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The battery business: Lithium availability and the growth of the global electric car industry

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ABSTRACT

This article presents a spatial analysis of lithium availability from the mid-twentieth century to the present time in order to clarify and contribute to the growing body of scholarship on the relationship between the global lithium supply and the viability of a modern, mass-market electric vehicle industry. Drawing on archival research conducted in Bolivia in 2012, this article advances the argument that the concept of 'lithium scarcity' is much more nuanced than is often portrayed. In addition, perceptions of a worldwide lithium shortage are more entangled with business demands for certain grades of lithium at certain price points rather than actual scarcity. This analysis of lithium availability is defined in terms of the basic tension between the supply of extractable lithium deposits on the one hand and the quality and price demands of battery manufacturers on the other. This tension has played a role in determining the evolution of the electric car from a luxury to a mass-market product and involves a host of complementary and competitive business and geopolitical actors.

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1. Introduction

Lithium (Li), the world's lightest metal, has been viewed as the critical component for accelerating and enabling the next incarnation of electric batteries – a key input into the global electric car industry (Vikström et al., 2013; Grosjean et al., 2012; Kushnir and Sanden 2012). More specifically, "a new generation of lithium-ion batteries, coupled with rising oil prices and the need to address climate change, has sparked a global race to electrify transportation" (Tollefson, 2008). Despite the geologic abundance and geographic diversity of global lithium resources, the price of electric battery-grade lithium has increased dramatically in 2015–2016. As a result, in November and December of 2015, the price per ton of 99% pure lithium carbonate (the most sought after type of lithium for electric car batteries) imported into China, increased by more than two-fold to $13,000 (The Economist, 2016a, 2016b). In the six months ending in May 2016, the price of pure lithium being exported to China increased 42% (Yu, 2016). The main reasons for this dramatic and rapid price surge include: a "supply squeeze" of lithium that is exported to China, long-term demand from start-up and established electric vehicle manufacturers, and the growing global market for portable electronic devices, electric tools, and grid storage applications (Jaskula, 2015; Yu, 2016). In spite of the widespread uses for lithium in various industrial and chemical applications, the main market for lithium during the 21 st century is expected to be for use in electric vehicles (EVs) (Gruber et al., 2011).

The timeliness of the growth in demand for lithium has to do with a combination of business-side (quality and price) factors more so than the literal scarcity of elemental lithium in the earth's crust. According to one recent study, lithium is readily available on earth and the world could triple lithium production from current levels and still have 135 years of supply available using solely known reserves (Jaskula, 2015). So why is there a global scramble for lithium resources at this point in time? It is the recent and rapid *consumption* of lithium in battery applications (growing 73% during the 2010–2014 period), during a period of comparatively low-growth (28%) in the *production* of lithium that helps to explain the increase in the price of raw lithium (Chatsko, 2015). This *consumption-production imbalance* is a driving force in creating an atmosphere of uncertainty surrounding global lithium availability today and serves as the unifying concept through which the distinct parts of this work connects into one cohesive whole.

One of the principal factors contributing to the hesitancy of some major automobile manufacturers contemplating the expansion of their electric vehicle (EV) offerings is the perceived global lack of access to lithium resources. The 'scarcity issue' has led lithium to be recently dubbed by The Economist (2016a, 2016b) as being "the world's hottest" commodity. Such concerns, especially

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among aspiring battery-producing economies – such as China and the US – have contributed to the doubling of the price per ton of lithium in the last two months of 2015. This phenomenon has played itself out on the geopolitical stage with different countries vowing to 'outpace' each other to become the dominant leader in lithium battery development, and by extension in the global electric car industry. The geopolitical rhetoric between countries has taken on dimensions more characteristic of competing multinational corporations (MNCs). Such concern about access to perceived scarce quantities of lithium is often given as the major limiting factor preventing the rapid and significant global expansion of the electric car industry.

In addition, because no single country has a monopoly on lithium resources and production, and because of the perceived national economic benefits that can be realized from investing in transforming the electric car from a luxury to a mass-market product, the geopolitical competition between countries that want to take claim for being at the forefront of the new electric vehicle industry, has spurred a 'battery war' (Levine, 2016).

According to Levine (2016: 8–9), "[T]he leaders of most of the world's industrialized countries – Japan and South Korea, Brazil, Finland, France, Germany, Israel, Malaysia, Russia, Singapore, South Africa, and the United Kingdom, not to mention the United States and China – decided it was a race, and so it was. In the words of a French Government minister, it was a "battle of the electric car"".[1] These realities of lithium procurement define the basic tension between the supply of extractable lithium deposits on the one hand and the quality and price demands of battery manufacturers on the other. It is this tension that has played a role in determining the evolution of the electric car from a luxury to a mass-market product and involves a host of complementary and competitive business and geopolitical actors.

To understand this tension, this paper uses the *consumption-production imbalance* to first consider the ways in which society has come to view lithium as increasingly valuable at this point in time. This exploration of the 'materiality' of lithium is crucial to understanding the likely growth and success of the electric car industry. Demand for lithium consumption appears to have surged ahead of lithium production over the last decade. The paper then engages in a brief history of the development of electric vehicles – trying to make sense of how demand for lithium (in the form of EVs) was not always alighed with production targets made public by EV manufacturers. Following this a spatial analysis of global lithium reserves and business actors is undertaken. Finally, the paper considers the economics of the lithium market, and explores the links in the lithium global supply chain in light of the needs of the EV industry.

2. Materiality of lithium

The idea central to the materiality of lithium involves an understanding that the recent surge in interest and in the cost (price per ton) of lithium is predicated on the *social value* that this metal has come to inherit and not on its literal scarcity. The recent increase in the social value of lithium has contributed to the increased *consumption-production imbalance* which lays at the heart of contemporary competition for lithium resources. Borrowing from Bridge(2009: 1218) it is the "irreducibly social nature of resources and the interactions that govern their availability and allocation" that have helped highlight contemporary academic and mainstream debates surrounding lithium extraction and development. The notion that resources are:

> "'natural things' also acts as a powerful blinder, as it obscures the way all resources are — necessarily — cultural appraisals about utility and value: the allure of diamonds, for example, has everything to do with the way these small, surprisingly common nuggets of carbon have become associated with a complex set of social understandings about wealth, beauty, love, commitment and power"

(Hartwick, 1998; Le Billon, 2006 in Bridge 2009: 1219) Likewise, lithium's value derives from its energy storage properties, low-weight, (potential) reliability, and perhaps most of all, its perceived usefulness in countering fossil fuel emissions – a key component of anthropogenic climate change. The current exploitation of and continued exploration for new lithium resources highlights the scale/quality paradox that Bridge refers to as one of the contradictory dimensions of 20th century resource mobilization.

In the traditional resource extraction arrangement, we see the production of more resources from lower quality reserves or supply. Evidence of "the 'technological treadmill' in natural resource industries: that is, the need for technological advance to offset the rising costs associated with extracting and processing resources of declining quality" (Hanink, 2000 in Bridge, 2009), can be seen – in the case of the existence of the process of extracting lithium from seawater. In 2010, South Korea declared that it will be able to extract lithium from seawater by 2015 (though at five times the current price of extracting lithium from lake brines) (Oliver et al., 2010). Also, as exploration continues, it is possible that higher quality resource stocks get discovered. In this sense, the very nature of the value of lithium is closely connected to its 'materiality' – its temporal and social utility. This premise – focusing on the materiality of a lithium – is central to understanding the current concerns that many potential electric battery manufacturers are faced with today. One of the most prominent cases involving the lithium scale/quality paradox relates to the abundance (scale) but low purity (quality) lithium in Bolivia – the country with the largest known reserves of lithium on earth (See Section 5.2).

Aside from the sheer quantity of lithium available, political stability of the host country, evaporation rates[2] and chemical purity also play a role in determining from which reserves EV manufacturers decide to source lithium. The materiality of lithium is also concerned with potential economic and environmental costs as well. While concerns exist about the negative social and environmental impacts (Harvey, 2014; Wan, 2014) of extractive mining, the way that lithium 'fits in' to the overall mineral extraction story is quite unique. Unlike most other types of mining, including artisanal and small-scale mining (ASM) which is often characterized by a heavy reliance on manual labor, hazardous working conditions and more frequent negative human and environmental health impacts (Hilson, 2002), one of the ways in which the bulk of lithium is harvested is through lake-brine evaporation – a process that is comparatively less harmful to people and the environment. In addition, as Langston et al. (2015) make clear, the mining industry is not homogenous and . . . policy approaches for dealing with the impact of specific mining activities require understanding the particular economic, political, social, and environmental context (Intergovernmental Forum on Mining, 2013). In the case of lithium extraction and production, all of these factors in combination are leading the metal to become increasing valuable to start-up and more established electric vehicle developers. Critically, the likelihood of yet undiscovered lithium

[1] French ecology minister Jean-Louis Boorloo, quoted by Agency France-Press, October 2, 2009.

[2] Even within the South American Puna Plateau evaporation rates differ dramatically: Salar de Atacama, Chile (3500 ml per year); Argentine Puna (2600 ml per year), Uyuni, Bolivia (1300–1700 ml per year).

reserves has also helped to drive the confidence levels of new and potential lithium battery makers as well asl electric car manufacturers. The potential for lithium exploration in pegmatite rocks promises to be especially helpful in expanding the likelihood of high-quality lithium production beyond currently known reserves. As Gruber states "known pegmatite districts have not been explored in any detail and it is likely that many others remain to be discovered . . . one positive outcome from this exploration is likely to be geographical diversification in lithium production that would counteract the geopolitically restricted distribution of brine deposits. (Gruber, et al. in Kesler et al., 2012: 67).

3. Electric vehicle development

From their invention, electric vehicles have been plagued by the *consumption-production imbalance.* Invented in 1834, the electric car has undergone a cyclical (boom-and-bust type) adoption trajectory as a consumer-oriented form of transportation. Upon their introduction in the United States, electric cars were much more mainstream than they are at present. In the United States in the 1930s, for example, the electric car was the most popular car (and type of car dealership). In the 1940s and 50s, as the internal combustion engine grew in popularity, American automobile owners, began transitioning away from electric cars – surmising that their limited range could be avoided by using a gasoline powered engine instead (Electric Auto Association, 2016). It appears that timing, consumer interest and consumer's availability to buy an EV have not been harmoniously aligned.

In 1966, Ford Motor company attempted to reintroduce the electric car to an American audience that was now much more aware of the problem of smog in U.S. cities (Levine, 2016: 19). In the late 1970s, General Motors developed the GE-100 (an electric concept car), and after a decade-long hiatus introduced of the Electric Vehicle 1 (EV1) in the 1990s where, once again, American consumers had access to a renewable form of automotive transportation.[3] During this period, the politics of underwriting these new, cleaner vehicles, with simpler engines, which were made of fewer moving parts, proved to be too disruptive for major US automotive insurance companies, and by 2002 all EV1 cars were either sent to the crushers or deactivated by General Motors (Paine, 2006). In China, much of the growth of electric vehicle production and consumption has been driven by Chinese government regulations aimed at reducing traffic and air pollution. Similarly, in Europe, the recent boom in sales of electric vehicles is attributable to government incentives (Boston, 2016).

Today, a number of societal, economic and technological factors are contributing to a second revival and broadening of the global electric car industry. These include 1) renewed worldwide concerns about global warming – given the record global high temperature levels brought on by anthropogenic climate change (Clark, 2016). There exists a geopolitical desire on the part of governments to develop petroleum-independent energy policies. 2) Car manufacturers and consumers have accelerated the revival of the electric vehicle as being not only environmentally beneficial but also as an aesthetically appealing alternative mode of transport (e.g. Symonds, 2016). This previously missing aesthetic component has driven much technology adoption. 3) The global financial crisis of 2008 and 2009 has convinced many in the US that the foundation of a new economy should be built on "substance and not financial, real estate, or dot-com bubbles" (Levine, 2016: 7). 4) Factors relating to the documented abundance of proven lithium reserves (Evans, 2008), and the high likelihood of the existence of new, as yet undiscovered lithium deposits (Gruber et al., 2011) have contributed to the technical feasibility of large-scale electric battery. 5) The strengthened use and reliance on global value chains, (GVCs) especially for US and Chinese companies (i.e., de la Torre et al., 2015) in important sectors such as the global automotive industry, have facilitated the connections between lithium producing regions (i.e., Latin America) with electric battery and vehicle producing regions (i.e., the US and China). In addition, because of the recent surge in demand for electric batteries for zero-emissions vehicles, lithium producers have proliferated. According to market analyst and geologist David L. Trueman, the Toronto Stock Exchange itself has sixty-seven companies listed on it that are in the business of lithium procurement (Fletcher, 2011: 155).

Most significantly, however, despite the increased adoption of li-ion batteries cost remains a prohibitive issue for EV makers. In the contemporary era, cost/price of lithium keeps the lithium consumption-production imbalance real and relevant. "One of the major impediments to reducing the cost of EVs remains the cost of their batteries, which can make up about 50% of vehicle production costs (Lytton, 2010 in Tsang et al. 2012: 12).

For all of these reasons, while carmakers and governments in the US, Japan, China and Latin America have shown an increased interest in gaining access to lithium resources, there is still a great deal of hesitation to move away from internal combustion engines. Nevertheless, the widening interest in EVs has propelled the recent release of popular electric car models such as: Tesla Roadster (2005), the Chevrolet Volt (2006), the Nissan Leaf (2009), the Toyota RAV4 EV (2010), the Fisker Karma (2012), Tesla Model S (2013), the Chevrolet Bolt (2015), and in Latin American markets, Chinese made BYD (build your dreams) has contributed to a dramatic increase in the number of companies incorporating lithium car batteries in their new models. Because of their size, China and the United States are viewed as the largest and most important markets for current and projected electric vehicle sales.

4. A spatial analysis of lithium reserves and business actors

Lithium exists in sufficiently abundant quantities and with enough geographic diversity that no single state actor currently controls the majority of its production or distribution. While approximately 70% of global lithium brine[4] resources are located in just four countries, Argentina, Bolivia, Chile and China (Kesler et al., 2012: 67), the global distribution of other forms of lithium-containing minerals (in pegmatite rock and other unusual sources) highlights the wide ranging, geographic dispersion of lithium (See Fig. 1). Lithium also exists in a variety of forms – lithium carbonate in continental brines (the chief source today and the type in Bolivian salt lakes, or *salares*), geothermal brines, minerals, clays and seawater. The potential rise in price of lithium carbonate will enable these other sources to become commercially viable.

Although pegmatite deposits containing lithium are widely dispersed geographically (more so than brine deposits), with notably large deposits located at Greenbushes (Australia), Manono-Kitolo (Democratic Republic of Congo) and Jiajika (China), even such large pegmatite deposits have estimated resources that are similar to only an average brine deposit. For this reason, and 'despite their smaller size and total estimated resource availability (3.9 Mt[5]), pegmatite will remain of interest because of their wider geographic distribution and consequently lesser susceptibility to supply disruptions and their more lithium-dominant

[3] Other, previous electric cars were introduced in the United States in the 1970s, such as the Cobalt, etc. but the EV1 began a widespread movement of consumers looking to electric vehicles as an alternative to gasoline powered cars.

[4] Mineral mixture, usually found in salt-lake basins.

[5] Mt = Megaton.

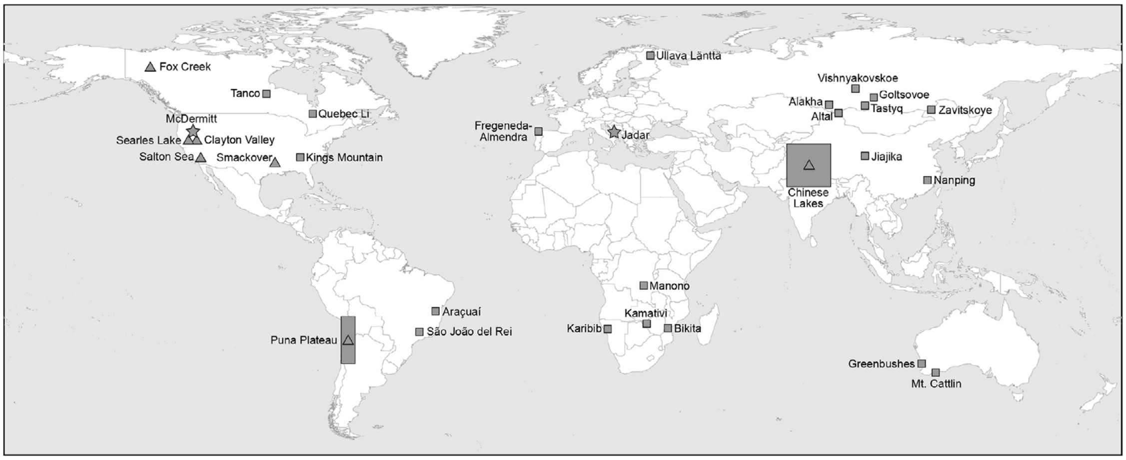

Fig. 1. Spatial organization of known global lithium resources.

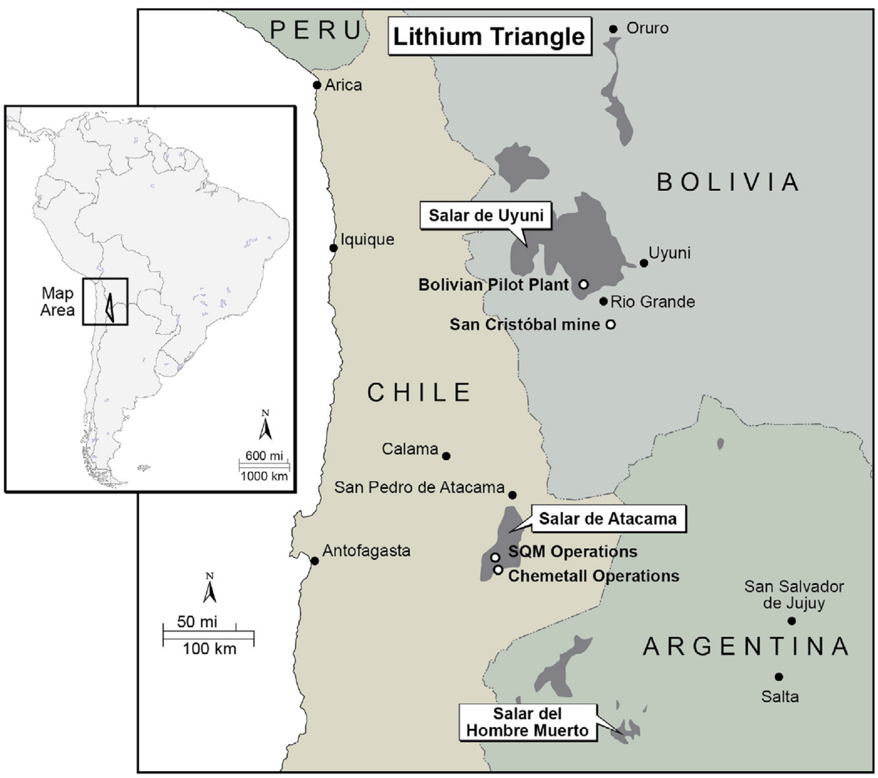

Fig. 2. The 'Lithium Triangle' – comprising areas of Argentina, Bolivia and Chile.

compositions, which might allow more flexible response to market changes' (Kesler et al., 2012: 55).

Currently, the world's most economically feasible lithium extraction/production takes place in high altitude, remote salt brines in the 'Lithium Triangle' area of Argentina, Brazil and Chile (See Fig. 2) and in the lakes of Qinghai Province and the Tibet Autonomous Region in Southwestern China.

The Lithium Triangle region is located far from population centers and transportation seaports. It has attracted investment in the form of lithium production facilities from both domestic (SQL – Chile) and foreign (Chemetall – Germany) lithium production firms. Likewise, the discovery of a high concentration of lithium salts found in the Drangyer Tsaka (Zabuye) lake in far western Tibet and in the Qaidam Basin lakes in Qinghai province (Lafitte, 2011) have attracted investment from the Chinese start-up automotive firm BYD (Build Your Dream).

The unique geographic and climatic conditions of these two regions have helped bring attention to South American countries like Chile, Bolivia and Argentina and to China as important geopolitical players with increasing clout at the front end of the electric battery global value chain. As Garrett (2004, 113) states "As far as is known, the Salar de Atacama, a few other Andean salars and the Tibetan region of China are the only places in the world where the humidity is low enough to allow . . . lithium salts to be crystallized in solar ponds on a commercial scale" (Garrett 2004, 113). The geopolitical logic of planning is not hat views extraction as "a lead sector that creates a series of 'spread effects', which drive economic expansion, moving an economy from one equilibrium (love level of development) to a new equilibrium characterized by higher levels of socio-economic well-being" (Gunton, 2003 in Bridge, 2008). The value chain connecting lithium production, electric battery manufacturing and electric vehicle development help to explain the intense interest many heads of states and companies have in investing in this sector.

4.1. Lithium business actors

These discoveries have given rise to a multiplicity of lithium business actors who are in the process of controlling its supply in order to match demand in a nascent commodity industry whose future remains highly uncertain but has been viewed as a key input for the global electric car industry. The rise in global prominence of lithium business actors contributes to the ongoing *consumption-production imbalance*. Two of the leading lithium business actors – Tesla (US) and BYD (China) have seen double-digit sales growth during the last few years. BYD "is on course to becoming one of the 500 largest companies in the world, and, like Tesla, consider itself 'a battery and engine maker first, car maker second' (Rapoza, 2016). Tesla has excelled at creating excitement for electric vehicles as well as setting expectations for its leading the way for the rapid expansion of the electric car market. Its new Model 3 electric car has projections of being "the biggest consumer product launch of all time" and Tesla is targeting the production of 500,000 cars by 2018 and 1 million cars by 2020 (Waters, 2016). It must be noted that such projections are speculative at best, given consumers, particularly those in the United States, 'range-anxiety' relating to driving EVs.

Early is its evolution to becoming one of the world's leading electric battery/vehicle makers, Tesla secured $465 in US government financing – in the form of a US Department of Energy loan – which it paid back five years early (Keane, 2013). Tesla confirmed its commitment to enlarging the electric vehicle market by its recent announcement of a $5.5 billion dollar investment in a battery production facility in Nevada – the US state with the largest known lake-brine lithium concentrations. At one mile in length, Tesla's 'Gigafactory' is slated to be the world's largest battery factory and is designed to further the drive to create mass market, affordable electric cars. Tesla believes the key to achieving this goal is to reduce the cost of its cars' electric batteries – one of the most expensive components of such cards by building its own electric batteries *en mass*. Tesla justifies its investment in order to prepare for what it envisions begin a "doubling of global lithium ion battery production from current levels" (Chatsko, 2015).

In part because the Chinese government also views the electric car industry as a valuable and scalable sector, BYD has attracted Chinese government financing (Lafitte, 2011). BYD, sometimes referred to as "China's Tesla" is projecting sales of 150,000 a three-fold increase over 2015 sales (Sheppard, 2016).

Complicating the traditional geopolitical ideas of competition between states, the rise of global value chains (GVCs) as a viable business operations process has put in motion an international competition to start-up and multi-national corporations. This competition has led lithium business actors such as Tesla, BYD and most other major, established car manufacturers to cross international boundaries in order to sources inputs – such as lithium – in order to produce the most appealing and cost effective consumer electric vehicles.

The announcement of the construction of the world's largest battery factory has led some to question the fact that Tesla "has yet to announce any lithium supply deals with big producers" (Sanderson, 2015). Tesla and Panasonic will need to start jointly producing batteries by 2017. Table 1 lists the world's top lithium producers through 2015. Global car companies will likely leverage their value chains and attempt to lessen supply risk by attempting to source lithium from a variety of these producers.

Table 1
Top lithium producers (2013–2015) and lithium reserve holders.

	2013	2014	2015	Reserves
Argentina	2500	3200	3800	2,000,000
Australia	12,700	13,300	13,400	1,500,000
Brazil	400	160	160	48,000
Chile	11,200	11,500	11,700	7,500,000
China	4700	2300	2200	3,200,000
Portugal	570	300	300	60,000
United States	870	W	W	38,000
Zimbabwe	1000	900	900	23,000
World Total (rounded)	**33,940**	**31,700**	**32,500**	**14,000,000**

UDSI/USGS 2016:100-101 & Hunt, 2015) Note: W = Withheld for competitive reasons.Source: (USGS Mining and Reserves Data (Metric Tons)).

5. Links to the global supply chain and the needs of the EV industry

5.1. Likely long-term price reduction of lithium

According to Kesler et al. (2012), the world's lithium reserves are adequate to support predicted growth of the global electric vehicle industry. This factor alone should help to eventually bring the price (cost per ton) of lithium down from its 2015–2016 high and should alleviate the tension associated with the current scramble for lithium. A second factor supporting the likely decline in price of high-quality lithium relates to the existence of yet-undiscovered reserves. As Bridge (2009) states: "a society's incomplete geographical knowledge has meant low-quality resources have often been used before high quality ones were discovered or became available" (Bridge, 2009: 1230).

A third factor, contributing to the long-term price reduction of lithium relates to the existence of substitutes for this metal in electric batteries. According to a committee report released by the American Physical Society, "Li (Lithium) is one, but not the only, important candidate for a light, high-performance battery in hybrid and electric vehicles" (Jaffe et al., 2011: 13), and, as a U.S. Geologic Survey report notes, "substitution for lithium compounds is possible in batteries . . . [e]xamples are calcium, magnesium, mercury, and zinc as anode material in primary batteries" (USDI/USGS, 2016). Over the long term, lithium is likely to become more affordable.

In light of the French government describing the need to secure lithium resources as "a battery race" among national economies, it might seem obvious that Bolivia, which possesses the world's largest known lithium reserves at the Uyuni Salt Flats (*Salar de Uyuni*), would be among the leading national economies involved with the development of the modern electric battery industry. Bolivia, however, has only recently been able to benefit from foreign investments in its mineral sector. Bolivia exemplifies what critics of extractive enterprises as agents of economic development based on the extraction of natural resources consider "a pathological disorder that leads inevitably to crisis" (Bridge, 2008: 392). Because of the complex political and historical abuses attributed to extractive processes in its mining sector, Bolivia, to date, is not among the world's top three producers of lithium.

Three problems explain Bolivia's challenges with employing its lithium reserves to realize national economic growth. First, and foremost, the quality/purity of the lithium salts in the Uyuni Salt Flats is not very high. Second, the remoteness of the Uyuni salt flats and the underdeveloped transportation infrastructure surrounding it, make potential shipment costs of lithium from this region very expensive. Finally, the government of Bolivia has a history of nationalizing industries such as the mining sector, so potential foreign investments at a remote salt flat that produces second-grade lithium is not immediately attractive to foreign investors – especially given the nearby alternative – of accessing lithium in the Salar de Atacama, in neighboring Chile. Not only is Chile's lithium of higher quality, (the evaporation process of lithium salts happens faster in Chile than in Bolivia) but both the transportation infrastructure and the business environment (protection for foreign capital) is more clearly codified within the Chilean legal system than it is within the Bolivian legal system. Ongoing, nationalist rhetoric and a recent history of nationalizing and seizing foreign assets, together with the lower quality (despite the larger over all area of Bolivia's lithium reserves), suggests that Bolivia and the Bolivian government is not currently organized in such a way as to play a major contributing role in the global electric car industry. In short, as Ricketts (2010) states: "There are too many unknowns. The importance of Bolivia's reserves was overestimated. It has half the world's lithium but it doesn't make economic sense to mine it".

Unlike silver and tin, lithium development in Bolivia is being discussed in more holistic and comprehensive development terms. According to Bolivian lithium expert Juan Carlos Zuleta, President Morales' objective is to convert Bolivia into the provider of rechargeable lithium-ion batteries that are used by not only electric vehicles or latest generation hybrids but also in millions of laptops, cellular telephones, watches, cameras, digital cameras and music recorders. However, according to Zuleta, the problem is that in Bolivia "there doesn't exist a strategy for exploitation, development and industrialization of the salt flat (of Uyuni). In this sense, Bolivian President Morales' saying that Bolivia's lithium is for Bolivians may be literally very true. The narrative of 'non-use' as an alternative to foreign exploitation of Bolivia's lithium is still widely viewed as a viable political option. For these reasons, the political tensions involved with internationalizing the country's lithium sector highlight 'the difficulty of realizing the potential of resources for broadly based development' (Bridge, 2008: 1236) in Bolivia.

5.2. Bolivian-Asian memorandums of understanding in the mining sector

As a series of official, bilateral governmental Memorandums of Understanding (MOUs) obtained from the Ministry of Mining in La Paz in 2012 make clear, Bolivia's large lithium reserves have attracted attention from governments and companies from around the world – including Asian government actors as diverse as China, Japan, South Korea, Spain and Iran (Ministry of Mining and Metallurgy, 2010–2012). These MOUs[6] also reveal the difficulty that foreign investors have had in commercializing Bolivia's lithium for use in larger sectors like the electric car industry and therefore add to the *consumption-production imbalance*. The difficulties associated with extracting Bolivian lithium resources into battery-grade inputs have contributed to the tensions and frustrations experienced by foreign governments who are eager to tap the world's lithium mother lode – in spite of its chemical impurities.

What do Asian investors offer the Morales administration that US and European investors do not? First, Asian state diplomatic and economic relations with South America are relatively recent. Unlike relations with the United States, Bolivia's relations with Asian economies have not (yet) been politically and economically exploitative. There is speculation as to the reasons for why Bolivia has not fully embraced the advance of lithium production within its borders. These reasons include: Bolivia's strategic and comprehensive approach to lithium extraction – one which emphasizes capturing value in all portions of lithium production from extraction to industrial assembly. According to Aliaga (2010), the Bolivian government's comprehensive lithium development strategy consists of learning (from zero) how to produce this primary product in an experimental phase in a laboratory, then to set up a pilot plant that produces 40 tons per month of carbonate and in the future to increase industrial production to 30,000 tons annually.

The paradox of Bolivia possessing the largest estimated quantities of lake brine lithium together with the country being one of the smallest producers of the metal, highlight the geopolitical tensions at play between President Evo Morales' nationalist discourse and the interests of the global electric car industry.

These MOUs highlight the challenges associated with converting Bolivia's lithium resources into part of the global electric vehicle value chain. Most notably, the reports and MOUs are *not* indicators of policy or action but rather can only suggest future *intention* of economic cooperation. Perhaps one of the reasons for the deliberate and non-committal language of these MOUs relates to Bolivia's history of nationalizing previously privatized sectors (e.g., Kohl and Farthing, 2012). Foreign firms that perceive a possible government take over of their investments/assets and technologies, are much less likely to consider operating and working in such an environment (Romero, 2009). These documents, apart from indicating a recent increase in collaboration between Bolivia and: China, Iran, Japan, and South Korea, offer signs of goodwill, cooperation and collaboration, without committing to any production targets or timelines. These MOUs do provide a scientific explanation of the current (natural) deficiency in the quality of lithium, as it exists at the Salar de Uyuni. This lack of lithium quality, however, together with the legacy of nationalizing formerly private/foreign companies, the remote/extreme conditions of the location of the Salar de Uyuni, and the still emerging infrastructure, are all factors that help explain why Bolivia, has not been able to attract foreign capital and investors and become a part of the electric battery/vehicle global value chain.

According to an MOU prepared by several South Korean government agencies focusing on developing processes and technologies appropriate for lithium extraction in the Uyuni salt flat, it is clear that the concentrations of magnesium (which are 18–24 times greater than lithium) make for a very expensive lithium extraction and purification process. The Korean government groups involved with the study have offered three processes that they believe can add value to lithium carbonate production at the Uyuni site. This MOU highlights the principle reason why much of Bolivia's lithium remains in the Salt Flat at Uyuni. In a brief MOU between Bolivia and Iran, both governments agree on the need to obtain Iranian financial, technical and scientific expertise in order to advance a series of development related projects in Bolivia. This document, however, does little apart from formalizing an agreement to mutually cooperate on a host of development issues. One possible reason that Iran and Bolivia signed a lithium technologies agreement has to do with both of these states' geopolitical worldviews. When Iranian President Ahmadinejad visited Bolivia in November 2010, Morales told him "I'm a big admirer of you and your people. Our people have the mandate to liberate ourselves from the empires" (in Wright, 2010). Such statements emphasize the idea that Bolivia's bilateral lithium accord with Iran is perhaps steeped more in symbolism than it is in economic intent.

An MOU between Bolivia's Corporacion Minera de Bolivia (COMIBOL) and China's CITIC Guoan Group (one of China's largest lithium producers) formalizes production projections that will only be realized if a subsequent extraction proposal is submitted

[6] MOUs are available upon request.

and approved. According to Aliaga (2010) President Morales has (whether inadvertently or not) set up difficulties for potential business partners by proposing that those interested in developing Uyuni's lithium offer a primary production phase of lithium batteries at the Uyuni salt flat itself and during a second phase (fabricate) electric cars in Bolivia. Like hydrocarbons, however, increasingly varied source types and the geographic diversity of world lithium reserves will likely lower lithium prices and, over the long term, will give a boost to energy intensive automobile manufacturing in industrially developed countries such as the U.S. (see Yergin, 2012). One major problem with this is that "Battery-making is capital intensive, highly automated, produces few jobs and requires nearly the same precision as the semiconductor industry. Also, auto manufacturers generally want batteries made near their assembly plants" (Bajak and Valdez, 2009). The logistical challenges and the associated costs of preparing high-quality lithium suitable for use in electric batteries are the main driving factors contributing to Bolivia's lithium discourse as being more "future looking" than pragmatically feasible in the present.

6. Conclusion

The contemporary scramble for lithium for the use in electric batteries for cars is full of contradictions that can be best understood as a global lithium *consumption-production imbalance*. Lithium is at one and the same time a "vital raw material" and the "world's hottest commodity" (The Economist, 2016a, 2016b) that is both replaceable (as an electric battery component) and whose high price will fall over time. That the world's largest known lithium reserves exist in a country (Bolivia) that is not among the world's largest lithium producers is a paradox that further adds to the contradictions surrounding global lithium availability. Such paradoxes and contradictions have fueled anxieties among electric vehicle manufacturers (eager to secure access to high-quality lithium) and countries (whose leadership views the electric car industry as an engine for national economic growth and global economic leadership). The tension between the supply of available lithium and the quality and price demands of electric battery and manufacturers has highlighted the materiality of lithium – emphasizing the metal's temporal importance in the contemporary global economy (Frankel and Whoriskey, 2016). What is clear is that Bolivia has the world's largest single lithium deposit. However, its undeveloped infrastructure, fickle regulatory environment and uncertainties surrounding the security of mining investments continue to present impediments to investors (Bates, 2016). Bolivian policymakers could benefit from welcoming foreign business and mining industry talent into the country with a clear understanding of the financial (and moral) responsibilities such talent has to the Bolivian government and people.

Potential difficulties in obtaining sufficient quantities of electric battery-grade lithium appear to have been instigated by the recent (2015–2016) lithium price increase combined with a simultaneous slow in lithium production. It is this confluence of factors – and not a lack of global lithium supply – that has driven the recent 'battery race' and has helped to solidify the importance and durability of the electric vehicle sector in the global economy. As this work has shown, new lithium resources existing in various geological formations and in distinct geographic locations – mean that more lithium is available today than at any time before.

Unlike availability, quality of lithium and price are constricting factors that continue to bring uncertainty to the growth and rate of expansion of the global electric car industry. Nevertheless, Tesla Motors forecasts the future of electric batteries expanding beyond electric vehicles to encompass a range of personal, home, office and as well as transportation related applications. As lithium demand gradually increases to meet the needs of emerging and established electric battery and vehicle manufacturers, so too would the demand for other metals such as copper and cobalt. With "each electric vehicle requiring four times as much copper as its gasoline counterpart, not including the copper used in recharging infrastructure and electricity generation" (MacKenzie in Sanderson, 2016a, 2016b), it is clear that the growth of the electric car industry is poised to 'raise many ships' in the realm of metallic natural resources.

Ultimately, the rise of the global electric car industry will not be constrained by lithium availability for two main reasons. First, sufficient proven reserves are known to exist in various forms in a variety of locations and new reserves and methods of extracting lithium are currently under development by a host of companies supported by a wide variety of government actors. Second, substitutes for lithium, such as zinc, could replace lithium for use in batteries, thereby allowing for the continued advance of electric car batteries and growth of the global car industry in a variety of different pathways. As is the case with the global food supply, access to lithium is limited more by logistical issues (cost-effective access) and quality, as opposed to quantity.

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