

Electrochemical Energy Storage
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Module - 11
Li resources and recycling of Li ion batteries
Lecture - 51
Global Geographic Distribution of Raw Lithium Resources


Welcome to my course Electrochemical Energy Storage and this is module number 11 where we will be discussing the Lithium resources and recycling of Lithium ion batteries one of the most important topics. And this is lecture number 51, where I will be talking on Global Geographic Distribution of Raw Lithium Resources.

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CONCEPTS COVERED

- Lithium resources
- Li resources – Is it sufficient?
- Market share of precursors
- Li consumption – market share
- Global distribution
- Li precursor share in battery use
- Price of lithium precursor

Lithium carbonate and lithium foil



So, you know that in my earlier lectures we talk at length about lithium ion battery and also sodium ion battery have been introduced. And then the hybrid battery; battery super capacitors along with super capacitors we have discussed. We have also discussed lithium sulfur batteries and lithium air batteries which are considered to be futuristic technologies.

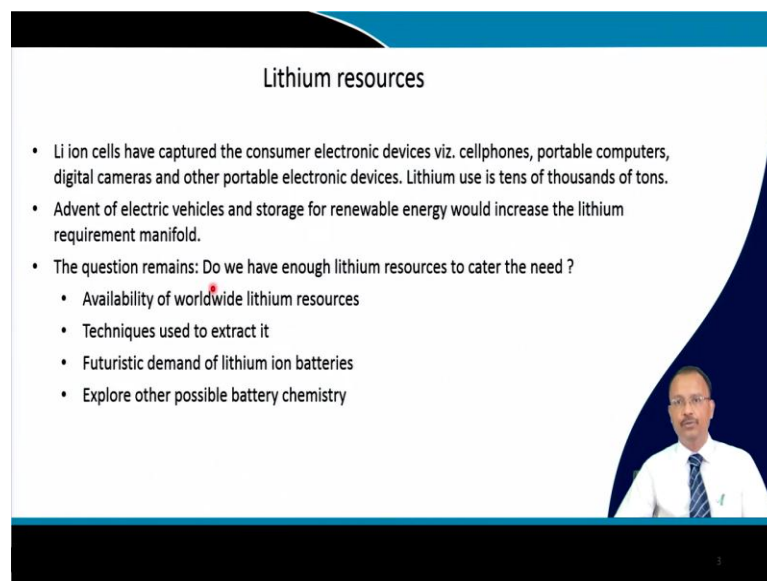
Now, particularly for lithium ion batteries we need to review what are the lithium resources. So, we will talk it about in this lecture and the question is whether the lithium

resources whatever we are having whether it is sufficient to cater the needs of lithium ion batteries?

And what are the market shares of various types of precursor material mostly lithium carbonate is used in case of the positive electrode material mostly for lithium ion batteries. And for lithium metal polymer batteries or lithium sulfur or lithium air batteries directly we use lithium foils.

So, the consumption of the market share of various types of raw materials that is available that we will be talking. And what is the global distribution of lithium resources. And in the battery how much lithium precursor is actually used because it is not only lithium, but you have other materials also used for the battery purpose. And finally, the price aspect of lithium ion precursor that we will be talking about.

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The slide is titled "Lithium resources" and contains the following text:

- Li ion cells have captured the consumer electronic devices viz. cellphones, portable computers, digital cameras and other portable electronic devices. Lithium use is tens of thousands of tons.
- Advent of electric vehicles and storage for renewable energy would increase the lithium requirement manifold.
- The question remains: Do we have enough lithium resources to cater the need ?
 - Availability of worldwide lithium resources
 - Techniques used to extract it
 - Futuristic demand of lithium ion batteries
 - Explore other possible battery chemistry

In the bottom right corner of the slide, there is a small video inset showing a man in a white shirt and tie speaking.

So, lithium ion cells as I have described in details that have basically captured the consumer electronic device market, which includes cellphones, portable computers, digital cameras and other portable devices and in such devices lithium use is roughly tens of thousands of tons according to the market prediction.

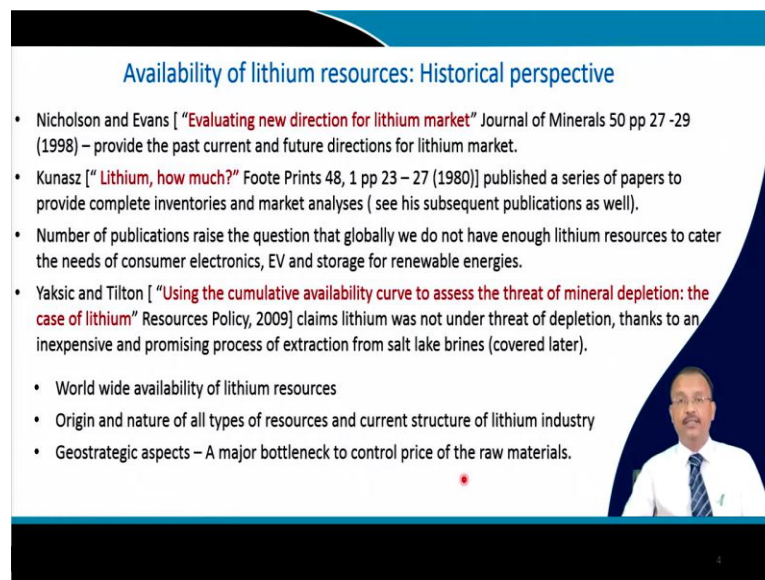
Now, on top of that we have electric vehicles and also storage for lithium sorry storage for the renewable energy. So, certainly the consumption of the lithium that we will increase many fold as compared to this tens of thousands of tons. Now, this is a burning

question that do we have enough lithium resources to cater all these needs, including the consumer electronic applications plus battery that will be used for electric vehicles and also in the storage, whether we have enough lithium?

So, we need to have a look that what are the availability of lithium resources throughout the world. And eventually how they are extracted what are the common technology of extraction and what are the futuristic demands of lithium ion batteries, because we will have to think of the future. So, what exactly how much do we need.

And of course, other battery chemistry that also needs to be simultaneously explored particularly in India where lithium resources are marginal at least as far as I know if it is invented afterwards that is a separate story. But, other chemistry like sodium ion battery replacing some of the uses particularly in the storage and also for smaller electric vehicles which have a large market share in India the electric scooty cycles those kind of thing auto rickshaws. So, there the use for the mobility also alternate chemistry one must explore.

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Availability of lithium resources: Historical perspective

- Nicholson and Evans ["Evaluating new direction for lithium market" Journal of Minerals 50 pp 27 -29 (1998) – provide the past current and future directions for lithium market.
- Kunasz ["Lithium, how much?" Foote Prints 48, 1 pp 23 – 27 (1980)] published a series of papers to provide complete inventories and market analyses (see his subsequent publications as well).
- Number of publications raise the question that globally we do not have enough lithium resources to cater the needs of consumer electronics, EV and storage for renewable energies.
- Yaksic and Tilton ["Using the cumulative availability curve to assess the threat of mineral depletion: the case of lithium" Resources Policy, 2009] claims lithium was not under threat of depletion, thanks to an inexpensive and promising process of extraction from salt lake brines (covered later).

- World wide availability of lithium resources
- Origin and nature of all types of resources and current structure of lithium industry
- Geostrategic aspects – A major bottleneck to control price of the raw materials.

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Now, regarding the availability as you can see that there are number of papers and which is coming up from 1998 and this Nicholson and Evans this particular paper I would like you to download and see they it provides basically the past in those days, current means around late 90's and future direction of lithium market.

Then this Kunasz he has published a series of papers and that basically provide the complete inventories of the market analysis. So, that is the studying paper long back in 1980 he predicted and subsequently he has other publications as well, where he has described the market analysis of lithium resources.

Now, all these literatures they basically raise the question that globally we do not have enough lithium resources to cater the needs for consumer electronics, for EV and for renewable energies. So, there were lot of questions asked. But finally, this Yaksic and Tilton in 2009 he made an important claim that lithium was not really under threat of depletion and this is mainly due to an inexpensive and promising process of extraction from the salt lake brines, which I will cover in details in the later part of the lectures in this module.

So, we do have lithium and we need extraction suitable extraction technique to get a sizable lithium production so, that I will talk about as a later part of this module. So, worldwide availability of lithium resources we will review and origin and nature of all types of resources.

And current lithium industry what exactly they are using and more importantly the geostrategic aspects that is a major bottleneck in some of the countries they have lithium resources. Some other country they have good technology to use the lithium resources, but they are far apart there are political issues, there are geological issues, geographical issues and that actually controls the price. So, we will shed light on it.

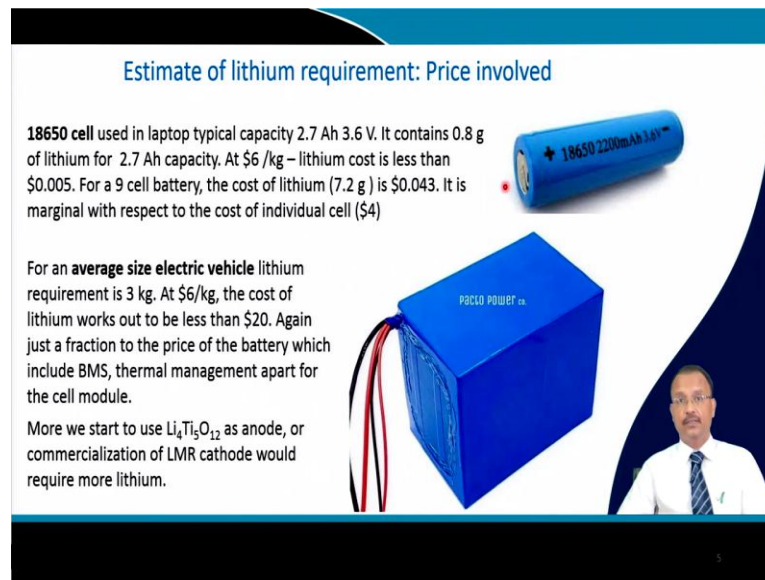
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Estimate of lithium requirement: Price involved

18650 cell used in laptop typical capacity 2.7 Ah 3.6 V. It contains 0.8 g of lithium for 2.7 Ah capacity. At \$6 /kg – lithium cost is less than \$0.005. For a 9 cell battery, the cost of lithium (7.2 g) is \$0.043. It is marginal with respect to the cost of individual cell (\$4)

For an **average size electric vehicle** lithium requirement is 3 kg. At \$6/kg, the cost of lithium works out to be less than \$20. Again just a fraction to the price of the battery which include BMS, thermal management apart for the cell module.

More we start to use $\text{Li}_4\text{Ti}_5\text{O}_{12}$ as anode, or commercialization of LMR cathode would require more lithium.



So, if you just see a normal 18650 cell that typically is used in laptop they have a nominal voltage about 3.6 volt and the capacity is around 2.7 ampere hour it can be increased as well, but let us take this is the base value. So, if you calculate the contains of lithium is about 0.8 gram to achieve this 2.7 ampere hour capacity.

So, if I assume that 1 kg lithium cost about 6 dollars then the cost of lithium per cell is very marginal as you can see. And for a 9 cell battery the cost of lithium is just 9 times of it. So, it is coming around 7.2 grams and this is coming only 43 cent. So, each of this cell they actually is sold at dollar 4. So, the cost is really marginal the source of the cost of lithium itself.

If you consider an average size electric vehicle lithium requirement of course, it will shoot up there are number of cells here so, about 3 kg if I assume at 6 dollar per kg. So, the lithium cost works out to be less than 20 dollars just a fraction of price of the battery, which additionally also include BMS Battery Management System, thermal management system and the cell packaging material.

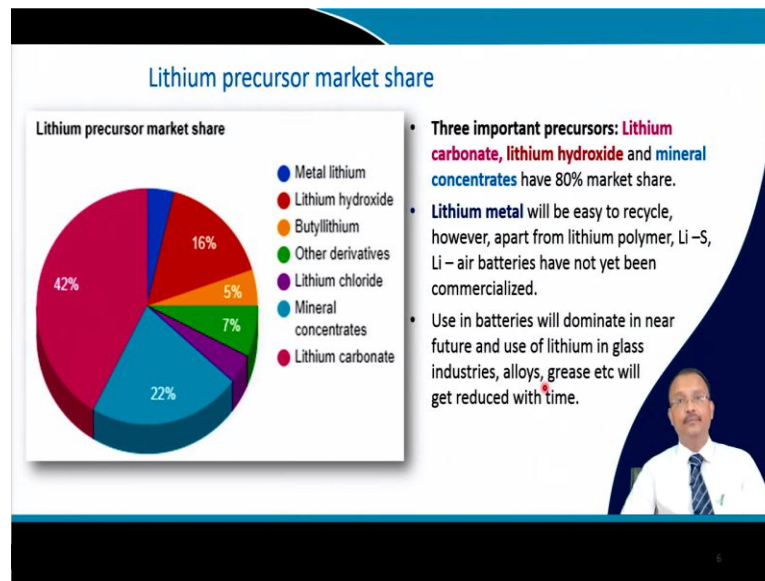
Now, we are assuming that as the positive electrode we are using lithium containing compound. And also in the electrolyte you remember that we use typically 1 molar concentration of lithium PF 6 salt. So, apart from that if you start using this LTO anode which also I have introduced. It is one of the most stable anodes that is available

commercially that has been used. So, it is not a source of lithium, lithium is coming still from your cathode material and getting intercalated into the structure of this spinel LTO.

But, in order to make this LTO you do need lithium and also if you start using lithium manganese rich cathode material which you might remember that this is used for elevating the voltage as well as the capacity and thereby the energy density of each individual cell. Although it has not yet been commercialized then we will have to think for additional lithium contains.

So, we cannot assume that each of this cylindrical cell only will contain 0.8 gram you will have to take into account how much lithium you need to make these types of anode. Or in case of the composite I mean the LMR types of cathode you need additional lithium. So, that must be taken into account.

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So, if you see the market share lithium is not only used in the battery application you have lithium used for other applications as well. And in this battery application as you can see that these are the prominent raw material. As I said metal lithium you can use.

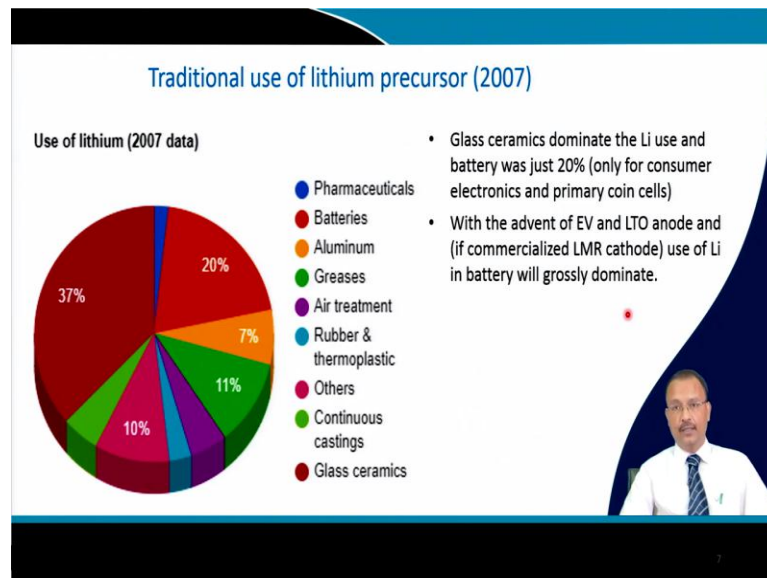
And mostly three important precursor that is used one is lithium carbonate, another one is lithium hydroxide and there are mineral concentrates particularly from the brine salt lakes. So, they all constitutes about 80 percent of the market share because as you can see lithium hydroxide here is 42 percent.

Then you have lithium hydroxide is mostly then lithium carbonate sorry this is lithium carbonate and lithium hydroxide the similar types of colors has been used. And the source which is mineral concentrate they constitute the bulk of the raw material that is used.

Lithium metal that is very easy to recycle we can get back the lithium directly. If I use lithium metal, but you know the technology that will be using this lithium metal is lithium polymer, lithium sulfur and lithium air batteries and none of them has been commercialized and in that respect it is only limited to our half cell which we do in our laboratories to use lithium metal. So, lithium metal will also is having a small share in this pie chart.

So, use in batteries will dominate in near future and use of lithium in glass industry, I will show that what are the other industries that uses one of them are glass industries, pharmaceuticals they also do use lithium. So, and alloys, grease. So, they will have to seek for the alternate technologies to use the lithium so, that we can use those lithium back into the battery purpose. So, battery will eventually they will grasp all the other uses of lithium as far as I my understanding goes.

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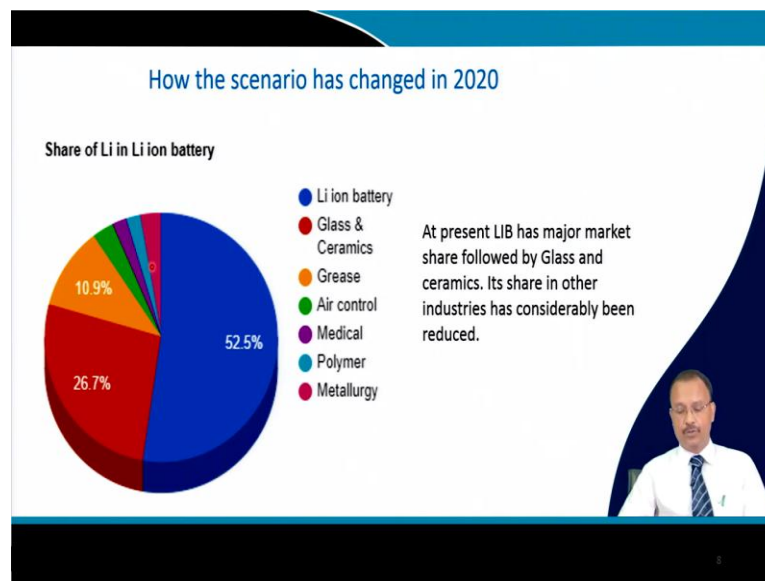
Now, traditional use of lithium as I was saying that you can see that pharmaceuticals they have a small share in making different types of antidepressant mostly. Then batteries they have a major share, but still it is the data of 2007. So, you can see about 20

percent that was the use and 37 percent use that was with the glass ceramics. The glass ceramics they used to have 37 percent.

Other than that you can see aluminum industries they make lithium aluminum alloy one of the most sought out alloy very difficult to make though. Then greases the grease they have a good market share, then air treatment rubber and thermoplastics and continuous castings. So, they are the some of the areas where they use lithium.

So, in those days in 2007 glass ceramics they used to dominate the lithium use and battery was only 20 percent and mostly those batteries were of course, the consumer cell electronics batteries and primary coin cells these are where the two uses. Now, with the advent of EV and as I said LTO anode and if commercialized this lithium manganese rich cathode materials use of lithium in battery will grossly dominate that was the prediction from those earlier papers you can just have a look they also predicted that it will take a major market share in coming days.

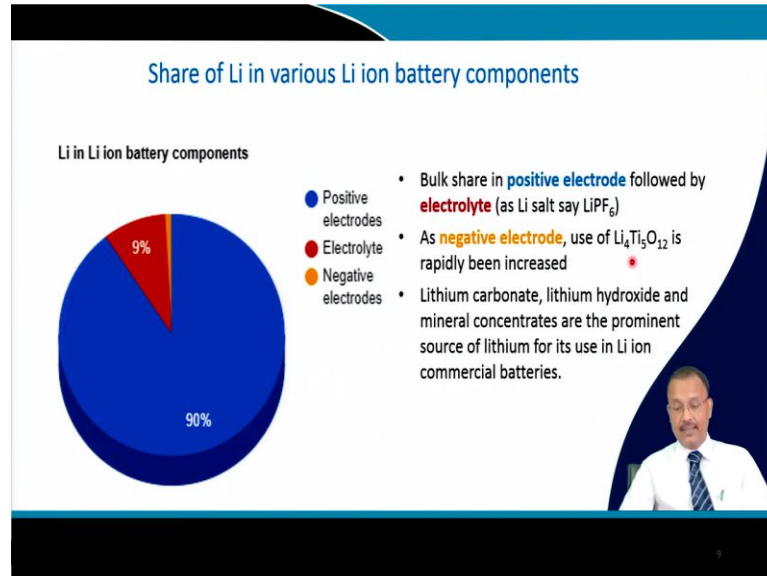
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So, the scenario it has been completely changed in 2020. So, you can see lithium ion batteries they have a huge share of 52.5 percent of the lithium use. Glass ceramic still they are the one 26.7 percent of lithium use, grease is still around 10.9 percent it has not changed much. Air control, medical, polymer and other metallurgy they take the other shares. So, the major market share has grown for lithium ion battery use and then the

glass industries. So, that is the scenario a year back which I have collected from open literature source.

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So, now, if you take a single cell bulk share is positive electrode as you can see about 90 percent share is the positive electrode where from the lithium actually rocks to the anode material typically graphite and then again goes back during discharge into the cathode structure positive electrode structure.

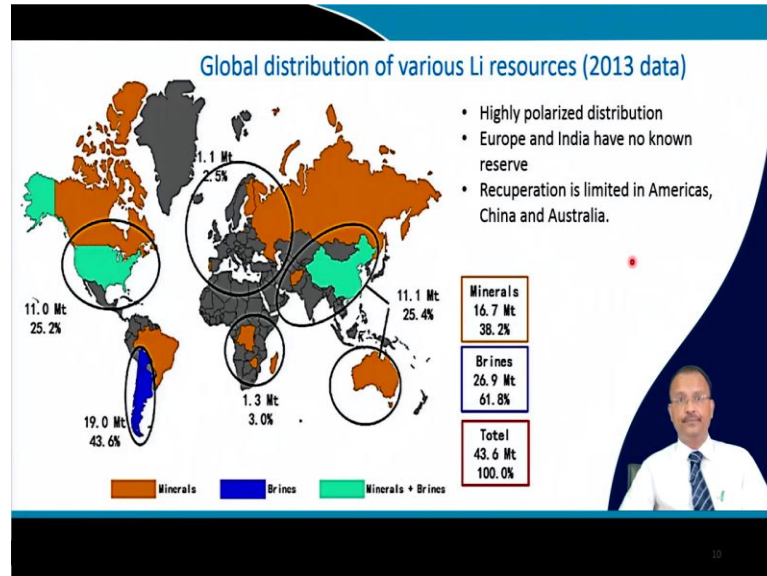
And also in the electrolyte you are using LiPF_6 salt. So, this also will take little bit more share about 9 percent. So, major use 99 percent is still in electrolyte and the positive electrode. Now, this little small piece that has been introduced because LTO has now been commercialized and this LTO they do not act as a lithium source in the full cell batteries. So, lithium is not coming here.

So, the structure change as I have already mentioned that lithium intake from this atomic percent and again it goes back during discharge, but that is having a little bit market share. So, then this graph will change progressively because this will be increased this will have increased use and one condition is that you know that nominal voltage is about 1.5 volt.

So, you do not need a 5 volt cathode material so, that you get about 3.5 volt around nominal voltage. So, lithium carbonate, lithium hydroxide and mineral concentrates they

are the prominent source of lithium for their use in lithium ion commercial batteries as it stands today.

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Now, if you see the global distribution of lithium this is a bit old data in 2013 data. So, this is highly polarized there are some countries where there is no lithium and India is one of them. And mostly as I said the minerals are there that is the raw material of lithium that is having about 16.7 million tons so, roughly 38.2 percent.

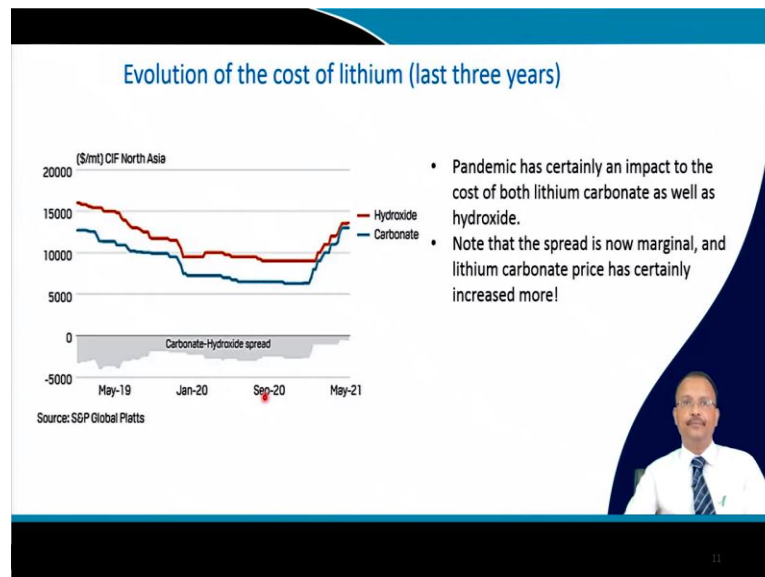
And the salt lake brines from the water they extract lithium which is having also a sizable share about 26.9 million tons. So, that is about 61.8 percent. And total reserve is about 43.6 million tons. Now, one thing is very interesting in Europe you know the Germany they are the leader for the automobile industries they are do not have any lithium resource.

The lithium resource is lying here in the southern part of South America and then Canada and US they have sizable resources and China is one of them particularly brines and minerals both of them they are having. And the problem in Australia also you have the resources mostly mineral US has both mineral and the brine resources. And mostly brine is your here this is the Chile, Bolivia, Argentina those countries. So, this is highly polarized.

So, India has no other option rather than to import lithium or recycling that I will be describing in this module. Recycling is another way and we are thinking very aggressively about the recycling. So, we can get battery from outside and this battery material can be recycle. So, that we have enough lithium resources to make our own cell.

Or you will have to purchase the cell from outside who have the resources they can sell it to us of course, the price will be controlled by them or you go to those countries and purchase the mines in your control. So, these are the things that we the Indians we are thinking in that way.

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So, if you look at the evolution of the cost of lithium in last three years time; so, starting from May 19 to May 21. So, you can see that the price was coming down both the hydroxide precursor as well as the carbonate precursor. And around this time the pandemic and that was included this later part of the curve is the spread of prices, hydroxide is slightly expensive as compared to carbonate. Because of the content of lithium per mole of lithium hydroxide.

And this spread is still there. So, you can see that this is slightly stabilized in this region from January 20 to about September October, but now it has started to shoot up. So, I guess that pandemic has certainly an impact to the cost of both this precursor both lithium carbonate as well as hydroxide.

Now, the spread of this price is now marginal you can see that this is actually marginal as compared to this region or this region exact current what is the actual cause of this is not really known to me. But, it is true that the cost of the raw material is now marginal. And in that respect certainly lithium carbonate price they have gone more. So, it has started from here. So, it has gone more. So, this spread is minimized due to the cost escalation of lithium carbonate as compared to lithium hydroxide.

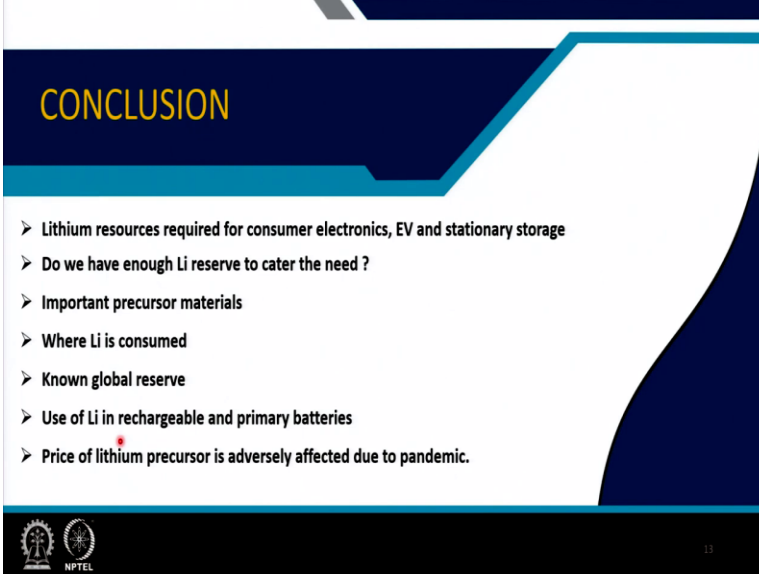
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So, this part of the data you will have to get from different resources some of the papers I have included and those are all initial papers which give a very good description of the lithium resources. So, we will have to read those papers to have a feel for that.

But, the book by this Christian this they have also talked about the Lithium batteries and other electrochemical storage system that is the title of this book in Chapter 11 this pages you can use as a reference for the study material, but you do have to read this cited references in this lecture to know more about this aspect of the module.

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CONCLUSION

- Lithium resources required for consumer electronics, EV and stationary storage
- Do we have enough Li reserve to cater the need ?
- Important precursor materials
- Where Li is consumed
- Known global reserve
- Use of Li in rechargeable and primary batteries
- Price of lithium precursor is adversely affected due to pandemic.

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So, in this particular lecture we talked about lithium resources required for consumer electronics, electrical vehicles and stationary storage. And then we raised the question and tried to answer it that do we have enough lithium reserve to cater the need for all these technologies.

Then we talked about important precursor materials what exactly are being used now in commercial lithium ion batteries, where these lithiums are consumed apart from the battery. So, glass industry is one of them making grease, lithium aluminum alloy, little bit medical uses. So, these are the common use of lithiums.

Then known global reserve country wise we have seen that both the Americas, Australia, China, Europe do not have lithium resources. India also do not have lithium resources little bit lithium resources are there in Africa south southern part of Africa.

And use of lithium in rechargeable and primary batteries and the price of lithium precursor is adversely affected due to pandemic particularly after the second wave we have seen a very sharp rise of lithium carbonate price.

Thank you for your attention.