World Lithium Resource Impact on Electric Vehicles

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The electric vehicle industry and movement have recently come under fire for reliance on lithium (Li) based batteries. Some experts suggest that there is plenty while other experts suggest there is not. Big surprise. But are we even asking the right question? Extensive research into sources of lithium production and supply suggest that there is no shortage of Li for, minimally, the next ten years. This is more than enough time to jump-start the electric vehicle (EV) revolution. The question should be: is it responsible to create a single resource reliant industry? If not, what is the new question and the right answer?

In this paper we will address the lithium supply debate to reconcile the diametrically opposing viewpoints of the experts using supply calculations, clarification of definitions, lithium mining and production and the economics of lithium products. We will further argue that it is not responsible to create another (oil being other) single resource based industry *but* that no proponent (to our knowledge) of electric vehicles is suggesting that should be the case. We suggest that the new question should be: once we provide the impetus to move away from an oil-reliant industry, what should the next steps be and how does lithium play a part in the larger plan?

However, to get there, there must be a path. We will demonstrate that there is sufficient Li in the earth's resources to power a shift away from oil-reliant automobiles. Once the EV revolution is underway, 1) it does not (and should not) have to be entirely Li reliant and 2) the economics of battery recycling will improve with volume to the point where the Li retained in the energy cycle reduces the need for further input to the point of sustainable levels. Additionally, we will discuss varying battery chemistries: diversifying fuel sources is fundamental to the entire ideology of the green energy movement. There is not, and should not be, one answer.

Lithium Supplies

Definitions of Earth Resource Quantities

Current debate in the electric vehicle (EV) market is fueled, so to speak, by contested estimates of the ability of the world's lithium supply and production to support the projected replacement of the current global vehicle market. The current lithium supply debate was initiated by a paper from William Tahil of Meridian International Research (MIR) titled, "The Trouble with Lithium: Implications of Future PHEV Production for Lithium Demand."[1] This was followed up with "The Trouble with Lithium 2: Under the Microscope"[2] by MIR in May 2008. A rebuttal paper, written by retired geologist Keith Evans titled, "An Abundance of Lithium,"[3] issued in March 2008, was the first high profile challenge to this assertion. Evans, a geologist by profession, has been involved with the lithium business since the 1970's and has represented several lithium mining companies. Evans and MIR rely on estimates of production (in terms of both infrastructure and usability) as well as total earth resources. There is a significant distinction to be made here since the arguments based on those estimates are somewhat different. Production increase keeping

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pace with demand is an infrastructure capacity problem: will the lithium mining companies be able to physically increase the amount of lithium coming out of their mines to keep pace with global demand during the projected EV shift? The global resource estimate is stated in terms of several different quantities: "resource," "reserve base," and "reserves." Indeed, some of the differences in MIR's and Evans' estimates stem from different quantity usage. The U.S. Geological Survey (USGS), Mineral Commodity Summary[4] definitions for the terms are:

> **Resource**.—A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.
>
> **Reserve Base**.—That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the *in situ* demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently sub-economic (sub-economic resources). The term "geologic reserve" has been applied by others generally to the reserve-base category, but it also may include the inferred-reserve-base category; it is not a part of this classification system.
>
> **Reserves**.—That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.

Lithium Mining Methods

Further differences in lithium estimates come from current and expected usability of different kinds of lithium. Lithium can be extracted by several current technological methods from various states (brine, clays, and pegmatites: for precise geological definitions of these materials see Evan's paper). Currently the brine (salt) flats are providing the majority of global production at the lowest cost. However, the externalities (hidden costs) of this brine extraction are potentially high. According to one source, extraction from the brines in Chile consumes 2/3 of area's drinking water[5]. The brine based facilities have caused a number of pegmatite facilities to cease production due to the higher cost of extraction. Pegmatite mines which have closed include Greenbushes, Australia; Kings Mountain, NC; and Pervomaisky, Russia[2,3]. The United States was the world's leading producer of Li until 1997, when it was surpassed by brine operations in Chile, running year round operations for the first time[6]. Brine and pegmatite methods are physically vastly different; but they compete for the same markets[7]. An increase in the price of Li would make pegmatite mines economically competitive and profitable again.

Future lithium extraction methods may use sea water as a source. Scientists at Saga University's Institute of Ocean Energy in Japan estimates that globally, seawater contains an estimated 230 billion tons of lithium[8]. Currently, desalination of seawater required to extract the lithium makes seawater an inefficient and time consumptive source. None of the resource estimates discussed use sea water as a source for their analysis. The potential environmental impact of Li mining in the oceans is still unknown and the current technology is not economically competitive and is not expected to mature enough in the short term. Additonally, lithium extraction from geothermal plants' wastewater is being reviewed by Lawrence Livermore National Laboratories in conjunction with Simbol Mining. The process is technology intensive, but the source is real and viable, though whether it works out to be economically viable remains to be seen.

Lithium Resources

As stated above, the primary difference between Tahil's/MIR's and Evans' estimates are tied to the definition of the mineral resources considered in their estimates. Evans focuses exclusively on the resource estimates including resource material and material that may be economical if the price of lithium increases or technology advances to reduce the cost of extraction. Tahil differentiates in his analysis between reserves and resources. Summaries of their estimates can be seen in Table 1 & Table 2. A detailed tabulation of the individual mine and country data is found in Appendix A. Evans and MIR roughly agree on the lithium resources in current mines (17.8 & 16.6 MT respectively). Though, the resource estimates are determined with different numbers from individual mines but ultimately arrive at approximately the same number. These are, arguably, the most understood and analyzed mines. It is important to note that, as of 2007, the USGS did not report any information for Argentina, Portugal, Russia, or reserve data for Bolivia. The substantial amounts of lithium in Bolivia and Argentina are recognized and accounted for by all other authors, including MIR and Evans. USGS quantities are therefore at the lower end of true resources available. Evans and MIR did calculate their own estimates independently from the USGS. The USGS provides a tabular summary of their estimates; Evans and MIR both detail their estimate bases.

Table 1: Lithium Resource Estimate (Millions Tons)

	Current Mines	Inactive Mines	Planned Mines	Total
Tahil	16.58	0.35	2.25	19.18
Evans	17.8	3.12	7.18	28.4
USGS – 2007	-	-	-	13.76

Table 2: Lithium Reserve Estimate (Millions Tons)

	Current Mines	Inactive Mines	Future Mines	Total
Tahil	4.06	0.15	0.35	4.56
USGS -2007	-	-	-	4.1

MIR's assertion that the focus should be on the reserve estimates and not so much on the resource estimates is a valid point. The MIR report states "*[Evans' report] 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 cost and lower production rates...*". MIR assumes that the market will not accept any increase in lithium material costs. This has not proved to be the case as Li prices have been steadily increasing with increased demand since

2004. Neither Evans nor MIR is entirely correct in their analysis of Li supplies. Lithium reserve estimates are demonstrably subjective. For example, MIR only considers the 30 km^2 epicenter of Salar de Atacama in Argentina in their reserve estimates although the entire salt flat has a total surface area of 3500 km^2. This is based on a 3000 parts per million (ppm) lithium density in the epicenter. This is less than 1% of the "highest quality lithium deposit in the world" being considered based on an arbitrary 3000 ppm threshold. It is unlikely that the entire salt flat would be mined, but it is highly likely that more than 1% will be. MIR uses a different threshold of 1000 ppm to estimate the reserves of Salar de Uyuni in Argentina. This is a third of the density used for Atacama with no explanation in the difference. MIR questions other planned facilities' estimated production rates again without supporting evidence. The Salar de Uyuni production rate of 60,000 tpy (tons per year) of Lithium Carbonate (LiCO) is questioned due the fact it is 50% higher than current production from Salar de Atacama, the largest producer in the world with a lower grade and lower evaporation rate. There is no technical, economic, or logistic reasoning that this can not be accomplished. MIR downgrades the estimate to 10,000 tpy in 2015. This is more than an 83% reduction based, again, on unstated reasoning.

The lithium reserve estimates are not completely objective either. This quantity estimate assumes entire concentrated areas are mined and that a potentially huge cost increase and environmental impact is acceptable. The correct estimate is going to be somewhere in the middle of the two extremes. It is difficult to predict exactly what prices the market will tolerate and when new extraction methods may help increase reserve estimates.

The geographic distribution of resources and reserves are shown from Figure 1 to Figure 3. The majority (over 50%) of the world's lithium reserves exist in Argentina, Bolivia, and Chile according to both reports. Evans' shows significantly more resources in the United States, China, and Russia than MIR. All estimates do indicate the majority of resources and reserves in are located in 13 countries (Argentina, Australia, Austria, Brazil, Bolivia, Canada, Chile, China, Finland, Russia, US, Zaire, Zimbabwe).

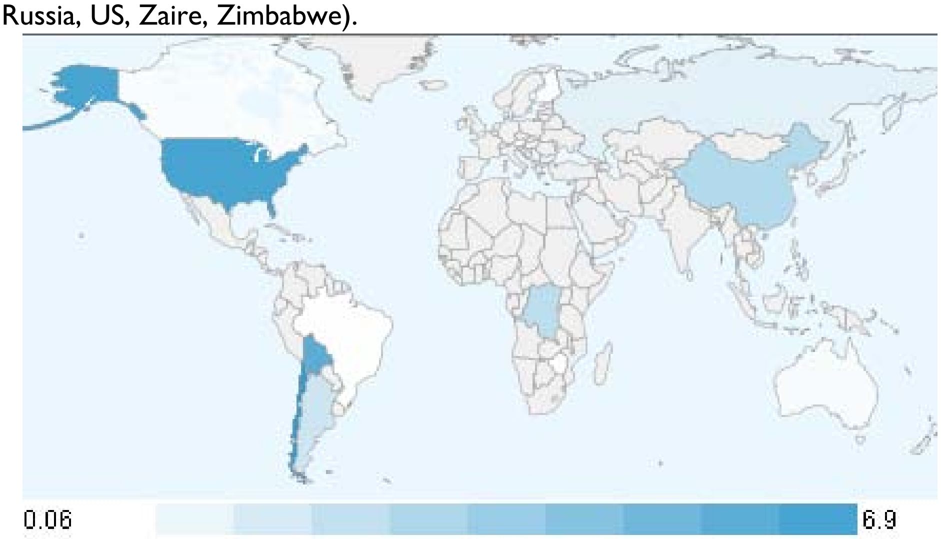

Figure 1: Evan's World Lithium Resource (Mton)

Figure 2: MIR World Lithium Resource (Mton)

Figure 3: MIR World Lithium Reserve (Mton)

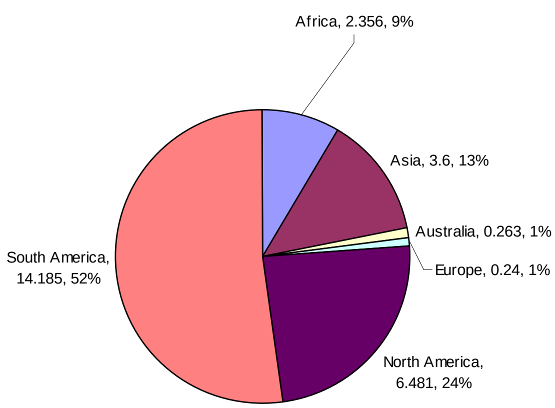

Figure 4: Evan's Lithium Resource by Continent

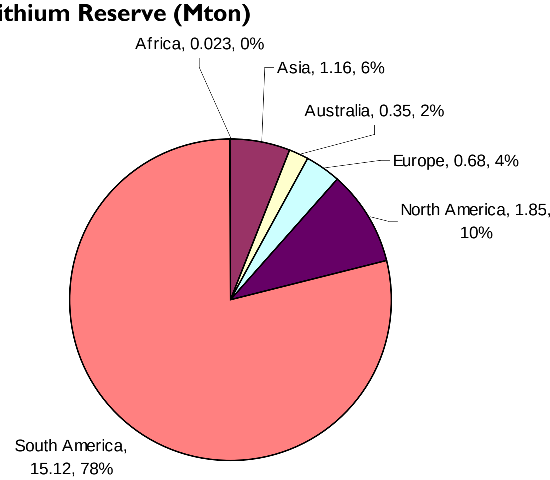

Figure 5: MIR's Lithium Resource by Continent

A couple of points of reference for what the resource and reserve estimates mean in the scope of current and projected lithium production. Current world production is estimated at 17,000 tpy for 2007 and 53,000 tpy for 2020. For the worst case analysis, using MIR's 2020 projected mining production levels (100% consumption) and current mine reserves (lowest estimate), the world supply will last for approximately 76 years. World production is likely to increase beyond 2020 but the numbers indicate enough resources for the short term. This shifts the discussion towards mining production capacity since there is clearly enough Li for the short term when using the lowest estimated of reserve and highest projection of mine output.

Recycling

Recycling of any battery that has potential to be used in electric vehicles is critical from an environmental, political, and economic standpoint. Significant recycling and reclaiming of materials can reduce the burden on the environment and required mining. Historically automotive batteries rank among the highest recycled products. Roughly 95% of US automobiles are recycled and over 75% of the vehicle by weight is recycled.[9] In the US, 99% of lead acid automotive batteries were recycled in 2006[10]. There seems no reason to suggest that batteries for electric vehicles would not follow a similar trend, with or without government regulation. EV batteries for a small 10 kWh (kilowatt hour) vehicle will weigh in excess of 110 lbs (50kg) assuming an energy density of 200 Wh/kg. The likelihood is high then, that they will only be removed by approved automotive facilities due to the safety precautions needed to handle large amounts of energy. This reduces the potential for curbside disposal or consumer landfill dumping. The top three US automakers have teamed together to fund OnTo Technology to research and develop technology to recycle nickel metal hydride (NiMH) and Li batteries with clean processes.[11] The US Department of Energy has been working to address the issue of recycling large quantities of EV batteries since the 1990's. Battery recycling companies have been hesitant due to the small volumes of hybrid batteries and will likely continue until a threshold is reached in the waste stream[12].

Batteries are divided into two groups, single use primary and rechargeable secondary. Primary batteries use lithium metal as a cathode[13]. Secondary batteries use lithium cathodes like $LiCoO_2$, $LiNiO_2$, and $LiMn_2O_4$. Lithium chemistries coupled with valuable commodities, cobalt and nickel, make it economically viable to recycle without any subsidies or tipping fees from the battery producers.[14] Lower value elements such as iron and phosphorous will be a greater challenge to create a profitable recycling program without additional incentives or more valuable Li. Several companies and organizations around the world are currently performing and improving primary and secondary lithium battery recycling (Toxco[15], OnTo, Chungnam National University[16], Sony, ACCUREC, SNAM). Admiralty Resources, a lithium mining company, lists the price of Li at \$6/kg in 2007 where cobalt peaked over \$110/kg in 2008[17]. If the price of Li does increase, the process of recycling lithium batteries becomes more profitable. Until then, it is dependent upon the company to recover the lithium when recycling the higher priced commodities (i.e.: cobalt). The Rechargeable Battery Recycling Corporation (RBRC), created in 1994 as a non-profit organization by the battery industry, has seen a huge growth in Li battery recycling since they started accepting used cell phones in 2004[18]. RBRC currently only recovers cobalt from the processed batteries but have seen a steady rise in the number of batteries recycled (Table 3).

Table 3: RBRC Lithium Recycling

Year	Lithium Ion Batteries Recycled (lbs)
2005	345,000
2006	656,000
2007	974,000

Current battery manufacturers are focused on getting a product to the market and too few are focusing past that. A cradle to grave approach or extended producer responsibility is recommended when producing quantities of batteries to support the automotive industry. ZPower has an interesting model for the portable battery market that considers the full life cycle of its batteries[19]. ZPower estimates a 95% recycling or reuse of their batteries and offers financial incentives to consumers who recycle their batteries. This is not only a social and environmentally responsible approach but economically sound as well. By reusing a company's original materials, the short term price fluctuation of any high value commodity is minimized. Battery manufacturers working with the major battery recycling companies during the design phase could benefit both the manufacturer and consumer without effecting performance.

The need to recycle EV batteries is not new to the government, auto industry, battery manufacturers, or consumers. Lithium recycling is in its infancy and will continue to grow with the increase in production. There are multiple locations worldwide that can recycle lithium today and they are likely to see a dramatic increase in recoverable material in the future.

EV Batteries Usage

Lithium based batteries are the focus of the future EVs and are the current state of the art of EV energy storage mature enough to satisfy the reliability criteria of the auto industry. Li is merely one type of chemistry in the energy storage world. It helps to think of the battery as only the fuel tank for the future car. The car still runs if you swap out to a different tank without changing the engine or anything else major. A car does not have to be re-engineered to accept a different battery as it would to make a gasoline car to run off of natural gas. The Tang EV from Commuter Cars and City EV from Think have demonstrated that they can operate with multiple chemistries and can be sold with multiple options for batteries[20,21]. Historically, lithium has had limited use in production electric cars from the major automotive manufacturers (Table 4). The 2008 production of hybrid electric vehicles from the major automakers are all using a NiMH battery[22]. NiMH has already proven itself with RAV4s still on the road today after 100,000 miles on them. Other chemistries, lead-acid, nickel cadmium (NiCd, also known as ni-cad), and varying lithium combinations (phosphorus, cobalt etc.) have their place with different types of vehicles. Large, heavy, stop-and-go vehicles have different requirements from a small commuter car. There are other considerations like the tradeoff between energy density and weight for the size and purpose of the vehicle. There is no one silver bullet for all EVs, just like there is no single automotive engine or fuel that satisfies every consumer's needs.

Table 4: Historical Production Battery Electric Vehicles (BEVs)[23]

Manufacturer	Model	Battery Type	Battery Capacity (kWh)	Claimed Range (km)	Claimed Range (miles)
Citroen	AX/Saxo	NiCd	12	80	50
Ford	Think City	NiCd	11.5	85	53
GM	EV1	NiMH	26.4	130	81
Honda	EV Plus	NiMH	-	190	118
Nissan	Hypermini	Li-Ion	15	115	71
Nissan	Altra EV	Li-Ion	32	190	118
Peugot	106 Electric	NiCd	12	150	93
Renault	Clio Electric	NiCd	11.4	80	50
Toyota	RAV 4	NiMH	27	200	124

Notice that, historically, the only Li-ion battery user has been Nissan. Lead acid batteries (not appearing on the table) are the common batteries used in do-it-yourself plug-in hybrid EV (PHEV) conversion kits.

An analysis of the planned future production Plug-in Hybrid EVs (PHEV) and Battery Electric Vehicles (BEVs) demonstrates the extreme shift in battery preference. Nearly all planned production EV's are being designed for Li chemistry batteries as seen in the summary below (Table 5).

Table 5: Current and Planned EVs[24]

Manufacturer	Model	BEV/ PHEV	Battery Type	Battery Capacity (kWh)	Claimed Range (mi)	Production Start
AC Propulsion	Ebox	BEV	Lithium	35	150	now[25]
Aptera	Type 1e	BEV	-	10	125	Late 2008[26]
Mitsubishi	iMiEV	BEV	Lithium	16-20	90	2009, Japan
Tesla	Roadster	BEV	Lithium		250	2008
Think	City	BEV	Zebra, Lithium	27	124	
Chrysler	Dodge Sprinter Van	PHEV	Lithium	-	-	2008
Fisker	Kharma	PHEV	Lithium	-	50	2009
Ford	Escape Plug In	PHEV	Lithium	10	30	-
GM	Volt	PHEV	Lithium	16	40	2010
Hymotion	Hymotion Prius	PHEV	Lithium	-	-	-
Toyota	Prius Plug In	PHEV	NiMH	-	7	2010

Aptera has not yet released its final battery chemistry.

Economics

Lithium supply is not simply a question of how much Li is in or on the earth. Projected need affects necessary production. The economics of battery making (especially recycling) directly affect the total lithium requirement for the projected future demand.

Battery capacity is measured in kilowatt hours (kWh) with certain amount of lithium (or other element) required to produce the necessary energy density. The cost of a battery is typically also measured by dollars per kWh. The size of the vehicle (and thus the power required to move it) dictates both the appropriate battery chemistry and the size (and thus the amount of material). Table 6 provides a rough guide to battery capacities required for average EVs and the amounts of lithium proportional to that battery capacity. A typical EV car battery costs the consumer between $3k and $10k. The lithium material needed for that battery at $7/kg is less than $80 for a large BEV, or less than 3% of the total battery cost. The cost of lithium is not the major driver in the manufacturing process and there is no reason the market should not tolerate an increase in the cost of lithium. Although the overall price of the batteries needs to come down to increase widespread usage, this is heavily dependent on manufacturing processes and reductions achieved from economies of scale.

Table 6: EV Battery Size for Various Type Cars[27]

EV Type	HEV	PHEV20	PHEV60	Mid Size BEV (Ebox)
Battery Capacity (kWh)	<3	6	18	35
Lithium kg	<1	1.8	5.4	10.5

Future Demand Forecast

With economies of scale driving much of the cost-savings in lithium mining and recycling, it is important to review the EV market and attempt to forecast the future of EV demand. The majority of EV market forecasting is done by private companies for various companies within the automotive industry. The following chart was compiled from individual market forecast points from this research. An estimate from Morgan Stanley for US only hybrid sales was doubled and plotted along with the other data points due to the large market share of the US.

Figure 6: Global Hybrid Vehicle Market Forecast Summary[28,29,30,31,32]

Research by Morgan Stanley shows the US hybrid vehicle demand forecast with hybrid EVs (HEVs) and PHEVs in Figure 7. The US EV market forecast is worth looking at as the largest market with 70% of the global market in 2005[33]. PHEV sales are not expected to really take off until the 2015-2020 time frame based on this report. The authors were unable to find data on estimates for BEV sales. The current major automotive manufactures are primarily focused on HEV and PHEVs at the moment. As they are the most likely candidates to quickly ramp up production to the 100's of thousands of vehicle per year, it is unlikely that some of the smaller independent BEV manufacturers will be responsible for sudden lithium demand increases in the short term.

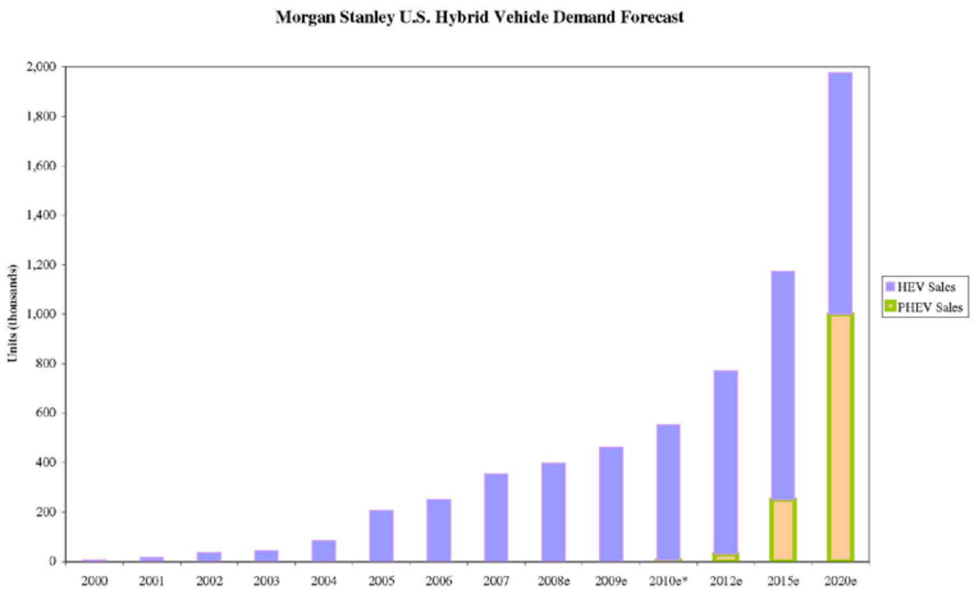

Figure 7: EV Sales Projections – Morgan Stanley[34]

With forecasts for the global and US EV market it is now possible to compare demand with manufacturing supply. The largest growth areas for lithium have been in the battery market, particularly secondary batteries. Batteries (automotive, small electronics and computers) currently account for over 20% of the end use market for lithium with other major uses including ceramics and glass, 20%; lubricating greases, 16%; and pharmaceuticals and polymers 9%. A compounded annual growth rate (CAGR) of 5% for other non-battery related products was used for this analysis. The global lithium battery market forecast has to look at the long term estimates, not a single year's or manufacturer's CAGR. The secondary battery market has had a 26% CAGR from 1995-2000 but it is slowing according to a report from Freedonia[35]. A table of the supply and demand numbers along with CAGRs used (based on Freedonia) can be found in the appendix A. Overall lithium production supply estimates were taken from MIR's research. The production was divided into three categories: automotive, non-automotive battery, and other. Lithium production remaining after accounting for growth in non-automotive batteries and other lithium markets was allocated to the automotive sector. The automotive category was then subdivided into HEVs and PHEVs due to the different size batteries and therefore Li required for each. The ratio of HEVs to PHEVs was based on the Morgan Stanley report for the US, assuming the trend would be similar globally. The total number of vehicle produced was calculated from the allocated automotive lithium while taking into account the ratio of HEV to PHEV for a given year and the amount of lithium required per vehicle from Table 6. HEVs and PHEVs were modeled to use 0.75 kg and 5 kgs respectively. The PHEV battery size is more conservative (larger) for longer range vehicles than most currently planned models (PHEV60).

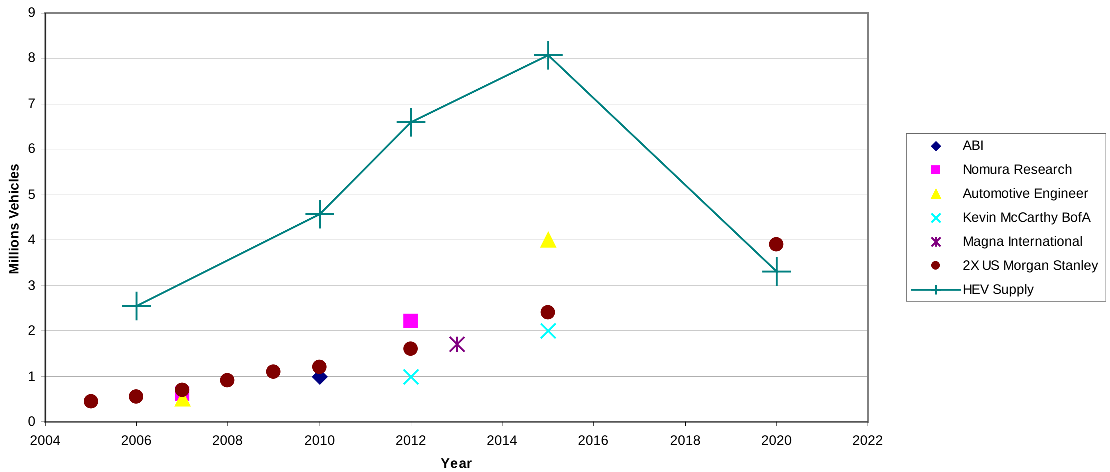

Figure 8: Global HEV Supply and Demand

As can clearly be seen in Figure 8, there is not a supply shortage until close to 2020. Contrary to MIR conclusions, there is actually a surplus until then. All of the forecasting numbers ignored any contribution from recycling, worst case supply and demand estimates, and assumed that all EVs use only lithium based chemistries. If there were to be a shortage due to increased demand, the price would also increase. This would make recycling a more profitable venture, exploration would increase, and likely to significantly contribute to the supply chain. So even under the extreme worst case estimates of Li shortage, there is not going to be a significant impact on EV production.

So what is the answer?

The answer is, quite literally, that there is no ONE answer. The question of a lithium powered future is not solely an issue of resource quantity equaling resource output. It is time for the dialogue on alternative transportation to move beyond lithium supplies; there are so many other far more pressing issues that need to be addressed. Three additional areas of concern to be addressed are; economic demands, foreign relations and the environmental impact of mining (among many others). Anytime a finite resource is ripped out of the ground and then sold on the open market a chain of reactions begins that cannot be ignored. It is true for oil and it is true for coal, as well as any other metal, mineral or other resource. These three elements are so fundamentally interrelated, they will be addressed here in combination rather than sequentially. An in-depth analysis of these issues by subject matter experts is well-beyond the scope of this paper and indeed they deserve their own critical review. What follows is in the nature of an overview of basic global issues rather than data analysis.

As previously stated, the argument that there is enough lithium or not enough lithium is, in a way, not the point. The concept of switching our current lifestyle from complete dependence on one resource to complete dependence on another is absurd and untenable. Clouds and eclipses may block the sun, droughts reduce the water supply, the wind may become more erratic etc. The earth's material resources will dry up. No source of energy we have yet harnessed is completely self-renewing or perpetual and to build a one-size fits all solution from a molecule of lithium merely shifts our tunnel vision and perpetuates the problem. The real driving force and ideology behind green technologies and the green energy movement is a diversity of energy generation and appropriation. A sizable system of solar panels just outside of a large city in the desert can supply its entire energy needs. The same cannot be said for foggy San Francisco. So how is lithium a part of that solution?

The economics of any single commodity market are the processes by which nations come into being and power grows and dies. Strip Saudi Arabia of all of its oil profits right this very instant and the result would basically be a well-populated desert. The same could be said for a number of nations where oil is very nearly their entire gross domestic product (GDP). Chile's Atacama region, home to the Salar de Atacam relies on mining for 45% of its annual GDP and 90% of its exports according to the Chilean government[36]. In 2007, according to La Tercera[37] the Atacama region reported an 11.6% growth in mining exploration grants, accounting for 22.7% of the total Chilean mining exploration area. Enter foreign policy. From a purely American perspective, the greatest downside to lithium is not its total availability, but where it is known to be available. American reserves are estimated at under 6% (MIR) and 23% (Evans) of the known world reserves. The US currently has only one active mine and is at the mercy of its importers until it is able to ramp up its own production. South America and China where the largest reserves reside (by any estimate) do not have governments which hold the US in high esteem. Evo Morales, current president of Bolivia, source of over half the current world Li production, in his own words "[doesn't] mind being a permanent nightmare for the United States." While Argentina and the US are generally on economically good terms (despite the growing majority of people who believe the US responsible for the current crisis), Argentina is suffering a period of great political and economic instability. According to the recent report made to the Senate Committee on Foreign Relations, "Argentina consistently registers the highest levels of anti-Americanism in Latin America in public opinion polls, which have been fairly steady at around 60 percent."[38] Russian relations are beginning to destabilize as well; Dmitri Medvedev and Venezuela's Hugo Chavez are finding themselves on the same team. These are the sorts of diplomatic relations the US enjoys as of this writing. Currently, the a large portion of known lithium reserves reside primarily in China, South America, Russia and southern Africa. In fact, with the possible exceptions of Australia, Canada and Portugal, the list reads like a Who's Who of regions the US has joyfully exploited at one time or another. Without digging even the slightest bit further into the economic science and math behind our trade relations with these countries/regions, it not a stretch to see the potential resource power struggle brewing. However, from a global perspective, the Li distribution not only relieves growing pressure on the oil based fuel markets, but also provides a diversity of supply that spreads the wealth and distributes the technologies. There is no reason, technologically speaking, why the Americans need to drive the same chemistry based car that the French do or the Chinese, or the British, or the Russians. The point has already been made that one of the greatest advantages to an EV is that they can be built to run with multiple chemistries while maintaining the economic advantages of high volume production.

Conclusions

For today however, Lithium will not power all 800 million cars on earth simultaneously. It doesn't have to. It can, and will, provide the "fuel," so to speak, to get the movement started with high volume turnover. Lithium's greatest advantage is that it is here, now. Cars are being manufactured that can go hundreds of miles on a single charge. High power recharging units are possible and being improved upon to reduce "fueling" time. Starting right now, lithium battery powered cars can be the next round of automobiles to be manufactured. Lithium batteries are not the only chemistries that enable an electrically powered vehicle and to assume so is absurd.

Additional research should continue with multiple chemistries, but lithium batteries should not be abandoned for "lack of supply." Unlike an oil or bio based fuel, lithium is not consumed and if reclaimed, remains a part of the energy cycle. As the green energy movement encompasses more and more green and renewable energy sources to provide that electricity, Chelsea Sexton is right on the money with the statement that "the dirtiest day your EV will have is the day you drive it off the lot."[39]

Appendix A

Table 7: Active Lithium Mining Operations[iii]

Mine Location(s)	Country	Type of Resource	Source	Li Reserve (M ton)	Li Resource (M ton)	LCE Production (tons per year)				
						2006	2007	2010	2015	2020
Salar de Atacama	Chile	Brine	Tahil	1	3	50000	54000	60000	80000	100000
			Evans		6.9					
Salar de Hombre Muerto	Argentinia	Brine	Tahil	1	0.8	15000	15000	15000	20000	25000
			Evans		0.85					
Salar del Rincon	Argentinia	Brine	Tahil	0.6	5.5			10000	20000	25000
			Evans		1.86					
Salar del Olaroz	Argentinia	Brine	Tahil	0.16	0.32	0	0	0	5000	5000
			Evans							
Salar de Uyuni	Bolivia	Brine	Tahil	0.6	5.5	0	0	0	15000	30000
			Evans		5.5					
Clayton Valley, NV	US	Brine	Tahil	0.118	0.3	9000	9000	9000	8000	8000
			Evans		0.04					
Zhabuye	China	Brine	Tahil			5000	5000	10000	20000	25000
			Evans							
Qaidan Basin	China	Brine	Tahil	0.5	1	10000	10000	20000	40000	50000
			Evans							
DXC	China	Brine	Tahil	0.08	0.16			5000	5000	5000
			Evans							
Tanco	Canada	Pegmatites	Tahil				3000	3000	3000	3000
			Evans							
Multiple Locations	Brazil	Pegmatites	Tahil			1500	1500	1500	1500	1500
			Evans		0.085					
Multiple Locations	China & Tibet	Brine/ Pegmatite	Tahil							
			Evans		2.6					
		Totals	Tahil	4.058	16.58	90500	97500	133500	217500	277500
			Evans	0	17.835					

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Table 8: Former Lithium Mining Operations

Mine Location(s)	Country	Type of Resource	Source	Li Reserve (M ton)	Li Resource (M ton)
Greenbushes, Mt. Marion	Australia	Pegmatites	Tahil	0	0
			Evans		0.243
Mt. Catlin	Australia	Pegmatites	Tahil	0.15	0.35
			Evans		0.02
Bessemer City & Kings Mt, NC	US	Pegmatites	Tahil		
			Evans		2.6
Pervomaisky	Russia	Pegmatites	Tahil		
			Evans		
Multiple Locations	CA	Pegmatites	Tahil		
			Evans		0.255
		Totals	Tahil	0.15	0.35
			Evans		3.118

Table 9: Future Lithium Mining Operations

Mine Location(s)	Country	Type of Resource	Source	Li Reserve (M ton)	Li Resource (M ton)
Kikita	Zimbabwe	Pegmatites	Tahil		0.023
			Evans		0.056
Osterbotten	Finland	Pegmatites	Tahil	0.35	0.68
			Evans		0.14
	Zaire	Pegmatites	Tahil		
			Evans		2.3
Hector, CA	US	Clays	Tahil		
			Evans		2
Searles Lake, CA	US	Brine	Tahil		0.02
			Evans		
Great Salt Lake, UT	US	Brine	Tahil		0.53
			Evans		0.52
Salton Sea, CA	US	Brine	Tahil		
			Evans		0.316
Smackover, AK	US	Oil/Brine	Tahil		1
			Evans		0.75
Koralpa	Austria	Pegmatites	Tahil		
			Evans		0.1
Multiple Locations	Russia	Pegmatites	Tahil		
			Evans		1
		Totals	Tahil	0.35	2.253
			Evans		7.182

Table 10: Global Lithium Supply and Demand

Year	Global Production (LCE)	Portable Battery CAGR	LCE for Portable Batteries	Non-Battery LCE Demand (5% CAGR)	Unallocated LCE for Automotive Batteries	Unallocated Li for Automotive Batteries	Cars Supported		PHEV/Hybrid Ratio
							Electric Assist Hybrids	Plug-In Hybrid	
2006	90500	21%	18100	72400	0	0			
2007	97500	21%	24375	63000	10125	1918	2556806	0	0%
2008	*109833*[4]	21%	29396	66150	14287	2706			
2009	*122167*	21%	35452	69458	17257	3268			
2010	134500	21%	42755	72930	18815	3563	4575479	36604	1%
2011	*154300*	*14%*	48826	76577	28897	5473			
2012	*174100*	*14%*	55759	80406	37935	7185	6606544	619364	9%
2013	*193900*	*14%*	63677	84426	45797	8674			
2014	*213700*	*14%*	72720	88647	52333	9912			
2015	233500	*14%*	83046	93080	57375	10866	8063525	1338545	16.60%
2016	*248500*	*12%*	92762	97734	58004	10986			
2017	*263500*	*12%*	103615	102620	57264	10846			
2018	*278500*	*12%*	115738	107751	55010	10419			
2019	*293500*	*12%*	129280	113139	51082	9675			
2020	308500	*12%*	144405	118796	45299	8579	3317607	1691980	51%

[4] Numbers in italic are linearly interpolated between next known data points

[1] Tahil, William "The Trouble with Lithium: Implications of Future PHEV Production on Lithium Demand" Dec. 2006 http://www.evworld.com/library/lithium_shortage.pdf
[2] Meridian International Research, "The Trouble with Lithium 2: Under the Microscope" 29, May 2008 http://www.meridian-int-res.com/Projects/Lithium_Microscope.pdf
[3] Evans, R. Keith, "An Abundance of Lithium", March 2008 http://www.worldlithium.com/An_Abundance_of_Lithium_1_files/An%20Abundance%20of%20Lithium.pdf
[4] US Geological Survey, Mineral Commodities Summary, January 2008 http://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2008-lithi.pdf
[5] CNET, "Mining lithium from geothermal 'lemondae', http://international.com.com/8301-11128_3-9881869-54.html, Dec. 23, 2008
[6] Warren, John "Evaporites: Their Evolution and Economics", Blackwell Science, UK 1999
[7] Moores, Simon, "Between a rock and a salt lake", Admiralty Resources, June 2007, http://www.ady.com.au/uploads/news/7cbbc409ec990f19c78c75bd1e06f215.pdf
[8] "Scientist Extract Lithium from Sea", Japan Times, April 18, 2004
[9] Argonne National Labs, "The CRADA team for end of life vehicle recycling", http://www.transportation.anl.gov/materials/crada_recycling.html
[10] Environmental Protection Agency, "Municipal Solid Waste Generation, Recycling, and Disposal in the United State", Facts and Figures 2006
[11] USCAR, "USCAR Awards Contract for Battery Recycling", EV World, 15 May 2007, http://www.evworld.com/news.cfm?newsid=15143
[12] Jungst, Rudolph J. "Recycling of Advanced Batteries for Electric Vehicles", Sandia National Labs
[13] Bernardes, A.M. et. Al, "Recycling of batteries: a review of current proceses and technologies", Journal of Power Sources, 2004
[14] Ra, Dong-Il; Han, Kyoo-Seung, "Used lithium ion rechargeable battery recycling using Etoile-Reatt technology", Journal of Power Sources, May 4, 2006
[15] Toxco, Safe Battery Recycling, http://www.toxco.com/processes.html
[16] Honeywill, Tristan, Automotive Engineer, "Manufacturing Cells", Mar 2008, Volume 33, pg. 22
[17] BHPbillton, Cobalt Open Sales, http://cobalt.bhpbilliton.com/
[18] Gabor, Linda, email, Director of Media Relations, RBRC, 08 September 2008
[19] ZPower, Clean Technology, http://www.zpowerbattery.com/technology/clean.htm
[20] Battery Technology, Think, http://www.think.no/think/content/view/full/264
[21] Specifications, Commuter Cars Corporation, http://www.commutercars.com/
[22] Alternative Fuels Data Center, "Model Year 2008: Alternative Fuel Vehicle and Advanced Technology Vehicle", National Renewable Energy Lab, October 2007
[23] Westbrook, Michael, "The Electric Car: Development and future of battery, hybrid and fuel cell cars", The Institution of Engineering and Technology, London, UK, 2001
[24] Madian, A.L., Walsh, L. A., Simpkins, K.D., Gordon, R.S., "U.S. Plug in Hybrid and Light Vehicle Data Book", LeCG, California USA, June,2008
[25] Specifications, AC Propulsion, http://www.acpropulsion.com/ebox/specifications.htm
[26] Details, Aptera, http://www.aptera.com/details.php
[27] Duval, M, "Advanced Batteries for Electric Drive Vehicles – A technology and cost-effective assessment for battery electric vehicles, pnower assist hybrid electric vehicles, and plug-in hybrid electric vehicles", EPRI, May 2004
[28] Coons, Rebecca, "Charging Up the Hybrids", Chemical Week, June 21 2008
[29] Migliore, Greg; Beene, Ryan, "Diesels May Hit 20% of US Market by 2020", Automotive News, April 2008
[30] Honeywell, Tristan, "Production: Manufacturing Cells", Automotive Engineer, March 2008
[31] Greimel, Hns, "Hybrid Market is Rising", Autotmotive News, December 2008, Vol. 82 Issue 6287
[32] "European Automakers Trailing the Hybrid Pack", Power Electronics Technology, January 2004
[33] Kenney, Brad, "U.S. Remains Largest Hybrid Market", Industry Week, June 2007

[34] “Autos and Auto Related, Plug in Hybrids: The Next Automotive Revolution”, Morgan Stanley Report, pg. 13, March 11, 2008

[35] Freedonia, “World Batteries to 2010”, August 2006

[36] Chilean Government – The Atacama Region, http://www.chileangovernment.gov.cl/index.php?option=com_content&task=view&id=1161&Itemid=88, 17 August, 2008

[37] Fuller, Adam “Chile’s Region III Surpasses Region II in Mining Exploration”, The Santiago Times, 08, August 2008

[38] “Argentina Rudderless”, Report to the Members of Committee on Foreign Relations: United States Senate, Second Session, September 9, 2008

[39] “Who Killed the Electric Car”, Writ. and dir. Chris Paine, Sony Pictures Classics, 2006