The lithium industry: Its recent evolution and future prospects

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Abstract

During the past decade there has been considerable change in the world lithium industry. This paper discusses this change and reflects on likely future developments. Lithium carbonate producers, based in Northern Chile, now play a dominant role in world production. One focus of the discussion is on the current structure of the industry, particularly at the level of the early stages of production. After considering potential growth in lithium consumption in the foreseeable future, the latter part of the paper considers relevant public policy issues concerning the future regulation of the Chilean industry.

Keywords: Lithium; Mineral supply; Mineral demand; Vertical integration; Predatory pricing; Limit pricing; Public policy issues

Introduction

As the lightest metal on the periodic table, lithium is widely distributed in trace amounts in most rocks, soils and natural waters. It is electrochemically reactive and has a low thermal expansion coefficient. It has also has the highest specific heat of the solid elements. Some lithium compounds also possess flat viscosity/temperature ratios. Because lithium and its compounds possess these attributes, many commercial applications have arisen over the past century.

World consumption of lithium had increased from less than 100 tonnes of lithium carbonate equivalent per annum in the early 1900 s to more than 70,000 tonnes per annum one hundred years later.[1] The main uses of lithium metal, lithium carbonate, lithium hydroxide, lithium bromide and more complex compounds are currently:

(a) In ceramic glasses to improve resistance to extreme temperature changes;
(b) to lower process melting points, and as a glazing agent, in ceramic (frits) and glass manufacturing;
(c) to lower the melting point of the cryolite bath in primary aluminium production;
(d) as a catalyst in the production of synthetic rubber, plastics and pharmaceutical products;
(e) as a reduction agent in the synthesis of many organic compounds;
(f) in specialty lubricants and greases used for working in extreme temperature and change conditions;
(g) in the production of both primary and secondary batteries; and
(h) in air conditioning and dehumidification systems.

Another use, not yet widespread, is the use of aluminium–lithium alloys in aircraft production while the addition of lithium carbonate to cement as a way of preventing concrete cancer has emerging appeal. One recent estimate of the percentages of uses[2] appears in Fig. 1.

During the past decade, the production (and consumption) of lithium has been increasing at an average of about 3% per annum. Some estimates for the period between 1984 and 2003 (British Geological Survey, 2005, p. 154), stated in terms of lithium carbonate, appear in Fig. 2. After sluggish growth of just over 1% per annum between 1984 and 1993, production

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[1] An alternative way of expressing lithium consumption is in terms of lithium metal equivalent. Approximately 5.32 units of lithium carbonate (Li_2CO_3) converts to one unit of lithium metal.

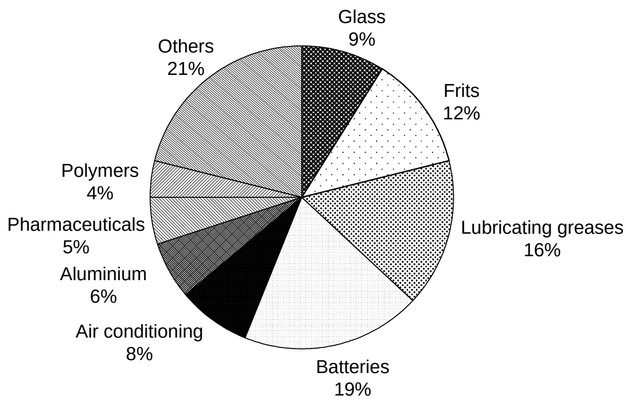

Fig. 1. Estimated uses of lithium by volume—2004.

surged between 1994 and 1997 in response to applications such as the widespread use of lithium in the production of monochromatic computer monitors. Although production fell back in 1998 in the wake of the Asian economic crisis, there has been significant growth again since 2001. Key to the market expansion between 2001 and 2004 has been the increase in use of lithium in rechargeable batteries and the demand growth from China.

In spite of the re-opening of some old aluminium producing facilities, due to the recent rise in the aluminium price, lithium use in aluminium production now appears to be in long-term decline. By contrast, lithium use recently has been rising in its applications as a catalyst. Proponents point to its considerable potential in battery applications. There has been strong recent growth in this area. Rechargeable lithium ion and lithium polymer batteries are now in widespread use in mobile telephones, digital cameras and several other appliances, replacing nickel–cadmium and nickel metal hydride batteries.

By the mid-1990 s, there appears to have been relative stability in the balance of annual lithium production and consumption. At that time, producing companies operated in the United States, Chile, Australia, China, Russia, Zimbabwe and Canada.

This situation changed dramatically in 1997 when the Chilean fertiliser company, Sociedad Quimica y Minera de Chile S.A. (Soquimich or SQM) entered the market. It

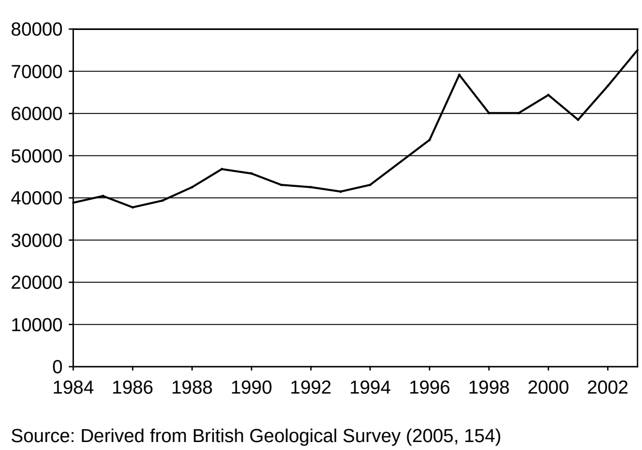

Fig. 2. Estimates of world lithium carbonate production 1984–2003.

produced lithium chloride as a co-product with potassium chloride from brines from the Salar de Atacama area in the Second Region in northern Chile, some 150 km east of Antofagasta. It then processed these into lithium carbonate in Antofagasta. SQM joined another producer—then the US-based Cyprus Foote Corporation—which also produced from this area. As a low-cost, high volume producer of lithium carbonate SQM drove down the market price by about 50%. This in turn forced the effective closure of, or reduction of production, at higher cost mining operations in the United States, Russia, Australia, Argentina and China. Several of these companies produced lithium oxide from raw materials such as spodumene, petalite and lepidolite.

The purpose of this paper is to consider recent developments in the lithium industry, and to reflect on likely developments in it during the next decade. Because of its high share of world output and potentially greater economic importance, the future of the industry has recently attracted closer study from the Chilean government. Understandably, its interest is in the longer-term welfare of its citizens and in ensuring that they derive the greatest possible long-term benefit from lithium exploitation. In pursuing this, it might open further areas for production, promote further use of lithium or charge higher taxes and introduce royalties to derive greater benefit from the economic profits of lithium producers.

The discussion in Section 2 reflects on key factors that influence the demand for lithium and how they have changed in the recent past. We then consider the production side of the industry and the major factors that influence supply. In Section 4 (Some further analysis), we undertake some further analysis of the industry, using some of the dimensions of the structure, conduct and performance framework[3] first among the lithium carbonate producers and then the other lithium mineral and metal producers. We move in Section 5 to analyse the potential for growth in lithium demand and supply. This leads to discussion of some mineral policy options for the Chilean government, before some concluding remarks are offered.

Factors affecting the demand for lithium

The amount of lithium, which society uses over any period, is a reflection of demand for the final goods that contain it as an input. The demand for lithium and its compounds arises because of the several key attributes mentioned in the Introduction.

[3] See for example Carlton and Perloff (2000) for an introduction to this approach. Under structure they consider the number of buyers and sellers, barriers to entry of new firms, product differentiation, vertical integration, diversification. In the conduct area, advertising, research and development, pricing behaviour, plant investment, legal tactics, product choice, collusion, and merger and contracts are important. Price, production efficiency, allocative efficiency, equity, product quality, technical progress and profits are issues relating to performance. A set of basic conditions, which relate on the one hand to demand (including elasticity of demand, substitutes, seasonality, rate of growth, location, lumpiness of orders and method of purchase) and on the other to production (including technology, raw materials, unionisation, product durability, location, scale and scope economies) are also relevant.

A further assessment is possible by reflecting on the impact of factors suggested by Tilton (1992, 47–48) in his standard discussion of the determinants of mineral demand. While recognising that 'literally thousands of factors affect mineral demand', and that one's time horizon is a key consideration, Tilton identifies income, own price, the prices of substitutes and complements, technological change, consumer preferences and government activities as major influencing variables.

Income changes, often reflected in terms of movement of Gross Domestic Product, lead to changes in the demand for consumer and producer goods and to consequent changes in mineral demand. In this regard, it is important to distinguish between income movements due to *trend growth* and to movements in the *business cycle*. As with other minerals, lithium use has moved up and down during the business cycle. World GDP has grown over the past century at around 2% per annum. However, lithium consumption has risen from a low base at more than 5% annually. There is a positive relationship between income movements and lithium use, but the strong growth rate appears to reflect the influence of other factors as well.

The movements in a mineral's own price also affect the demand for it, particularly over the long run. First, higher prices for any mineral increase the production costs of the final or intermediate goods in which it is used. If these costs are passed on to consumers, the demand for final and intermediate goods and their mineral inputs will fall. The converse argument applies. Secondly, a rise in the price of a mineral input into a final or intermediate good, encourages substitution of other minerals with similar attributes for the first mineral. Price falls have the opposite effect.

The real price of lithium and its compounds appears to have been falling gradually over an extended period. However, real prices of other minerals have also moved down or remained stable.[4] Because of these parallel trends, own price effects on lithium demand have generally been small. The dramatic fall in the price of lithium carbonate in 1998 was an exception to this. However, since the contribution of lithium inputs to the total costs of production of final products is small, its short-run price elasticity of demand is low and the demand for lithium compounds has not increased dramatically.

The above discussion leads logically to the consideration of substitutes and complements and their prices. The possibility of the substitution of one mineral for another is an important continuing issue in the discussion of mineral demand. Tilton (1993, p. 369) notes that material substitution can take several forms, and that it can result 'from the introduction of new technology, from shifts in the composition or quality of final goods, and from changes in the mix of factor inputs used in producing these goods.' Price plays a role in influencing this process, though again its importance is affected by the extent to which a mineral's price contributes to the overall cost of the intermediate or final good, in which it is an input.

In the same way as with the demand for final goods, a rise (fall) in the price of a substitute mineral will increase (decrease) the demand for the mineral in question. In the case of some of key applications, the following substitute minerals for lithium metal and its compounds seem relevant

Use	Substitute minerals
Glass manufacture	Sodium and potassium
Primary aluminium production	Sodium and potassium salts
Lubricants	Calcium and aluminium soaps
Battery production	Zinc, magnesium, nickel–cadmium, sodium and mercury

Technological change can have dramatic effects on the demand for particular minerals. The impact can be in either a positive or negative direction. Hence, the arrival of the automobile dramatically increased the demand for steel and iron ore after World War I and since. In a dramatically opposite fashion, the introduction of synthetic nitrates decimated the demand for natural nitrate products from the northern parts of Chile after World War I.

In the case of lithium, changed design in modern aluminium smelters has reduced the need to add lithium carbonate to aluminium pot lines to lower the melting point of the cryolite bath. By contrast, there has been considerable expectation that batteries containing lithium may become widespread in a rapidly growing electric motor vehicle industry. Already there is major use of lithium ion and lithium polymer batteries in applications such as mobile telephones, cameras, laptop and desktop computers. Recent growth in this later area has been strong. Lithium metal polymer primary batteries are also a promising application as an energy backup in telecommunications systems for cities. However, it now seems a distinct possibility that hybrid vehicles using fuel cell technology will become more popular among consumers in the medium term. Sales of electric vehicles have been disappointing.

Changing consumer preferences have also affected mineral demand. This has been important for metals such as lead and asbestos. It does not seem to have been of major significance in the case of lithium.

Government activities, such as a decision to go to war, can have a sudden and rather dramatic effect on the demand for some minerals. The US defence industry has experimented with lithium alloys in aerospace applications, but the penetration of this use has not dramatically increased lithium consumption. If there are policy developments in governments promoting electric vehicles, and lithium batteries are adopted widely in them, some potential exists for growing lithium demand arising from this area. The probability of this in the near future seems low.

Recent lithium production and factors affecting supply

In the past, several companies have mined lithium ores, which they have then refined into lithium metal, lithium

[4] See Howie (2003) for long-term estimates of prices of twelve common minerals.

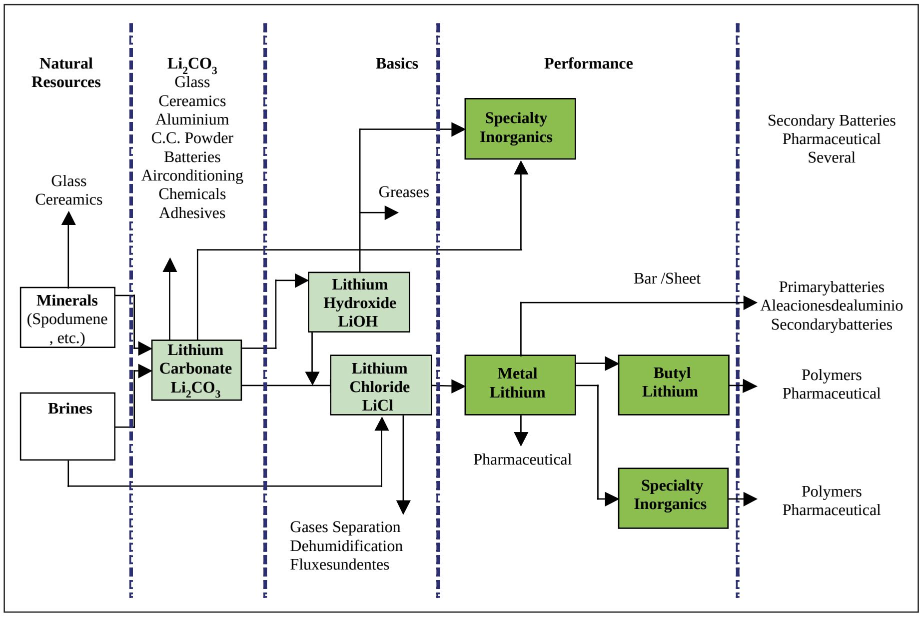

Fig. 3. The processing of lithium.

Table 1
Indicative value of different lithium applications in 2002

Application	Main compound	Volume (%)	Amount (000 tonnes)	Estimated price ($US per kg)	Estimated value ($ US mill)
Glass/ceramics—melting points	Li	8	5.8	2	11
Glass/ceramics—glazing	Li_2CO_3	13	9.4	2	18
Aluminium	Li_2CO_3	6	4.3	2	8
Lubricants	LiOH	17	12.2	4	48
Batteries	Li_2CO_3	12	8.6	12	101
Polymers	Li_2CO_3	5	3.6	4	14
Pharmaceuticals	Butylithium	5	3.6	15	53
Air conditioning	LiBr	11	7.9	6	46
Synthetic rubber	Butylithium	5	3.6	15	53
Other	Li_2CO_3	18	13.0	3	38
Total		100	72		390

Derived from Kingsnorth (2001) and Jimenez (2003).

carbonate with different purity grades, and associated compounds for downstream uses. The processing of lithium ores such as spodumene is energy intensive, its transport costs are high and because it occurs in relatively small deposits, it is difficult to take advantages of economies of scale in production. This adds considerably to its cost. By contrast, lithium carbonate, produced from lithium chloride obtained from brines, has recently become much cheaper to process.[5] This change in the operation of the industry is outlined simply in Fig. 3. Applications of lithium carbonate are now more widespread and discussion of lithium production and consumption now focuses more often on lithium carbonate than on lithium metal. Whereas producers of lithium chemicals from brine held only about one third of market share in 1995, this had reached three-quarters by 2003.

Table 2
Estimated lithium production and sales 2003

Segment	Volume		Sales	
	kt LCE	Percent	$US million	Percent
Minerals	16000	20	25	5
Lithium carbonate	31500	40	61	12
Basic chemicals	14700	18	45	9
Performance chemicals	17400	22	383	74
Total	79600	100	514	100

Source: Jimenez (2004).

[5] The Foote Mineral Company and the Chilean government agency, CORFO collaborated between 1974 and 1980 to adapt Foote's processes to the specific conditions of the Salar de Atacama. In 1980 both organizations formed a commercial company to exploit part of the lithium reserves of Salar de Atacama (Sociedad Chilena de Litio Ltda., SCL). SQM has subsequently adapted and improved this process.

Table 3
Estimated value of early-stage and later-stage production and sales of compounds of the lithium carbonate sector in 2002

Producer	Amount (tonnes)	Percent	Value early stages ($US million)	Price per kilo ($)	Value All stages ($US million)
SQM (Chile)	21500	39.5	37	1.73	37
Chemetall (Chile)	10300	18.9	18	1.73	20
Chemetall (USA)	8700	16.0	15	1.73	130
FMC corporation	900	1.7	2	1.73	150
Xianjiang NFM Corp (China)	13000	23.9	22	1.73	23
Total	54400	100	94		360

Sources: Various annual reports FMC Corporation, 2003.

Consideration of the 'early stages' of the production of lithium minerals and lithium metal is a major focus of this paper. Yet, several players see the key part of the industry in the production of downstream compounds, and their sale to the manufacturers of final products. Following the indicative estimates in Table 1, if one takes the broader view, the industry produced approximately 72,000 tonnes of lithium carbonate equivalent in 2002 with a value of approximately $US 400 million.[6] Jimenez (2004) has estimated that this reached almost 80,000 tonnes in 2003 and that its total value exceeded $US 500 million-see Table 2. Though these data are more broadly based, they reflect the importance of downstream value adding in a clear way. Given this background we now consider the lithium carbonate and lithium metal producers in turn.

The lithium carbonate producers

In 2002, there were three producers of lithium chloride or carbonate from brines. They were SQM (in Chile), Chemetall (in Chile and the United States) and the FMC Corporation (in Argentina). The China Xinjuang Nonferrous Metals Corporation of Mingyuan (in China) produced lithium carbonate from domestic and imported ores. As already noted, SQM and Chemetall have played dominant roles since the late 1990 s. Perusal of Ober (2003) and SQM (various years) suggest that the estimates in Table 3 closely reflected the level of lithium carbonate consumption in 2002. Together, Chemetall and SQM were responsible for around 75% of the market. The market share of SQM has been rising and may have been as high as 45% by 2003. In its 2002 Annual Report, SQM reported sales of lithium and lithium derivatives of $US 37.3 million. This had risen to $US 49.6 million in 2003.

Chemetall and the FMC Corporation have recently been the most active producers beyond the 'early stage' levels. The US-based FMC Corporation now produces only limited amounts of lithium carbonate. It has obtained its major supplies since 1997 in purchase agreements from SQM's Chilean operations, even though it maintains production facilities at the Salar de Hombre Muerto in Argentina, largely on a care and maintenance basis.

[6] These estimates are derived from Jimenez (2003). Other authors, such as Mora (2002) have estimated that lithium consumption had reached 72,000 tonnes per annum of LCE by 2001.

Lithium minerals

While there has been growth and dynamic change in the lithium carbonate sector, demand for lithium metal has been subdued. Three companies—Sons of Gwalia in Australia, the Tantalum Mining Corporation of Canada and Bikita Minerals in Zimbabwe—continued as the main lithium ore producers after the mid-1990 s. Four other companies (Zabaikalsky GOK in Russia, and Arquena de Minerios e Metais Ltda., Companhia Brasileira de Litio-CBL and Socieda Mineira de Pegmatitas (each in Brazil)) played minor production roles.

The pegamatitic minerals that have been used as sources for lithium are spodumene, lepidolite, petalite, amblygonite and eucriptite. Spodumene and petalite concentrates are used directly as sources of lithium oxide (Li_2O) in glass and ceramics highly resistant to thermal expansion. As can be seen from Fig. 1 above, this segment accounted for as estimated 21% of lithium applications in 2004.

Lithium minerals remain competitive in some applications in glass and ceramics, because of the presence of aluminum silicates, specifically in normal glasses and ceramics. In neo-ceramics and performance glasses, lithium carbonate is more competitive because its higher lithium content. A summary of some relevant technical characteristics appears in Table 4.

There has been a significant supply overhang situation in the lithium minerals market. This seems confirmed from the data in Table 5 (derived in part from Mining Journal (2002)). These data refer to 2001.[7] In 2001, Sons of Gwalia alone, had the capacity at its Western Australian mine to meet this demand. Yet, it struggled to sell all of its production. The company processed its spodumene ore to a concentrate of lithium dioxide (at around 5.5%) and sold this mainly in China, but also to some extent in Europe. Chinese customers have blended Australian material with their own lower grade spodumene concentrate to produce lithium carbonate and then lithium metal, which they have used to reduce melting points in glass and ceramics production.

The size of the lithium minerals market is now quite small. According to the Western Australian Department of Minerals and Energy (2001, p. 44) the value of lithium production by Sons of Gwalia in 2001 was only $A16.5 million (around $US

[7] Because of confidentiality provisions in data reporting, we have been unable to derive estimates for subsequent years.

Table 4
Technical characteristics of lithium oxide sources

Source	Formula	Li_2O (%)	Melting point (°C)
Spodumene concentrate	$Li_2O \cdot Al_2O_3 \cdot 4SiO_2$	7.5/4.8	Up to 1450
Petalite concentrate	$Li_2O \cdot Al_2O_3 \cdot 8SiO_2$	4.5	Up to 1400
Lithium carbonate	Li_2CO_2	40.4	Up to 750

Source: Evans, (1988).

9 million). It appears that the size of the lithium minerals sector is likely to be about $US 25 million annually in its 'first-stage' production. Yet, companies producing lithium ore have continued their operations and if prices increase, their viability may be enhanced.

Factors affecting supply

A standard analysis of metal supply, following Tilton (1992), suggests that demand for a co-product such as lithium, will be influenced by its own price, the price of co-products, input costs, technological change, strikes and other disruptions, government activities and market structure.

A rise in the own price of a mineral will stimulate supply, while a fall will typically reduce it. As noted in the Introduction, with the entry of SQM to the industry in 1997 there was a decline in price of approximately 50%. Lithium carbonate producers in the United States and Argentina soon ceased operations and lithium metal producers also struggled.

Because of its specialist nature, and the few producers involved, the market for lithium is relatively 'opaque'. Ober (2002, p. 46.3) notes that

> Since lithium pricing became very competitive when SQM entered the market in 1998, it has become difficult to obtain reliable price information from the companies or trade publications

Producers usually negotiate directly with consumers and neither party publicly reports prices received or paid. Despite this difficulty, Ober provides some 'educated' estimates about the way in which lithium carbonate prices have been moving, utilising US Customs data—see Table 6. These data probably reflect long-term contract prices such as those possibly negotiated between SQM and the FMC Corporation.

SQM obtains lithium chloride as a co-product with potassium chloride, which is used in the production of muriate of potash, an agricultural fertiliser. The fertiliser industry have recently been characterised by heavy competition, supply overhang and reasonably static prices and revenues.[8] It seems unlikely that movements in the price of potassium chloride will adversely affect lithium supply in the foreseeable future.

Table 5
Production capacity and sales of lithium minerals 2001

Company	Capacity (tonnes)	Sales (tonnes)	% Content of Li_2O	Lithium Carbonate equivalent (tonnes)
Sons of Gwalia	150000	80000	4.0	9500
Tanco	21000	15000	2.6	2075
Bikita minerals	55000	41000	1.4	3054
Sub-total	226000	116000		14629
Brazil	6000	6000	Na	
Others	25000	20000	Na	
Total	257000	162000		na

Source: Mining Journal (2002).

It is possible to consider the issue of movements in input costs from a number of perspectives. The first is to consider the cost of key inputs such as labour and energy in domestic prices. These have not undermined the competitiveness of lithium chloride (or potassium chloride) from brines. Energy costs are considerably more important in producing lithium minerals from materials such as spodumene, petalite and lepidolite.

Relative exchange rates can take on an important dimension, bring sudden competitiveness if exchange rates fall, or lost competitiveness if they are rising. The movements in each of these areas have significantly affected recent supply. The *status quo* seems likely to remain, even though the dramatic fall in the exchange rate of the Argentinian peso in 2003 must have improved the competitiveness of FMC's Argentinian operations.

The rise of lithium carbonate production from the brines of the Salar de Atacama has been possible because the process technology of removing lithium chloride is very competitive, given its high concentration levels. These stand at an average of 0.15%. This is considerably higher than average levels in other salt lake deposits such as the Salar de Hombre Muerto (0.061%) and Silver Peak in Nevada in the United States (0.016%). The application of this technology enabled SQM to make profits, even when prices fell after they began production.

Strikes and other disruptions have not been common in any of the lithium producing areas in the recent past. Also, in nations such as Chile, the passage of statutes such as Decree

Table 6
Estimated lithium carbonate prices 1996–2004

Year	Price per kilogram ($US)
1996	2.70
1998	1.39
2000	1.45
2001	1.48
2002	1.59
2003	1.70[a]
2004	1.87[b]

Source: Ober (2002, 2003), SQM (2002, 2003).

[a] The authors of SQM (2003) report that sales prices for lithium carbonate increased slightly in 2003. Based on Ober (2003) we have assumed a similar percentage increase to that which took place in 2002.

[b] This estimate is based on SQM's Press Release issued on 13th November, 2003.

[8] The authors of the SQM Annual Report 2003 (p. 38) report that potassium chloride sales rose from $US38.2 million to $US40 million between 2002 and 2003 with static production levels.

Law 600 in 1974, and Decree Law 1748 some ten years later, have created a favourable mineral policy environment to ensure the orderly and competitive development of the lithium industry.

An important factor that influences supply is market structure. Competitive markets drive down prices and lead to greater consumption of commodities. As a relatively small mineral sector, in which economies of scale are important, the lithium industry has not had a highly competitive structure with producers who are price takers. Critics of its current structure might highlight the existence of market power and the danger of collusive behaviour. This would bring rising prices, or constrained production levels, or both. In highlighting some of the elements of the structure–conduct–performance framework the discussion in Section 4 considers some of the important issues currently affecting the industry.

Some further analysis

The lithium industry—its size, concentration and importance to the fortunes of major producing companies

In terms of the minerals and energy sector, lithium is a minor metal. The estimated sales of lithium and its compounds in 2003 were $US 514 million from 11 locations—four areas producing lithium carbonate and seven lithium minerals. By contrast, in the world copper and gold industries sales exceeded $US20 billion.[9]

Even in Chile, the size of the lithium sector is relatively small. Though the Salar de Atacama deposits now account for around 60% of world lithium output, this directly generated less than $US 60 million in sales in 2003, at best only about 1.5% of the country's copper revenues. The lithium sector is located in the nation's second region, which accounts for 20% of world copper output, attributable in large part to the production of major mines such as Escondida and Chuquicamata. Hence, even at regional level, the industry is relatively small.

As is apparent from the preceding discussion, the industry is highly concentrated, with four producers responsible for around 90% of world production. Two of the producing companies—Chemetall and the FMC Corporation—are large specialist chemical processing corporations. SQM produces specialist fertilisers, associated industrial chemical, iodine and its derivatives and lithium chemicals. Sons of Gwalia[10] has been mainly a gold and tantalum producer, with lithium minerals at best a co-product but probably now a by-product from its tantalum, tin and lithium operations in Greenbushes in Western Australia.

The production of lithium chemicals contributed only 7% of company revenues to SQM in 2003, though its contribution to profits may have been considerably higher than this. The relative contributions of lithium processing (largely of downstream compounds) to the revenues of the FMC Corporation in 2003 was at coincidentally similar levels—around 8% ($US150 million) of the company's reported revenues of $US 1921.4 million. Chemetall's revenues from lithium compounds were at similar levels to those of FMC. In the case of Sons of Gwalia, the recent contribution of lithium to its revenue and profitability has been minimal. From perusal of data from the company's 2003 Annual Report, we estimated revenues of $A22 million from lithium mineral sales. This was around 4% of the company's annual revenue. Tantalum contributed 34% of revenue and gold 62%.

Operational strategies and vertical integration of the lithium carbonate producers

The decline of the lithium minerals sector has been directly associated with the expansion of lithium carbonate production. While both sides of the industry presently possess long-term supply capacity, and their fortunes depend on the way demand for lithium and its compounds grow, the lithium carbonate producers now seem close to dominating the industry. For this reason, we pay most attention to this group.

A key part of the Chemetall competitive approach has been to ensure security of lithium carbonate supply for its wide array of downstream lithium compounds, which it markets to manufacturing and other firms throughout the world. The company's lithium business has grown significantly since the mid-1990 s, with both internal and external policies driving this growth. A major external thrust involved the purchase of the US-based Cyprus Foote Mineral Company in 1998, gaining access to its brine operations in the Salar de Atacama that had been operating since 1984, as well a the Silver Peak operations in Nevada. Chemetall has generated internal growth relevant to the European and Asian market, by establishing the Taiwan Chemetall company in 1996 and building a butyl-lithium manufacturing plant there.

In a somewhat contrasting fashion, SQM quickly obtained major market share through strong internal growth. As noted in Table 6, lithium carbonate prices stood at around $US 2.70 per kg in 1996. In 1998, after SQM entered the industry, prices fell dramatically. By following a low pricing strategy, supported by a strong investment policy, SQM forced higher cost producers out of the industry. As a result, SQM supplied lithium carbonate to clients in nearly 40 nations in 2001 (SQM, 2001, p. 18) and in 50 nations by 2003. (SQM, 2003, p. 27).

Even with low recent prices, SQM's lithium carbonate production is apparently enhancing the profitablity of the company. This is because its total cost of production is considerably less than the estimated lithium carbonate prices in Table 6. In its 2002 annual report, SQM (2003, p. 24) reported that revenues from lithium carbonate sales in 2002 were $US 37.3 million of the company's total sales of $US 553.8 million. It is conceivable that as much as half of this could have been profit. This amount had risen to $49.6 million out of $691.8 million sales in 2003.

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[9] There were more than one hundred copper mines and several hundred large and medium size gold mines. The small-scale mining sector also has importance in gold production.

[10] After this paper was submitted, Sons of Gwalia was placed in administration because of difficulties arising from its gold hedging program.

While there are substitutes for lithium in many of its applications, there is considerable actual and potential market power in the industry. Chemetall's vertical integration strategy seems designed to derive many of its recognised benefits.[11] In their well-known textbook exposition on industrial organisation, Carlton and Perloff (2000 p. 378–394) consider six potential benefits to a firm of a vertical integration strategy.

These include:

(1) Lowering transaction costs of buying from or selling to other companies;
(2) Assuring a steady supply of a key input (at a reasonable price);
(3) Correcting market failures due to externalities by internalising them;
(4) Avoiding government restrictions, regulations or taxes;
(5) Better exploiting or creating market power; and in a related vein
(6) Eliminating the market power of other firms in an industry.

The second benefit seems clearly to apply to Chemetall's lithium business and the first, fourth and fifth benefits may also be relevant.

However, vertical integration also has potential costs. It may be more expensive for a vertically integrated firm, than a firm in a more competitive market, to supply its own factors of production and distribute its product. Management costs may be higher in a large firm than in a competitive market. In addition, merger costs may also be high in moving into a vertically integrated framework of operation.

Despite this, SQM also seems interested to pursue vertical integration strategies more forcefully. An appealing reason to do so relates to the higher potential for adding value and increasing profits with downstream processing and product differentiation strategies. It has, for example, developed its own process for butyl-lithium production that it is now operating from a new plant in Bayport, Texas. It also acquired a significant inventory of lithium hydroxide in the United States, potentially to produce other lithium products. It has recently announced plans for a new lithium hydroxide plant in Antofagasta, planned to begin operations in 2005.

Though it does not currently undertake significant first stage production of lithium carbonate, the FMC Corporation appears also to have a *de facto* vertical integration strategy. This occurs through its ownership of the Salar del Hombre Muerto, purchased in 1995. Should its purchase price of lithium carbonate rise dramatically, FMC Lithium could produce more 'first-stage' lithium feedstock from its Argentinian operations. While its costs of production are unlikely to be as competitive as those of the Chilean-based producers, they would assure a steady supply of a key input at a reasonable price.

Pricing policies

The high level of concentration of producers, and the recent continuing rises of lithium carbonate prices since 2001 seems to imply the exertion of market power, significant barriers to entry and associated strategic behaviour to ensure long-term profits.

One interpretation of the estimated prices in Table 6 above is that SQM has followed some elements of a predatory pricing strategy, forcing other producers from the industry. Yet, recent prices remain below those of the middle 1990 s and current Chilean producers are making significant profits. Even when prices stood around $US 1.40 per kg SQM and Chemetall were apparently generating surpluses from their lithium carbonate production. Most predatory pricing behaviour involves production at less than cost for some period. This does not seem to have happened.

Recent pricing behaviour may be consistent with a strategy of limit pricing to discourage entry to the industry. Potential producers are unlikely to feel that there is enough market share available to them at current contract prices. This perception may change, however, if lithium is a co-product or by-product with other minerals for which there are more open markets, or if exchange rates move strongly in favour of nations, in which there are previously marginal deposits.[12]

The future of lithium

Commentators have identified two uses, secondary batteries and nuclear fusion, which may have a major impact on the future consumption of lithium. It seems unlikely that there will be any major advance in the second area in the next 30 years.[13] A major potential market for secondary batteries is in electric cars, which have developed slowly. Their emergence has been constrained because the production cost of secondary batteries, in comparison with conventional batteries, has been high. Sympathetic government policies also have not promoted their adoption.

Against this background, any prediction about the future use of lithium is subject to considerable uncertainty. After discussion with industry analysts, our approach has been to offer three scenarios over the next decade—high *growth*, *likely*, and *low growth*. These place upper and lower boundaries on the use of lithium and its compounds. Furthermore, our emphasis is on trends in use, as well as recognising the Chilean government's effort to achieve sustainable development in the lithium mining industry, through wealth creation via the generation of economic rent and profit.

Derived from the work of Mora (2003), our estimates assume that primary lithium consumption in 2001 was 72,000 tonnes of lithium carbonate equivalent (LCE) or 13,500 tonnes of lithium metal equivalent. Our approach has also been to use

[11] Vertical integration describes a situation in which 'a firm participates in more than one successive stage of the production or distribution of goods and services.'

[12] For example, at the time of revisions to this paper, the company Admiralty Resources, was proposing the extraction of lithium from the Rincon Salar in Northern Argentina.

[13] However, the Inter project reincorporation could change this estimations.

Mora's percentage estimates of applications of lithium in that year. While these differ to some extent from those shown in Table 1, they appear more in line with longer-term consumption patterns.[14]

Estimates of future use

Glass and ceramics

Glass and ceramic manufacturers use a well-proven technology that involves the addition of lithium oxide, typically produced from lithium ores, to reduce fusion temperatures, permit control of contaminant emissions, and produce a better quality product. This application is now in its full maturity phase. In 2003, glass and ceramic applications used just over 4000 tonnes of lithium metal equivalent (or 21,600 tonnes of LCE). While still positive, future consumption growth seems likely to be relatively small. The likely growth scenario seems to be a 2% rate of average annual increase until 2010, followed by a 1% annual growth rate in the following decade. A high growth scenario is a 3% average annual growth rate during the period, while a low growth view might perceive no growth at all.

Aluminium

The application of lithium to aluminium production is also in a mature phase. The classical process, which aluminium producers have used use is the electrolysis of alumina (AL_2O_3), melted in a bath with aluminium fluoride, calcium fluoride and cryolite. They add lithium carbonate (3.5% by weight) to this bath. Primary aluminium production continues to rise at a steady rate.[15] Yet, new production technologies do not incorporate lithium. For this reason, our view is that the consumption of lithium in this application will increase marginally in the likely scenario but is destined for significant long-term decline.

Lubricants

As can be seen in Table 7, our estimates of lithium applications for lubricants in 2003 were 12,000 tonnes on lithium carbonate equivalent (or more than 2250 tonnes of lithium metal equivalent). This represented 16% of world consumption. The likely growth for this type of application is determined by the growth in areas such as cement, mining and railways. While recent growth in this area has approached 5% per year, our view is that the likely scenario until 2010 is a 3.5% average annual rate of growth. A low growth scenario is for 2% average annual growth, while a high growth scenario is for 5%.

Secondary batteries

For the past decade, there has been a strongly increasing demand for lithium for use in lithium-ion, and now lithium-polymer rechargeable batteries. By the end of 2003, lithium ion batteries had replaced nickel metal hydride batteries as the most common battery in mobile phone and laptop computers. Their position will be challenged in the next few years by lithium polymer batteries. While demand for lithium rechargeable batteries grew at 15% per annum during the 1990 s, the rate of increase is the foreseeable future seems likely to be less than this.

A key area in which demand has been more subdued is in the electric vehicle and hybrid electric vehicle markets. Their development has been driven by legislation mandating or encouraging future use of such vehicles in several European nations and states of the US. Most of the major car producers have been active recently in the development of production models. Examples include the Toyota Prius and the Honda Insight. These make significant use of rechargeable batteries.

While demand for these vehicles continues to grow, their rate of market penetration is currently much slower than predicted by authors such as Meade (1994). Major motor vehicle producers have so far been unable to market electric and hybrid electric vehicles that are price competitive with those with internal combustion engines. Even the subdued predictions of Baumgartner and Gross (2000) that electric vehicles would account for 1.5% of new vehicles production and 0.5% of all motor vehicles by 2007 now seem optimistic.

This is in part because there have also been major improvements in the fuel efficiency and clean running qualities of internal combustion engine vehicles. Authors such as Lave and MacLean (2002) and Carlsson and Johannson-Stenman (2003) have recently argued that electric vehicles will remain 'socially unprofitable' at least until 2010. Furthermore, lithium batteries have not yet made any significant market penetration in this field. While Delucci and Lipman (2001, p. 386) seem more optimistic about the future of electric vehicles, there is considerable uncertainty in this area. Nickel metal hydride batteries continue as the preferred battery, though their critics point to their weight, costs and relatively short service lives as problem areas.

In these circumstances, Ohr (2002) suggests that lithium consumption in secondary battery production might grow at 4% per annum in the foreseeable future. Yet, recent growth has dramatically exceeded this. Our view is that the likely scenario for the use of lithium for secondary battery production will increase at 12% per annum until 2010. In the low growth and high growth scenarios, we assume 10% annual growth and 15% growth, respectively.

Primary batteries

Average annual growth in the alkaline battery consumption has recently averaged between 5 and 6%. This has come from growth in use of cameras, games, hearing aids, as well as from new products such as portable compact disc players. These are

[14] There were particularly low percentage figures for lithium applications in aluminium production in 2002. These appear to have recovered in 2003. Mora's taxonomy also allocates a much lower percentage to the residual 'other uses' category. It seems also that the percentage of use of lithium in the aluminium industry in 2002 was excessively low in 2002.

[15] Between 1990 and 2002 primary aluminium production rose at an estimated average annual rate of 2.7 % per annum.

Table 7
Predicted world lithium consumption in 2010

Application	Use in 2003			Projected Scenarios-2010		
	%	LCE	Li metal	Low growth	Likely	High growth
Batteries	19	14.252	2.679	27.774	31.507	37.911
Lubricants	16	12.002	2.256	13.786	15.167	16.888
Frits	12	9.001	1.692	11.845	12.666	13.535
Glass	9	6.751	1.269	8.884	9.499	10.151
Air conditioning	8	6.001	1.128	7.380	8.166	9.023
Aluminium	6	4.501	846	3.637	5.170	5.697
Pharmaceuticals	5	3.751	705	4.936	5.640	6.309
Polymers	4	3.000	564	3.217	3.690	4.262
Other uses	21	15.753	2.961	18.095	19.374	21.128
Total	100	75.012	14.100	99.553	110.879	124.904

emerging markets and they seem likely to grow significantly until 2010, before moving into a more mature phase.

A likely scenario is that lithium consumption will grow by an average of 8% per annum for the next five years. In the low growth scenario, annual growth rates of 6% per annum are suggested. Our high growth scenario is for growth rates of 10% per annum until 2010.

Air conditioning

The technology is well established and consists in air-drying, and placing air in direct contact with lithium bromide or lithium chloride solutions. Lithium consumption for this use in 2003 was approximately 6000 tonnes of lithium carbonate equivalent. In Europe, North America, Oceania and much of Asia this is a mature application. On the other hand, in China, Latin America and Africa further strong growth of air conditioning is likely. Our view is that in the most likely case, annual average growth will be around 4.5% per annum until 2010. In a low growth scenario, we assume a 3% rate of growth, while in a high growth scenario we assume 6% average annual growth.

The pharmaceutical industry

The increase in lithium consumption is likely to be modest in this sector, with some decline in its use to treat maníc depressive disorders, but increasing as a catalyst in some new drugs for fat treatment, AIDS and cancer. In predicting future consumption in a low growth scenario, we have assumed 4% average annual growth in the pharmaceutical industry and other applications. In the most likely scenario, we have assumed 6% average annual growth in the pharmaceutical industry and other applications. In a high growth scenario, we assume 8% average annual growth.

Polymers

This category, which includes using lithium in synthetic rubber production, accounted for 4% of lithium consumption in 2003. Our predictions are annual growth rates of 1; 3 and 5%, respectively, in the low growth, likely and high growth scenarios until 2010.

Other uses

In 2003, this set of applications accounted for approximately 21% of lithium use. The applications in this category include a base for other chemical products, carbon dioxide absorption, and in disinfecting water. More stringent environmental regulation seems likely to promote significant consumption growth in the latter two applications.

In predicting future consumption in a low growth scenario we have assumed 2% average annual growth. In the most likely scenario we have assumed 3% average annual growth. In a high growth scenario we assume 4% average annual growth.

A summary of these predictions for lithium consumption by the year 2010 appears in Table 7.

Our estimates of total consumption growth range between 4.2% per annum in the low growth scenario, to 6.2% per annum in a likely scenario. Our high growth scenario suggests increased consumption at 8.2% per annum. The British Geological Survey's estimated average annual rates of growth over the past two decades (3.3%) are considerably less than our likely growth scenarios.

While the preceding discussion has taken account of likely declines in lithium consumption because, for example, of the substitution of alternative technologies in aluminium production, it does not incorporate unexpected consumption growth (or for that matter decline) because of the rapid emergence of new applications. A complementary way of viewing future demand growth potential is in terms of the entries in Fig. 4.

The 'mature applications' of lithium and its compounds reside in the bottom left-hand quadrant of this figure. As already discussed, this group includes applications in glass and ceramic production, lubricants, aluminium, air conditioning and synthetic rubber production. These generate about 75% of current cash flow in the industry but have low potential market growth. They provide the cash flows necessary for new

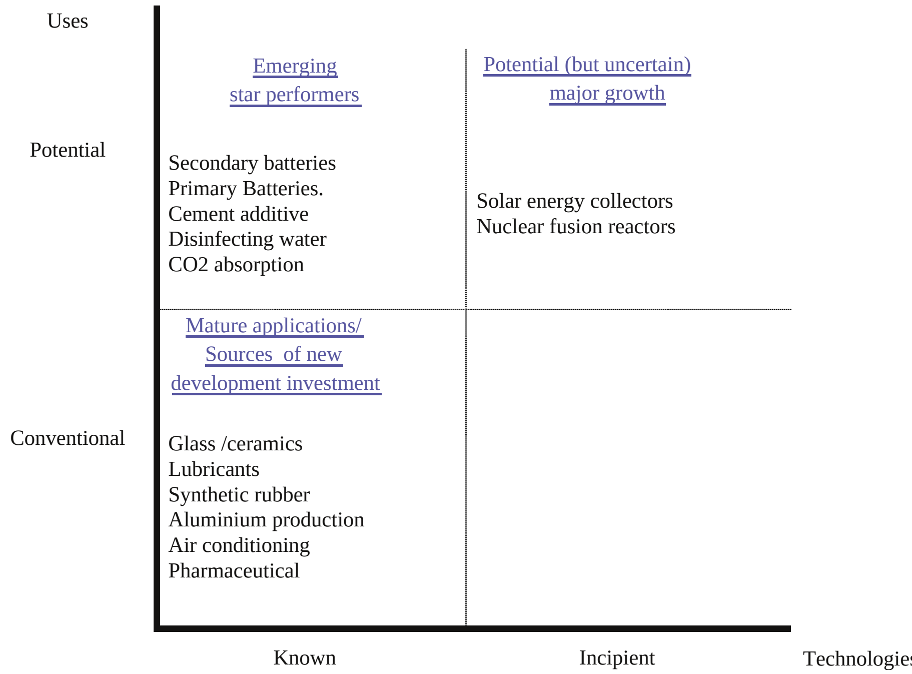

Fig. 4. Conventional and potential uses of lithium and the promise of emerging technological developments.

research and development efforts to bring diversification and growth into other markets.

We have placed the water disinfection and carbon dioxide absorption applications in the upper left quadrant-labelled 'emerging star performers'—even though they do not strictly coincide with a strategic marketing definition of sectors that will generate high market growth and greater market participation. Our view is, however, that environmentally focused public policy in the next two decades is likely to affect this situation in a positive fashion.

In the top right-hand quadrant marked 'potential (but uncertain) major growth,' we identify promising markets with incipient technologies that have yet to prove themselves fully. Potential applications in this area are solar collectors of energy and the nuclear fusion process. These seem long-term, rather than short- or medium-term possible uses.

Supply and public policy issues

Estimating mineral reserves is a difficult task, and changing technology affects any such exercise. Perhaps the most comprehensive continuing recent efforts to estimate reserves have been those by Phillip Crowson in his *Minerals Handbook* series. With respect to lithium, Crowson (2001) derives an incomplete estimate of world reserves of lithium of 3.4 million tonnes (around 18 million tonnes of lithium carbonate equivalent). He goes on to suggest that the total figure is more than 9 million tonnes of lithium metal (more than 46 million tonnes of LCE). The lower level of these estimates implies 250 years of supply at current usage rates. Chile possesses the overwhelming share of readily accessible high-quality current lithium reserves in the Salar de Atacama.

The Chilean government, and the broader Chilean community, therefore have a close interest in the fortunes of the industry and its contribution to the national economy. At one level, their focus is on the Chilean-based lithium carbonate industry retaining its recently established world leadership. Given the strong reserve position and a strong mining culture, their expectation would be that most if not all of the predicted increase in lithium demand should be supplied from Chile. As can be seen from Table 7, this amounts to new production increments that we expect will increase annual lithium carbonate consumption by between around 24,000 and 50, 000 tonnes between 2003 and 2010.

In line with current thinking about mineral policy in major mining nations, it seems reasonable to argue that the Chilean government should emphasise sustainable development issues in its public policy stance concerning the development of the lithium industry. This combines elements of economic, physical, and social and cultural dimensions.

In seeking to ensure economic sustainability as a result of mineral exploitation, governments typically aim to obtain a fair share of the resource rents emanating from mining projects. They seek to utilise these rents by investing in other areas that will ensure a sustainable stream of economic activity following the exhaustion of mineral deposits. The normal ways to access such rents is through company taxation and royalty payments. Governments may trade off these payments if mining companies invest in downstream value adding activities within the region or the nation.

In a globally competitive environment, national governments often compete strongly with one another to attract foreign capital to develop new mining projects. The Chilean foreign investment regime has been very successful over the past two decades in attracting major resource sector investment. In combination with a series of other favourable factors[16] this has led to Chile's re-emergence as the largest copper producer and a significant gold producer. As in many developing nations, however, there is a continuing concern that these policies may have provided opportunities for mining companies to reap excessive profits. Where evidence of this emerges, government may change its mineral policy stance. The move by the Chilean government to revise its royalty regime in 2003 and 2004 has led to typical claims of increased sovereign risk. In extreme cases it may also result in investment in regions perceived to be more profitable.

In the case of lithium, Chemetall and SQM have operated in what appears to be a favourable income tax environment but with rather different royalty frameworks. These have arisen in association with the particular circumstances surrounding the development of each project.

Even today, according to the Chilean legislation, it is not possible to grant mining licenses for lithium. Chilean legislation regards lithium as a material of 'national interest'. The Decree Law N° 2886 of 1979 establishes that only the Chilean State, through its companies or via special operational agreements, with specific conditions established on a case-by-case basis by the President of the Republic, can mine, process and trade lithium compounds. The same legislation has affected the of granting mining licenses on some compounds used in the manufacturing of fertilizers; in particular nitrates, iodine, phosphates, potassium salts and calcium carbonate.

The only exception to this approach is for mining licenses granted before the passage of Decree Law 2886.

The State of Chile, through its Development Agency CORFO,[17] conducted a program in the 1970s to measure the technical feasibility and the economic potential of the mineral resources in the Salar de Atacama (potassium, lithium, magnesium, boron, sulphates). As a result of those activities, CORFO identified two independent projects. These were the *Lithium Project*, and the *Potassium Salts and Boric Acid Project*.

CORFO and the Foote Mineral Company formed Sociedad Chilena de Litio (SCL) in 1980 to develop the Lithium Project. Between 1988 and 1989, CORFO sold its 45% share of SCL to Foote Mineral Company for US$ 15.2 million. While CORFO did not retain any rights over lithium sales or production it kept a 2% royalty on discarded salts (potassium and magnesium) from the lithium extraction process. From the seventh year of the agreement, this royalty will increase to 3%. The State of Chile also granted to SCL an exclusion period for lithium extraction from Salar de Atacama from 1980 to 1988.[18]

In 1983, through an international tender, CORFO commissioned studies and other rights related to the *Potassium Salts and Boric Acid Project* to a consortium headed by Amax Co. and Molymet S.A. In 1986, a second company was created. This was Sociedad Minera Salar de Atacama Ltda. (MINSAL). Its shareholding was CORFO (25%), Amax (63.75%) and Molymet (11.25%).

The purpose of this company was to develop a project to produce potassium, lithium and boron salts from the Salar de Atacama brines. In 1986, MINSAL began the development of a feasibility study, which was completed in 1989. It included a positive recommendation for building an industrial complex for the production of potassium chlorate, potassium sulphate, boric acid, lithium carbonate and lithium hydroxide, with an estimated investment of US$ 380 million. In September 1991, AMAX recommended an incremental approach for the development of the MINSAL project in Salar de Atacama, beginning with the production of potassium chloride. In September 1992 AMAX sold his 63.75% share of MINSAL to SQM. CORFO established new conditions in order to agree to this change. In 1993, MINSAL increased its capital, meaning that CORFO participation was reduced to 18.18%. Also in the same year Molymet yielded its rights on MINSAL to SQM. In 1995, CORFO decided to sell its participation in MINSAL in the Santiago Stock Exchange. Those shares were bought by SQM in about US$7 million.

In 1993, CORFO agreed with MINSAL a royalty payment of 5% of the F.A.S. value on lithium production sales, plus 0.5% of the value in plant of lithium production sales. The last value increased to 1.8% from 2001. SQM has operated under this royalty regime since it began lithium carbonate production in 1997.

Reflecting the institutional evolution of the country and the particular history of the Salar de Atacama projects, Sociedad Chilena de Litio (SCL) and SQM have confronted different royalty environments over time. The recent changes to mining taxation introduced by the state of Chile will maintain this difference.

[16] For a discussion of these factors see papers such as Lagos (1997) and Maxwell (2004)

[17] Corporación de Fomento de la Producción.

[18] In 1988 Cyprus Minerals Co. completed its purchase of Foote Minerals Co. The company was renamed Cyprus Foote Mineral Co. In 1993 AMAX merged with Cyprus Minerals Co. to form Cyprus Amax Minerals Company. In 1999 Phelps Dodge acquired Cyprus Amax. In 1998 Chemetall GmbH, a subsidiary of Metallgesellschaft A.G. (MG) purchased Cyprus Foote Mineral Co. from Cyprus Amax Minerals Co.; Cyprus Foote's operations in Chile, Sociedad Chilena de Litio Ltda., were also part of the agreement. The new subsidiary was called Chemetall Foote Corp. In 2004, Rockwood Specialties Group, Inc. acquires Chemetall and other three former divisions of Dynamit Nobel, the chemical unit of MG Technologies A.G. Rockwood is a specialty chemicals and advanced materials company, based in Princeton, USA and is a subsidiary of Rockwood Holdings, Inc. The company was formed in 2000 when Kohlberg Kravis Roberts & Co. L.P., a private equity investment group from New York, USA, bought several divisions from Laporte.

\In many cases vertically integrated companies find it more profitable to locate value-adding downstream processing plants close to markets. Hence the decision of SQM to locate its butylithium plant in Texas, rather than Antofagasta or another Chilean city, reflects a decision related to profitability. Economies of scale and agglomeration, together with a lack of appropriately specialised human capital in mineral economies, usually justifies such decisions. Stewardson (1992) has noted that the level of downstream processing was similar in major mineral exporting nations such as Canada, Brazil, Australia, Chile and South Africa. While major downstream processing seems desirable in mineral-based activities in these nations, the economics of bulk-transportation, discriminatory tariff regimes in non-mineral economies seeking to develop their manufacturing sectors, and excess capacity in established smelters and refineries abroad, have usually mitigated against major value-adding taking place close to mines.

One way that government might encourage national value adding is by supporting locally based research into such activities, based in universities or publicly supported research institutes. Such policies do not guarantee success in building downstream processing. If properly targeted, however, they will, however, increase the probability of this occurring. The development of locally based research nodes may attract related activities and eventually establish agglomerations of human and physical capital that will establish such activities in a profitable way.

In the past two decades, more active environmental policy has been a major force in the area of physical sustainability as it relates to mining. As already noted, the recent rates of extraction of lithium and potassium compounds from the Salar de Atacama will not bring exhaustion of these resources for more than a century. Notwithstanding this, it is important that the extraction takes place in a fashion that causes minimal disturbance to the sensitive surrounding physical environment. It is important, therefore that future exploitation occurs in line with world's best environmental management practice.

As in most mining nations, careful management of the physical environment has been only quite recent in Chile and in South America more generally. It is essential that the key Chilean Government organisations such as the Regional Environmental Commission for the Second Region (COREMA), together with the government organisation CORFO, that has been responsible for managing this development, play active roles. Such activities might involve the development of interpretive models that monitor and predict the availability of the resource, and consider the impacts of current rates of exploitation on the surrounding environmental quality. This will enable informed decisions concerning requests to increase rates of exploitation, as well as the development of standards to internalise negative environmental impacts. Such policies would presumably extend to development of a mine management and closure policy that ensures appropriate level of rehabilitation as the operations in the Salar proceed.

The social and cultural impacts of mineral exploitation are also important. These take place with greatest intensity in the regions surrounding a mine, though with the emergence of 'fly-in, fly-out'[19] (FIFO) mining practices this seems to be changing. The operations of SQM and SCL (Chemetall) in the Salar de Atacama host FIFO workforces. Yet most reside in Antofagasta. The companies have also located lithium carbonate plants in Antofagasta and SQM is now constructing a lithium hydroxide plant there. These developments seem consistent with mining contributing in a positive way to the economy of the Second Region. Yet, in the light of our earlier comments about the size of the lithium industry, these impacts will be relatively small.

Some concluding remarks

Many of the smaller mineral sectors are dominated by few producers, who apparently possess high levels of market power. Extensive information about them is not widely available in the public domain. This study of the lithium industry, with its particular focus on Chilean production, has sought to provide some appreciation of the recent operations and future growth of one of these sectors.

Despite the desirability of competitive markets, the location of deposits and economies of scale in production of lithium and its compounds make continuation of the status quo—a few major producers pursuing vertical integration strategies to enhance their profitability—the most likely continuing industry outcome. The small size of the sector, together with potential competition from other materials in its end uses, will promote this.

In discussions with current industry players, our initial impressions were that there is likely to be a major expansion in lithium demand over the next two decades. Closer analysis, however, suggests that average annual percentage growth in lithium consumption, will be more modest. The present mining operations will meet this demand without difficulty.

In this situation the public policy position of the Chilean government should remain relatively stable. On one hand, it should support the continued competitiveness of current producers in the Salar de Atacama. Yet it should also enhance the welfare of its citizens by encouraging economic development in the Second region. It should also ensure that the environmental management of the mining areas, and the taxation and royalty streams that flow from continuing exploitation of its natural resource base, are sufficient to promote sustainable development. Since current producers are now generating considerable economic profits, there is some opportunity for movement in this area. Any initiatives to increase taxation and royalties could productively be accompanied by incentives for industry to undertake research and development in downstream applications.

[19] The term 'fly-in. fly-out' tends to be used broadly and also applies to other forms of long-distance commuting.

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