MARTY ROSENBERG
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DON SADOWAY INTERVIEW

Hi and welcome to Grid Talk. Today we very pleased to have with us, Don Sadoway, who's the John F. Elliott Professor of Materials Chemistry at MIT where he's been on their faculty for 44 years, soon to become Emeritus, but still a full-fledged faculty member.

Q: Hi, Don. Thanks for joining with us.

A: My pleasure to be here, Marty.

Q: So, we're really here to talk about all things energy storage. Don is one of the leading thinkers and developers of new technology for energy storage and there's a lot happening on that front so without further ado, Don, let me just by way of background and to kind of launch our conversation, you're a founder of Ambri, Boston Metal, Sadoway Labs, Avanti Battery, Pure Lithium, and Lunar Resources if I have them all…if not, I'll stand corrected. Tell me why all of these startups and what are they up to?

A: Well, the startups came about because of discoveries. I, unlike some people in this arena that are dusting off some old technology taking a new run at it, everything that I've been

working on is a new discovery and I want to have science in service to society and that means I have to commercialize the technology. Step One, of course, is to publish in the highest-ranking journals that I can to make sure that people see that the discovery has been subjected to intense scrutiny but then it comes time to commercialize in order to have it available for society, and each of those companies has a story behind it.

Q: Can you give us a 30,000-foot story on each one?

A: Yep, just a…

Q: Just a sentence or two, really so we have a scope…

A: Yes, so…

Q: Go ahead.

A: Go ahead.

Q: Ambri seems like the most recent startup?

A: So, Ambri is actually the rebranding of the Liquid Metal Battery Corporation which we started in 2010 and it was to commercialize the liquid metal battery which I invented at MIT around 2007-2008 and by 2010, we knew that we had reduced it to practice and two of my students came to me and said, "It's time for startup," and here we are.

Q: And Boston Metal?

A: A similar story. I had been working on electrolytic production of steel as early as the late 1980s when people would

laugh at the notion that you would use electricity to make primary steel starting with iron ore and I persevered and around about 2011, with a post doc, we discovered a practical inert anode where no platinum-group metals; it was an iron-chromium alloy and that would allow us to evolve oxygen and we said, "It's time to start a company to commercialize green steel." And even in 2012-2013, this was viewed as a little bit silly, but today, green steel is very much a topic of conversation.

A: Sadoway Labs?

A: This is the latest; I started it last year. In spite of all the other companies which are all commercializing discoveries, I decided to accelerate the rate of discovery, so Sadoway Labs is designed to be a skunkworks sort of fusion of Arthur D. Little and Bell Labs where I can go in the back and in very short order, do some quick experiments to see if something is feasible as opposed to writing proposals and waiting for the nonsensical nasty reviews and begging for money, but rather to have the funds on hand to move quickly, and so, Sadoway Labs is supposed to be the discovery generator for the next litter of companies.

Q: Avanti Battery? Sounds like a wine. What inspired the name?

A: Well, I drove the Avanti automobile for many years. I've always loved that beautiful design by Raymond Loewy and I knew that if I had the chance…I wanted to name Ambri Avanti but there

was a hair salon on Newberry Street called Avanti and so Phil Giudice said we can't go with Avanti. I said they're not going to confuse us with a hair salon but anyways, so now I had the freedom to name my new company Avanti and this was a discovery of a new battery chemistry, lithium-free. It's aluminum as the negative and sulfur as the positive and no volatile flammable electrolyte; it's a molten salt electrolyte, low-melting molten salt and with the discovery of the aluminum-sulfur battery I knew I had the elements for a company and that's what Avanti is about.

Q: Pure Lithium?

A: Pure Lithium; I was invited to join the forces with Emily Bodoin who had been working at Argonne Labs on a technology to extract lithium from brines and to go in one step to deposit lithium as a metal on copper thereby extracting lithium and fabricating the lithium metal electrode in one step, and she wanted to start a company and she reached out to me because of my deep knowledge in nonaqueous chemistry and electrometallurgy and so we joined forces and I'm actually sitting right now at the world headquarters of the Pure Lithium and it's moving forward with this very efficient, low-cost extraction process for lithium metal.

Q: And last on my list is Lunar Resources?

A: Yes, Lunar Resources, this is started by Elliot Carol down in Houston with myself and Alex Ignatiev, who's a professor retired from the University of Houston;who worked on photovoltaics and we wanted to take a look at how we might exploit the lunar surface for various products right there using the local resources and they were aware of some of my early work on molten oxide electrolysis with NASA to generate oxygen on the moon and they said we read that you're generating iron and silicon, and have you ever thought about extracting silicon for photovoltaic cells? And so, we joined forces and that was the genesis of Lunar Resources.

Q: So, if I have you right on this; future extraction of minerals from the moon, is its business plan?

A: Yeah, that's correct and please don't ask me more business questions. I have the humility to say I'm not the business mind here. I'm the electrochemist. If you want to know more about that, I refer you to Elliot Carol.

Q: Okay, so we have a diverse enterprises here. Could you tell me just collectively for all of them: are any of them generating revenue yet? What's the magnitude of revenue collectively from all of them?

A: So, the oldest is Ambri and it's on the verge of releasing first product into customer hands. We have been manufacturing but

we have to be exhaustively testing to make sure that the durability is there. We don't want to suffer the embarrassment of having a battery get into customer hands and fail prematurely. So, it's ready. We've got customers. We've got a big order book and customers coming from various sectors and we can get into that if you want to probe deeper. And then next in line I think is Boston Metal which is now building industrial prototype cells to extract liquid iron from iron ore and right here in Woburn, Massachusetts, about two miles from where I'm sitting, is a 25,000-ampere cell that is turning ore into liquid metal and oxygen as the byproduct and they're on the path to upscale so let's say 2025, they should be at industrial installation pouring liquid metal and people will be fighting over who's going to get to use true green steel in their products whether they're appliances, automobiles, what have you.

Q: So, your expertise is electrochemistry and nonaqueous media. To what extent does that expertise touch all of these enterprises and if there are non-chemists among us, could you describe what that means?

A: Well, Marty, you're absolutely correct. That's the unifying feature of all of the work that I've been doing and continue to do; it's nonaqueous electrochemistry. Water is a fantastic solvent. We wouldn't be having this conversation, you and I, if

it weren't for water. But when it comes to industrial electrochemistry, I'm not interested in water. It's low voltage, low current. I know some people like aqueous flow batteries. They like metal air batteries. I just have no interest in that stuff. So, early on in my career I was drawn to industrial electrochemistry as it applies to metal production, so things like aluminum, magnesium; they're extracted in tonnage amounts using electricity but the electrolyte is not an aqueous solution; not a water-based solution; it is a molten salt so instead of dissolving salt in water, you take the salt up to a high temperature and you melt it. And that's how we make worldwide aluminum- is by molten salt electrolysis, and I became smitten by that field. It's different from aqueous electrolysis. There are some similarities but there are important differences. And operating temperatures for aluminum, it's almost 1,000 degrees Celsius. And then I became fearless with the molten oxide electrolysis, we take iron ore which is an iron oxide and I say like dissolves like so if you have an iron oxide then you need a molten oxide as the solvent. And we went up to 1,650 degrees to dissolve iron ore into molten oxide solvent. People said you're crazy and I said, just crazy enough that this might be fitting and that's what we have, and we make liquid iron. By the way, all tonnage metal, iron, magnesium, copper, aluminum—these are all

made as liquid metals. Nobody electro-deposits solid metal and makes tonnage metal. If you make solid metal like titanium, that's why titanium is so expensive because the process by which we make it is so inefficient and so, that's what drew me to this. And then round about 2005 one of my colleagues came to me and he said, "You know, you've been doing all of this work on molten salts and high-temperature electrochemistry, have you ever thought about any transferable skills that might apply to batteries?" And I about that time, I started thinking about stationery storage on a massive scale and that's what the first step was in my thinking towards the invention of the liquid metal battery, and I've just continued on that path.

Q: That really gets us to the heart of why I want to talk to you. I don't think a lot of folks outside the energy industry realize we're on the cusp of a major deployment of energy storage. According to Federal figures at the USEIA, there are about 1,600 megawatts of storage as of 2020. By 2023 that's going to reach 12,000 megawatts, a significant ten-fold increase from just 2019 levels. Do you see this as being transformational in a way that people in the industry and the outside maybe don't realize yet?

A: Oh, I think you're right because the original model of the grid and it is fantastic. I mean some people have said that the

grid is the most remarkable engineering feat of the 20th Century. This gigantic thing and it has to operate so that supply equals demand everywhere at all times. It's not just generation, it's transmission; it's distribution; it's just amazing that the thing works. But now, we want to go to carbon-free generation of electricity and that leads us to solar and wind which are intermittent, and we have to deal with the intermittency. And nobody wants green electricity that's only available part-time; they want it all the time, so that means storage. And no one has ever had the challenge of storing thousands of megawatts hours of electricity. So, as we meet that challenge, we have new design opportunities and the biggest one that I see is that we don't have to put the storage right next to the generator. So, let's say you have this gigantic solar array but the load center where most of the electricity is being consumed is in the city so why would you put the storage next to the solar arrays in the country? Why not put the storage distributed all over the city and this gives, I think, untold resiliency and it's going to make our grid even better.

Q: So, you see storage being deployed across metro areas and near residential areas, industrial areas, commercial areas?

A: I do, provided it's correctly designed. It's not going to be lithium-ion because lithium-ion is unsafe and no fire marshal is

going to allow you to put a hundred-megawatt-hour storage facility in a downtown urban area. But a liquid metal battery; you bet. A liquid metal battery could be in the basement of every one of the skyscrapers in Manhattan.

Q: So, this ramp-up to 12,000 megawatts by 2023…by the way, I venture to guess you're saying that's just the tip of the iceberg of what's coming. How much of it at least initially, the first year or two, will be conventional technology? How much with the new technology be? What kind of role will that be playing and how long will it take to scale it up?

A: Well, Marty, again, you're right. I think in the race to get something into the marketplace they will go ahead with lithium-ion, just as they've been using lithium-ion in automobiles which I think is insane, but it's the best technology that we have. But let's go back to say, 1990 where we had nickel metal hydride technology was the dominate storage battery technology. And, round about '88-'89, everybody had their very first phones. They weren't smartphones, they were the candy bars or flip phones and they have their very first portable computers and they were all running nickel metal hydride and people adopted it because it was the best that we had at the time. But, as soon as lithium-ion emerged, everyone switched to lithium-ion. All the hard work had been done. The phone is agnostic; it doesn't care where the

electrons come from. And we're going to see the same thing with massive stationery storage. People are going to start using whatever technology's out there right now and then as soon as something better comes along, they'll jump to it, so I'm optimistic about liquid metal battery because once people realize what this thing can do, and it's been demonstrated at scale. Marty, the thing here is in this capital intensive/risk-averse sector, nobody wants to be first when it comes to radical innovation. Everyone wants to be first to be second. Once they've seen that it works, and they have a third party that can give attestation and say, "This stuff really works."

Q: As one of our reigning experts on the topic, how long do you do you think it will be before that dawns on people that it works and let's switch over?

A: I think it's going to come at some point in the next two or three years because Ambri is planning on releasing its first product into customer hands by this time next year and it's going to be somebody that's going to be surprising—I can't name names just yet but let's just say, it's going to be a user, a heavy user of electricity in a commercial enterprise that involves a lot of data processing, cloud computing, stuff like that and they want to be a hundred percent green and they have the intelligence not to spend money on a lithium-ion deployment. And once they can

say, “Yeah, this thing really works” and it’s going to be high-speed production for Ambri.

Q: Let’s get back to the basement of all the skyscrapers in Manhattan.

A: Sure.

Q: How long to an appreciable share of them have liquid metal batteries in their basement or on premises?

A: Well, it comes back to the first acceptance by the market that liquid metal battery really works and so after that first deployment occurs with the data centers, at that point people are going to start saying, “Does this thing have the potential to go inside the basement of a skyscraper?” But they’re going to have to see that first because as I said earlier, Marty, you try to put gigantic storage inside a building in Manhattan, the first line of defense is going to be the fire marshal and that fire marshal has to be a hundred percent secure in his belief that that technology is safe, and once that fire marshal is satisfied, that’s green-light, red-carpet.

Q: So, once these batteries are ubiquitous, let’s say it starts in two-three years then it’s a significant ramp-out…ramp-up after that…

A: Yeah.

Q: What is that going to do to solar and wind energy deployments in this country? Do you think they'll explode significantly beyond their current level?

A: Ah, I would expect so, but honestly, Marty, I don't follow that end of the industry so I'm not sure whether frustration with storage is in some way holding them back or not, but to the extent that it is holding them back, then absolutely, getting that obstacle out of the path is going to be advantageous.

Q: So, you've been in this field as I said earlier for more than four decades.

A: Yes.

Q: What's your sense of the pace of innovation and deployment now versus earlier in your career?

A: Well, things have changed a lot. I mean, first of all, there's an appreciation for the problem. I don't think that people even understood how the grid worked. I think they thought—even as recently as 15 years ago, they thought well, solar's cool. It's like additional water. It gives us added electricity. No, it doesn't. If supply exceeds demand, it's not a bonus; it's a problem because then the voltage is wrong, the frequency is wrong. What's worse than no electricity? It's bad electricity. Every time you plug in your device you blow the motor. And I don't mean blow the fuse. You fry the motor. And so, only over

time did people appreciate that storage is critical if we're going to use the intermittent renewables. And then the pace of innovation…I have to say this carefully. At some level it saddens me to see that the majority of efforts in the large-scale stationery storage are looking to legacy chemistries. I mean, people are still using lithium-ion. Lithium-ion burst on the stage probably around 1991, so I'm not going to say there's been a lot of innovation. In fact, even in lithium-ion the innovation has all been in the manufacturing. The price has come down so much; I mean, even as recently as 2010 it was still priced at $1,000 a kilowatt hour, and now it's below $200 a kilowatt hour. And it's not because of new changes in the chemistry. It's because just becoming more and more proficient at manufacturing. But we see the folly of this which is the growing demand for the lithium-ion chemistry which means we have supply chains tied so tautly right now that they're practically snapping. Nickel, manganese, cobalt, graphite, even lithium itself; if you take a look—go back to your projections, Marty, and do a back-of-the-envelope calculation, what is the tonnages of all of these battery metals that we're going to need? And I didn't even say anything about copper; all of this stuff has to be wired and the wiring is copper and copper itself is under demand far in excess of supply, so this is an opportunity for innovation. I'm working

on Avanti, the aluminum/Sulfur battery is no cobalt, no nickel, no manganese, no volatile flammable electrolyte, no graphite, forget the silicon. This is no lithium. Aluminum and Sulfur with a molten salt electrolyte? You can go into your backyard and make this stuff. Why aren't people thinking about this? Because they're all wrapped around the axle of familiarity.

Q: Right. Well, Don, congratulations by the way. Last month you were name a finalist for the 2022 European Innovator Award. That's awarded by the European Patent Office. Reflect a little bit now that you're stepping down as professor…

A: Yeah.

Q: I don't see you as a man that's going to go out and play golf. I think you're going to be engaged in all of these enterprises, maybe starting a few more. You are descendent of Ukrainian parents. I'm sure that's given you pause on the state of the world.

A: Correct.

Q: Where do you see yourself right now in terms of making a contribution that's meaningful with your life?

A: Well, I've got to play to my strengths and I understand nonaqueous electrochemistry and I think that there are more contributions that can be made in making a sustainable and profitable world; putting people to work in valuable and well-

paying jobs and at the same time, decarbonizing, deep, deep decarbonization. And, you're absolutely correct. I'm not a golfer. I don't intend to sit on a veranda in a rocking chair. I'm moving aggressively. I've had a good run at MIT. It's ben 44 years of teaching, research, mentoring. But I found last year on sabbatical, I could go much faster and I still have a lot of ideas and I want to get them moving quickly. The last thing I want to do is write a proposal and send it to some agency in Washington. I'm done with that.

Q: Thank you, Don. We've been talking to Don Sadoway. Thanks for joining us, Don.

A: My pleasure Marty. You ask good questions.

Thanks, Don. Don is Professor of Materials Chemistry at MIT; soon to be Professor Emeritus and in no hurry to slow down.

Thanks for listening to Grid Talk and thanks for our participation with Don Sadoway. You can send us feedback or questions at GridTalk@NREL.gov and we encourage you to give the podcast a rating or review on your favorite podcast platform. For more information about the series or to subscribe, visit SmartGrid.gov.

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