ESK outlook 2017-2025

Forecast of Demand of Battery-Dependent Appliances (BDA) Lithium Batteries (LIB) and Lithium (LCE) - upstream analysis

With black swans scenarios and geopolitics in the unicorns era

Outlook 2017-2025

More than 8 million electric vehicles will be sold in the year 2025, against 1 million sold in 2017. There are 150 GWh of lithium batteries available in the world, but 790 GWh will enter by 2025, enough to provide electricity to a city of 3 million homes for one month. Fifty per cent of the world population will carry a battery in their pocket. Almost 800 thousand tons of Lithium (LCE) will be needed in 2025, about 3.2 times the current demand, the details and reasons in the following report.

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Jun 2018

Description of the chapters and their contents

1.- CONTEXT	**Analysis of the context in which this study is conducted, applying technological factors, high-impact disruptive innovations, called "black swans", the increasingly present geopolitical factors that "twist" the inertia of the free competition and market and, lastly, the merging factors of the Internet era with the era of the energy revolution for climate change that cause an exponential economy.**
2.-METHODOLOGY	The methodology explained in the singular terms of this study, mainly based on our own judgments and only using references validated in the baseline of the results from 2016 and 2017.
3.-RESULTS AND INTEGRATED PROJECTIONS	The final results of the year-by-year projections, until 2015 of the annual ton demand of LCE (lithium carbonate equivalent), the demand until 2025, of batteries, expressed in GWh and the demand of each one of the categories that make said demand. All of this separated by subcategory.
4.- ANALYSIS, SCENARIO AND PROJECTIONS PER CATEGORY	Each category and subcategory is analyzed in detail, looking into its technological evolution and market experience, as well as its projection in both senses. The foundation and the projections of the annual demand until 2015 in aggregated and disaggregated terms, as well as the upstream effects, are shown in detail.
4.1 ELECTROMOBILITY	Electromobility is analyzed based on three subcategories, light and semi-light electric vehicles distinguishing the hybrids (PHEV) and the fully electric (BEV), as well as the heavy vehicles, primarily looking into the E-buses.

	4.2 STATIONARYBATTERIES	**The use of energy storage in the electrical grid is analyzed in three categories. On the generation, distribution and demand sides. Their uses and trends, as well as their problems are looked into.**
	4.3 PERSONAL ELECTRONIC DEVICES	The evolution of the personal electronic devices, especially smartphones, laptops and tablets are researched from its past evolution to its possible projection.
	4.4 OTHER DEVICES	Hundreds of other devices that use batteries are appearing. In this section we analyzed in detail the E-bikes, portable electric tools and other devices in emerging stages.
BLACK SWANS AND GEOPOLITICAL CIRCUMSTANCES		Every category presents, in addition to the analysis and projection curves, a list of potential contingencies that might radically change the projections, based on the potential high-impact disruptive innovations and geopolitical factors that might deform the market through the influence of the governments and their struggle for a global supremacy.

Outlook 2017-2025: from mainstream to upstream

CONTENT

¿The era of unicorns?

The Unicorns, from an Innovation point of view, are those companies that are able to invoice more than US$1 billion in some of their capital raise stages. They are disruptive companies that are developing high-impact technologies and with influence on humanity.

Unicorns started appearing in the 1990s, some of them have in fact

changed humanity and we don't have to identify them, because we can see them daily in the press as well as their founders discussing subjects that are more associated with political leaders than with entrepreneurs.

Many unicorns may be born in the next decade and it is hard to predict where or what their objectives will be, but they must be considered as part of the outlook for the next few years.

Glossary

Term	Meaning
LCE	Lithium carbonate equivalent, standard unit to measure the different types of lithium derivatives.
LIB	Lithium Batteries
EV	Electric vehicle in general
ICE	Internal combustion vehicle
BEV	Full electric vehicle
HEV	Hybrid vehicle, with both electric traction and internal combustion.
PHEV-X	Pluggable hybrid vehicle with X autonomy of km (miles) in electric mode
E-BUS	Electric bus, in general. There are several categories of electric buses
GWh	Giga Watt per hour, energy measure used in the electricity world. One million kilowatts per hour.
Energy Density	Energy that can be stored for each mass unit (kg) of battery (or cell)
Cyclability	Useful life measure or number of complete loading and unloading cicles guaranteed by the manufacturer in battery's use window range (usually between 10 and 90%).
Off/on-Grid	Electricity auto-generation solution by a final user completely disconnected from the electricity grid (off) or complementarily connected to the grid optimizing both sources according to the occasion (on).
GHG	Greenhouse gases
BDA	In general "Battery-Dependent Appliances" as EV, Portable electronic devices, notebooks, E-Bike, drones, etc

Main references and their use in the study

CITED WORKS

argonne national Lab USA. (2017). *BACPAC Anl 12-55 model Lithium batteries design and calculation.*

ESK consulting. (2017). *Iota and Epsilon .*

International Energy Agency (IEA.org). (2017). *world energy outlook 2017.*

International Energy Agency. (2017 y 2018). *EV outlook 2017 y EV outllook 2018.*

- (International Energy Agency, 2017 y 2018), EV Outlook used for the Determination of the 2017 electromobility's baseline
- (International Energy Agency (IEA.org), 2017)WEO used for the underlying analysis and electricity projection criteria in the world.
- (argonne national Lab USA, 2017), BACPAC was used for the determination of the mass parameter (Kg) of LCE to KWh in a lithium battery.
- (ESK consulting, 2017), Development methodology used to connect exponential evolution phenomena in the industries and the market being studies.

Projection Adjustments and their margin of error

The projections shown in this document are responsibility of the author and they are based on the results of the analysis shown in the same document. These projections are trends based on empirical observations, as well as on economic and market criteria, justified in every case. This study was designed as an informed reflection tool. If the criteria are wrong or debatable, the projections obviously will differ. The public scenario is unique, and the optimistic or pessimistic scenarios could come from the changes of diagnoses in terms of unexpected events (see BLACK SWANS and GEOPOLITICAL CONTINGENCIES in every category).

One thing is saying what and how ...

Another thing is saying how much

SUMMARY

The present study is based on the holistic research, both technological and market, and on key circumstantial facts of the markets and industries that use lithium batteries.

The expert judgment of 10 years of study in subjects related to said research is applied case by case, using consensus analysis and examples based on internalized experiences on this emerging industry in its first decade.

The methodology is based on the hypothesis that two global processes born separately 20 years ago and originated by very different events, are rapidly converging and, furthermore, merging into a new replenished and growing phenomenon.

These phenomena we have denominated by the Greek letter "**Iota**", symbolizing "**I**nternet" and the Greek letter "**Epsilon"** for the phenomenon in the **E**nergy industry of the last 20 years, are generating, in a continuous feedback, a series of exponential evolution consequences where the elements of the "mobility or portability" and the electric autonomy of the electronic devices, along with the use of emerging primary sources of energy based mainly on the sun and the wind, essentially variable in their availability, have a common denominator which is the need for electricity storage sources, being the lithium battery, which we have called "vector", the winning storage element so far, which we foresee will continue for at least one decade, given

THE AUTOR: With almost 40 years of experience, Electrical Engineer. The first 10 years in the field of engineering he worked as director of large telecommunication projects in Chile. In the second decade he actively participated in Innovation subjects, including the foundation and operation in 1994 of the first ".com" in Chile, Telemultimedia, one of the firsts in the world. In the third decade he worked in the international field as CEO of the Chilean subsidiary of the Japanese NEC Corp., mainly in the industry of information technology. The last 10 years he joined the University of Chile as an expert professor of the energy center and the department of Industries, where he has actively promoted the link between science and the company. He founded in 2010, taking charge of the successful no profit "*think-tank*" "Lithium Innovation Center", co-financed by the companies SQM, Rockwood and Marubeni, along with the University. Since 2010, he has been studying electro-mobility and lithium batteries, acting as an expert consultant and speaker in different parts of the world, and he has been interviewed in different media interviews. He has been an activist of these technologies and he is recognized for his opinions on a national and international level. Likewise, he advise and cled the foundation and direction of the science-based innovation center Openbeauchef (Science-based Innovation). During this last decade he founded two companies, "ESK Consulting" and "Elibatt Lithium Batteries". He has been CEO and Board Member several times, consultant and advisor in energy and technology subjects on a local and international level, for a few years he has been the analyst of investment scenarios using his own methodology "Iota+Epsilon" based on expert knowledge methods. He periodically issues his opinions in his own eskorpion.com column and in media mainstream and television. He is currently requested about it by international or local companies and goverments, especially investment funds or related activities. He is part of the Gerson Lehrman Group board, as senior advisor. He is also the senior advisor of the Energy Center of the University of Chile. He is the director of the software company TINET.cl, a company expert in digital transformation. Founding member and "principal" of ESK consulting

the already-committed investments in research and engineering, installation, production and massive and industrial operation. This inertia that quantitatively reflects a relevant industrial decision and huge amounts of committed money, implicitly avoids its sudden replacement.

...the present document uses very few referenced sources, which are chosen because of their independence and global consensus prestige. They are used in the baseline, or data of the recent past (2016 and 2017). The judgments and projections correspond to the author's well-informed opinions and analysis based on his own experience gathered from the basis of the observed and analyzed behavior of the last 20 years with the Iota-Epsilon methodology.

Fig. 1 Downstream from raw material to the demand, going through the batteries

Figure 1 shows, in a dramatic and complex image, how many industries of different areas are developed, namely; mining, chemical, industrial, electronic, software, etc., until reaching the different demand of **BDA**[1]. The present document analyzes and researches the final markets and their vertiginous changes, in order to return upstream to the previously-committed industries and considering the economic phenomenon of the knowledge area where we are now, combined with the innovation potential of each industrial segment.

The result of this analysis directly affects the demand of key raw materials, such as cobalt, nickel, manganese ...and particularly this industry's key material, lithium, which is the only element that includes any combination of the chemistry of the cathode's active material of the cells that make the batteries.

[1] **BDA: Battery-dependent appliances, como por ej.- Electric Vehicles, Smartphones, PV solar installations, etc**

While there is an agreement that Lithium is abundant in the entire world and that there isn't a risk of having problems with the reserves and resources or problems with the supply of the processed material in the long term, we mustn't underestimate the fact that the speed of change that is happening is very relevant and that starting the real operation of high-quality grade Lithium batteries require some development years and numerous mining-based investments. Therefore, it is essential being able to predict the demand of Lithium (and other materials), which will affect its price if it is not synchronized with the demand. Since the price is not relevant in the driven final product, the battery, there isn't an excessive pressure on behalf of the requestors of said supplies who are more concerned about the safety and quality of the supply than the circumstantial price.

…The high prices of the LCE in the last few years have to do with the real-time demand, and therefore the growth's gradient. This could not be associated with an irreversible phenomenon, but if the demand continues to be greater than the supply, this price could remain for a long time. The complexity of this material's market, in terms of how the contracts and prices are negotiated, case by case, and the few incumbents in the origin of the material, not in the reserves but in the production operation, complicate the entry of new players. This aggravated by the excessively-complex way, to say the least, in which the countries that own those resourses administrate the material's production, as if they were handling uranium instead of a simple and abundant material[2].

Our methodology focuses on a delicate analysis of the technological and strategic context of the mainstream, symbolically speaking, full of tributaries and isolated conceptualizations with their own merits, because they are from different and diverse worlds and in different levels of development and state of the art.

Generally, the analysis avoids leaning on references from other studies[3], since its intention is to generate its own hypothesis built from its own expert experience and several personally-constructed analysis. The basic foundation is to start with a reasonably-reliable recent baseline, therefore the research has focused on finding consensus data regarding the 2017 already-closed numbers or, eventually, from 2016 if the 2017 data is not available.

Then, the analysis takes the liberty to project these base data based on criteria and claims, which are explained in detail in the same.

A couple of phenomena, which are more and more present today, are specified in each case as a reflection tool, like the unexpected high-impact innovations (for better or worse) called

[2] **This is particularly relevant in the so-called "lithium triangle" in South America where geopolitical factors have taken this material as an example and a struggle flag for a long history of dependence on raw materials. This implies naturally to mix opinions with emotions and many aspects beyond the technical aspects, creating post-truths about lithium by mixing desires with realities. That is only one example "of geopolitical factor in the chain of Iota-Epsilon related industries. Of course there are hundred of this type of factors in Asia, USA, Europa, etc.**

[3] **This statement is partially true. Strictly speaking, this is not a "blind" study. The analyzed studies represent a context and boundary conditions to be considered, but always as a results comparison reference, not using the referred ones. On the other hand, this study does gather the base data reports which are an initial level of the same, the elapsed years and with recent statistical references. Likewise, the determination of key parameters like lithium's density/KWh in a battery or scientific research and market and geopolitics behavior data are gathered from widely-recognized public sources, properly referenced.**

black swans[4], as well as the geopolitical events that are causing today major market deformations due to global strategies coming from the economic and political volatility, and from radical changes of government leadership, along with the lack of precision regarding the political course of some developed nations or regions, in general.

Obviously, the **Iota+Epsilon** effect is additionally considered as the key catalyst that enables the implicit technological changes in this development, as well as the real industrial powers that affect today's political decisions due to the accumulated knowledge in key technologies, like the artificial intelligence combined with "big data", thus the ability to create new markets based on the insight of the potential clients. The phenomenon of creating new markets, foreseeing a social need through delicate studies based on social networks and sophisticated algorithms that process a vast number of data and can determine trends and vice versa influence the same, strengthening what people wish to follow but without expressing it, through artificial intelligence machines that learn individual behavior reinforcing the insights of person's decision.

...A FEW RESULTS

The demand projection of LCE (*Lithium Carbonate Equivalent*) between 2016 and 2025, calculated on the basis of the vectors and drivers foundations, shows a growth from 215,500 tons in the year 2017[5], to 793,000 tons in 2025.

[4] Nassim Nicholas Taleb Black Swan is an event with the following three characteristics. Firstly, it's an atypical case, because it is outside the field of regular expectations, since there is nothing in the past that can aim convincingly to its possibility. Secondly, it leads to an extreme impact. Thirdly, despite its rarity, human nature makes us come up with explanations for its presence after the facts, so it is explicable and predictable

[5] We know that in 2017 the demand for LCE was 230 thousand tons. We prefer to use our reference based on foundations, because that is what we project

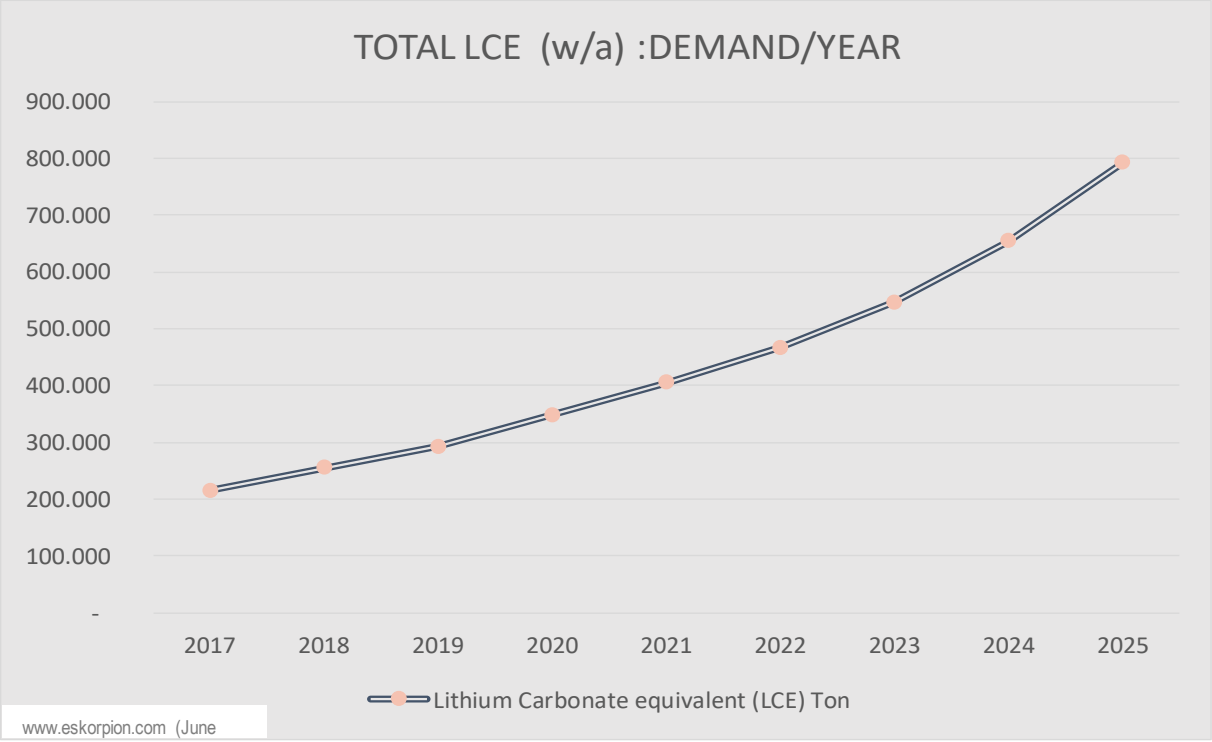


Fig. 2 2016-2025 LCE projection demand with adjustments of market's purchase model[6]

The total demand will be connected to the battery demand (vectors) in different segments, in this case

- **Electromobility (EV),**
- **Stationary batteries for energy storage**
- **Batteries for portable electronic devices**
- **Batteries for other devices**

In Figure 3 we can see that the main "driver" impacting the lithium battery demand is the electromobility market, focused on light and utility vehicles, on one hand, and buses on the other. However, a sustained growth is observed regarding the use of electric storage systems in the energy grid, in the use of temporary compensation of variable energies, like balance of the demand in the distribution and serves (backup) in the generation cases. The case of the projection for the final home or industrial demand seems to be relevant, which is analyzed in detail in the respective chapter.

[6]**There is a demand adjustment due to the inventory purchases and clients' reservations.**

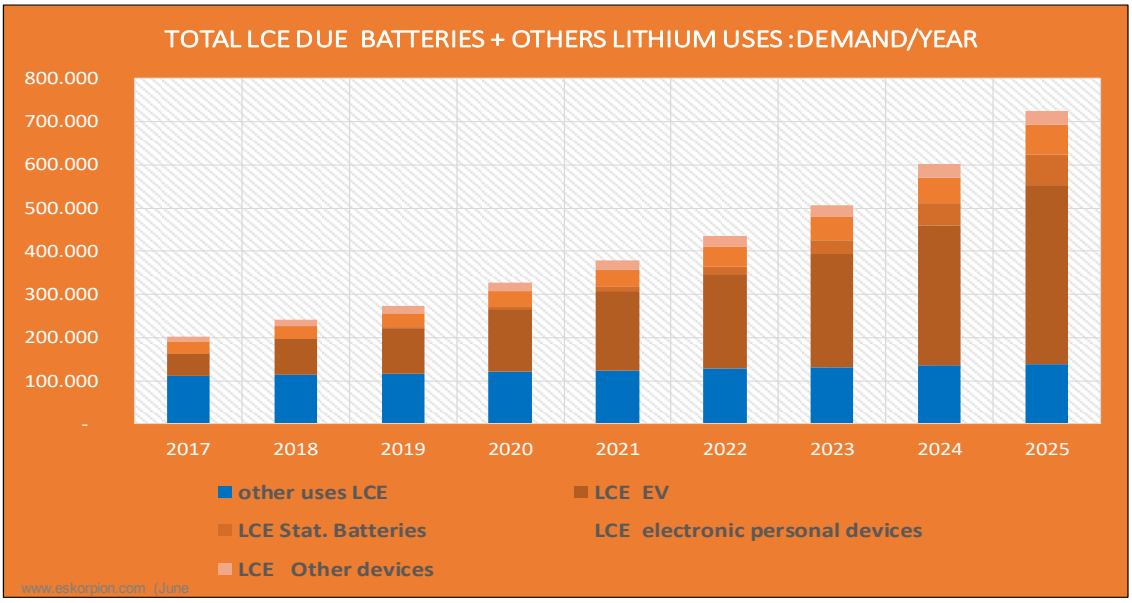


Fig. 3 Annual demand of energy in lithium batteries and others lithium uses.

Likewise, there is a not-so-relevant growth in portable devices, possibly due to the fact that it is a mature market with a great implementation in more than 50% of the world's population.

Indeed, the sustained participation in the other devices will increase as new applications are created and demanded, especially on a people and homes level.

the current participation of the lithium demand for other known and traditional uses like lubricants, glass, ceramics, medications, etc., (about 100 annual thousand tons of LCE) is still relevant in the year 2018, but its participation will be less relevant by the year 2025, although new uses will be foreseen as well as a discreet growth of the demand in this category.

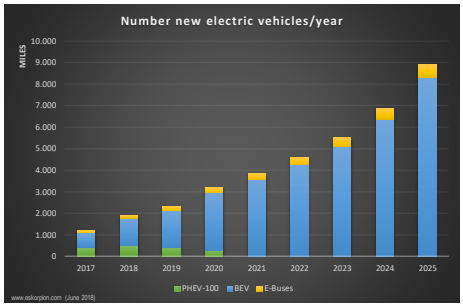
Regarding Electromobility ;the mainstream of the battery use in the future, will continue leading the absolute demand of stored energy.

In this case we can see a very accelerated growth of the demand, even larger than the one seen in several studies of the recent past year, reaching more than 3 million registered units in 2017 (against 2 million "On the road" in 2016). The registered sale of 2017 reaches 1,100,000 units[7]. In 2017, China became the first world player regarding supply and demand of electromobility and a powerful political influencer in this field

...More than 50% of the world's population carry a lithium battery in their pocket, even in poor countries...

[7] **IEA, EV Outlook 2018. The relevance and seriousness of EIA studies are considered a must in the studies of electrical engineering and global energy policies. This is why they are used as the basis chosen for the electromobility reference of the year 2017**

The number of vehicles considered in this study[8] would increase considerably in terms of new registers per year, reaching more than 8.3 million registers in the year 2025, considering the buses. Likewise, it is projected, in the short term, the end of the transition of light hybrid vehicles with range extension (a referential extended range of 100 km is considered for this study, PHEV-100) due to how competitive the pure electric vehicle (BEV) will become, which is estimated to occur very soon based on the recent trends in China and the promises of new electric models from the main brands.



When considering the demand in terms of energy in batteries, we can see that the relative value of the buses is taking great importance, since the use trend of completely-electric large-range buses (> 250 km) implies an energy demand per bus equal to 5 BEV light vehicles. With this, a demand of 560 GWh would be reahced in 2025, against approximately 110 GWh in 2018. The accumulated energy availability in lithium batteries (LIB) during that period would reach almost 3.5 TWh.

The buses

Public transportation is an issue in itself. There is a demand for thousands of bus fleets in every city and those are decisions promoted by transportation authorities, putting pressure on private and public operators in either direction. On the other hand, the electricity distribution companies are acting and strongly influencing this sector, even acting as provider and lessor of electric bus fleets, thus promoting the technology of completely-electric buses, for obvious reasons. These new clients of the distributors consume in one month the electricity of 30 homes. A fleet of 5,000 buses, normal in any big city in the world, is equal to 150,000 new homes in terms of demand.

...The demand of lithium carbonate and lithium hydroxide would grow more than anticipated by the recently-published studies, due to the agents that are accelerating electromobility and the demand of stationary solutions for the auto-generation of NCRE in the demand...

[8]Vehicles were considered with an impact on the size of the battery. For this study, an utility truck is the equivalent of a passengers vehicle and the high-tonnage trucks are not considered because the penetration of the batteries in this category will be slow and with marginal effects.