Fundamentals of Electric Vehicles
Technology and Economics
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Lecture 23
Batteries in Future

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Will now come to every day you hear news about a new battery. I will call this try to cover that in Batteries in Future. Again reasonable amount of material is been taken from battery university. The important thing is which parameter will it be better? First thing that I want to point out is there any other battery in which is expected to touch a 100 dollars per kilo watt hour?

I do not see that in near future, 5-6 years. 10 years? Yes, but I still look at other batteries which are promising and may be in 5, 6, 7 years they will start touching 100 dollars per kilo watt hour. But that is the current cost and 100 dollars will fall down further. So need to compete with existing cells in terms of specific energies, costs, number of cycles and temperature range.

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Cost is a very important probably the most important parameter if it does not compete in cost what will it do. Weight will matter, material ofcourse all these are related. Number of cycles matter because at the same cost if you get more number of cycles it effective cost becomes less. Temperature range this is something of immense concern. Can I get (())(02:00) in India, can I get something which will work at 50 degree centigrade better.

Ofcourse these are cells I can always make by pack work in a, even if the temperature outside is 50 degrees I can make it work at close to 25 degree centigrade by cooling. Lithium ion batteries that you get today you will see its cathode will start getting more and more nickel that is helping increase the energy density.

And in anode you are adding more and more silica as I told you it started with NMC111, 433, 532, 622, 811 and now nickel-rich, so nickel rich cathode and silica-rich anode instead of graphite use more silica the problems on fusing silica it is not as easy to use helps in improving the energy density and reducing cost. This will happen there will still be a lithium ion battery with some variation.

The battery which promises quite a bit is lithium polymer, they are mostly pouch cells and I will explain what is pouch cylindrical another cells. The difference between this battery and the currently use lithium ion battery in the currently lithium ion battery electrolyte is liquid. In this electrolyte is dry powder. It is like not powder it is more like a plastic like film it does promise

and can make things better more safer. The problem is at room temperature it has a poor conductivity you have to heat it to 60 degree centigrade.

So, that is not very desirable for which keep, in India anyway the temperature is high if it is a 10 degree centigrade heating 260 makes a huge difference, but in our India you may be a little be able to use it we keep on looking at it. There is also another thing which is gelled electrolyte instead of the liquid electrolyte or powder electrolyte plastic film like electrolyte gelled gives you slightly higher specific energy density makes a battery thinner.

So, you will see lithium polymer coming in once in a while. You will not know still lithium ion battery. They are future batteries lithium sulphur, lithium ion with solid electrolyte somewhat like this Graphene Supercapacitors, Redox-flow battery, Aluminium-graphite battery, Solid-state batteries and Hydrogen fuel cells and you will keep on hearing every day about the somebody say I have came with lithium-sulphur, somebody say it is solid electrolyte, graphene batteries supercapacitors, redox flow, aluminium graphite, solid-state batteries and hydrogen fuel cells.

All of them have a, they are certainly future battery no, no doubt but all of them have serious limitations today and we look at some of that. So, as I told you these are the future batteries and let me come to look into little more detail I have again put a table of all the possible future batteries and how does it really look like.

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Chemistry	Lithium-air	Lithium-metal	Solid-state Lithium	Lithium-sulfur Li-S	Sodium-ion Na-ion
Type	Air cathode with lithium anode	Lithium anode; graphite cathode	Lithium anode; polymer separator	Lithium anode; sulfur cathode	Carbon anode; diverse cathodes
Voltage per cell	1.70–3.2V	3.60V	3.68V	2.15V	3.6V
Specific Energy	13kWh/kg theoretical	300Wh/kg	350Wh/kg (est.)	500Wh/kg or less	90Wh/kg
Charging	Unknown	Rapid charge	Rapid charge	0.2C (5h)	Unknown
Discharging	Low power; inferior when cold	High power band	Poor conductivity when cold	High power (2,500W/kg)	Unknown
Cycle life	50 cycles in labs	2,500	100, prototype	50, disputed	55 typical
Packaging	Not defined	Not defined	Prismatic	Not defined	Not defined
Safety	Unknown	Needs improvement	Needs improvement	Protection circuit required	Safe; shipment by air possible
History	Started in 1970s; renewed interest in the 2000s. R&D by IBM MIT, UC, etc.	Produced in the 1980s by Moli Energy; caused safety recall	Similar to Li-polymer that started in 1970	New technology; R&D by Oxis Energy, Bosch and others.	Ignored in the 1980s in favor of lithium; has renewed interest
Failure modes	Lithium peroxide film stops elect movement with use. Air-impurity cause damage	Dendrite growth causes electric short with usage	Dendrite growth causes electric short; poor low temperature performnce	Sulfur degrades with cycling; unstable when hot; poor conductivity	Little research in this area
Applications	Not defined; potential for EV	EV, industrial and portable uses	EES, wheeled mobility; also talk about EV	Solar-powered airplane flight in August 2008	Energy storage
Comments	Borrowed from "breathing" zinc-air and fuel cell concept	Good capacity, fast charge and high power keep interest high	Similar to lithium-metal; may be ready by 2020; EVs in 2025	May succeed Li-ion due to lower cost and higher capacity	Low cost in par with lead acid. Can be fully discharged

The table was taking time I am actually putting enough data for lithium air, lithium metal, solid-state lithium, lithium sulphur and sodium ion. They are first set of 5 future batteries; solid-state lithium a lot of talk is there. Now look at it. If I could get lithium air it is 1.3 kilo watt hour per kg. Today we have 300 watt hour per kg it will become 1300 watt hour per kg this will make it almost equivalent to petrol I would love to see that, what is the limitation?

The best that somebody has shown me is 50 cycles in a lab that also and ofcourse very expensive that is a different issue. It actually came from there is other battery call zinc air which used to be proposed some time back. So it actually borrowed what is called breathing from zinc air and fuel cell concept and brought it good research work if you are doing your PhD work on this do you expect it to come in next 10 years? Unlikely and compete, come its, come even today you can see it.

Lithium metal battery this is more like the current 300 watt hour per kg I do not know how much further you can go but the most important thing you can charge very rapidly 3C charges is no problem that is the… number of life cycles are also not bad. Safety very unsafe today. The second is all the experiments have shown that very quickly develops what is called dendrite growth causes electric short circuit with usage.

So, yes promising, will it compete in cost? We do not even know, anything close 200 dollars not when it comes a week start with our 1000 dollars and then it has to come down. But you will see

lithium metal or more of my lithium metal sometime. Solid-state lithium again 300 watt hour kg and possibly can go up. It also does reach it can also charge very rapidly 3C is no problem. It is a bad when it is cold weather. It is a very poor conductivity does not work at all.

Cycle life in all protypes has not exceeded 100 this has promises I will not say that but will it get stress and compete with currently lithium ion battery with silica and nickel rich in 5 years unlikely, but you will see more of it. Lot of excitement at times but okay 10 years on the line I do see one of these two taking over.

Lithium sulphur is another variation it goes to 500 watt hour kg so better. Today its charging discharging rate is not good. High power you can do you can do high power. Cycle life the only reported cycle life is 50 cycles, and that is disputed whether it was really 50, it is could be even lower. So, yes good work something can happen. Lithium sodium iron this looks like a sodium iron or sodium ion this not iron I mean, I think is a mistake should be sodium ion.

It is a very similar to lithium ion except using sodium. So it will be cheaper unfortunately, watt hour kg is not good still it will be cheaper, but weight will be higher right now the life cycles are not good. Those Somebody else told me you can get 500 cycles I do not know. Low cost it will be in power with lead acid whether it will able to do depth of discharge of 85 percent we do not know.

So many of these things we will not know how much depth or discharge. So even after it comes it has to actually go a long way before it replaces the lithium battery.

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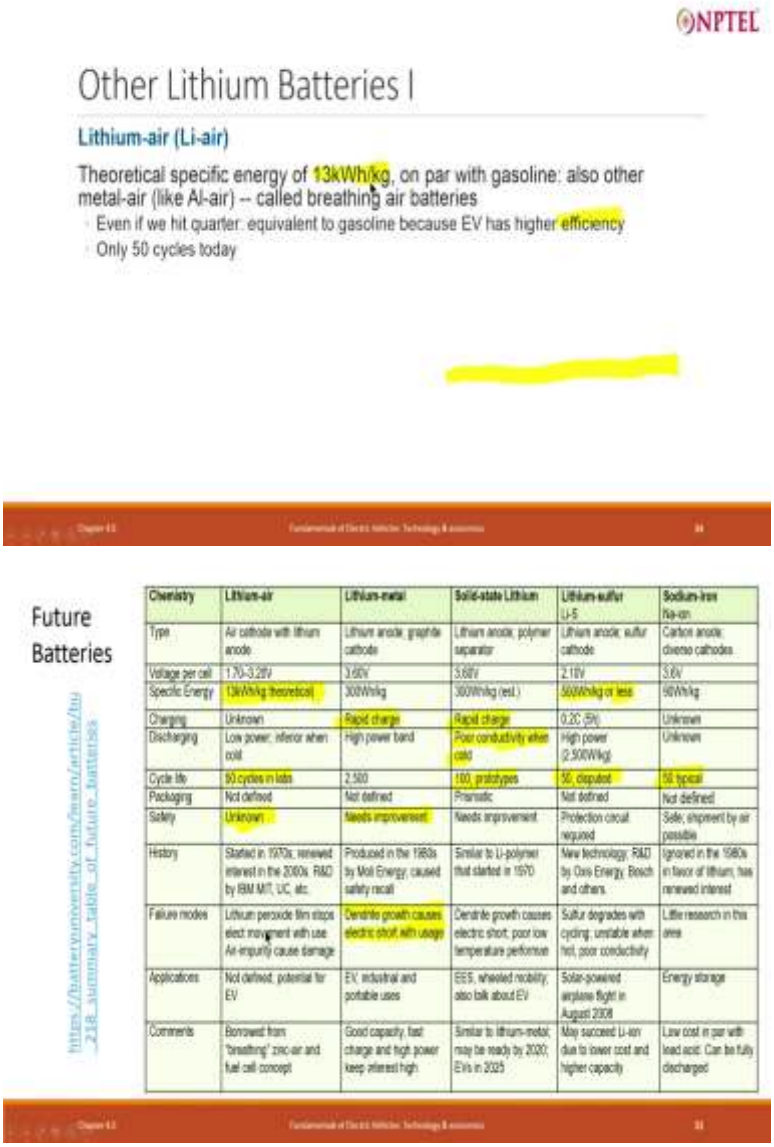

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So that I told you the biggest interest is not 13 it is 1.3 I made a mistake it is 1.3 kilo watt hour per kg 1300 watt hour per kg on par with gasoline so sorry about this. So lithium air it is 30 watt hour kg sorry it is 13 kilo watt hour kg. So this is very good so it is right on par with gasoline. So actually on par with gasoline in terms of energy density but since electrical vehicles are 4 times more energy efficiency you actually require very little of it.

Actually, as I point out, even if I reach quarter of that instead of 13 kilo watt hour I can get 3 kilo watt hour I still will be on par with gasoline this will be fantastic. But today it cycles are very small lithium ion metal 300 watt hour kg dendrite growth that induces safety hazards is a serious

problem rapid charge is the major advantage decent life. Solid-state lithium as I told you anode with pure lithium and solid-state solid polymer electrolyte or a ceramic separator high energy density poor conductivity at cool temperature number of cycles are doubtful.

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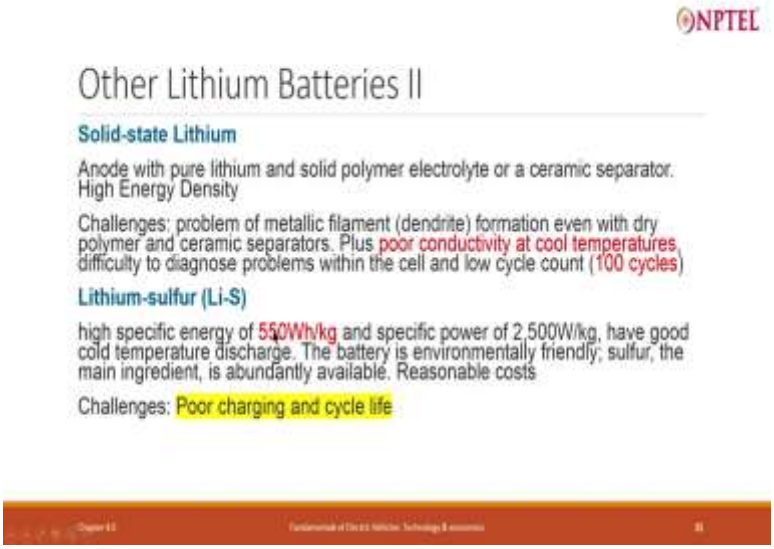

Lithium sulphur better in terms of energy density poor charging and cycle life.

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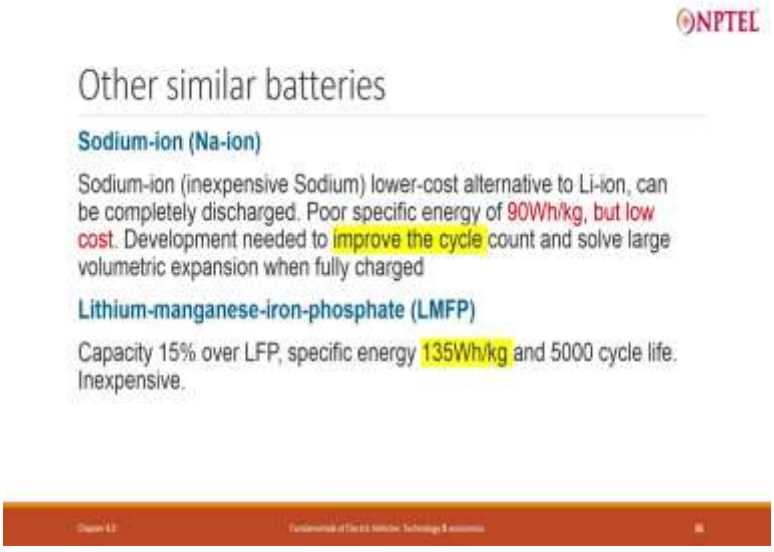

Sodium ion can compete in cost today, see you cannot say because it is not 300 it is going to be as expensive because a replacing the expensive lithium and cobalt with sodium so this can

improve inner cost. The cycle life is still a problem. There is a another called LMFP lithium manganese iron phosphate. Somebody has come that some of the Chinese came it is a much better life cycles, but watt hour per kg is again a problem I do not think any of these things should be ruled out we should watch new work can be done.

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Every day people are doing PhDs not one or two 10s 50s of PHDs the other battery which are talked about quite a bit is the battery called flow battery. It is a redox battery also redox. It is very long life 20,000 cycles is no problem very high capital cost ofcourse not good for EVs, but for fixed application. But even for fixed high application when the cost is very high the interest cost itself will be higher than new battery I can buy a new lithium battery every year by for the interest costs itself that is a problem and is not gone beyond a certain point.

Fuel cell is another thing talked about a lot in the last 15 days I worked with one of the Indian RND house which says that we are the leaders in hydrogen I actually work out the cost, effective cost today to walkout to be at least 5 times that of a lithium ion battery usage cost at least 5 times that is a dilemma even more but can it come up in future very likely.

You should watch this out super-capacitors very high charge-discharge rate but extremely expensive extremely that is what it is. So people everyday newspaper carry they do not even have this basic knowledge that I talked about if they even went to battery university you will find

enough of this. A media people should started saying go to the battery university these papers and then do it or even this would have captured what I am talking about.

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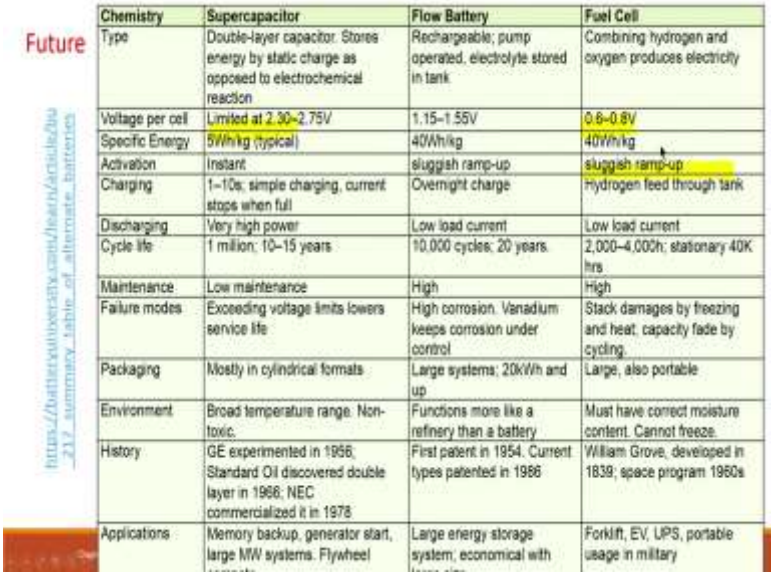

Chemistry	Supercapacitor	Flow Battery	Fuel Cell
Type	Double-layer capacitor. Stores energy by static charge as opposed to electrochemical reaction	Rechargeable; pump operated, electrolyte stored in tank	Combining hydrogen and oxygen produces electricity
Voltage per cell	Limited at 2.30–2.75V	1.15–1.55V	0.6–0.8V
Specific Energy	5Wh/kg (typical)	40Wh/kg	40Wh/kg
Activation	Instant	sluggish ramp-up	sluggish ramp-up
Charging	1–10s; simple charging, current stops when full	Overnight charge	Hydrogen feed through tank
Discharging	Very high power	Low load current	Low load current
Cycle life	1 million; 10–15 years	10,000 cycles; 20 years	2,000–4,000h; stationary 40K hrs
Maintenance	Low maintenance	High	High
Failure modes	Exceeding voltage limits lowers service life	High corrosion. Vanadium keeps corrosion under control	Stack damages by freezing and heat; capacity fade by cycling.
Packaging	Mostly in cylindrical formats	Large systems; 20kWh and up	Large, also portable
Environment	Broad temperature range. Non-toxic.	Functions more like a refinery than a battery	Must have correct moisture content. Cannot freeze.
History	GE experimented in 1956; Standard Oil discovered double layer in 1966; NEC commercialized it in 1978	First patent in 1954. Current types patented in 1986	William Grove, developed in 1839; space program 1960s
Applications	Memory backup, generator start, large MW systems. Flywheel	Large energy storage system; economical with	Forklift, EV, UPS, portable usage in military

So, coming to the end of this. So if I look at it if I look at super-capacitor basically today it is 5 watt hour per kg very expensive. Flow battery is better 40 watt hour kg I talked about that expensive is the main reason and fuel cell is also 40 watt hour kg. But again you will it is extremely expensive.

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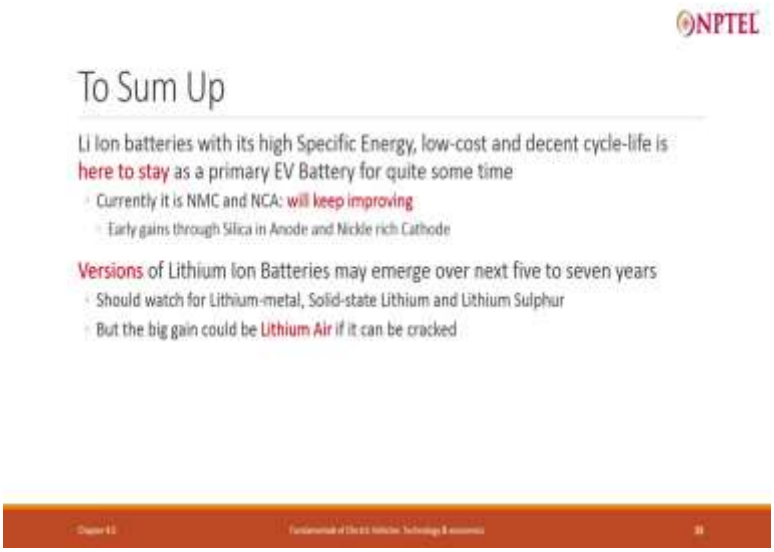

To sum up lithium ion batteries with its high specific energy low cost and decent cycle life is here to stay. The person who got Nobel Prize this year on lithium ion battery he is a 96 year old man, the key person working with him I putting his name Ramakrishnan or somebody who actually delivered on behalf of good ridge his Nobel Prize lecture. He is a alumni of IIT Madras and he was in one of the conferences recently in India not recent year several months back.

And he said but we keep on talking about alternate batteries is that and all that. I will not be very surprised if 20 years down the line you still have the lithium battery as a dominant battery. I think that says it all he may wrong but 10 years strong line week may see something else but it is it is not that it is given that you will see something else.

Versions of lithium ion battery may emerge in 5 years to 7 years. Ideally I like to see a lithium air battery that is the real one not solid state not this. If I was a youngster 45 years back some and I was going to work even though I did not have background I will love to work on lithium air battery that I think if it is cracked it will make a difference.

Till that time we will have to keep on doing things. Other batteries may more useful for stationary applications I want to reserve my judgment because the weight there does not matter so but I think this is what it is.