communication with Ernesto Tironi, General Manager of Corfo at the time of the transaction.

31 The figures do not add up to 100 because there had been a capital increase by SQM, which diluted Corfo's share.

32 19 December 2007, Bulletin 5655-08.

(CEOs – contratos especiales de operación). This project, which modified the Constitution and the Mining Code, impeding the application of CEOs was not voted in the Senate but gave rise to the beginning of the debate. The project also proposed that the State was entitled to exercise the first option regarding purchasing lithium or radioactive products from companies producing them as a by-product, paying separation costs. In the case of lithium this would apply to companies producing, for example, potassium salts and boric acid from brines and that simultaneously extracted lithium salts.

It is apparent that Senator Navarro's interest went beyond lithium, extending to radioactive materials. What was the motivation to introduce such changes at that time, after 17 years of government by the Concertación coalition?

On 30 September 2009 during the discussion period of the Senate session, senator Ricardo Núñez indicated that the demand for lithium had grown 7 to 8% per year over the last decade, which had led to its price rising from 1,760 to 6,000 dollars per ton[33]. He requested the Senate to send an official letter to the Ministry of Mining requiring it to provide information regarding administrative concessions and special operations contracts that the ministry itself or the CChEN had granted for the exploration, mining or benefit of lithium.

On 1st December 2009 senators Ricardo Núñez, Camilo Escalona and Juan Pablo Letelier submitted a second constitutional reform project[34] that affected radioactive materials and lithium. With regard to the latter, it indicated that "in light of the established rules it is evident that lithium has the status of a non-concessible substance only by virtue of the constitutional organic law governing mining concessions and the Mining Code, but not according to the Political Constitution of the Republic." Further on it stated that "the strategic nature of lithium is only indirectly protected in the organic-constitutional legislation and more specifically in the previously stated decree law[35]", so that it would "be sufficient to reform the respective constitutional organic law to enable lithium to dispense with its status as a non-concessible substance and, therefore, allow it to be subject to normal mining concessions as established in the Constitution itself." Chile's presidential regime leaves little room for reform initiatives of the parliament, therefore most parliamentary initiatives have a purely political purpose, knowing from the start that they will never become law.

This was the first debate in certain depth about lithium that had taken place in the country since the metal was discovered accidentally by Anaconda Copper Company when looking for water in the Salar de Atacama in 1962. Article 6 of DL 2,886 of October 1978, prepared and enacted by the Military Junta, made greater reference at that time to the importance of lithium in Chile, although it was quite succinct in its definition. "Because of their national interest, natural atomic materials and lithium." No discussion had taken

33 This assertion possibly referred to the nominal price, because the real price had not increased, as shown in Figure 13.

34 Senate Bulletin 6781-07 of 1st December 2009.

35 Decree Law No. 2,886 of 14 November 1979.

place, to this day, regarding its strategic importance, neither was a definition advanced regarding what a "strategic" resource meant for the country.

4.4- What is a strategic material?

For the United States the meaning of strategic material was clear. The co-director of the U.S. Institute for the Analysis of Global Security (IAGS), Gal Luft, stated in 2010 that in the case of the United States, the definition of a strategic material[36] was, first, a material required to supply the military and the essential needs of the civil population during a national emergency. And second, materials that were not found or produced in the U.S. in sufficient quantities to meet the indicated need. Another way of expressing these definitions is to speak of strategic materials when they are essential to defense systems or when they fulfill a unique function, without viable alternatives.

In his presentation, Gal Luft provided another criterion to consider a material strategic in nature. This depended on two conditions, which need to occur simultaneously. One is the criticality of its application (whether there are viable substitutes in the short term) and the second is the vulnerability of its supply.

The latter leads immediately to discard a multinational policy promoting the lithium triangle (Clarín, 2011) to control the supply and/or price, because the abundance of lithium at a global level would mean that the United States and other countries such as Japan, Germany and China, all heavily involved in the development of technologies for producing lithium batteries for automobiles and other applications, would develop alternative sources for lithium mining even if they were more expensive in the short term.

From the perspective of a country like Chile, the definition of strategic material or resource does not coincide with that of the U.S. If Chile were to define strategic materials and resources, stronger emphasis would have to be placed on their weight in the generation of the current gross domestic product and, possibly, on domestic exports. Ultimately, the small size of the Chilean market suggests that in the short and medium term, until Chile reaches full development, a good part of government revenues, corporate surpluses and employment will issue from exporting industries. Such revenues, surpluses and employment are key to ensure that Chileans will have access to the materials and goods they need, oil and other fuels, consumer goods and food, obtained from the local market or from imports.

The main candidates to be considered strategic materials according to this definition would be copper, molybdenum, gold, cellulose and fruit, and perhaps other resources. But on no account would it include lithium, which in 2011 represented only 0.3 to 0.4% of the country's exports, and was not likely to become a major fraction of the GDP and of exports in the next decades. In 2015, in spite of the rise in lithium prices, exports of this metal were 0.4% of the total goods exported by Chile.

36 Dr. Gal Luft, presentation, "How Strategic is Lithium?", Technology and Rare Earth Metals Center, International Lithium Alliance, Institute for the Analysis of Global Security, Seminar "El Litio y la Economía Nacional" (Lithium and the National Economy), organized by Sonami, 5 August 2010, Santiago, Chile.

Some opinion leaders have argued that lithium could be strategic for Chile because of its great technological importance in energy storage and other applications, and because it could become a substitute for oil. Any of these assertions would require a strong commitment by the State to invest resources in research and innovation to develop national scientific and professional capabilities, which had not occurred until 2016. Chile abandoned the model of supporting state research in 1987 when Hernán Büchi was Finance Minister, establishing that the State would no longer finance research institutes, specifically CIMM, INTEC and others.

Now, what are the duties of the State when it defines a material as strategic? Obviously, if it uses the definition mentioned above, the State should at least ensure the following aspects of each strategic material: state institutions with comprehensive knowledge of the different markets at a global level, including the entire value chain, and the opportunities and challenges that are involved for the country; free access to markets, ensuring that no barriers are set up to prevent such access, for example by stating that one of the materials is toxic; comprehensive knowledge of the properties of such materials, in particular regarding their effects on human health and the environment; early knowledge regarding possible substitutes and their technical and commercial viability; promoting the competitiveness of these industries at a national level, including the development of research and innovation to ensure that the country is at the leading edge in terms of knowledge and technologies concerning these resources and materials.

Anyone can appreciate that the State only meets a small portion of these tasks at present with regard to materials that could be strategic. Even the Nuclear Energy Commission ceased its research on lithium in the 1990s, although it would appear to have taken up this matter again recently.

4.5- Cochilco's Strategic Report on Lithium

In December 2009 the Chilean Copper Commission (Cochilco, 2009) published a report entitled "Antecedentes para una política pública en minerales estratégicos: litio" (Preliminary data for a public policy on strategic minerals: lithium). This occurred at the end of the first term of President Bachelet, when there was already a new president elect. The title of the Cochilco document suggested conclusions that would be of interest to the country. The document would be used profusely later on, thus making it important to analyze aspects of its contents.

The report considered the historical price of lithium carbonate in nominal terms, which mistakenly induced the three companies that controlled the market – FMC, Chemetall, and SQM – to increase the price by close to 250% between 2004 and 2008.

This fact was cited by several opinion leaders, including the constitutional reform project sponsored by senators Isabel Allende, Camilo Escalona, Juan Pablo Letelier, Pedro Muñoz Aburto and Fulvio Rossi[37]. Former Congressman

37 Bulletin 8,299-08, Chilean Senate, July 2012.

Antonio Leal[38] used the Cochilco 2009 report to reach the conclusion that "For this reason and for the battle that is being waged worldwide against carbon dioxide and the excess use of fossil fuels, global demand for lithium increases between 7 and 8% per year and its international price has risen from 1,700 dollars to 6,000 dollars per ton in a few years, and this price will continue to increase in accordance with its greater demand in the world market."

According to the economic theory of commodities, future prices can rise due to increased demand or costs, a decrease in the value of the dollar or a restriction of supply. Increased demand would lead to higher prices only if there are restrictions on supply, which in the case of the lithium industry could not happen, at least in the next several years, because up till 2015 there was an overcapacity in mine lithium production.

Moreover, the Cochilco 2009 report gave credibility to the Tahil estimates regarding reserves and resources discussed in chapter 11, which had been discredited by Evans. This provided the occasion to conclude in the report that "No consensus exists regarding whether the current lithium reserves can meet future demand or not." This matter will be discussed in depth in chapter 5.

In 2009 an optimistic scenario was a 7% growth in demand over the next 10 years and also high figures in the following decades. In 2017, this growth scenario was the most conservative, and yet the global debate did not reveal any apprehension about a shortage of reserves.

Cochilco's report of December 2009 confirmed the assertions Senator Núñez had made a short while before in the Senate and served as a basis for the arguments presented by many opinion leaders later on. It is normal for this to be the case, because the Chilean Copper Commission is a serious and respected institution in Chile. This does not mean, however, that all its assertions are well founded, as I believe has been established before.

4.6- Events since December 2009

At the end of 2009 a "Lithium Desk" was created, aimed at examining policies for the future of lithium in the country. On 15 January 2010 the Minería Chilena journal reported that this group had made a field visit to the SQM premises in Salar de Atacama. The visit had taken place prior to the presidential election of October 2009. The desk was chaired by the Ministry of Mining and was made up by representatives of Sernageomin, Cochilco, CIMM and CChEN. One of the objectives of the "desk" was to create a Lithium Institute that would give value added to the metal.

The Minister of Mining, Santiago González, stated[39] that the objective was "not only for us to be exporters of raw material but also to contribute with technological research and development to improve the elements we extract."

On 22 December 2009 Minería Chilena reported an interview held with a senior executive of Codelco, who had stated "Next year we hope to carry out a study that will allow us to quantify our lithium reserves." The publication

38 El Mostrador, 18 June 2012.

39 18 January 2010, sustentable.cl, El Portal del Medio Ambiente.

indicated that a discussion was under way in Congress regarding a "constitutional reform project seeking to consign the exploration and mining of natural atomic materials and lithium solely to the State and companies under its mandate", in reference to the previously mentioned project proposed by Senator Núñez.

On 4 February 2010, the El Mercurio newspaper published the following editorial: "In 1982, Law No. 18,097 governing mining concessions, based on an outdated criterion that considered lithium to be a non-concessible material, in the belief that because of its future potential in the nuclear fusion industry – even though very far into the future – needed to remain in the hands of the State." Further on it stated: "The restrictions thus in force rapidly turn into major obstacles for national production, both for those that have been granted production permits and other companies that aspire to do so." "At this stage of socioeconomic knowledge, it is untenable for its production to be developed by a state corporation. Maintaining metals out of the reach of private investment arise from an obsolete idea regarding the creation of wealth and ignores the concept of present value. There are those who continue to prefer that the State decide how much and when to produce a resource, but today it is evident that the state bureaucracies that make the decisions in these cases are not nearly as knowledgeable as the rest of the economic players regarding the optimal opportunities for doing so. This perception also leads to postponing extraction, in the hope that possible higher prices in the future will be beneficial for the country, and that it should be in the hands of state and not private extraction to transfer such wealth to the population".

That same day the La Tercera newspaper also presented an editorial on the subject of lithium, indicating the convenience of lifting the restrictions on lithium mining. It stated: "There is historic evidence that countries have erred when they presume to determine the best time to mine the resources, sacrificing the welfare of society by limiting or postponing their development".

Numerous letters were sent to both newspapers in the course of the following days, giving opinions regarding lithium.

On 3 May 2010 nine congressmen presented a constitutional reform project[40] on the subject of lithium, as follows: "A proper interpretation of the constitutional rules and the organic law makes it possible to assert authoritatively that even in the case of mineral substances, lithium is non-concessible through the express will of the State, and also belongs solely and exclusively thereto. Furthermore, such a legal regime would appear to provide sufficient protection of the national interest in a natural resource that was stated in its time to be strategic for the security of the nation. It was thus understood by the constituent and legislative powers, and for this reason they prevented the private sector from substituting the State in the mining or exploration of such natural resources by way of a regular mining concession, denying it the right to establish some sort of mining property. Meanwhile, we confirm that lithium continues to be a strategic substance, although today not for national defense reasons but to become a new support for national development, and in this sense it is essential to create the necessary consensus

40 Bulletin 8247-07 of 3 May 2010.

regarding what could be the most demanded energy source toward the end of the century".

This project called for a debate and proposed to modify article 19, No. 24 of the Constitution, specifying that "In the case of lithium, the President of the Republic will require authorization from the National Congress to enter into such special operation contracts".

On the 18th of the same month a group of four Congressmen[41] proposed that lithium should be declared concessible, eliminating the reference to lithium contained in article 3 paragraph 4 of Law 18,097 regarding mineral concessions, article 7 of the Mining Code, article 5 of Decree 1886 and Law 18,302 creating the CChEN. That is to say, the proposal was to extend access to lithium to private companies, the same as other Chilean minerals with the exception of nuclear substances.

On 28 July 2010 during the regular session of the Senate, Senator Juan Pablo Letelier requested that an official letter be sent to Corfo to require it to provide a record of its lithium lots and a copy of the rental contracts, the authorization for those contracts, to explain why the Corporation had refrained from working the rest of the lithium lots, the quantity and origin of the contributions made to the CChEN to finance lithium research, and the contribution allocated by the tenant companies (SQM and SCL) to lithium research and development. Finally he requested the delivery of the minutes of the Merino commission, where the Mining Code had been discussed and the strategic nature of lithium established. Senators Carlos Cantero and Alejandro Navarro adhered to this request.

In 2010 two seminars on lithium took place, one organized by the Sociedad National de Minería (Sonami) on 5 August[42], and a second event[43] organized between 10 and 11 November by the United Nations Economic Commission for Latin America and the Caribbean, ECLAC. Senator Juan Pablo Letelier spoke at the first seminar. In November 2011 the Universidad Católica de Chile held a third seminar on lithium where numerous experts spoke, including the president of the Senate's Energy and Mining Commission, Senator Carlos Cantero.

It is impossible to summarize the content of these seminars, but at the risk of leaving out several concepts, I venture to assert that the position of the companies and the lithium industry was to indicate that the known lithium reserves and resources were abundant and that there was no concern that lithium might become scarce, confirming the opinion of geologist Evans. As was already indicated, the estimated resources of the two lithium-producing companies in Chile were in the higher range shown in Figure 2, close to 40 million tons of lithium metal equivalent.

The opposing arguments were made by Senator Letelier at the Sonami

41 Bulletin 6940-08 of 18 May 2010.

42 Entitled "El litio en la economía nacional" (Lithium in the national economy)

43 Entitled "El desarrollo sostenible del litio en América Latina, asuntos emergentes y oportunidades" (Sustainable development of lithium in Latin America, emerging issues and opportunities).

seminar, where he reiterated the arguments that had been previously mentioned regarding the reform projects presented by different senators and congressmen, in addition to the request for information set forth in a regular session of the Senate.

In reference to the seminar of the Universidad Católica of 2011, the Minería Chilena journal of 18 November summarized the debate as follows: "the demand for lithium, used especially in the manufacture of automotive and technological batteries, is envisaged to double over the next 10 years, but the current concession system does not expedite its production. It was stated that even though its production costs are advantageous due to its abundance in the salt lakes, Chile could lose its leadership in the industry given that Argentina and Canada, among other countries, are actively developing this metal".

During January 2012 The Senate's Mining and Energy Commission held two sessions analyzing the situation of the lithium industry at a global and Chilean level. These discussions revealed strong differences in the opinions of the different senators[44].

On 31 January 2012 the La Tercera newspaper published an opinion column written by Gustavo Lagos[45] in which he asserted that "Chile has the best lithium reserves in the world in Salar de Atacama and other salt lakes, and in 1998 displaced the United States as leading producer. In spite of the increase in production since then, in 2012 it will be equaled or overtaken in production terms by Australia and perhaps Argentina later on. This is due to an obsolete legislation that declares lithium to be "strategic" and has hindered the development of various salt lakes and the Salar de Atacama itself".

Later on he added, "One alternative is to hand over its operation to state enterprises, but no state companies possess the technology to work this metal, there are very few specialists in Chile, and the State gave up its interest in lithium a long time ago. In 1988 it closed Corfo's Mixed Salts Committee, nobody knows what happened to the resources earmarked for research in the metal, and in the 1980s and 90s Conicyt (National Commission for Scientific and Technological Research) rejected three major projects to develop technologies for lithium batteries and production."

4.7- CEOL bidding process

On 7 February 2012, Mining Undersecretary Pablo Wagner announced that the government would extend an international tender for a Special Operations Contract for Lithium (CEOL – Contrato Especial de Operación del Litio) that would "make it possible to work the mineral in locations where today it is forbidden".[46] "The CEOLs include the option to extract lithium in an equivalent of 100,000 tons over a period of 20 years, starting as of the time of signing the contract. The strategic nature of the mineral only allows two companies, SQM and SCL, to mine the resource in the country. Notwithstanding, Chile is the

44 Observations by Gustavo Lagos, who participated in the Commission sessions of January 4 and 11.

45 Professor of the Pontificia Universidad Católica de Chile.

46 La Tercera, 8 February 2012.

main producer of lithium, controlling 41% of the market at a global level". "Whoever is awarded the bid will determine how, when and where it will be put into operation". This could be in several salt lakes. It added that "The tender will be awarded to the bidder offering the largest sum for the CEOL". Wagner estimated that the government would obtain 350 million dollars for each project awarded during the operations period of the contract. This included a royalty of 7% over the lithium price.

Among the interested parties were SQM, Li3 Energy, Minera Copiapó, the Australian-Canadian Talison Lithium Limited, the U.S. Pan American Lithium Corp and the Taiwanese Simbalik companies.[47]

On 14 February, Juan Carlos Guajardo, Executive Director of Cesco, commented[48] "The government has decided to promote Special Operations Contracts for Lithium (CEOLs) to increase the domestic production of this metal, restricted up to now due to being considered a strategic mineral and, therefore, not subject to concession, unlike what occurs with the immense majority of national mining resources. By opting for this administrative track and not for the modification of its strategic status through the enactment of a law, the aim is to increase production rapidly, in light of the fast-growing competition of other countries. This desirable haste should not, however, overshadow the necessary search for a widespread support that will provide stable foundations for the development of the lithium industry in Chile. Mining is a long-term activity, therefore political legitimacy is essential."

Guajardo added that "it is necessary to address aspects such as Salar de Atacama, where two companies have been mining lithium resources thanks to direct contracts with Corfo. This Salar accounts for 80% of national reserves, therefore although the CEOLs are valuable to generate greater competition and options, they would only be able to access 20% of the national reserves. The quality and quantity of this mining resource in the Salar is such that it would be unthinkable to propose a general policy on the basis of CEOLs without considering how it would affect the situation of Salar de Atacama. It is therefore desirable that Corfo, through its contracts with both SQM and SCL, ensure that the revenue obtained is consistent with the levels that would be reached with the CEOLs, and that the currently dominant players will continue to participate in the lithium market, but without affecting the ability to compete of new players that we seek to attract". "A second aspect is to seriously consider the possibility of developing this industry technologically. This is not to say that we should seek to compete today in the sophisticated manufacturing of lithium batteries, but that we should establish, within the framework of the CEOLs, mechanisms that will allow large corporations interested in the resource to contribute technology that would initially make it possible to develop products other than lithium carbonate, which is one of the most basic products in the value chain of the industry. Finally, it will be necessary to strengthen the environmental assessments of salt lake mining operations in order to ensure a good balance in these special geological bodies. The current situation of lithium in Chile is far from encouraging".

47 Diario Financiero, 8 February 2012.

48 La Tercera, 14 February 2012.

As a result of the announcements regarding the CEOLs, on 23 February of that same year the Confederación de Trabajadores del Cobre (Copper Workers Confederation) extended an invitation to establish a forum that would defend lithium mining by Chilean state companies.

On 24 March former President Ricardo Lagos participated in a forum organized by the Federación de Trabajadores del Cobre, FTC, where he proposed to set up a task force to debate about lithium[49]. Placing emphasis on the history of mining in our country, the former president stated that, at the time, when the subject of the royalty was discussed, the idea was that "so as not to repeat history, if we are going to receive state revenue from a natural resource, our obligation is that such revenue be used for an investments other than to finance running costs. Therefore, what is extracted from there must be invested so that it can become the capital of the future, that is what history teaches us." Lagos also indicated that the core of the theme is that, although it is true that the State has the power to extend special operations contracts, there is doubt regarding the characteristics that such contracts will have. In this sense he raised several queries, such as "Does the government have a concrete opinion on the subject or is this something we can debate about? What will be the consequences of the upcoming tax modifications?"

He added "This is why I believe it would be important to establish a task force, with the participation of members of parliament and experts in the field, to debate not only about who can be part of this market or the taxes that could be applied, but also regarding the carbon emissions that will be generated". "It would be extremely negative for this issue to be addressed assigning it urgency status, which I understand would be for this year, and not allow us to debate about it. Can we give ourselves six months or a year to reach a consensus about the economic issues that are being raised in this bidding process? Is there a minimum in terms of the cost that is going to be put on the table, or is there no minimum? This is a very delicate subject", added the former president.

Mining Undersecretary Pablo Wagner, who also participated in the forum, added, "In terms of demand in the case of vehicle batteries, worldwide production in 2010 was 141,000 batteries, and is expected to increase to 1,700,000 by 2015. In China, for example, there are one thousand companies producing lithium batteries and for this reason, to enter that market on the upswing, which would be in 2020, we have to start working now, there are already countries that will begin to produce in 2014", said the undersecretary. In addition to this, he emphasized that in our country we have five salt lakes that cannot be mined, because under the 1932 regime – changed in 1979 – they were already subject to concession, and moreover "there are more than 50 salt lakes closed down and basins that could be worked, which would allow us to have resources available for the next 1,500 years", stated the mining authority, who also indicated that with regard to prices, these are stable in value and will be increasing toward 2020. This concludes the information provided on the Terra portal.

49 http://economia.terra.cl/noticias/noticia.aspx?idNoticia=201203241100_TRR_81019646

Former President Lagos was concerned about different aspects of the proposals made by senators and congressmen in terms of projects to modify the Constitution in Congress and did not address the issue of the State's exclusive right to mine lithium.

In a session dated 11 April 2012 the Senate's Energy and Mining Commission debated on the subject of lithium. Senator Carlos Cantero, chair of the commission, asserted that "the strategic nature of lithium is obsolete and anachronistic, harking back to the Cold War, due to the nuclear use of the material.[50]" "I am in favor of imposing a mixed mining system between private parties and the State, which necessarily would involve giving value added to the mineral", he said. He also expressed his concern about the scant amount of research and development conducted in Chile regarding the material. "I asked and there is no Conicyt project associated with lithium research, therefore there is no research going on, and with only two companies mining lithium, neither is there a powerful industry behind it." According to Senator Cantero, in addition to discussing about a working model, it is necessary to create human capital, and in this sense he thought it expedient to promote a National Lithium Institute, funded by a royalty paid by the industry itself (BCN website, 12 April 2012). The same website cited Senator Isabel Allende at that session: "I feel that it is serious for members of parliament to have heard about the implementation of the CEOLs through the press" and added that "the debate on lithium should not be carried out behind the backs of the citizenry or the Congress." Coinciding with Senator Cantero, the senator emphasized the importance of creating and funding a National Lithium Institute, in light of the impending development of the automotive industry using electric or hybrid power (BCN website, 12 April 2012). Quoting opinions advanced by Cochilco, Senator Allende considered that it is necessary to discuss and plan a clear public policy and to update data and studies regarding the mineral, and at the same time generate value added, "so as not to repeat what happened with copper, which we don't develop and sell unrefined". The senator added that "lithium should be a strategic material, and Codelco should be at the leading edge in terms of lithium research and mining. This, after a public and informed discussion." A different opinion was expressed by Senator Jaime Orpis (UDI), who stated to be in favor of granting the mineral concessible status. In the senator's view, "we are entering into a post-oil era, a fossil fuel that will last for 38 more years, making electricity the great power that will move the future."

For Orpis, given that 70% of oil is consumed by transport, a massive transformation of the automotive industry should be taking place in the short run, "making it fundamental to have new projects up and running as soon as possible in order to stop losing ground and become leading producers instead of irrelevant ones."

Added to the above scenario, the senator mentioned the energy crisis there is in Chile and the boost that is being given to Non Conventional Renewable Energies. In this sense, he referred to the fragility of the Central Interconnected System, "which is exposed to overloads and fluctuations, a problem that could

50 http://www.bcn.cl/carpeta_temas_profundidad/litio-el-commodity-del-futuro.

be overcome using high-capacity lithium batteries." According to Orpis, without the speedy implementation of the CEOLs, Chile would be deprived of its leading position in the lithium business due to inaction, which sooner or later would lead to it losing capacity (BCN website, 12 April 2012).

According to GEM (Gestión y Economía Minera – Mining Management and Economics), a consulting company responsible for the figures used by the Ministry of Mining for the CEOLs, the projection of demand contemplated an expected scenario for 2020 where batteries for electric cars would capture 25% of lithium demand. With regard to the automotive industry, analyzing the trends of the new prototypes for hybrid and electric cars with a database of more than 100 new electric and hybrid cars, GEM estimated that for 2020 these should capture around 12% of world automotive supply (BCN website, 12 April 2012).

On 19 May Decree 16/2012 of the Ministry of Mining was published in the Official Journal, "Establishing requirements and conditions of the Special Operations Contract for the exploration, mining and benefit derived from lithium deposits, which the State of Chile will enter into in accordance with the national and international bidding terms and conditions that will be approved to this end".

As was previously mentioned, the contract would be for 20 years and with a maximum amount of extracted lithium of one hundred thousand tons of metal. The performance of the contract would be supervised by a Coordination Committee made up of three representatives of each of the parties. One of the State representatives would chair the Committee meetings. This defined the procedures to certify the quality of the lithium products. The contractor could sell the contract after no less than three years, with the Minister's prior authorization. Once a year the contractor would be required to provide all information required of it by the Coordination Committee, with copy to the Servicio Nacional de Geología y Minería (Sernageomin – National Geology and Mining Service). The State would be entitled to use all geological, geophysical and similar data, but this information would not be transferred to third parties without the contractor's authorization. The Decree also established the grounds for terminating the contract.

On 9 June the government called for tenders of the CEOL, establishing 12 September as the deadline for submitting bids.

On 19 June Senator Letelier referred to the CEOL in Congress[51], stating that the lithium market was not a competitive market and was concentrated in four companies, and that the CEOL represented the fine print, a legal loophole used by the government. Referring possibly to the years in which lithium was awarded to the two companies operating in Salar de Atacama, he indicated that "20 years ago nobody knew about the uses of lithium, 20 years ago nobody was aware of the strategic importance of lithium, it was thought to be important solely in the nuclear industry. Today this is not the case, as indicated by Senator Allende." He added that "this policy for the sale of our natural resources through extraction contracts is to allow other industries to build the components making

51 19 June, http://vimeo.com/44319068.

up the production chain. What is under discussion here is whether we are going to have an industrial development policy in Chile or whether we are going to continue to export raw natural resources for others to add value to." Later on he asserted that "Whoever participates in this bidding process should have one thing clear, and the companies who will be submitting bids for these contracts should have it very clear, that in Chile there is no consensus regarding the use of lithium, and therefore they must be ready to face the consequences. In Chile there is no consensus about what is being done, the majority of the Chilean people have a negative opinion of the whole thing".

On 20 June Codelco announced that it would purchase the CEOL bidding terms and conditions and would study the possibility of submitting a bid for the mining of lithium in conjunction with a partner.

This caused favorable reactions in several of the players, for example, the Codelco supervisors, but provoked wariness in others, who thought that it was a device to calm down those who opposed the CEOLs.

On 29 June Gustavo Lagos stated[52] that "For the first time since the Chilean Lithium Society, SCL, started to work this metal in Chile in 1984, there is a State corporation showing interest in it". "The State had many opportunities to participate decisively in the development of the Chilean lithium industry over the past 30 years, but did not take advantage of them".

He added, "Codelco is the great copper corporation of the world, but it knows very little about lithium and does not have the professionals required to develop a lithium mining project. Its main objective is to create a gigantic portfolio of projects that is key to its survival in the copper business, and to achieve this it needs to get the government to return around 1 billion dollars per year of its own profits over the next four years, in order not to get excessively in debt. It is, moreover, in a confrontation with Anglo American over the ownership of the former Disputada de Las Condes mine". "It isn't realistic to think that Codelco could become a leader in lithium. It could, however, participate in this bidding process with a company that is knowledgeable in lithium, placing lots in Salar de Maricunga as a capital contribution without getting further into debt and as a minority partner. It is desirable that a potential partner not be one of the four major lithium companies worldwide, in order to make this industry more transparent and competitive."

Finally, he asserted that "The winning bids, i.e., those of greater value, will probably be those that have already started projects and have advanced exploration and engineering studies in place, which will allow them to start production soon, in three or four years. Chile is the world leader in lithium production and extractive technologies. It will lose the former in a year or two. And if it doesn't take advantage of the opportunities it could lose the latter. Lithium development in the country does not have to rely on Codelco, but on the understanding by all the political forces that to go ahead now with a high effective tax on profits is much better than to save lithium for later on, waiting for hypothetical opportunities, as some have suggested and some other countries have done with scant results. Chileans need economic development now."

52 Column in La Tercera, 29 June 2012.

Indeed, potential bidders that have not carried out any exploration or completed some engineering study, even at a conceptual stage, would delay much more in starting up production, possibly four or more years. Codelco has not taken these steps. In the meantime, the only ones that could have real possibilities of increasing production in Chile are the two companies that are already working lithium in the Salar de Atacama.

On 26 July 2012 the Senate website published that "in order to invalidate the administrative actions that allowed the call for bids and preparation of the terms and conditions of the Lithium Special Operations Contracts (CEOLs), Senators Isabel Allende, Ximena Rincón, José Antonio Gómez, Pedro Muñoz, and Jaime Quintana, together with union leader Raimundo Espinoza, president of the Federación de Trabajadores del Cobre (Copper Workers Federation), and Pedro Fierro, president of the Federación Nacional de Trabajadores del Petróleo de Chile (FENATRAPECH, National Federation of Chilean Oil Workers) filed an invalidity action subject to public law[53] before the Seventh Civil Court of Santiago." The same source added that "This action aims at stopping and invalidating the lithium bidding process initiated by the government last February and approved through administrative channels. The action is sponsored by Mr. Patricio Zapata, professor at the Universidad Católica de Chile." It was reported that Senator Allende, chair of the Senate's Energy and Mining Commission, "specified that the aim was to annul certain administrative actions taken during the government of President Piñera, such as: Supreme Decree 16 (2012) of the Ministry of Mining, establishing requirements and conditions for the special operations contract concerning the exploration, mining and benefit derived from lithium deposits, which the State of Chile will enter into in accordance with the public and international bidding terms and conditions that will be approved to this end."

In addition, "This also includes Resolution No. 16 of 2012 of the same ministry, which approved the mentioned terms and conditions", and moreover, "we request the competent court to extend a precautionary measure to prohibit actions and contracts in order to render the award of the mentioned bidding process impossible and paralyze the process". The senator expressed that "we consider that the above enforced rules are null because they were issued contravening the wording of the Constitution regarding the status assigned to lithium as a non-concessible substance or substance not subject to concession. With these terms and conditions an attempt is made to disguise via a special operations contract a covert concession of lithium in the entire Chilean territory." (from the Senate website, 26 July 12).

Commenting on this court action, on 12 August La Tercera published an editorial stating that it was based on a "deviation from the purpose of such administrative action" because it did not conform to the regulations in force. It defended the constitutionality of the government's legal act and added that "what is more serious is that by filing this suit, the members of parliament are disregarding the procedure contemplated in the Constitution for impugning

53 http://www.senado.cl/prontus_galeria_noticias/site/artic/20120726/pags/20120726131817.html

the constitutionality of a decree, which is what they are in fact doing. A requirement in this regard should be submitted to the Constitutional Tribunal within a period of 30 days after the Decree is published, and by a minimum of one-fourth of the members of the respective Chamber (10 senators), nothing of which has been met in this case. The courts of law should avoid having their function distorted by these means, and should state their lack of jurisdiction to pronounce themselves regarding the disputed regulation."

On 16 August Senator Allende responded to this editorial by means of a letter addressed to La Tercera, arguing that the legal action "reflects our conviction in the sense that the lithium mining contracts that are being offered by the government go way beyond what is allowed by the legal framework. You are also mistaken (referring to the La Tercera editorial) in stating that the Constitutional Tribunal is the only means to impugn government administrative actions. The truth is that public law nullity is a consolidated and legitimate instrument."

Senator Allende added: "By acting the way we have, we are exercising a right and performing a duty. Exercising the right of any person to request legal protection. And the duty of all Chileans to defend the natural resources that the laws have reserved expressly for the State".

The bidding process was carried out and on 12 September was awarded to SQM, which submitted a bid with a value of more than double that of its closest contestant, Consorcio Posco. Two days later, this Consortium denounced that SQM had four pending disputes with the Treasury, which is part of the State, and therefore SQM's application failed to meet the bidding terms and conditions. The company explained that these disputes were with the Treasury and not the State. SQM had signed a sworn statement asserting that it complied with the bidding terms and conditions. It did not inform the government about the disputes and the government did not – or did not wish to – investigate whether the sworn statements were truthful. SQM's behavior was considered so reckless that the prevailing hypothesis was that its intention had been to win the bidding award with an overstated bid and subsequently annul the process without paying the initial bid and leaving its competitors out of the running.

This caused a great scandal at a national level, and President Piñera, who was traveling abroad, ordered that the bidding process be annulled and also requested the immediate resignation of Undersecretary Wagner, who had gone ahead with the process. The most serious repercussion is that this led to the demise of the CEOLs and paralyzed new investment in lithium for many years. Chile had been condemned to reduce its share in the global market.

During those days I wrote a column stating that, "I supported this bidding process as a way of energizing this industry, which had been paralyzed for 17 years in terms of new projects ever since SQM started mining lithium in Salar de Atacama in 1997. But I do not support the irresponsibility and lack of seriousness that was revealed during the process." The saddest part is that much later on, in 2015, we found out that SQM had made payments for services not rendered to Undersecretary Wagner's sister-in-law, who had redirected those funds to the Unión Demócrata Independiente (UDI) political party. Although no evidence has been found up to now that Wagner had given SQM special

consideration in the CEOL bidding process, that doubt still remains in public opinion. Simply unacceptable.

These SQM operations were carried out from the office of Patricio Contesse, General Manager of SQM at the time, who is currently under prosecution for these and other payments to politicians. La Tercera of 1st January 2016 showed that SQM payments to officials of political parties for services not rendered covered the entire political spectrum. Between 2008 and 2012, these included: UDI received 45% of the identified funds (close to 15 million dollars), Renovación Nacional 11%, Christian Democrats 11%, Regionalista Independiente 10%, Socialists 10%, Social Democratic Radicals 7%, Partido por la Democracia 3% and sundry independent politicians 5%.

SQM was not the only company involved in the illegal funding of politicians, many other large Chilean companies were also in the same boat.

4.8- The 2014 Lithium Commission Report.

On 11 July 2014 President Bachelet created a commission with the purpose of preparing a proposal for a national policy on lithium. The Commission was made up of 18 persons from both the public and private sectors, including an international expert, as set forth in Supreme Decree No. 60 of the Ministry of Mining, dated 24 October 2014.

In December of that year, the commission submitted to President Bachelet "a diagnosis and a set of proposals to enable the country to address a national policy on lithium that will safeguard the public interest, title to the mineral and others related thereto such as potassium, boron and magnesium; generate benefits for society as a whole, protect areas that are rich in biodiversity wherever they may be, ensure the protection of areas of environmental value affected directly and indirectly by production activities and ensure respect for the neighboring communities, in particular those inhabited by indigenous peoples."

I shall analyze the proposals I consider to be most relevant. These are divided into two types. First, the guidelines, and second the actual policy proposed.

Among the guidelines, the commission document indicates in the introduction that "since the commencement of its sessions, the commission has noted the absence of the State in activities related to lithium production and, therefore, the need for an invested State that will safeguard the mineral resource and its sustainable and inclusive operation, maximizing and capturing its economic revenue with a long-term view."

The foregoing sentence is an admonition to Corfo, which had been in charge of lithium ever since the first agreements were signed with the two companies that began lithium operations in the Salar de Atacama. Corfo had paid quite a lot of attention to lithium until the Mixed Salts Committee was dissolved in 1987, after which lithium experts emigrated to other destinations. The royalty paid by SCL since 1988 for working potassium salts, and by SQM for the rental contract starting in 1996, failed to encourage the State to improve the institutionality of lithium management, and no resources were allocated to lithium research and development, which the Mixed Salts Committee used to do.

There are four guidelines resulting from the work of this commission that I consider fundamental and which are contained in chapter 2 of its report "Visión estratégica para una política nacional del litio" (Strategic view for a national lithium policy) and in the chapter setting forth its conclusions and main proposals for a public policy.

The first is that it reaffirms the strategic nature of lithium and therefore the functions of the CChEN arising from the nuclear interest in lithium. This is analyzed in chapter 6.

Secondly, the need for a sustainable management of the salt lakes, ensuring continuity of the natural ecosystems and their relationship with the social and economic surroundings. To this aim, the document proposes the need for a public institution to coordinate the necessary actions to achieve that objective, and equipped with the necessary resources to attain that purpose. In particular it indicates that such an institution should "regulate the exploration and extraction methods" and "the maximum brine extraction flows", as well as "the maximum annual programs for lithium sales".

The authority should be empowered to fix maximum brine extraction quotas for well-founded environmental reasons, which would be related to the hydrogeology of the salt lakes. This discipline studies groundwater circulation, natural charge and discharge, the water table, and in short the sustainability of the surface ecosystems existing in a salt lake and its surroundings. Chile has very few hydrogeologists at present, and for this reason the companies extracting lithium and other elements from Salar de Atacama have a large contingent of foreign hydrogeologists on hand.

The third guideline is suggested by the following phrase: "The maximization of the economic rent of the resource in the long term makes it necessary to continually adjust total production to market conditions." Later on the document insists on the role of the State in the economic management and rent maximization of those who are mining lithium and other elements.

For the above economic, environmental and social reasons (I did not deal with the latter), the document proposes to "create a new public enterprise or state corporation, or even a subsidiary of the currently existing mining companies, but devoted solely to this purpose". Among other actions, this new company should take over – on its own or preferably with third parties – the working of the salt lakes, receiving title to the claims of the current state operators, and assuming "the obligations and rights issuing from the right of possession, including the contracts the current operations have ongoing at Salar de Atacama, as well as the share that other state companies may have acquired through mixed partnerships prior to the creation of this new company."

The commission's document indicates that it "almost unanimously" considers it necessary to create a state company devoted to the utilization of the salt lakes, and of lithium in particular. It also indicates that a "majority" agreement was reached concerning the creation of a State company that "will have a controlling role in all salt lake mining projects developed in the country".

The composition of the commission was far from representative of the country and therefore it could not formulate a national policy, only propose it. I say this because I have recently seen in the written press that some opinion leaders refer

to the commission's proposals as the "National Lithium Policy". The truth is that this does not exist. These are valuable guidelines because they represent the thinking of a Ministry of President Bachelet's government and that of a group of people who have devoted study and time to prepare them. But they are not binding vis-à-vis any state body. So much so that after the preparation of this guideline, Corfo modified the Rockwood Lithium Agreement, later to be called Albemarle, as will be seen in the following section, increasing its production quota and contravening the wish of the commission that a state company should control production in the future.

The underlying theme in these guidelines is the creation of a state company and the role it should play. In this regard, it seems appropriate to create a new state company in view of the fact that Codelco owns the Pedernales salt lake and has concessions in the Salar de Maricunga. It can obviously, as it already announced, create a subsidiary company and associate with third parties to operate the concessions.

The fourth guideline is that the newly created state company should control all lithium production in the country. To force Codelco or any other company to be the controller of lithium mining in Chile is absurd. There are not enough experts available to carry this out, neither does the State have the required capital.

Moreover, the oversight of the environmental and social aspects of the surroundings is not something a company should address, but a public institution. Whatever the newly created company may be, it cannot act as judge and jury.

The most surprising aspects of these guidelines are the two paragraphs that refer to the planning of production to maximize income. When they were written they already had in view that the proposal would be for a state company to "control" the production of all operations in Chile. This could be done, but would undoubtedly lead to what is called a lithium cartel. Several considerations should be analyzed in this regard, the first being that no company with international presence should be involved in this adventure, even if holding minority shares, due to anti-cartel regulations.

Moreover, this assumes that the market experts of the new company would be in a position to beat the market. This is a typical belief among some of the political sectors of the country, which have repeatedly posited the need to manipulate the copper market. They never managed to do so with Codelco, but were now trying it out with lithium.

It is possible that they are not clearly aware of the failed cartels in history, including the oil cartel and several in the copper industry, particularly CIPEC (1968-1987). This issue is discussed in greater depth in chapter 8.

There is also the experience of countless operations in the commodities markets that were disastrous for the large mining companies, to such an extent that in all of them future operations that were not linked to hedging were forbidden. One example is the Metallgesselschaft debacle at the beginning of the 1990s, through the fault of its executive president, who bet heavily and lost, causing the bankruptcy of this major company. And, lastly, there are three recent Codelco operations where it bet on the future, losing in two of them and,

as we now know, saving itself in the third by mere chance. I refer first to the agreement with Minmetals to finance the construction of the Gabriela Mistral mine, in which copper was sold at very low prices for more than a decade.

There is also the operation that was undertaken to ensure that the Salvador mine could continue to operate. A gamble was made on a price that resulted in billions of losses for Codelco. And, finally, there is the experiment at the beginning of the 2000s, when several multinationals and Codelco, independently, announced reductions in production or inventory buildups. This action was taken due to the impossibly low prices that prevailed at the time. The initial result of these actions made prices rise, but the experiment was successful in the case of Codelco, because when selling off the built-up inventories quite a while later, as promised, the price was higher. If this had not been the case the experiment would also have been a failure.

The historic lesson learned is that it is a bad idea to bet on prices established in the future. Markets are immensely more dynamic and surprising than the predictions of any businessman, let alone those of a group of government officials, no matter how expert and intelligent they are. In the matter of commodities markets, it is worth remembering that there is no way to go against the divine providence of the Market God that Adam Smith dubbed "the invisible hand".

It is a very bad idea to think that Chile, even if it had a major fraction of world lithium production in the future, could gamble with its price, favoring the interests of the State.

Now, the second reading of the agreements of the Lithium Commission came after the guidelines had been prepared. This apparently began due to the rejection of the Ministry of Finance and the transformation of the guidelines into policies that could be implemented in practice. These policies were: to accept the view regarding the salt lakes and the need to advance toward its governance and a larger State role; to accept the creation of a public lithium enterprise, which would be a Codelco subsidiary, and the creation of a Corfo Committee for non-metal mining and salt lake governance. These policies were discussed and approved in the House of Representatives on 18 July 2016 and included the consent of President Bachelet.

The Committee for non-metal mining and salt lake governance would abide by the following principles for its operation: To respond to the demand for greater sectoral coordination, the design of a national policy for the governance of the salt lakes, promote the sector and safeguard the salt lakes, encourage the generation of value and improve project oversight. This Committee was created in 2016, it is presided by the Ministry of Mining and its governing board is made up by the undersecretaries of Mining, Economy, Development and Tourism, Environment, Energy and Finance. There are also representatives of Corfo, Sernageomin, CChEN, Cochilco and the Dirección General de Aguas (DGA – General Water Authority), as well as two expert professionals, Gonzalo Gutiérrez and Miguel Herrera. Arlene Ebensperger was designated Executive Director of the Committee via public contest.

The duties of the Committee are to coordinate with other public entities, study the available resources, manage technical information, plan State actions for their management, encourage technological development and design

productive research and development programs. It is also required to propose the design of an institutional model, support the administration of mining claims, ongoing contracts and others, advise the Ministry of Mining in future bidding processes, and support activities related to the communities living in the area, in particular indigenous communities.

Thus, we can observe that the most controversial guidelines of the Lithium Commission were not implemented, supposedly because they did not have a majority vote. But the supporters of those guidelines continue to be active in the political system pursuing much more radical – and above all more statist – objectives.

4.9- Modification of the 1980 Basic Agreement between Corfo and Foote.

The Basic Agreement entered into between Corfo and Foote Mineral Company giving rise to SCL on 13 August 1980, was modified by mutual agreement of the parties on 29 December 2016.

The new agreement (or 2016 agreement) is quite complex and increases the lithium quota that Albemarle can extract and process, as well as the period to do so, imposing much stricter obligations on this company.

This book does not intend to explain the details of the new agreement, only to analyze some of its more salient aspects.

The Agreement indicates that Chile has lost and will continue to lose its share in the international lithium market, and that this must be reverted because lithium demand will grow very importantly in the next decades in light of the goals set by the Paris Climate Change Agreement.

Given that Albemarle is now holder of the lots at the Salar which had been awarded to SCL in 1980, Corfo cannot modify that ownership until the agreement expires and the lots are returned to Corfo. In other words, nobody except Albemarle can work the lots until it meets the lithium extraction and processing quota it was initially granted. Moreover, Corfo considered it imperative to authorize the expansion of lithium production with Albemarle due to the high increase in its demand, considering that not to do so would represent the loss of an opportunity for the country.

The 2016 agreement ratifies the strategic nature of lithium for Chile. It grants Albemarle a new quota, in addition to the original one, of 262,132 tons of lithium metal equivalent (LME) to be extracted and processed by 2044 at the latest. This is subject to environmental approval if needed and to compliance with all current environmental legislation. Moreover, the agreement indicates that Albemarle will build, within a certain period of time, a new plant for battery-grade lithium carbonate (99.5% purity). Failing that the quota would be reduced from 262,132 tons to 43,360 tons of LME. In the event that Albemarle does build a battery-grade lithium hydroxide plant the new quota will be increased by 34,766 tons of LME.

Albemarle shall pay a stepped, progressive and marginal commission applicable to the new quota of lithium carbonate, ranging from 6.8% to 40% of the price of the compound, depending on the price level. The larger rate is paid in the event that the sales price to unrelated clients is higher than 10,000 dollars

per ton of lithium carbonate equivalent (LCE). In the case of sales to related clients, a complex mechanism is established to estimate the price that should be used to estimate the commission that will be paid to Corfo. Commissions of different levels are also established for the sale of lithium hydroxide, potassium chloride, magnesium chloride, potassium sylvinites and carnalites. Albemarle will begin to pay the commission in advance, as of 2017, even if plant number three has not been built (Article 4, number 6 of the New Agreement).

The 2016 Agreement sets preferential prices for sales to national companies developing specialized products in the country. This benefit has a cap of 25% of the new production quota. The sales price will be the lowest market export parity of the last six months.

Albemarle's contribution to research and development in Chile will increase from 2 million dollars to a range between 6 to 12.4 million dollars as of 2017. The agreement establishes that "The Council of the Corporation (Corfo) will determine the institutions that will receive all or part of the annual research and development (R&D) contribution for each area, which will be eligible solely to those in which representatives of universities and/or State Administration bodies have representation, participation or some sort of influence in their management. As a condition to receiving the annual R&D contribution, the Corporation shall require each institution to undertake to respect the purpose for which the contribution is made and to comply with the objectives and goals that the Corporation will establish by means of an agreement signed with each institution. Albemarle will make the annual R&D contribution as determined by the Corporation, during the first week of August of each calendar year.

On 1 February 2016 Corfo and Albemarle signed a memorandum of understanding, which indicates in greater detail the areas that are eligible to receive R&D contributions from the latter. The modification of the original agreement between Corfo and Foote is made "so that its development is consistent with the National Lithium and Salt Lake Governance Policy, and in order to establish rules that will make it possible to achieve efficiency and sustainability of Lithium and the Salar de Atacama as a natural resource, share value with the community, contribute to research and development of lithium applications, salts for thermal applications, solar storage and energy, generate investment for the manufacture of value added products, and incorporate modern and innovative technology in the productive processes, thus improving the development and productive capacity of the territory and the country, as well as expanding lithium production to maintain Chile's leadership and market share at a world level and promote the development of electromobility and the country's insertion in the electro-thermal solar industry, given the advantage of our territories in terms of high solar radiation."

The new agreement benefits the indigenous communities through the implementation of an agreement in which Corfo and Albemarle become partners by receiving 3.5% of their annual sales and the indigenous communities become overseers by establishing a joint monitoring protocol with the company in Salar de Atacama.

4.10- Reflections on the new agreement

The 2016 Corfo - Albemarle agreement captures numerous benefits for the country, the Treasury and Corfo, including the R&D program that will be financed by Albemarle, the benefits to the indigenous communities, investment commitments and new production, among others. But above all, it increases Albemarle's production quota by 200%.

This action by Corfo may give rise to sundry criticism, but it shattered the prevailing immobility and restored dynamism to half the current productive capacity of the country. It is lucky that Corfo did this.

The same agreement with Albemarle ratifies that given the nature of the original 1980 agreement between Corfo and Foote, there was no alternative other than to increase the production permit, albeit establishing conditions that were more favorable to the State. The most obvious justification for not entering into a similar agreement between Corfo and SQM was because they were involved in an arbitration dispute and no agreement had yet been reached at the time of publishing this book.

The new Corfo-Albemarle agreement highlights another aspect, which is that any investor wishing to produce lithium in Chile – including SQM if its quota in Salar de Atacama is increased – and any producer in the Salar de Pedernales or Maricunga, which are two of the most lithium-rich salt lakes after Salar de Atacama, will need to sit at the negotiating table with Corfo to see what agreement can be reached. The conditions for an agreement in the latter salt lakes would possibly be different from those achieved with Albemarle, because the costs involved in producing lithium would be higher. Thus, the agreement with Albemarle would mean that any negotiations on lithium production in the future would be on a case-by-case basis. A dangerous concern for future investments, above all considering that at present there are many projects in different parts of the world where the investment conditions are clear and not case-by-case. Why would an investor choose Chile if by investing somewhere else it could obtain the same or better profits and save time in negotiations?

It would therefore be important for Corfo to establish clear rules for future investments as soon as possible.

Another aspect that should be analyzed is the form that was adopted to carry out the agreement, with a royalty at the nominal price of lithium. This means that the price will increase in the future due to inflation. Taking both the producer price index and the consumer price index over the past 10 years in the United States, this results in an average inflation of 2% per year. If, starting from the 2016 price, say 6,000 dollars per ton of technical-grade lithium carbonate, we can estimate that the nominal price of technical-grade lithium carbonate in years 2025, 2035 and 2045 will be 7,000, 8,560 and 10,440 dollars per ton, respectively. Therefore, without considering the market but only inflation, Albemarle would be situated in the higher range of the commission scale established in the new agreement even if the price in constant currency remains the same. Furthermore, what would happen to production costs during this period? The same as with the price, i.e. there would be an inflationary effect. So, even if lithium prices and costs remain constant in real terms, Albemarle

would have to pay higher commissions every year, without improving its profits.

The high cycles of lithium prices will coincide more and more with global economic cycles, because a fundamental part of its production will be earmarked for mass consumption goods such as electric vehicles. For this reason, the behavior of lithium costs to a great extent in the future will follow the same behavior of the costs of the large commodities markets such as oil, coal, aluminum, iron and copper.

During high global cycles there will be great demand for lithium and, if the cycle is protracted, the cost of producing lithium should increase, as occurred with copper during the super cycle and during all previous high cycles. The industry margins should rise, except at the end of the high cycle when prices begin to decline. It is at that time when percentiles 90 and 100 of lithium production costs will "collide" with the price, the same as happened to copper prices in 2015 and a year before with the price of iron. Although low-cost producers such as Albemarle and SQM are more protected than higher cost producers when prices decline, it also reduces their margins.

During low-price global cycles, everything depends on the costs of the marginal producer. If they are very high, then producers in the 1st quartile in terms of costs (Albemarle and SQM) obtain important margins. If the marginal cost producer is competitive, the 1st quartile producer will find itself in a more precarious situation.

4.11- Albemarle and SQM tax burden

Prior to 2010 SQM paid income tax and a royalty on lithium and other products consisting of 6.8% of the FOB Chile price value of lithium, 1.8% of the FOB Chile price value of potassium products, and 5% of the FOB Chile price value of magnesium chloride or bischophite. As of 2010, SQM, the same as Albemarle, began to pay an additional tax on concessible substances, known as Mining Royalty No. 2, voted during the government of President Piñera to finance the reconstruction required after the 2010 earthquake. This tax amounted to 5% on the gross profit margin and continued to be applied in 2017.

In 1987 Corfo authorized SCL to produce potassium salts and imposed a royalty of 2% on the sales price of that product for six years, and 3% thereafter.

As was already mentioned, as of 2017 Albemarle began to pay the commissions established in the new Agreement with Corfo.

One of the paradoxes of the terminology used in the country's lithium contracts is that the commission that Corfo charges is in fact a royalty that is paid in relation to the price, whereas the so-called mining royalty is a tax on profits.

Overall, it seems convenient that for a lithium tax policy to be sustainable over time it is necessary for it to be based not on the price of lithium but segmented into two parts. A first, in the form of a fixed quota, would be based on lithium sales, and a second to capture excessive profits through a marginal and progressive tax on profit margins, all this measured in real and not nominal currency. The sustainability of a tax policy is based not only on extracting the

maximum revenue from the companies in the short term, but to ensure that investment will continue to flow so as to ensure that the Treasury's revenue will be maximized over the long term.

5. LITHIUM RESOURCES

Figure 2 provides some of the values of lithium reserves and resources reported in the literature from 1955 to date. The first thing observed is the large number of estimates there are from 2006 onward, whereas before there were only two experts reporting such data. The estimates for lithium reserves and resources over the last five years vary between 17 and 56 million tons of contained lithium (LME – lithium metal equivalent). This shows the interest that lithium has been generating due to its potential applications in the future, with a large number of companies throughout the world exploring new lithium prospects with the intent of entering this new field.

This does not consider the lithium that could be recovered on the basis of seawater. According to Yaksic (2009), the cost of producing lithium carbonate from seawater was between 7 and 10 USD/lb[54], obtained originally by Steinberg and Dang (1975), when there were great expectations for the demand of nuclear fusion reactors and it was thought that there would be insufficient conventional lithium deposits to meet that demand. Considering that 20% of lithium was recovered from the oceans, the resources were 44.8 billion[55], according to Yaksic. Even though these costs were estimated in 1975, with less technological options than those existing in 2011, it is difficult to think that in the near future there will be enough demand to mine lithium from the ocean. Prior to that it would be more expedient to deplete the substantial reserves and resources available at lower costs.

Figure 2 also shows how inadequate the standards[56] to estimate what the reserves and resources of lithium really are. In 2009, Weil et al (2009) reviewed the values of reserves and resources cited for lithium and concluded that the estimates for lithium reserves varied between 4 and 30 million tons of contained lithium, and that the estimates for lithium resources varied between 8 and 56 million tons.

Weil and his coauthors concluded that the terminology used by different stakeholders varied up to the point that even the reserve estimates were very

54 In dollars of 2009

55 Thousands of millions

56 The definitions used are those of the Committee for Mineral Reserves International Reporting Standards (CIRSCO), as well as those of other organizations such as the USGS.

different. Moreover, the resource estimates[57] included measured, indicated and inferred values. CRIRSCO defined a method to classify the tonnage and grade of reserves and resources, which had to be reported for each site by the companies carrying out the exploration or operation of the sites. According to Weil (2009), the companies did not respect this standard and therefore comparisons between the reported figures were limited.

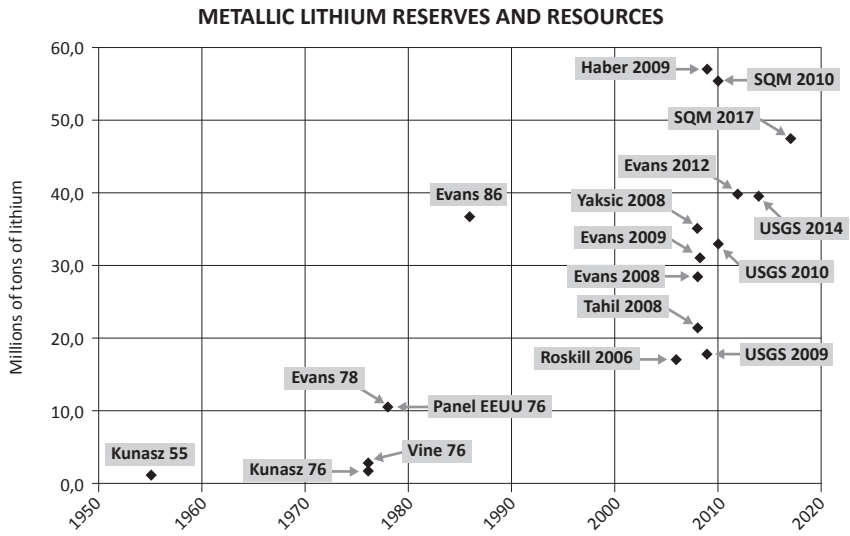

Figure 2: Lithium Reserves and Resources, Sources indicated in the Figure

The most consistent sequence in the evolution of lithium reserves and resources was made up by the Panel convoked by the U.S. National Research Council (NRC) in 1976, Evans' estimate in 1986 and more recent Evans estimates in 2008 and 2009. The 1978 estimate was 10.6 millions of tons of contained lithium, and in 1986 Evans increased the estimate to 36.7 million tons, as detailed in the section on the period between 1967 up to Chile's entry into the industry.

Evans (1986) overestimated the lithium resources present in hectorite in the United States, establishing them at 15.1 million tons (Figure 2). In his papers of March and July 2008 and in 2009, Evans allocated only 2 million tons of contained metallic lithium to hectorites, thus reducing the value of resources and reserves to 29.8 and 30.1 million tons of lithium, respectively. In his last estimate, in 2009, Evans adds resources issuing from geothermal brines to the count, which he valued at one million tons, and from oil brines, which he valued

57 According to CRIRSCO (Committe for Mineral Reserves International Reporting Standards, Australia) a mineral resource is a concentration or occurrence of a material of economic interest in the earth's crust in a manner, quality and quantity such that its economic extraction is seen as a reasonable prospect.

at 750,000 tons of lithium. Moreover, Evans added 850,000 tons of jadarites[58] in 2009, in line with a Rio Tinto report regarding a new mineral found near Belgrade in Serbia.

This Figure (No. 2) does not include the lithium deposit reported in 2010 in Afghanistan (Afghanistan, 2010), which is calculated to possess 36.8 million tons of contained lithium, establishing total global resources at 92.1 million tons in an optimistic scenario.

According to Evans (2008) and SQM (2009), SQM had conducted explorations confirming the existence of brines rich in lithium and other salts down to a depth of 200 meters, which would confirm the figure of 6.9 million tons, whereas before drilling had only gone 40 meters deep, resulting in an estimated 4.29 million tons.

Table 1 indicates the years of the estimates, their author and the tons of reserves and resources.

The distribution of reserves and resources according to the origin of the ore in 2009 were reported by Evans in 2009 (2009) and added up to 29.8 million tons of contained lithium. Of these, 59% was in continental brines, 25.6% in pegmatites, 3.3% in geothermal brines, 6.6% in hectorites, 2.5% in oil brines and 2.8% in jadarites. The distribution of reserves and resources per country in 2009 were, according to Evans, the United States with 25%, Chile with 23.1%, China with 11.2%, Argentina with 8.5%, Zaire with 7.7%, and 24.5% distributed among other countries.

According to Evans (2009) seven deposits in the world accounted for 72% of reserves and resources. These were: Salar de Atacama in Chile with 23% of reserves and resources, Salar de Uyuni in Bolivia with 18.4%, the pegmatite deposit in Kings Mountain, North Carolina, with 8.7%, the pegmatite deposit of Manono in Zaire with 7.7%, the Zhabuye salt lake in Tibet 6.7%, and the Rincón and Hombre Muerto salt lakes in Argentina, with 7.5%. As previously mentioned, Kings Mountain was closed down by Chemetall, Manono is practically undeveloped and would also have high costs due to the distance involved in transporting the ore to the port, and the Olaroz, DXC in Tibet, Cauchari, Diablillos, Salinas Grandes and Uyuni salt lakes are undeveloped, although there is a pilot plant in the first of these. Among the seven largest deposits, only two are being mined, Salar de Atacama and Salar de Hombre Muerto.

All in all, lithium resources increased 2.81 times from 1976 to 2009, as estimated by Evans and the NRC, whereas production rose 2.89 times, i.e. almost the same as the resources. The rate of growth of the resources since 2009 was, however, much greater than the production rate, fueled by the feverish interest of electric vehicle and vehicle manufacturers, who have been promoting and supporting the exploration and production of lithium in different parts of the world. The use of lithium batteries in vehicles will be analyzed further on.

According to Gerry Clarke (Clarke, 2011), who published the Lithium Availability Wall Map 2011, there were more than 100 projects in different stages of development in June 2011, with 10 projects starting production

58 Formula $LiNaSiB_3O_7(OH)$

between 2010 and 2014, most of which were not considered in Evans' 2009 list of deposits containing lithium resources. Moreover, the four largest companies in the world[59] would increase their production by 55% between 2011 and 2015.

In any event, according to Evans' estimate, in 2009 there were sufficient lithium resources to produce the metal for 1,150 years at the production rate of that year. Considering an increasing demand due to vehicle manufacturing, the resources would be enough to last for hundreds of years[60].

Evans' (2012) estimate revealed that Chile had lagged significantly behind in resources, from 40% in 1976 to 24% in 2008 and 17.8% in 2012.

In 2017, lithium mining projects multiplied fourfold with regard to those there had been five years before, due to the effect of the mass production of electric vehicles (Deutsche Bank, 2017). Deutsche Bank indicated that the greater part of the reserves were concentrated in 130 deposits and that the 15 largest deposits represented 50% of global resources. For this reason, companies with access to capital and which control the large high-quality deposits are in a good position to take advantage of this boom for the demand of batteries. Estimates of the U.S. Geological Service, USGS (2017) indicated a total of global reserves for 2016 of 14 million tons of contained lithium (LME), with Chile holding a 50% share, China 22.8%, Argentina 14.3% and Australia 11.4%. The resource scenario was quite different, because Chile appeared with a marginally higher amount of resources vis-à-vis its reserves (7.5 million tons of LME), but this represented 19% of the 39.5 million tons of LME of global resources. This is due to the large amount of exploration that had been developed one or two years before. On the other hand, SQM (2017, working document, Santiago, Chile) estimated that world resources were 47.4 million tons of LME, with Chile participating with 8.2 million, i.e., 17.2%. It should be added that this information confirms new explorations in Salar de Atacama, with a substantial increase in reserves and resources.

Finally, the British Geological Survey (BGS, 2016) quoted an estimate of global resources provided by Evans (2014) of 40 million tons of LME. This figure is very similar to the Evans 2012 estimate shown in Table 1.

It can be concluded that the most recent estimates of lithium reserves and resources have converged toward very similar values, revealing that there is much more agreement than before regarding the methodologies used to measure these variables.

Figure 3 shows the exponential growth trend of global lithium resources, indicating, once again, that the best incentive to conduct exploration and discover new resources and reserves is the prospect of growing future demand.

59 Talison, SQM, Chemetall and FMC

60 Demand model developed by the company SignumBox Inteligencia de Mercado, personal communication with Daniela Desormeaux, 2012, Santiago, Chile

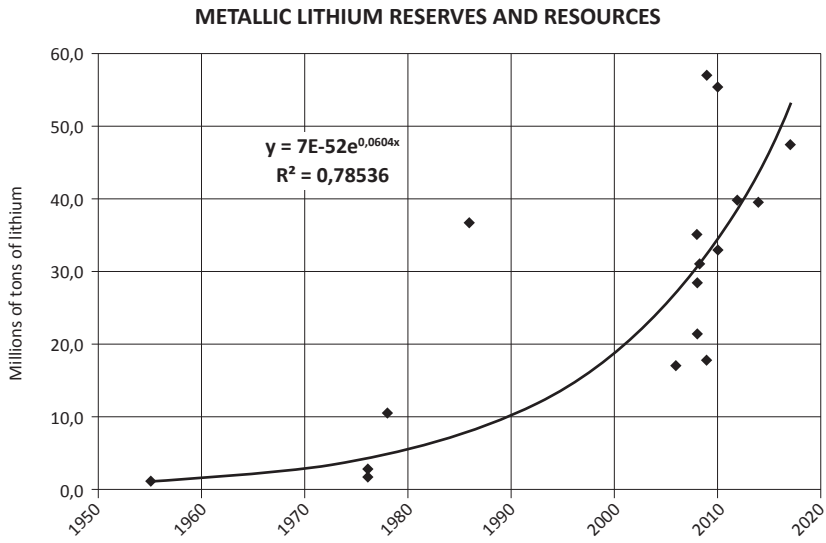

Figure 3: Exponential growth of global lithium reserves and resources.
Sources indicated in Figure 2.

5.1-An economic review of resource availability

Yaksic (2009) published Figure 4, which represents the estimated extraction costs of lithium in terms of the available resources in two scenarios. The cheaper-to-extract lithium resources, which would therefore produce greater profit, were those of Salar de Atacama, which were estimated at much less than they are at present. The most expensive lithium resources to extract were those from the ocean, 22,500 USD/ton lithium carbonate equivalent (LCE). In the lower scenario the cost was slightly higher than 15,000 USD/ton LCE.

Figure 4 shows only an infinitesimal part of the lithium contained in oceans, estimated at 224 billion (thousands of millions) tons of metal, of which Figure 4 calculates that only 20% is recovered. The cost of extraction from seawater was estimated on the basis of a paper published in 1975, therefore it is presumable that current extraction costs from seawater may have decreased considerably. This suggests that the future trend is that, with new technologies, the curve of lithium availability or resources will take a downward turn.

The data were obtained on the basis of a collaboration between USGS and various producing companies. Yaksic developed two scenarios, one optimistic and one pessimistic. The first represented a high demand for primary lithium in the future and therefore a greater theoretical difficulty in meeting demand, and thus both the price and production costs would be higher than those of the optimistic scenario. When Yaksic published this paper, the debate between Tahil and Evans regarding the amount of lithium resources that were available was in full swing. This debate is addressed in chapter 11.

In consequence, the optimistic scenario was the one with less future demand.

	U.S. Panel 1976	Evans 1986	Evans 2008-a	Evans 2009	Evans 2012
Pegmatites	**5,939,000**	**7,430,000**	**7,654,100**	**7,654,100**	**9,930,000**
North Carolina (previous operations)			230,000	230,000	230,000
North Carolina, undeveloped	3,150,000	3,150,000	2,600,000	2,600,000	2,600,000
Barraute, Quebec	109,000	109,000	90,000	90,000	230,000
Bernic Lake, Manitoba	47,000	47,000	18,600	18,600	
Other, Canada	112,000	512,000	147,000	147,000	430,000
Bikita, Zimbabwe	113,000	113,000	56,700	56,700	56,700
Manono, Zaire	2,340,000	2,340,000	2,300,000	2,300,000	2,300,000
Greenbushes, Australia		1,100,000	223,000	223,000	1,500,000
Mount Marion, Australia			19,800	19,800	93,500
Mount Cattlin, Australia (Galaxy)	41,000	41,000	20,000	20,000	90,000
Karalpa, Austria			100,000	100,000	134,000
Larritta, Finland			14,000	14,000	14,000
Sundry, Russia			1,000,000	1,000,000	1,000,000
Sundry, Brazil	18,000	18,000	85,000	85,000	185,000
Sundry, China			750,000	750,000	750,000
Sundry in the rest of U.S.A., Canada, Namibia, Argentina	9,000	9,000			317,000
Continental brines	**4,672,000**	**9,908,000**	**17,590,000**	**17,590,000**	**25,160,000**
Silver Peak, Nevada	118,000	118,000	40,000	40,000	40,000
Salar de Uyuni, Bolivia		5,500,000	5,500,000	5,500,000	8,900,000
Salar de Hombre Muerto, Argentina			850,000	850,000	850,000
Salar de Rincón, Argentina			1,400,000	1,400,000	1,400,000
Salar de Olaroz, Argentina			300,000	300,000	1,200,000
Salar de Caucharí, Argentina					1,520,000
Sal de Vida, Argentina					1,020,000
Salar de Diablillos, Argentina					530,000
Salar de Atacama, Chile	4,290,000	4,290,000	6,900,000	6,900,000	6,900,000
Salar de Maricunga, Chile					200,000
China and Tibet (sundry)			2,600,000	2,600,000	2,600,000
Searles Lake, Great Salt Lake, U.S.A.	264,000	264,000			
Total others	**0**	**19,100,000**	**3,066,000**	**4,600,000**	**4,800,000**
Geothermal brines, California, U.S.A.		4,000,000	316,000	1,000,000	1,000,000
Oil brines, U.S.A.			750,000	750,000	850,000
Hectorites, U.S.A.		15,100,000	2,000,000	2,000,000	2,000,000
Jadarites, Serbia				850,000	950,000
Total	**10,611,000**	**36,438,000**	**28,310,100**	**29,844,100**	**39,890,000**

Table 1: Lithium resources and reserves estimated by a Panel in U.S.A. 1976 and by Keith Evans for the other years (tons)

It is paradoxical that these scenarios could currently be designated in reverse order given that the hoped-for high future demand represents a great business opportunity for the large producing countries such as Australia, Chile and Argentina.

Yaksic estimated high demand due to vehicle batteries, which would involve consuming 17.5 million tons of contained lithium between 2008 and 2100, i.e. less than half of what is indicated in Figure 4, which would make it unnecessary to extract metal from seawater even if no new deposits are discovered. The annual production of lithium in 2100 required in this scenario was estimated at 1.76 million tons LCE, i.e. some 10 times world production in 2015. Yaksic also estimated that in the event that it became necessary to extract lithium from seawater, this would not increase the cost of lithium batteries significantly.

It is evident that the demand for lithium in this scenario of high demand (pessimistic according to the authors) is more conservative than the potential scenarios that would arise 10 years after the studies of Yaksic et al.

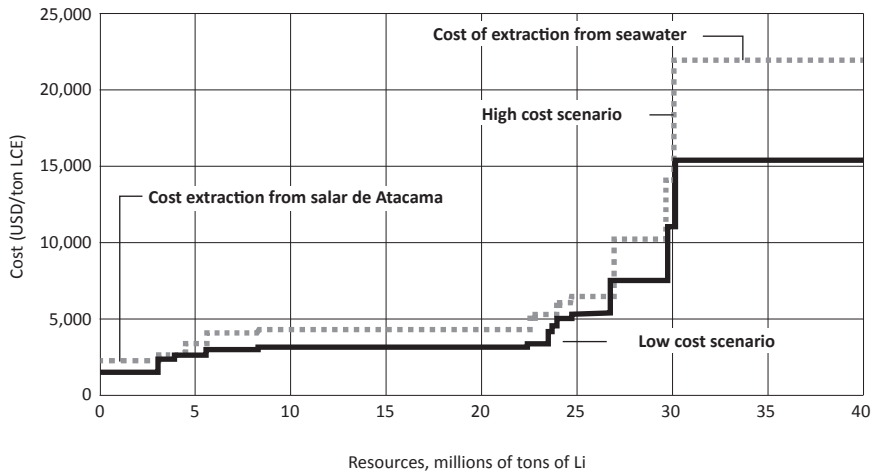

Figure 4: Cumulative cost curve. Source: Adapted from Yaksic et al, 2009

This economic look at the availability of mineral resources is a much more reliable indicator than the classic technique of estimating the years of life of an element's reserves or resources, or even worse, to think that they should be fixed in the future, as the Club of Rome did in 1972, and more recently major publications regarding copper (Elshkaki, 2016; Ali, 2017). The economic focus was applied by Aguilera and others (2009) to estimate the availability of oil in the world, predicting correctly what would happen a few years later with the entry into production of oil extracted from shale and clay in the United States. This would lead to an increase in reserves of 90% between 2008 and 2014 according to the US Energy Information Administration, and made it possible to increase supply and significantly reduce the price of the commodity.

6. DEMAND

In addition to the thermonuclear demand generated by the United States and the Soviet Union after the Second World War, the United States and the world experienced an almost unprecedented economic growth between the end of World War II and 1969 (Krugman, 2009). This was assisted by the Marshall plan, which accelerated the reconstruction of the parts of Western Europe that had been destroyed by the war (Eichengreen, 2007). It is therefore not surprising that production in the 1950s increased to almost 8% per year, and that over the following decade it reached more than 12%, a record for the lithium industry up to 2010. In spite of the two oil crises in 1974 and 1979, which were followed by two of the most serious depressions after the Great Depression of 1929 (Krugman, 2009), the lithium industry managed to get through those crises successfully and increase its production significantly. In fact, during the 1970s the industry achieved its second best annual growth mark of slightly under 10% per year.

By the 1970s the potential of lithium in batteries for electric vehicles was already known and extremely high projections were being made for the use of this metal (Chilenskas, 1976).

In 1985 renewed doubts arose regarding the capacity of the industry to provide sufficient lithium to support the needs of the aeronautics industry, which would require ultra-light lithium- aluminum alloys (Evans, 1986). Using the same criteria as in 1977, however, lithium reserves and resources were estimated at 36.7 million tons of lithium metal equivalent (LME), i.e. more than three times what had been estimated ten years before and sufficient to meet the needs for these new uses over several decades.

One of the curious aspects of such ostentatious projections of future demand in 1985 is that they occurred during a period in which demand increased very slowly (1984-1993), whereas from 1994 until the beginning of the Asian crisis in 1997, lithium consumption increased more rapidly due to the use of the metal in the new monochromatic monitors for computers (Metal Bulletin, 2009).

Toward 1990 the use of lithium in ceramics and glass had risen to 52% with regard to total consumption, lithium in aluminum manufacturing remained at 31%, and the use of the metal in lubricating greases had dropped to 8%. The use of lithium in batteries had increased marginally and was less than 10% (Roskill, 1990). Again in 2007 doubts were raised about the capacity of the industry to provide sufficient lithium to meet its demand in batteries and particularly in

lithium ion batteries for electric vehicles (Tahil, 2006).

But in 2007 there was already a consumption pattern that supported these estimates. In 2008 lithium consumption in batteries had reached second place among the greater uses of the metal, accounting for 20% of the market (Roskill, 2009), after glass and ceramics (37%), displacing its use in aluminum manufacturing (7%) and in lubricating greases (13%). According to Roskill (2009), lithium was used in close to 80% of lubricating greases at a global level in 2007. Lithium batteries had displaced nickel-cadmium and nickel-metal hydride ones in many electronic applications. In 2009 it was estimated that 90% of portable computers and 60% of cell phones used lithium batteries (Metal Bulletin, 2009).

It is necessary to segment the 2000-2008 period into two parts, the first from 2000 to 2003, characterized by the sequels of the Asian crisis, with low demand and prices for minerals. Lithium production practically did not grow between 2000 and 2003, and even decreased by 13% from the beginning of the Asian crisis in 1997 until 2003, indicating that the industry had an overcapacity in production. As of the end of 2005 China's power in the market began to emerge and demand increased very acutely for all mineral commodities until the global financial crisis of 2008. In the case of lithium, its most important use during this period (see Figure 5) was in the ceramics and glass industry, which was strongly influenced by the growth in construction and the automotive industry (Metal Bulletin 2009). Lithium batteries for electronic uses substantially increased the use of lithium as of 2000, from 6% that year to 20% in 2008. Due to the rise in the use of lithium batteries, its use in other applications declined in relative terms, with the exception of lubricating greases, which maintained their global market share.

Figure 5 shows the demand for lithium according to its use from 1975 (2,630 tons of contained lithium or 14,280 tons of LCE) to 2015 (177,000 tons of LCE). These figures were obtained from several Roskill reports and do not include demand in the USSR prior to 1990 or Russia after 1990. They show a rise in the use in batteries as of 2000, a reduction in the relative use in ceramics and glass since 1990 and in aluminum refining since 1975. As of 2008 and up to 2015 a growth in the use in batteries (37%) is observed, against a decline in all other uses.

The largest lithium market in 2008 was lithium carbonate (40%), followed by lithium ores (24%), lithium hydroxide (13%), lithium bromide (5%), butyllithium (3%), and metallic lithium and lithium chloride with 1% each (Roskill, 2009).

In 2012, carbonate had increased its use to 54% of the world market[61]. In 2015 technical and battery grade carbonate represented 17% and 31% of the global market for lithium products, while hydroxides (technical and battery grades) represented 7% and 6% respectively. The other major use was a technical grade concentrate obtained from the ores (19%). Other uses such as bromides, butyllithium, battery grade metal, represented 2, 5 and 2% respectively, whereas the remaining 10% was assigned to other uses (Roskill, 2016).

61 Personal communication, D. Desormeaux. SignumBox, Santiago, Chile

The growth of lithium consumption between 2010 and 2015 was 7.8% per year, due to the explosive demand for electric vehicle batteries, whereas its growth between 2000 and 2010 was 6.6% per year. The first figure would be substantially exceeded over the next years.

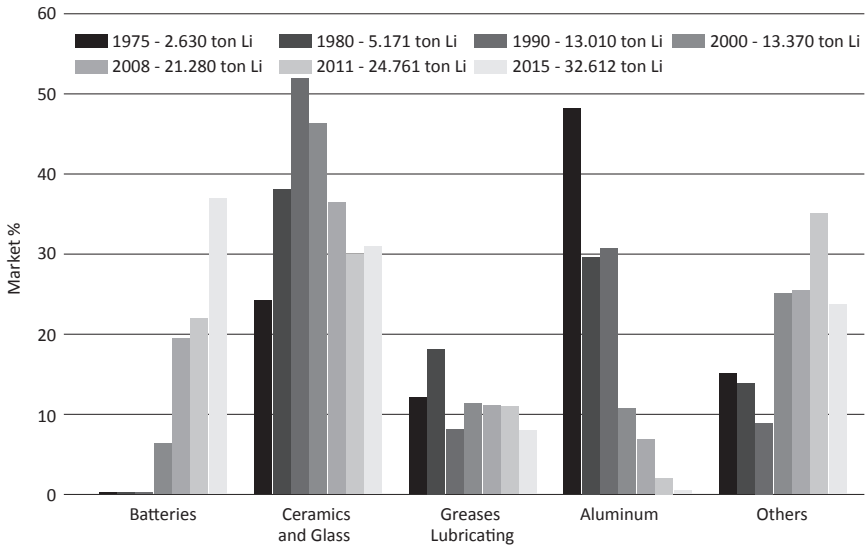

Figure 5: Uses of lithium at a global level (except for USSR and China prior to 1990 and Russia after 1990) in 1975, 1980, 1990, 2000, 2008, 2011, 2015. Sources: Roskill 1990 for uses in 1975, 1980 and 1990; Roskill 2009 for uses in 2000, 2008; Roskill 2012 for uses in 2011, and Roskill 2016 for uses in 2015. The estimates cited by Roskill 1990 corresponded originally to the Lithium Australian Prospectus, 1986 for years 1980 and 1990 , and the 1975 estimates were originally made by the U.S. Bureau of Mines, USBM.

There are various projections regarding the increase in lithium demand. Roskill (2016) ventured that the most likely consumption scenario between 2015 and 2020 would be 5.8% per year, whereas between 2020 and 2025 it would be 6.8% per year. These predictions were made possibly before becoming fully aware of the expansion plans of Tesla in the United States.

A more recent estimate by the Deutsche Bank (2017) situates the rise in demand between 2016 (212,000 tons LCE) and 2019 at 21% per year, which would be explained by a greater projection for the growth of electric vehicles and an increase of inventories in line with automotive market maturity. Citi Research (2017) situates the increase in demand at 11.9% per year between 2016 and 2021. The latter projection would be closer to the estimates made by the producing companies themselves, which place the growth of demand at between 12% and 15% per year over the next few years. This means that every year a new production of between 25,000 and 30,000 tons of LCE would have to be added to meet this demand, something that the industry considers feasible.

The sales projection for electric vehicles up to 2050 made by the International Energy Agency (IEA, 2011) is shown in Figure 6, which indicates that in that year slightly less than 60 million plug-in electric vehicles (PEV) would be sold, of which 47 million would use batteries (battery EV, or BEV) and slightly less than 13 million would be hybrid (hybrid EV, or HEV). The IEA developed these scenarios at the request of the G8[62] in order to reduce carbon emissions by 50% in 2050. This issue is addressed in greater detail in the section about lithium batteries.

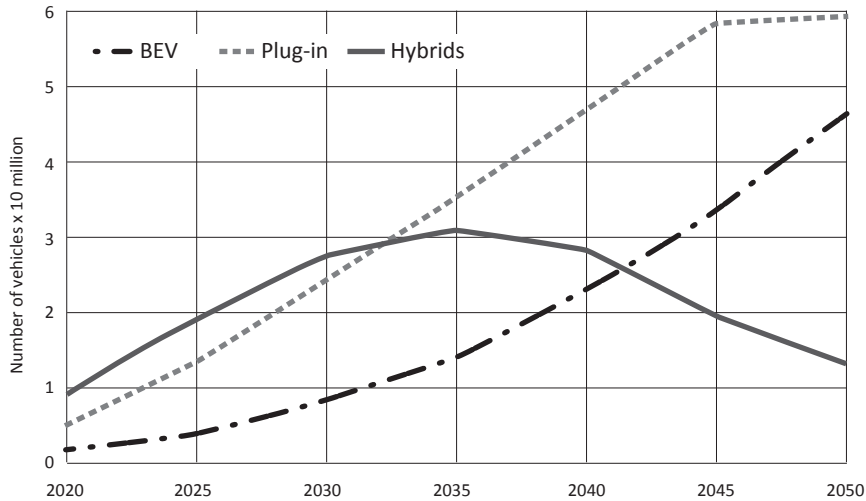

Figure 6: Projection by the International Energy Agency (IEA) 2011, for electric vehicles using batteries (BEV), hybrid vehicles (Hybrids) and plug-in vehicles (Plug-in). The sum of hybrid vehicles and those using batteries is equal to the plug-in vehicles.

On the basis of the IEA scenario, Hofer et al (2016) concluded that for a high scenario vis-à-vis the IEA base scenario, the lithium demand for electric vehicles in 2050 would be 1.86 million tons of LCE, and in a low scenario the demand would be 876,000 tons.

It is important to note that these figures, estimated solely for the demand of electric vehicles and stationary applications in 2050, are higher by almost 6% than the global value of the lithium market estimated by Yaksic (2009) for 2100.

The recyclability of the different lithium ion battery technologies is analyzed in chapter 6.4.

The remaining uses of lithium, which represented approximately 63% of demand in 2016, would grow at much lower rates, possibly 2 to 3% per year. This would mean that in 2050, between 101,000 and 128,000 additional tons

62 G8 is a group of eight countries: Germany, Canada, U.S.A., Italy, France, Japan, United Kingdom and Russia.

of LCE would be required for the remaining uses of lithium vis-à-vis those demanded in 2016 (212,000 tons LCE).

Overall, in 2050, between 977,000 and 2 million tons of LCE would be required for the high and low Hofer scenarios and for the rest of the uses of lithium, respectively. This would lead to productions of 4.6 to 9.4 times more lithium per year than that demanded in 2016.

6.1-Lithium batteries

The scientific superiority of a lithium-based battery was never under discussion due to the intrinsic features of this metal, the lightest found in nature and which, of all the elements of the periodic table, can generate greater difference in voltage. What was under discussion in the past up to 2014 was the technological superiority of other battery systems.

The winning technology among battery systems needs to comply with at least five conditions: be affordable, last a long time (10 years), provide great autonomy to the vehicle (> 500 km), have an appropriate amount of power and be recyclable.

The technology of the lithium ion battery has been available since the 1970s with the creation and theoretical development of solids chemistry by professors John Goodenough from Oxford University in the United Kingdom, and Paul Haggenmuller from the Solids Chemistry Institute of Bordeaux in France. The first lithium ion battery was formulated by professors Stanley Whittingham and Brian Steel from the Binghamton and Imperial College universities, respectively, both in the United Kingdom, and was based on a cathode of titanium disulfide (TiS_2), a material that could incorporate lithium into its crystalline network. In the second half of the 1970s Exxon Inc. tried out this cathode, using a lithium-aluminum anode. At that time there were several hundreds of researchers in the developed countries who were working on discovering new materials and methods for more efficient lithium batteries. They worked at the main universities and research centers of the world, as well as at the main battery-producing companies at a global level.

Anyone examining the annals of the meetings of the Electrochemical Society of the United States and the International Society of Electrochemistry based in Europe can confirm this. The amount of resources earmarked for research and innovation in materials for lithium batteries adds up to several tens of billions of dollars over the past four decades. As a result, several thousand materials have been tested in lithium battery cathodes and electrolytes. Sometimes the materials seem to be similar, but small stoichiometric changes modify the ionic and electronic conduction properties, as well as the reversibility of the reactions.

By generating electric current, the lithium ions shift from the electrolyte (ionic conductor) to the cathode (ionic and electronic conductor), where they insert themselves, penetrating the crystalline channels of the cathode material. The speedier the movement of the lithium ions into the crystalline channels, the greater the power generated. When charging the battery, the opposite process takes place. For this reason these materials permit thousands of discharge and charge cycles without becoming degraded and using up very little energy in

the process. That is to say, almost all the energy in the discharge is delivered to the circuit that needs power, for example the electric motor of a vehicle, or the electronics and screen of a cell phone or computer.

As the battery becomes discharged the composition of the cathode changes, increasing the lithium content. The cycle ends at a point in which the anode-cathode potential is no longer useful to provide power, and it is necessary to charge the battery.

In 1985 Akira Yoshino first tried out lithium cobalt oxide ($LiCoO_2$) in the cathode of a lithium battery. This material had been discovered by Professor Goodenough and is currently the material of preference used in lithium ion batteries for all types of electronic applications and particularly in iPhones. During the 1980s the lithium manganese dioxide cathode was tested in laboratory batteries.

Some of the most significant advancements in lithium batteries after the 1970s and 80s were the launch by Sony and Asashi Kasei of the first commercial battery in 1991, which used the cobalt oxide cathode. This was followed by the discovery of lithium phosphates as cathode materials in 1996 and the incorporation of dopants such as aluminum, niobium, zirconium and nickel into cathodes in 2002 to increase their electronic conductivity.

The main manufacturers of lithium ion batteries, according to The Economist (2016) were Samsung, LG, Sony (Japan/China/Singapore), Panasonic, ATL (Japan/Hong Kong), and Lishen, Coslight, BYD (in association with Hong Kong), BAK, Hitachi Maxwell (in association with Japan) of China (Roskill, 2016).

Catl, the highest-growth battery company in China, with a financial worth of 11.5 billion dollars (Financial Times, 2017), announced that in 2020 it will be larger than the Tesla battery giga-factory. Its president indicated that in 10 years there should only be 10 battery manufacturers in the world, with the three first dominating 60% of the market. Goldman Sachs estimated that the lithium battery market would reach 40 billion dollars in 2025.

In 2015 lithium ion batteries with a 60 GWh capacity were manufactured, and their competitors – the nickel-cadmium and nickel-metal hydride batteries – represented 5.4% and 1.6% of the market, respectively (Roskill, 2016). In addition there were 25 companies in 2015, many of them in the U.S., which produced lithium ion batteries for large applications, network storage, heavy duty work and transport.

Figure 7 shows the 31% average annual growth of the lithium ion battery market from 2000 to 2015. Also shown is the market growth of two competitors, the nickel-metal hydride battery and the nickel-cadmium battery.

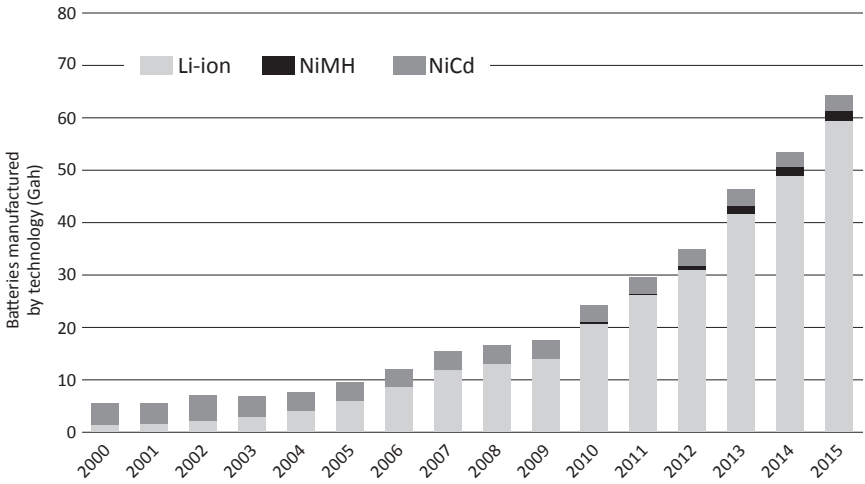

Figure 7: Global production of batteries 2000-2015, Source: Roskill 2016

In present-day electric vehicles, lithium cobalt oxide is still used, but also other materials such as lithium manganese dioxide, nickel cobalt aluminum oxide, and other cathode materials (Tesla, 2017 website). In 2017 close to 40% of the cobalt in the world has been used for lithium ion batteries, and Tesla foresees that this quantity will increase to 55% in 2019. For this reason it has established an agreement with Panasonic to supply those batteries. The long-term supply contracts between manufacturers of electric vehicles, battery manufacturers and lithium producers are increasing and will possibly transform this industry, perhaps not to the point of producing a vertical integration but certainly to enter into long-term contracts between the different participants in the production chain.

This has given rise to incentives to expand not only the exploration of lithium deposits but also cobalt deposits. And, of course, copper is fundamental, because an electric car uses two to three times more copper (between 50 and 75 kg) than a gasoline-powered car. But not all is silky on the road to the future. Apple announced last March that it would stop buying cobalt from the Congo Democratic Republic, because child labor was used in this industry. There is no question that Apple knew what alternatives it would use for its batteries when this announcement was made. This begs the question, is cobalt supply going to be enough in the future if the best lithium ion technologies are based on the lithium cobalt oxide cathodes? My guess would be yes, because exploration for cobalt is just booming at present. The world cannot depend on one country supplying a substantial amount of any material.

6.2-Lithium in electric vehicles

In 2006 a strong debate started over the advantages of lithium batteries in comparison with its competitors, which is described in chapter 11, Tahil versus Evans. This debate ended in 2009 without any agreement having been reached. But the hard facts showed that lithium batteries were superior to their competitors. All major manufacturers that were selling electric vehicles had adopted the lithium ion battery. Following is a list of the vehicle models marketed in 2011:

- Coda, priced at USD 37,400, with 134 horsepower (HP), a 33.8 kwh battery with an 8-year or 161,000 km guarantee, and a range of 190 km.
- Mitsubishi i-MIEV, priced at USD 20,490, 63 HP, a 16 kwh battery, range of 160 km, 5-year guarantee.
- Nissan Leaf, USD 27,700, 107 HP, 24 kwh battery, range 100 km, 8-year or 161,000 km guarantee.
- Tesla Roadster, USD 109,000, 248 HP, 54 kwh battery, range 390 km, 7-year or 161,000 km guarantee.
- Chevrolet Bolt, USD 32,780, 149 HP, plug-in hybrid, 20 kwh battery, range 56 km in battery mode and 600 km in hybrid mode, 8-year or 161,000 km battery guarantee.
- Fisker Karma, USD 79,900, 403 HP total, 20 kwh battery, electric range 80 km, hybrid range 402 km, 10-year or 161,000 km guarantee.
- Honda Civic, USD 24,000, hybrid, 110 HP, 20 kwh battery, range 210 km.
- Honda FXC Clarity, 3-year lease for USD 600 per month, hybrid battery-fuel cell, 386 km range.
- Honda Fit, based on lithium ion battery, to be announced.

Among higher-range brands, no commercial electric vehicles were found that were powered by anything other than lithium ion batteries. In 2011 there were several hybrid vehicles (Toyota Camry, Toyota Highlander, Toyota Prius, Ford Fusion, Ford Escape and Honda Insight) that used nickel-metal hydride batteries. But the evidence was that those batteries would be replaced by the lithium ion technology. Toyota and other hybrid car manufacturers that incorporated nickel-metal hydride batteries abandoned this technology in 2012 and changed to lithium ion ones.

The announcement in 2014 by technological magnate Elon Musk, founder of Tesla, regarding the construction of a mega-factory for electric vehicles in Nevada, which would manufacture 500,000 electric vehicles five years later, unleashed a world race to emulate Tesla and motivated the Chinese government in 2016 (Deutsche Bank 2017) to reformulate its electric vehicle manufacturing program, reducing the subsidy to that activity in order to increase competition, and increasing the subsidy to batteries with more stored energy, speedier recharge and greater manufacturing costs.

This subsidy consisted, first, in financing up to 50% with local government funds in respect of the state subsidy they were already receiving; secondly, establishing a cap for the subsidy level based on the autonomy of the manufactured electric vehicles, and third, maintaining a goal of five million cars manufactured per year by 2020. In turn, the Chinese manufacturers announced their commitment to the lithium ion technology because it would be dominant for at least 5 to 10 years. According to the Deutsche Bank the commitment of the Chinese manufacturers to lithium was high, recognizing that lithium-specific technology was evolving. The subsidy would decrease over time with the reduction of manufacturing costs. In 2017 many manufacturers in China have been increasing the capacity of the batteries in order to have access to better subsidies. For example, for batteries of more than 150 kwh the Chinese government established a subsidy of 319 USD/kwh, while for batteries between 85 and 95 kwh the subsidy was 213 USD/kwh (Deutsche Bank, 2017). This could ultimately constitute between 50 and 75% of the manufacturing cost of a battery in 2017.

The specificity of the subsidies reveals that the Chinese government has a group of experts, scientists, engineers and economists, trained at the best universities in the world, who are up to speed on the latest that is occurring in the automotive industry and in batteries, as well as among the lithium producers and processors. China uses a similar strategy to others that have been applied previously in other industries. At the start of the race it established very high subsidies and provided relaxed environmental rules. Later on it began to increase requirements and reduce subsidies in order to get manufacturers to develop new and cleaner technologies.

This is what happened in the copper smelting and refining industry as of 2000, when the government subsidized this activity without imposing any environmental restrictions. The industry grew exponentially, reducing smelting and refining charges to practically zero in 2002 to 2004, and displacing the Japanese industry that had been the market leader for the past two decades. Once this was achieved, it began to reduce the subsidies, establishing increasingly more stringent environmental requirements and shutting down smelting plants that failed to comply with those requirements. At present China has close to half the smelting capacity of the world and has developed a totally new technology that not only complies with offering lower-cost alternatives than its competitors but also with the capture of practically all air emissions.

To make the smelting plants profitable, over the past 15 years China developed processes and technologies to recover around 20 valuable elements contained in the concentrates.

Other countries also have subsidies. In the United States, for example, each electric vehicle up to 200,000 per year per manufacturer, is given a subsidy of USD 7,500 (Deutsche Bank, 2017).

Both in China and other counties, markets for electric vehicles encompass the entire spectrum, from light vehicles up to large buses and trucks.

In 2016 sales of electric vehicles (EV) in the world increased by approximately 10%, with 780,000 units sold (Deutsche Bank, 2017), 160,000 sold in the U.S. and 76,000 by Tesla.

The following pages will address some of the most important manufacturing plans of electric vehicles announced up till 2025.

Tesla announced sales of 400,000 vehicles in 2017 and 500,000 in 2018, plus the construction of four new mega-factories, all in Nevada (Tesla website). According to the Deutsche Bank (2017), the goals announced by Tesla are overstated. One of its models is called Model X, an autonomous SUV with a solar panel roof and a 5-star safety rating. In addition to vehicles, Tesla teamed up with an electricity generating plant in Vermont, Green Mountain Power (GMP), to install Powerwalls, fixed battery units, and provide up to 2,000 of these to the homes of EV owners at a rate of 15 USD/month or a lump sum of USD 1,500, eliminating the need to have generators operated manually with diesel to provide electricity to their cars. This would represent a lower cost than the existing alternatives and make it possible to obtain a recharge of the fixed units during non-peak hours and thus maximize the reduction of greenhouse gas emissions (GHG).

Chevrolet would be manufacturing between 30,000 and 80,000 Chevy Bolts in 2017 (Deutsche Bank, 2017). It also partnered up with the Lyft company to manufacture autonomous vehicles, emulating Tesla.

Ford announced the manufacture of thirteen EV models over the next five years, for example, a hybrid model of the F-150 pickup truck, a Transit minibus in 2019 and a hybrid Mustang in 2020. It will also make SUVs with 480 km autonomy in 2020.

Volkswagen will introduce 30 EV models with the aim of producing between 2 and 3 million EV in 2025, including Porsche and Audi models. Around 20 of these models will be for sale in 2020. During the Motor Show in Paris in 2017 it displayed the I.D. concept with an autonomy of 600 km, which will be released on the market in 2020. Audi plans that 25% of its vehicles in practically all its models will have an electric version by 2025.

Renault launched its Zoe model in 2016, planning to increase its autonomy to 400 km.

Mercedes has set itself the goal of producing 10 of its models in electric version by 2025, reaching figures of between 15 and 25% of its sales worldwide. At the 2017 Paris show it announced that in 2020 it will have for sale an electric version of the GLC model with an autonomy of 500 km, at the same price as the gasoline model. It is also working on placing on the market an urban truck (Urban eTruck) with an autonomy of 200 km and a load capacity of 26 tons.

BMW added a Mini model and a BMW X3 SUV to its EV offerings. Its goals are for 15 to 25% of its global sales to be EV by 2025. It also offered those who bought the i3 electric model an upgrade of the battery to extend its autonomy to 180 km.

Mazda estimates that by 2020 between 5 and 10% of all vehicles sold will be electric. Nissan works with Renault to develop the Leaf model vehicle with an autonomy of 320 km. It also cooperates with Renault to manufacture the Zoe model. Hyundai launched its IONIQ model that costs less than USD 20,000 in the U.S. but has very little range, less than its competitors the Chevy Bolt and the Tesla 3. The company plans to introduce its EV SUV model in 2018 with an autonomy of 320 km.

Toyota, the second largest vehicle manufacturer in the world, already has a hybrid plug-in Toyota Prius in 2017, with a predecessor non plug-in Toyota Prius already solidly entrenched in the market. it also has the Toyota 86 Sport Scion FR-S. Its CEO, Mr. Toyoda, is working with an in-house team to design the electric car for 2020.

The hypothesis is that the current electric models do not sufficiently appeal to clients. Toyoda's concept is similar to what Steve Jobs said of Apple, that the computer should be the extension of a person.

In an interview with Green Car Reports, Mr. Toyoda said (Toyota website), *"Tesla is producing (electric) cars. And Toyota is producing (electric) cars. But what Tesla is producing is something close to an iPhone."*

One of the key aspects in this race among EV manufacturers is to ensure lithium supplies in the future, and in the past two to three years customer loyalty has increased. Clients from large global automotive and battery companies are seeking vertical integration, or else seeking to ensure that supplies from major lithium mining companies such as Albemarle, Tianqi and SQM are safeguarded. This results in requesting mine producers and the entire subsequent chain to diversify their production sources in order to buffer them from natural events, strikes, political or regulatory changes.

6.3-Manufacturing cost of lithium ion batteries

According to Albemarle (Goldman Sachs, 2016) the cost per kwh in lithium ion batteries was USD 1,450 in 2006, dropping to USD 750 in 2010 and again to USD 200 in 2017. The price curve continues to descend. This was expectable as the demand for lithium batteries rose.

At the same time, however, the price of lithium increased, making it a more important component vis-à-vis the total value of the battery. While Evans (2009) and others estimated that the price of lithium was close to 1% of the price of the battery, The Economist (16 January 2016) indicated that the cost would not exceed 10% in value and 5% in weight.

It is therefore necessary to revisit Evans' (2009) assertion, who added that even if lithium prices were to double, this would not represent an impediment for its use in that application[63].

In 2011 the cost of lithium in batteries, according to Rockwood[64] (2011) data, considered that each kwh of power would require 2 lbs of lithium carbonate[65]. The cost of battery grade lithium carbonate was, approximately, 5,000 dollars per ton, therefore a 10 kwh battery would contain 20 lbs of lithium carbonate, costing USD 45.4. That is to say, the lithium in the Coda[66] battery would have

63 Evans argued that a 2 kwh battery requires 6.6 lbs of LCE, which considering a price of 2.8 USD/lb (2009) resulted in a total of USD 18.5. Doubling that to USD 40 in a battery that cost several thousands of dollars would not constitute a financial limitation, even less considering that the car would cost 20,000 dollars or more.

64 Owner company of Chemetall

65 0.167 kg of metallic lithium (167 grams) provides 1 kwh of power

66 The metallic lithium weighed 12.45 kg (67.6 kg of lithium carbonate) according to Rockwood's 2011 power-weight ratio.

cost close to USD 153.4 in 2010, with the value of the vehicle being 244 times higher than that of the lithium. Therefore, the 2011 estimate was already close to what The Economist reported in 2016.

In the case of the Mitsubishi i-MIEV, the value of the car was 282 times higher than the lithium value in 2011. That meant that the lithium value represented less than 0.5% that of the vehicle, and could therefore double or triple its cost without affecting the economic viability of these cars. If we adopt the ratio proposed by Evans (2009) of 3.3 lbs of lithium carbonate for each kwh of power, the above-mentioned costs would first have to be multiplied by 1.65, resulting in the lithium content costing 0.7% of the vehicle, still a modest figure.

Table 2 presents data of the Tesla 100 D obtained from the Tesla website, and of lithium carbonate at the spot market price in November 2017.

Tesla 100 D model (Tesla website)	
kwh in battery	100
Range (km)	475
Car price (USD)	101,000
Battery cost (estimated) USD	18,998
Theoretical efficiency (kwh/100 km)	18 to 20
Actual efficiency (kwh/100 km)	21.1
Estimated weight of lithium carbonate (kg)	319
Estimated weight of lithium (kg)	59
Lithium carbonate cost in the battery at spot price December 2017 (USD)	5,748
% price of lithium carbonate with respect to price of the car, %	5.7
% price of lithium carbonate with respect to price of the battery, %	30.3

Table 2: Lithium and lithium battery data in the Tesla 100 D model. Source: Tesla website

6.4-Recycling of lithium batteries

Recycling of lithium batteries used in electric vehicles is and will remain a key aspect in determining which technologies will be viable in the future. Lithium ion battery technologies in which recycling the lithium would be more expensive than to produce it directly from the mine or a deposit would be destined to disappear in the medium term.

In the study on the recyclability of the materials that make up the different lithium battery technologies, both for electric vehicles and energy storage, the question Hofer et al (2016) answers is, how much lithium will there be available from the recycling of lithium ion batteries over the 2020 to 2050 period? For

this he analyzes the current recycling technologies, the amount of lithium that would be available on the basis of each technology, and their cost.

The cost estimate also includes the recycling of other battery materials, such as cobalt, manganese, nickel, aluminum, copper and iron. There are many authors who had analyzed some of these questions, but none before had simultaneously addressed such a long period, the recycling cost, or considered stationary batteries.

Hofer analyzed the recycling of four lithium ion battery technologies: lithium cobalt oxide ($LiCoO_2$) (LCO), lithium manganese oxide ($LiMnO_4$) (LMO), lithium iron phosphate ($LiFePO_4$) (LFP) and lithium nickel manganese cobalt oxide ($Li(NiMnCo)O_4$) (NMC). All these technologies are called thus depending on the cathode material. Lithium represents up to 3% of the weight of any of these batteries.

It is estimated that in 2050 there will be 200 million batteries available for recycling, considering an average life of 9 years per battery.

Hofer's work concludes that the only two lithium ion battery technologies whose variable costs would be lower than the price of lithium, i.e. that they would be economic to recycle, are those that contain cobalt in the cathode. For the other two technologies the lithium recovery would cost more than the price of the metal.

The lead-acid batteries used in conventional vehicles (diesel and gasoline) do not appear to be threatened by substitution in the short run because, for now, not only are they lower-priced than their lithium ion competitors, but also because in Europe, Japan, U.S.A. and other G7 countries 100% of the batteries are recycled.

Many companies, for example Umicore and Toxco, currently have lithium ion battery recycling facilities and this is an issue that is subject to intense research and dynamics due to the economic implications involved. These scenarios could change radically over the next few years.

Whoever develops more economic methods to recycle lithium will have an immense market advantage over the rest of the recyclers, and this could lead to changing the preferred battery materials. Now, the main lithium producers – Australia, Chile and Argentina – are far away from the largest vehicle consumption centers and are therefore at a disadvantage to become large recycling centers. But they can develop technology and install recycling plants nearer to the consumption centers, or else charge a royalty for the use of the technology by third parties. The recycling of lithium could be a niche of interest for research in lithium-producing countries in the southern hemisphere.

Finally, although it might seem counterintuitive, recycling will be more and more pivotal to increasing demand, and thus the primary production of a metal or element.

This logic is valid when demand increases, because if it remains the same or declines, recycling definitely becomes a substitute.

6.5-Nuclear fusion

Nuclear fusion is a process that occurs in the sun, where various light isotopes[67] fuse together to create heavier atoms, generating an immense amount of energy, as predicted by Einstein's famous formula $E = mc^2$. This formula allowed scientists to explain the processes of nuclear fusion that occur in the sun and other stars. According to Wikipedia the sun generates, every second, 760,000 times the energy used on earth.

The two isotopes considered for nuclear fusion are deuterium and tritium[68]. While the first can be extracted from water and is abundant[69], tritium is very scarce and has to be "manufactured" artificially. Tritium has a half-life[70] of approximately 12.3 years, which explains its scarcity in nature and the time required to dismantle a reactor.

The use of lithium in fusion reactors is known and has been projected since at least the 1970s (Bogart, 1976). Lithium is irradiated with neutrons in a plasma[71], generating yttrium plus an isotope of helium. The plasma in the Tokamac[72] reactors operates at temperatures above 150 million degrees centigrade. The most efficient way to generate tritium is for the irradiated lithium to be a combination of a high proportion of the lithium 6 isotope and a small fraction of lithium 7 (natural, non-radioactive state of lithium). Lithium is, up to now, the most efficient element that has been found to generate tritium in nuclear fusion reactors. But there are alternatives, among them beryllium (Fasel, 2005).

According to a CChEN report by physicist M. Zambra (2008), the international Thermonuclear Experimental Reactor, ITER, located in the south of France, was intended to "scientifically and technologically demonstrate the viability of energy through nuclear fusion in a deuterium and tritium plasma." The reactor was designed in 1988, would be built in 2016 with a purely demonstrative power of 500 MW[73], would have a useful life of 21 years and cost 13 billion euros. It would be dismantled in three phases, the first consisting of 5 years of deactivation, a second of radioactive decay that would last several decades, and a final dismantling phase lasting 6 years.

According to Zambra (2008), after the ITER project there were two other projects in the pipeline, DEMO and PROTO. The first could begin to be built before the conclusion of the ITER project and would depend on the results

67 Isotopes, according to Wikipedia, are "atoms of the same element, whose nuclei have a different number of neutrons and therefore differ in terms of mass." Isotopes emit radiation, which can be of different types.

68 Both are isotopes of hydrogen

69 There are 33 grams of deuterium per cubic meter of water

70 According to Wikipedia, half-life is "the time required for a quantity of radioactive nuclei of a radioactive isotope to reduce to half its initial value."

71 According to Wikipedia, plasma is "the fourth fundamental state of matter, a fluid state similar to the gaseous state but in which a certain proportion of its particles are electrically charged and have no electromagnetic equilibrium. This makes it a good electrical conductor and its particles respond strongly to long-range electromagnetic interactions.

72 Toroidal or "hollow doughnut" reactor

73 Megawatts

obtained with the ITER. The DEMO reactor would have four times the power of ITER and its purpose would be to generate energy. The DEMO reactor could "have a net electricity-producing capacity to meet a small part of the world's demand in 2050", according to Zambra. In turn, the PROTO reactor would have a 1.5 gigawatt (GW) capacity, would begin to be built in the 2050s, and be ready in the same period. Zambra (2008) concluded that "large-scale production on the basis of nuclear fusion reactors would be consolidated by year 2100." He added, "the forecasts for the use and consumption of lithium in fusion reactors would require between 6.3 and 8.9 tons of lithium per year to generate 1.5 GW over a period of eight thousand hours[74]." The construction of a 1.5 GW reactor would require additional lithium for the neutron bombarded blanket. There were two designs for the blanket, according to Fasel (2005), both involving other elements associated with lithium. The design with a lower use of lithium, on the basis of lithium oxides and silicates, required 174 tons of metal, whereas the second design, based on water cooling, required 787 tons. Fasel made estimates of the duration of lithium reserves and resources, considered to be 17 million tons[75], at 600 years solely for nuclear fusion, without considering recycling the lithium in the reactor.

On balance, in 2017 plans regarding controlled nuclear fusion continue to be very much in the future. My point is not that it is unreal or will not happen. It may happen, and earlier than expected. What I am saying is that it makes no sense to hoard lithium for this reason. We must not forget that our mineral resources are merely a means to arrive at full development and do not constitute an end per se.

74 One year has 8760 hours.

75 Evans 2012 estimated global lithium reserves and resources at 39.8 million tons

7. PRODUCTION

7.1-From 1984 to 2011

Figure 8 shows world lithium production from 1984 to 2016, including the four main players, Chile, Australia, Argentina and the United States.

Up to 2012 there was consensus among the industry experts that it was difficult to estimate production accurately. There were strong differences in the estimates between, for example, the USGS, the Canadian government, the Roskill company, the British Geological Survey, and the two leading geologists in the industry, Keith Evans and Ihor Kunasz. The reason for these differences was that some of the lithium ore-producing companies reported the tons of mineral exported without indicating the average grade of lithium in those minerals. The lithium content in the main minerals could vary up to more than 100%.

There were also difficulties in following the production of the brine deposits. In the case of Chile, for example, SCL produced lithium carbonate and chloride directly from the brines, but it also produced part of the chloride from the carbonates, whereas SQM produces lithium hydroxide monohydrate on the basis of lithium carbonate[76]. In addition, both companies sold purified lithium chloride brines to third parties, which typically contained between 5 and 6% lithium.

Figure 8 contains a series of uncertain figures, especially with regard to the U.S. production during many years which were not reported by the USGS. Of late the USGS has started reporting U.S. production again. The United States began to reduce its importance in world production, from being the main global producer since the beginning of the industry until 1995, when it was outperformed by Chile. In 1996, however, the U.S. was back to being number one, but only for that year because from 1997 to 2008 Chile completely dominated world production.

The U.S. production reached a low of less than one thousand tons of contained lithium in 2011, representing under 10% of Chilean production. The data for Australia and the USSR are also uncertain prior to 2006. Subsequently the Australian data have been reported by Talison Lithium and Galaxy Resources.

The explosive increase in world production that occurred in 1996-1997 cannot be explained, because it more than exceeds the effect of SQM's entry

76 Information obtained from SCL and SQM

into production in Salar de Atacama, FMC starting production at Salar de Hombre Muerto, and Australia's growth of production during those years due to the expanded capacity of Sons of Gwalia in the Greenbushes deposit in Western Australia.

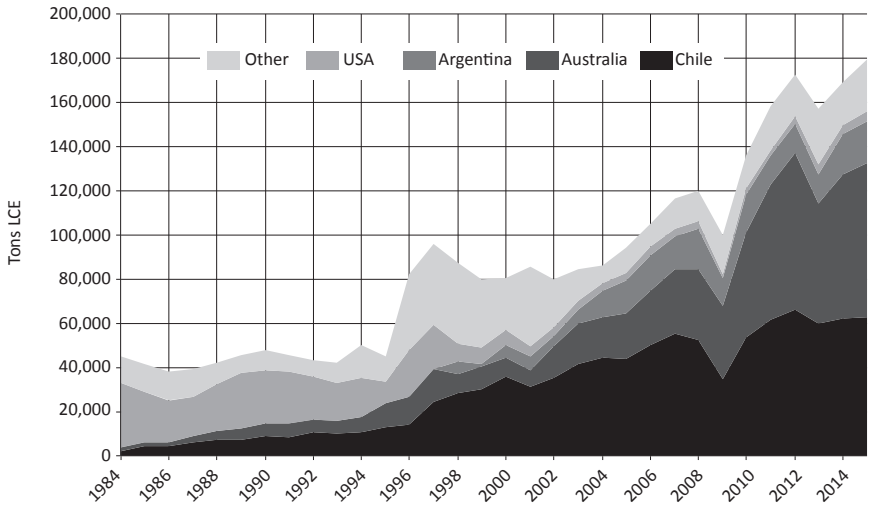

Figure 8: World lithium production 1984-2011 expressed in tons of lithium carbonate equivalent. To transform these figures into metallic lithium content it is necessary to multiply by 0.189. The figure includes the production of the four main players at that time, the United States, Chile, Argentina and Australia. Sources: between 1984 and 1993 world production was based on data provided by the British Geological Survey; between 1994 and 1999, data provided by USGS[77], and between 2000 and 2011, based on Roskill's (2012) data. U.S. production was obtained indirectly from USGS data, Chile's production was adopted from Roskill between 1984 and 1989, and on the basis of the data of the Chilean Copper Commission between 1990 and 2011, considering only lithium carbonate production. Argentina's production was adopted from the USGS until 1999 and from Roskill as of 2000. Australia's production was adopted from BGR Polinares (2012) between 1984 and 1993 (as a proportion of the world total), from USGS between 1994 and 1999, Roskill between 2000 and 2006, the Talison and Galaxy companies from 2007 to 2008, and Roskill (2016) from 2009 onward.

Figure 8 shows the growth by decades of contained lithium production from 1984 to 2011. This resulted from the demand that arose in the different periods at a global level and therefore was affected by the booms and busts of the world economy during that period. This graph indicates that the period of greatest production growth, responding to higher demand, coincided not only with the high growth of the United States and Europe but also with the existence of lithium carbonate that was accessible for use in many applications.

77 USGS Mineral Commodity Summaries

The response of production to demand was observed again as of 2005 with the commodities boom prompted by China, was interrupted momentarily by the 2008 financial crisis, and continued thereafter.

Figure 9 shows the beginning of the SQM operation in Salar de Atacama, and of FMC in Argentina in Salar de Hombre Muerto in 1996-1997, as well as the stimulus to production growth generated by Talison Lithium in Australia in 2007.

The pegmatite mines of North Carolina closed down with the development of the salt lakes in Chile and Argentina. In 1996 Foote closed its mine in Sunbright, Virginia, because it already had sufficient and cheaper lithium hydroxide production capacity in the Silver Peak salt lake in Nevada.

Up till 1998 FMC (ex Lithco) produced lithium from the Hallman-Beam open pit mine near Cherryville in North Carolina, but during that year the mine was closed down and sold to a company that would use it for construction materials (Roskill, 2003).

In 1999 FMC decided it would be more economical to reach a long-term agreement with SQM in Chile to provide the lithium carbonate it needed to produce other lithium products at its plants in the U.S. than to continue operating its lithium carbonate plant in Salar de Hombre Muerto in Argentina, which was not competitive at that time. Simultaneously, it was expanding its plant to manufacture butyllithium and other organic lithium reagents in Bessemer City. And in 2002 it established an alliance with the Scottish AEA Battery Systems to promote a new and revolutionary battery technology (Roskill, 2003).

The entry into production of the Chilean and Argentine salt lakes, as well as the closure of the U.S. mines explains, at least partially, the production boom in 1996-1997 and its subsequent decline.

Figure 9 clearly shows that the policy of three of the four major companies in the face of the 2008 crisis was to reduce production (by 27%) in 2009, instead of reducing the price. Both SQM and SCL strongly reduced production, but Talison Lithium did not, because it was in an intense process of productive expansion. This meant that during that year Australia's production exceeded that of Chile by 35%, according to Sernageomin and Cochilco data, and by 15% in terms of the country's lithium exports.

After SCL began to produce lithium carbonate in 1984, it inaugurated a potassium chloride plant[78] in 1988. In 1997 it started to produce lithium chloride and in 2004 it produced high-purity lithium carbonate for use in manufacturing batteries. It also produces other products such as magnesium chloride, sodium chloride and potassium chloride (potash). SQM began to produce lithium carbonate together with potassium salts in 1997 and as of 2005 it inaugurated a lithium hydroxide plant.

The production figures for lithium salts provided in the Sernageomin and Cochilco yearbooks are misleading, because in some years the productions of lithium carbonate, lithium hydroxide and lithium chloride are added together, which is not a correct procedure. As an example, in 2011, the Cochilco and

78 Presentation by Monica Engel-Bader of Chemetall, on 5 August 2010 at a seminar on lithium organized by Sonami, Santiago, Chile.

Sernageomin yearbooks reported that the total production of lithium salts was 69,597 tons and that the production of lithium carbonate was 59,933 tons. They do not indicate, however, whether this latter value includes all types of lithium salts produced in the country, which include hydroxide, chloride and lithium-concentrated brines. It is known that part of the lithium chloride produced by SCL is based on lithium carbonate and that another fraction is produced from purified brine[79]. As previously indicated, SQM produces lithium hydroxide on the basis of carbonate. Therefore it is not possible to arrive at a definitive conclusion regarding the total production of lithium salts in Chile. As a reference, Chile's total exports in 2011 were 61,728 tons of LCE[80].

It was not possible to explain the differences between the production figures provided by Sernageomin and Cochilco between 1992 and 2011 and the country's lithium exports. Between 2004 and 2008 exports were, on average, 10% lower than production, as shown in Figure 9, whereas between 2009 and 2011 exports were close to 5% higher than production. Adding the total tons of lithium salts, expressed in LCE, exported by Chile between 2002 and 2011, they were 1.5% lower than the tons of lithium carbonate production reported for that period by Sernageomin and Cochilco. This could lead to the impression that, in effect, the 59,933 tons reported by these institutions in 2011 represent the total lithium production for that year, expressed in terms of lithium carbonate.

The uncertainty regarding production in Chile that arises from the reported production figures requires an effort to generate reliable values that could serve as a reference for professionals and opinion leaders who consult these yearbooks on a regular basis.

It seems logical to recommend that the production numbers cited should account for the entire lithium production of the country and that it be expressed in the same units. These can be in lithium carbonate equivalent (LCE) or else metallic lithium. Moreover, the total production value should include the purified brines that the producing companies sell to third parties, even if they are exported as unfinished products. What is of interest, ultimately, is the total lithium sold abroad, because Chile so far is not using lithium to develop products of the metal in the country itself. Both Albemarle and SQM apparently exported brines under special circumstances after having requested the CChEN's permission.

In any event, the published values regarding the production of lithium salts by Cochilco and Sernageomin led many to think that Chile continued to be the world leader in lithium production in 2011. Reports by Talison Minerals and Galaxy Resources, both from Australia, allow us to conclude that Australia outperformed Chile in terms of lithium production in 2011, with a total of 62,560 tons of lithium carbonate equivalent (LCE), whereas Chile would have produced 59,933 tons that year. In the event that Chile's production was in fact higher than the figure indicated by Sernageomin and Cochilco, there would

79 Information provided by the company.

80 This value includes all lithium salts that were exported from the country, including concentrated brines.

have been a virtual tie between Australia and Chile in terms of their 2011 production, representing close to 38% each.

What is important here is not the exact figure for Chile's production in 2011, but the trend. According to the number adopted for world production in this book, Chile would apparently have produced 37% of the total. Australia's expansion in production capacity, however, indicates that Chile will continue to lose ground in market share during this decade.

Talison has followed an expansion policy in its production, and in 2012 attained a production capacity of 110,000 tons of LCE, while Galaxy Resources has a capacity of 17,000 tons, also in tons of LCE. In 2012 SCL had a production capacity of 24,000 tons of lithium carbonate, plus 5,000 tons of lithium chloride. In turn, SQM had a production capacity of 50,000 tons LCE in 2012. This made the country's total close to 78,000 tons LCE[81]. On the other hand, Talison had already outperformed SQM in production in 2008[82], thus becoming the largest lithium producing company at a global level.

Talison only began producing lithium in 2007 at the Greenbushes mine in Western Australia after having purchased the deposit from Sons of Gwalia Advanced Mineral Division, and in four years it became the world's prime producer. The Greenbushes mine had begun to mine lithium in 1974 (Roskill, 2009). Talison exports spodumene concentrates and is the main supplier of lithium to China, which consumed one-third of world lithium in 2011[83].

At the end of 2010, Galaxy Resources of Australia made its entrance into production at the Mount Cattlin mine in Western Australia[84]. This company produced 9,760 tons of LCE based on spodumene ore in 2011, compared to 52,800 tons LCE produced that year by Talison Minerals, also from Australia.

Galaxy Resources owns a plant that transforms lithium concentrate (based on spodumene ore) into high-purity lithium carbonate (for batteries) in Jiangsu, China, with a capacity of 17,000 tons LCE. This is a substantial capacity, comparable to FMC's production in Salar de Hombre Muerto in Argentina in 2010. Galaxy owns concessions of pegmatite mines in Quebec, Canada, and acquired Lithium 1, the Sal de Vida project located in the eastern sector of Salar de Hombre Muerto in Argentina, and announced a production of 25,000 tons of lithium carbonate. It also announced in July 2012 that it had completed the feasibility study to manufacture batteries in Jiangsu, China, where it intends to produce 600,000 batteries for e-bikes, or electric bicycles, in conjunction with companies of the Asian region.

Figure 10 shows the entry into production of SCL in 1984 and of SQM in 1997, and the reduction in production of both companies in 2009. In 2010 demand recovered to 2008 levels, although still with a production overcapacity of around 30%[85], which would increase to over 40% as of 2012 due to the

81 Information obtained from SCL and SQM.

82 SQM exported 30,285 tons LCE, while Talison produced 32,000 tons LCE.

83 Presentation at the Wedbush Clean Technology & Industrial Growth Conference, 15 September 2011, Australia.

84 Galaxy Resources Report, July 2012

85 K. Evans, 2010: Keith Evans, The Northern Miner, 18 October 2010

mentioned expansions in capacity. When there is overcapacity it is usual for price wars to ensue in order to remove the higher-cost production from the market.

7.2-From 2011 to 2017, and projections up to 2015

No productive development took place in Chile since 2011, as shown in Figure 11. In fact, Chile reduced its production. This contrasts sharply with what happened in the rest of the world due to the explosion of battery demand for electric vehicles in 2015, increasing the 100 lithium deposit projects in 2011 to 400 in 2016.

In 2015 Albemarle, a company specializing in chemical products and catalysts since 1887, purchased Rockwood Holdings, thus becoming one of the top chemical companies in the world.

By buying Rockwood, Albemarle inherited the expertise for processing lithium chemical products that Foote, Cyprus Foote and Chemetall (Figure 1) possessed. Thus, Albemarle now has productive mining operations in Salar de Atacama and a processing plant in Salar La Negra in Chile, Greenbushes and Kwinana in Australia, Silver Peak in Nevada, New Johnsonville in Tennessee, and Kings Mountain in North Carolina. It also has chemical operations in India, Germany, Jordan and the United States. Tianqi, a Chinese-owned company, holds a 51% share of Talison Lithium, which operates the large Greenbushes mine in Australia and is therefore its controller. Albemarle owns the remaining share. In addition, Tianqi has several spodumene and brine deposits in China.

According to Deutsche Bank (2017), half of the lithium production was based on brines in 2016, but since then 75% of the new production originates from minerals and the remainder from brines. Citi Research (2017) projects that in 2025 the proportion of lithium production based on minerals and brines will be 60/40, whereas in 2016 it was 40/60.

Between 2015 and 2017, five salt lakes in China started to produce lithium, with a total production of 26 kt LCE, as well as several lithium ore mines – Mt Cattlin and Mt Marion in Australia – with 27 kt LCE each. Numerous small mines were also opened in China, Zimbabwe and the rest of the world.

The new projects and expansions under construction or at an advanced stage of development in salt lakes include (Citi Research, 2017):

- Orocobre in Salar de Olaroz started producing in 2015 and will reach 27 kt LCE in 2021.
- Second Albemarle lithium carbonate plant located in La Negra, Chile, which will produce 25 kt LCE. Begins operations in 2017.
- Third Albemarle lithium carbonate plant located in La Negra, Chile, which will produce 24 kt LCE battery grade and could expand its production to 44 kt. Expects to begin operations in 2020. This plant will be built thanks to a new quota the company was assigned by Corfo in 2016. It approved its Environmental Impact Assessment in 2017. Moreover, there would be an additional quota for production expansion at Salar de Atacama if Albemarle is able to demonstrate its new technology

that makes it possible to increase production efficiency, producing more lithium carbonate from the same amount of brine.

- Expansion of SQM's production from 48 kt LCE in 2017 to 63 kt LCE, with the expansion process due to start in 2018. The greater part of the expansion is to be in lithium hydroxide. At the end of 2016 SQM had a residual portion of its permit left, allowing it to produce a further 480 kt LCE, which will expire at the end of 2023.
- Production at Salar de Cauchari Olaroz in Argentina is scheduled to start up in 2019 with an initial goal of 25 kt LCE in 2019 and another 25 kt LCE in 2020. The owner of this project is Minera Exar S.A., which in turn belongs to Lithium Americas Corp. and SQM. At the time of finalizing the funding for the construction of the plant, Jujuy Energía and Minería S.E. (JEM-SE) will participate with 8.5%.
- Minmetals in China is installing a brine plant that will start production in 2018, reaching 10 kt LCE in 2021.
- Quinghai Bohua and Tibet Developments have been producing 2 kt and 1 kt LCE respectively in China since 2016.

Lithium projects originating from minerals:

- Greenbushes from 80 kt LCE to 160 kt LCE after 2020. With that and the expansions at Salar de Atacama, Albemarle is set to capture half the projected world growth as of 2021 (DB 2016).
- Pilbara Minerals in Australia will start producing in 2018, reaching 50 kt LCE in 2021.
- Altura Mining in Australia will start producing in 2018, reaching 32 kt LCE in 2021.
- Nemaska Lithium in Canada will start producing in 2019, reaching 30 kt LCE in 2021.

There are also four potential projects in the Rincón, Sal de Vida, Hombre Muerto and Diablillos salt lakes in Argentina, and 11 projects based on minerals located in the United States, Australia (two), Finland, Canada (three), Zimbabwe, Mexico, Brazil and other countries. With regard to the Pedernales and Maricunga salt lakes in Chile, it is likely that production will not start up until after 2025. At Maricunga there are many owners, including Codelco, who will have to reach agreements among themselves before building production facilities. Codelco created Sociedad Salar de Maricunga S.A. with three executives in charge. The purpose of the company is to continue negotiating the Special Lithium Operations Contract (CEOL) in order be able to explore and mine the mineral.

Salar de Pedernales belongs to Codelco, which needs to carry out exploration activities prior to setting up a business plan.

There would appear to be an across-the-board agreement to grant Codelco the necessary permits to mine both properties in these salt lakes. What is to happen to private lots will depend on the next President of Chile. If State control of operations at Maricunga continues to prevail, Codelco would first have to accept to act as controller or it would be necessary to create a second

State company independent from Codelco to do so.

Figure 9 shows lithium production in Chile from 1984 to 2015, indicating clearly that it came to a standstill after 2011. Neither of the two companies, Albemarle and SQM, expanded their productions in Salar de Atacama. Figure 10 shows the lithium productions of SCL-Albemarle and of Minsal-SQM, as well as of Chile as a whole, from 1984 to 2025. It is estimated that Chile's future production will be solely in the hands of Albemarle and SQM, with the values that have already been announced and in compliance with the new agreement that has been signed between Corfo and Albemarle.

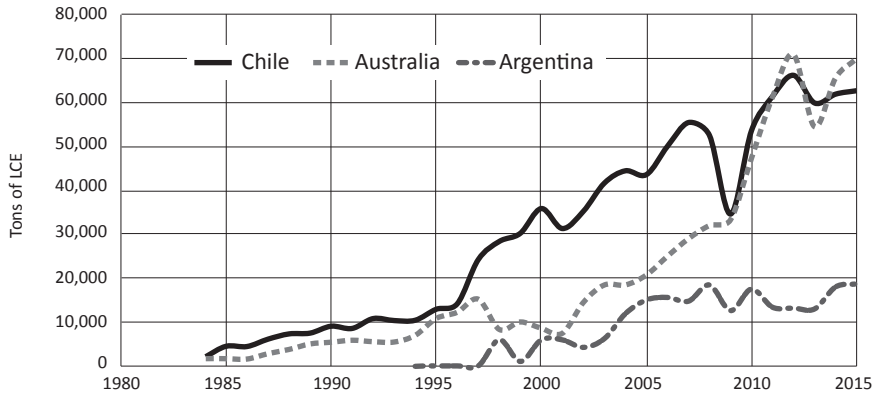

Figure 9: Lithium production in Chile, Argentina and Australia, expressed in tons of LCE, between 1984 and 2015. Chile's production was adopted from Roskill between 1984 and 1989 and from the Cochilco yearbooks (line corresponding to tons of lithium carbonate) from 1990 onward. Exports were obtained from the export records between 1990 and 2001. Between 2002 and 2008 the Comex database was used. Between 2009 and 2015 the Roskill 2016 data was considered.

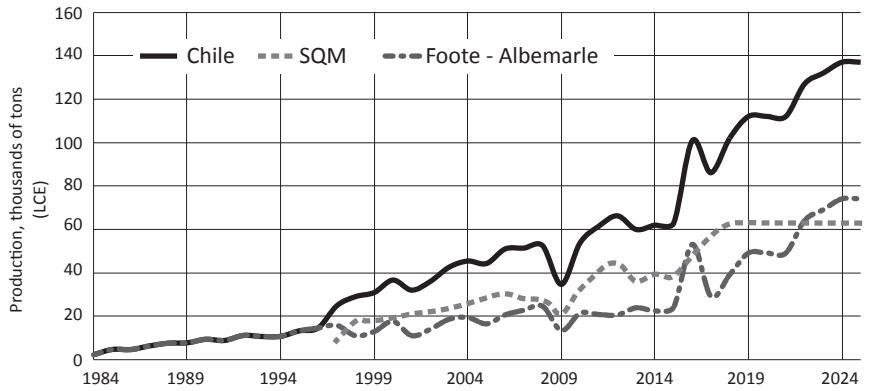

Figure 10: Production in Chile, Albemarle and SQM 1984-2025. Sources, announcements made by SQM and new agreement between Corfo and Albemarle.

Figure 11 shows the increase in Chile's share in the lithium industry between 1984-2004, its decline in this market between 2005 and 2015, and the projection for 2016-2025.

The reduction in Chile's global share in lithium production between 2005 and 2017 was due to three circumstances. First, the explosive increase in demand and resulting entry of numerous players into the lithium production market. This trend would continue over the following years. Second, the resounding failure of the CEOL bidding process in 2012 during the government of President Piñera. And third, the immobility resulting from the opposition to the CEOL process and its radical proposal, a situation that was documented in the report of the 2014 Lithium Policy of the Presidential Commission.

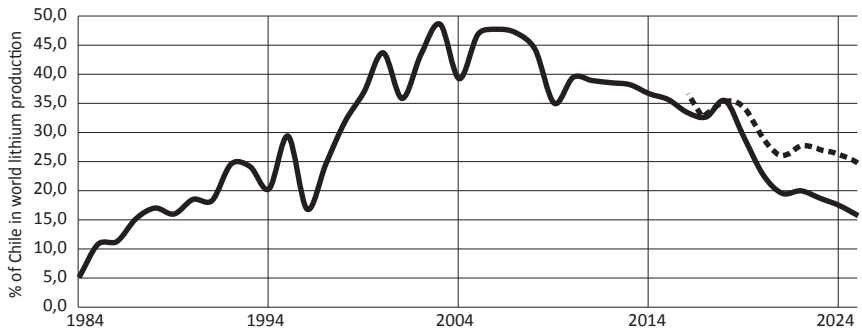

Figure 11. Chile's share in world lithium production (expressed in units of lithium carbonate, LCE) 1984-2015. The 2016-2021 figures were taken from the high-case and base scenario of Citi Research 2017, and those from 2022 to 2025 considered an average growth of world production of 14% and 6.5% average per year, respectively.

Figure 12 shows production projections published by Deutsche Bank 2016-2019, with a growth of 27% per year[86], Citi Research base scenario 2016-2021 with a growth of 15% per year, Citi Research high-case scenario 2016-2021 with a growth of 22% per year, and high demand projection 2015-2025 by Roskill, with a growth of 9.3% per year. Roskill's production projections are not included because they correspond to production capacity and are considerably higher than the others. The commissioning of many of the announced projects have experienced considerable delays in the past few years, but at least up to year 2021 there should be enough overproduction to supply Citi Research's (2017) base demand scenario. Citi Research concludes that in 2021 there will be a total production of 432 kt LCE and a demand of 379 kt LCE. In the event that the Citi Research high-case scenarios or those of Deutsche Bank indicated in Figure 12 should take place, there would be a scarcity of lithium for a certain period, giving rise to high prices, but this would be an isolated occurrence, as happened in 2016.

86 Given that this value is higher than the projected demand, it is expected to lead to overproduction and, therefore, to a reduction in price.

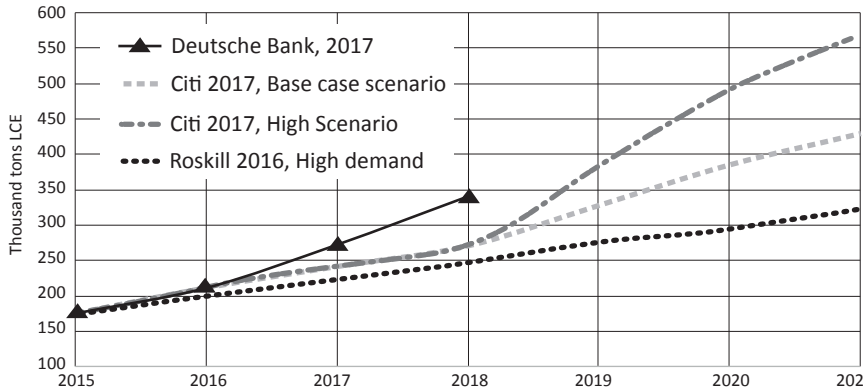

Figure 12: Projections for lithium production growth provided by Deutsche Bank 2017, Citi Research 2017 base and high scenarios, and Roskill 2016 high demand projection.

An important aspect that emerges from this lithium boom is the direct shipment of minerals by sea from Australia to be processed in China. It is possible that this will not prosper, however, because of the cost (Citi Research 2017).

A second aspect is the geopolitical risk involved in producing lithium based on brines, which is analyzed as high in South America, and particularly in Chile and Argentina, whereas lithium produced on the basis of minerals will occur fundamentally in Australia and the U.S. (Citi Research 2017).

Three, the development of processing technologies has made it possible to transform minerals directly into lithium hydroxide over the past few years, thus rendering the transition from lithium carbonate unnecessary.

Four, the processing capacity required by the minerals to be transformed into lithium carbonate or hydroxide could turn into a bottleneck at some time, leading to a rise in prices.

Five, production is starting to become fragmented among many producers, which will make the four leading producers lose ground in market power over the next 10 years in spite of their announced expansions. According to Citi Research (2017), the Herfindhal-Hirschmann (HH) index that measures the concentration of producers of a certain industry will decline from approximately 0.23 to 0.05 between 2016 and 2025. An index of 1 means that there is only one producing company, i.e. a monopoly, whereas a number close to zero is indicative of high fragmentation of production.

8. LITHIUM PRICES

8.1-The determination of lithium prices

Like metals and non-renewable natural resources, lithium is governed by the same economic laws of supply and demand. The beginning of the lithium industry at a global level was similar to the appearance of other metal industries in history. After the discovery of lithium in the early 19th century, the initial applications of lithium began to emerge slowly. This is understandable given that there was little demand, that the deposits of the metal were not known and the extraction and processing methods had not yet been developed.

Establishing the price of lithium products also arose in a similar manner to that of other metal industries. With only two lithium-producing companies of some importance, both of U.S. ownership until the 1990s, the price of the products were set by those companies in their negotiations with end clients, and the smaller companies followed their lead. At numerous times during the brief history of lithium, however, the major companies set prices that were considerably different among themselves.

The producer price used by lithium companies is one of the four methods applied to establish the price of metals (Strauss, 1986). The other three methods are, first, the metal exchanges, such as the London Metal Exchange (LME), or the Commodity Exchange of New York (COMEX). Second, prices negotiated directly between producers and buyers, such as those used in spot contracts for copper concentrate. The last are prices quoted periodically by a highly prestigious independent institution which are then adopted by producers and buyers. Some industries use several of these methods simultaneously. Strauss cited lead (Pb) as an example, which was sold in the 1980s in Europe at LME prices; in Japan most sales were negotiated at the producer price; in the U.S. sales were made with reference to Metals Week, a highly-regarded journal in mineral markets. The price of a lithium product is set as agreed between the producer and the client, and each client can negotiate a slightly different price. The price indicated by the Industrial Minerals journal is just a reference and does not determine the final price of a product.

Prior to each negotiation the producer has a cost curve estimate of the industry[87], and is therefore aware of the marginal cost of each product, which establishes the minimum price. The marginal cost of the industry is the one

87 Prepared on the basis of market research and in-house analysis

corresponding to the producer with the highest costs. The cost curve does not vary much in short periods, unless there are special disruptions in the market, but they can also change in line with the quality required, exchange rate conditions, supply, demand, urgency with which the client needs the product, etc. When there is a scarcity of lithium in the market the price can rise, whereas when there is overproduction the price usually drops, to the point where a marginal cost producer can sustain losses in a given year. The price "propagation", whether downward or upward, can be rapid, and it is therefore necessary to have agents close to the clients, talking to them and gauging the market heartbeats, a process similar to that of the metal exchanges during transaction periods.

If the price proposed by a producer is too high, the client will reject it and go to a different producer. The producer will thus realize immediately when the proposed price is higher than market standards. On the other hand, if the price is too low, the client will increase the tonnage to a maximum, and there again the producer will immediately realize that the proposed sales price is lower than market standards.

In 2008, 85% of world production was generated by only four companies, the German-based Chemetall, recently acquired by the U.S. Rockwood company; Sociedad Química y Minera de Chile, Soquimich (SQM), FMC[88] Lithium Division (ex Lithco), and Talison of Australia (Metal Bulletin, 2009). The four largest global lithium producers in 2015 were Albemarle, Talison (Tianqi) and SQM, with FMC in fourth place but considerably smaller than the other three. Jointly they held 76% of the market (Roskill, 2016). These companies had many more contracts than the smaller producers. That is why we speak of producer price, even if the producers do not agree on the price they will charge. The price cited for lithium is the result of hundreds of contracts that are signed every month. The key is that both the producers and the intermediate and end clients have pledged their loyalty to each other, and it is not very usual for the latter to change suppliers. With the explosive emergence of electric vehicles, long-term supply agreements are beginning to be established between vehicle manufacturers and battery manufacturers, with prices that vary depending on the market.

Thus the spot market, which is very small in relation to the total, is made up of producers and buyers who have not established mutual loyalty. In the past years the spot price was only important in China, due to a temporary shortage of lithium. The spot market has increased lately due to shortages of supply.

8.2-Cartels

It is necessary to differentiate between producer prices and prices established by cartels, monopolies and oligopolies. As examples of monopolies, Strauss cites Chilean nitrate (saltpeter) at the beginning of the 20th century and cryolite

88 FMC Corp (Lithco) was previously Food Machinery and Chemical Corporation, and should not be confused with Foote Mineral Company, which also uses the abbreviation FMC.

produced in Greenland[89] in the 1980s. In both cases these countries controlled over half the market, set much higher prices than those that would have prevailed in competitive markets (Wagner, 2005) and in both cases synthetic substitutes were developed, driving the original minerals out of the market. The Ivittuut mine closed down operations in 1987 because producing synthetic cryolite became cheaper than extracting the natural product from the mine. During World War II the United States occupied Greenland mainly to ensure cryolite supply for the production of aluminum.

In the case of oligopolies – a few companies dominating the market – Strauss cited the examples of the aluminum, nickel and molybdenum industries after World War II. In the three cases the companies that dominated these industries exercised a stringent control over prices, imposing stability and economic logic on the markets. These criteria can be defined as providing an appropriate return to producers and maintaining prices sufficiently low to allow the expansion of demand, penetrating the supply of other industries and generating substitution. According to Strauss, these policies were highly successful and made it possible for aluminum, for example, to increase its demand to double that of copper between 1950 and 1973, replacing many of the uses of the latter. The price variations that these industries introduced from year to year were in great measure related to changes in production costs. The London Metal Exchange began to trade in aluminum in 1978 and in nickel in 1979. These metals ceased having the price stability they had had before and became instead highly volatile, which they remain to this day, along with other mineral commodities traded on the stock exchange. The introduction of futures trading in the years after the 1980s would exacerbate the price volatility of these commodities even more (Strauss, 1986). Up to 2010 the price of iron was set annually by three companies – Vale, Rio Tinto and BHP Billiton. By 2005, however, several buyers used the spot price of this metal, increasing volatility to levels that exceeded those of aluminum and copper prices. The global crisis of 2008 changed this, because the spot price of iron dropped lower than the annual price set by the three major companies, and leading Chinese steel manufacturers chose to trade on the basis of the spot price. Thus, the annual benchmark established by the three leading companies collapsed, whereupon an agreement was reached to establish a quarterly price based on the spot price, much more transparent and adjusted to supply and demand conditions (Lagos, 2012). In turn, the price of gold, which had been set by the U.S. up till 1974, began to be established by the market as of that year, also leading to greater volatility since then.

Very few cartels have been successful during their entire history, with diamonds perhaps representing the most protracted success story. Some cartels have been successful during certain periods and have failed resoundingly in

89 According to Wikipedia, cryolite is a sodium aluminum fluoride (Na_3AlF_6). In its natural state it is found in Ivittuut (Greenland). Its importance derives from its ease in dissolving aluminum oxide (Al_2O_3); for this reason it is used in molten form as an alumina fluxing agent to obtain this metal via electrolysis. The large quantities of this mineral used in the industry cannot be obtained from natural deposits, and it is therefore produced artificially on the basis of aluminum salts and hydrofluoric acid.

others, the more prolonged ones. The oil cartel is an example of brief successes and lengthy failures. The OPEC countries had 81% of global reserves in 2010 and produced 42% of world oil that same year. The OECD had 3.7% of global reserves in 2010 and produced 19% of world oil. As posited by Radetzki (2012), high oil prices are explained by the lack of technical and financial capacity that some the OPEC member states have had to increase their production capacity over the past 40 years. Indeed, Iran, Iraq, Libya and Venezuela held 44% of proven oil reserves in 2011 and yet their production capacity was considerably lower than in 1970. The loss of production capacity of these countries in 40 years was equivalent to the total consumption of the European Union. Saudi Arabia, one of the OPEC countries, was the only large producer of that conglomerate to increase its production capacity in the past 40 years. Kuwait and the United Arab Emirates also increased their production capacity during that period. The behavior of the four mentioned countries – Iran, Iraq, Libya and Venezuela – is explained by their voracity in spending oil resources rather than reinvesting. The result in terms of per capita income achieved by Iran, Iraq, Libya and Venezuela after four decades of squandering is paltry: 4,700, 3,900, 11,300 and 10,000 dollars per capita, respectively[90].

In the case of copper, there were several cartels historically, one of them successful during the 1930s (Guzmán 2007). The copper CIPEC cartel created in imitation of OPEC in 1968 was extremely ineffectual during its entire duration and was finally dissolved during the 1990s.

Another classic example is the International Tin Agreement (ITA) created in 1956 and made up by several countries, some of them with serious economic problems which sought to stabilize the price of the metal so as to ensure a steady income (Strauss, 1986). Another characteristic of this market was that the main producers were developing countries – Thailand, Malaysia, Indonesia and Bolivia – whereas the industrialized countries did not produce the metal to any significant extent. At the same time that the ITA was operating, tin was traded on the London Metal Exchange (LME). This agreement also included consumer countries. The ITA was based on export quotas of the producer countries and on the creation of a common pool that made it possible to have an inventory available to store tin in times of low prices, avoiding a drop under the limits set by the ITA. The relevant aspect is that the ITA began to operate in 1956 at market prices, and 10 years later it still had prices that were comparable to those of copper but which had risen 70% above the price of other commodities such as zinc. In 1976 the price of tin had increased 125% over the price of copper, taking as a reference the price ratio of 1956. In 1978 the price of tin was 210% higher than that of zinc and 356% that of copper. In 1980 the price of tin began to decrease systematically in the markets, and the ITA was unable to stop the plunge. Moreover, due to the high price of tin, numerous deposits were developed in other countries that were not ITA members, among them Brazil, Canada and China. During the world economic crisis of 1981-1982, tin consumption declined but did not subsequently recover as occurred with other metals. Strauss comments that in the Paley report discussion ordered by the

90 OPEC Annual Statistical Bulletin, 2010-2011

United States in 1952, it was concluded that tin had been the lowest-growing metal between 1950 and 1973. Between 1973 and 1985, tin consumption in industrialized countries declined by 25%. Thus by 1985 the ITA's efforts to avoid the drop in price became impossible, because the accumulated inventory was too large and the common pool came to an end. The tin market crumbled, leaving the producer countries in serious difficulties, Bolivia among them. Strauss indicates that during the 29 years of the ITA's lifetime, there was never a reduction in price. The developing countries continually exerted pressure to increase the price in order to collect the revenue they needed. The result was that the price became increasingly less realistic, until the market collapsed.

8.3-Historic prices

I will analyze the price of lithium carbonate as a flagship product, from 1966 to 2017, in order to establish the profit policies that were pursued by the handful of large companies in this industry.

The world price of lithium carbonate became stabilized at levels close to 7,000 dollars (2015 currency) per ton with Foote Mineral Company's initiative to extract lithium from brines at the Silver Peak salt lake in Nevada, in 1966 (Figure 13). This price, expressed in constant currency, had been dropping linearly, with brief interruptions, since 1936[91], the earliest record found (Figure 14). This new deposit made it possible to introduce novel uses for lithium because the mining cost was substantially lower than that of extracting lithium from minerals such as pegmatites, lepidolites, petalites and others used up till then.

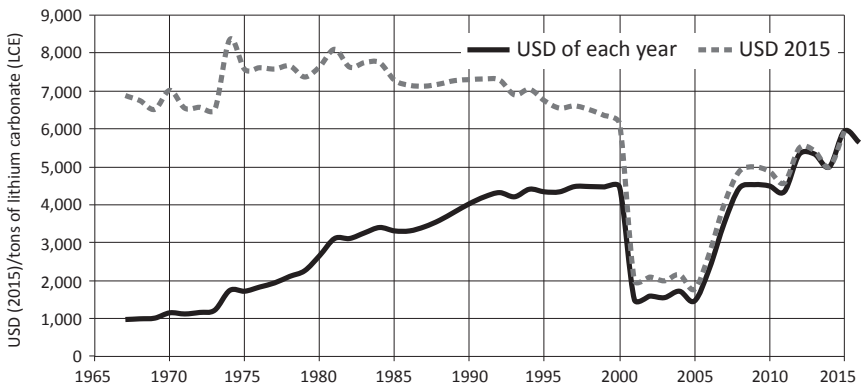

Figure 13: Price of technical grade lithium carbonate in the U.S., expressed in current or nominal dollars (of each year) and in constant 2010 dollars per ton of lithium carbonate. The 2015 dollars were calculated using the consumer price index, CPI, of the United States. Sources of current prices: from 1966 to 2009 (USGS 2010); prices for 2010 and 2011 obtained from the U.S. Industrial Minerals journal; prices from 2012 to 2015 obtained from Roskill (2016).

91 The 1936 price was 44,000 dollars per ton of lithium carbonate

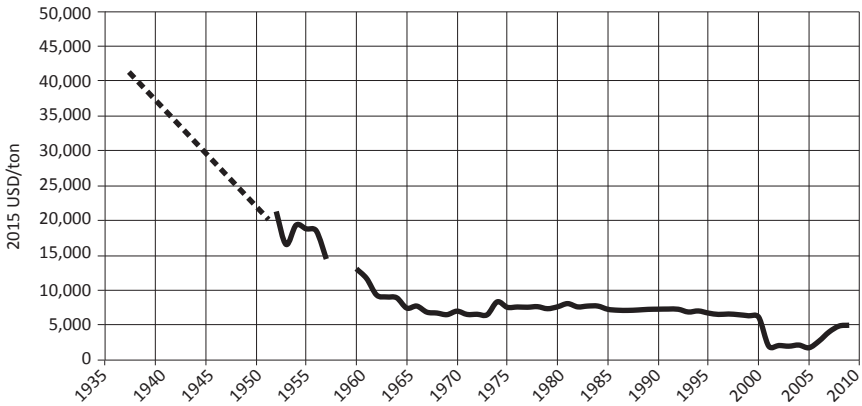

Figure 14: Price of technical grade lithium carbonate, USD in 2015 currency/ton: 1935-2000

The price of lithium carbonate, unlike that of some metals, experienced insignificant variations during the recession that struck the U.S. in 1969. The price of some metals experienced a major increase at the beginning of the oil crisis in 1974, but unlike these, the price of lithium carbonate remained relatively stable during and after this event, and at a significantly higher level (15%) than the previous period. The global economic crisis that began in 1979, also due to oil, and which culminated in 1982 with a major drop in the GDP of the United States and of the world, also failed to affect the price of lithium carbonate to any extent.

Between 1966 and 1997, the price fluctuated between a minimum of 6,019 USD (2010) per ton in 1997 and a maximum of 7,666 USD (2010) per ton in 1979, i.e. a maximum difference of 27%. In the same period the difference between the minimum and maximum price of copper in constant currency was 376%. From 1979 to 1982 Foote and Lithco increased prices at least once a year, maintaining equivalent increments.

The Asian crisis that began in 1997, added to the entry into production of the Minsal project in Chile by SQM in 1996 and the Salar de Hombre Muerto in Argentina by FMC (ex Lithco) in 1997, made the price plummet to a minimum of 1,623 USD (2010) per ton in 2005. It is understood by analysts that SQM forced the price down in order to remove producers with much higher costs from the market. In fact, the U.S. producers closed down their operations. The entry into production of SQM meant that from two companies – Foote and FMC (ex Lithco) – having dominated production till then, there were now three.

The price recovered with the commodities boom generated by China as of the end of 2005 until the global economic crisis of 2008, but this did not last long due to the injection to the economy of substantial sums of money by the central banks of the United States, the European Union, China, Japan and other countries. At the end of 2008, after only three or four months of crisis, the price hit rock bottom, and from January 2009 onward the world situation

began to recover until reaching an average level of 4,593 USD (2010) per ton in 2009, still much lower than the price levels there had been in 1997. The price of lithium carbonate during 2010 and 2011 was similar to that of 2009, situating itself at 4,500 USD/ton in 2011 and close to 5,000 USD/ton in 2012.

A year-by-year analysis of the price policy of the main lithium-producing companies leads to the conclusion that from 1953 to 2011 they reduced their prices by 20% in relation to the consumer price index of the United States. During numerous years of this long period, these companies increased the price to match the inflation rate of the previous year, and in others, years when the industry experienced crises or difficulties, they reduced it significantly. The latter occurred in the 1950s and 1960s and on two occasions since 2000.

In terms of the price increase of lithium carbonate, from 1953 onward five events were identified in which the industry increased prices significantly[92], over the inflation rate of the year. The first was on the occasion of the U.S. nuclear program of 1954, the second was the first oil crisis in 1974, the third was the second oil crisis in 1979, the fourth was due to the commodities boom generated by China as of 2005, and the fifth and last was in 2015, motivated by the explosive increase in the manufacturing of electric vehicles.

The price rise of practically all commodities in 1974 and slightly later in 1979 was generated by an increase in mining costs due to oil prices rising from 3.3 USD/barrel[93] in 1973 to 11.5 USD/barrel in 1974, and from 12.8 USD/barrel in 1978 to 35.7 USD/barrel in 1980. The behavior of prices and production of the main mineral commodities was significantly different during global economic recessions due to the increase in oil prices in 1974 and 1979-1980, and is related to the specific situation of supply, demand and overcapacity of each industry. Different media in Chile[94] mentioned insistently that, due to higher demand, the price of lithium should increase significantly in the future. Between 1984 and 2011 demand increased an estimated 3.6 times, and yet the real price of carbonate and other lithium salts decreased.

In 2015 and 2016 the price of industrial grade lithium carbonate (98.5% purity) sold via contracts increased significantly, to 5,940 and 5,640 nominal dollars (Roskill 2016, Deutsche Bank 2017), but the effect is considered to be temporary by Deutsche Bank, Citi Research (2017) and other organizations, due to the entry into production of numerous deposits in the following years, in addition to announced expansions.

The seaborne contract price of battery grade lithium carbonate (99.5% purity), rose to slightly under 15,000 USD/ton during some moments of 2016 (Deutsche Bank, 2017). The spot price for battery grade lithium carbonate placed in China rose at certain times during 2016 to close to 26,000 USD/ton, and the same occurred with the price of battery grade lithium hydroxide.

The most important effect of the high demand experienced in 2015 and 2016

92 Significant is understood to be when the price is 100% higher than the inflation rate of the year before.

93 Nominal prices.

94 For example Antonio Leal in the El Mostrador e-newspaper, 18 June 2012, Santiago, Chile.

was to increase the price of technical grade lithium carbonate (98.5% purity) from close to 5,000 USD/ton up till 2014, to slightly under 10,000 current dollars in 2022, as projected by Deutsche Bank.

A second major effect of the explosion of electric vehicle manufacturing as of 2015 is that the price differential between battery grade and industrial grade lithium carbonate expanded substantially from practically zero in 2014 to 7,000 USD/ton at its peak demand in 2016, but is estimated to subsequently decline to 3,200 to 3,500 USD/ton on a permanent basis, although the Deutsche Bank price projection only goes as far as 2025. A secondary effect of the electric vehicle boom is the leveling of the price of battery grade lithium hydroxide and carbonate, according to Deutsche Bank.

Events such as those of 2016 can obviously repeat themselves, such as the spot and contract prices for battery grade products experiencing temporary increases due to a delay in the entry into production of the announced projects, strikes, earthquakes, etc. The nominal price of industrial and battery grade lithium carbonate projected by Deutsche Bank for 2025 was 7,700 USD/ton and 11,500 USD/ton respectively. This means that the price in 2025 would be around 6,300 and 9,500 USD (2015 currency) per ton, considering an inflation of 2% per year in the U.S. This would be a modest rise in the price of industrial grade lithium carbonate and a slightly more significant rise for the battery grade product (see Figure 15).

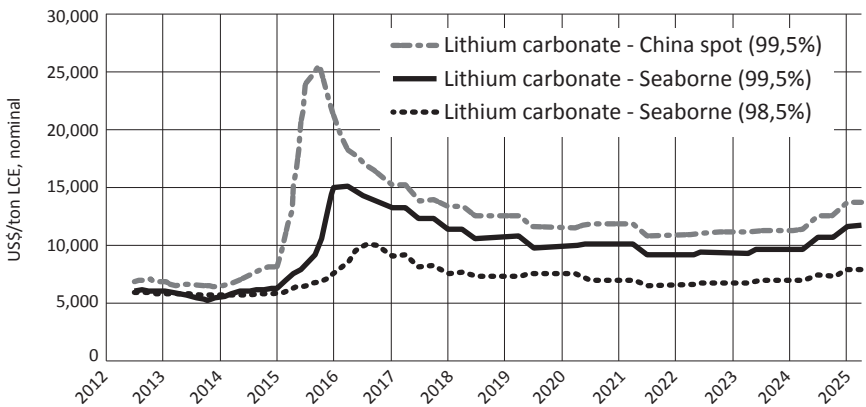

Figure 15: Nominal price of various products from 2012 to 2016 and projection of the nominal price of lithium, Deutsche Bank, 2017

The other factor that affects prices, but at a slower rate than the supply and demand hiccups, is the increase in the cost of consumables, e.g. the soda ash required for processing brines. In 2011 and 2012 there were numerous announcements in different parts of the world regarding an increase in lithium products due to higher costs. Another factor that can trigger a price increase is supply scarcity at a cost that is higher than the marginal cost of current projects.

In 2011 it was projected that the entry of new players into the market could

derail the price- setting scheme that the market-leading companies[95] had had in place, leading to greater volatility.

Deutsche Bank (2017) also projected, although this does not appear in Figure 15, that the spot price of battery grade lithium hydroxide would maintain a differential of some 1,500 USD/ton LCE vis-à-vis battery grade lithium carbonate. This, however, is disputed in the industry because it is considered that the new lithium hydroxide plants, especially in China, will tend to make both prices converge in the future.

These types of considerations are key at the time of developing a production strategy for lithium-producing companies, because a price differential of 1,500 USD/ton LCE is sufficiently attractive to increase the number of lithium hydroxide producing plants. Unfortunately, the market is much more dynamic than even the best strategies.

95 In 2011 there were five major companies: Talison Lithium, SQM, Chemetall/Rockwood, FMC and Galaxy Resources

9. THE COSTS OF PRODUCING LITHIUM

The costs of lithium products depend on the type of deposit from which they are extracted and the grade or concentration of lithium in those deposits. But also, in the case of brines, they depend on the impurities and other components, as well as on the climate. The impurities and other components in brines increase the extraction cost because it is expensive to separate certain elements and substances, like for example magnesium.

According to Pavlovic (2002), deposits with a low magnesium/lithium ratio are the Zhabuye salt lake in Tibet, which contains practically no potassium, Salton Sea in California[96], Salar de Hombre Muerto in Argentina, Silver Peak in Nevada and Salar de Atacama in Chile[97]. Meanwhile, the Salar de Uyuni in Bolivia, with the greatest lithium resources on the planet, has a magnesium/lithium ratio 3.4 times higher than Salar de Atacama, while the Great Salt Lake in Utah has 39 times more and the Dead Sea has 247 times more.

The concentration of lithium in brines is the key ingredient to be considered for the potential economic development of lithium. The salt lakes with the highest average concentration of lithium, in descending order, are: Atacama (0.15% by weight), Zhabuye (0.097%), Hombre Muerto (0.062%), Uyuni (0.035%), Silver Peak (0.023%), Salton Sea (0.022%) and Great Salt Lake and Dead Sea with 0.004% and 0.0015% respectively.

Climate is also key because the solar evaporation of the salts is very dissimilar in the different salt lakes, with this method being economically unviable in many salt lakes and making it necessary to introduce more expensive methods than that of evaporation. Among the salt lakes in current operation that use solar evaporation are Salar de Atacama and Silver Peak, whereas Salar de Hombre Muerto, Cauchari and Olaroz, all in Argentina, have rain in summer, a lower evaporation rate and they reduce the brine volume requiring evaporation by means of a selective lithium absorption process.

There are many other salt lakes containing lithium apart from this brief listing. Among these are the Coipasa and Empexa salt lakes in Bolivia, Rincón (0.033% Li), Cauchari (0.052%) and Olaroz (0.058%) in Argentina, and more than 30 salt lakes in China (Pavlovic 2002, Roskill 2009).

Pavlovic (2002) indicated that lithium-containing brines from oilfields had concentrations of between 0.006 and 0.022%, i.e. the maximum lithium they

96 Salt lake of geothermal origin

97 With a 6.4 magnesium/lithium ratio

contained was 6.8 times less than Salar de Atacama. The chemical complexity of these brines would not make them economically attractive until the appropriate technologies are developed, given their high magnesium content, among other factors. With regard to geothermal brines, Pavlovic (2002) wrote that their lithium content was up to 3.7 times lower than Salar de Atacama and were also at a high temperature and contained numerous and complex impurities such as iron, manganese, silica, lead, magnesium, etc.

Lithium in clays was discovered in the locality of Hector in California during the 1970s. This gave rise to the name hectorites to designate these clays, as rich in lithium as that found in pegmatites (Pavlovic 2002). Other similar deposits were also discovered in the western United States. The Hector deposit was already in operation by 2002 on a small scale and its lithium products (gels) were used directly in cosmetics, paint and drilling mud. The cost of manufacturing lithium carbonate or other salts on the basis of hectorites was high, however, because it was necessary to break through the strong crystalline structures of the clays. For this reason it was thought that these deposits could not be developed on a large scale to extract lithium with the technology available in 2002. In the past few years, however, the Western Lithium USA Corp. (WLC) company has successfully researched a process to extract lithium from its hectorite deposit in Kings Valley, Nevada, which consists in the initial roasting of the clay (0.35-0.36% Li) with anhydrite ($CaSO_4$) and dolomite.

The global process, now improved, was developed initially by the US Bureau of Mines in the 1980s. The WLC process makes it possible to recover potassium sulfate and sodium sulfate as by-products, which would allow the extraction of lithium to be profitable. Basic research at a laboratory level of the process for recovering potassium sulfate and sodium sulfate, as well as lithium, was carried out in 2009 and 2010 at the Universidad de Antofagasta[98].

in 2011 the operating costs to produce lithium salts from brines varied between 1,000 and 1,760 USD/ton LCE in Salar de Atacama in Chile, between 1,760 and 2,650 USD/ton LCE in Salar de Hombre Muerto in Argentina, between 2,200 and 2,870 USD/ton LCE in salt lakes in the U.S., and between 1,760 and 2,650 USD/ton LCE in the Taijanair and Zhabuye salt lakes in China[99]. Yaksic (2009) mentions higher values for lithium production in Salar de Atacama.

It is likely that the costs of producing lithium in the other Chilean salt lakes will be higher than those of Salar de Atacama.

By 2015, however, the operating or cash costs involved in producing lithium in salt lakes had risen to 1,750 USD/ton LCE in the two operations in Salar de Atacama, 3,750 USD/ton LCE in the Zhabuye salt lake, and 3,100 USD/ton LCE in the salt lakes operated by Rockwood in the United States (Roskill 2016). The cash cost of extracting lithium from the salt lake operated by Orocobre in Argentina is close to 1,500 USD/ton LCE, but its corporate costs would lead it to be nearer 5,000 USD/ton LCE. It is necessary to consider that some of the above-mentioned costs, such as those of Salar de Atacama,

98 Personal communication by Pedro Pavlovic

99 Presentation by Andrés MacLean, Vice President of Cochilco, 2011, Santiago, Chile

include credits for by-products, although they do not cover all these credits, and therefore a shared value criterion is applied between the extraction of lithium and the by-products.

Meanwhile the cash cost of extracting and processing lithium from minerals begins at close to 5,700 USD/ton LCE both at Greenbushes (Tianqi) in Australia as well as in operations in China and other countries.

The cost curves published by Roskill in 2016 and before do not make it possible to arrive at an accurate estimate of the marginal cash cost of producing lithium, because the information published only covers part of the total production. In 2015 the highest cash cost published by Rockwood was close to 6,000 USD/ton LCE, but there were operations with significantly higher costs, which would establish the LCE price in the markets.

The increase in nominal value of the cash costs between 2011 and 2015 was due in part to inflation, which was 8.3% between 2010 and 2015 in the U.S., i.e. an annual 1.6% increase in the inflation rate. Normally the costs of mining and processing brines and minerals also increases over time due to the decline in the concentration of the main element extracted. This, without taking into account that during periods of flourishing demand it is likely that the consumables to produce lithium may also contain an additional scarcity factor vis-à-vis other products that are subject to lower increases in demand.

10. VALUE ADDED

The metals and concentrates that Chile produces from deposits, such as copper, gold and others, use leading edge technology and therefore have value added. Chile does not export rocks. Copper and other metals are not picked from the earth like blackberries by the roadside. And it might seem that the technology to extract lithium from brines is trivial and could be achieved by anybody. But then, why did Corfo not do this itself when it began its mining operations in Salar de Atacama? Why did it have to invite the only company in the world (Foote) that had the technology for extracting lithium from salt lakes? The answer is evident. Because the technology was not that simple.

Value added is equal to the gross production value, i.e. sales, minus the intermediate consumption, i.e. the costs that do not constitute value added per se. The costs representing value added are salaries, construction, if any, and certain financial costs. Among the costs that constitute value added, the most important in a mineral-producing company are salaries.

In times of growth, the value added represented by salaries is much lower than the difference between gross production value and intermediate consumption, whereas in a low-price cycle this order can be reversed.

If we apply the above formula, adopting the highest cost value of Salar de Atacama (1,760 USD/ton of lithium carbonate), the value added for a ton of lithium carbonate in 2011 was equal to the price (4,500 USD/ton) minus the cost (1,760 USD/ton) plus the salary cost per ton of LCE. Let us suppose that this was 20% of total costs, that is to say 352 USD/ton. Then the value added per ton LCE was 3,100 USD/ton. Considering a royalty of 6.8% over the price and a 35% tax, the value added was distributed as follows: 11% in employment, 38% in taxes and 51% for the company. For this same example, the tax collected by the State as a percentage of total profits would have been 42%.

On the other hand, let us suppose that the cost of manufacturing hydroxide on the basis of carbonate is one thousand additional dollars per ton of lithium carbonate. This calculation is a little more complex because it is necessary to consider the price of lithium hydroxide in 2011, which was 5,091 USD/ton of hydroxide monohydrate, and the lithium content in the hydroxide, which is lower than the lithium content in carbonate. This means that to produce a ton of lithium hydroxide monohydrate it is necessary to use 0.88 tons of lithium

carbonate[100]. Taking these factors into account, the value added of producing lithium hydroxide on the basis of a ton of lithium carbonate in this example would have been USD 3,575, i.e., 16% more than that of producing lithium carbonate. In this example, and at the prices considered, value was added to the country by producing hydroxide. Now, the analysis from the perspective of a company is made in terms of profits and not value added. There are differences between the two analyses.

It is also necessary to consider that the price between the different lithium products is not constant, therefore the analysis conducted can be valid for 2011 but could disappear later on, as was previously suggested in this book.

The production of a compound of greater value and comparable lithium content, at a cost that is not proportionately more expensive than the higher price, results in greater value added. The price differential between lithium hydroxide and lithium carbonate varied relevantly over the past decade, but was higher for hydroxide than for carbonate, with the exception of the mid-1970s when it was possibly distorted due to the sale of inventories undertaken by the nuclear programs of the United States and the USSR. The price of hydroxide became three times higher in terms of the lithium contained in each compound. As of 2009 the relative value of these salts continued to vary, but on this occasion around a factor of 1.3.

In 2011 SQM had the largest plant in the world for transforming lithium carbonate into lithium hydroxide. The plant is located in Salar del Carmen, to the north-east of Antofagasta. The Chinese, however, developed a cheaper technology to transform spodumene directly into hydroxide. One of the research studies that are being conducted in Chile is to develop a process that will transform purified brine directly into hydroxide – again, not so simple.

Other lithium products have greater value added than hydroxide, but they also have much more reduced markets. These markets have been developed by Chemetall and FMC, and recently by Chinese companies. Over the past decade SQM developed the technology to produce butyllithium, setting up a plant in Texas, U.S.A. Butyllithium has a smaller market than lithium chloride[101], but it is still considerable and is used as a catalyst for pharmaceutical products and for manufacturing synthetic rubber. But butyllithium is a highly dangerous product, because it can explode if stored or transported incorrectly. For this reason, the plants that manufacture this compound are located near to the end user, and thus it was not economical to set up this plant in Chile[102].

At present the products with the highest purity used to manufacture batteries have greater value added. This could change, however, with the construction of too many plants in the world, and especially in China, to undertake this transformation. It is interesting to note the experience of Galaxy Resources, which built a plant to transform spodumene concentrate into lithium carbonate in China. From the perspective of Australia, the value added of employment

100 Considering an efficiency of 100% in the process. It is usual for the efficiency to be at least 5% lower.

101 Including lithium chloride earmarked for derivatives

102 Personal communication by P. De Solminihac, 2012

will remain in China, and a crucial part of the taxes will also remain in China. It is not clear that any profit will return to Australia because the Galaxy Resources capitals are mainly Asian. Nonetheless, the know-how should remain with the company, in Australia. This has, for now, an intangible value, which will need to be appraised at the time of selling the company.

11. THE TAHIL VS EVANS DEBATE

The last global debate on lithium was initiated in December 2001 (Tahil, 2006) with the publication by William Tahil, Director of Meridian International Research, of a first article entitled "The trouble with lithium". Keith Evans, one of the two leading experts on lithium reserves in the world[103] since the 1970s, responded in March 2008 with an article entitled "An abundance of lithium" (Evans, 2008-a). Tahil was swift in counterattacking with "The trouble with lithium: 2", which was published in May 2008 (Tahil, 2008). But Evans had the last word, responding to Tahil's second article in June 2008 (Evans, 2008-b) with "An abundance of lithium, part II", and finally in January 2009 with a third article, "Lithium resources, are they adequate?" (Evans, 2009).

Although the debate seemed to come to an end in 2009, it actually went on until 2012 or 2013, because some of the queries posed by Tahil had not been answered.

The thesis Tahil posited in his first article were, in his words: "The world has become enamoured with the Li ion battery. While this may be sustainable for portable electronics goods, it is not sustainable for EV applications." (Tahil, 2006).

Tahil conducted an analysis of lithium reserves and resources to arrive at this conclusion. The reserves considered were 6.2 million tons of contained lithium, whereas the reserve base[104] was 13.4 million tons of contained lithium, without including Russia. Tahil disregarded the reserve base in his analysis of lithium availability for batteries in the future and adopted solely the reserve value of 6.2 million tons, added to an unknown figure for reserves available in Salar de Uyuni[105]. Tahil added, "If the world was *[sic]* to swap oil for Li based propulsion, South America would become the new Middle East. Bolivia would become far more of a focus of world attention than Saudi Arabia ever was. The USA

103 The other one is Ihor Kunasz, former chief geologist of Foote Mineral Company, and subsequently of Chemetall, now retired.

104 According to the USGS definition, all reserves are contained in base reserves.

105 In 2006, as well as at present, the lithium in Salar de Uyuni was considered as a base reserve and not as a reserve.

would again become dependent on external sources of supply of a strategic mineral, while China would have a certain degree of self sufficiency." Later on, Tahil explained how China would achieve this: "The Chinese still produce some Lithium Carbonate from spodumene but normal economics do not apply in China and this is likely to cease when the DXC salt lake project comes on stream."

Let us examine Tahil's words, "If the world was *[sic]* to swap oil for Li ion based propulsion, South America would become the new Middle East". The main problem with this argument is that oil produces energy and lithium only stores it, so how can lithium replace oil? Necessarily the energy that recharges the lithium batteries has to come from somewhere. The basic problem of energy generation is not resolved with batteries, they only improve emissions and efficiency in the use of the fuel, because the latter will be concentrated in just one place – the plant supplying the electricity to recharge the batteries – and not issue from thousands of mobile sources such as the vehicles circulating at present on the streets.

Tahil also flatly rejected the use of spodumene to provide lithium for batteries. Therefore, the total effective reserves, not counting spodumene, that he considered in 2006 were around 5 million tons of contained lithium.

With regard to batteries, he indicated that 0.3 kg of metallic lithium per kilowatt hour (kwh) capacity was required. A small 5 kwh battery could power a plug-in hybrid electric vehicle[106]. Thus, in a conservative scenario, the 60 million vehicles produced annually in 2006 would require 90,000 tons of lithium, equivalent to five times the global lithium production of that year. He added that a 5 kwh battery was marginal and that to power a small vehicle to run 32 to 48 km before having to connect it to the power network would require an 8 kwh battery. Therefore, the total lithium production for that year would have only been enough to power 10% of the vehicles manufactured, i.e. it would be necessary to have ten times this amount to provide lithium batteries for the entire vehicle fleet.

Tahil (2006) based some of his main conclusions on a 2001 PhD dissertation by Bjorn Anderson, from the University of Chalmers in Sweden (Anderson, 2001). The dissertation compared the technology of nine battery systems and concluded that there was no certainty that there would be sufficient lithium to power 200 million electric vehicles, which was already amply insufficient at the time because there were 900 million vehicles in circulation in the world. Moreover, Tahil broadened his analysis to encompass some battery systems that were not analyzed by Anderson, based on zinc and iron, which were lower in cost and more accessible in terms of production. Those systems[107] constituted one of the research programs preferred by Meridian International Research in 2011, as indicated in the website of that organization[108]. Tahil hypothesized that these battery systems could be produced for all electric vehicles in the world, close to one billion in 2006, and that only 3% of the zinc reserves and

106 PHEV

107 This refers to the zinc/air battery

108 http://www.meridian-int-res.com/

resources would be needed, in comparison with the 24% of lithium reserves and resources.

Tahil added that, if all the lithium required for all electric vehicles were produced, the metal would have to come from the heights of Bolivia, Chile and Argentina, which are at more than three thousand meters above sea level, in remote regions, with temperatures varying between +25°C during the day and -25°C at night, without roadways, telephone or electricity. Billions of dollars in investment would be required in the course of a decade to build productive and transport facilities. Tahil continued indicating that the first world producer at that time was Chile in Salar de Atacama, and that the third producer was Argentina in Salar de Hombre Muerto, where relations with nearby communities were not exactly smooth. Tahil added in 2006 that considering the growth of the automotive industry and even taking into account advances in lithium technologies, it would soon be necessary to have available one million tons per year of lithium carbonate or 368,000 tons of metallic lithium, which was equal annually to close to 2% of the known reserve base of lithium.

With regard to costs, Tahil asserted that the lithium ion battery would cost close to 350 USD/kwh, whereas the zinc/air battery would cost less than a third of that value. A 30 kwh zinc/air battery for a vehicle was projected to cost one thousand dollars in 1998, while a lithium ion battery of the same capacity could cost nine thousand dollars. In terms of recharge, the zinc/air battery could be resupplied like a gasoline-powered vehicle, quickly, with a viscous liquid for the electrolyte and with zinc.

Evans' response in March 2008 provided realistic reserve and resource values and did not enter into a debate with Tahil. In fact, Evans cited Tahil's 2006 article on just one occasion. Evans prepared his estimates on the basis of the conclusions reached by the NRC Lithium Panel of the United States in 1976, which concluded that the reserves and resources of this metal were 10.7 million tons of contained metallic lithium.

Tahil was quick to respond to Evans and in May 2008 published his second article, "The trouble with lithium: 2". Here he concluded that the mass production of lithium carbonate would not be possible without causing irreparable ecological damage, and that the lithium ion battery was incompatible with the notion of the "Green Car". He also concluded that the highly focused geographical concentration of lithium production would exacerbate the already strained geopolitical relations between Latin America and the USA. With regard to reserves and resources, Tahil wrote that Evans' estimate included deposits that contained from 8 parts per million (ppm) of lithium to 3,000 ppm, and that the total provided by Evans was 28 million tons of lithium, as compared to the 11 million cited as the reserve base by the USGS. Tahil went as far as to reduce his reserve estimate from close to 5 million tons of contained lithium in December 2006 to 4 million in 2008.

Different reasons led him to reach this conclusion.

Tahil questioned the reserves and resources of Salar de Atacama, in particular SQM's explorations during the initial decade of the 2000s, which had increased the estimate of lithium resources in Salar de Atacama from 4.29 million tons (MT) to 6.9 million tons, because these explorations went deeper than the

previous 40-meter mark, drilling down to 200 meters. According to Tahil (2008), porosity decreases exponentially at greater depths, so that below 40 meters it would be practically zero and would reveal instead the presence of solid rock made up exclusively of halite or common salt (Kogel, 2006). "Below the current extraction depth of 30 metres, there is no Lithium in the Salar de Atacama", indicated Tahil in his second article. "Extracting Lithium from 200 meters depth is impossible." "The claim of 6.9 MT to 200 meters depth fails to take this into account and is therefore a gross exaggeration."

Moreover, he argued that the Salar de Atacama nucleus, where the brines had high concentrations of lithium, encompassed a surface area of 30 square kilometers, and that, prior to SCL beginning its mining operations in 1984, it contained 450,000 tons of metallic lithium[109], i.e. 6.5% of the total resources that were reported to be in the salar. Later on he asserted that the British firm Hydrotechnica had estimated that the porosity in the most lithium-rich nucleus was 4.4% and not 10% as estimated by Corfo. Therefore, the 450,000 tons of lithium contained in that nucleus would be 200,000 tons, meaning that half of these reserves would have already been extracted from the salt lake since 1986. He thus concluded that the USGS had estimated the total reserves of the salt lake at 3 million tons of lithium, and considering that it was only possible to recover 50% in the medium to high lithium-rich sectors, "the upper limit to Recoverable Reserves cannot exceed 1.0 MT."

He added that to extract 50% of the lithium reserves from the salt lake would take many decades and would destroy it. In line with this reasoning Tahil explored the expansion of production announced for the following years, from 10,000 tons of metallic lithium extracted in 2007 to double that amount, and concluded that this would cause considerable environmental impact on the ecosystem of the salt lake.

With regard to Salar de Hombre Muerto, Tahil estimated that the extractable reserves would be 375,000 tons instead of the 850,000 tons reported by FMC. In respect of Salar de Uyuni, Tahil indicated that the extractable reserves were around 600,000 tons, discarding the base reserve estimate of 5.5 million tons made earlier on. In terms of Salar de Rincón, with reserves and resources estimated at 1.4 million tons, Tahil reduced that estimate to 250,000 tons of lithium. He also ruled out the productive potential of the Salton Sea, Smackover, Bonneville, Great Salt Lake and Dead Sea salt lakes. In addition, he scaled down the potential of the Chinese salt lakes from 2.6 million to half, Salar de Olaroz to almost half and conversely, increased the potential of Searles Lake by more than three times Evans' (2009) last estimate.

Tahil then proceeded to dismiss the lithium resources and reserves contained in pegmatites, hectorites, hydrothermal and oilfield brine lakes. Perhaps by mistake he included one small pegmatite deposit in Finland. Furthermore, he made no mention of the pegmatite deposits in Russia and some in Canada. In this way he arrived at a total of extractable reserves of 4 million tons of contained lithium.

109 Above the 35 meter layer, which is what Tahil considers to be economically sound to develop

In his article of January 2009, Evans responded in detail to Tahil's estimates, indicating that the resources mentioned by him in 2006 amounted to 6.8 million tons of lithium, that the origin of many of the figures mentioned was unknown and that several were of his own creation.

One thing that attracted Evans' attention was that Tahil discarded all reserves and resources other than continental brines. In particular, he dismissed pegmatites for the manufacturing of batteries and asserted that only brines were economical and viable reserves for use in batteries. Evans availed himself of the criteria used by the NRC Panel in the U.S. in 1976, asserting that they had identified all the resources and reserves that might be developed in a context of high demand. Figure 16 shows the resource and reserve estimates higher than 200,000 tons stated by Tahil in 2008 and Evans in 2009.

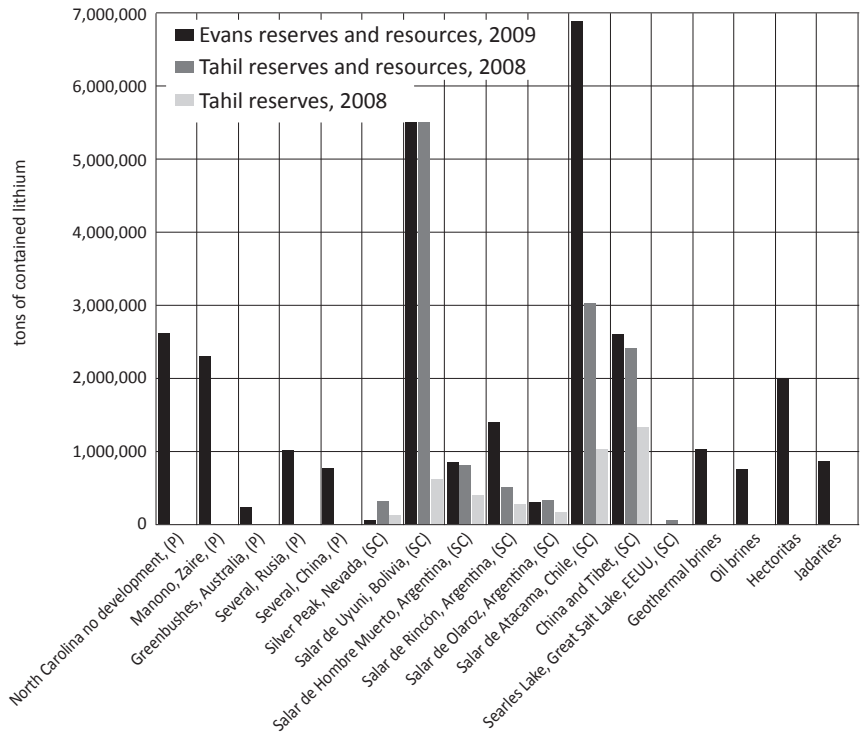

Figure 16: Estimations by Evans 2009 and Tahil 2008 for reserves and resources, and Tahil estimate for reserves. Only resources and reserves higher than 200,000 tons of contained lithium are shown.

The high demand scenario that was in place in 1976, when it was thought that the new batteries and fusion reactors were just around the corner, did not generate the same concern because they did not feel restrained by the "strict" USGS definitions regarding reserves, one of whose experts was part of the NRC

panel. USGS' definition of reserve was "That part of the reserve base which could be economically extracted or produced at the time of determination with existing technology, at today's price, for a specific market". The problem with this definition is that prices change, increase with greater demand, and technology develops. An example of the latter was the development of the technology to separate magnesium from lithium, which made it possible to transform the brines from numerous salt lakes in the world into reserves.

On the other hand, Evans asserted that the technology to produce lithium carbonate from spodumene was well known and had been already applied in China, and that it was just a matter of demand increasing to activate the necessary projects. With regard to lithium originating from other types of deposits, he indicated that work was under way to develop extractive technologies, including the above-mentioned jadarites, that it was possible to achieve good quality concentrate via magnetic separation, and that the production of lithium carbonate on the basis of that concentrate was simple.

Evans emphasized that in Tahil's second article he had contradicted himself because he discarded pegmatites but at the same time asserted that the production of high-purity lithium carbonate for batteries was cheaper and more viable if based on pegmatites rather than on brines.

The third Evans article (2009) was incisive, because he exploited every one of the errors detected in Tahil's articles. For example, Tahil had discarded the large Manono deposit in Zaire, indicating that it was a "speculative" resource. That deposit had been reported precisely by the NRC panel in 1976, referring to the obtainable recovery and ore grades. Tahil also failed to recognize in his articles that the Bikita deposit in Zimbabwe had been mined for many years as of World War II. In fact, a major part of the strategic reserves of the United States was processed on the basis of those minerals in the 1950s. With regard to pegmatites, Evans also indicated that Tahil had cited the lithium grade in the North Carolina deposits erroneously.

In terms of continental brines, Evans was implacable with Tahil, asserting that he was known for his conspiracy theories. To this end he cited an article written by Tahil in 2006 in which the subtitle read "Incontrovertible proof that the World Trade Centre was destroyed by underground nuclear explosions." Likewise, according to Evans, Tahil wrote that any increase in the reserves of Salar de Atacama over time was suspicious and that the "incontrovertible truth" was what he had unilaterally decided the reserves of that salt lake to be.

With regard to the resources of Salar de Hombre Muerto, Evans asserted that Tahil's estimate was correct and that, if he had applied the same criterion to Salar de Atacama, its resources would have increased to 10 million tons of lithium. In addition, he added, "about a third of the reserve at Hombre Muerto (is) at a depth of between 40 and 70 meters – a depth that Tahil says is too great for brines to be present."

In respect of Salar de Rincón, Tahil was wary of the increase in resources and reserves reported by the Admiralty Resources company[110], although this increase was generated by a drilling survey of the entire salt lake, while the

110 This company holds the permit to develop the salt lake

previous figures only involved part of it.

As for Salar de Uyuni, Tahil's estimate coincided with that of Evans, although some of the other figures reported by the former were mistaken, which Evans attributed to an erroneous interpretation of the 1976 NRC report. Evans' advantage in this debate was that he participated as one of the main characters in preparing the NRC report.

Evans devoted more than two pages of his 2009 article to explain Tahil's mistaken reasoning regarding the reserves and resources (R&R) of Salar de Atacama, because Tahil had reduced SQM's estimated R&R to less than half. In brief, Evans indicated that what Tahil had written about this salt lake was nonsensical. Among the more salient errors were: mining of the salt lake did not begin in the most lithium-rich sectors but in those areas where the chemistry of the two brines used adjusted to the process that Foote had proposed, which was based on obtaining a lithium feed that represented the average grade of the salt lake. Moreover, its agreement with Corfo did not consider potassium recovery; the same applies to SQM, which had only one well in the area where the richest lithium and potassium sources were found. Thus, Tahil's assumption regarding the mining of the richest part of the salt lake first was wrong; finally, Evans indicated that the lithium grade would decline in the salt lake in line with its further development, as occurs in all deposits. But even the lithium grades at the end of mining the Salar de Atacama would be 45% higher than the lithium grade in Salar de Hombre Muerto, and 272% times greater than in Salar de Rincón.

Furthermore, the extensive drilling surveys carried out by SQM occurred in 2007 and, as a result, the company reported new exploratory drilling and increased the total lithium R&R to 6 million tons, indicating that the technology used in this prospection was much better than indirect technologies such as geophysical inference, used over 30 years ago. Therefore, the increase assigned by Evans to the R&R of the salt lake was justifiable.

With regard to the R&R, although Tahil did not discard the productive potential of the geothermal and oilfield brines, neither did he take them into account. Tahil also failed to assign R&R to hectorites. And he did not consider – because they were too recent – the new resources reported by Rio Tinto close to Belgrade in Serbia. These were jadarites, as mentioned before.

Evans did not consider Tahil's assertion regarding the state of war of the Argentine activists against the mining of the salt lakes of that country worthy of response. And even less did he deign to respond to Tahil's assertion about the preparation of the U.S. "Fourth Fleet" to keep Latin America under control. With reference to the destruction of Salar de Uyuni argued by Tahil due to the extensive development it would require, Evans asserted that the mining operations would only involve around ten of the 9,000 square kilometers. Regarding Salar de Atacama, Evans stated that the two companies operating there were fully compliant with all environmental regulations, which conformed to international standards, and they were also subject to strict oversight.

Tahil did not respond to Evans' 2009 publication.

Tahil did not consider that the industry of all minerals is developed through incentives, and that hundreds of new deposits had been reported since he

published his second article. In particular, at that time the Afghanistan resources had been discovered, which would increase the reserves and resources reported by Evans in 2009 to more than double. In addition, Tahil disregarded the effect of technological development on lithium production and battery manufacturing costs.

Tahil mentioned the recycling of lithium ion batteries in his second article, indicating that it had reached close to 600 tons in years 2005 and 2006 in Europe. The political considerations that Tahil expressed regarding Latin America are simply unbelievable. In terms of Chile, he suggested in his publication of May 2008 that it was worrying that the Senate Mining Commission had questioned the legality of the contracts signed with Minsal and SCL more than 20 years ago. Next he expressed anxiety regarding the political future of South America due to left-wing leaders such as Hugo Chávez, Evo Morales, Luiz da Silva, Michelle Bachelet and Cristina Kirchner. Well, he did not get to see Ollanta Humala, or Michelle Bachelet being replaced by Sebastián Piñera and Luiz da Silva by Dilma Rousseff. And he completely overlooked Rafael Correa in Ecuador.

Tahil indicated, "The trend is clear. The supply of 70% of the world's Lithium[111] will increasingly come under state control, as oil exports are politically controlled by the OPEC nations today. Unlike OPEC, which has in general shared little of its oil wealth with the general populace, the New Governments of South America see themselves as more socially responsible and unlike the previous regimes are not politically aligned with the USA." He later adds: "In the current US climate of "reducing dependence on foreign oil", exchanging dependence on oil from perceived hostile nations of the Middle East, whose governments have in fact been allied with the USA, for dependence on "Foreign Lithium" from nations where both the populace and the governments are no longer sympathetic to the USA, would be unwise."

It is important to comment on Tahil's 2006 article on "Peak Oil". Tahil mentioned it in reference to the rise in oil costs that had been observed since the beginning of the commodities boom in 2004-2005, as proof that a peak in oil production would soon occur, after which it would be a question of waiting for oil production to start to decline because its price would be too high and few would be able to buy it.

Radetzki (2011) argued that the commodities boom of 2004, stimulated assertions about the Peak Oil theory, which posited that "the peak [of world production] will occur when half the ultimately recoverable resource has been produced". This theory is upheld by a specialized organization, ASPO[112], which has been maintaining for several decades that the peak will occur very soon, certainly within a decade. According to Radetzki, by 1920 the current U.S. Geological Service (now USGS) reported that the oil in that country would be depleted before the end of the decade. Eighty years later U.S. production had increased 6.9 times. Well, now the ASPO has repeated this forecast in reference to the commodities boom.

111 Which would be in the salt lakes of Chile, Bolivia and Argentina.

112 Association for the Study of Peak Oil

Radetzki adds that "Peak Oil expresses contempt of economic analysis, and gives no attention to economic considerations", and that "the clear case of depletion is a situation where exploitation becomes increasingly more expensive and where the price rises in consequence, leading to falling demand, in the extreme case down to zero." And no observation of this nature has been reported with regard to the depletion of a natural resource, not in the 20th century or in this one. What there has been in many cases is substitution, the adoption of one material to replace another, of the same or higher quality and at an equal or lower price.

For this reason, postulating the impending depletion of oil, followed by its replacement with lithium and the subsequent environmental and political catastrophe, as forecast by Tahil for this metal, is certainly a scenario worthy of soap-box preachers.

I chose to reproduce some of the last Tahil quotes because they add color and entertainment for the readers. But in truth it seems unnecessary to respond to them all. For example, the notion that Argentina, Bolivia and Chile would cooperate to establish a lithium cartel seems fanciful, to say the least, coming from someone who knows very little of the political and economic history of these three countries.

Ultimately, Tahil stated that the world had become infatuated with lithium, but omitted to mention that he had developed a strong aversion to this metal, which he expressed in his 2006 and 2008 publications, loaded with assertions that were technically and scientifically unjustified. He came to accept that the 78 million laptop computers and the 1.1 billion cell phones manufactured in 2007 could be powered by lithium batteries, but he was unable to accept how lithium might be able to power the 60 million vehicles manufactured that same year, of the close to one billion vehicles circulating in the world. To avoid this, did he conjure up in his mind this plot of the Southern Cone of America against the United States? Infatuation and aversion are both legitimate feelings, but unfortunately for Tahil, the inexorable market favored the former and ignored the latter. In this age of information the market is stimulated mainly by an infatuation with ideas, signs, symbols and goods that circulate around the world through many media.

The idea of utilizing a white metal, the lightest and intrinsically the most powerful electrically, as well as innocuous in nature, has seduced humanity, because it seems to embody energetic qualities as or more impressive than those of oil, a substance that has dominated world development since the industrial revolution. It is paradoxical that lithium is at the same time the element of the periodic table that can best perform the function of powering a transport vehicle using clean energy, and a key element to unleash a nuclear fusion reaction, which could, if well controlled, generate the entire energy of the planet, also cleanly. It's almost too good to be true.

12. RESEARCH IN CHILE

Research on lithium in Chile was carried out at least as of the 1960s, mostly by geologists who studied the presence of lithium and other elements in Salar de Atacama. At the same time, there was a handful of chemical engineers who had studied the crystallization of salts at the Universidad de Chile and several of them worked with lithium-producing companies, among them Felipe Vergara, Nancy Parada, chemical scientists and engineers who had become interested in lithium.

Upon analyzing the 1982 to 2011 database of Fondecyt **(National Fund for Scientific and Technological Development)** projects, which allow individual researchers to develop basic science, it was concluded that 24 projects dealing with lithium had been awarded over the past 30 years, i.e. less than one per year. These were developed by 13 main researchers, 71% of the projects were on the subject of battery materials, 17% on lithium processing, and 12% on other matters. Of these, 30% were developed at Universidad de Santiago, 24% at Universidad de Chile, 17% at Universidad Católica del Norte, 4% at Universidad Técnica Federico Santa María (UTFSM), and 3% at the Chilean Nuclear Energy Commission (CChEN). Since 2001 the number of lithium projects has declined.

In 1986 the First Chilean Symposium on Lithium (Lagos, 1986) took place, and at the end of the 1980s the Chilean Navy examined a project to install lithium batteries in their submarines. The electric power corporation Enersis (now Enel) studied a project to install electric buses in Santiago and other cities in Chile. Also at the end of the 1980s, Corfo's Mixed Salts Committee commissioned several Chilean institutions to carry out research projects on lithium. At the end of the 1980s the U.S. Department of Energy launched a 10-year project in conjunction with Ford Motor Company, General Motors and Chrysler, as well as with Argonne National Laboratory, with funding totaling 2 billion dollars of that period to develop batteries for electric vehicles.

At the beginning of the 1990s a group of researchers in Chile submitted two major projects to Fondef (Conicyt Fund) to develop materials for batteries and processes for the Chilean mining industry. Both projects were rejected by Conicyt. Subsequently, the group of researchers from the institutions that that been awarded Fondecyt projects broke up due to the lack of interest of the Chilean State in promoting lithium research. Two symposia on lithium were held during the 1990s, but the topic lost momentum.

During that same period SQM created a Research and Development (R&D) Center focusing on lithium technologies, which throughout the years created 16 international patents on lithium processes. The Center had around 18 persons working in R&D.

In November 2010 the Universidad de Chile created the Lithium Innovation Center (CIL – Centro de Innovación del Litio) with the support of Chemetall/ Rockwood, SQM and Marubeni. The purpose of this Center was to resolve the four major problems associated with lithium ion batteries in the course of the following five years: reduce their cost to one-fifth of the current price; increase the range of use per charge to more than 300 km, maintaining their current size and weight; improve their fast charging speed to less than 15 minutes, and extend their useful life beyond 10 years of use (more than 1,000 charge cycles).

Thus, the laudable initiative of Universidad de Chile in creating the Center should be considered an almost romantic gesture, given that the State had remained neutral on the subject for the past 30 years.

For Chile to be able to advance in creating value added at any point of the value chain of lithium materials and products, the first thing that needs to be done is to encourage the academic community to become involved in the matter. Without a numerous group of highly capable, qualified and experienced people it is almost impossible for Chile to become involved in the creation of value for lithium products, beyond some processes that are located nearby to the deposits and consequently cannot be appropriated by institutions or companies that are not close to the deposits. It is not fortuitous that the Australian company Galaxy Resources decided to develop the value chain of its lithium concentrates in China and not in Australia.

Corfo's initiative in 2017 to allocate slightly more substantial resources to lithium innovation and to invite companies to set up business in Chile in order to take advantage of being able to purchase metals at a preferential price in the country itself, could provide interesting technological results. At least it is a new vision that has not been tried before, and could be more likely to succeed than to assign resources to areas in which competition is fierce, such as battery manufacturing or the development of new materials for batteries. These latter ideas would be valid if and when they were backed by a credible hypothesis, but if the method used is trial and error it is almost certainly doomed to failure.

13. FINAL COMMENTS

I will first analyze some trends observed in the lithium industry at a global level, and subsequently discuss the situation of the lithium industry in the country.

Before I do, it is useful to comment that very possibly the kindling of the debate that began in 2007 with the Bill on lithium presented by Senator Navarro occurred slightly less than a year after Tahil's first publication regarding lithium. The arguments proffered in the parliamentary debates and even in the 2009 Cochilco report used not only Tahil's ideas but also his language. Hence the importance of analyzing this author's publications.

I will address four issues related to the global industry. First, the explosive growth of demand. Second, is it possible to produce the quantity that this explosive demand requires? Third, what will happen with the price?, and finally, what effect will the new producers have on the price?

It is estimated that the growth rate in the use of lithium will be higher in the future than it was in the past, which averaged 6.5% per year since 1940. Today, minimum rates of 6.8% are forecast up to 2050, with the possibility of reaching double digits.

With this growth rate up to 2050, approximately 10% of the known resources, excluding those extracted from the sea and lithium recycling, would be used in total according to the projection for the demand of batteries conducted by the International Energy Agency in 2011.

With regard to the production to meet this demand, there are only short-term projections available, and these indicate that from now to five or ten years hence the industry could provide new production to meet the demand. Most importantly, however, is to note that it has never been observed that an increase in the demand of any commodity, no matter how explosive, has led to a scarcity of supply in the long term. As was previously discussed, when the right incentives are in place, investment in technologies and exploration will appear on the scene.

We have already mentioned the example of the Club of Rome, but it is not the only one, there are many.

The last was the real crisis that hit the United States in 2011 with regard to the export controls China would place on "Rare Earth Elements" (REE), which are important in a series of sophisticated technologies such as wind turbines,

certain types of light bulbs, computers, electric vehicles and other products. The alert had been raised a year before in a report of the U.S. Department of Energy, which indicated five elements that could become scarce in the market, the most important of them being dysprosium. China was the sole producer of some of these elements, which are used in small quantities to modify the properties of materials.

In February 2015 the MIT Technology Review queried, What happened to the Rare Earth Crisis? First, many companies bought sufficient quantities to maintain high inventories of these elements, after which the price started dropping. Others, like General Electric, conducted research to lower the REE in light bulbs, achieving major reductions. Siemens was considering technology that would not require dysprosium and Nissan announced in 2012 that it had reduced the dysprosium it used in engines for electric vehicles by 40% via the development of a new manufacturing process. Another occurrence is that the development of the Mountain Pass mine in California, which seemed to be a safe bet when the price of these elements rose in 2010 and 2011, has not been able to go ahead because the price of these substances dropped later on due to substitution. The final result is that there was no scarcity of these materials and, if there had been, other deposits such as Mountain Pass would have been developed. The important thing in this case is that substitution occurred only because of the threat that the material would become scarce.

In terms of production there are two trends we need to bear in mind. First, producing lithium from brines continues to be far and away cheaper than doing so on the basis of pegmatites and other minerals, and Chile has the best salt lake in the world to extract lithium. At the same time, it has other salt lakes whose extraction and processing costs have not yet been reported. And second, pegmatites and other minerals – but not brines – have gained ground in the increase of reserves and resources over the past years, and this trend will probably continue and reflect on production.

The third issue is, what will the price levels be like in the future?

From a theoretical perspective, the price of lithium can increase in the long term only if there is a structural change in the supply of the metal – for example, if the technologies to produce lithium do not keep up with demand and the marginal production costs rise considerably. This will benefit low-cost producers, for example those of Salar de Atacama, and will thus increase their income.

If, on the other hand, lithium mining projects were insufficient, that would also increase the price, but in this case with fatal results for the industry, because if the lack of supply were to extend over time, prices would rise very high and result in substitution.

Substitution up to 2050 is unlikely, unless the price rises substantially, for two reasons: first this metal represents a low percentage of the battery price, and second, the demand for lithium batteries would represent 87% of lithium demand in the scenario set forth by the 2011 International Energy Agency. That is to say, substitution could occur in other segments of the market, which would be quite small.

Why is it that the price of lithium cannot rise substantially unless a structural

change takes place? Simply because the average profit margin of the industry, before taxes, should remain the same in the long run. If the profit margin of the industry were to skyrocket, this would rapidly attract many investors who would increase production and make the price drop. If, conversely, the average margin of the industry were to fall, investors would no longer be interested and therefore there would be less future production, making the price rise.

The fourth issue I will analyze is, What effect would the entry of new producers into the lithium industry have? As previously mentioned, this would involve a dispersion of production among many producers. These new players should not cause a drop in prices unless a price war were to ensue, as occurred in 1997. It is unlikely that conditions will lead to this because the new producers would probably not have as competitive prices as the current lower-cost producers.

The mere entry into the scene of these new producers should not bring about a price reduction, for two reasons. First because it is not in their interest, and second and more importantly, because very competitive mechanisms are used to set the current price. The new producers would possibly generate more contracts similar to those in place at present because there would be more buyers, more processors and more battery manufacturers avid to ensure a supply of lithium. It is thus likely that the spot market will continue to be very small. All things considered, with a very large number of sellers and buyers, it is possible that lithium will be traded on the stock market. Although the stock market has more transparent mechanisms than the sum of many contracts between private parties, its disadvantage is that it usually increases volatility. This is what happened with multiple metals in the past.

In respect of the development of the industry in Chile, I will analyze three issues. First, the stagnation of production and one of its causes, the State's attempt at controlling production. Second, What objectives do I think Chile should have for the lithium industry, including what income to strive for and when and how much to produce? And third, the value added and innovation required.

Chile came to account for almost half the world production of lithium between 2003 and 2006, and is now slipping irremissibly downward, and may drop to a fourth or even lower level within the next ten years. The causes of this were discussed in chapter 7. I will address the third cause mentioned in greater depth by the Comisión Nacional del Litio (2014), which consisted in thinking of "a controlling role (by the State) in all brine mining projects developed in the country." Although a more palatable interpretation of this report emerged later, the sole idea that many people in the left wing political parties of the country still uphold the "State ownership of production" philosophy makes it a worthwhile topic to discuss.

Radetzki (2017) in the second edition of his book A Handbook of Primary Commodities in the Global Economy, indicates that state enterprises have played a major role in the production of many commodities for several decades. The peak of these enterprises took place at the end of the 1970s and in the 1980s, but due to poor results a wave of privatizations occurred in the 1990s. Oil-producing companies were the only survivors, and very few mineral producers. Codelco is possibly the most successful example of the latter.

There is a belief that state-owned enterprises behave differently from private companies. Indeed, it is so in numerous cases, because their primary goal, which is to maximize profits in the long term, is subordinated to "the pursuit of a broader set of social goals, or of specific agendas that politicians in a position of influence choose to pursue." (Radetzki, 2017). Technological development might become one of such goals, which could in effect lead to companies forgetting their main purpose.

Codelco was subject to goals of this nature particularly in its first decades of existence. This began to wane after a while thanks to the efforts of its executives, who resisted continual political pressure to use the company's power for agendas other than its own. From this perspective, one of the greatest achievements was the modification of its corporate governance in 2009, which gave the board of directors the power to issue clear rules regarding the actions that could be subject to political pressure and at the same time increase the transparency of the company's operations. The goal is still far from being achieved, but the progress made is important. Even with this new board we have heard that the pressure continues.

Could anyone think that a state lithium corporation, even if a Corfo subsidiary, would be spared this same experience?

But up to now we have only been referring to one of the consequences of having a state enterprise. It is convenient to examine, What fueled nationalization in the world in the past decades?

Radetzki writes that these enterprises were frequent in developing countries because of the belief that public ownership would accelerate the process of economic development. There were, also, other reasons for nationalizing mineral-producing companies. First the "generalized perception of national wealth as a national asset"; second, the idea that these were strategic industries because they ensured an influx of foreign currency that was very scarce at that time for governments. Third, the size of these enterprises made them very important to the countries' economies. Fourth, the power these enterprises wielded was enormous, and governments had very little control over the fundamental decisions they made. And, lastly, there was no risk that the deposits might escape governmental control – once the investments were made, they were captive.

Anyone reading these lines will remember the causes underlying the nationalization of copper in Chile in 1971.

When these causes are transferred over time to half a century later, and to lithium, only a few survive. Indeed, the deposits are state-owned and the metal is considered to be strategic, presumably because it is hoped that the Chilean lithium industry will become very sizeable in the future. This is not the case[113], and moreover if the growth of the lithium industry in Chile is lower than the growth of Chile's total exports – as has occurred during the past 10 years –, lithium would be destined not to exceed 1% of the total. Even if lithium production were to increase fivefold, which is highly unlikely before 2025, the

113 In 2016, even when lithium prices were high, its exports represented only 0.76% of the country's total exports of goods. It did, however, represent a major increase vis-à-vis 2015, where it reached 0.43%.

weight of lithium in exports would be hard pressed to reach 5%.

Therefore, it seems unlikely for lithium to be strategic given the size of the industry in the country. Neither is it strategic in terms of national defense. Then, Why does it continue to be considered strategic? This is a question I leave open because I do not have an answer to it.

Copper nationalization had a gestation period of at least a quarter of a century. When it occurred it did so with epic intensity, felt by all Chileans at the time. To recover our most valuable natural resource, capture all its revenue, conduct the entire management of the four largest mines, and demonstrate that the country was competent to do so.

What epic would the nationalization of lithium represent at this time? It may possibly be a legitimate belief among a political elite that thinks it can do better than the private sector from a country perspective. But it is not an epic for the Chilean people. In the Minerobarómetro[114] of 2012, 42% of Chileans thought that lithium was a metal or mineral, 11% thought it was a medicine, 5% a chemical element, 3% other things, and 39% did not know. This leads me to the second aspect I wish to analyze and that I think may be able to unblock the debate we have been having.

What could be the objective of the lithium industry in the country? I think we can agree that it is to maximize long-term economic, environmental and social revenue for the State. I include in this revenue not only taxes, but environmental protection of the salt lakes, employment, coexistence with the communities living in the surroundings of these ecosystems, building human capital, and innovation. The goal is certainly not to be the main producer in the world.

The economic rent of a commodities company is maximized by starting off with the production of the more globally competitive deposits, implementing world-class technology and management. When demand is high, many deposits should enter into production simultaneously.

Why expand production now and not later? Because it is necessary to take advantage of lithium prices to produce development and welfare for the country as soon as possible, because no one can guarantee that demand for this metal will last indefinitely.

China announced that it would subsidize lithium batteries for 10 years, and that later on it would have to review whether it continued to be the best technology available.

Another example in which lithium extracted from deposits would not have perpetual demand is that in a much more developed world than today, for example in 2050, world population may have stopped growing and average economic growth could be (as foreseen) at very low levels, slightly over 1% per year. In this scenario, the demand for primary commodities (not only lithium) could be seriously threatened by the supply of secondary, i.e. recycled, metal.

Whether production increases through companies in which the State is a participant but not a majority one, or through private companies, it is

114 A national poll from Arica to Magallanes of a sample of 1,200 people, 18 years old or more, in face-to-face interviews and with a sampling error of 3%.

immaterial in the case of lithium. To do so in a wholly-owned State company imposes capital requirements that the State is unable to meet either now or in the future, as we have already seen in the case of Codelco. It was necessary to reach the edge of the abyss for the State to return some of the profits that this company produced.

The State has too many other obligations that are more pressing than to finance public enterprises. What is fundamental is to maximize the capture of economic rent for the State, ensuring that there will be investment in the future. This means that private producers should be extended sufficient incentives to invest in Chile instead of in other countries.

It is therefore essential that the State set the tax rates for lithium mining companies, with clear, stable and, if possible, simple rules. If these rules need to differentiate the total tax burden due to the costs of each operation, there should be a clear regulation in place for this.

The problem that arises with regard to tax rates is not domestic, it is international and not only concerns commodities industries but all industries. While the public frequently thinks that taxes are too low, entrepreneurs and investors think they are too high. Finding a balance with shared perceptions is complex but not impossible to achieve. These balances are not long-lasting, because the world changes rapidly, which makes it necessary to be well prepared to participate in these debates with the best arguments.

Let us examine the third aspect, the creation of value and innovation.

We have heard insistently in the country that it is necessary to add value to lithium, and many times this is associated with having our own manufacturing and industrial processes. The notion that value added is associated with these activities harks back to the 19th century and first half of the 20th, when protectionism was in place and it was possible for small and inexperienced countries to manufacture consumption goods. Today, with globalization, this cannot happen because manufacturing and industrial operations run by companies without technological advantages (which require continual investment) will very probably destroy value instead of creating it. We have the example of the five Chilean state-owned copper smelters, which destroyed value in the past decade due to lack of investment and for operational reasons. Conversely, the two private copper smelters not only managed to outperform the five state-owned ones in terms of environmental protection (they emit less gases) but they did not sustain economic losses over the same period.

The other case of industrial processing is the semi-manufacturing of copper. Chile has several semi-manufacturing plants that produce cables, sheets, pipes and other copper goods. But their economic results have been historically meager or negative, the same as occurred with almost all semi-manufacturing companies in Europe and the U.S. with the exception of a few survivors. In Europe and the U.S., many semi-manufacturers emigrated to China. In Chile Madeco merged with Nexans, of French origin, in order to be able to continue competing.

In the globalized world, what ensures the creation of value added is technological innovation and, temporarily, low-cost manpower and services. The latter, in any event, no longer exists in Chile. Another alternative is to discover and develop a rich deposit, but this has to be carried out using appropriate

technologies, which is no trivial matter. If not, why has no South American country – excluding Brazil with Vale and Chile with Codelco and Antofagasta Minerals – been able to develop mineral deposits without the presence of multinational corporations? Not only because the latter have the necessary capital but also the know-how, technology and market savvy. We only have to look at what happened to oil companies such as Shell Billiton, BP, Mobil, Exxon and others, which entered into the mining business after the 1972 Club of Rome report, thinking that the mineral business would be very good because, being a scarce product, prices would increase. They were wrong and the last oil company to sell its mining interests was Exxon in 2002 (La Disputada).

Developing some sort of "proprietary" technologies for lithium could include extracting and processing it at a lower cost, transforming lithium into products of greater value, manufacturing products containing lithium and even inventing new uses for lithium.

Unfortunately, it is not enough to say that it is necessary to become involved in technological development, and up to now there has been no magical answer about how to achieve it. Chile has made slow progress in innovation.

In this respect I fully maintain what was written in 1986 in the prologue to the book "El litio, un nuevo recurso para Chile" (Lithium, a new resource for Chile). It stated then that "Lithium has at least two applications with great future projection that are currently limited by the development of new materials: in power batteries for transport and in nuclear fusion." Later on it added "This book also includes an exploration of the ideas and issues that would allow us to make major contributions to the world lithium industry of the future. This is particularly relevant considering that as of 1992 we could be the largest lithium producers in the world. Why, then, not be one of the producers of lithium technologies? Why not integrate our lithium industry vertically, from extraction to sophisticated products? It is certainly something we never did before with any of our other raw materials."

But together with maintaining these points of view, I also observed that Chile had not displayed any vocation for research and innovation in lithium over the past decades. The scientific policies of the last 35 years had resulted in the allocation of a majority of national funds to projects other than lithium. Foreseeing this reality, I and many others abandoned scientific research into lithium 27 years ago.

Who should finance innovation? At a global level this burden is shared by states and enterprises. In Chile the participation of enterprises in innovation is very low in comparison with the State, and the State's investment in innovation is much lower than that of the OECD countries.

To require the State to have an enterprise finance research directly, as is the case of the 2016 Corfo-Albemarle Agreement, is to recognize that there are serious doubts as to what the State would do with those resources if it managed to capture them.

It is enough to review the country's history to verify that the funds that originally should have been earmarked for research were allocated to finance other goals, many of them undoubtedly very laudable. This occurred with what is known as Royalty 1, approved in 2005, the purpose of which was to finance

research and innovation in the country. In fact, that was the justification – not the cause – of that Law, to generate new resources for innovation, resources that nobody had yet appropriated. The relentless social and political pressures, however, made it impossible to vote in the Royalty Law 2, which was to regulate the use of Royalty 1.

This lengthy digression leads me to conclude that the reason for the low budget assigned to research and innovation in Chile is because neither the governments nor the parliament, nor the companies, nor the public, are convinced that this is the only way to progress towards development.

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