The Trouble with Lithium 2

Under the Microscope

Meridian International Research
Les Legers
27210 Martainville
France

Tel: +33 2 32 42 95 49
Fax: +33 2 32 41 39 98

29th May 2008

Contents

1 Executive Summary

This report analyses recently published[1] revisions to Lithium Reserves, analyses realistic Lithium Carbonate production potential from existing and future Lithium resources and discusses major factors of increasing importance in the development of future Lithium production for the Automotive Industry.

Our main conclusions are as follows:

1. This report confirms our previous assessment[2] that realistically achievable Lithium Carbonate production will be sufficient for only a small fraction of future PHEV and EV global market requirements, that demand from the portable electronics sector will absorb much of the planned production increases in the next decade and that other battery technologies that use unconstrained resources should be developed for the mass automotive market.
2. This report shows that the major economically recoverable Lithium Brine Reserves are lower than previously estimated at only 4 million tonnes of Lithium.
3. This report confirms that mass production of Lithium Carbonate is not environmentally sound, it will cause irreparable ecological damage to ecosystems that should be protected and that LiIon propulsion is incompatible with the notion of the “Green Car”.
4. This report confirms that the highly focused geographical concentration of Lithium production will exacerbate the already strained geopolitical relations between Latin America and the USA.

The recent paper “An Abundance of Lithium” catalogues numerous Lithium deposits. It includes a wide spectrum of deposits in which the concentration of Lithium varies from a low of 8 ppm to 3,000 ppm or more in some parts of the Andes. Total Global Lithium Reserves of 28 million tonnes are postulated in comparison with a Reserve Base estimated by the USGS to be 11 million tonnes.

1. An Abundance of Lithium, Whitepaper, RK Evans, 2008

2. The Trouble with Lithium: Implications of Future PHEV Production for Lithium Demand, MIR, 2006.

The document is not useful for the industrial and strategic planning purposes of the battery and automotive industries. It confounds geological Lithium deposits of all grades and types with economically viable Reserves that can be realistically exploited and relied upon as a dependable source of sustainable supply by the mass production scale of the automotive industry. Many of the deposits catalogued cannot be considered to be actual or potential Lithium Reserves. They would have higher production costs and lower production rates than the South American and Chinese brine deposits, coupled with unproven and heretofore undeveloped processes.

All such nebulous resources were excluded from our previous analysis “The Trouble with Lithium” for these reasons. In fact, more thorough consideration of the Salar de Atacama and Salar de Uyuni show that global recoverable Lithium reserves are only in the order of 4 million tonnes.

We cite the opening lines of the Handbook of Lithium and Natural Calcium by Donald Garrett[3]:

“Lithium is a comparatively rare element, although it is found in many rocks and some brines, but always in very low concentrations. There are a fairly large number of both lithium mineral and brine deposits but only comparatively a few of them are of actual or potential commercial value. Many are very small, others are too low in grade”.

This statement summarises the nature of Lithium deposits. A simple catalogue of geological Lithium deposits cannot be used to estimate realistic potential and achievable Lithium production. In the present report, we analyse the main Lithium Reserves, Reserve Bases as well as the major deposits that are not of economic value to illustrate the potential Lithium Carbonate production that could realistically be expected over the next 12 years.

It is our conclusion that total Chemical Grade Lithium Carbonate production is unlikely to exceed 200,000 tonnes per year before 2015.

Production of high purity (99.95%) Battery Grade Lithium Carbonate as required for Electric Vehicles will be significantly lower.

If existing demand from the portable electronics sector for 99.95% Lithium Carbonate continues to grow at the current rate of 25% per annum, by 2015 if optimum production increases occur, there will be only 30,000 tonnes of Chemical Grade Lithium Carbonate available to the Automotive Industry (including from Chinese sources). This would be sufficient for less than 1.5 million GM Volt type vehicles worldwide.

3. Handbook of Lithium and Natural Calcium, Donald E. Garrett, Academic Press, 2004

2 Current Production Resources

2.1 The Lithium Triangle

Some 70 percent of the world’s economic Lithium deposits (Reserve Base) are found in one small location on the Earth - the Lithium Triangle where the borders of Chile, Bolivia and Argentina meet. It is bounded by the 3 Salars of the Salar de Atacama, the Salar de Uyuni and the Salar de Hombre Muerto.

FIGURE 1 **THE LITHIUM TRIANGLE**

The Lithium Triangle has sides of approximately 360km, 280km and 560km in length. Within this tiny area is located over 70% of the world's Lithium Resources. Exports from all three countries will pass through the Chilean port of Antofagasta. The cities of Potosi, Salta and Antofagasta will become the tri-partite Lithium capitals of the world if the automotive industry attempts to base its forthcoming propulsion revolution on LiIon battery technology alone.

2.2 Salar de Atacama

The Salar de Atacama is the highest quality Lithium deposit in the world. As a brine source, extraction is much less expensive and less energy intensive than from hard rock minerals. The concentration of Lithium in the brine is the highest in the world and the rate of natural evaporation in the Atacama Desert is the highest in the world. In absolute size the Salar de Atacama is the second largest single deposit but is the largest deposit, larger than the Salar de Uyuni, in terms of its economically recoverable Lithium content.

FIGURE 2 **SALAR DE ATACAMA**

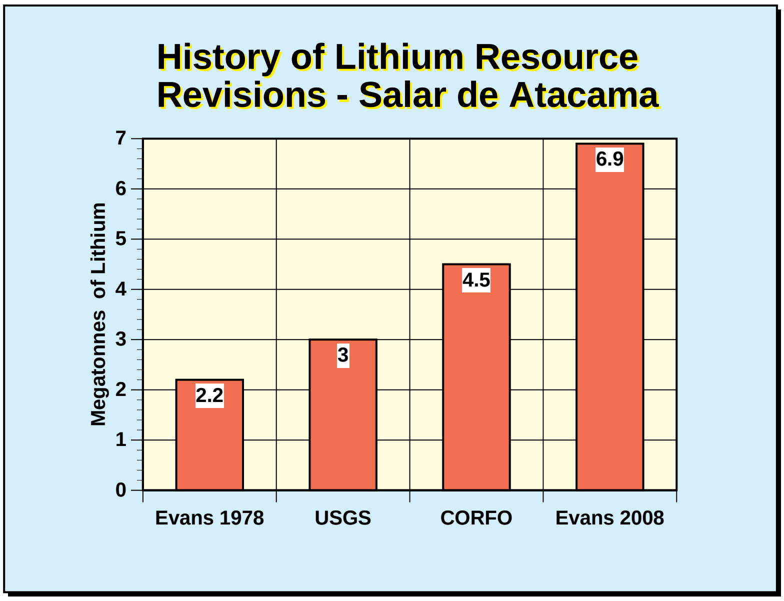
In 1978, the Lithium content (Reserve Base) of the Salar de Atacama was estimated to be 2.2MT to 60m depth[4]. The USGS estimate the Lithium Reserve Base in the Salar to be 3MT. The Chilean state mining company CORFO estimate the Reserve Base in the Salar at 4.5MT of Lithium metal, some 50% higher than the USGS estimate. In a recent paper [Evans 2008] the Chilean mining company SQM state that the Lithium reserves in the Salar de Atacama are 6.9MT based on a depth of **200 metres** into the Salar. SQM's concession extends to a depth of 40m.

The following graph shows how estimates of the Salar's Lithium content have increased.

4. Lithium Reserves and Resources, RK Evans, Energy, Vol. 3, No. 3, 1978

FIGURE 3

HISTORY OF RESOURCE REVISIONS - SALAR DE ATACAMA

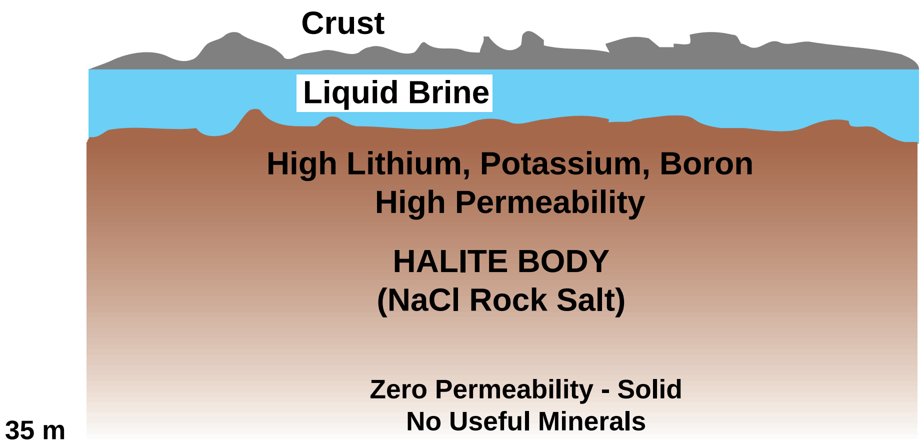


Geological Structure

To understand how much useful brine containing Lithium there is in the Salar de Atacama, we will look at its geological structure.

A salt lake bed consists of dried out Sodium Chloride or Common Salt. This forms a solid deposit called Halite or more commonly Rock Salt. The top of this halite body near the surface is relatively porous and permeable to water flow - it forms an aquifer through which flows the brine containing Lithium and other useful minerals (potassium, boron, magnesium). Further down into the halite body, millennia of cementation from precipitation of salts by earlier brine flows and compaction block up the pores and the halite rock becomes more and more impermeable and solid. This means that the useful brine, containing Lithium and other soluble salts, is only located in the top 40 metres of the dried salt bed at the most. A thin crust of salt then forms above this top layer of liquid and liquid containing rock salt.

FIGURE 4 **SCHEMATIC CROSS SECTION THROUGH SALAR DE ATACAMA**



Seismic surveys of the Salar de Atacama carried out in the 1970s showed that the highest porosity extends to a depth of 20 - 25m with some additional lower porosity halite down to 35m. Below this depth, salt cores show complete recrystallisation of the halite into a solid mass, devoid of any pores[5]. This means there is no Lithium to extract below the current pumping depth, only solid rock salt. Only the upper 30m has high transmissivity, i.e. only in this region can brine flow relatively freely to refill the areas from where it is pumped out.

- Below the current extraction depth of 30 metres, there is no Lithium in the Salar de Atacama.

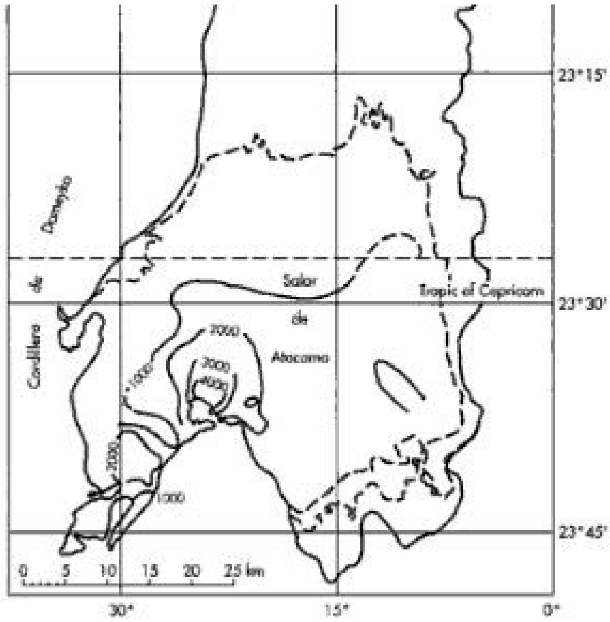
While the Salar de Atacama has a total surface area of 3500km^2, it's central Halite Nucleus is 1000 - 1400km^2 in area. The main area of commercial importance in the Salar is the top 15m-30m layer beneath the surface crust of this Nucleus. Below this top 30m layer, the nucleus is solid rock salt down to 600m and even 900m in places.

The contour map below[6] (Figure 5) shows the lines of equal Lithium concentration (Isopachs) in the Salar and the Nucleus.

The contour map shows that the distribution of Lithium is far from homogeneous. The southern half of the lake bed demonstrates a Lithium concentration of 1000 - 1500ppm. The area of highest concentration where production is currently located lies in a very small area on the southern shore approximately 100km^2 in extent. The contour lines go up to 4000ppm, within which concentrations as high as 7000ppm have been found. The 4000ppm area is about 8km^2 in extent; the 3000ppm area is some 20km^2 in extent and the 2000ppm area is about 80km^2 around that.

5. Industrial Minerals and Rocks, P604, JE Kogel, Blackwell, 2006
6. Idem, P605

FIGURE 5 SALAR DE ATACAMA - LITHIUM CONCENTRATION CONTOURS



- The Epicentre of World Lithium Production and Resources is an area of some 8km^2 - 30km^2 in extent.

In the very central 8km^2 region, assuming 10% porosity (CORFO figure) and a brine depth of 40m, a Lithium concentration [Li] of 4000ppm and a brine specific gravity of 1.2g/cc, the total Lithium resource in place in the 1970s before production commenced would have been approximately 150,000 tonnes or 820,000 tonnes of Li_2CO_3 equivalent. The 20km^2 region at 3000ppm would have contained 288,000 tonnes of Lithium or 1.5MT of Li_2CO_3 equivalent.

- The Epicentre of the Salar de Atacama in which the Lithium concentration exceeds 3,000ppm is 30km^2 in area by 35 metres deep.
- Before Lithium Production commenced this Epicentre held some 450,000 tonnes of Lithium metal.

SCL commenced Lithium Carbonate production from this resource in 1984 with a capacity of 13,000 tpy. SQM commenced production in December 1996 with a capacity of 18,000 tpy. We estimate that Total

Lithium Carbonate Equivalent (LCE) production from the Salar de Atacama to date is in the order of 500,000 tonnes.

TABLE 1

ESTIMATED LITHIUM CARBONATE (LCE) PRODUCTION TO DATE - SALAR DE ATACAMA (tonnes)[a]

Year	SCL	SQM	Total
1984 - 1996	100,000	-	
1997	14,500	9,000	
1998	14,500	18,000	
1999	14,500	18,000	
2000	14,500	19,000	
2001	14,500	21,000	
2002	16,330	22,000	
2003	16,330	24,000	
2004	16,330	26,000	
2005	16,330	28,000	
2006	22,000	28,000	
2007	22,000	32,000	
TOTAL	**280,000**	**245,000**	**525,000**

a. 1kT of Li = 5.28kT LCE

Therefore about 100,000 tonnes or some 20% of the Lithium metal in the central epicentre of the highest grade Lithium deposit in the world has already been extracted - and possibly 5/8ths of the very best deposit at over 4,000ppm within this.

SQM are currently engaged in expanding Li_2CO_3 capacity at their plant in the port of Antofagasta by 50% to 48,000 tpy. This may require accessing areas of the salar of lower Lithium concentration. As production is increased, resources of lower grade will have to be brought into operation, requiring increasing amounts of resources for a diminishing return.

It can be seen that expanding production much beyond 100,000 tpy of Li_2CO_3 would require covering an extensive area of the salar with production wells, pipelines and evaporation ponds. The environmental damage to a unique ecosystem and area of natural beauty that has remained undisturbed for millennia would be substantial.

It is well known to halite geologists that the porosity of halite decreases very quickly with increasing depth - it decreases exponentially. This means that the volume of free space within the Rock Salt or halite deposit of NaCl decreases exponentially - at double the depth, the free space or pores available to hold the Lithium containing brine will have decreased by four - at triple the depth, reduced by a factor of nine and so on. There is a very definite limit to the depth from which the brine can be pumped out and this limit is about 40 metres in the case of the

Atacama. SQM's wells operate at about 30m depth and 40m is the depth to which their concession extends.

It can be seen that SQM's concession only extends to 40m depth for a very good reason: below that depth the Halite Body is solid rock salt devoid of Lithium or other useful minerals.

All the minerals of interest are only in the fluid intrusions in the pores in the upper 35m of the halite body - not in the halite itself.

The impermeability of rock salt is well known. Oil and Gas are often found beneath salt domes and salt caverns have been proposed for storing sequestered CO_2. In fact, the salt core samples from the Salar de Atacama referred to above were taken by an oil drilling company.

Production cannot be increased by drilling deeper into the increasingly solid nucleus of the Salar - this would in fact decrease production. Production can only be increased by expanding drilling and well installations over a greater surface area of the salar.

Therefore only the upper surface liquid layer can be considered, up to 35m deep. In 1978, Evans estimated the Lithium content in the SQM concession to be 2.2MT to 60m depth. The USGS estimate is 3MT and the Chilean state mining company CORFO estimate is 4.5MT. The latest claim, based on a 200m depth, is 6.9MT. Therefore there has been 100% reserve base inflation since the late 1970s with little justification.

As shown above, extracting Lithium from 200m depth is impossible. Much below the current exploitation depth of 30m the halite or rock salt becomes completely solid Sodium Chloride with no liquid brine in it at all and therefore no useful minerals to extract. The claim of 6.9MT to 200m depth fails to take this into account and is therefore a gross exaggeration. CORFO calculated an effective porosity of 10% for the upper 30m of the Salar de Atacama nucleus but this did not include the southern area where it is very low[7], between 0.43% and 5.25%. This is the area with the highest Lithium concentration. The mean effective porosity of the Salar de Atacama in the upper 40m of SQM's 820km^2 claim area was estimated by the UK consulting geologist firm Hydrotechnica to be 4.4%. If so, this would reduce the central Epicentre Lithium content from 450,000 tonnes to 200,000 tonnes and would mean some 50% of the Lithium in this central area has already been extracted.

- If the porosity in the top layer of the Atacama in the Southern Area is only 4.4% as estimated by Hydrotechnica and not 10% as claimed by CORFO, then Before Lithium Production commenced this Epicentre contained some 200,000 tonnes of Lithium.
- 50% of this would already have been extracted since 1984.

7. Garrett, 2004, Op. Cit.

Given that Evans' original 1978 Lithium Resource estimate for the SQM concession was 2.2MT to a depth of 60m and 40m is the maximum depth to which Lithium is found, the USGS estimate which takes into account the rest of the nucleus (but at lower concentration) is probably the upper limit. It would not be prudent to rely on more.

With a 50% recovery factor and taking into account the reality from studying the [Li] contour map that only the higher concentration areas of the salar might be exploited, the upper limit to Recoverable Reserves cannot exceed 1.0MT.

However, extracting anything like that 50% of the Lithium in the Salar would take many decades and would destroy it. Production today takes place where the Lithium concentration is highest. Future production sites elsewhere on the nucleus will experience lower Lithium concentrations, lower production rates and higher costs.

Conclusion

Lithium is only found in the top 35 metres of the Salar de Atacama.

Since 1984 some 100,000 tonnes of Lithium have been extracted from the richest grade deposit on the Southern Edge of the Salar.

The most realistic assessment based on the known low porosity of this Southern Edge is that before production commenced, this southern high grade zone contained 200,000 tonnes of Lithium. The maximum it would have contained was 450,000 tonnes.

Therefore 50% of the highest grade Lithium deposit in the world may already have been extracted.

While the nucleus may contain 3MT or more of Lithium in total, access can only be gained to this by wholesale destruction of the salar by expanding wells and pipelines over a much greater area of its surface. In reality, the realistic recoverable reserve is less than 1MT.

Increasing investment and resources will be required to maintain production at current levels as the Lithium content in the salar continues to fall. Any increase in production will require accessing lower grade areas of the salar and an exponential increase in resources per unit production increase.

2.3 Salar de Hombre Muerto

The Salar de Hombre Muerto was the second Lithium salt deposit to be put into production in South America after the Salar de Atacama. It is located about 220km south west of the Salar de Atacama. Production of Lithium from the Salar de Hombre Muerto commenced in 1997 - 1998.

Rather than solar evaporation, FMC use a proprietary alumina adsorption system to directly extract Lithium from the brine. A supply of fresh water is required to wash out the adsorption beds when they are full of Lithium and refresh them. In 1997, the Salar was reported[8] to contain only 130,000 tonnes of Lithium metal, which is certainly too low. Garrett cites 800,000 tonnes which appears reasonable for the size and grade of the salar. The salar is small in surface area but brine can be extracted from lower depths than in many other salars.

The concentration of Lithium varies between 220 - 1000 ppm and FMC extract where it averages 650ppm. The concentration exceeds 700ppm over large sections of the salar.

Production is about 12,000tpy of Li_2CO_3 and 6,000tpy of LiCl. This is used by FMC as feedstock for their Lithium chemicals business. The reserve is estimated to last 75 years at the current extraction rate, which is about 5,000 tpy of Lithium metal. This would give a Total Reserve of 375,000 tonnes or about 50% of the 800,000 tonne resource. This is in accordance with what one would expect. The extraction rate is 1.25% of the reserve per annum.

2.4 Salar de Uyuni

Although production has not yet commenced at the Salar de Uyuni, we analyse it in this part of the report because of its perceived importance as the single largest Lithium deposit in the world. It contains over 40% of global Lithium brine resources and several initiatives have been made in the past to exploit it.

It is stated [Evans, 2008] that the Salar de Uyuni contains Lithium Reserves of 5.5MT. This figure is however the total Lithium metal resource estimated to be contained in the Salar, not recoverable reserves. Since the 1980s, some Bolivian and other sources have estimated the resource at 9MT. The USGS estimate is 5.4MT.

The Salar de Uyuni has a high Mg:Li ratio of 18.6:1, three times higher than the Salar de Atacama. The higher this ratio, the more difficult it becomes to produce Lithium. This high ratio in Uyuni will prevent the formation of Lithium Chloride (LiCl) in the evaporation ponds unless Magnesium is removed before evaporation and concentration

8. Minsal Lithium Carbonate - Slightly Ahead of its Time, Peter Harben, George Edwards, Industrial Minerals No. 353, Feb. 1997, P25-39.

commences. This has heretofore been one of the major stumbling blocks to exploiting the Salar de Uyuni. A similar problem exists at the Salar de Rincon, where Admiralty Resources will be pre-treating the raw brine with Calcium Hydroxide to reduce the Magnesium content before evaporation commences (see below).

FIGURE 6 **SALAR DE UYUNI**

At 10,000km^2 in area, the Salar de Uyuni is the largest salt flat in the world. However, the concentration of Lithium varies widely in different parts of the salar and the area of highest Lithium density above 1000ppm is in a small area in the south east where the Rio Grande enters the salar. This area is about 280km^2 in extent. Levels as high as 4.7g/l or 4700ppm have been found here but that is in a very small focused epicentre. The area with [Li] greater than 3000ppm is about 50km^2 in extent. Across the rest of the lake, Lithium levels fall to 500-600ppm. Production would be focused in this small south east quadrant and would offer diminishing returns in other parts of the lake bed. One can see by looking at the contour map[9] of Lithium concentration (Figure 7), that in fact, most of the Lithium in the Salar de Uyuni will remain inaccessible or would take decades to extract, not counting the irreversible environmental damage in covering its surface with brine extraction facilities and evaporation ponds. As with the Salar de Atacama, expanding production outside a central high concentration epicentre (the Rio Grande lagoon region) will result in steeply diminishing returns. The solar evaporation is 1,500mm per year, less than half the rate at the Salar de Atacama.

9. Quaternary Geochemical Evolution of the Salars of Uyuni and Copaisa, Ventral Altiplano Bolivia - F. Risacher, B. Fritz, Chemical Geology 90 (1991) 211-231

FIGURE 7 **LITHIUM CONCENTRATION COUNTOURS - SALAR DE UYUNI (g/l)**

Note the small area on the southern edge where the Lithium concentration exceeds 1000ppm. Contour lines are in g/l (multiply by 1000 for ppm).

Geological Structure

The structure of the Salar de Uyuni is very different to the Salar de Atacama. This difference must be understood by the reader due to its very important implications for the production potential of Lithium from the resource.

Whereas the brine containing halite layer in the Salar de Atacama is 35 metres thick, the Uyuni halite deposit is very thin, being only 11 metres thick at the thickest point and only 2m to 5m thick in the south east area of high Lithium concentration. The halite is however porous all the way through, with a much higher average porosity of 35% and is filled with interstitial brine. This means that the quantity of Lithium available per unit surface area is much lower and a correspondingly greater area of the salar will have to be exploited for an equivalent Lithium production.

Assuming a 200km^2 epicentre at 2000ppm, 3.5m deep, 35% porosity and brine density of 1.2g/cc, the total Lithium resource in the central richest region would be about 600,000 tonnes before applying a recovery factor of 50% giving a Recoverable Reserve of 300,000 tonnes.

- The Recoverable Lithium Reserve in the Central Highest Grade Epicentre of the Salar de Uyuni is 300,000 tonnes

This is in agreement with Risacher and Fritz's estimate for the total amount of Lithium in the Southern Fringe of 500,000 tonnes.

FIGURE 8 **UYUNI SALT BODY DEPTH CONTOURS**

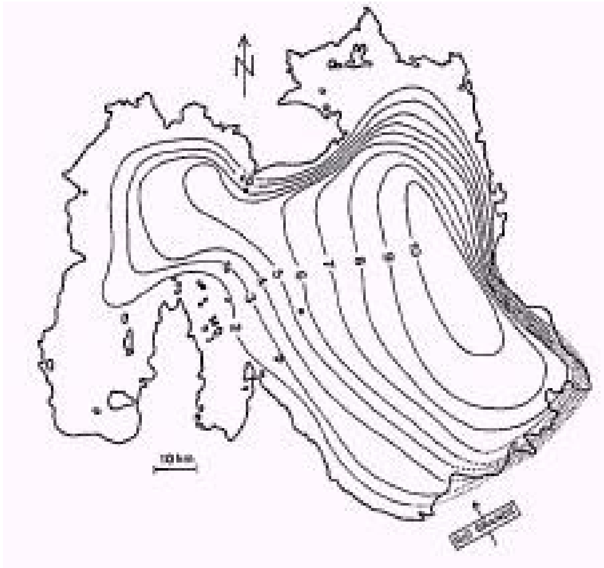
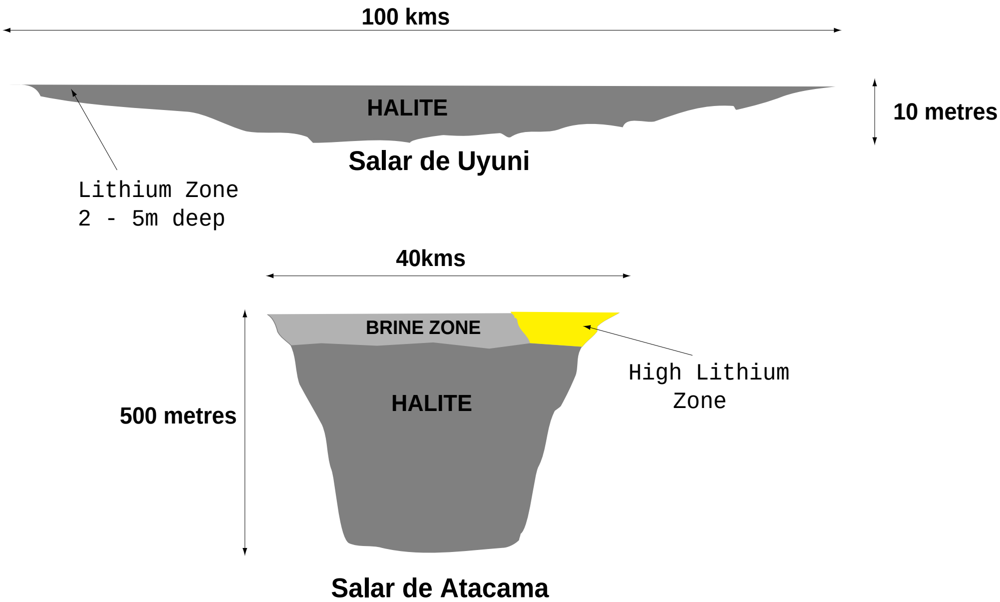


FIGURE 9 **IDEALISED CROSS SECTION - UYUNI vs ATACAMA**



Production Potential

In late March 2008, President Evo Morales of Bolivia signed a decree investing $5.7M to set up a state owned pilot Lithium extraction plant on the Salar. It will be run by a “General Directorate of Evaporative Resources of the Salar de Uyuni” under the state mining company Comibol. There is now a clear intention by the Bolivian Government to nationalise the entire mining industry, even if joint ventures will be used with foreign companies to develop resources.

It has been reported[10] that Bolivia have stated an intention to produce 1,000 tons of Lithium per month from 2013, or 60,000tpy of Lithium Carbonate Equivalent (LCE). This would be 50% higher than current production from the Salar de Atacama, the largest producer of Lithium in the world. The grade of the Uyuni resource is about 50% that of the Atacama, the Mg:Li ratio is three times as high and the evaporation rate is 1,500mm per annum compared to 3,600mm per annum or 40% of that experienced at Atacama.

Taking these factors into account it is highly unlikely that anything like 60,000 tpy of LCE will be produced from the Salar de Uyuni in 2013. If everything goes according to plan, a more realistic assessment might be 10,000 tpy by 2015 and 30,000 tpy by 2020.

When the real grade and distribution of Lithium in the Salar de Uyuni are considered, it can be seen why it is not a particularly attractive resource. The central epicentre is lower in quality than the Atacama. Compared to the 30-35m depth available in Atacama, Uyuni is only 2 to 5m thick at this point. The higher porosity (between 3.5 and 8 times as porous as Atacama depending on whether the CORFO or Hydrotechnica figures are used) makes up for this much lower thickness of the deposit to some extent. The total amount of Lithium stored in the epicentre is thus comparable to the Atacama but spread out over at least twice the surface area. In addition the Mg:Li ratio is 3 times as high and the evaporation rate only 40% of that at Atacama. Even with the higher porosity, the amount of Lithium in the salt body per unit area is much lower than in the Atacama. (If the Atacama deposit is 35m deep versus 3.5m and has 10% porosity versus 35%, then overall the Atacama has nearly 3 times as much interstitial brine per unit surface area and the concentration of Lithium in that brine is higher). Therefore, a much greater surface area of the Uyuni will have to be exploited for an equivalent production with concomitant environmental degradation. The deposit is so thin it is difficult to see how pumping from wells would be feasible. There might be a temptation to excavate large depressions into the surface and let them fill up with brine to then be pumped out, or a trench system similar to that used at the Bonneville Salt Flats. This would be highly environmentally damaging.

The Salar de Copaisa to the north of Uyuni contains 200,000 tonnes of Lithium in lower concentration.

Environmental Factors

As noted above, the Salar de Uyuni is the largest salt flat in the world and is the brightest object on the Earth's surface visible from space. Some in the tourist industry classify it as a Natural Wonder of the World and it is undoubtedly an area of outstanding natural beauty. During the southern spring the salar becomes a flamingo breeding ground. The

10. www.evworld.com/artcle.cfm?storyid=1457 "Peak Lithium or Lithium in Abundance?", JC Zuleta Calderon, accessed 23/05/08.

rains often flood the surface of the salar between January and March. The flamingo breeding season is from December to February. The discharge of the Rio Grande into the salar, adjacent to where the Lithium concentration is highest, creates a permanent lagoon area used by the birds.

FIGURE 10 **VIEW OVER THE SALAR DE UYUNI**

Some 60,000 tourists visited the Salar de Uyuni in 2006 despite the poor infrastructure and this number is increasing. Infrastructure is being improved with a new road recently constructed between the town of Uyuni and the regional capital of Potosi to improve tourist access.

Production of Lithium from this unique ecosystem can only be environmentally damaging. Anything more than limited and very careful recovery of Lithium is incompatible with the production of “Green Cars”.

Conclusion

Although the Salar de Uyuni appears to be a large deposit in absolute terms, the Lithium is dispersed over a very wide area in a very thin deposit.

The real exploitable reserve is therefore only in the order of 300,000 tonnes of Lithium, not several million tonnes.

2.5 Salar del Rincon

The Salar del Rincon Lithium resource in Argentina has been under development since 1999 and commercial production of Li_2CO_3 is now scheduled for 2008 - 09.

FIGURE 11 DRILLING RIG ON THE SALAR DEL RINCON

It has been stated recently [Evans, 2008] that the Salar del Rincon has proven and probable in-situ reserves of 1.86MT of Lithium metal. This is in fact a total resource - not the economically and technically recoverable reserve. The JORC Inferred Resource Estimate (produced by independent consultants) issued by Admiralty Resources (ADY) to their investors on the 27/07/05 estimated the reserves at 250,000 tonnes of Lithium metal or 13% of the latest figure. The independent October 2004 geologist's report performed by Pedro Pavlovic, the leading Chilean expert on Lithium deposits, estimated the Ultimately Recoverable Lithium content at the same level - 250,000 tonnes. Pavlovic based this on an estimated porosity for the salar of 8% - 10%, in line with other salars in the region.

On 27/07/07 Admiralty Resources issued a new JORC compliant report revising upwards the Lithium metal reserves in the Salar del Rincon to 1.4MT. This was produced by Dr. George Sorentino, who is now ADY's Technical Director for the project.

This latest estimate by ADY is shown in Table 2 below.

TABLE 2 **SALAR DEL RINCON - LITHIUM RESOURCES 27/07/07**

	Low	Expected	High	Uncertainty
		kilotonnes		
Proven Reserves	746	911 ± 53	1,098	± 10%
Probable Reserves	288	492 ± 72	762	± 25%
Total Reserves	1,035	1,403 ± 26	1,861	± 15%

Therefore Evans' figure for Lithium Reserves in the Salar del Rincon is the most optimistic figure of 1.86MT presented by ADY. This represents an increase of 744% in reserves since 2004.

While these figures are presented by ADY as Reserves they are in fact Resources in place i.e. the amount of metal claimed to be geologically present. Reserves are how much of that resource in place one can realistically extract and produce. In a recent presentation, ADY state that their process now in pilot testing demonstrates over 70% recovery factor, compared to 42% in the Salar de Atacama. Assuming this is the case and that pilot scale efficiencies will not fall in large scale production, it must be underlined that the actual reserve would be 70% of 1.4MT or 1MT of Li metal, not taking into account the fact that recovery efficiency and production rate will fall at a certain point in the future as the concentration of Lithium in the Salar falls.

Therefore a more realistic assessment of ADY's latest figures would be to estimate Recoverable Lithium Reserves at no more than 1MT and almost certainly less. It is unlikely that the Salar del Rincon has higher Lithium resources or reserves than the Salar de Hombre Muerto.

ADY have based this increase in resources on findings from a drilling survey that the effective porosity of the Salar is 38%, not 8%. In other words, they have found that the halite rock is far more porous than previously thought and therefore contains more interstitial Lithium bearing brine.

At the seven production wells they have drilled, the porosity was only 4.7% and 8% at two of the wells and 38% at the other five. However, ADY's report states that "the crystalline mass of the Salar has a porosity of 3% - 8%, but the presence of very large cavities containing brine increases the effective porosity to 38%. The system of interconnected caverns and geodes is that main contributor to the Salar's effective porosity".

This is not quite the same thing as the salar having a porosity of 38%. If a well does not enter into these cavities, which may or may not be interconnected with other brine filled cavities, the well will be in halite of 4.7 - 8% porosity. Each cavity will be in communication with a varying number and volume of other cavities. Once a cavity system has been emptied, it will be subject to the 3% - 8% porosity and related low permeability and flow rate within the crystalline mass surrounding it to refill it. Therefore even if the average porosity is 38%, leading to a higher amount of Lithium overall in the salar, this does not necessarily mean that the recoverable reserve or production rate can be increased accordingly.

Noting that this latest report does confirm that the crystalline mass of the Salar has a porosity of 3-8%, it may be prudent to continue to base independent reserve assessments on 10% porosity, giving a Recoverable Reserve of 250,000 tonnes of Lithium metal.

When evaluating this resource, it should also be noted that incorrect claims have been made concerning the replenishment of the salar with Lithium inflows. In his 2004 report[11], Pavlovic calculated that 4000m^3 of water enters the salar every day in the form of precipitation, ground water and surface (river) water. Of that, three quarters is precipitation and therefore unequivocally free of minerals.

In the report of 22/12/04 by Dr. Carlos Sorentino, it is stated that Pavlovic concluded that 4000m^3 of brine enters the salar every day and that "at the salt concentrations indicated, this represents an annual mass input of 9.3MT of salt.... compared with the project's forecast consumption of 0.26MT/year".

This has been used by ADY to indicate that the salar is being replenished with Lithium and to imply it is therefore a virtually inexhaustible resource[12].

This is incorrect. Pavlovic was referring to water inflows, 78% of which are precipitation, not surface or underground water. There is therefore little or no replenishment of the Salar with Lithium, certainly not in comparison with the extraction rate and the resource will deplete as it is extracted.

Due to the high Mg:Li ratio (8.6:1) in the Salar del Rincon, the phase chemistry does not allow Lithium Chloride brine to be produced unless some of the Magnesium is removed at the start of the process, to lower the Mg:Li ratio. ADY intend to do this by pre-treating the raw brine with Calcium Hydroxide to remove Magnesium and then treating with Sodium Sulphate to remove Calcium. (Similar treatment is also required at Atacama to reduce the Sulphate and Calcium content before solar concentration). This will be performed before the brine is pumped into the solar evaporation ponds. A similar process or another method will

11. "Evaluation of the Potential of the Salar del Rincon Brine", Report by consulting geologist Pedro Pavlovic to ADY, Dec. 2004

12. Rincon Salar Update, 1str November 2006, Admiralty Resources NL

also be required at the Salar de Uyuni which has an even higher Mg:Li ratio of 18.6:1. This accounts for the recent interest by the Bolivian authorities in the Rincon operations. The higher Mg:Li ratio will add more cost and more requirement for bulk reagents to the process compared with extraction in the Salar de Atacama.

ADY project that in 2009-10, they will produce 8,000 tonnes of 99.0% Li_2CO_3 and 2,000 tonnes of battery grade material at 99.99%. This production split matches the current global market shares of these materials. 2,000 tpy of Battery Grade Li_2CO_3 would be sufficient for 90,000 GM Volts or ten times as many 1.5kWh HEV0 batteries. Full production of Li_2CO_3 is planned to reach 17,000tpy, of which one can project 4,000tpy will be battery grade.

2.6 Other Brine Resources

Clayton Valley

Clayton Valley or Silver Peak, Nevada, has been producing Lithium since 1966. The concentration of Lithium has fallen from 360mg/l (ppm) to 230mg/l today. In 1992, Clayton Valley's reserves were estimated at 118,000 tonnes of Lithium. The lake is only 50km^2 in area. Its Lithium Carbonate production of about 9,000 tpy is used by Chemetall Foote internally for manufacture of Lithium chemicals, supplementing their main source of supply which is now the Salar de Hombre Muerto. Production is in decline. The Solar Evaporation Rate is 900mm per year, one quarter of that at the Salar de Atacama.

China

There are three main salt lakes of interest in China:

- The East Taijinaier Salt Lake in the Qaidan Basin, Qinghai Province, North of Tibet
- The DXC Salt Lake in South West Tibet
- The Zhabuye Salt Lake in Western Tibet

In August 2005, a 5,000 tpy Li_2CO_3 production plant using brines from the Zhabuye Salt Lake was opened. The Chinese say this will increase in the long term to 20,000 tpy of sustained production. This salt lake is in a very remote region at an altitude of 4,400m or 14,500 feet. Evaporation rates are therefore lower than at the Chilean or Argentinian lakes. Li_2CO_3 occurs here naturally, crystallising on the shores of the lake, which is remarkable.

The Qaidan basin is said to be the largest Lithium resource in China. This region, north of Tibet, was once a vast lake. It now contains some 33 salt lakes. Pilot production of LiCl and Li_2CO_3 (500 tpy) from the Taijinaier salt lake was started in 2004 and full scale production is now gearing up. The CITIC Guoan Scientific and Technical Co. officially inaugurated a 35,000 tpy capacity Li_2CO_3 plant in Golmud, Qinghai

Province on the 11th January 2007. It will take some years for production to reach this figure, but makes the facility the largest Li_2CO_3 plant in the world ahead of SQM's 28,000 tpy plant at Salar del Carmen near Antofagasta, which is now expanding to 38,000 tpy.

CITIC Guoan hold a large stake in MGL, the largest Chinese manufacturer of LiCoOx cathodes for LiIon batteries.

The DXC Salt Lake in central Tibet has a Lithium concentration of about 400mg/l or 0.04% and a Mg:Li ratio of only 0.22. Extraction is attractive from that perspective, but the lake is a small resource, containing only 1MT of LiCl or 160kT of contained Lithium. With a recovery efficiency of 50%, the total Lithium Carbonate production that could be expected from the lake would be in the order of 400,000 tonnes. The lake is also 4,400m above sea-level and over 400 miles from the nearest rail head by rough gravel roads[13]. The Canadian company Sterling Group Ventures are considering exploiting this resource with a 5,000 tpy facility.

Salar del Olaroz

Near to Salar del Rincon in northern Argentina, Orocobre Ltd are taking advantage of growing Lithium demand to explore the potential of the Salar de Olaroz. This is a much smaller lake bed than Rincon but is said to have a higher Lithium concentration of 900ppm. Based on a 10% porosity estimate, the total amount of Lithium in the resource is projected to be some 325,000 tonnes of contained Lithium. Mg:Li ratio has not been reported. Geological mapping of the surface has just commenced. First production can not be expected for at least 5 years.

2.7 Mineral Resources

Western Australia - Greenbushes

The Greenbushes pegmatite 300km south of Perth is the largest and highest grade Lithium hard rock mineral resource in the world. However, the primary mineral extracted from this mine is Tantalum.

The Tantalum and Spodumene operation at Greenbushes is also the largest producer of spodumene concentrates in the world, destined for use in high temperature ceramics and glass.

In late 2007, after three years in administration, the mine owner Sons of Gwalia were bought by Talison Minerals. Australian spodumene concentrates production capacity is 150,000 tpy. Two grades of concentrate are produced with a Lithium Oxide content of either 4.8% or

13. Qualifying Report for DXC Salt Lake Deposit, Nyima County, Tibet, China. N. Tribe & Assoc. Ltd, 20/5/06.

7.5% (Li_2O). This production should now be assured for the foreseeable future.

Sons of Gwalia ceased production of Li_2CO_3 from spodumene in 1998, after SQM entered the market with low cost brine source Lithium Carbonate.

Mt. Cattlin

The Australian mining group Galaxy Resources are planning to develop another spodumene/ Tantalum resource in Western Australia at Mt. Cattlin and state that they intend to produce Lithium Carbonate from spodumene. Analysis of their figures, stating 24.8MT of ore at 0.56% Li_2O content, shows that the deposit contains 65,000 tonnes of Lithium metal. At an impossible 100% recovery factor this would produce some 350kT of Li_2CO_3. When recovery factors are taken into account less than half that or 150,000 tonnes could be produced over the lifetime of the mine. The ore grade is even lower than the resource in Finland (q.v.).

North Carolina

North Carolina ceased being economically competitive as a Lithium Carbonate producer in the 1980s. The Lithco plant in Bessemer City had a Lithium chemical capacity of 15,000 tpy of Li_2CO_3 equivalent, but did not produce exclusively Li_2CO_3. The Cyprus Foote Mineral Company Lithium Carbonate plant (Kings Mountain, NC) had a capacity of 8,000 tonnes per year, producing 99.1% Li_2CO_3. This would require further processing to bring it up to 99.95% battery standard. The Bessemer City mine was shut in 1998 and the Kings Mountain mine and facility was closed in 1986.

Based on the figures [Kesler] cited by Evans, the average Lithium concentration in the North Carolina deposit is 70ppm. The USGS do not include these deposits in their estimates since they were superseded by brine production. Given the National Security priority that has been given to reducing dependence on foreign oil, the North Carolina deposits could in theory be re-developed, to reduce dependence on foreign Lithium, though it cannot be as economic as brine.

In his 1992 book “La Industria del Litio en Chile” (The Lithium Industry in Chile), Pedro Pavlovic estimated relative Li_2CO_3 production costs as follows:

TABLE 3

LITHIUM CARBONATE PRODUCTION COSTS

Location	Cost per kg Li_2CO_3 (1992 dollars)
FMC/ Lithco, Bessemer City, North Carolina (Spodumene)	\$2.43 / kg
Cyprus Foote Mineral Co, Silver Peak, Nevada (Brine)	\$1.65 / kg
Sociedad Chilena del Litio, Atacama (Brine)	\$1.10 / kg

The relative cost of producing Li_2CO_3 from spodumene in the USA would now almost certainly be even higher than twice the cost of that from the Salar de Atacama given the increase in the cost of energy in recent years.

2.8 Other Producing Resources

Zimbabwe

Bikita Minerals in Zimbabwe have been producing lithium containing concentrates for the ceramics industry since the 1960s. According to Garrett, the proven reserves are 23MT of ore at 1.4% Lithium Oxide content, i.e. a resource in place of 150,000 tonnes of Lithium but Reserves - what can realistically be produced - are estimated by the USGS to be only 23,000 tonnes. Lithium Carbonate has never been produced from this Lithium source. Production of Lithium minerals today from Bikita is about 30,000 tpy (i.e. a Lithium Carbonate equivalent content of 1000 tonnes since this is unprocessed ore, not a glass grade concentrate).

In December 2007, in parallel with the passing of the "Indigenisation and Empowerment Act" which appropriates 50% of white owned businesses to black control, the mine was taken over by "war veterans" and the management evicted.

Russian Federation

Russia produces spodumene at the Pervomaisky mine south east of China. Lithium carbonate used to then be produced at Novosibirsk but this ceased[14] when SQM entered the market.

14. Industrial Minerals and Rocks, P607

Portugal

Portugal's spodumene production is nominal and used for glass/ ceramic applications.

Canada

Tanco in Canada produce 24,000 tpy of glass grade spodumene (5% Li_2O) as a by-product of Tantalum mining. The contained Lithium metal is 560 tonnes or 3,000 tonnes of Lithium Carbonate equivalent. This is too small a Lithium resource to be considered for Li_2CO_3 production.

Avalon Ventures in Canada are developing a hard rock lithium resource for a "new mineral composite material for non-combustible materials" they have developed, i.e. a high temperature ceramic. The raw ore contains 1.34% Li_2O compared to 4% at Greenbushes in Australia.

Brazil

Brazil has produced a limited quantity of Lithium hard rock minerals for many years. Kogel cites deposits of 300 - 400kT of spodumene and petalite ore. Companhia Brasileira de Litio produced about 1,500tpy of Li_2CO_3 from spodumene concentrates as of 2003.

In Brazil, all lithium-related activities are controlled by the CNEN (Nuclear Energy National Commission) due to its nuclear applications.

2.9 Conclusion

When the structure of the two largest Lithium deposits in the world (Atacama and Uyuni) are considered in detail, it is apparent that the recoverable reserves will be far lower than the total quantity of Lithium metal present in the salt bodies. We would put the upper limit on the recoverable reserves in the Salar de Atacama at 1MT and less than that in the Salar de Uyuni.

Therefore Total Global Lithium Reserves are in the order of 4 million tonnes.

3 Future Potential Resources

3.1 Introduction

This chapter examines the major potential Lithium deposits that are cited as possible future sources of the metal. It covers the nature of each resource and estimates how much Lithium Carbonate could realistically be produced from them.

3.2 Mineral Resources

Osterbotten, Finland

Lithium mineral deposits were discovered in Finland in the 1950s and numerous studies have been carried out over the years into exploiting it. The start up mining company Keliber (4 employees) have obtained environmental permits to produce 6,000tpy of Li_2CO_3 from spodumene in the Lantta/ Osterbotten regions, using a new production process. The company have recently been taken over by a larger Norwegian mining group. They plan to start Lithium Carbonate production in 2010.

The mineral resource they are exploiting contains 3MT of spodumene at 0.92% Li_2O, compared to 4% Li_2O at the highest grade spodumene resource in the world at Greenbushes.

The total amount of Lithium geologically present is therefore 13,000 tonnes or 68,000 tonnes of Li_2CO_3 equivalent. If half of this is recoverable, Keliber are projecting production of 6,000 tpy of Li_2CO_3 from a Reserve of 35,000 tonnes or 16% of the reserve per annum, giving a mine life of 6 years.

There are other deposits in the area, presumably of lower grade and/or smaller in size.

6,000 tpy of (battery grade) Li_2CO_3 would be sufficient for some 270,000 GM Volts per year. After 6 years, production would cease.

China, Jiajika

The Jiajika pegmatite is claimed by China to contain 1.03MT of ore at 1.28% Li_2O. This gives a total Lithium resource of 6,000 tonnes of Lithium metal. Chinese Lithium Carbonate production is now shifting away from domestic and imported hard rock minerals to domestic brine resources.

Democratic Republic of the Congo (Zaire)

Regarding the Democratic Republic of the Congo, it is stated [Evans, 2008] that “the pegmatites could contain 2.3MT of Lithium”. Garrett cites estimates of 309,000 tonnes. A figure for how much Lithium is in the deposit does not inform about its quality, grade and feasibility of extracting it. As a hard rock source, Lithium Carbonate production costs will be much higher than from brine. It would be more feasible to restart production in North Carolina rather than develop an entirely new resource in such a politically unstable and undeveloped region.

Kogel does describe the Manolo and Kittolo pegmatites in the Congo as "probably the largest hard rock lithium resources in the world... their dimensions imply spodumene reserves that dwarf the currently known world reserves". She goes on to say: "The deposit may not have an economic value for years however because of very poor transportation facilities. The deposit is 2,200km from the Angolan port of Lobito".

In comparison, the high grade Greenbushes mine is 300km from Perth and situated in a developed politically stable country.

This is a speculative resource that can not be counted as a reserve nor relied upon for planning purposes.

Hectorite Clays

The Lithium bearing clays at Hector, California have been mined since the 1950s for their swelling characteristics. Here they contain 0.53% or 5300ppm Lithium [Kogel, P609] but have never been exploited for their Lithium content, despite numerous studies, since it is chemically easier to extract it from pegmatite hard rocks minerals, despite the lower Lithium concentration.

Evans cites a deposit of 2MT of Lithium in the hectorite clays of Oregon and Nevada with a reserve cut-off percentage used of 0.275% or 2750ppm. Since it has not yet been proven to be economically recoverable, it cannot be considered to be a reserve. Research on extracting Lithium from boron clays in Turkey in 2005 estimated[15] that a concentration of 4,000ppm was required for a Lithium Carbonate cost in Turkey of double then market rates.

15. “Between a Rock and a Salt Lake”, Industrial Minerals, June 2007, P69

Studies have been carried out on extracting Lithium from hectorite and montmorillonite clays since the late 1970s. As with spodumene, extraction of Lithium from clay also requires an energy intensive process of calcining in a rotary kiln at 900^{o}C. Gypsum and Limestone are required[16] as co-ingredients during calcining in the ratio of approximately 5:3:3 parts of clay: gypsum: limestone. Between 70% and 80% of the Lithium can be recovered with this lime-gypsum water leaching process. The cost of electricity or natural gas is the single largest item of direct costs.

In 2003, Turkish researchers estimated the cost of producing Li_2CO_3 in Turkey from domestic boron clays containing 3000ppm Lithium at $6,500 per tonne, not including capital costs. This relatively low cost was based on the owner of the boron clays (Eti Holding) using limestone they already own and gypsum waste from their boric acid plant. The market price has now risen to over $10,000 / tonne (low grade) and continues to rise. Turkey has clays in the area of Bigadic containing 2000 - 2500ppm Lithium which might therefore be able to produce some Lithium Carbonate in future, but it is only economic at current market prices and the process has not yet been tested on even a pilot scale.

No commercial scale or pilot scale Lithium extraction from hectorites or other clays has yet been performed and the automobile/ battery industries cannot factor such a speculative possibility with an unknown time scale into their planning.

3.3 Brines

Searles Lake

Searles Lake is located 200km north of Los Angeles. It is a small salt lake, only 100km^2 in area with a very porous halite body (35%) 8m thick and a high density 1.3g/cc brine. In the central section the Lithium concentration [Li] is 50-80ppm, falling to 10-70ppm at the edge. Production of salts at Searles Lake started in 1916 and in 1936 production of dilithium phosphate was commenced. In 1951, a plant was constructed to produce Li_2CO_3 to support the US thermonuclear bomb program. This production of Li_2CO_3 ceased in 1978 and in 1995 the reserves of high quality brine became depleted.

It can be seen that Searles Lake is a much less attractive resource than Clayton Valley, having at best 80ppm Lithium concentration in a small central area. The total amount of Lithium in the lake can only be low. If we take 100km^2 at 50ppm, multiplied by 8m of halite, 35% porosity and density of 1.3g/cc, the total Lithium content would be 18,200 tonnes of Lithium. This is too small a resource at too low a concentration to be economically viable.

16. Recovery of Lithium from a Montmorillonite Type Clay, RH Lien, US Bureau of Mines, Report 8967, 1985.

Great Salt Lake

The Great Salt Lake is divided into a northern and southern section by a railway causeway which crosses the lake. The northern section has a Lithium content of 40-64ppm and the southern part 18-43ppm. A system of two 20,000 acre ($81km^2$) ponds at the northern end are used to produce NaCl, MgCl and particularly potassium sulphate (K_2SO_4).

The end liquor from the magnesium plant contains 600ppm of Li and the K_2SO_4 plant has achieved 700-1600ppm of Li. Garrett states that tests have been performed on extracting this Lithium by solvent extraction or selective crystallisation - if the Lithium from the K_2SO_4 plant was recovered it could amount to 41 tonnes of Lithium metal per year.

A major difficulty in producing Lithium from the lake is the very high Mg:Li ratio of 250:1.

The Evaporation rate at the GLS and at Clayton Lake/ Silver Peak is 1,800mm per year or about half that at the Salar de Atacama.

The Great Salt Lake is estimated to contain 526,000 tonnes of Lithium. In 1978, the recoverable reserve was estimated[17] at 286,000 tonnes.

As a further comparison, the two existing 20,000 acre pond systems are filled 4 to 10 inches deep with brine during the 24 month evaporation process. At 50ppm, the total Lithium content of these ponds if filled to a depth of 10 inches would be 2,400 tonnes. However, studies have shown that only 41 tonnes could be extracted.

Salton Sea

The Salton Sea is attracting significant interest as a possible new source of Lithium production. We will examine its potential in some detail.

The Salton Sea is a salt lake 200 feet below sea level in southern California, formed in 1905 when the Colorado River burst a levee. Situated at the southern end of the lake is an area of geothermal activity, called the “Salton Sea Known Geothermal Resource Area” or SSKGRA. This geothermal resource consists of a $60km^2$ underground lake of superheated pressurised hot brine, containing $4km^3$ of brine which extends northwards under the Salton Sea. The surface lake is currently receding as more of its inflow water is used for other purposes and plans exist to expand the geothermal capacity northwards as the lake recedes, permitting access to more of the underground hot brine.

The underground brine has a Lithium content of 100 - 250ppm. The average value is taken as 200ppm, which is about the same as at Clayton Valley, Nevada. At a brine density of 1.2g/cc and an estimated

17. Evans, 1978 Op. Cit.

volume of $4km^3$, the total amount of Lithium in the underground brine would be 960,000 tonnes or 1MT in round figures.

Studies have been carried out since the 1970s into recovering minerals from this resource, which also contains metals such as lead, zinc, manganese, strontium, barium and tin. Calenergy currently operate 10 geothermal wells in the SSKGRA producing 326MW of electrical power, making this the largest geothermal power station in the USA. Wells have been added steadily since the first power plant started operating in the mid 1980s. Hot brine and steam at a temperature of 260^{o}C comes to the surface under its own pressure where it is used to drive steam turbines to generate electricity. The spent brine is then re-injected back into the underground reservoir.

FIGURE 12 **PROPOSED SALTON SEA GEOTHERMAL POWER STATIONS**

Recovery Potential

From December 2002 to September 2004, Calenergy operated a Zinc recovery plant to extract Zinc from the spent brine. They invested $285M in the plant, including a 49MW geothermal well to power the Zinc recovery operation. The projected annual Zinc production was 30,000 tonnes but only limited production was achieved despite efforts to increase production. The Zinc recovery operation was therefore shut down.

In 2003, Calenergy subsidiary Obsidian Energy obtained permission to build a separate 10 well power plant nearby with an additional 185 - 215MW capacity. Construction was supposed to commence by the end of 2008 but has now been put off by up to 3 years and will be scaled back to one or two 50-60MW plants.

The start-up company Simbol Mining now plan to develop this resource to meet the forthcoming growth in demand for automotive LiIon batteries. They intend to process spent brine from the geothermal stations and hope to reach 100,000 tpy of Li_2CO_3 production using a selective adsorption technology, similar to the strategy used by Chemetall Foote at the Salar de Hombre Muerto in Argentina. 100,000 tpy is a third more than total current global production and 6.66 times existing global battery grade (99.95%) Li_2CO_3 production. Simbol believe that battery grade Li_2CO_3 demand will grow by a factor of five (to 75,000 tpy) by 2013 which is in our view not an exaggeration - this would be sufficient for 3.3M GM Volt class vehicles.

We will now examine how much brine would have to be processed to produce 100,000 tpy of Lithium Carbonate from the Salton Sea.

100,000 tonnes of Li_2CO_3 is equivalent to 19,000 tonnes of Lithium metal.

Lithium concentrations at different wells have been measured at 117ppm to 245ppm. The recent Obsidian Energy proposal shows a Lithium content of 187ppm.

At a Lithium concentration of 187ppm, brine density of 1.2g/cc and assuming an optimistic 50% recovery efficiency, Simbol will have to process over 460,000m^3 of brine per day. Comparing this to the oil industry, this is equivalent to 2.9 mega barrels per day (2.9Mb/d), or one third of Saudi oil production and more than the UK sector of the North Sea at its peak. This production will be focused on a small geographic area 7,000 acres in extent, located in some of the USA's prime agricultural land and an area which produces much of its fruit.

It is generally agreed for the SSKGRA that 22Wh of electricity can be produced per kilogram of brine per hour. Calenergy's 326MW plant would therefore have a throughput of 14,800 tonnes or 32.6M lbs of brine per hour. Calenergy were feeding 20M lbs/hr into their Zinc Recovery Plant. Obsidian Energy stated for their 200MW proposal that their 10 wells would have a combined flow rate of 15M lbs/hr out of the reservoir but this refers to a two phase flow of steam and liquid brine combined. Only the liquid brine contains minerals. This will now be substantially reduced, to around half that flow rate when the plant is finally built.

At a Zinc concentration of 320ppm, Calenergy had a Zinc throughput of 20M lbs x .00032 = 6400 lbs/hr or 2.9 tonnes/hr. Even at 100% annual operating capacity of 8760 hours, the total Zinc throughput would only have been 25,000 tonnes before considering recovery efficiencies. It is not surprising that the 30,000tpy target could not be met.

If Simbol and/or Calenergy recommence mineral recovery from their geothermal operation, this time to extract Lithium at a concentration of 187ppm and assuming 25% plant downtime and 50% recovery efficiency, they will produce:

- ((20M lbs/hr x .000187ppm) / 2,200 lbs/tonne) x 6570hrs x 50% = 5,580 tpy of Lithium.

- The Annual Lithium Production Potential from the Calenergy Geothermal Facility on the Salton Sea would be 5,500 tonnes.
- This amount of Lithium could potentially produce 29,000 tonnes of Li_2CO_3.

If the proposed Obsidian Energy plant is also taken into consideration, assuming that the 7.5Mlb/hr of combined steam and brine is 50% liquid, the annual Lithium Carbonate production potential would be an additional 5,000 tpy for a total of 34,000 tpy of Li_2CO_3.

To compare these figures with oil industry flows, 20Mlb/hr of brine is equivalent to 1.1Mb/d of fluid.

It is very unlikely that wells would be permitted to be drilled into the geothermal resource purely to extract Lithium. Mineral recovery will only be possible in conjunction with geothermal power generation. The existing Calenergy operation causes a drop in reservoir pressure of 8psi per year. The smaller (200MW) Obsidian Energy operation would increase the pressure drop to 14psi per year. This is viewed as sustainable for the 30 year life of the plant. However, the priority for this resource is its use to generate electricity and the existing power generating companies would not allow the waste of the geothermal potential by a pure mineral recovery operation, not to mention the reduction in their own power generating capacity that would be caused by pressure reduction.

Therefore any increase in Lithium production will have to go hand in hand with further development of geothermal power generating capacity. Ultimately it is estimated that 1000Mwe of capacity could be installed, double the existing Calenergy and originally proposed Obsidian Energy plants combined. Therefore a projection of 100,000 tpy of Li_2CO_3 from this resource is probably at the top end of what may ultimately be achievable at an unknown point in the future. No pilot plant has yet been established to test the proposed Lithium recovery method and establish its viability.

A Solar Evaporation Pond system could not be used due to land constraints, a relatively low evaporation rate, the problem of disposal or processing the much greater quantity of other salts and the overriding requirement for the spent brine to be re-injected back into the geothermal reservoir. Therefore a direct adsorption technology would have to be used, as Calenergy were doing to recover Zinc and as FMC carry out at the Salar del Hombre Muerto. This approach requires fresh water to flush the captured Lithium out of the adsorption beds and recharge them. Water use is a very significant issue in this part of Southern California where increased water demands are causing the Salton Sea to shrink. The current plans for management of the Salton Sea intend to let it shrink to a certain extent, which would open up more of the geothermal resource for exploitation; however, these plans do not take into account any extra water demands from future mineral recovery operations. Water use is therefore another constraining factor that must be taken into account when considering the future Lithium production potential of the Salton Sea.

Smackover Oilfield Brines, Arkansas

The Smackover oilfield brines are an extensive underground geothermal brine lake. On top of the brine floats crude oil, with natural gas above this. Oil production commenced in the 1920s and for decades the brine was considered to be of no value. In the 1950s it was realised that the brine contained very high levels of Bromine and commercial production of Bromine commenced. The brine contains many other minerals as well including Lithium.

Garrett states: “A few of the world’s oil field waters have a medium-high Lithium content, with limited areas of the extensive Smackover brines in the US perhaps being the highest. One zone in both Texas and Arkansas has [Li] of 50-572ppm. The Texas brine has an average of 386ppm and the Arkansas brine averages 365ppm. The brine is found at a depth of 1800m to 4800m. Brines are commercially processed to recover Bromine”. Garrett estimates that the Smackover brine contains 1MT of Lithium.

The Smackover brines are currently the largest source of Bromine in the world, accounting for 40% of world production. The largest Bromine plant in the world was established there in 1961. Some 15,000 wells pump out brine and send it via a pipeline network to two processing plants where the bromine is extracted. The spent brine is then re-injected into the underground reservoir. Peak brine flows of 352Mb were reached[18] in 1997, falling to 300Mb in 1999, 321Mb in 2000 and 308Mb in 2001. Bromine production in Arkansas is under growing competition from producers on the Dead Sea.

We will now estimate how much Lithium could potentially be recovered from the brine already processed for Bromine extraction.

Taking a recent average annual brine flow rate of 320Mb and assuming an average Lithium content of 365ppm, with a specific gravity of 1.2g/cc, the total Lithium content of the brine currently processed by the Bromine industry would be 22,000 tonnes. At a 50% recovery rate, some 11,000 tonnes of Lithium could be recovered per annum from the existing brine flows.

The Smackover brines have been exploited for Bromine by numerous chemical companies over the years. The current operators are Great Lakes Chemical Company and Tetra Technologies. Neither of them have yet seen fit to commence Lithium recovery operations, despite the significantly higher concentration of Lithium in this resource than at Silver Peak, Nevada. Recovery of minerals other than Bromine has been studied. If other factors do not militate against it, this resource may

18. Arkansas Oil and Gas Commission

be one of the most promising ones to develop, given that a large scale brine extraction, processing and re-injection industry is already well established. The Mg:Li ratio is about 4 or 5 to 1. ([Mg] = 1850ppm).

- The Potential Annual Lithium Production Rate from the Smackover Bromine Brines of Arkansas would be 11,000 tonnes (55,000 tonnes LCE).

As with the Salton Sea, a solar evaporation pond system would not be viable, not least because of the need to re-inject the spent brine into the reservoir to maintain pressure. On the other hand selective adsorption technology requires a fresh water supply to flush and recharge the adsorption beds. Union County and surrounding areas in southern Arkansas where much of the brine extraction is concentrated were declared “Critical Water Use” areas some years ago due to over-exploitation of the underground Sparta Aquifer. Bromine production is one of the major users of this aquifer. In the late 1990s the USGS recommended that water use from the aquifer should be reduced by 70% to prevent irreparable damage to it with serious consequences for drinking water supply. Although steps have been taken to reduce exploitation of the aquifer, water use continues to be a high priority issue in the area.

The impact of future Lithium and other mineral recovery on water demand would therefore be additional factors that would be taken into consideration before production could commence.

Bromine production from Smackover in 2006 was 240,000 tonnes, with a total value of approximately $360 million. At a current Lithium Carbonate price of $10,000 per tonne, 36,000 tonnes of Lithium Carbonate would produce the same revenue. Approximately 7,000 tonnes of Lithium would be required to produce this. Therefore production of even quite a limited quantity of Lithium Carbonate such as 5,000tpy would make a significant contribution to revenues from the Smackover brines. The Dead Sea could not compete with Smackover in Lithium production due to its very low Lithium content (18ppm).

Bonneville Salt Flats, Utah

The famous Bonneville Salt Flats west of Salt Lake City are cited by the Bureau of Land Management (BLM) as being one of the most important natural features in Utah. They attract thousands of visitors each year. The subsurface brines contain 20-60ppm of Lithium and the Magnesium concentration is 4000ppm. The Mg:Li ratio is therefore in the order of 100:1.

Potash (KCl) has been produced at Bonneville since 1917. Intrepid Potash operate the remaining potash recovery facility at Wendover with 8,000 acres of solar evaporation ponds into which they pump 5 billion gallons of brine per year[19]. Intrepid have invested several million dollars

19. www.intrepidpotash.com/loc/wendover.html accessed 15/05/08.

and cooperate with the BLM to pump salt back onto the flat to combat salt loss from the lake bed.

Intrepid are the largest producer of potash in the USA and this Wendover facility has capacity for 120,000 tonnes of potash per year. They also produce Magnesium Chloride, due to the high Magnesium content.

At 40ppm, the 5 billion gallons of brine processed every year contain some 900 tonnes of Lithium. At an optimistic 50% recovery, some 2,000 tonnes of Lithium Carbonate Equivalent could be produced each year from the current operation, compared to Potash production 60 times as high.

- The Potential Annual Lithium Production Rate from the Bonneville Salt Flats of Utah would be 450 tonnes or 2000 tonnes LCE.

Lithium recovery from the Bonneville potash operation has been studied[20]. The potash end liquors reach a Lithium content of 5000ppm. Process tests allowed bischofite to be harvested throughout the year, involving complex heating and cooling of the liquors. The very high Mg:Li ratio means that recovery of high purity Lithium is very difficult.

In 1985 the Bonneville Salt Flats were designated an Area of Critical Environmental Concern due to their unique geology, history and scenic beauty[21].

Dead Sea

The Dead Sea has a Lithium concentration of only 10 - 20 ppm and very high ratios of other minerals. The Mg:Li ratio is 2000:1. The brine is concentrated in solar ponds in Israel and Jordan to produce potash and the end liquor often has Lithium levels of 30ppm. Laboratory studies have been carried out [Garrett, 2004] into extraction of this Lithium without economic success.

Other Chilean/ Argentinian/ Bolivian Salars

There are many other salars in the Andes which have been surveyed for their Lithium potential. The best ones are covered in the literature (Garrett, 2004). These range in Lithium content from 150 to 400ppm. For instance, the Salar de Surrie lies to the south of the Salar de Atacama at an elevation of 4,480m (14,700 feet). It is 150km^2 in area and has a Lithium content of 340 - 389ppm. Evaporation rates will be much lower and irreversible environmental damage inevitable to a remote unspoiled region. The Salar de Lagunos has an [Li] of 412ppm. The absolute size of both resources is very small in comparison with Atacama or Uyuni. The Salar de Copaisa in Bolivia, north of Uyuni,

20. US Patent 4,287,163 DE Garrett, M Laborde, 1981
21. www.utah.com/playgrounds/bonneville-salt.htm, accessed 15/05/08.

covers 2,500km^2 and contains only 200,000 tonnes of Lithium. The concentration is therefore very low.

China

The Chinese salt lakes have been studied extensively for their potential Lithium and other mineral resources. Garret cites Lithium resources for the Zhabuye Salt Lake and Qinghai (Taijinaier) Salt Lake of 1MT each. Zhabuye contains 500-1000ppm of Lithium, has been extensively studied for its Lithium extraction potential and a 5,000 tpy Li_2CO_3 plant started operation in 2005. Potash has been extracted in Qinghai for many years and studies on extracting Lithium date back to 1983. The large 35,000tpy Li_2CO_3 plant opened in Golmud (Qinghai) in 2007 will take some time to reach full capacity.

A factor that could be considered in the light of recent events is the status of Tibet. The Tibetan-in-exile group "Stop Mining Tibet" seeks to lobby public opinion against western mining companies to cease operations in Tibet, on the grounds that the Tibetan people receive no benefit from the exploitation of their mineral resources by the Chinese occupants. Sterling Group Ventures who are developing the DXC salt lake resource are one of the companies specifically cited by this organisation.

3.4 Seawater

Seawater has been promoted as a virtually inexhaustible source of Lithium since the 1970s. We now examine the Lithium extraction potential of Seawater.

As a comparative yardstick, let us consider the River Nile, one of the largest rivers in the world.

The Average Discharge Flow Rate of the River Nile is 300,000,000 cubic metres of water per day. This is 22.2 times the flow rate of the entire Global Oil Industry (85Mb/d).

The density of Seawater is 1.206 tonnes per cubic metre.

Therefore if the Nile was Seawater, the flow rate in weight terms would be 360M tonnes per day.

Seawater contains 0.17ppm of Lithium by weight.

Therefore a flow of Seawater equivalent to the River Nile would contain 61.5 tonnes of Lithium per day.

In one year, a flow of Seawater equivalent to the River Nile would thus contain 22,500 tonnes of Lithium, or about the same as current Global Contained Lithium Production.

If all the Lithium could be extracted and converted to Battery Grade Lithium Carbonate, this would be sufficient for

22500 tonnes x 5.28 x 1000kg / 16kWh x 1.4kg

or 5,300,000 GM Volts per year.

In recent laboratory scale tests on extracting Lithium from Seawater, Saga University in Japan extracted 30g of Lithium Chloride (LiCl) from 140,000 litres of Seawater.

140,000 litres of Seawater contains 28.7g of Lithium.

30g of LiCl contains 5g of Lithium.

Therefore some 17.4% of the Lithium in Seawater was extracted by this process.

This means that to produce enough Lithium Carbonate from Seawater for 5.3M GM Volts one would need to process not One River Nile but Five River Niles of Seawater each year (not counting subsequent yield losses for producing the high purity Li_2CO_3 required).

So an equivalence can be established between One River Nile and One Million GM Volts per year.

- One River Nile Flowrate of Seawater or 22.2 times the Continuous Flowrate of the Global Oil Industry is required to produce Sufficient Lithium for One Million GM Volts.

This does not take into account the volumes of fresh water and Hydrochloric Acid required to flush out the unwanted minerals and extract the Lithium from the Lithium Manganese Dioxide adsorption columns.

Let us compare this to Global Oil Production of 85 million barrels per day.

One Barrel of Oil contains 42 US Gallons, giving a Total Daily Oil Volume of 85M x 42 = 3,570 Million US gallons per day or 13.5 Million cubic metres per day.

Therefore the Total Flow Rate of the entire Global Oil Industry is 13.5M cubic metres per day or less than one twentieth of the 300M cubic metres of Seawater that would need to be processed just for 1M cars.

- A Seawater processing rate equivalent to the entire Global Oil Industry would produce sufficient Lithium at 100% Extraction Efficiency for 45,000 GM Volts per year

If the Global Oil Industry was to process 85Mb/d of Seawater instead of Oil, the Total Lithium Content would be 2.77 tonnes per day or 1000 tonnes per year - one twentieth of existing world Lithium production even before the real extraction efficiency of 20% and Li_2CO_3 purification losses are taken into account. At a realistic recovery efficiency, some 6,000 GM Volts at the most could be produced per year from a Seawater flow rate equivalent to the entire global oil industry.

It is clear that Seawater will never be a viable source of supply for meaningful quantities of Lithium.

If production was established at the Dead Sea where the Lithium concentration is 18ppm or 100 times higher than in Seawater, then some 300 tonnes of Lithium per day would pass through a processing plant with a volume capacity equivalent to the entire current Global Oil Production of 85Mb/d, processing some 16 million tonnes of brine per day. At 20% extraction and conversion to battery grade Li_2CO_3, this would be sufficient Lithium for less than 5M GM Volts per annum. The engineering scale of the operation could only be described as Pharonic.

4 Production and Market Factors

4.1 Introduction

This chapter summarises the main Lithium producing resources and estimates potential and possible Lithium Carbonate Equivalent (LCE) production in 2010 and 2015.

Since the early 1990s, global LCE production has increased from less than 50,000 tonnes per year to reach 80,000 tpy or more. Batteries now account for about 20% of total Lithium metal demand.

Total Lithium demand has therefore been growing at 4-5% p.a. but more recently demand from the battery sector has been growing at 25% p.a., leading to ongoing shortages of supply. This shortage is leading the existing producers to increase production and prompting others to consider entering the market, before demand from the automotive industry has even commenced.

Consideration of future availability of Lithium for the automotive industry therefore needs to consider a number of factors:

1. Future overall production and supply of Lithium Carbonate.
2. Production of the high purity Battery Grade 99.95% Li_2CO_3 required for (PH)EV applications.
3. Competition for Lithium products by other, established, market sectors.
4. Security of supply and reliability of suppliers.
5. Potential price volatility.
6. Environmental sustainability and compatibility with the concept of the "Green Car".

After presenting an analysis of production potential from already producing and possible future Lithium resources, this chapter proceeds to discuss these other factors of equal importance in evaluating the suitability of Lithium as a strategic material for the automotive industry.

4.2 Lithium Carbonate Production

The table below summarises the main Lithium Resources, Recoverable Reserves and Potential Chemical Grade Lithium Carbonate production to 2020.

TABLE 4 **LITHIUM RESOURCES/ PRODUCTION ASSESSMENT**[a]

Deposit	Resource (Li metal)	Reserve (Li metal)	Current Li_2CO_3 Production 2007	Probable Li_2CO_3 Production 2010	Optimum Li_2CO_3 Production 2015	Optimum Li_2CO_3 Production 2020
Lithium Brines						
Salar de Atacama	3.0MT	1MT	42,000	60,000	80,000	100,000
Hombre Muerto	0.8MT	0.4MT	15,000	15,000	20,000	25,000
Clayton Lake	0.3MT	0.118MT	9,000	9,000	8,000	8,000
Salar del Rincon	0.5MT	0.25MT	-	10,000	20,000	25,000
Salar de Uyuni	5.5MT	0.6MT	-	-	15,000	30,000
Zhabuye	1.25MT	0.75MT	5,000	10,000	20,000	25,000
Qinghai	1.0MT	0.5MT	10,000	20,000	40,000	50,000
DXC	0.16MT	0.08MT	-	5,000	5,000	5,000
Salar Olaroz	0.32MT	0.16MT	-	-	5,000	5,000
Salton Sea	1.0MT	-	-	-	5,000	10,000
Smackover	1.0MT	-	-	-	10,000	25,000
Bonneville	-	-	-	-	-	
Searles Lake	0.02MT	-	-	-	-	
Great Salt Lake	0.53MT	-	-	-	-	
Dead Sea	2.0MT	-	-	-	-	
Minerals						
Greenbushes			-	-	-	-
Bernic Lake			-	-	-	-
Osterbotten			-	1,000	6,000	-
Bikita			-	-	-	-
Hectorite Clay			-	-	-	-
Jiajika			-	-	-	-
Brazil			-	-	-	-
Total		**4MT**	**81,000**	**130,000**	**234,000**	**308,000**
Non-Automotive Demand (High)			**85,000**	**109,000**	**203,000**	**263,000**
Available for Automotive			**-**	**21,000**	**31,000**	**45,000**

a. Figures in tonnes except MT = Megatonnes

The table shows current LCE production in 2007, likely production in 2010 and possible production in 2015 - 2020.

The figures for 2010 are what we estimate to be a reasonable and realistic forecast based on known current developments.

The figures for 2015 and 2020 are optimistic projections (High Production in the following scenarios) based on an optimum conjunction of events to develop new resources and smooth development of resources already under exploitation.

China

The most significant increase in Lithium Carbonate production planned over the next 5 to 10 years is in China. The Chinese are projecting a very large increase in production to 55,000tpy of LCE by Citic Guoan at Qinghai (Taijinaier) alone by 2010. We have chosen to be more realistic in our assessment. Much of this increase may be destined for domestic consumption and the nascent Chinese EV industry. It is also more difficult to produce battery grade Li_2CO_3 from brine sourced Lithium Carbonate than it is from hard rock mineral produced Lithium Carbonate. Although brine sourced Li_2CO_3 is much cheaper than that produced form minerals (spodumene) it has higher level of impurities (sodium, boron, calcium, magnesium) and is more technically demanding to purify. As the Chinese switch from Li_2CO_3 produced from imported or domestic spodumene to Li_2CO_3 produced from domestic brine, new and more complex processing will have to be established. This may account for reports that Chinese sourced Li_2CO_3 is no longer being accepted by Japanese LiIon battery manufacturers due to contamination with impurities. The largest manufacturer of laptop computer batteries, Sony, produced 20 million LiIon laptop batteries in 2007, accounting for 25% of the market. They had to recall 10 million of them due to quality problems - one eighth of all the laptop computer batteries sold worldwide. This was the largest such recall to date. Therefore production of LiIon batteries will not necessarily increase simply in accordance with extra Lithium Carbonate production.

Other Areas

Outside of China, the Salar de Atacama remains the main location where Lithium Carbonate production may be able to be increased significantly over the next 10 years, but at great environmental cost. Successful large scale production from the Salar de Uyuni is not a fait accompli - production is unlikely to reach current Atacama levels for many years.

The most attractive undeveloped resource outside South America may be the Smackover Brine of Arkansas. This has a relatively high [Li] of 365ppm and a large brine processing and bromine extraction industry is already in place.

4.3 Current Lithium Market Factors

Existing Market Demand

20% of the Lithium produced today is used by the battery sector, an increase from 9% in 2000. Batteries are the fastest growing source of Lithium demand, increasing by 25% CAGR according to Roskill Information Sources.

This is borne out by the global increase in demand for laptop computers and mobile telephones. Some 78 million laptop computers were sold in 2007, a 23% rise over 2006. In April 2008, Quanta Computer, the world's largest contract laptop computer manufacturer, increased their 2008 sales forecast[22] from 36M to 40M units, versus 32M units sold in 2007. This is a 25% increase over 2007.

In early May 2008 it was reported that a shortage of LiIon batteries is restricting laptop computer sales[23].

The potential for further growth is illustrated by the One Laptop per Child (OLPC) foundation project to supply each of the 2 billion children in the developing world with a $100 laptop computer. OLPC have placed a contract with Quanta to commence manufacture. Other companies are also developing ultra low cost laptops and this sector is seen as a new high growth market. Shipments of laptop computers could easily continue to grow by 25% or more for many years, fuelled by these new low cost products. At 80M units per year, it would take 25 years to supply 2 billion laptops. If the OLPC project is serious, production of 200M laptop computers per year for the OLPC market alone would be required, not including growth from the existing market and other new markets.

Similarly, mobile phone sales have increased as follows: 2003 - 517M; 2004 - 670M; 2007- 1,114M; 2008 (projected) - 1,225M. New products such as 3G phones and the myriad of other portable devices will continue to fuel high growth rates.

It can therefore be seen that Lithium demand from the existing battery sector will continue to grow by at least 25% per annum, far outstripping overall Lithium market growth of 4-5% p.a.

In a recent presentation, Admiralty Resources comment that expanding Lithium production may still not meet global demand (from existing applications) and that current market conditions suggest a 30% shortfall in supply of Li_2CO_3.

22. www.pcworld.com/businesscenter/article/145259/ worlds_largest_laptop_pc_maker_raises_shipment_target.html, accessed 23/05/08.

23. www.channelregister.co.uk/2008/05/06/batteries_compal_shortage/ “Battery shortage leaves Compal Forecast Flat”, 6/05/08, accessed 23/05/08.

Talison Minerals (owner of the Greenbushes mine) also reported in late 2007 that they could have sold an extra 5kT LCE of mineral concentrates if it had been available, as demand for heat resistant cooking tops in Europe continues to increase.

Market Projection Scenarios

If battery grade Lithium Carbonate Demand from existing applications continues to grow at 25% CAGR, the effects on availability for automotive applications will be very significant.

In the following table, we show the effect of Lithium Carbonate demand from the existing battery sector continuing to grow at 25% CAGR while other existing market applications continue to grow by 3-4%.

TABLE 5 **POTENTIAL EXISTING LITHIUM CARBONATE APPLICATIONS DEMAND (NON-AUTOMOTIVE)**

Year	Battery Grade Li_2CO_3 Demand (tonnes)	Other Grade Li_2CO_3 Demand (tonnes)	Nominal Li_2CO_3 Demand (tonnes)	Battery Market Share
2006	15,000	60,000	75.000	20%
2007	18,750	63,000	81,750	23%
2008	23,400	66,000	89,400	26%
2009	29,300	69,000	98,300	30%
2010	36,600	72,600	109,200	33%
2011	45,800	76,000	121,000	38%
2012	57,220	79,700	136,900	42%
2013	71,500	83,500	155,000	46%
2014	89,400	87,400	176,800	51%
2015	111,700	91,000	202,700	55%

We projected earlier than total chemical grade Li_2CO_3 production could, under optimum conditions, reach 234,000 tonnes in 2015. This would leave only some 30,000 tonnes of Chemical Grade Li_2CO_3 available for automotive use in 2015, including Chinese production (and assuming battery grade processing capacity also rises accordingly and not taking into account process yields on purifying chemical grade into battery grade Li_2CO_3). This would be sufficient for a maximum of 1.3 million GM Volt class vehicles worldwide including Chinese supply.

If production follows a more conservative growth profile (Low Production Scenario), with no development of untried resources such as the Salton Sea and Smackover Brines and environmental constraints limiting growth at the Salar de Atacama and the Salar de Uyuni, global Li_2CO_3 production might well reach only 170,000 tonnes by 2015 and 220,000 tonnes by 2020.

Current market supply is so tight and the potential sources of supply are so limited that relatively small variations in the amount of Lithium Carbonate produced in future from each resource have a major impact on future automotive availability.

Figure 13 shows these relative scenarios up to 2015, in which demand continues to be fuelled by high growth from the global portable electronics society, as well as a low demand growth scenario.

FIGURE 13

LCE NON-AUTOMOTIVE DEMAND AND TOTAL SUPPLY

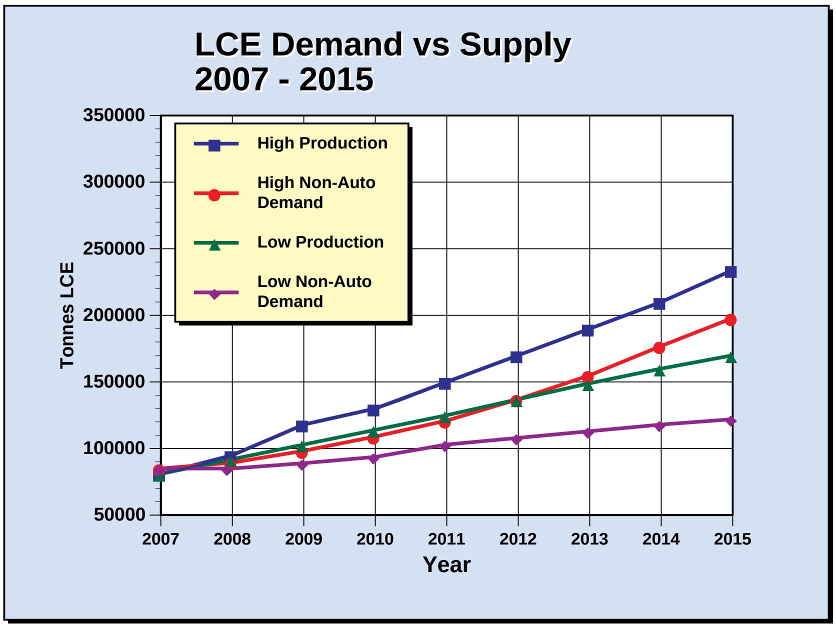
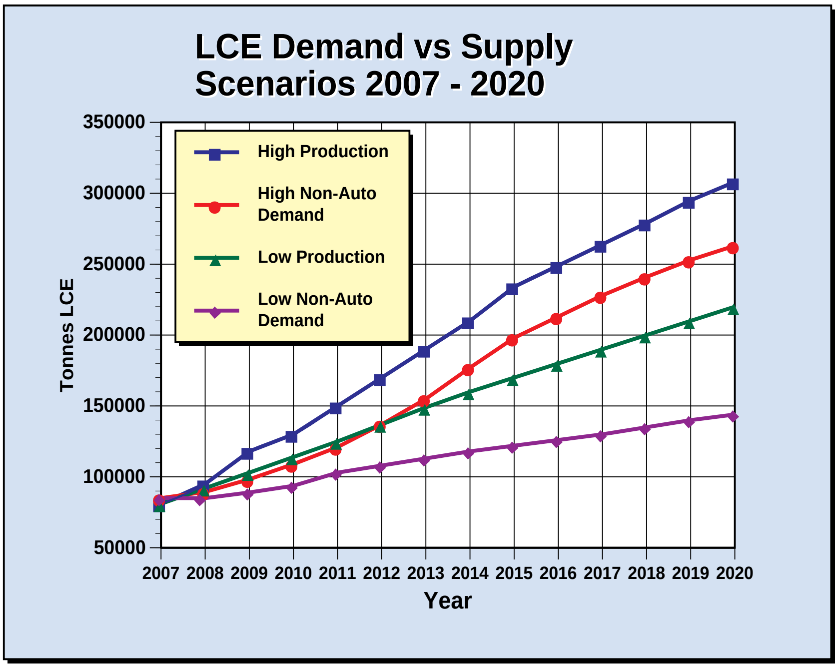


Figure 13 shows that a continuation of current high growth in portable electronics LiIon demand combined with a more constrained production growth scenario will lead to insufficient supply for existing markets in 2013.

In Figure 14 below, we show the following scenarios out to 2020:

1. The High Non-Automotive Demand Scenario encounters sharply reduced portable electronics demand after 2014 so that the overall LCE demand increase falls to 4% p.a. again by 2020.
2. Low Non-Automotive Demand Scenario - very conservative growth in existing LCE market demand from 2007 - 2020 of 4% p.a., i.e. a continuation of the historical 1990 - early 2000s LCE growth rate.
3. High Production nearly quadrupling and Low Production nearly tripling current LCE production from 2007 to 2020.

FIGURE 14 **LCE NON-AUTOMOTIVE DEMAND AND TOTAL SUPPLY - 2020**



- In the High Production scenario combined with High Non-Automotive Demand driven by continued growth in the global portable electronics society, some 30,000 tonnes of Li_2CO_3 will be available for automotive use in 2015 and (with sharply reduced growth rates after 2014) 45,000 tonnes in 2020.
- In the best case combination of the High Production scenario combined with the Low Non-Automotive Demand scenario in which existing LCE demand grows overall at only 4% p.a. from 2007 to 2020, some 110,000 tonnes of Li_2CO_3 will be available for automotive use in 2015 and 160,000 tonnes in 2020. This would be nominally sufficient for 5M and 7.5M GM Volt class vehicles respectively.
- In the Low Production scenario where environmental factors are not disregarded and untried new resources take time to develop combined with the conservative Low Non-Automotive Demand Scenario (4% growth p.a.), some 50,000 tonnes of Li_2CO_3 will be available for automotive use in 2015 and 80,000 tonnes in 2020. This would be nominally sufficient for 2.2M and 3.6M GM Volt class vehicles respectively.
- If LCE demand growth in the High Non-Automotive Demand scenario does not slow down after 2014, it will outstrip even the High Production scenario well before 2020.

Production of Battery Grade (99.95%) Lithium Carbonate

The chemical grade Lithium Carbonate produced from brine and previously from spodumene is not suitable for use in batteries. It must be further purified to at least 99.95% purity.

The processes used to produce this high purity Battery Grade Lithium Carbonate from Chemical Grade involves several reaction and recrystallisation steps plus in some cases passing through an ion exchange resin[24] to produce the ultra high purity product. Process losses occur on each step.

The highest yield that might be expected with these processes[25] is about 70%. Therefore it is possible that only 70% of the primary Lithium Carbonate production may be processed into high purity battery grade reagent. Unpurified Li_2CO_3 is recirculated back to improve yields, but then there are further yield losses in producing the battery electrolyte salts used in LiIon batteries ($LiPF_6$ and $LiBF_4$).

Therefore it may be prudent to reduce the gross Lithium Carbonate production and potential figures in this report by 30% to account for processing losses into battery grade material suitable for Electric Vehicles.

Production Factors

SQM are investing $52M in their Antofagasta Lithium Carbonate plant to increase capacity from 32,000 tpa to 48,000 tpa. This does not include extra raw material imports (soda ash), extra tanker trucks to bring the LiCl brine down from the Salar de Atacama nor the increased number of extraction pumps and increased evaporation pond area required. The brine tankered from the evaporation ponds to the Li_2CO_3 plant contains 6% Lithium; therefore the volume will increase from 85,000m^3 to some 130,000 m^3 per year, with a 50% increase in tanker road traffic.

To produce 1 ton of Li_2CO_3, more than three times that weight of LiCl brine has to be tankered down from the Salar and 1.8 times as much weight of Soda Ash has to be imported. Therefore nearly 5 times as much weight of material has to be transported to the plant as leaves it in finished product.

As we have illustrated, it seems likely that 50% of the very best Lithium deposit in the world, the 3000- 4000ppm heart of the Salar de Atacama, has already been extracted. Certainly, at least 20% has been extracted. If 50% has been extracted, only some 500,000 tonnes LCE remains in the high concentration core, which by now will be much lower in concentration than in 1984. It is probable that in the next decade, increasing investment and resources will be required to maintain production. If the current [Li] is 3,000ppm, then extending production

24. See US Patent 7,214,355 for a description of various processes
25. See US Patent 6,592,832

into the wider areas of the salar where [Li] is 1500ppm will require double the number of wells and area of ponds for the same production. Environmental Impact Assessments will be required beforehand. The environmental impact would undoubtedly be severe.

We have also illustrated that the highest grade central Lithium node in the Salar de Uyuni contains only 500,000 - 600,000 tonnes of Lithium, in a much more spread out and thin deposit than the Salar de Atacama. A trench system of production similar to that at Bonneville may have to be adopted causing significant environmental damage. It is evident that the vast majority of the 5MT to 9MT resource in the salt pan remains inaccessible without destruction of the salar.

It must also be remembered that Lithium Chloride (and subsequently Lithium Carbonate) is not produced from brines in isolation. The major product of these operations are potassium and magnesium salts, which in any case have to be precipitated out as solid and removed before Lithium Chloride can be produced. In 2001, SQM produced 650,000 tonnes of potash (KCl), 150,000 tonnes of K_2SO_4 and only 21,000 tonnes of Li_2CO_3.

ADY's main bulk products at the Salar del Rincon will be KCl and Na_2SO_4.

Therefore the issue will arise of marketing the other salts in a competitive market and the cost of producing them and disposing them back in the salar if they cannot be sold. Once the other solid salts have been precipitated out, they cannot be easily disposed of back in the salar but only left on the surface. Therefore increased Lithium Carbonate production cannot be considered in isolation from the major global market for muriate of potash (KCl) and other salts.

Battery Recycling

The European Union have set a mandatory target for 45% of portable equipment batteries in the EU member to be recycled by 2016.

In 2006, 20% of all batteries were recycled; however, the number of LiIon and NiMH batteries recycled fell compared to the previous year. LiIon recycling fell from 635 tonnes in 2005 to 547 tonnes in 2006. The level of recycling in the Eastern European member states is particularly low.

As with all EU directives, there are widespread concerns that the 2016 target will not be met.

There are no such recycling directives in the USA.

4.4 Conclusion

It is apparent that if Lithium Carbonate demand from the portable electronics sector continues its current high growth rates during the next decade, intense competition will arise between the automotive industry and the electronics industry for supply of LiIon batteries. Planned and possible Lithium Carbonate production increases will not be able to meet demand from both sectors. The portable electronics sector is experiencing chronic shortages of Lithium today and its growth prospects, driven by new low cost products aimed at new multi-billion unit markets, do not appear to be undimmed.

Foreseeable Lithium production increases may be able to more or less match demand from the growing portable electronics society until 2015, at the risk of causing permanent environmental damage to the Andean Altiplano.

Realistic Lithium production increases have no prospect of also meeting the demands of an entire product and propulsion revolution in the Global Automotive Industry in the next decade.

Even if non-automotive Lithium demand was to level off at 120,000 tpy in the mid 2010s (50% higher than current demand), the level of surplus Li_2CO_3 possibly available in the optimistic High Production Scenario in 2015 could only meet demand for 4 to 5 million GM Volt class vehicles and up to 8 million GM Volt class vehicles worldwide in 2020, or a small fraction of global automotive requirements.

Finally, new Chinese brine-sourced Li_2CO_3 cannot necessarily be relied upon by battery manufacturers in other parts of the world, for quality reasons, domestic EV demand and Chinese policies to reduce exports of strategic materials as currently experienced with rare earth metals.

5 The Wider Environment

5.1 Geopolitical Environment

In Chile, exploration and exploitation of Lithium is considered a strategic activity and along with offshore hydrocarbons and the production of nuclear energy, is the sole preserve of the state. In 1982, Chile passed a law ruling that as a strategic material Lithium could not be awarded in concession to private entities. Under the Chilean Constitution, Lithium is State Property. There have been moves by the Chilean Senate's Mineral Committee to investigate the concessions awarded to SQM and SCL for Lithium extraction under previous Governments. Technically, they might be illegal. Certainly Chile, Argentina and Bolivia are well aware of the strategic implications of Lithium both for automotive batteries and for future nuclear power technologies. Lithium was used in the first fusion bombs and is still used for this application. Both Lithium 6 and 7 would be used in a future magnetically confined "hot-fusion" technology. In 2006, construction of the international ITER fusion research centre at Cadarache in France was agreed and fusion with a Lithium plasma will be one of the research avenues.

Chile has proposed the establishment of an "Institute of Lithium" to bring together SQM, SCL and Lithium users with the Chilean Atomic Energy Commission to look at development of Lithium industries in the country, such as Li-Al alloys, LiIon batteries, Nuclear Fusion and Cement. With their market leading position of 36% of global Li_2CO_3 supply and the best resource in the world, there is likely to be renewed impetus to develop value added products from their Lithium resources.

In Argentina, the incoming Kirchner government have imposed a 10% export duty on all mineral exports to boost government receipts. Everywhere in South America, the people are demanding accountability, a much greater financial return from the exploitation of their immense mineral wealth by foreign companies and protection of the environment. Salta Province in Northern Argentina, where the two Lithium salars are located, is described by local activists as being in a state of war against the "mining invasion".

A cause celêbre in Chile is the Pascua Lama gold mine project by Barrick Resources. Barrick intended to "remove" three glaciers to gain access to the gold deposit, depriving 70,000 farmers of their water supply from the glacier melt water. The agriculture of an entire valley would be devastated. Needless to say, this does not endear foreign mining companies to the local populace. Despite receiving an environmental permit the project has not yet been able to proceed.

In Brazil, all lithium-related activities such as the industrialisation, import and export of lithium minerals, production of organic and inorganic chemical products and alloys are controlled by CNEN (Nuclear Energy National Commission) due to its nuclear applications.

It is apparent that Lithium will become a more and more strategic material. The South American nations intend to develop free of what they perceive as post war US neo-colonialism as evidenced by the new wave of political leaders who have been swept to power in recent years: not just Hugo Chavez, Evo Morales or Luiz de Silva but also Michelle Bachelet in Chile and Cristina Kirchner in Argentina. In Chile, the largest producer of Lithium in the world with the best quality resource, Lithium is legally State Property. Just as Resource Nationalism is increasingly being felt from the oil producing countries who are increasing their own consumption and reducing exports to conserve oil for future requirements, Chile, Bolivia and Argentina may well follow the same path. South America will also require electric vehicles and might decide Lithium is worth more to them to maintain their own motive power. Chile’s current Lithium Carbonate production of about 45,000 tonnes could nominally support manufacture of 2M GM Volt sized 16kWh batteries per year. Future production increases could support a domestic LiIon battery industry. Chile and Argentina may have sufficient leverage in future to persuade foreign LiIon battery manufacturers to establish local production facilities in return for privileged access to Lithium Carbonate.

In April 2008, the US Navy reactivated its Fourth Fleet to patrol Latin American and Caribbean waters. The fleet was dissolved in 1950 after the Second World Water but is being revived to send a signal to the socialist governments of South America. Ecuador intend to shut down the US military base in the country and both Brazil and Argentina have protested about US plans to install a new military base in Paraguay near the Bolivian gas fields. Latin America could be self sufficient in oil for many years should it choose to reduce exports. The idea of a South American Defence Council has been relaunched by Brazil, specifically excluding the USA.

The trend is clear. The supply of 70% of the world’s Lithium 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: indeed there is a very strong backlash in Latin America against the real or perceived neo-colonialism of US foreign policy.

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 politically 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.

China's Lithium brine deposits are located in Tibet. This is also a politically sensitive region. While there is no doubt that stability will be maintained and there is no physical risk to Li_2CO_3 supply to the Chinese LiIon battery industry, an ethical and moral issue might arise in basing Electric Vehicles on Lithium from Tibet.

With much of the world's Lithium Ion battery manufacturing capacity installed in China and China's growing need for sustainable oil free transportation, it would not be surprising to see China prioritise its own EV industry. Planned Chinese Lithium Carbonate production increases could easily be absorbed by a domestic EV industry, leaving little available for export. As the dollar becomes weaker there becomes less and less incentive to export to the USA.

From a security point of view, the USA could redevelop its domestic Lithium resources and set up domestic LiIon battery manufacturing capacity as a strategic asset if the automotive industry intends to rely on LiIon batteries as the sole solution rather than also adopting other battery technologies which use unconstrained resources.

5.2 Nuclear Fusion

This report will not consider in detail the extra demands a future Nuclear Fusion infrastructure would place on Lithium supply. However, the ITER reactor under construction at Cadarache in France will test the concept of using Lithium to breed Tritium for subsequent fusion with Deuterium. Various figures have been quoted in the industry stating that a 1GW power station would require a Lithium blanket weighing 146 tons, replaceable 5 times during the reactor life and would consume 3 tons of Lithium per annum. US installed electrical power capacity is approximately 460GW.

Lithium will be used to produce tritium in magnetically confined nuclear fusion reactors using deuterium and tritium as the fuel. Tritium does not occur naturally and will be produced by surrounding the reacting plasma with a 'blanket' containing lithium where neutrons from the deuterium-tritium reaction in the plasma will react with the lithium to produce more tritium. ($^6Li + n > {}^4He + {}^3H$). Various means of performing this will be tested at the ITER reactor.

Other figures state that 2MT of Lithium would be required over 20 years just to replace current fission reactors and operate those new Fusion Reactors. This would be between 30% and 50% of Global Lithium Reserves.

5.3 Environmental and Ecological Factors

Lithium is a rare and scarce metal found only in significant quantities in two remote, unspoiled and fragile parts of the Earth: the Andes and Tibet. The Salar de Uyuni is quite justifiably recognised as a Natural Wonder of the World. To extract enough Lithium to meet even 10% of global automotive demand would cause irreversible and widespread damage to these environments, that have taken millennia to form. On the other hand, the alternative and superior battery technologies of ZnAir and Zebra (NaNiFeCl) depend on common metals and materials that are already the mainstay of industrial civilisation and found ubiquitously.

The concept of the “Green Car” is incompatible with the fact that if LiIon batteries are used to propel it, it will be produced at the expense of two of the most fragile and beautiful ecosystems that are left on this planet. The degradation of the salars and effects on their wildlife will be hard to defend and justify, when it was completely avoidable by using metals that are already well established in our industrial infrastructure.

It would be irresponsible to despoil these regions for a material which can only ever be produced in sufficient quantities to serve a niche market of luxury vehicles for the top end of the market. We live in an age of Environmental Responsibility where the folly of the last two hundred years of despoilment of the Earth’s resources are clear to see. We cannot have “Green Cars” that have been produced at the expense of some of the world’s last unspoiled and irreplaceable wilderness. We have a responsibility to rectify our errors and not fall into the same traps as in the past. This means using materials and resources which cause an absolute minimum of environmental damage and which allow Electric Vehicles to be produced not for a niche market but for the mass market.

6 Conclusion

Realistic analysis of the world's Lithium deposits and potential sources shows that maximum sustainable production of battery grade Lithium Carbonate will only be sufficient for very limited numbers of Electric Vehicles. Projections of overall Lithium Carbonate production must take into account that a much higher purity of 99.95% is required for LiIon battery production. Therefore battery grade Li_2CO_3 availability will further lag behind overall industrial Li_2CO_3 production.

Existing demand for Li_2CO_3 for portable electronics batteries is stretching the ability of the Lithium producers to keep pace even before the first automotive batteries 100 times as large as a laptop computer battery reach the market.

If all future Li_2CO_3 production increases are purified into battery grade material, it will still only be sufficient in the most optimum scenario for at most 4 to 8 million GM Volt class vehicles worldwide per annum by 2015 - 2020.

It appears that at least 20% and quite possibly as much as 50% of the highest grade Lithium deposit in the world, within the Salar de Atacama, has already been extracted at a production rate 10 times lower than that required to sustain automotive industry requirements.

The Salar de Uyuni is a very thinly dispersed resource and its realistic producible Lithium reserve is only in the order of 300,000 tonnes. This combination of factors at the two largest Lithium salt deposits means that great caution and realism must be exercised in forecasting potential future global Lithium production volumes.

Increasing Lithium Carbonate production significantly will destroy some of the most beautiful and unique ecosystems in the world for a material that can only supply a niche automotive market. LiIon powered cars are not "Green Cars" but Environmentally Destructive Cars.

The geopolitical scenario of a world outside China being dependent on the Lithium Triangle of Bolivia, Argentina and Chile for nearly all of its future Lithium Carbonate supply should be sufficient in itself to give pause to the headlong adoption of LiIon batteries by the automotive industry.

