VENKAT SRINIVASAN: So welcome back again. We’re going to move into more sessions before we go to the breakouts. Just to remind everybody, we have breakout sessions this afternoon. The purpose of these sessions if you’re here for the one on workforce, the one we’ll be listening to right now on domestic supply chains and manufacturing, is all to set the stage for what the connotations have been until now, and then start getting your thoughts on where we have to go so that we can have that robust connotations in the breakouts. So again, use this next forum to kind of get a sense for what the connotations have been, the challenges, the opportunities that we have.

But we want to hear from you, right? That’s the main purpose of this meeting. So keep your thoughts, go to the breakouts, and tell us what you’re thinking. So I want to call out Mark Willey, one of my colleagues from the Pacific Northwest National Lab where he is an advisor to moderate the next session where they’re going to focus a little bit on the manufacturing challenges and ultimately thinking about how are we going to secure the domestic supply chains for all the technologies that we need to ensure that we have a clean energy economy. So with that, Mark?

MARK WILLEY: Thanks, Venkat. Okay, so this is going to be an interesting session, a little bit different than we heard this morning. But on a topic that’s near and dear to my heart. Most of you probably do not know me. I actually come from the private sector. So before I joined PNNL I was actually working at a materials manufacturer that did semiconductor materials, but also some battery work and before that I worked at another company in semiconductors.

So most of my life has actually been spent in manufacturing and ramping equipment and materials, but not in this field. Well, partly in this, in the battery field, but mostly in the semiconductor field. But it turns out there’s a lot of synergies between those two manufacturing fields and there’s a lot of lessons to be learned from how we did things back in the ‘90s, through ramping U.S. semiconductor manufacturing, and ‘80s.

The other thing I wanted to do is make sure I acknowledge Greg Krumdick who’s actually sitting in the front here. He’s really the person that did everything for this group here. He was really the one who did all the day to day activities. I’m supporting him today to lead the discussions here.

So this afternoon we have four speakers. And the way we’re going to set up our discussion is we have the first two speakers are from the DOE, one from AMO, Advanced Manufacturing Office; and the second from this new Manufacturing and Energy Supply Chain’s office. And what they’re going to do is set the stage in terms of tell us, what are these two offices doing, how are they supporting this electrification, what activities they have. And after that what we’re going to do is we’re going to have two industry companies come on and give you their perspective of the challenges of ramping supply chains in manufacturing within the United States.

And so, I wanted to say a few things before they come on here in terms of what we’re doing here in terms of electrification. Most people, when they think about ramping the industry in the United States for this electrification, think about all these gigafactories [phonetic] and the cell producers that are happening. But really, we really have to think about the full supply chain, the full amount of companies that are going to be coming in and actually coming back into the manufacturing space. I think this is, everybody knows the volume. Somebody mentioned the volumes this morning and somebody else mentioned the fact of this ramp that’s going to happen.

These are significant challenges, and from a manufacturing perspective, specifically in the United States for over the last fifty-plus years, we’ve offshored a lot of that manufacturing. And so I think when, you know, if I had to say two things that you have to think about in terms of our discussion space, it’s really thinking about how we can help this manufacturing come back to the United States; how we can make sure that we don’t just offshore our responsibility for the environment, when we did that in the past with manufacturing. How we bring that back in new ways where we actually can have it here in the United States and control the environmental and workforce issues.

And with that I think it’s also this whole thing about not in my backyard that we need to get past in America. Which is, when we bring back manufacturing I want everybody to understand that we’re bringing back manufacturing in a different way than we did it in the past. When people think about manufacturing they think about the 1950s or ‘60s; you think about these big oil refineries, or I wouldn’t say oil refineries, but these big chemical plants that are just dumping pollutants into the environment. That is not what we’re going to do here as we bring back electrification.

And I think we need to get past that and make sure that we have an open mind, and make sure that we do it the right way. Because if we don’t do it the right way in America, it’s being done somewhere else that’s going to affect globally how things are running. So with that I’m going to introduce our first speaker, Diana Bauer from the Advanced Manufacturing Office. Diana Bauer serves as the Acting Deputy Director of the Advanced Manufacturing Office within the Office of Energy Efficiency and Renewable Energy at the U.S. Department of Energy. In this role Diana is responsible for technical coordination and strategic planning. Before coming to the DOE, Diana led the Extramural Sustainability Research Program at the Environmental Protection Agency, which focused on green engineering, green chemistry, green buildings, and transportation systems. So could we all give a round of applause for Diana here?

DIANA BAUER: Thanks Mark. And I just want to say it’s my absolute pleasure to be here today. I’ve been involved with the Energy Storage Grand Challenge for over two years and it’s great to see it growing up to what it is here. And thanks so much to the folks from Argonne for hosting today. Next slide, please.

So today I’m going to talk a little bit about kind of the focus areas of manufacturing and supply chains, and energy storage, some of the challenges and then also talk about some of the work that we’ve supported in AMO and are planning to support. And in addition, some of the activities that have been led by the National Lab Coordination team. And I’ll also, this is actually quite an exciting moment for manufacturing and DOE because we have an abundance of offices now that address manufacturing. So I will kind of lay those out and kind of explain our vision for how they will work together in the storage space, and also some news from AMO at the end. Next slide, please.

So in terms of the way we originally framed the thinking for manufacturing and supply chain innovation for energy storage, as we discussed, as we’ve been discussing, the critical materials supply chains are very important, but also accelerating the scale up of manufacturing. So getting innovation isn’t just in the new technology; it’s also in the way that the technology is produced.

So doing manufacturing scale up in parallel with or at the same time as some of the technology innovation is really important and valuable. And then also we want to just address the technical barriers in production and manufacturing, to improve performance and also reduce costs. Next slide, please.

Here this eye chart here is a figure from the Energy Storage Grand Challenge roadmap, which was published in December of 2020 and is available on the website if you want to look further. Just a few points to make here. You can see that for various, or first of all we have various storage technologies. We have lithium ion or lithium-based batteries including lithium ion and also solid state flow batteries, other battery chemistries, various mechanical engineering storage, chemical energy storage, and also thermal storage.

And so we want to think, as we think about manufacturing we want to think across the different technologies and you will see that recycling is important across multiple of the technologies. We have a lowering manufacturing cost for various components, and there’s some variation among the different technologies about where to focus, but that’s an important area. Improving performance of various components is also important. And the manufacturing scale up, scale out, again accelerating that pathway from innovation related to manufacturing and full scale deployment, and doing that in parallel with the technology innovation.

And then finally for some of these technologies it’s also really important to, as we’re innovating individual components, figure out how to integrate systems more efficiently and test them so that we have performance both at the component and the system level. Next slide, please.

So in the next slides I’m going to talk a little bit about three different technology focus areas that either have been recent focuses of AMO, current focuses of AMO, or like look to the future on focuses for AMO. So I’m going to be talking about lithium ion flow batteries and then also thermal storage. So first of all, for lithium batteries, we’re focusing on cathodes and then also cell manufacture, because those are dominant costs for lithium batteries. And so in terms of our focus, that’s where we’re at. Next slide, please?

But then also supply chains are really important and kind of thinking about understanding where cobalt comes from, where lithium comes from, where nickel comes from. And then also where these materials are refined, where cells are produced, et cetera. So as we’re standing up production of energy technologies, of storage technologies, we want to help to make the supply chain cohesive so that we’re not mining lithium and then sending it elsewhere to be refined so that we sort of maintain control of our supply chains. Next slide?

So as I mentioned, we’re also doing some work in flow batteries. Flow batteries, if you compare flow batteries to lithium ion batteries, you can see that they’re a little bit further behind in terms of technology readiness level, a little bit further behind in terms of manufacturing readiness level. But they’re really important potentially for long duration storage, and you heard this morning about the long duration storage energy shot.

So we’re working with the Office of Electricity on the supply chains on improving kind of the full manufacturing supply chain and innovation pipeline for flow batteries. Next slide? So as I just mentioned, we’re working with the Office of Electricity and so we’re focusing on – we, AMO – are focusing on new chemistries and designs, innovative manufacturing capabilities, accelerated scale up. And with these new chemistries and designs, streamlining and securing the domestic supply chains. And so we work hand in hand with OE on this in terms of, they are working on testing the full systems, making sure that the functionality is predictable, et cetera, and we’re thinking about this across the full life cycle through to end of life and recycling. Next slide, please?

So another earth shot that I haven't heard about here at this meeting yet that was announced last week is the industrial heat earth shot which AMO is in a leadership role for. And basically the goal there is to reduce greenhouse gas emissions by 85 percent or more by 2035. Next slide, please? And you’ll notice on this slide there’s a combination of pathways and in the middle there, integrating clean energy – integrating clean heat from alternate sources includes storage. So storage is really central to a de-carbonization of industry. And process heat is actually is about 9 percent of total emissions, greenhouse gas emissions, from energy related sources across the full economy. So it’s very significant. Next slide, please?

So I noticed that I have basically no time left, but here’s some major activities from the manufacturing and supply chain track. We have a subgroup looking at analysis. We have manufacturing for energy storage, which is focusing on battery, lithium battery chemistries, flow batteries, solid state, as well as thermal, and looking at things like material manufacturing device fabrication, et cetera. Next slide, please?

And then we also have energy storage for manufacturing which is looking at things like thermal storage and other technologies. And for both of these, there will be a workshop report available soon on the website. Next slide, please? So here’s the layout of the offices that I mentioned earlier. Basic energy sciences is focusing on basic research. The Advanced Manufacturing Office, which you can see down there, along with vehicle technologies and Office of Electricity is focused on applied research and development. Then we have some new offices including the Manufacturing and Energy Supply Chain Office, and also the Office of Clean Energy Demonstrations, which are focused on large-scale demonstrations and scale-up of manufacturing. The loan program office is also in there. Next slide, please?

So AMO in two weeks is multiplying into two manufacturing related offices. The first is Industrial Efficiency and Decarbonization, and the second is Advanced Materials and Manufacturing. IEDO is focused on industrial decarbonization, so thermal storage, the application of thermal storage will be really important in that office. Advanced Materials and Manufacturing, manufacturing of clean energy technologies, including storage. So that’s where the work on alternative battery chemistries, flow batteries, et cetera, will be housed. And I think that’s my last slide. Thanks.

MARK WILLEY: Great, thanks Diana. So I didn’t mentioned actually, so we’re going to have the two DOE speakers and then the industry speakers actually are going to focus on two different sections. And one section is going to be on manufacturing and that’ll be Billy Woodford from FORM Energy, and then Eric Gratz is going to focus on supply chains and he’s from Ascend Elements.

The other thing I wanted to mention, and I forgot to say this initially, which is that we’re going to have a breakout session after, I think it’s in about two hours now where we talk about manufacturing challenges. And during that section is really when you can ask the questions and try to pull out from the different industry folks what they’re having issues with or what they’d like from either DOE support, or just in general.

So during this session we’re not going to actually have any questions like the last session. So without further ado, our next speaker is Steven Boyd. He’s from the Manufacturing and Energy Supply Chains Office. As a program manager for DOE’s newly established Office of Manufacturing and Energy Supply Chains, Steven manages federal staff and resources to strengthen and secure the manufacturing of energy supply chains needed to modernize the nation’s energy infrastructure and support a clean and equitable energy transition. Specifically, he is focused on addressing the supply chain for large capacity batteries. This includes establishing domestic production and processing of capabilities for critical materials and guiding investment in battery recycle and materials. Let’s give a round of applause for Steven.

STEVEN BOYD: Right, thanks Mark. Hi, everyone. Let’s get into some slides here. I’m going to talk a little bit about manufacturing energy supply chains and sort of where this office came from, where we sit in DOE and try to orient folks, because I know it’s a little bit new. I’ve gotten a number of questions from people. Okay, go ahead and go to the next slide, please. So this is where things started for us. These are supply chain reports from a number of different sectors, fourteen specifically, that were directed through an Executive Order.

And this is really kind of a bit of a lay of the land in terms of where we see some needs for the domestic supply chains and how this is going to be strategic for DOE. It doesn’t necessarily mean we’re coming out of the gate swinging on all of these kind of things, but I think this helps to establish some of the scope and some of the, I think, needs that the DOE is trying to address with this sort of work in supporting America’s supply chain. Let’s go ahead and go to the next slide, please.

And so kind of in reaction to this, and as part of this process, DOE specifically decided to optimize the structure and make some of these changes we’re going to talk about here to address our energy supply needs and the domestic capabilities and trying to establish those that are going to help support this energy economy and transformation that we’re talking about here.

So you see the Secretary’s quote there. And then there at the bottom that’s what I’m here to talk about here, the Office of Manufacturing and Energy Supply Chains, securing the energy industrial base supported by clean, resilient, domestic supply chain. So I realize this is an eye chart, so I just kind of pulled out with highlights the two important parts of what I’m trying to say here.

So under the Secretary, you see we had, so just on the left here, S4, we heard from Dr. Richmond, her remarks this morning, that’s the Under Secretary for Science and Innovation. So that’s kind of the typical R&D that you all are probably familiar with and maybe are most accustomed to in DOE. Research and Development focus, and that includes EERE and all the technology offices, including like Vehicle Technologies Office, where I come from, or AMO, that Diana just spoke about, as well as the Office of Electricity and the Office of Science. Probably heard from John and Linda this morning, right? So that’s where all those folks are.

And then on the right here you have the Under Secretary for Demonstration and Development. And so that is including some of these newer areas, including myself, Manufacturing Energy Supply Chains, as well as offices like the Office of Clean Energy Deployment and the Loan Program Office. Okay, so that’s how we fit into the bigger picture of DOE. Actually, different Under Secretaries for these offices. Next slide, please?

So this is a number of different descriptive bullets that I’m not going to read for you. But the idea here is that we’re really focused on the energy infrastructure and strengthening supply chains for energy, including an equitable energy transition. So this is catalyzing some of the developments that we know need to happen. Engaging with companies, agencies and stakeholders. Developing clean manufacturing and domestic workforce, right? A lot of the themes that we’ve touched on today. And this is sort of the holistic view of what we can do with our energy economy. Let’s keep going. Trying to keep us on time here. But I did want to kind of tee this up a bit in terms of what we’re describing here.

And so specifically for the Office of Manufacturing and Energy Supply Chains, I wanted to highlight these three different areas that I think are going to be critical and important to us and immediately lay out some of the different actions and programs that we’re going to be implementing in the near term here. The first of those is facility and workforce assistance. So there’s a number of programs there, many of these that do come from the Bipartisan Infrastructure Law, but not necessarily all of them.

You can read about these that are there, but we’ll go ahead and move on to the battery and critical materials. And that’s where I’m housed for now. And in particular, that’s all the different sections that were described in Bill 40207(b) and (c) which is $6 billion dollars and it’s really focused on the establishment of a vertical supply chain for battery manufacturing in the U.S. Some of that we have now, like things like cell manufacturing. There’s been a lot of announcements around that.

Some of the parts and pieces are a little bit less or even maybe not done here domestically at all. And so that’s definitely something that we want to change, that we want to affect, as well as the different project I mentioned here, the Rare Earth Element Demo Facility. This is the demonstration of different rare earth element separation technologies.

And then lastly there, Energy Sector Industrial Base. This is right now I’m highlighting the transformer and EPS rebates, but generally the idea that we’re going to be looking at national and regional energy supply chains, looking at issues and strategies and really doing a deep dive here on what that means. It’s very core to a lot of the reasoning behind this office. Next slide?

This is a quick one, but I did want to leave it in here, which is in my part of MESC [phonetic], batteries and critical materials, a lot of the actions we’re taking and many of the plans we have set in place are really grounded in some pretty large documents, including the Executive Order for Supply Chains, that I first mentioned. As well as this one, which is a little bit more digestible, and a pretty easy read.

And so if you’re interested in batteries, as many of you are here I would think at the Energy Storage Grand Challenge Summit, this is a great document to kind of pick up. There’s five key goals there. This is from the Federal Consortium for Advanced Batteries, which is an across the government group that we lead at DOE that is focused on kind of all these areas that are going to support energy storage and batteries, lithium batteries, specifically. Okay, next slide, one more.

I did want to include a slide on Inflation Reduction Act. There’s a bunch of stuff in the IRA. It’s almost like another round of bill, really. There’s a lot of really important actions that DOE is going to take that sort of further support supply chains and the idea of this energy economy and guiding some of these other investments that you see are mentioned here. Including things that are important to us in clean energy and batteries, like advanced manufacturing tax credits and more investments in electric vehicles and some of these other things. And I’m just highlighting a few of them here. And I can’t say that all of these necessarily will be done or implemented in or through MESC, but I know we’re looking at some of those and so I wanted to call attention to that as well. Okay, I think that’s the end of my slides there. Thank you so much for your attention. I hope that this was helpful. Happy to talk individually with anyone as well as we get you to the workshop. Thank you.

MARK WILLEY: Thank you, Steven. So this next section is really where we step into the actual companies operating in the space and understanding the challenge of manufacturing and supply chains. The first speaker is William Woodford who told me I could call him Billy, I guess if everybody else can. So Billy’s going to come out and talk about his company.

I did want to acknowledge two things that are going on that have already been discussed, I think, at least partly today which is the other kind of large organizations or discussions going on with manufacturing and supply chains. And one is that is the Li Bridge, and I believe Venkat mentioned that this morning. It’s been really interesting to be a part of that and see all the companies comping together to try and support the ramp of this manufacturing in the U.S. The other one, we’ve got Jim Greenberger from NAATBatt here.

I know when I was on the, again I’m on the private side, and looking for help to understand how to ramp manufacturing, the NAATBatt organization was a great place for midsized companies to come in and really talk to other companies in the U.S. and understand how to communicate, and how to bring out partnerships and that kind of stuff. I think it’s a great organization. Again coming from the semi side, the semi side was not as I would say friendly when I was there. So I just wanted to say those two things.

Okay, so let’s bring up Billy. So, Billy Woodford is a Co-Founder and CTO of Form Energy. His career has focused on developing robust low cost energy storage systems based on electrochemical platforms, both in the academic and startup roles. Prior to Form Energy, Billy was Director of Advanced R&D at 24M Technologies where his team focused on low cost automotive and grid storage lithium ion development. Okay, let’s give a round of applause for Billy.

BILLY WOODFORD: Hi, I’m Billy Woodford, Co-Founder and CTO at Form Energy. It’s a great pleasure and an honor to be here. So thank you to the organizers for invitation. As I’ll sort of mention as I step through here, Form Energy, we had some deep roots in J CESAR [phonetic] and at Argonne. And so it’s almost ten years ago, I think nine and a half, that I was here for the J CESAR kickoff, and thinking about what kinds of electrochemical couples could be used for that very low cost storage.

So, I know this is a manufacturing and supply chain focused session. Most of my comments today are really directed at how did we go through the technology selection phase, so as we thought about tackling this challenge of multiday storage. And in our problem statement five years ago when we founded Form Energy is very aligned to the long duration storage shot. How do you reduce the fully installed cost of grid scale energy storage by a factor of ten and what was the thought process that we went through? What were some of the requirements and selection criteria that we used? And I think there are still some green shoots.

You know of course we have selected a technology and we’re well on our way to productizing and manufacturing that, but there are other areas that I think are ripe for exploration. And I think are some opportunities where the national labs in the DOE system can really toward some of these problems to find other shots on goal for multiday storage. So, why don’t we get into it? And next slide, please.

So Form Energy, we’ll introduce the company a bit. Today we’re a team of over 300 people in three sites in the U.S. We started the effort in the Boston area, that’s where I live, in Somerville, Massachusetts. That’s where we really focus on our electrochemistry and materials R&D. We have a site in Berkeley, California where we’re working on the system design engineering of our battery module and power plant, and then in the Pittsburgh, Pennsylvania area we have pilot manufacturing. And so we operate in three sites and everybody’s really focused on this mission of enabling a new kind of energy storage and multiday storage. If you’ll go to the next slide, please.

We started as a team of five founders and we’ve pulled together a great leadership team with a lot of experience in the energy industry, in utilities, developing utility scale products, also on the policy side. So really a really strong group all the way around. Next slide, please.

We’ve also brought in a number of long term patient investors, folks who are really committed to seeing through this mission and to enabling a new class of grid asset. So of course many thanks to those who have supported us along the way. Next slide, please.

The challenge as we saw it, and five years ago and this has of course sharpened over those five years, is really, how do you enable the renewable grid of the future to have the kind of resiliency and reliability that we demand from our grid system? And I heard earlier in the day some comments about utilities being risk averse and not willing to take risks on serial number one. Utilities are risk averse because we as a society place tremendous pressure on them to be risk averse. We demand this incredible reliability from them.

And so what we really wanted to do was to partner with those utilities and to think through what was the kind of storage product that would allow us, in my very simple framing of this, to have our cake and eat it too, to have low coast renewables with resiliency and reliability? And fundamentally what’s required is a new kind of storage, something that really bridges multiple days of duration.

Lithium ion, it does what it does very well, and what it does very well is to cycle once a day every day. And so, maybe a very simplified thesis that we have is that lithium ion can eat and likely will eat everything that happens inside the single day. And so the white space as we saw it was, well how do you go beyond a day? Anything from 24 hours to a season was the white space that we initially sort of set out to tackle. And the first step in that was to narrow that down to a precise first product, so with a specific duration, and then to select a technology.

And so we actually didn’t start from a specific technology. We didn’t start the company as an iron air battery company; we started the company as a multiday storage company, and then spent a year and a half in a technology selection phase and with this as our problem statement. This is really what we wanted to go after, was developing a new kind of storage, grid scale storage, from the meter storage, that would enable reliability and resiliency in the utility sector. Next slide, please.

And so the one step further thought exercise is what’s the kind of battery that enables you to replace the high capacity factor natural gas in the system? Not just how do you go replace the peaker plants, but how do you replace the 30 to 50 percent capacity factor natural gas assets? Those are what’s provide flexibility into the system today and so that was the bogey.

This is actually a slide from some of the early pitch decks, the early kind of high level company overview decks. I’ll explain the plot that is on the right hand of the slide. The axis here are a fully installed cost. So this is of a grid connected system in dollars per kilowatt hour. That’s on a log scale. And on the X axis, on the horizontal axis is duration. And so duration, again, is run time. So it’s an energy to power ration of the system. And there are a couple of different datasets that are shown on here.

The first is lithium ion, and those are the flat lines that cut across. And some drawn both at the time currently lithium ion pricing, so it shows $300 dollars a kilowatt hour. Today it’s probably closer to $200 dollars a kilowatt hour, maybe $230 or so for grid connected systems. So this is inclusive of a landed system.

This is not a cell cost, this is not a module cost. This is a have a medium voltage, inter-connected system. You know, our view is lithium ion, future state lithium ion, you can get that down to $100 dollars a kilowatt hour. Maybe you can get a little bit below that, but that is an aggressive future state lithium ion cost.

The sort of purplish data points are pumped hydro. So pumped hydro is really the existence proof of long duration storage. And those are data points that my co-founder, Yet-Ming Chiang pulled, so those are the historical costs of installed pump hydro systems in the U.S. inflation adjusted to 2017 dollars. So yet went back and found all of the public records that stated what it cost to install pump hydro systems all around the U.S. and inflation adjusted those.

And you see that plotted versus duration has this sort of one over duration cost dependency. And that’s indicative of the de-coupling of power and energy. This is why there is interest in flow battery architecture, to de-couple that and pay for expensive power systems that de-couple the energy cost. And the slope is, this asymptote at very low cost because the cost of the asymptote is the cost of water. And so it’s water plus the cost of the concrete to build the tank.

And so the yellow bar here or the yellow box was drawn before we had a technology selected, but saying really what is the landings on that we need to end up in in order to be successful? You have to extend out to where pump hydro would get to. And if you go to the next slide please.

Another way of framing this, and this is a little bit further on – and I apologize for some of the formatting challenges with this. The vertical axis here is now a power cost. So it’s an all-in cost still, but now represented as dollars per kilowatt instead of dollars per kilowatt hour. And again, duration is the axis. And now you’ll see a couple of things. One is the cost will go up with duration, rather than down and that’s just because we’ve changed the unit of measure to power measure.

The intercept is the cost roughly of your power components and the slope of any one of these technologies is the marginal cost of energy. The marginal cost of adding my energy storing media, plus the tank that I need to put it in. And I’ll start with, you know, there’s a band that goes basically horizontally, which is pumped hydro, and that’s really the costs of the existing pumped hydro assets. New go [phonetic] pumped hydro would be more expensive than that, because we built mostly the good sites. We preferentially selected those.

Lithium ion, you know, the power costs are very low, but the slope is very high. That’s the cost of active materials, which is measured in tens of dollars per kilowatt hour to add marginal hour. I need to add a marginal kilowatt hour. Another technology that’s instructive to compare here, so of course we’ve drawn on the iron air cost structure, and iron air is interesting we think for 100 hours because you get below this threshold cost of $2,000 dollars a kilowatt, or $20 dollars a kilowatt hour.

By comparison, zinc air, and now already this gets to some of what I was hoping to share today is, it’s not just the cost of the active material; it’s also the cost of the tank that you need to put it in. And zinc has many advantages. Zinc air is, it’s a very interesting technology for many applications. But as you scale to multiple days’ duration the energy and density actually becomes challenging. If you compare iron air to zinc air, in the iron air system the charge and discharge products are both solids.

And so the energy density is relatively high for an aqueous system. Whereas in zinc air, the discharge product is soluble. The zincate is stored in solution and so the energy density is lower. And the cost of storage, of just storing my electrolyte, becomes a significant addition to the marginal hour, the cost of a marginal hour. And so that’s why the slope of zinc air is much higher. I’ll step through a little bit more of that, but that’s one example. If you’ll go to the next slide, please.

These were the selection criteria that we used and this was before we’d selected iron air. It’s really thinking about, if you’re looking for true multiday storage, you need a different set of selection criteria than you would use to pick a daily cycling lithium ion cell. I’ll pick cycles. Number of cycles that you need for multiday storage is very different than what you need to do managing the duck curve or moving a solar peak within a single day.

If you look at lithium ion duty cycle, again that’s a cycle a day every day. To take a limiting example of seasonal storage, and we didn’t end up choosing seasonal storage, but if you look at seasonal storage, what do you need? You need two cycles a year. You don’t need tens of thousands of cycles a lifetime. And so when you’re back at the chemistry selection phase you don’t need to select for something that can do 4,000 cycles or 5,000 cycles; you need to select for something that can do a few hundred cycles. And of course there’s a sliding scale.

As you move away from seasonal storage and back toward sort of days or weeks of storage, it’s a different number of cycles, but it is a different number of cycles than you need for the daily cycling application. So for a hundred hour application that ends up being about a dozen cycles a year, so that was just to give you some sense of a third data point on that line.

A second of course is charge to discharge rate. And you don’t need 1c1c [phonetic] cycling to do a 100 hour application or a 24 hour application or a 1,000 hour application, but it does also really change how you think about the cost. And so you do need to cost that out as sizing for the power that you need. A third of course is density, and I already touched on that a little bit.

This is an early slide and so there are some pieces of this which we set out really to think about could you have a storage system design that was different than lithium ion systems, where you really have this built like infrastructure. And I spent a lot of time looking into the way that we design, build, construct water treatment facilities. I will say we didn’t fully reach that aspiration.

What we ended up selecting is something that has a modular scalable manufactured component that looks more like a lithium ion system. But I do think there are still some fertile ground in that, of really thinking through how do you build energy storage as infrastructure projects? Things that look like pumped hydro and are constructed like pumped hydro, rather than like manufacturing a battery cell, manufacturing a module, manufacturing an enclosure, and field-deploying that.

If you’re going to go down the modular enclosure system, the energy density really does matter. You do have to pay for a lot of boxes to put stuff in and so the amount of energy you get into that box really matters a lot to your final cost structure.

And then last, of course, is scalability, and we really thought about that as, let’s not pick something that doesn’t have an entitlement to scale. And Venkat, in some of your opening remarks you remarked on this. This is a terawatt scale problem; it’s a terawatt hour scale problem. And so we spent a lot of it me digging into the mineral commodity summaries. And as we were evaluating battery chemistry, is really saying, you know, things that might look interesting on a cost basis but which don’t have an entitlement to scale.

You know, if you’re going to go build a 100 megawatt energy storage project, and you need a few percent of the world’s supply of something, you should not even consider scaling that thing up. And yeah, I don’t have necessarily more detail on that to share publically, but there is a lot of effort put into that and I think there is some straightforward metrics that can be developed around that. Next slide, please.

This is, this is in the early days, this was in the pre-J CESAR days. This was my map that I’d constructed of taking the periodic table. And there’s many of these that are available, but this is taking the periodic table, scaling by the crustal abundance of the various elements. Oxygen is artificially pinned down. If you let oxygen takes its full size it sucks all the oxygen out of the periodic table. So that’s constrained artificially by two orders of magnitude relative to what it should be.

But already you can just, as an eye chart if you can’t read something on this you don’t need to spend a lot of time thinking about it from this technology selection perspective. And you can see there are some other things, than iron. And this is maybe one of the points I will get to, is, aluminum and silicon are very interesting. I think that there’s reversibility challenges with many aluminum and silicon issues. But I think those are worthy problems of attention and of effort. And I think that there is some really strong fundamental science with clear application and clear applicability that can be done around aluminum and silicon based systems. Next slide, please?

This is, further eye chart. You know, I’m going to skip the eye charts. This is some of the work that was done during J CESAR. It’s a map of all the chemistries. This is actually, this is published. That is in the Aqueous Sulfur Air Breathing Battery paper that Yet-Ming Chiang and others in MIT and with J CESAR has published. You can find that one outside of these slides.

The point is there are very few things that get to below a few dollars a kilowatt hour of cost to chemistry, if you look at the known electric chemical couples. And so the ones that we know of, the ones that exist by sort of the combinations and permutations in the periodic table, really are the set that we can select from. You have to be just a couple of dollars a kilowatt hour chemistry cost. And you go to the next slide please, this will make the point why.

The cost of chemistry is just one piece of this. You have to really think through what is the cost of a fully deployed system. And if I’m going to work within aqueous chemistry at a low voltage. And so I can’t make the selection just based on the chemistry and materials; I have to cost that out. What are the extra costs I’m going to have to pay for power electronics, for a DCDC converter, to use an aqueous chemistry.

So when we did our selection, it was out at the plant level. How do I make a bi-directional power plant and we selected iron air for that. That is, I think I’m out of time. So maybe this is a good stopping point. I think I’ve made my main point, which is that we selected iron air, but this set of considerations, and really thinking about what are chemistries that have an entitlement to scale, and then how to think through the fundamental science and chemistry challenges that are associated to those.

So aluminum air, silicon air, can we make those systems actually have a little bit of a reversibility and have them be enabled to solve some of these long duration storage challenges I think are interesting green shoots for further development. Thanks, everybody.

MARK WILLEY: All right, he got you guys to laugh a little bit, so that’s good, I think. So our next talk is going to be on, from Ascend Elements, from Eric Gratz. And before he talks, just quickly, one thing that’s really interesting about this ramp again in manufacturing for the batteries and energy storage in the U.S. is this thought of circular supply chains. I forgot, this morning the lady was talking about these things we didn’t think about 20 years ago. I mean, would you have thought that recycling would be at the beginning of this whole ramp in manufacturing 30 years ago? I think not.

So Eric Gratz from Ascend Elements. He’s the CTO at the company, which is a battery recycling and engineered materials company. He worked closely with Professor Wong at the Worcester Polytech Institute. Eric helped to develop the innovative battery recycling technology that has grown into Ascend Elements. The technology, now known as the hydro to cathode direct precursor synthesis process is the world’s most efficient way to recycle lithium ion batteries and manufacture sustainable cathode active materials for new electric vehicle batteries. Okay, let’s all give him a round of applause.

ERIC GRATZ: Thanks for having me. So I’m excited to be here at the Energy Storage Grand Challenge Summit. And I’ll talk a little bit about recycling, but primarily I’m going to talk about supply chains. I think it’s hot in the news. So next slide? I’d like to start with we were winning. So DOE set the goal of $100 dollars of a kilowatt hour and we were, for EVs, we were marching towards that. S

So when I first heard that, we were over $1,000 dollars a kilowatt hour, so it was the long shot. Tesla was at about $137 dollars a kilowatt hour in 2020, and there are more wins on the way. More energy dense electrodes, dry coding, et cetera. According to NREL, four hour energy storage roughly follows the cost reductions in EVs, just delayed by a few years. So things were looking good. Next slide.

And then supply chain crunch. And so now if you can buy your sub-$200 dollar kilowatt hour battery, good on you. Next slide. So, fundamentally why? The reason for this is it takes us four years to build a gigafactory, and right now in North America and most of the world, ten years to build a mine. And so we have a supply chain crunch from the car, but it goes all the way back to the supply chain. Next slide.

So how do we solve this? We need technologies that break the current materials paradigm. And so my opinion on this is new lithium streams. The biggest cost limiter in lithium ion right now is the price of lithium is $78 dollars a kg today. So that affects LP, it affects NMC, whatever chemistry you’re using. And we also need new methods of processing. And then finally for North America we need environmentally friendly processing methods. Next slide.

So we do have a global supply chain for the raw materials. But, go to the next slide and I’ll dwell on that. Refining happens in China. So over 90 percent of the nickel, cobalt, and lithium refining is happening in China. Conversion to cathode may happen in Korea, maybe in North America, it’s coming online in Europe, et cetera, but the raw materials refining is happening in China.

This is a handy little chart that maybe is hard for you all to see, but it’s from Bloomberg and it ranks where everyone is. So it gives the U.S. a total score of 6 for lithium ion. What I think is interesting is we’re currently 13th for environmental, and 15th for raw materials. But by 2025 they have us going to, wait, sorry - 7th for the environmental. So we’re making significant gains there as we learn more about these materials and how to process them. But we make basically no upgrade in the raw materials supply chain. We go up two spots. We’re slowly falling behind the rest of the world.

All right. So how do we do this? As I said, new sources of lithium, but also develop new methods to purify industrial and technical grade lithium into battery grade. And since I’m giving my message to the DOE, these are two independent things. I see many, many grant opportunities to make battery grade lithium and there’s a lot of technologies out there on the market to make battery grade lithium.

Sometimes there’s a business case to make a lithium sulfate, lithium chloride, et cetera and you can use different technologies. So what we’re really trying to do is develop a lithium supply chain. And this, from a recycling, perspective maybe goes to part of why I would say this. So this is the flowchart for a Chinese lithium recycler, lithium ion battery recycler. This is just the flowchart for the lithium recovery to make battery grade lithium. So you can think of the scale that you would need in order to make that work. Next slide.

So when we look at lithium, the biggest opportunity I see, and there’s others, but the one that we’re, it doesn’t appear to be actively going after with a lot of gusto, I thank the DOE for the geothermal lithium prize or challenge. So that was well received. But we’re falling behind Europe. Europe will have geothermal lithium production by mid-2020s, and in North America we can read articles about it. It’s a huge opportunity for us.

In terms of recovering lithium, there’s been a lot of press and investment into direct lithium extraction. This, in my view, is very exciting. It can drastically reduce the times to bring on new lithium purification plants. One thing that I don’t think gets enough traction or talked about, is talked about enough, is if it can handle sodium. So if we’re just procession brines maybe it’s not the biggest problem or issue. But when you’re looking at technologies that can rapidly scale for multiple streams, the ability to process sodium is a huge win. So, some of these can do this and other ones need a little bit more work. All right, next slide.

And then finally to my third point, environmentally friendly methods to process materials. I think it’s fairly obvious, but technologies that work in Asia aren’t going to work in North America. We see zero precursor production from Asian companies in North America. Yuma Corp [phonetic] is doing precursor production here, but none of the Asian players have come to North America to make pCAM.

The primary reason for this is the sodium sulfate production from the pCAM. There’s also, depending on your source, sodium sulfate from lithium. So that needs to be addressed. Exactly, we’re seeing cathode is coming but not precursor to exactly why I just said, environmental concerns. Next slide.

And so the biggest issue with precursor is permitting and environmental risk, and then finally related to those is cost, but it all goes to the sodium sulfate. So in Asia they admit it into the ocean. Here in North America, we have challenges with desalination plants and salty water that they produce. So just pumping sodium sulfate into the ocean may be allowed in some locations in North America now, but it’ll definitely be brought up by environmental groups in the future, so it’s a thing we need to reduce or eliminate.

But if you’re going to talk about precursor, you have to talk about what the output product is. So current winning CAM technologies, lithium iron phosphate, especially for energy storage, lithium space, low cost, long cycle life, makes sense. Mid nickel single crystal materials, so that’s 67 percent of the market right now. And then high nickel, the core shell and gradient technologies that require a lot of article engineering are taking about 70 percent of the market.

So what we can do to invest in and make these, solve these supply chain challenges? It’s very low cost LFP processes. Costs for LFP in China are very, very low, so there’s a lot of challenge for us to compete on that. Single crystal CAM, there’s possibilities for one pot synthesis, whether it’s direct from metal. There’s a few different things out there. Those are potentially very interesting.

And then for high nickel, we’re really looking at technologies that can reduce the sodium sulfate production from the precursor. Can have a lot of challenges to make the gradients and the core shells that the battery manufacturers are requiring in one pot synthesis.

All right, so a quick transition from my opinions. At Ascend Elements, we have the hydro to cathode process. We can do the solvent extraction, so we can make the cobalt sulfate, nickel sulfate, manganese sulfate from spent lithium ion batteries. But our core technology, where we have the IP around, is instead of removing the individual metals, is removing the impurities and then co-precipitating the NMC hydroxide precursors and converting those to cathode materials. Next slide?

So recycling is a solution that can address some of the supply chain challenges, but today if we recycled every available battery out there and put it back in the supply chain, it’s about 15 percent of the market. So we need other. Part of the problem, but no one thing is going to solve everything. One of the big advantages we see to the hydro to cathode processes is it produces 3.5 times lower the sodium sulfate versus if we do solvent extraction and then take those nickel cobalt manganese sulfates and convert them to pCAM. Cathode material performs as well as virgin material. So this is a paper in Joule. You can read it. Next slide?

This slide here shows the performance of an NMC111 getting 5,000 cycles. We’re actually getting essentially the same performance from our 532 single crystal material. So I think that’s actually very interesting for energy storage. One of the challenges we have for energy storage is that you’re still using primarily the batteries that are being used in the EV. So as the EV goes to very high nickel material, becomes actually a little bit less attractive for energy storage. Where if you’re not going to use LFP, you would use like a single crystal 532 material. Next slide?

Recently we’ve announced our Apex 1 Facility in Hopkinsville, Kentucky. So that will convert spent batteries into cathode materials for new vehicles. Those cathode materials could power up to 250,000 EVs per year. Next slide? And this slide shows our other sites. So currently in Georgia we have our base site where we have shredding and solvent extraction to make the metal salts. That site can handle 30,000 tons of batteries.

One interesting thing about both the Covington in Georgia site and our Apex site is the selection process. So the workforce actually was part of our selection process. We wanted to make sure that we would able to get the right kind of skilled workers in both locations before finalizing on those sites. And that’s part of the reason why we see a lot of EV manufacturing and battery companies going to the southeast is there’s a strong skill sets in those regions that are transferable.

In Covington, Georgia, we have a diverse group of skill sets from high level engineers to people who are shredding batteries. But they’re all really excited to be part of the energy transition, and so we’re really thankful to have them, and thankful that you guys had me here today.

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