Electrochemical Energy Storage
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Module - 06
Sodium ion rechargeable cell
Lecture - 30
Future Perspective of Na ion cell

Welcome to my course Electrochemical Energy Storage and this is module number 6, where I am describing the sodium ion rechargeable cell. The technology is very similar to lithium ion technology.

So, in earlier lectures we talked about the specific positive electrode material, then we talked about negative electrode materials, then we talked about the electrolyte that is being used for sodium ion batteries.

And then finally, we also showed you a case study, some of our own results, that how we have used some of this anode and cathode materials based on poly ionic compounds building a symmetric cell. And in today's lecture, we will talk about the future perspective of sodium ion cell, where exactly we stand.

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And, as I told earlier, that commercialization if you see as compared to the lithium ion batteries. The commercialization aspect of sodium ion battery is still it is in its in fancy.

So, only one company is there, so mostly I have followed what exactly they are doing. So, in the process we will be showing that where are the sodium ion batteries market and what is their major applications, stationary storage for renewable energy that was indeed one of them.

But transport application also, it is coming up for small vehicles and which will be particularly useful for Indian perspective replacing lead acid battery using sodium acid battery, sodium ion batteries. And, Some of the features of the commercial sodium ion cell that I will describe in this particular lecture.

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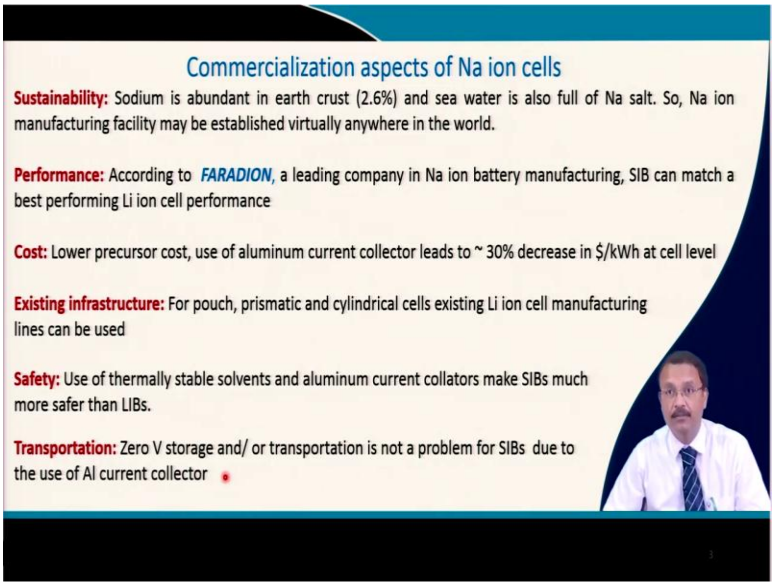

So, if you see the commercialization aspect, the first one is sustainability; the raw materials are plenty in earth crust 2.6 percent sodium is there and also a huge source in the sea water it is full of sodium based salt. So, that manufacturing facility of sodium ion cells unlike lithium ion cell, that can be made anywhere in the world in fact.

And, there is one company at least whose website I could find; the company name is FARADION and it is considered one of the leading companies in sodium ion battery manufacturing. And they have claimed that sodium ion battery can match the best performing lithium ion performance.

So, will have a look that what is the latest status as far as their report. Cost certainly its having lower precursor cost and one can use aluminum current collector. So that itself will lead to about 30 percent decrease in kilo watt hour energy cost in terms of dollar at the cell level.

And, you can use existing lithium ion infrastructure. So, for pouch you know how to make the pouch cell, you know how to make the cylindrical cell. So, those kind of facility also can be used for the manufacturing of sodium ion cells. So that is one major advantage that you will not have to change the whole infrastructure the way we are facing changing the sodium this lead based infrastructure with the advent of lithium ion battery. So that part is not there.

Safety is better and thermally stable solvent and aluminum current collectors, that basically makes this sodium ion battery much more safer as compared to lithium ion batteries.

Transportation; that is also a bit better, because this zero volt storage or transportation is not a problem so you can exactly store it at its discharge state and current collector is one of the major reasons for that.

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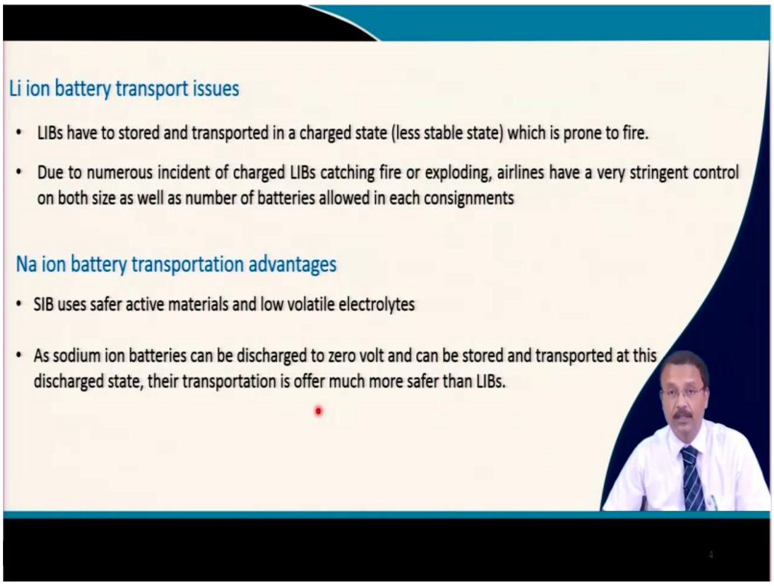

Now, lithium ion battery, although I will be talking more about it in my 4th coming lectures that transport is an issue. This lithium ion battery that have to be stored and transported in the charge state, and as you know charge state is less stable state because the positive electrode is without lithium and it is prone to fire, so that is one problem.

And there are innumerous incident of charge lithium ion battery that catches fire or they are exploding airlines have a very stringent control on both size as well as number of batteries that is allowed for each consignments. So these problems are there.

So, sodium ion battery they are safer. Active materials and usually the electrolyte is less volatile having low vapor pressure. And, sodium ion batteries can be discharged as I set to zero volt and can be stored and transported at the discharge state, so their transportation is much more safer as compared to lithium ion batteries.

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Now, here is some incidents 2016 a Tesla model car S Tesla S that crashed and killed both their passengers. And, you might have it is known to you that in 2019 many of this passenger aircraft due to the use of the lithium ion batteries they catches fire and they were grounded.

And, fire in the warehouse of the lithium ion battery that is also reported in 2014 as far as some newspaper reports. So, safety is a major concern for lithium ion cells.

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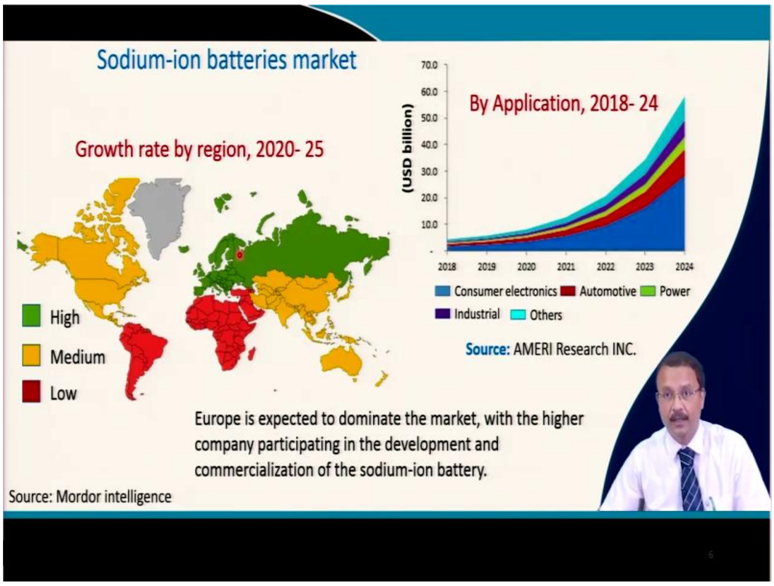

If you look at the market of sodium ion battery, you know that the high market is in this region, including India and Australia they have medium market and also the whole part of US that is considered as a good market. South America and Africa also they have low market.

And these are the actual use. Consumer electronics is one of them, although it will be a bit heavier the due to the battery automotive is coming up then power is marginal, this power use for the sodium ion batteries.

Industrial use is always there and this part is others. So it is growing up. As you can see starting from 2018 not long back, 3 years back it is trying to pick it up the US billion US dollar market as you can see it is exponential almost rising. And it is predicted that 2024 it will reach about 60 US dollar billion market.

So, this is quite encouraging for us to study sodium ion battery. And, as you can see Europe is expected to dominate the market. Many of the companies they will participate. Not all of them they are start they have started to manufacture cells in the commercial level, but Europe is in the fore font and in India also I am pretty sure that it will come up in a big way in near future.

Some of the groups academic group we have started working on sodium ion battery is not very well spread as compared to lithium ion battery, but it is quite satisfactorily the progress is quite satisfactory and I guess that the market will come up in very near future.

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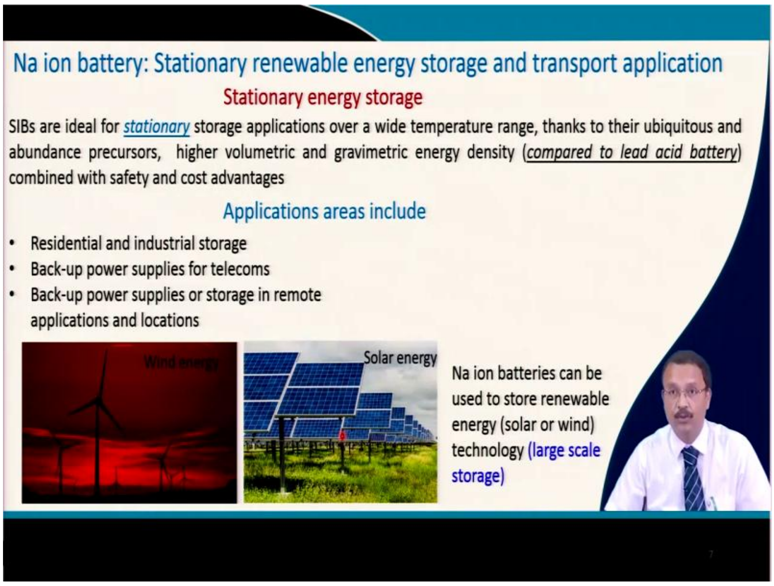

Now, mainly two applications, as I mentioned one is this stationary energy storage and this is basically for the renewable energy and mostly targeted wind energy as well as solar energy.

And, it is quite interesting because this storage can be over a wide temperature range. And, as I said, the raw material they are plenty and higher volumetric and gravimetric energy density of course, that compared to lead acid battery.

Sodium has sodium ion battery is having an edge. And, safety is another concern which is relatively better as compared to lithium ion batteries and of course, the cost advantage is one of the major advantages.

So, this application area could be targeted as residential and industrial storage UPS battery replacing lead, that is one area; backup power supplies for telecom that is another area. You know the mobile phone towers they need the storage and if it is incorporated with the renewable energy source then storage is important.

Stationary storage where gravimetric energy density will not play a major role, so that is another area. Backup power supplies or storage for remote applications and locations like in Bengal, Sundarban area, were plenty of sunlights are there and storage is a concern to electrify many of the villages. So, it can come up in a big way. And, mostly people are trying for to store the renewable energy and mostly solar and wind, and these are considered as large-scale storage.

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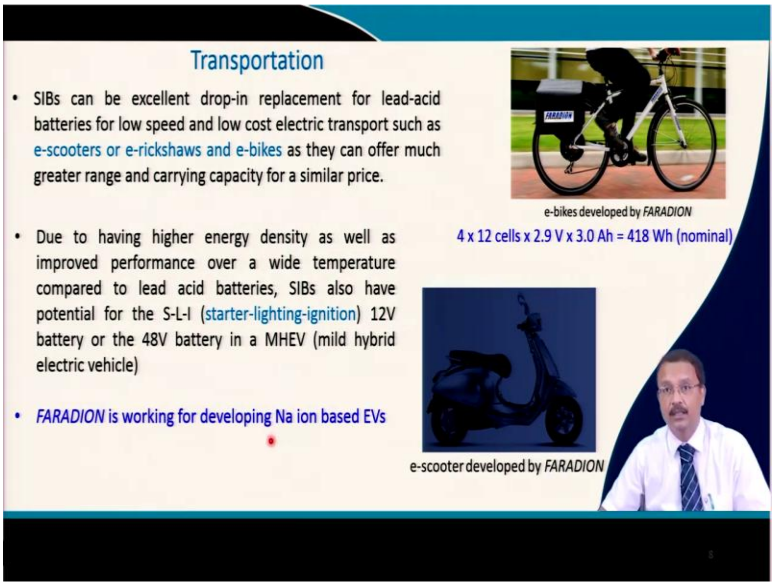

Transportation is another area that is being considered in a big way. And, one thing is lead acid battery replacement with sodium ion battery low speed and low cost electric transport in Europe cycle is one of them. The e-cycle in India e-scooters or e-rickshaws along with the e-bikes that will come up in a very big way.

And, the range are quite good for this low scale application. And, FARADION they have actually made this kind of battery which you can see one can carry, in a carrier of a e-bike. They use typically a matrix of 4 by 12. I will talk about the how to connect the batteries in series and parallel to increase the voltage and capacity respectively.

Typical voltage is a bit low as compared to lithium. It is 2.9 volt and 3 Ampere hour battery total it will give you about 418 watt hour, that is a nominal energy that you can get out of it.

Due to having higher energy density as well as improved performance over a wide temperature as compared to lead acid battery, sodium ion battery also is potentially useful for this start light and ignition this natural 12 volt battery or the 48 volt battery for mild hybrid electric vehicles.

So, one demonstration, I think I showed one of the pictures from FARADION site that e-scooter is already developed by them and small car also ran by this sodium ion batteries. So, in electric vehicles also it is slowly adventing.

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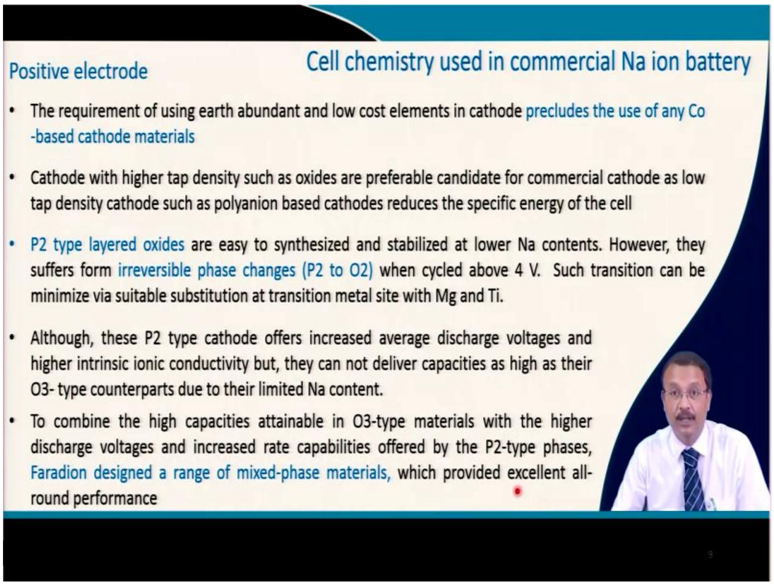

If you see the cell chemistry and try to compare with the umbrella of positive and negative electrode which already I discussed in my earlier lectures. You see the requirement of using the earth abundant and low cost element cathodes that actually precludes the use of any cobalt based cathode materials.

So, it will be less expensive and cobalt is toxic as well. So, cathode with higher tap density, you know the tap density is important because of weighted packing on the current collector surface, oxides are preferable for commercial cathode. Although, I have a special fascination for poly ionic base material, but as you can understand making those material is a bit tricky and you will have to anneal it in organ ambient.

So, oxide is good, layered structured material. And, poly ion based material they are having relatively low tap density. So, industry prefers the oxide based candidate. And, we already talked about P2 based layered cathode oxide. They are very easy to synthesize, but unfortunately they have lower sodium content.

You know that basically, your capacity is related to the participating electron moles of electron and that is in fact, related to how many lithium or how many sodium you can extract from your positive material. So, they are the source of your this movable alkali ions.

So, they are P2 type of layered oxide is having a problem and they also suffer irreversible phase transformation from P2 to O2 type. Remember that in the first lecture of this module we talked about this kind of orientation P2 to O2 kind of phase transition that takes place.

Of course, above 4 volt if you charge it. So, this kind of transition minimize the suitable, it can be minimized by suitable substitution, aliovalent substitution of magnesium and titanium.

And although, these P2 type of cathode, they offer increased average discharge voltage and higher intrinsic ionic conductivity, which is also important. That you need to increase the ionic conductivity for sodium ion to move inside the positive electrode. So, they cannot deliver capacity as high as their O3 type counterpart due to their limited sodium ion content. So, that is one of the problems.

Therefore, the thing that is most probable and FARADION exactly did that. The combine the high capacity attainable O3 type of material with higher discharge voltage and increased rate capabilities offered by the P2 type phase. So, basically, they mix this together.

So, they designed a range of mixed phase materials, which is another way for lithium ion battery also, it is possible that if you can makes say layered based positive electrode with your spinal based material.

So, not much studies have been done, but many of the companies in their own R&Ds, they are working in this type of mixed phase materials and it is proved that they provide excellent all round performance.

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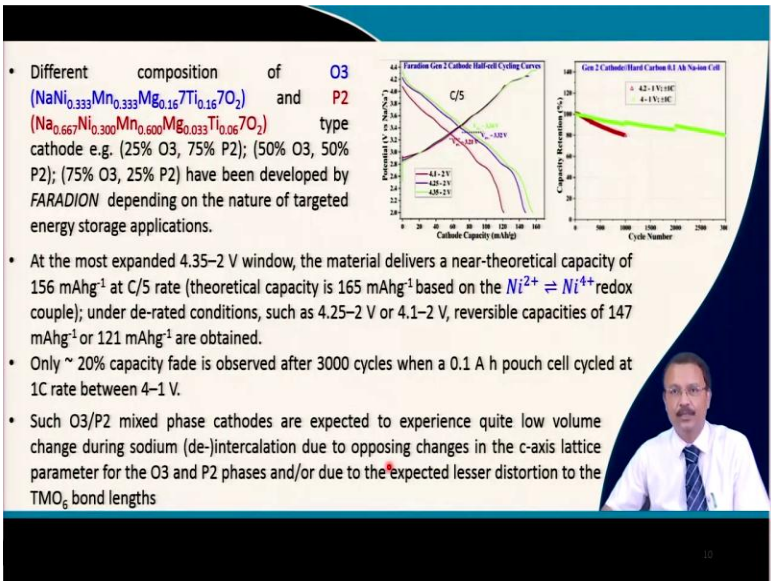

So, different compositions that has been tried of O3, which is a typical composition this one, and P2 type of cathode and they have mixed it with 25 percent of O3 with 75 percent of P2 and various other combinations. And, they have developed depending on the nature of the targeted energy storage application of course, that what is exactly needed.

So, that is one way the industry grows, that it is not arbitrarily the select the composition, but they have a stringent specification of the battery that is needed and then accordingly tune the composition to meet the electrochemical characteristics.

The voltage window is 2 to 4.35 volt. Material delivers a near theoretical capacity about 156 milli Ampere hour per gram at little bit low rate about C by 5 rate. And, if you can calculate the theoretical capacity of this material, you will see that this is about 165.

And the redox is 2 to 4 nickel plus 2 is oxidized to nickel plus 4 valance state and also 4.1 to 2 volt reversible capacity is 147, or in this voltage range basically 121 milli Ampere hour per gram that capacity was obtained.

So, 20 percent capacity is fade up to 3000 cycles, when a 0.1 Ampere hour pouch cell cycled at 1 C rate at 4 to 1 volt. That is part of that data that I have taken from their application note in the website. There are many other reports I would like you to go through their website and see that what exactly the composition they are using and try to understand that where from this plateau actually comes.

If you do the differential capacity plot you get the oxidation and reduction peak and you will have a fairly good idea that what kind of reaction is going through during the charge and discharge operation.

So, this mixed type cathode which is O3 P2 type they are expected to experience quite low volume change. That is one of the other concern. So, this is due to the opposing change in C axis lattice parameter of the O3 and P2 phase.

So, one is expanding, another one is contracting. And, that basically is related to the crystal structure. The transition metal and oxygen octahedra, the tilt of it along with the lattice parameter that is playing a major role to cancel the volume expansion. So that is a good sign. So, this is the material that they have used.

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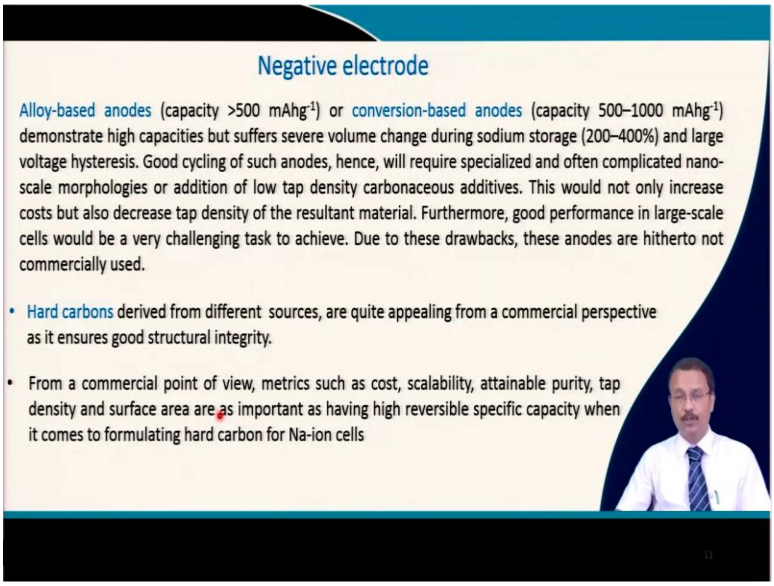

Alloy based anode can be used for making a full cell or conversion cathode which are having very high capacities. But, as you know that they have the problem of voltage hysteresis, they have the problem of volume change which is SIS 200 to 400 percent.

So, cyclability of this anode is complicated. Again you will have to go for the nano structuring or addition of relatively low tap density, carbonaceous, additive, that is also another concern. So, this will eventually increase the cost and also it will decrease the tap density of this oxides.

So, basically due to this drawbacks they are not commercially used. So, alloy based anodes and conversion based oxides they have not yet been used. So, the commercially, hard carbon basically they are derived from different sources. They are important and quite appealing for commercial perspective.

It actually gives you very good structural integrity. So, from commercial point of view, cost, then scalability, purity, tap density, surface area, they are very important for the commercial adaptability. And also the higher reversible capacity when it comes to formulate hard carbon and as a negative electrode to form the sodium ion cells.

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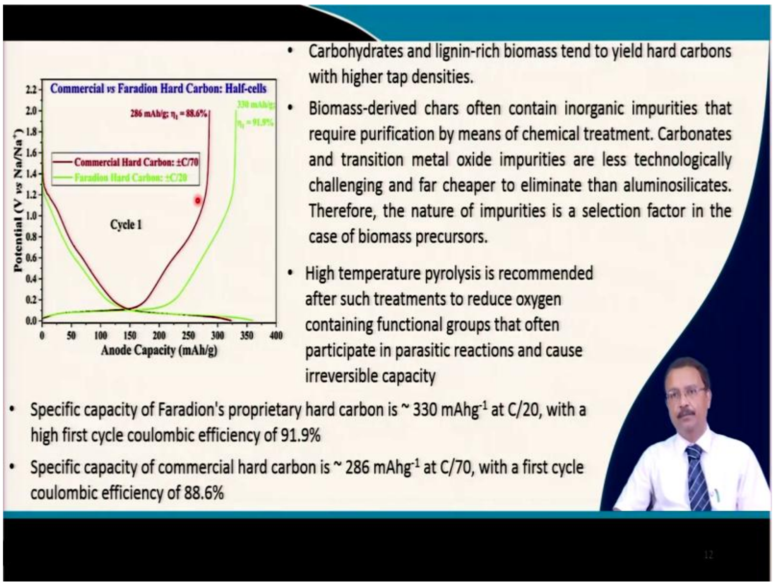

So, usually carbohydrates and lignin rich biomass tend to yield hard carbon. And you remember what is hard carbon? They are spacing is a bit larger as compared to your graphitic materials.

So, graphite cannot be used for sodium ion battery because of their shorter spacing between the layers. So, this biomass derived chars. This often contain inorganic impurity that require purification by means of chemical treatment.

So, the carbonates and transition metal oxides, they are less technologically challenging and far cheaper to eliminate then aluminosilicate. So, that is also another point. So, nature of impurities and selection factor in case of biomass precursor that is very important.

Usually, high temperature pyrolysis that is recommended after such treatment to reduce the oxygen containing functional groups, that often participates in parasitic reactions and cause irreversible capacity.

So, specific capacity of Faradion proprietary hard carbon, I do not know how they make exactly. So, that is 330 milli Ampere hour per gram at C by 20 rate, with a high first cycle coulombic efficiency it is about 91.9 percent.

So, this is the typical discharge and followed by the typical charge for commercial hard carbons and Faradion based hard carbons. So, you can see that their discharge capacity is a bit high as compared to the other commercial hard carbons. And also, they are having better columbic efficiency as compared to the commercial one.

So, some modification somewhere is needed. The chemical modification to get the exact anode material and they have confined their research to this mixed type of oxides as positive electrode and the hard carbon based negative electrode materials.

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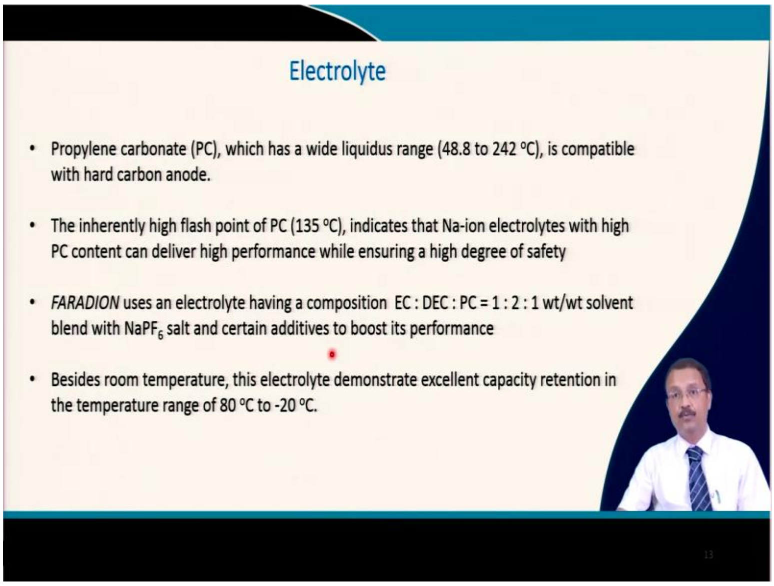

Electrolyte, as you know that salt is needed and a cyclic and linear type of mixed solvent that is required. So, propylene carbonate, propylene carbonate, that has a wide liquidus range it is starting from 48.8 to 242 degree Celsius. And you know that the phase diagram that I described, when I was talking about the electrolyte, so both for lithium ion as well as for sodium ion so that was covered in those lectures.

They have high flash point PC 135 degree Celsius. So, that indicates that sodium ion electrolytes with high PC content can deliver high performance, that ensure a high degree of safety, that is true.

FARADION basically use the electrolyte having a composition of EC with DEC and PC. So, they used 1 is to 2 is to 1 watt by what watt percent and difficult to actually know that what exactly whether they are in all their cells they are using that, but this is one of the guidelines and blend it with sodium PF 6 salts, not sodium park loaded and certain additive to boost it performance.

Then you know that what kind of additives are probable. They should have the flame retardant additive or FEC kind of additive. So, this kind of additive also they are using to make their own electrolyte.

And, beside room temperature this electrolyte demonstrates excellent capacity retention in the temperature range of 80 to minus 20 degree Celsius. So, they can cover a wide range. Room temperature of course, most of the cells will be used in room temperature, but apart from that, if you off shoot the temperature to higher range or if you reduce it to minus 20 degree Celsius then also it is claimed that this cells work.

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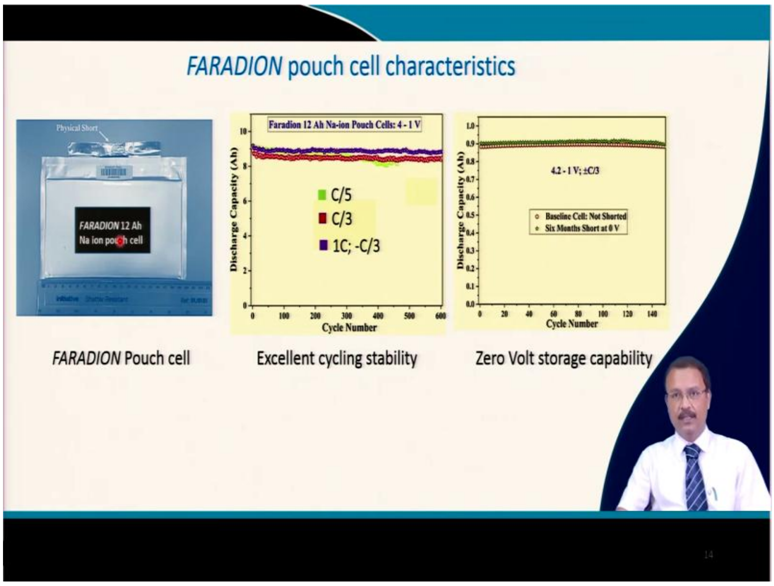

So, this is the type of the cell that is there in the market; 12 Ampere hour sodium ion pouch cell. You know how to make this pouch cell and you can see that it is something similar to that, a very the design you must be familiar with now.

And, you see the cycling stability at C by 5, C by 3, 1 C, this is quite good and again back in C by 3. So, this is up to 600 cycle numbers. So, discharge capacity for this cell is quite good, it is a 9 Ampere hour cell targeted, probably they have gotten little bit less than 12 Ampere hour.

And, zero volt storage capability that is also quite good up to 140 cycles. So, this have been commercialized using the positive, negative and electrolyte material that just I had mentioned.

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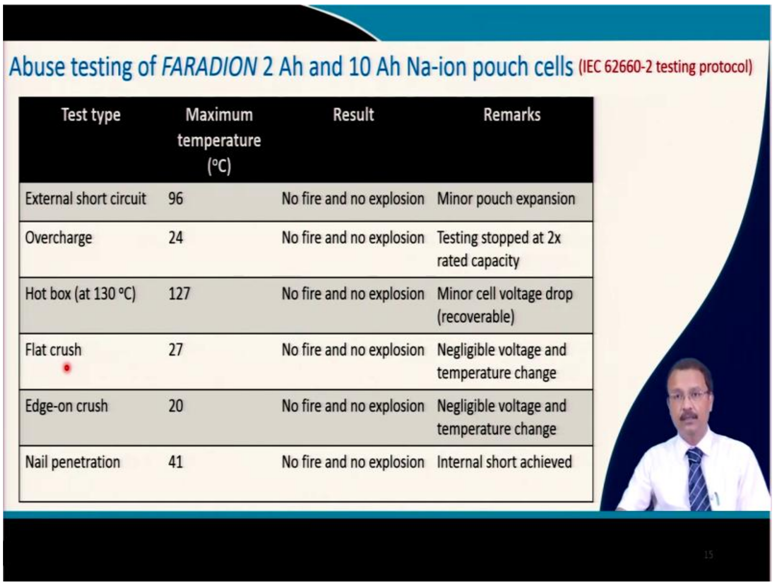

So, abuse test I will talk in a separate lecture. So, for commercialization you need to do this types of abuse test. So, FARADION 2 Ampere hour and 10 Ampere hour sodium ion pouch cell. This is actually you will have to do based on certain testing protocol; standard testing protocol.

What they do is external short circuit, they short circuit the cell. So, no fire or explosion takes place and minor pouch expansion only was reported. Overcharge maximum gave only 24 degree Celsius.

So, that is not sufficient to reach the flash point of the electrolyte, so no fire or no explosion takes place. Then at there is a hot box test that 130 degree Celsius, temperature was 127 degree for the cell and there was no fire or explosion. Then there is a flat crush; this is a called a crush test and we will talk in details that how this tests are actually done. So, there also temperature rise was 27 degree Celsius.

So, flat kind of crush test as well as edge kind of crush test, both were done. And then there is a nail penetration test, that is also one kind of short circuiting. You just penetrate a nail across the anode and cathode. So it will short circuit the anode and cathode. So temperature raised, but there was no fire or explosion. So, that actually indicates that commercial level the cell quality is quite good quite acceptable.

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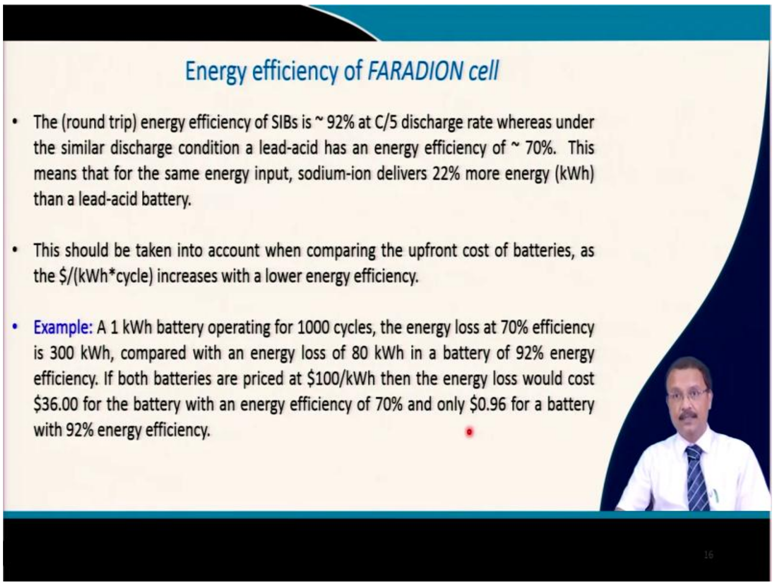

So, energy efficiency, the round trip energy efficiency is about 92 percent at C by 5 rate. As you can see that all the test are basically done at little bit lower rate. And you know that what is the criteria because sodium ions are relatively heavier.

The lithium ions, so if you try to extract it too fast then capacity feeding cannot be avoided. The lead acid energy efficiency; if you compare with lead acid, it is only 70 percent so; that means, that the for same energy input sodium ion delivers 22 percent more energy than lead acid battery.

And this in fact, should be taken into account for cost calculation. So, this cost calculation is dollar per kilo watt hour into cycles. So that increases with lower energy efficiency. So, if I have higher energy efficiency, eventually the cost is going down.

There is a small example I have given, 1 kilo watt battery that operates 1000 cycles energy loss at 70 percent efficiency is 300 kilo watt hour and compared with an energy loss of 80 kilo watt hour in a battery with 92 percent energy efficiency.

If both batteries are priced at say 100 dollars per kilo watt hour, then the energy loss will cost about 36 dollars for the battery with an energy efficiency of 70 percent that is lead acid battery and only 96 cent for a battery with 92 percent energy efficiency.

So, you can imagine that there is a huge cost effectiveness because of the energy efficiency of this sodium ion cell when you compared with lead acid cell.

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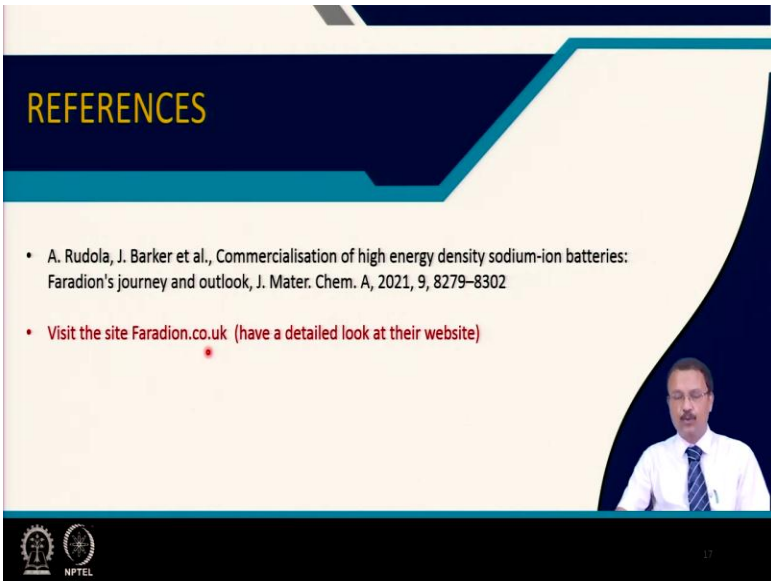

So, the reference for this particular lecture is again this paper, which talks about the commercialization aspect of high energy density sodium ion batteries that was published from Faradion. So, this is you should have a look and also you should have a detailed look of Faradion website and see that if they have new update.

Whatever I have included here they are pretty recent update I have gotten it. And, as far as the commercialization is concerned, there is no book where you can actually see about the commercialization aspect of sodium ion battery. So that is only one source as far as I know, and if you can find some other source you can share it with me, but this is one of the sources.

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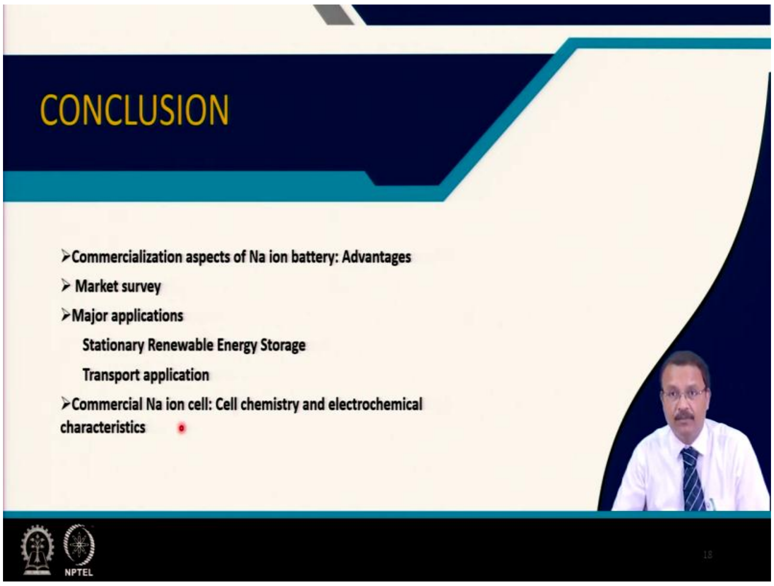

So, in this particular lecture we talked about the commercialization aspects of sodium ion battery, what are their advantages. Then a brief market survey and also a brief application survey and how it is going, what are their demands.

Then major applications are basically stationary renewable energy storage and second one is the transport application. And then, a typical commercial sodium ion cell, their characteristics, including their cell chemistry we have described.

Thank you for your attention.