{ FEATURE }

Professor Jeff Dahn stands next to Ravi Kempaiah and the Watt Wagon bike at the 1/3-of-a-mile Scotia Speedworld track, where Ravi broke the 12- and 24-hour world records for distance ridden on an e-bike.

THE WIZARD OF LITHIUM-ION

Talking past, present and future battery technology with a master of the craft

Dalhousie University in Halifax, Nova Scotia, Canada, has one of the largest and most advanced university laboratories in the world devoted to studies of all aspects of lithium-ion batteries. And at its helm sits Professor Jeff Dahn.

If you use lithium-ion batteries, then you have been affected by his work. He's been working with batteries since 1978, and he and his associates have helped make vast improvements in materials used to make lithium-ion batteries safer, more energy dense and longer-lasting.

He has been co-creator of many patents, including the invention of NMC, which stands for lithium nickel manganese cobalt oxide. NMC is used as a positive electrode material in lithium-ion batteries, which is now used in at least 10 percent of all lithium-ion batteries.

When Tesla announced their Gigafactory, he reached out to Tesla and formed the first university research partnership between Tesla and

Photo Courtesy of Tiến Nguyễn

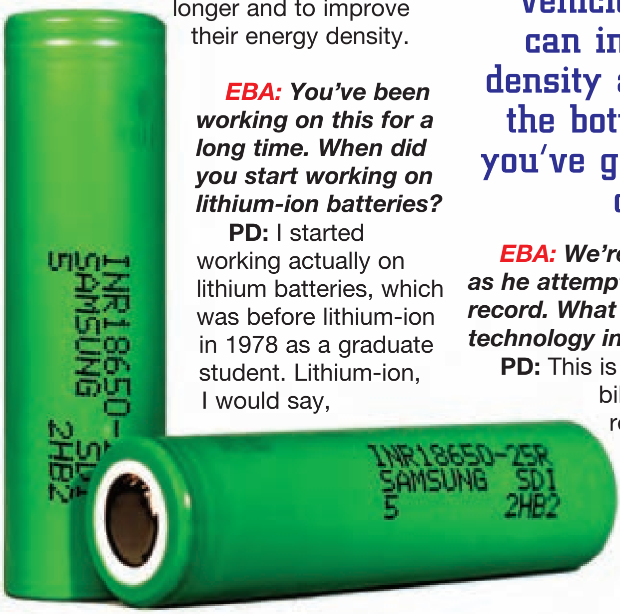
Dalhousie University. *Time* Magazine called Professor Dahn "Tesla's New Weapon".

We sat down with Professor Dahn at a racetrack in Halifax where Ravi Kempaiah was attempting to break the Guinness World Records for distance on an e-bike. This is our exclusive interview with Professor Dahn, a remarkable and very affable man who is passionate about batteries, energy storage and how it will affect our environment and our future.

MEET THE PROFESSOR

***EBA:* Professor Dahn, tell us a bit about you and what you're working on these days?**

Professor Dahn: I'm a Professor of Physics and a Professor of Chemistry at Dalhousie University in Halifax, Nova Scotia, Canada, and I work primarily on lithium-ion batteries. We have three main focuses: to make lithium-ion batteries cost less, to make them last longer and to improve their energy density.



***EBA:* You've been working on this for a long time. When did you start working on lithium-ion batteries?**

PD: I started working actually on lithium batteries, which was before lithium-ion in 1978 as a graduate student. Lithium-ion, I would say, came into the into play around 1986 or so. People started doing research in the area and was commercialized in 1991 by Sony.

***EBA:* What's the current state of lithium-ion batteries?**

PD: Lithium-ion batteries are pretty amazing at the moment. They're used in electric vehicles and grid-energy storage, in your laptop, and pretty much any device. They're quite amazing, you know. You can expect to get easily 1000 charge-discharge cycles out of a lithium-ion cell—even a relatively poor lithium-ion cell will last four to five years, so they're really state of the art in rechargeable power sources.

> "I really believe that one of the biggest impediments to the mass adoption of electric vehicles is cost. You can improve energy density and so forth, but the bottom line is that you've got to get the cost down."

***EBA:* We're out here with Ravi as he attempts to set a world record. What do you think about the technology in the bike he's riding?**

PD: This is quite an amazing e-assist bike, with a titanium frame, really robust gearing system and a fantastic motor. He has a battery pack that's about double the energy that you would have in a typical e-assist bike. I've ridden e-assist bikes all over Europe, and they're absolutely fantastic! It's not like sitting on a bike and doing nothing; you're biking more or less normally, but you're going twice as fast, so during a day you can travel twice as far. Hills present no problem because you just ask for more assist. They're really an absolutely wonderful machine.

***EBA:* With your grasp of chemistry, how do you think of what chemical would enhance what part of what type of battery?**

PD: In the lithium-ion battery, there's really several things you have to think about when you're trying to improve them. You have the negative-electrode material, the positive-electrode material and the electrolyte. These three things are the things that you try to work on to improve the cells, so if you have in mind, for example, increasing the energy density of the cell, then you're looking at changes to the electrode materials.

And if you're looking at increasing the lifetime of the cell generally, then you are looking at changes to the electrolyte. The reason for that is that when a lithium-ion cell is degrading, it's because of unwanted reactions between the electrolyte and the charged electrode materials, so you have to stabilize and hinder or prevent those reactions as much as possible. So, there's these three things that you're working on all the time—the positive, the negative and the electrolyte.

***EBA:* What you think of the solid electrolytes?**

PD: The solid electrolyte is a system that could really improve the lifetime of cells and, in addition, it's not a combustible system, so in principle it can improve safety as well. I think it's really important to continue working on

the research community is looking to find the next big thing, beyond lithium-ion. But to be honest, at this moment, there's no real clear thing out there that people can say, "That's the next thing!" At the moment, the bet remains on lithium-ion. The kind of projections you see in the next five years it will at least double in terms of production capacity around the world. Maybe even more!

***EBA:* Do you think energy storage capacity as well?**

PD: Oh, yeah! Energy storage is booming at the moment. You see announcements from the various companies about very large-scale energy storage systems, coupled with solar popping up all over the place. It's just booming!

DIFFERENT TECHNOLOGY

EBA: What about technologies like aluminum-ion or graphene? Are those on the horizon?

solid-state batteries, and it's happening all over the world. There are a lot of claims being made about solid-state batteries will be ready in a few years, and we'll see what happens. I don't know how close to this state of readiness it really is at this time.

***EBA:* Where is better technology going right now?**

PD: I would say the next five years looks like a vast expansion in production capacity of lithium-ion to meet the demand of vehicles and grid. In the same time,

PD: The real interesting thing about an element like aluminum is, for every aluminum-ion you transfer from the positive electrode to the negative, you transport three electrons through the wire, so in principal it can give you a three-fold advantage over lithium, if you can make it work. The real issue with aluminum is that if you can find an electrode material that aluminum can diffuse rapidly through, like lithium can diffuse rapidly in graphite, or in positive electrode materials like NCA, which is in Ravi's bike.

The thing about aluminum is that it's triply charged—three plus. And it is very difficult for a triply-charged ion to diffuse rapidly in solids. It just polarizes the environment and makes bottlenecks that make it very difficult, so finding electrode materials that are functional for aluminum and other ions like magnesium that people have talked about are very difficult. I don't know what will happen in that space.

***EBA:* What about the amount of charge needed for something like a Tesla semi? To have a 500-mile range, that battery is massive. Won't it take a long time to charge?**

PD: Well, the size of the battery doesn't have much to do with its ability to charge rapidly. It's all a question of having the available power. At this point in time, any lithium-ion battery can be charged in roughly half an hour. So, if you have a giant truck, and let's just say it has a megawatt-hour battery in it, then you'd have to have 2 megawatts of power to charge it in half an hour. It's all a question of having the right-size cord and plug available to provide the juice that you need.

> **"The research community is looking to find the next big thing, beyond lithium-ion, but to be honest, at this moment, there's no real clear thing out there that people can say, 'That's the next thing!' At the moment, the bet remains on lithium-ion."**

What a lot of people are talking about and wanting is the ability to be able to charge in a shorter amount of time. This is a situation where you can make some trade-offs in the lithium-ion cell to promote faster charging, but most of those trade-offs lead to a lower energy density, which means a bigger battery, so you have to sort of balance the speed of charging with the energy density that you require.

***EBA:* Half an hour to charge a battery is reasonable. If you were doing a cross-country trip on a bike, stopping for a half hour is completely reasonable.**

PD: Oh, yeah. I don't think anybody think this bike of Ravi's can go about 125 kilometers before it needs to be charged. If you don't need water and to go to the bathroom after that amount of cycling, I mean, you'll be happy to take a half-an-hour break!

***EBA:* Is there a place for capacitors in all of this?**

PD: The real difference between capacitors and batteries is the energy density. Even a super-capacitor might have an energy density of around 10 Wh per kilogram, whereas a lithium-ion battery these days is 250 Wh per kilogram, so the energy density is really low. The advantage of a capacitor is that it can really accommodate a very rapid delivery or storage of energy, so

very high-power capability. The place you could see it that might make sense is in capturing regenerative braking, for example. Right now, lithium-ion batteries are very good at that. Maybe there would be some space for a capacitor, but I just don't think the vehicle companies want to give up any volume for that type of thing.

INTO THE FUTURE

***EBA:* Do you have any thoughts on the distant future of battery technology?**

PD: I think that if you look at where lithium-ion is today, and you imagine what we could do. The best possible battery of all? In terms of energy density, I think you can probably get another 50 percent beyond lithium-ion. To go beyond that, you really need to get a new periodic table. We need new elements. We need new properties.

Maybe people would say I'm a pessimist, but it is really difficult to imagine a system based on the periodic table we have today with massive energy density, a factor of more than one-and-a-half the best lithium-ion of today.

"In terms of energy density, I think you can probably get another 50 percent beyond lithium-ion. To go beyond that, you really need to get a new periodic table. We need new elements. We need new properties."

***EBA:* This is what you are working on today.**

PD: Yeah. I work on mostly lithium-ion. Improving lifetime, increasing energy density, and lowering cost. We do have a project called "Beyond Lithium-Ion" with very high-density cells, but at the moment their lifetime is about one-tenth that of lithium-ion. They will have a place in some specialty markets, but not the big markets.

I really believe that one of the biggest impediments to the mass adoption of electric vehicles is cost—the cost of the battery. I had a conversation with Martin Eberhard (one of the founders of Tesla) long ago, standing next to a Tesla Roadster. This was in 2009. Martin said, "Look, the batteries we have in this Roadster now, the thing goes 240 miles. It's a comfortable car; it's really awesome. The real issue is the cost. If the batteries cost one-fifth of what they do now, no one would drive a gas-powered car."

That conversation stuck with me. Martin's message was that you can improve energy density and so forth, but the bottom line is that you've got to get the cost down. Then people are really going to jump in here.

***EBA:* Is that going to improve as production goes up, like that from the Gigafactory?**

PD: A lot of it is associated with economies of scale, but it also comes back to the fundamental material costs associated with the cell. Ravi's bike uses a positive-electrode material called NCA, which is lithium nickel cobalt aluminum oxide. Probably 80-percent nickel and about 15-percent cobalt in the positive electrode. Cobalt is expensive, so we have to get rid of the cobalt. This has been a big research focus for us recently, making materials with the same properties, but with no cobalt to help drive down the cost. Every little thing you can do, to nibble away here, nibble away there, and slowly you bring the cost down.

***EBA:* If you compare prices of bike batteries over the past few years, the prices have come down.**

PD: Oh, yeah. There are some really nice graphs that chart historical data for costs and also make projections into the future. Cell costs below $100 per kilowatt-hour (kWh) are projected and pack costs around $130 per kWh are projected.

***EBA:* Professor Dahn, thank you for taking the time to talk to us and answering our questions!**

PD: It's really fun sitting out here in the sun watching Ravi go in circles! ■