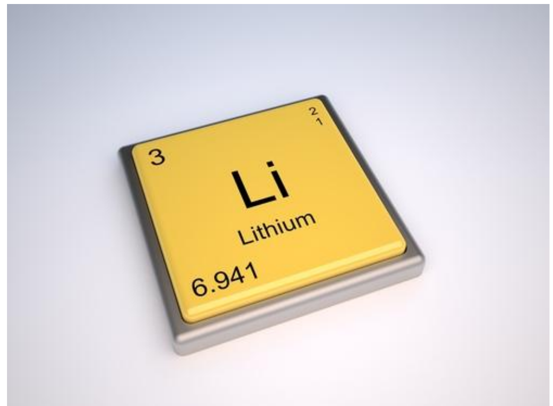
The Lithium Market



Lithium (chemical symbol: Li) is the lightest of all metals. It does not occur as a pure element in nature but is contained within mineral deposits or salts, including brine lakes and seawater. The contained concentration of lithium is generally low and there are only a limited number of resources where lithium can be conomically extracted.

Lithium and its chemical compounds exhibit a broad range of beneficial properties including:
- The highest electrochemical potential of all metals.
- An extremely high co-efficient of thermal expansion.
- Fluxing and catalytic characteristics.
- Acts as a viscosity modifier in glass applications.

Chemical Applications: Lithium can be processed to form a variety of chemicals including lithium carbonate, lithium bromide, lithium chloride, butyl lithium and lithium hydroxide. The fastest growing and second largest market for lithium globally is for use in batteries.

Other Applications:

- **Rechargeable batteries for a variety of devices like mobile phones, laptops, digital camera and more utilize lithium.**
- **Certain non-rechargeable batteries for items like clocks and pacemakers also make use of the metal.**
- **Lithium metal can also to form alloys with aluminum or magnesium, which is used for armor plating and in aircraft, bicycles, and trains.**
- **Lithium carbonate is used in the field of making glass and ceramics. It is also involved in producing aluminum.**
- **Lithium stearate is used in cosmetics, plastics, and its grease is used in aircraft and marine applications as well as other areas.**

Lithium use in Batteries:
Lithium has a number of uses but one of the most valuable is as a component of high energy-density rechargeable lithium-ion batteries. Because of

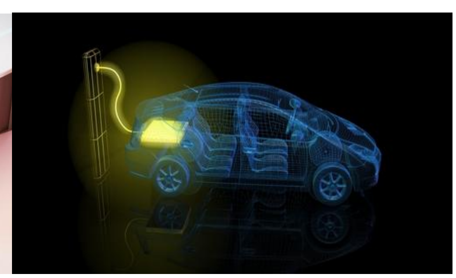
concerns over carbon dioxide footprint and increasing hydrocarbon fuel cost (reduced supply), lithium may become even more important in large batteries for powering all-electric and hybrid vehicles. It would take 1.4 to 3.0 kilograms of lithium equivalent (7.5 to 16.0 kilograms of lithium carbonate) to support a 40-mile trip in an electric vehicle before requiring recharge. This could create a large demand for lithium.

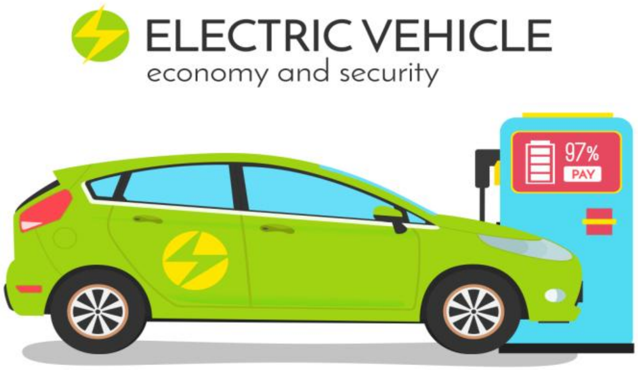
Batteries:
There are two types of lithium batteries,

Primary (non-Rechargeable): Including coin or cylindrical batteries used in calculators and digital cameras. Lithium batteries have higher energy density compared to alkaline batteries, as well as lower weight and long shelf and operating life.

Secondary (rechargeable): Key current applications for lithium batteries are in powering cell phones, laptops and other hand held electronic devices, power tools and large format batteries for electricity grid stabilisation. The advantage of the lithium secondary battery are its higher energy density and lighter weight, compared to nickel cadmium and nickel metal hydride batteries.

A growing application for lithium batteries is a power source for a wide range of electric vehicles, including electric bikes, scooters, buses, taxies, and passenger electric vehicles. There are three main categories of electric passenger vehicles; Hybrid Electric Vehicles, Plug-In Hybrid Vehicles and Electric Vehicles.





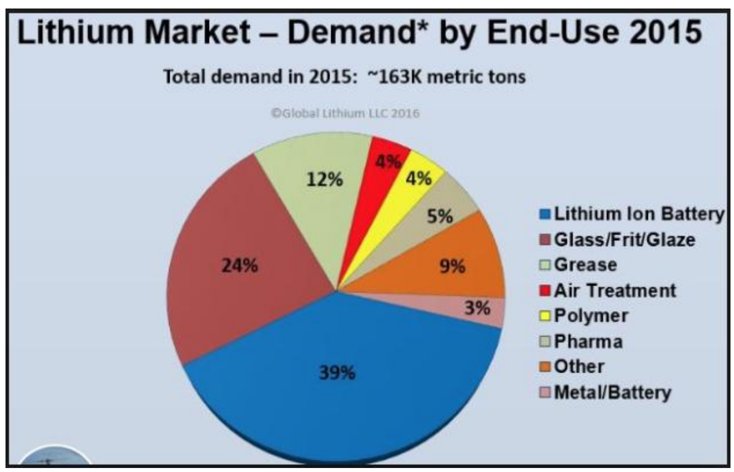
Lithium Battery For Green Energy

The electrification of vehicles is strongly supported by governments around the world due to increasing political and consumer focus on climate change and energy security. The introduction of mass produced passenger electric vehicles has the potential to significantly increase the future consumption of Lithium.

Other Chemical Applications:

Lithium chemicals are also used in a variety of other applications including:

- Lubricants: Lithium is used as a thickener in grease, ensuring lubrication properties are maintained over a broad range of temperature.
- Aluminum Smelting: the addition of lithium during aluminum smelting reduces power consumption, increases both electrical conductivity and reduces fluorine emission. The process increases strength and lightens the end product. These new aluminium/ lithium alloys are now being used in the auto and airline industry for fossil fuel savings.



- Air Treatment: Lithium may be used as an absorption medium for industrial refrigeration systems and for humidity control and drying systems.
- Pharmaceuticals: Lithium is used in the treatment for bi-polar disorder as well as in other pharmaceutical products.

Glass and Ceramics:

Glass: including container glass, flat glass, pharmaceutical glass, specialty glass and fiberglass. These glass products may be designed for durability or corrosion resistance or for the use at high temperatures where thermal shock resistance is important. The addition of lithium increases the glass melt rate, lowers viscosity and the melt temperature providing higher output energy savings and moulding benefits.

Ceramics: including ceramic bodies, frits glazes and heatproof ceramic cookware. Lithium lowers firing temperatures and thermal expansion and increases the strength of ceramic bodies. The addition of lithium to glazes improves viscosity for coating, as well as improving the glazes colour, strength and lustre.
Specialty Applications: including induction cook tops and cookware. Lithium's extremely-efficienthighoftermalco expansion makes these products resistant to thermal shock and imparts mechanical strength.

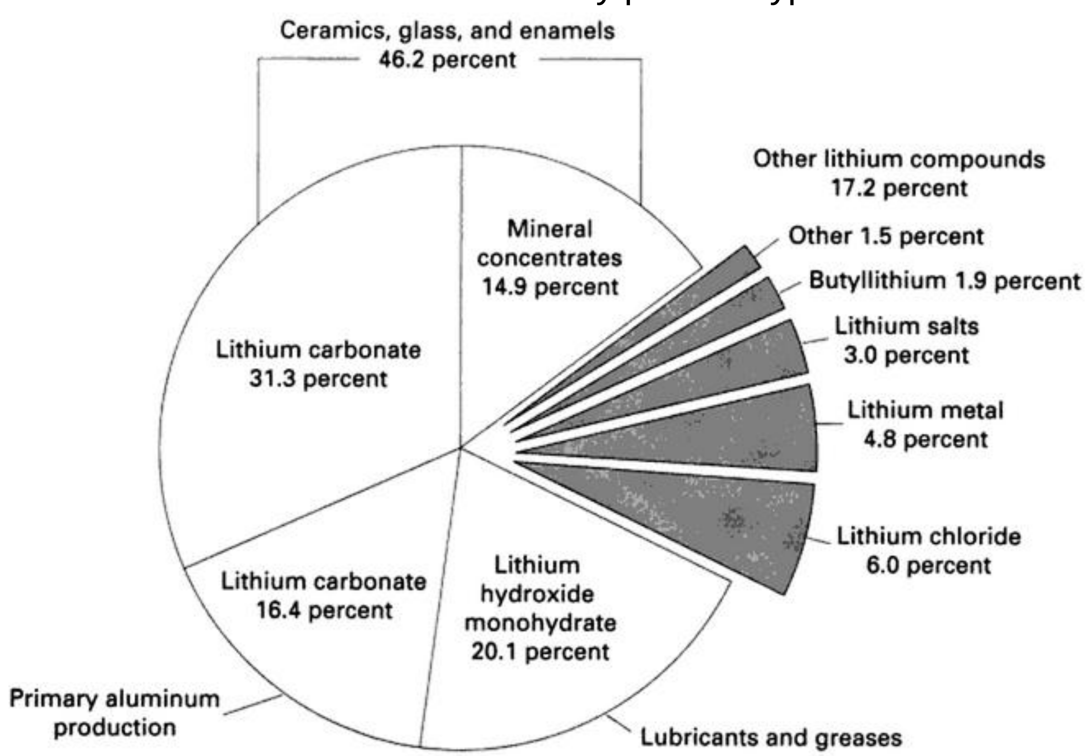
Other Technical Applications:

Lithium is also used in a variety of metallurgical applications, including:

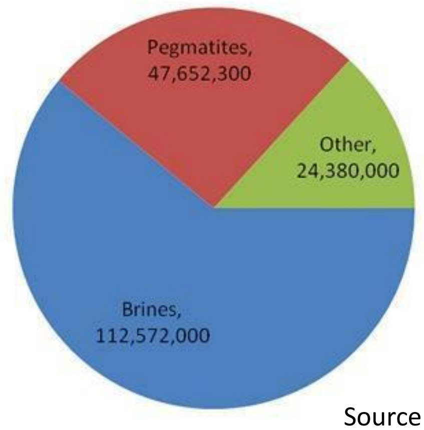
Steel Castings: the addition of lithium to continuous castings moulds fluxes assists in producing thermal insulation and lubricates the surface of the steel in the continuous casting process.

Iron Castings: in the production of iron castings, such as engine blocks, lithium reduces the effect of veining, thereby reducing the number of defective casts

Estimated world Lithium demand by product type



Global Lithium Reserves



Source USGS

Global estimates suggest there are more than 30 million lithium resources, however, it is important to know that most deposits are not economically viable. For instance, some of the deposits, both brines and hard rock, may have high levels of impurities that make processing very costly, while others are in isolated parts of the world and would require high infrastructure expenditures, deeming them uneconomical. In the case of brines, the weather in some regions is not appropriate for the solar evaporation process. There are also many other factors, thus it is necessary to spend a significant amount of time and resources to determine the feasibility of these projects before considering them as viable resources (Euro Pacific-Canada, August 2013)

According to the United States Geological Survey (USGS) it is estimated that the global lithium reserves are in the 16 million tons. These estimates exclude lithium occurrences and resources that have not proven economic.

GLOBAL LITHIUM RESERVES

Country	Reserves
United States	35,000
Argentina	2,000,000
Australia	2,700,000
Brazil	48,000
Chile	7,500,000
China	3,200,000
Portugal	60,000
Zimbabwe	23,000
Canada	80,000
*Total	16,047,000

*Global Lithium Reserves from U.S. Geological Survey, Mineral Commodity Summaries, January 2018

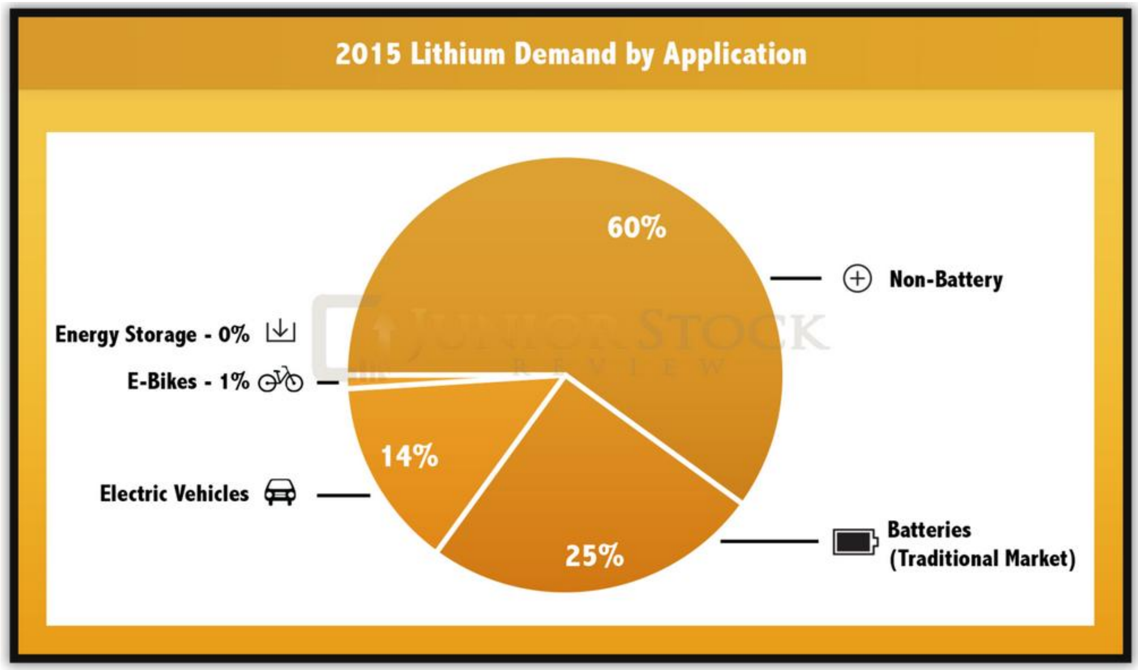
World Resources:

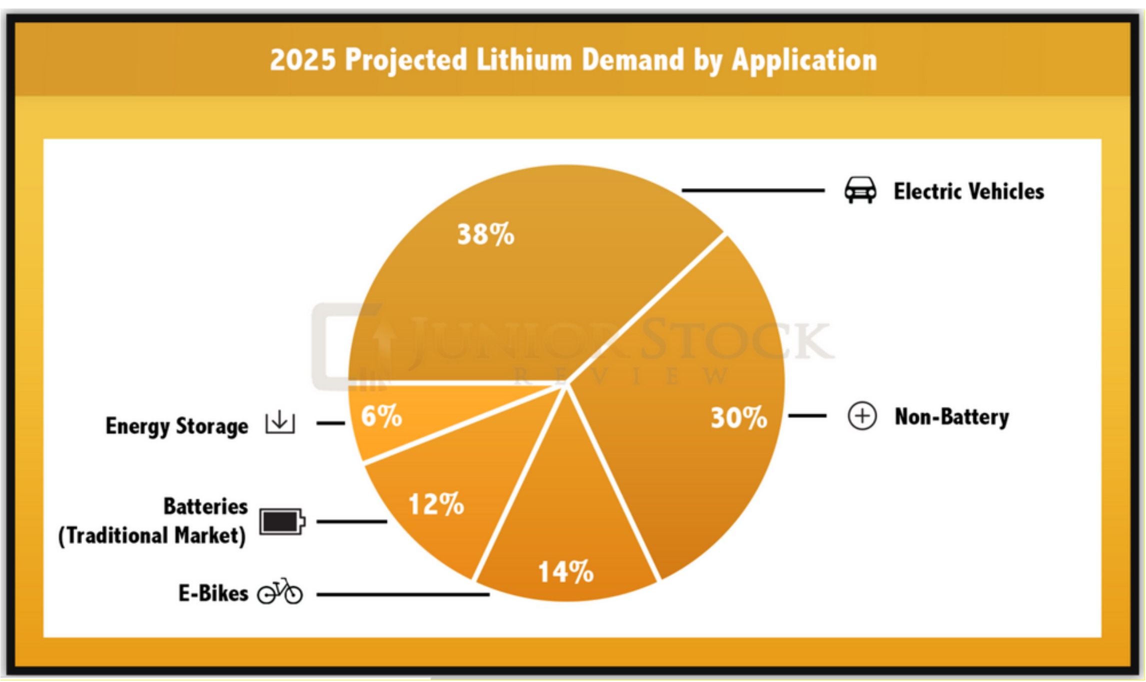
Owing to continuing exploration, lithium resources have increased substantially worldwide and total more than 53 million tons. Identified lithium resources in the United States, from continental brines, geothermal brines, hectorite, oilfield brines, and pegmatites, have been revised to 6.8 million tons. Identified lithium resources in other countries have been revised to approximately 47 million tons. Identified lithium resources in Argentina are 9.8 million tons; Bolivia, 9 million tons; Chile, 8.4 million tons; China, 7 million tons; Australia, 5 million tons; Canada, 1.9 million tons; Congo (Kinshasa), Russia, and Serbia, 1 million tons each; Czechia, 840,000 tons; Zimbabwe, 500,000 tons; Spain, 400,000 tons; Mali, 200,000 tons; Brazil and Mexico, 180,000 tons each; Portugal, 100,000 tons; and Austria, 50,000 tons.

Lithium Present and Future Market Demand

Source: Deutsche Bank Markets Research – *Lithium 101* – pg.23

Lithium Demand by Application:





Source: Deutsche Bank Markets Research – *Lithium 101* – pg.23
http://www.mining.com/web/lithium-supply-demand-story/

In this study below, we review the relevant geological features of the best characterized pegmatite

Pegmatites are commonly found throughout the world:

- These are course grained igneous rocks formed by the crystallization of post magmatic fluids.
- They occur in close proximity to large magmatic intrusions
- Lithium containing pegmatites are relatively rare and are most frequently associated with tin and tantalite.
- Lithium-rich granite pegmatites are much less common making up less than 1%
- Granite pegmatite-ore bodies are the hard-rock source of lithium
- The Lithium minerals that occur in granite pegmatites are
  a) spodumene, (b) apatite, (c) lepidolite, (d) tourmaline and (e) amblygonite.

Lithium hard-rock recovery can be broken down into a few key steps:

1. crushing of the ore, then
2. concentration by froth floatation, followed by
3. hydrometallurgy and
4. precipitation from an aqueous solution. From here, depending on the application the manufacturer will create either
   - Lithium hydroxide
   - Lithium carbonate

which can be sent to factories to be manufactured into its final form.

When evaluating a hard-rock lithium deposit, the few key things to look for:

- Lithium Grade – The most important figure in any type of deposit. The higher the grade of lithium, the more economic the deposit.
- By-Products – can help reduce the cost per ton because they have value. Not to be confused with 'harmful' impurities,
- For lithium hard-rock deposits, tantalum, beryllium and caesium are examples of profitable by-products of the refinement process.

- Impurity Levels – Lower impurity levels will lead to increase their use in end use applications, such as glass and ceramics.
- Location - Access to good infrastructure is key to a profitable mining project

Images of Lithium after different processes:

Petalite → After Crushing → Spodumene Flotation

Spodumene Concentrate → Roasted Concentrate → After Acid Roasted Concentrate

For the sake of this narrative we are excluding the Brine based deposits as they are located all over the world but only a small number of them are considered to be economical for the recovery of lithium, potash, boron and potassium.

The Great Transition, Part I: From Fossil Fuels to Renewable Energy:

http://www.earth-policy.org/plan_b_updates/2012/update107

Lithium-Ion Batteries:
Possible Material Demand Issues

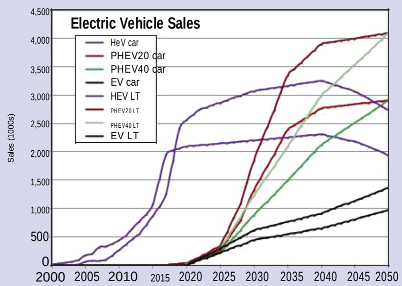
Argonne NATIONAL LABORATORY

Overview

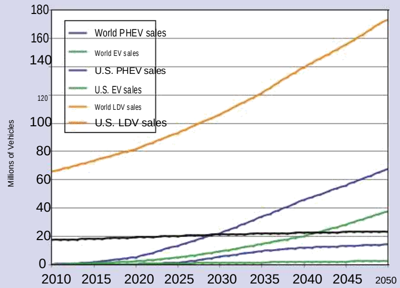
How much lithium would be required if hybrids, then plug-in hybrids, and then pure electric vehicles expanded their market share extremely rapidly? We estimated an upper bound on the quantity that could be required by using four promising lithium-ion battery chemistries. To evaluate the adequacy of future supply, we compared total demand to (1) estimates of production and reserves and (2) the quantity that could be recovered by recycling.

How Many Vehicles Will Be Sold in the United States and Worldwide?

- U.S. light-duty vehicle sales by type were projected out to 2050 by using a very optimistic scenario for market penetration of electric-drive vehicles, including hybrids, plug-in hybrids, and pure battery electric vehicles. In this scenario, 90% of sales (or 21 million vehicles) have electric drive in 2050, and sales to that date total 465 million.



- The International Energy Agency (IEA) projected world light-duty vehicle sales, which grow much faster than U.S. sales, on the basis of World Bank economic and United Nations population projections. This graph shows the IEA scenario for the growth in electric-drive vehicles that would be required to meet IPCC CO_2-reduction goals. Pure EVs (as opposed to hybrids) were assumed to account for over 20% of global sales by 2050 (vs. 10% in Argonne's optimistic scenario).



What Kind of Batteries Might They Use?

- We considered four promising battery chemistries, all of which contain lithium in the cathode and electrolyte, and one of which uses lithium in the anode as well.
- We estimated how much material would be needed if all batteries for electric-drive vehicles were made from each chemistry.
- The battery material masses and chemical compositions were combined to give the total quantity of contained lithium in each battery pack. The maximum quantity of lithium contained is 13 kg, and it is much less for most chemistries and vehicles considered.
- Lithium makes up less than 3% of battery mass.

Battery Chemistry

	NCA Graphite	LFP (phosphate) Graphite	MS (spinel) Graphite	MS Titanate
Negative (anode)	Graphite	Graphite	Graphite	$Li_4Ti_5O_{12}$
Positive (cathode)	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$	$LiFePO_4$	$LiMn_2O_4$	$LiMn_2O_4$

Calculated Lithium Required per Battery Pack (kg contained Li)*

Battery Type	NCA-G				LFP-G				LMO-G				LMO-TiO			
Vehicle range (mi) at 300 Wh/mile	4	20	40	100	4	20	40	100	4	20	40	100	4	20	40	100
Li in cathode (kg)	0.34	1.4	2.8	6.9	0.20	0.80	1.6	4.0	0.15	0.59	1.18	3.0	0.29	1.2	2.3	5.8
Li in electrolyte (kg)	0.04	0.10	0.20	0.55	0.045	0.14	0.26	0.66	0.03	0.09	0.17	0.43	0.05	0.17	0.34	0.85
Li in anode (kg)	0	0	0	0	0	0	0	0	0	0	0	0	0.30	1.21	2.4	6.1
Total Li in battery pack (kg)	**0.37**	**1.5**	**3.0**	**7.4**	**0.24**	**0.93**	**1.9**	**4.7**	**0.17**	**0.67**	**1.4**	**3.4**	**0.64**	**2.5**	**5.1**	**12.7**

*To convert to carbonate equivalent, multiply by 5.3

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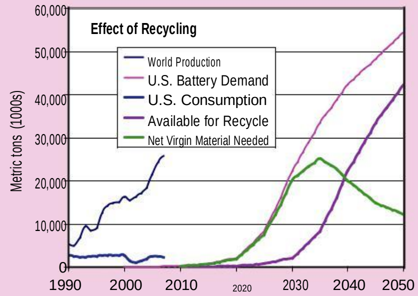
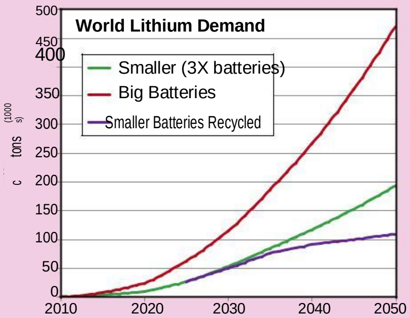
How Much Lithium Would Be Needed Each Year?

- We used the vehicle demand from the high-EV-penetration scenarios and quantities of lithium (using NCA graphite chemistry) per vehicle to estimate the potential demand for lithium, for the United States (right) and the world (below).



(Note: U.S. consumption excludes imported batteries)

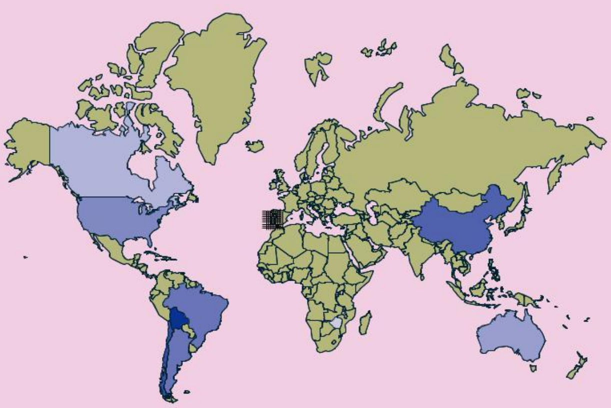
- The maximum quantity of lithium that could be available for recycling was estimated by assuming that all material could be recovered after a 10-year (United States) or 15-year (rest of world) service life.



- The availability of recycled material would reduce annual U.S. demand in 2050 from over 50,000 tonnes to about 12,000 tonnes, after a peak in the 2030s of 25,000 tonnes, which is approximately equal to current world production (top graph).

- The IEA assumed the vehicles would have large (12–18 kWh) batteries. Production of these batteries would cause world lithium demand to rise to 20 times the current level. But many new vehicles are likely to be city cars or even electric bicycles, which would drop 2050 demand to 8 times the current level. With material recycling, demand for virgin material in 2050 would be only about 4 times the current level.

Where is the Lithium?



Country	Reserve Base (tonnes)
Bolivia	5,400,000
Chile	3,000,000
China	1,100,000
Brazil	910,000
Argentina	not available
United States	410,000
Canada	360,000
Australia	220,000
Portugal	not available
Zimbabwe	27,000
World total (rounded)	11,000,000

How Does the Demand Compare to the Resource Available?

- Even by using the U.S. Geological Survey's (USGS's) conservative estimates of lithium reserves, the available material will not be depleted in the foreseeable future.

Category/Source	Cumulative Demand to 2050 (contained lithium, 1000 metric tons)
Large batteries, no recycling	6,474
Smaller batteries, no recycling	2,791
Smaller batteries, recycling	1,981
USGS Reserves	4,100
USGS Reserve Base	11,000
Evans and others	30,000+

- If new capacity is not built fast enough to match demand, the price could go up, but the problem will not be that there is no more lithium, at least for the next 40 years.

- Bottom line: Known lithium reserves could meet world demand to 2050.

Can Lithium-Ion Batteries Provide a Bridge to the Future?

- Lithium-ion batteries may not be the “silver bullet” that permanently s all of the world's energy storage but they can certainly make a la contribution for at least several while the next breakthrough is sought.

- Reports that we are running out of lithium are premature.

- Lithium demand can be met, even with rapid growth of electric drive.
  - Scenarios extended to 2050; new technologies are likely in the next 40 years.
  - Better batteries, additional exploration could extend supply.
- Cobalt supply and price will reduce the importance of NCA-G chemistry.
- Batteries can be reused for lower-performance applications before recycling.
- Recycling processes are needed that:
  - Recover all recyclable materials to extend material supply and moderate prices,
  - Process all likely chemistries, and
  - Minimize energy and environmental impacts.

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