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BATTERY TECHNOLOGY FOR TRANSPORTATION:

FROM SCIENTIFIC DISCOVERY TO MARKETPLACE

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PARTICIPANTS:

Welcome and Introductory Remarks:

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P R O C E E D I N G S

MR. EBINGER: Good morning, ladies and gentlemen. Delighted to have you all here on this chilly morning. I'm Charlie Ebinger, the director of the Energy Security Initiative at Brookings, and on behalf of myself and my colleagues and our friends at Argonne National Laboratory who made this event possible, we are delighted to have you all here.

Before proceeding, I would like to give special mention and thanks to my colleague, John Banks at Brookings, who was the person that made the outreach to most of the speakers and your assistants and associates. And we also want to thank all of them for their timely response to getting all the participants to agree to come with us today. I think we have a stellar lineup here, and I'm sure we'll have a lot of interesting discussion.

I think this is a great time for such a discussion, because battery technologies are kind of in the forefront of not only our domestic but also international policy debate on the future of transportation and storage and a whole host for electricity and a whole host of other topics.

I just came back from a very interesting conference, predominantly -- interestingly -- a petroleum conference in Norway with the leading international oil and gas companies, and the hottest topic on the agenda was indeed the future of transportation fuels and particularly the role of electric vehicles in that mix.

We also of course very recently have had the announcement of the very exciting Argonne-GM relationship and the Argonne-Envia deal, which highlight the momentum that is being created in this whole sector.

And, clearly, as oil prices continue to rise and the specter -- if we have any more disastrous political events in the Middle East so they may rise still further, not only electric vehicles but all vehicles running on alternative fuels are certainly getting more and more both domestic and international attention.

And it also speaks to a much wider issue of the whole competitiveness of the United States in the future world market, and clearly we want to be a leader in the electric vehicle technology area and not see one more industry slip from our grasp and taken over by foreign competitors.

And finally, in recent months there's been more and more talk and discussion about the so-called space race for the best advanced electric vehicle battery, a race that is now involving a number of countries, including, obviously, our own, Japan, South Korea, China, to name only a few.

We have two great speakers this morning to kick us off before our broader panel discussion, and the format we will pursue is that Dr. Isaacs will commence his address. That will be followed, before questions and answers, by Dr. Sandalow, and then we will move into broad questions for both speakers from the floor.

I'm not going to take a lot of time to introduce the speakers since you have their bios in your program, but just very briefly let me say that we are delighted to have Dr. Isaacs here today who, as you all know, has served as director of the Argonne National Laboratory and president of the University of Chicago, Argonne LLC, for the last seven and a half years. Before become Argonne's director, he was the deputy director for Programs. His responsibilities there included leading the laboratory's strategic planning process and overseeing the laboratory directed research and development program. He has also been director for Nanoscale Materials at Argonne and was a professor of physics in the University of Chicago's James Frank Institute. And finally, for 13 years he was a member of the technical staff at the Bell Laboratories as Director of the Minerals Physics Research Department and as Director of the Semiconductors

Physics Department. He is a graduate of MIT, and we are delighted to have him here with us today.

Dr. Isaacs.

DR. ISAACS: Thank you, Charles, for setting up this important event and inviting me and the panelists to speak here.

So, in 2006 there was a documentary -- probably many of you saw it -- called *Who Killed the Electric Car?* It claimed to prove conclusively that the electric car had been effectively scuttled by an unholy cartel, including government, including big, bad business, and including our own SUV-loving public. The award-winning documentary featured even a mock funeral for the famous GM EV1, which many of you may remember.

The real -- the point of it was that there was a hard-hitting, very acerbic, very, you know, informational type of movie that American industry would actually never allow the electric vehicle onto the roads. Too much concern with combustion engines, too much concern with the way things were. And today, just five years later -- that's five years ago -- GM Chevy Volt this year is going to roll off -- it's already rolling off the assembly line. *Motor Trend* called this automobile the 2011 Car of the Year and "a car of the future you can drive today." So, other carmakers, too, are getting into the businesses, as you know. Mitsubishi, Nissan, Ford are all trying to get their electric vehicles onto the road today in America.

So, very rapid turnaround and consumers are responding enthusiastically, so much so that the same filmmakers have to go back and remake that movie, and they now have a new movie coming out called *The Revenge of the Electric Car*. (Laughter)

What we're here to talk about today really is the development of a practical lab of real electric cars, which has extraordinary implications for our global environment and for our nation's energy security. A fully electrified U.S. transportation system -- cars and light trucks -- not heavy trucks but just cars and light trucks -- could cut American oil consumption by a third. That's equivalent to about 7 million milk barrels of oil a day -- it's tremendous; it's a third of our petroleum consumption -- and in addition reduce our well-to-wheels carbon footprint by 25 percent. So, those are really remarkable numbers to think about, which really is the reason why we're thinking about electrification of our transportation system.

Equally important, the electric car is the advanced battery system that powers it. It really holds in many ways -- and I'll talk a little bit about this in the next half hour -- ways of helping us revitalize our manufacturing sector in the U.S. and position us to be global leaders for decades to come. A new high-tech -- a new, very fundamentally high-tech device that could help us drive the economy.

To give you an idea of how far we've come and how fast, in 2005, a leading consultant for the battery industry published a research paper that asked the question, "Why are there are no volume lithium-ion battery manufacturers in the U.S.?" And there were none as of 2005. Today the U.S. is in the forefront of international lithium-ion battery research and new battery manufacturing plants opening up across the nation. You'll hear more about this with the panel, as some of the panelists are actually involved in that manufacturing.

Thanks to the stimulus program, which included almost $2-1/2 billion for manufacturing facilities for batteries, it really spurred, not only for batteries but for electric vehicles, more than a half-dozen -- some project even a dozen in the next couple years advanced battery manufacturing plants will open up or be near completion within the next few years.

The White House predicts -- and we heard this in the President's speech last week --- predicts that by 2015 the U.S. will boast 40 percent of the world's battery-making capacity for vehicles. That's an important distinction, but 40 percent. That's a remarkable change from 0 to 40 percent.

Already advanced battery manufacturing is helping to put thousands of Americans to work. Just last Friday, for example, Mitsubishi announced that in Illinois its expanding operations. It had an ailing plant in Illinois. It was ready to shut it down. Instead, they're going to revamp that plant and start creating electric vehicles, in particular batteries. The State of Illinois is contributing to it. This is coming at some cost to taxpayers but worthwhile. As part of -- the State of Illinois will help Mitsubishi expand the plant; and in exchange, Mitsubishi has committed locally to provide over a thousand automobiles in the next three years just in local communities. So, there are these deals being made as a public-private partnership being established.

At the same time -- and an interesting piece of it is that at the same time Eaton Corporation, which is an Illinois manufacturer -- I'm from Illinois -- is working with local officials in Normal, Illinois, to develop a citywide charging network to host those cars, to allow those cars to actually go from work back to home and back to work again. And those charging stations will be made here in the U.S. by a U.S. company in Lincoln, Illinois. All important points. And almost every day we hear similar stories, so they're going on and on, and I could go on and on.

Let me give you one more. Last Wednesday, San Francisco Bay area air quality management district awarded about $4 million to four companies to install charging stations in homes and public places around the Northern California area.

Private investors are also seeing the commercial promise of these new advanced batteries, and we'll hear some more about this later today from private investors. The National Venture Capital Association reports that in 2005 battery-related startups drew about $51 million in venture investment. Fifty-one million. And last year that investment jumped to 205 million. So, that's a surefire sign that also this economy, this piece of the economy, is really starting to take hold. Over the past 5 years, in fact, battery companies have drawn almost 775 million in venture capital.

So, for those of you in the IT business, okay, it's not a huge amount, but for those of us in the electric business, electric cars and batteries, it's a huge start, and one can imagine it's growing dramatically as we start matching the federal investment in the same.

So, these investments are also creating jobs in the U.S. It's not just about generating money for companies; it's about creating jobs and I'll talk a little bit more about this in a few minutes in an example with GM. GM in fact -- the Center for Automotive Research reports that GM is seeking to hire a thousand engineers to start really ramping up their electrical vehicle fleet, principally around the Volt. But also other companies. Chrysler is looking for a thousand; Ford is looking for 750. A study just done this past year. So, those are numbers. They're not the millions that we need in this country to replace the full lost job spectrum in the last few years, but they're an approach to that, and they're actually just at the very beginning.

Anthony Earley, chairman and the CEO of DTE Energy and a member of Ford's Board of Directors, predicts that electric cars and related battery development will create 40,000 new jobs in Michigan alone by 2020. So, that's a pretty impressive number, especially for a state that needs those jobs so badly.

So, these are really success stories, and part of my message today is I believe these are success stories ultimately that point back 15, 20 years ago to basic research that was done around the country. And I'll talk a bit about these. All of these innovations, all the investments that I've talked about, all of these exciting new vehicles are here because 15, 20 years ago material scientists at Deeley Labs, at universities, and Argonne, for example, started taking a closer look at lithium and chemistries and the way that these chemistries can be used to store energy. Lots of energy in a small volume.

So, everyone knows that our federal government is facing serious financial strains, that the unemployment rate is still really unacceptably high, near 10 percent -- floating around 10 percent for some period, and that many American families are still trying to recover from the recession. And so it's in times like this that some people will ask the question why are we investing tax dollars in intellectual pursuits that only a relatively small number of people -- scientists and engineers -- are pushing? Many of those people are here in this room with us today.

So, today I'd like to answer those questions in a somewhat proud fashion that I think we really are making inroads, and we can show direct proof that the kind of work we do in a lab like Argonne or a university like MIT can end up really driving not only innovation but also job creation. It's a very important fact I think.

In collaboration with peers and national labs -- it's not just Argonne alone, of course -- I represent Argonne, but there are many labs -- in collaboration with universities and private industries, our years of fundamental research have made it possible to develop safer, reliable, cathode materials and batteries that are now starting to see their way into automobiles.

The Chevy Volt, which I'll come back to again, and the Argonne-developed materials inside the GM battery that drives its wheels and its motor demonstrate that American ingenuity powered by American investment can renew our industries, create good jobs, improve our energy security, and ultimately protect our environment.

The electric vehicles, advanced batteries, the infrastructure that supports them represent a culmination of years of sustained financial investment by the federal government and by industry. In particular, I'm here to talk a little bit about the Department of Energy Investment through the Office of Science where the fundamental science gets done and through the Office of Energy Efficiency and Renewable Energy -- EERE, which many of you have heard about, which invests very much more in the applied and even in the industry applied research interface.

The work I'll describe reflects years of persistent scientific inquiry, not always leading to the final solution, not always leading to that piece of nugget that ends up being the billion-dollar idea but often other directions. But it's the persistence and the courage to stick with that kind of investment. And, most importantly, they demonstrate the extraordinary results we can achieve when federal government and laboratories and universities work in close collaboration with industry.

So, let me stress something. I'm not here today in any way to declare victory. We have a lot of work to do. A lot of work to do. But I think we're starting to see, once again, sparks of that innovation, if you will, ecology, which really allows the innovation to go from, let's say, a bench top all the way to something like a GM Volt.

I would also say we have a long road ahead. There's a lot left to do. We just succeeded in creating energy storage technologies that are starting to get out there that will challenge the internal combustion engine and make it possible to fully electrify the American transportation fleet, and we've made a great start but we're not there yet.

So, what I'd like to do is take a few minutes just to give you a story. It's an anecdotal story from Argonne, but it shows how the science and the materials and the engineering went from a laboratory finally into an automobile, because it gives sort of a sense, a flavor of what I think is the important partnership that represents the meeting here today. It represents people coming together from businesses, from engineers, and from engineers and scientists to solve some of these challenging problems.

So, let me start with this story, which started quite -- years back, in fact 40 years ago at Argonne we started very basic research in energy storage and batteries, old systems like lead acid systems -- still around but older systems that led us to do a lot of fundamental electric chemistry -- electrochemical energy storage systems.

In the mid-1990s when people started really thinking seriously about electrifying vehicles, the Office of Science and in particular Basic Energy Sciences within the Office of Science began to infund an intensive -- this is back in the early to mid-'90s -- an intensive study of lithium-ion batteries. So these are the fundamental materials that go into lithium-ion batteries, including the electrodes and the electrolytes, but mostly focused on things like electric chemical processes and electric chemical properties.

The challenge was that existing electrical energy storage materials at that time were way short of being sufficient. They could power maybe a flashlight but weren't really sufficient to put into an automobile. Not even close to being put into a high-range-type vehicle.

So, before I go on and talk more about the story, let me just remind or suggest, tell you how a battery works. And just to remind you, there are three major components to a battery. There is a cathode, there's an anode, and there's an electrolyte.

The cathode is typically a material which -- a complex material usually; it's not just a simple material. Typically it's got three or four components, three or four different kinds of atoms. And it ideally can host lots and lots of lithium -- this is for lithium-ion -- lots and lots of lithium -- and remain stable -- because materials become unstable when you try to change them too much internally -- remain stable both in the lithium-rich phase, which is the phase which a battery sits discharged, and lithium port phase after it's given up all its lithium to the anode in a charged state. So, these two -- so, that material itself -- the cathode is probably one of the most complex pieces of a battery.

Another piece is the anode. So, you have a cathode and the anode, and the other side is the anode, and the anode takes up the lithium, takes up the charge, the lithium, from the cathode upon charging. So, I charged the battery, lithium is moved from a cathode into an anode, and then sit there readily able to recycle back into the cathode as I plug my battery into something, like an automobile or a flashlight or a telephone. So, the battery then is used, and the lithiums then proceed back to the cathode from the anode.

And, finally, there's an electrolyte which sits between the two. It's a delicate balance, but it's a lot about chemistry, but in the end the lithium allows the ions to diffuse back and forth readily and rapidly between the two electrodes.

And that's basically a battery. What we'll talk about a lot today is lithium-ion, lithium battery, the cathode side because of the complexity, but also we do a lot of work on electrodes.

So, originally our research in lithium-ion and the material itself focused entirely on looking at atomic structure of materials -- understanding how these materials were made, how they were put together, and how to discover new ones. And this line of inquiry -- little plug for us -- this line of inquiry required a fully integrated use of Argonne's core capabilities. Materials discovery, really brand new materials, never seen before; advanced characterization, and I'll talk about that in a minute; and also leadership computing. And computing is another area where everyone in this room is going to see more and more impact as we go to, you know, engineering more complex systems, engineering batteries, engineering whole automobiles. You have to think a lot about how we model those systems, how we accelerate the discovery to those systems. And, just for example, not on automobiles but in airplanes -- of course Boeing now does an entire model of their jet with the idea that they'll never need wind tunnels some day, that they'll do it all on a computer. That computer is now capable of doing the same kinds of things for battery in automobiles.

So, one of the key elements -- and this is the plug for Argonne -- the key element to discovery and materials is understanding what you have and trying to tweak what you have to something which satisfies the outcome you want, whether it's high-energy storage or whether it's a material for superconductivity.

We used something called the advanced photon source, which is a source of X-rays, and those X-rays are used to cycle through lots and lots of materials and figure out which materials are most suitable. The reason we use X-rays is that they're penetrating. So, this is an important point. We can take a whole battery -- not just a chunk of material -- take a whole battery, stick it in a beam, and actually understand it -- just like you do with a dental X-ray and your teeth -- really understand that battery and make innovation happen. So, that's one of the things we do at the lab.

So, using new approaches like this, we created the lithium and manganese-rich cathode materials, and I want to emphasize manganese-rich materials -- and Jeff may mention this later on when he has his panel discussion -- Jeff Chamberlain -- really unique materials that were different from before because of the manganese-rich component that were remarkably more stable and importantly replaced previously used cobalt and nickel-rich systems.

I should also mention in passing that research on the anode size is equally interesting. I won't go into details here. We still use graphite. Very standard material. We use graphite. It works well, because lithium goes and out of graphite very well. But the future may not be graphite. So, the other thing people are looking at these days, believe it or not, is silicon. So, it's an age-old material that we use in transistors in every device. One day we may be using silicon in batteries. And so -- I should mention that the graphite which we use today was patented years ago at Bell Laboratories. I'll mention that again in a few minutes. It was patented at Bell Laboratories and ultimately developed by Sony in the '90s to use in batteries.

So, all this research, particularly on the cathode side, resulted in the issuance of an important set of patents in 2004, and that's where things change for us. We're doing basic research, and I don't want to bore you too much -- I'm a condensed matter physicist -- I won't bore you too much with the condensed matter side, but we filed some patents. Those patents actually became the core of what really propelled us to be able to interact much more with industry. And so in the mid-'90s after we had patented this portfolio of inventions, we started getting funded from a different part of DOE, the Office of Vehicle Technologies, which focuses much more on getting not only applied work done and actually taking materials to, say, sticking them into cells and batteries but actually taking those batteries and working closely with industry to understand what's scalable, what's manufacturable. And this was a lot of the work that went on again from federal funds at Argonne.

And so the morale of the story in the end is that these materials in a battery situation ended up being extraordinary. Very quickly, they're extraordinary because they can charge at higher voltage -- 4.6 volts in detail -- but because they charge at higher voltages, they also can have much higher capacity, roughly twice the capacity than previous batteries had, and so this is really the secret to what happened here.

So, additionally, I should also mention that using manganese has an appeal because it's not cobalt, and it's not nickel. Manganese is just much cheaper, and so it turns out that overall it was an important invention.

So, the point is that these cells represented a radical leap forward. They were cheaper -- I should say safer, meaning they didn't run away; there wasn't thermal runaway. And also, importantly, they were longer lasting. You could recycle them many, many more hundreds of times rather than just dozens of times.

So -- and I'll also say that this is a rare breakthrough to have both -- have all three of those things: safety, price driven by the fact that materials were cheaper, and they were longer lasting all in one, if you will, series of patents. So, it was really remarkable. It wasn't just luck; it was a lot of hard work. But I guess there's always some luck involved -- but a lot of hard work to get those things out there.

So, as the drive toward electric vehicles -- this is in the mid-'90s where we started patenting these -- and as the drive toward electric vehicles heated up in the past, even in the past several years, many years later, Argonne began to see -- we began to see substantial interest from the auto industry and the materials industries who were starting to make and think about batteries, and this culminated, as Charles just said a few minutes ago -- Charles Ebinger said a few minutes ago -- in a contract which we are very happy about, which was a licensing deal with LG Chem to make cells and make batteries ultimate went into the volt. So, that's sort of the end of the story.

Already LG Chem is building a $303 million manufacturing plant in Holland, Michigan, and the plant of course did receive stimulus funds. I'll come back to this in a little while, too. This is this federal-private partnership again or public-private partnership and is expected to create something on the order of 400 jobs.

GM has licensed the technology as well, in part for its own testing so they can build their own technology on top of ours to do product development but is also working closely with other battery manufacturers as well. Envia, which is represented here today, also has licenses to some of our materials, and in fact just last week -- I believe maybe it was two weeks ago -- GM announced that they were going to invest 7 million in Envia's efforts to develop some new batteries as well.

A whole list of other licenses I'll just mention briefly. BASF. When we think about licensing at Argonne, we think very carefully about being very broad in our way of impacting, you know, jobs and impacting the economy and impacting technology, so we generally try to be fairly agnostic in terms of licensing. We've also licensed to BASF, who has a new facility for a manganese and materials company. Many of you know, the largest materials company in the world broke ground in a new facility in Elyria, Ohio, and the new plant was awarded 25 million under the stimulus program. So, again, this federal -- this public-private partnership, which really made a big difference.

So, I want to stress that we've come a long way, but there are many scientific challenges to overcome.

And just one more bit of technology before I go on to the next part of my talk, which is, you know, what's next?

Lithium-ion is a very important technology right now. We're about a factor of 2, maybe 3 away from the ideal limit in terms of what, say, for example, the Gulf will use or the Mitsubishi's cars will use in a lithium-ion battery. But a factor of 2 doesn't get us even close to what gasoline can do. So, today we fall short by -- even if you optimize lithium-ion as best you could, it's still very important. It could still get us a 150-mile car, maybe even a 200-mile car. But it still doesn't come close to what gasoline packs in terms of energy. So, if you look at just a number, gasoline packs something like 10,000 of watt hours per kilogram, so what you really ideally want to do is take the weight of a tank of gasoline and replace by just a battery and have it be able to drive the car the same range, the same 4- or 500 miles that a current 20-gallon tank of gas can do. We're about a factor of 10 away from being able to do that today. And even if you optimize lithium-ion, we're a factor of something like 5 away.

So, whereas lithium-ion is very important for us, what's next? And, again, this points back to meeting a lot of fundamental science, a lot of fundamental technology development to get us there.

So, in an attempt to radically improve the energy density -- you may hear about some of this today -- people are thinking about new systems with new chemistries. There are quasar fuel cells, and that's one path, but one of the things people are talking a lot about for on-board energy in a car is lithium -- what's called lithium-air or, more precisely, lithium-oxygen. A step toward lithium-oxygen is something called lithium-sulfur. And ideally these systems -- just a little technology -- will use an anode made of lithium-metal and an electrolyte and then a catalytic air cathode that breathes oxygen basically that takes lithium and combines it with oxygen and makes a chemical bond. There are huge challenges in this, because you can do that once, once you bond the lithium to oxygen -- you can do that once -- but getting it back out is really hard. So there's very important catalysis in chemistry that has to be done, very basic research, but if we can do it in principal, on paper, we can have a battery that's at least 10, 20, about 10 -- maybe 5 to 10 times more energy density than we have today with lithium-ion.

So, it's the future, and it's something we're thinking about all the time, and it could create that opportunity for a real 500-mile vehicle. So, a 50-mile is important as a stepping stone. It probably won't transform the way we drive our cars today in the U.S. in particular, but a 500- or even a 400-mile, 300-mile vehicle would transform the way we do business here in this country. So, we're looking forward to doing that kind of work.

Okay, so we need to develop, of course, a lot of the basic science and an understanding behind lithium-ion, but at least at this point we believe we are facing known unknowns. So, there are tough problems, but we think they're known. Whether we can actually build a lithium-air battery, lithium-oxygen batter we don't know yet. But at least we think we know what the challenges are. We think we know what the barriers are. And they are fundamental in nature, and they're chemistry, they're material science, they're hard problems but not intractable problems. And they're problems actually that are related to many other parts of energy. For example, not to weigh in too philosophical, but the whole problem of converting sunlight to fuel, which is what plants do every day. Taking carbon dioxide, H_2O, and sunlight and making sugars and alcohols for life is a very similar problem of catalysis. How do you crack these very, very tightly bound molecules and use pieces of those molecules like hydrogen out of H_2O and the carbon and the oxygen out of CO_2? It the same kind of problem. It's a very tough problem a lot of scientists are working on. An in 15 or 20 years, maybe even 10 years, maybe there'll be eureka moment in 5 years. We can hope solve those problems.

So, I should also remind you that these are tough problems, but remember what I told you in the story about the lithium-ion battery. The research there started way back in about 12, 13 years ago. So, it took about 10, 12 years for that research and for those fundamental discoveries in manganese-rich materials -- these lithium manganese-rich materials -- to make it into an automobile. So, thinking of time scales like 10 years for research to actually make it into a usable device is not a crazy time scale to think about.

As *Foreign Policy* magazine recently noted, the future of the electric car industry belongs not to the scientists and engineers who perfect batteries we have now, like lithium-ion, but to the ones who figure out what comes next in the 2020s, in the

2030s, and beyond. So, the stakes for our national economy are really high. We have to invest now. The research from IHS Global Insight predicts that advances in battery technology will allow hybrids in electric cars to grab up to 15 percent of the world's new car sales by 2020.

So, 15 percent, what does that mean? It's a big number. At today's production rates, that's about 7-1/2 million cars. That's a lot of cars. So, depending on how you sell them for -- there was a recent article by *Foreign Policy* magazine -- assuming a cost of about 30K per car, 30,000 per car, this is about $225 billion per year. So, that's a big industry, just in electric vehicles at 15 percent of the U.S. numbers. So, that's roughly equivalent, just as a comparison from foreign policy -- roughly equivalent to Toyota's entire global sales in 2009. So, those are big numbers. So, the potential here for economic stimulus from these kinds of fundamental innovations is huge. So, there's real hope that the U.S. can make a big difference in this industry.

Another important point. I read recently a report, which is not quite released yet, but I have permission to talk about it, by Ralph Broad. Some of you may know him. He's a veteran and consultant to the battery industry and a leader in the Kentucky Argonne National Battery Manufacturing, Research, and Development Center. He did a study. He made a report where he compared the cost of manufacturing batteries in China and the U.S., and he found that the U.S. manufacturing is cost competitive, which to some people is a surprise. In fact, probably in many industries one could argue it's cost competitive, especially on the high the high-tech side. And the reason he gave is that, first of all, materials. The battery -- a large part of the cost of batteries are materials. Materials cost the same no matter where you are. If you buy them from China or you buy them from Russia or you buy them from the U.S. mining companies, it's pretty much similar. Partly also because advanced battery manufacturing is highly automated. So, if you think about the advantage China has in low-cost skilled labor, it's kind of deluded by the fact that a lot of manufacturing of things like batteries, and certainly higher tech even when you talk about chips for computers, is very much automated. So, the costs for skilled workers to run factories are roughly equivalent, according to Ralph Broad, and Chinese utility costs are twice as high as ours here in the U.S.

So, the government funding to defray some of the upfront costs -- because in the end that's what it comes down to is the cost of capital based on these other equivalent factors -- if we see some of these upfront costs like we have n the recovery money going in to battery manufacturing, we can realistically be competitive in a large and growing world market, like in batteries.

Once we had the technology to challenge the internal combustion engine. So, the idea, according to Ralph Broad, is that we are cross-competitive now. Why are we so tepid or so nervous about investing here in this country and making these things? He's kind of saying there's a myth out there and we ought to just defray that myth; it's not real.

So, where is the U.S. going to do this critical needs-driven research that I keep talking about? And of course, there are a few answers to that. Let me give one example out of the DOE recently, since I am basically a creature of the Department of Energy now. One of the answers is Department of Energy's Energy Frontier Research Centers, EFRCs. There are 46 of these, and I'll talk about them again in a minute. But the EFRCs are very interesting, because they focus on a single, very tough challenge. For example, I mentioned to you this tough challenge in lithium-air batteries on catalysis. Tough words, chemistry. But it's a real tough problem. There are EFRCs out there focused on one problem -- catalysis. At Argonne, we have something called the Center for Electrical Energy Storage, which is also focused on one problem in energy storage, which happens to be the interface between the electrode and the electrolyte. Also very important. That's where the lithium atoms pass from inside to outside the electrode, and that interface really drives a lot of the behavior of a battery. So, we have a program looking specifically at that. And it's really focused on basic materials research, basic chemistry, and developing and working these systems. We also do, by the way, at Argonne not just the fundamental science. We do cost modeling; we do diagnostics and performance testing of batteries; we do electric chemical cells and complete systems; and we also do manufacturing process engineering. But we couple that with this EFRC, which is the fundamental part which focuses on really solving a single, critical problem in the energy spectrum.

Let me stress that Argonne's research, as important as it is, because I keep talking about it, is not nearly the only thing going on out there. Deeley has a huge portfolio of energy. I mentioned they've got 46 EFRCs, but that's only a small piece of it. EERE clearly funds a lot of people in this audience to do manufacturing, scale up to do a lot of types of things out in the energy business.

Another thing I should mention is DOE's applied battery research programs managed by the Office of Vehicle Technologies in the EERE span multiple national laboratories and universities and industry. Just through DOE's programs, Argonne itself works with many institutions. We have a lot of partnerships to solve these problems, like in the EFRCs. We work with Lawrence Berkeley Lab. We work with Sandia, Idaho, National Lab; Brookhaven National Lab; NREL, National Renewable Energy Laboratory in Oakridge; as well as Army Research Lab, NASA, and the JPL, Jet Propulsion Labs. So, we work with all those institutions -- not alone, of course -- with those institutions collaboratively to try to address these problems. We also work closely -

- the national labs in general, but Argonne in particular works closely with research -- particularly in battery -- with many industries, including Dow Chemical -- the material side -- Dow Chemical, Dupont, 3M, and BASF; and on the battery manufacturing side, such as A123, who's here today, and Johnson Controls and Enterdill. So, we are very broadly integrated into this -- let's call it this ecosystem of innovation. We certainly don't play alone, and we're certainly not funded alone to do these things in a vacuum.

I'm very proud of DOE's track record -- not just Argonne's but DOE's -- in being able to bring together with a reinvigorated, you know, thrust in energy, and I just want to quote Secretary Chu where he says, "We are revving up the remarkable American innovation engine. That will be the basis of new prosperity." I will say it's not enough, just to add to Secretary's Chu's if I may -- add to the Secretary's quote -- it's not enough to rev up the engine, or should I say the motor, in the case of an electric car. We need to keep it running smoothly, and we need to make sure it has plenty of charge. We need to charge it up. And that's really where funds, federal funds, are very important right now.

America's expanding clean energy industry is fairly well consumed right now. The industry is fairly well consumed with what is required to commercialize, as industry should be, and manufacturing the current technology. So, they're really focused on commercialization. And that means that we in the Deeley labs must continue to discover and deliver to keep looking at the 10- to 20-year horizon. So, we really must be looking out there so we can serve in some sense -- the Deeley labs and universities can serve as that long-term research arm of what industry can do.

So, let me just talk a little bit about -- go back to my past a little and talk a little bit about some of my own historical experience and this idea of an innovation ecology or ecosystem from some of my research and past experiences at Bell Labs. And

I know Secretary Chu talks about Bell Labs a lot. I'll relate my own personal experience from Bell Labs.

In the words of *Wired* magazine, Bell Labs served as a Nobel Prize magnate, and that's an important statement, and I'll tell you why. So, even 30 years -- it wasn't just Bell Labs, of course, it was places like Xerox Park -- IBM Research had it's own incredible set of Nobel prizes -- General Electric, Westinghouse were all conducting long-term research in physical sciences. Every one of those places had a physical sciences research lab where they did fundamental research in semiconductor physics and chemistry. All the things that we enjoy today on your I-phone or your telephone came out of work done at IBM, at Bell Labs, at many of these places. They were private institutions that were driven, that were doing mission-driven research, which is distinct from universities. The universities should and always will be doing very unfettered open research. Places like Bell Labs and IBM did very mission-driven research, much like the DOE labs are doing today. And their mission-driven research, by the way, led to really important discoveries, like the charge couple device, right? So, last year in 2009, the CCD won a Nobel Prize. So, it was great science done in the '60s to quantize photons for looking forward at Bell labs. They were looking forward to optical telecommunications and, by the way, all of us make telephone calls using photons today much more so than electrons. They were trying to quantize those things. They were trying to detect them and use new device. That device was a basic discovery of science, but it also ended up winning a Nobel Prize and changing the way all of us live today just because you can take a photo of your grandchild or, you know, you can have that photo of your grandchild that minute, the minute it's taken. So, I think it's very important to think about, you know, this idea of mission-drive science, not just in the context of applied research or basic research but there's a continuum here that the basic research ultimately does drive these important innovations.

The problem is in the last few years -- and this is where I get on my soap box a little -- in the last few years industry has really given up. There are a few exceptions. Certainly in the pharmaceutical industry there's still quite a bit of R&D. But most institutions don't do as much as they used to do, at least in this area of fundamental materials discovery, looking at brand new materials. I mentioned before that the graphite -- what we use in batteries today and in automobiles -- the graphite anode was discovered and patented at Bell Laboratories many, many years ago. We don't do that kind of fundamental research today, and that was done in the spirit of really basic research, having fun sticking lithium into graphite layers and understanding how it went in and came out. Fundamental chemistry, fundamental physics, good science. And that led to our ability to do the technology today. It just doesn't exist at the same level it used to exist. And their decision to cut back on research, by the way, is all sensible. It makes a lot of sense with quarterly reports, profit-and-loss statements.

So, you know, the real problem here is of course to really innovate -- and we've described in my example here with GM, for example, in Argonne -- it takes years. It's not just a one-year process. We'd like to take 15 years -- and Jeff Chamberlain's thinking about how to take a 15-year problem and make it a 5-year problem, but I'll bet half the people in this audience have thought about how you accelerate discovery. It's a very hard problem, and at the very least, you have to have the right components in place, in the same place, to make that happen.

But without the research anymore in industry, what do we do? What does the U.S. do? And that's the real question. How do we recreate a sort of research system that will deliver? And so right now private industry cutting back means that the federal government at some level has to step in, and that research -- the physical sciences research that ultimately leads to the discoveries -- is a huge responsibility; it's a huge burden and one which I think the federal government needs to think about very carefully.

It's equally sobering to think about what happens if we can't do this. What if we don't do it? What if we just forget about -- you know, what if we just say let's let industry do all the research for us. It's very sobering to think about it. I think things are changing in this country. I think in the last five years that things -- people are starting to think differently. And a great example, of course, is the Recovery Act, which did invest about 1.6 billion into advanced research. The EFRCs I've mentioned a couple times -- those were funded in part by these recovery dollars, so the idea of taking -- you know, really investing in the future means really investing in the stuff that's hard to invest.

But what's important is not just how much we're spending on basic research but the way in which those dollars are being spent to promote collaborations and partnerships, and that's what I talked about a few times.

And so once again let me let me just talk briefly about the EFRCs.

I need to sort of try to finish up, right, in about five minutes.

But the EFRCs are really unique places, and there are three things that DOE's done recently. One is the Energy Frontier Research Centers, which focus on a single, high, very challenging energy problem, and there are 46 of those -- about $250 million in those. There's also something called energy innovation hubs, which the Secretary has promoted. Very important. There are three of those today, one in nuclear energy, one in energy efficiency, and one in solar fuels -- all very three, very good problems. They're different from the EFRCs in that they don't focus on one problem; they focus on one big outcome. They focus on one really challenging outcome, like taking sunlight and making fuels of sunlight and CO_2 and H_2O for artificial photosynthesis.

And those really bring together the kinds of people I'm talking about. They'll bring together engineers and scientists and industry under one roof much like IBM used to be, much like Bell Labs used to be. So, those are very critically important, I think, for the way this nation is headed and very important for the future of electrical energy storage.

Okay, so I'm just going to try to finish up here, so.

So, I just want to make a few more points. You know, this idea of really having once-in-a-lifetime opportunities -- I think we're here today. We have this incredible energy infrastructure that's now building up in this country. We've got, of course, the automobile industry that's gearing up to make electric vehicles, and that will really promote -- and the science behind it -- will really help to promote growth and industrial development. And we're seeing some really promising ecosystem development, which I'll talk about in a minute. Carmakers are looking at the possibility of repurposing used car batteries, so this is another opportunity with batteries. So, repurposing used car batteries for other things like homes or even grid storage, so take the old batteries and reuse them.

Perhaps even more interesting and forward looking is thinking about how do you use these car batteries in automobiles on the grid if you really do have 5 million electric automobiles plugged into the grid every night. The electric power companies have this extra storage mechanism out there, right? So, one can imagine new kinds of grid management where you actually use these automobiles as temporary or distributed storage. There are lots of cool ideas out there, and it's not just batteries, and it's not just the auto industry. It's really a much, much broader set of problems out there.

So, we cannot fill these gaps without really large-scale, real commitment to long-term and well-funded and well-coordinated research programs. The funding for this research must reflect the scope of our mission and potential value of the technology, like batteries; to our national security environment and economic future.

It is has been said many times that our ongoing attempt to create new green energy systems is this generation's mission to the moon, and so let me just take an example -- the moon -- to remind you how NASA did it, because that was a really bold -- really bold -- experiment, and it worked. In that case, we didn't assign one group to creating a jet propulsion system or a rocket propulsion system and another set of researchers independently landing technology. It was all done with NASA and industry coordinating the whole thing. We didn't ask NASA to build a rocket while engineers in private industry design their own proprietary modules for examples. We certainly didn't say let's build the technology to them there and then we'll figure out how to get them back. So, there was a real collaborative effort. It was really geared up. There was a commitment.

A lot of people talk about the Manhattan Project. I think that's a little old, but it's in the same kind of example where there was a commitment to doing something really big -- and in that case the ideas was to get to the moon. So, the race to the moon was great, it was well coordinated, it wasn't perfect. I'm sure there are stories in this audience. It wasn't perfect. There were a lot of mistakes, but there was one outcome that was desired. There was one big outcome. And that was just to get to the moon.

So, this is a well-articulated national goal that was funded essential at all costs. Let's just make it happen.

So, an ultimate success story in energy storage will, I believe, require the same kind of effort. We're seeing the very beginning of it, but we're starting to develop a national long-term vision for how to really make this happen at every scale to ensure energy independence. And I think today's conference really marks a strong step to successful thinking publicly, privately, how do we work together to really make this happen and how do we open up our -- if you will -- our research? How do we open up our books to really make this happen as a joint group?

So, let me just finish with a few final statements about the innovation ecosystem and what I think is here in this room today.

I believe that we can do this, by the way, and as we heard what President Obama recently said, “We can win the future.” We can win the future, but to do this, we really need to sustain our commitment to basic science, applied science, and hooking those all up to industry, and so we must -- really must, from my point of view make sure that we leave this room -- and I’m sure you guys do this -- that we make the public understand what this long-term investment needs, right, because there is today understandably a real nervousness about long-term investment because we have short-term problems. But if we give up the long-term, we give up everything in my opinion.

So, I want to conclude by saying something about the innovation pipeline. I’ve talked about a pipeline, and I think the pipeline analogy is okay if you have a single problem and you’re working in a single institution, and you have one long pipeline you can draw a line through. And I drew a line through our battery innovation, but it’s not a single pipeline. It’s much more appropriately described, I think, as an ecosystem. Ultimately, it’s probably a more interrelated system in which various components contribute to and depend on each other. And it’s not just the single line. You know, we have an idea and we know one day in 10 years it’ll ended up in a manufacturing process and making billions of dollars for the company.

So, the challenges we face are large and complex, and we can address most of them effectively and efficiently by working together in an energy innovation ecosystem, collaborative, public-private -- I think that’s very important and I made the case for that, I believe, to enable this ecosystem. I think we have to invest money, time, and our passion into scientific research and create and expand the innovation ecosystem that will create extraordinary new products, like we've described here today. And as we approach the task of developing a new advanced battery industry in the U.S., we must work with a sense of mission and focus, just like with the shot to the moon.

So, 10 years from now, 15 years from now, you know, what I would love to see is that we could say the national labs really did for batteries in many ways what Bell labs did for the transistor, right, basically innovating or the CCD -- the charge couple device. Innovating brand new things, like the lithium-oxygen or lithium-air battery that couldn't have been in any small PI-driven type of energy; couldn't have been done outside or in absence of the industry needs out there, which are clearly batteries that rival batteries that rival gasoline. And so we really need breakthroughs in material science, and so one of the reasons I'm here a little bit is to stand on my soapbox and say that there's an ecosystem that needs to be developed, that needs to be nurtured; but at the core of that ecosystem is the basic discovery science that we need to do.

Our stockholders at the national labs in particular are the American taxpayers, and so we have the freedom, no, the mandate, really, to collaborate closely with a wide range of universities and industries to make this happen, and our goal is not simply hand off the technology. When I was at Bell Labs, Bill Brinkman, who's now director of the Office of Science, really started this concept, because Bell labs wasn't perfect either. There were stovepipes; there were cylinders of excellence at Bell Labs, and he made the strong comment that if you have an idea, you can't just throw it over the fence. You walk with it, you take the idea and you move it straight through all the way to a business unit or product. It's very important that we have the ability in our science, in our engineering, in our businesses to make that transparency happen.

So, in his recent State of the Union Address, President Obama set a goal of 1 million electric vehicles by 2015. I think the goal is achievable -- we'll hear more about it today -- if we continue to invest and really move toward discovery and collaboration in this discovery.

As a national lab, we are really inspired by a renewed sense of mission. I talk about mission-driven science. We at the national labs are really focused on that now. Energy mission is really what we drive to. We get the next Nobel Prize, but we're also focused on solving the problems. We're focused on things like understanding materials and chemical processes, computer modeling to accelerate discovery and innovation, designing new materials from first principals for specific needs, and really predicting behaviors of materials that have not been made yet, much like new electrodes, new cathodes. So, we can do it. It's not going to be easy. It'll require a lot of investment. It'll also require a lot of collaboration. It'll require an emphasis on basic fundamental research that leads to scientific breakthroughs. And so let me just conclude by quoting Winston Churchill, because he's a great man to quote. He said 70 years ago in the early days of another great struggle, "Put your confidence in us. We shall not fail or falter. Give us the tools and we will finish the job." Thank you.

MR. EBINGER: Thank you, Dr. Isaacs, for that -- I don't know what to call it -- a tour of the horizon. I personally found that one of the more inspiring speeches I've heard in a long time as we often think of our country, particularly in our industrial sector and technology centers sinking into a noncompetitive position. We realize that is not the case, and we thank you for your inspired leadership changing that. And also as a young boy who remembers the threat posed by *Sputnik* and then as a college student when we landed on the moon, I'm glad to see we have a vision out there to take us to the next great leap, not only for our own country but for mankind.

Our next speaker is a dear friend and former colleague at Brookings, David Sandalow. The only thing I can say when David left Brookings we lost our greatest supporter for electric vehicles and alternative transportation fuels. He was a true champion of this for a long, long time and inspired the rest of us who were fortunate to be his colleagues.

Davis is the assistant secretary for Policy and International Affairs at the Department of Energy where he helps coordinate policy and manage international activities at the department. Before his work at DOE, he was, as I mentioned, a senior fellow and colleague at the Brookings Institution where he was a prolific publisher publishing two very widely regarded books, *Freedom from Oil*, and he was editor of *Plug-in Electric Vehicle: What Role for Washington?* Previously to these assignments, David served in the State Department as assistant secretary of state for oceans, environment, and science; and he was also formerly senior director for Environmental Affairs at the National Security Council and associate director for the global environment at the White House Council on Environmental Quality.

It's a privilege and a pleasure to introduce and an old friend, David Sandalow.

MR. SANDALOW: Thanks, Charlie. It's great to be back at Brookings and great to share the dais with Eric Isaacs. I'm not a physicist, unlike Eric, but spending the morning with one is a very familiar experience after two years with the Department of Energy. Steve Chu has really brought not only analytic rigor and leadership but a passion for physics to the Department. One of my favorite experiences I remember with him in the past couple years is we showed up for a meeting and were told when we arrived at this meeting that it was going to be delayed by about a half hour. And the people who were there were horrified that they had this cabinet member sitting in their foyer and were delaying him by half an hour, and he said no worries. And I could tell he meant it. And he pulled out his computer and he started working. And he explained to me that before he had taken office he had written an article on the general theory of relatively for *Nature,* I believe, and they'd gotten peer review comments back but he'd been so busy as Secretary that he hadn't been able to incorporate them in the article, so this was a moment to actually incorporate the comments.

As he sat there working on his article on the general theory of relatively, I thought for sure this is the first time this has ever happened in this place, so it's really fun and it's -- you know, it's fun to spend time with people who, you know, throw off phrases like "having fun sticking lithium into graphite anodes," which, you know. (Laughter) People whose ideas may not find that familiar but on the street it be an unusual experience, so. So, it's a lot of fun to be here.

And as I thought about today's topic I was reminded of three trips that I've taken in the past year. One was to the Paris auto show. It was an exciting event. Dozens of manufacturers were displaying new products, and as I walked through the gates, the crowd there -- the very first paper that was put in my hand was a magazine about the show with the headline "An Electric World," and that was the hot topic of the Paris auto show last fall.

I went to the test track where there were more than a dozen electric vehicles available for driving. I got to drive one around the streets of Paris, and then a little while later I had fun listening to a briefing on the Chevy Volt by a French person with Mo-Town music blaring in the background. It was great. (Laughter)

The second trip this reminded me of was a trip to Tianjin, China, where I visited an enormous lithium-ion battery factory. The factory had more than -- it has today more than 1 million square feet of floor space and the capacity to produce over 20,000 battery packs a year. As I toured the plant, the manager described the rapidly growing electric vehicle and battery manufacturing industry in China.

The third trip this reminds me of is a trip to Livonia in my home state of Michigan, where there was an opening of a new lithium-ion battery manufacturing facility by A123 Systems. Michigan's governor spoke about the growing electric vehicle industry in the state and around the Midwest. And A123 announced more than 3,000 jobs that it's creating at this facility and others in southeastern Michigan thanks in part to an almost $250 million grant under the Recovery Act. And, by the way, I should note that A1213 was founded with a $100,000 grant from the U.S. Department of Energy.

So, ladies and gentlemen, the electric vehicle industry is taking off around the world. At least 20 manufacturers have announced plans to bring electric to market in the next few years. Israel has ambitious plans to transform its vehicle fleet to electric drive, and in China more than 20 million electric motorcycles were sold last years, and cities are beginning to invest heavily in public infrastructure for electric cars.

Here in the United States, the electric vehicle -- so many plants are opening in Michigan, in Tennessee, in California. More than 30 new factories for batteries, motors and other electric vehicle components are opening around the country.

Last month President Obama highlighted the importance of electric vehicles in his State of the Union Address reiterating his call to put 1 million electric vehicles on the road by 2015. And today the Department of Energy is releasing a report on progress toward that goal. The report, which will be available online midday, documents plans by U.S. manufacturers for production capacity in the range of 1 million electric vehicles by 2015 according to company announcements and news reports. The report describes policies adopted and programs underway that will help achieve the 1 million by 2015 goal -- the goal's new policies and programs proposed by President

Obama. The current plans of manufacturers, together with these policies put the President's goal within reach and, importantly, they position the United States for much greater growth in the electric vehicle fleet and in this industry of the future in years to come.

Now, the benefits of that growth will be enormous. Today more than 95 percent of the energy in our vehicles comes from one product -- petroleum. That doesn't seem strange to us. We grew up with us, as did our parents and our grandparents. But our overwhelming reliance on a single fuel for transportation has far reaching consequences. Diversifying the fuel mix in our vehicles would offer tremendous benefits: improving energy security, protecting the environment, and creating jobs in the industries of the future.

Now, to be sure, petroleum will continue to play an important role in our transport sector for years to come, and for that reason the administration is committed to making oil production safer and more environmentally responsible than ever before. And several technologies can help transform the transport sector in the years ahead. Advanced biofuels have tremendous promise. Natural gas can power trucks, fleet vehicles, and more. Fuels cells could revolutionize drive trains. And widely available technologies today will significantly improve fuel efficiency in the years to come.

But electric vehicles are especially promising. They're quiet, fast, and cheap to drive. No technology has more potential to dramatically transform driving in the years ahead. With electric vehicles, torque is instantaneous, and pickup can be excellent. I haven't had this experience but the Tesla website talks about one of their favorite things to do is to sit somebody down in the passenger of Tesla, which people here will know is a hundred-thousand dollar all-electric sports car that goes 0 to 60 in 3.9 seconds, and what they say on their website is they like to have people sit in the passenger seat and then say oh, turn on the radio. And as the person reaches to turn on the radio, they floor it, and the G forces are so great, they can't reach the radio as a result of the acceleration from the Tesla.

With electric vehicles, driving costs drop dramatically to the equivalent of roughly 75 cents per gallon at national average electricity prices. I drive a converted Prius plug-in converted with an A123 battery, and a trip out to Dulles this weekend I got 80 miles to gallon on the average back and forth in my trip with that, so very economical.

With electric vehicles, pollution in our cities would fall dramatically, and because electric motors are so much more efficient than internal combustion engines, electric vehicles promise significant reductions in global warming pollution.

In countries and companies around the world, they are already positioning themselves to benefit from this industry of the future.

We're here in Washington, so another point -- electric vehicles are also a topic that brings Democrats and Republicans together. In the U.S. Senate, for example, leaders on this issue include Senator Jeff Merkley, Senator Debbie Stabenow, Senator Carl Levin, Senator Lamar Alexander, and Senator Orrin Hatch. In the U.S. business community, leaders include FedEx CEO Fred Smith and GE CEO Jeff Immelt.

So, to help launch this conference today, I thought it might be useful to briefly summarize the steps that President Obama and Secretary Chu have taken to position the U.S. for leadership in electric vehicles and battery technologies and summarize the President's recent announcements in this area.

So, first, through the Recovery Act, the United States has made unprecedented investments to build our domestic manufacturing capacity for electric vehicles and battery technology. These investments include $2.4 billion in loans to three of the world's first electric vehicle factories in Tennessee, Delaware, and California. It also includes $2 billion in grants to support 30 factories that produce batteries, motors, and other electric vehicle components. Companies are matching each dollar for dollar, doubling the impact of taxpayer investments. We're building the capacity to produce 50,000 electric vehicle batteries annually by the end of 2011 and 500,000 batteries annually by December 2014.

We've made investments in manufacturers such as Nissan, Tesla, and Fisker, as well as battery and component suppliers like A123, EnerDel, and Celgard, creating or saving thousands of jobs. These plants will have the capacity to produce 250,000 electric vehicles and batteries to power 500,000 plug-in hybrid electric vehicles.

Second, Recovery Act funds are supporting the largest ever coordinated demonstration of EVs in the United States, including nearly 13,000 vehicles and more than 22,000 electric vehicle charging points in more than 20 cities across the country. Companies are matching this $400 million public investment dollar for dollar. This effort will provide important and detailed real world operational data, and vehicle usage, time of use, and charging patterns, and potential impacts on our nation's electric grid.

Third, the Recovery Act funded a consumer tax credit of up to $7,500 for the purchase of plug-in electric vehicles.

Fourth, the Department of Energy is supporting a broad portfolio of battery R&D that stands basic research to applied development, and Dr. Isaacs has already spoken about this. The Office of Science supports fundamental basic energy research on enabling materials through energy frontier research centers. The Applied Research Projects Agency-Energy, or ARPA-E, conducts transformational research on revolutionary, game-changing energy storage technology. One of the requirements for their programs is that they be acronyms that form English words, and their acronym for the battery program is BEEST -- battery and energy efficient storage technology, I think.

The battery research program of the Office of Energy Efficiency and Renewable Energy is focused on applied development and demonstration of advanced batteries to enable large market penetration of electric-drive vehicles. Meanwhile, new technology has continued to move from DOE laboratories to the market, and we've just heard about the best example from Dr. Isaacs, or a great example. Argonne National Lab recently licensed advanced cathode technology to General Motors and battery suppliers, LG Chem and Envia.

And then fifth, we've worked with local leaders in their efforts to encourage electric vehicle adoption and drive consumer demand, hosting a widely attended workshop last summer. Cities around this country are working on permitting for electric vehicles, permitting for installation of chargers, and we have a program to support that with technical assistance.

But these steps are just a start. President Obama has recently proposed three important new steps. First, making electric vehicles more affordable and accessible for American consumers: The existing $7,500 tax credit will be improved by giving consumers the ability to receive this benefit at the point of sale, similar to the "Cash for Clunkers" program. The current individual credit will be reformed into a tax credit claimable by dealers and others with clear transparency requirements to ensure the benefit of the credit is passed on to consumers.

Second, by rewarding communities for leadership in reducing regulatory barriers and developing comprehensive electric vehicle-friendly infrastructure: If the Department of Energy were beginning a competitive program now to help communities across the country become early adopters of electric vehicles through regulatory streamlining, infrastructure investments, vehicle conversions, deployment of electric vehicle incentives such as parking and HOV access, partnerships with major employers and retailers, and workforce training. The FY 2012 budget will expand this initiative so that up to 30 communities across the country would receive grants of up to $10 million each on the basis of their ability to demonstrate concrete reforms and use the funds to help catalyze electric vehicle deployment.

And then third, we're advancing innovative vehicle and battery technologies with increased R&D. Increased investments in R&D will be critical to the deployment of the new technology. The Recovery Act and prior year investments are already making progress on advanced technology vehicles through research initiatives like ARPA-E. The ARPA-E program is aimed at developing a battery that will go 300 miles on a single charge. This year's budget will significantly broaden R&D investments in technologies like batteries and electric drive, including an over 30 percent increase in support for vehicle technology R&D and a new energy innovation hub devoted to improving batteries and energy storage for vehicles and beyond.

So I'll close with two quotes. The first is from President Obama who said, "The nation that leads on energy will be the nation that leads the world." And the second is from the greatest hockey player of all time, Wayne Gretzky, who famously said, "Skate to where the puck is going."

The energy challenges we face today are vast. Our patterns of energy use threaten our national security and have played a role in two wars this country has fought in the past two decades. The ways we use energy are disrupting the climate system and threaten terrifying disruptions in decades to come. And at the same time billions of people around the world still lack access to basic energy services. These problems can seem insurmountable, yet I believe that revolutionizing energy technologies in the decades ahead -- I believe we can and will revolutionize energy technologies in the decades ahead as much as we've revolutionized communications technologies in decades past. I believe we can meet ambitious goals such as putting one million electric vehicles on the road by 2015 and doubling the share of clean electricity in 25 years as President Obama called for in his State of the Union address last month.

I believe that “skating to where the puck is going” means investing in clean energy. From Paris, France, to Tianjin, China, to Lavonia, Michigan, a new era in transportation is already underway. We can transform the transport sector with electric vehicles, saving drivers money, cutting pollution, reducing oil dependence, and creating many thousands of good jobs in the process. Thank you.

MR. EBINGER: Thank you, David, very much. It’s very exciting to hear what the Administration is doing in taking us on a path to the future. Dr. Isaacs, if we could get you to come back up, we’ll take questions from the floor. We have a roving mike so if you would please kind of raise your hand, and we’ll try to get underway here. Let me put on these glasses so I can see the audience.

Yes, ma’am? And if you would, please, identify yourself when you ask the question.

MS. CRESPO: Hi. I’m Jackie Crespo from Cassidy and Associates, and I want to thank you both. I was curious if we could talk a little bit more about supply -- I mean, I’m sorry -- not supply, demand-driven incentives, because a lot of the things that President Obama announced were supply-driven incentives. And I would like to kind of hone in more on the community- or city-driven incentives that you talked about, Mr. Sandalow, specifically thinking about the parking and the HOV lanes because this is something that I’ve looked in more deeply. And I’ve got folks in my firm who are old highway transportation guys who kind of throw back at me, well, you’re so excited about these electric vehicles, but we have a near-bankrupt highway truss system. So now you want to increase the carrying capacity of these roads for folks who aren’t paying into the system because effectively unless they're plug-in hybrids, if they're all electric vehicles, they're not buying gasoline. They're not paying the gasoline tax. They're not paying into the system. And there's a bit of a stigma of these freeloaders now who are getting access to the highway, but not paying.

So can we think through some of these incentives, and how do we get away from this free loader sense and actually think through incentives that are sustainable?

MR. SANDALOW: Great question, thank you. Look, a couple of things. I think first of all, states are going to devise their own plans in this area and devise HOV lanes and those types of things, but largely state responsibilities. We have some technical assistance programs to work with states and localities on those types of things, including for municipal permitting and a variety of other issues where -- some cities, for example, have raced way out ahead to facilitate rapid permitting of home chargers. Other cities are looking at how best to do it.

In terms of consumer incentives, I would point to the tax credit as the single most important part of what the President has proposed, you know, on the consumer side. It's an existing tax credit by the way, but what the President has proposed is to reform it and improve it to make it for American purchasers.

And then I think, broadly, electric vehicles are patriotic. This is a way that we can really make a difference for our nation's future, for promoting energy security, improving the environment, saving drivers money, creating thousands of jobs.

MR. EBINGER: Do you have anything to add, Dr. Isaacs?

DR. ISAACS: Well, I would just say that if you go to the state of California now with the $7,500 tax credit that the federal government is giving you and the $5,000 tax credit that the state of California is giving you, you can buy an electric car for almost nothing, right? For $20,000 you can have a Nissan Leaf.

MR. EBINGER: Questions? Yes?

MS. MANDEL: Hi. Jenny Mandel with Greenwire. A question about the Energy Innovation Hubs, also the EFRCs which you touched on but didn't focus on: DOE has tried before to push these. At first there were eight, three got funded. Congress was just not very receptive to it. What is DOE doing differently now to sell this plan, to make it more clear, to better communicate what it is about them that makes it worth funding them now in a more difficult funding environment than it was two years ago? Thank you.

MR. SANDALOW: We're obviously very hopeful that this proposal will gain widespread support. As I mentioned in my remarks, this is a topic -- this topic of electric vehicles -- that does have pretty broad bipartisan support. And there have really been -- I'm obviously a Democrat and there have been in my opinion real leaders on the Republican side of the aisle on this issue. I would single out Senator Lamar Alexander and Senator Lugar as well and Senator Hatch who have really been tremendous leaders in this area. So I think there is potential for building broad coalitions precisely because electric vehicles are patriotic, and this is something that makes such a broad difference. I think we -- I think there's real opportunity to move forward here.

DR. ISAACS: So I would add just to follow up, you mentioned the EFRCs, hubs, and ARPA-E. In particular, EFRCs and ARPA-E are getting tremendous bilateral -- I mean everyone supported those, right? So they are now funded. The issue of the hubs is really articulating the difference between a hub and what an EFRC does, for example. And I tried to do that a little bit. I mean, the EFRCs are really focused on a single grand challenge, say, in science or technology whereas the hubs are really meant to be, like Secretary Chu says, Bell Labs-like. They're much broader and they're attacking -- rather than attacking a single science problem, they're attacking a global outcome like electric vehicles or like energy efficiency. So they are very distinct. In terms of actually getting full support for them, there's still a challenge, I think. Three of them have been supported. There's a lot of discussion about three more getting supported with ultimately the goal of eight. And I think really it will come down to articulating the strategy and distinction between those three major components, which is now in a much more mature phase and will get articulated in the coming year.

MR. EBINGER: Yes, sir?

MR. SANG: James Sang (inaudible). Dr. Isaacs' old world was characterized by a fairly useful, fairly elaborate road-mapping and exercises that were actually, eventually -- and now are international. Is this field one where, in fact, those kinds of exercises, given that there are many partners or many players, would be useful?

And also, as we talk about installing infrastructure, do we need some standards for this area so that all the pieces fit together, all the different ideas about whether you just continuously charge up battery packs or replace battery packs that are like work or you don't wind up going down the wrong way?

DR. ISAACS: So from a technology point of view, roadmap is very useful. In fact, we've worked on that quite extensively in thinking about a technology roadmap. And when I was discussing this before, I said, there are a lot of known unknowns. And so when you have known unknowns, you can at least put them down on a roadmap. And so, in fact, several of us are involved now. It's not a -- it's actually on an international level, but some of us are involved, and Jeff can comment more about this. I'm thinking about what a roadmap looks like from today where we're looking at lithium-ion batteries with several hundred, you know, watt-hour per kilogram out to gasoline at the 10,000 level.

So the answer to your first question is absolutely, a road-mapping exercise is, I think, very useful, but also quite doable because it helps to, I think, codify the kinds of partnerships which I think are important in the activity of making a roadmap. But also once you have a roadmap, you can have people raise their hand and say, hey, I can do that, and industry can come in and say, I can do that. So it would be a very useful exercise.

MR. SANDALOW: Your standards question is a great one and a very important one. And yes, it's very important that we work on developing standards in this industry. And I think there's some wide standards out for level 1, level 2 chargers. But we've had discussions both here in the United States, but then internationally about standardization. This is an industry that is exploding all over the world, and standardization can make a real difference in technology penetration if we do it right.

MR. EBINGER: Do you have a question?

MR. SLOAN: Thank you. Stuart Sloan. How do you rebut the charges that industrial policy in this country has generally been a failure? People look back to synfuels and in this case the administration is not only picking technology, a particular technology, but subsidizing particular companies?

MR. SANDALOW: There have been tremendous successes. I'd say this is part of the story. One that leaps to mind, I think, many people today say that shale gas and hydraulic fracturing of shale gas is the greatest energy innovation of the past decade. It's a claim that's out there a lot. And it certainly is transforming the U.S. energy landscape and energy landscape around the world. If you trace back the core technology that is used for "fracking," it was started with grants under the Department of Energy in the 1970s and 1980s. And some of the basic innovations in lithium-ion batteries that are right now creating tens of thousands, hundreds of thousands, of jobs for Americans also have their origin in that type of funding. So, Dr. Isaacs summarized in his remarks and you can elaborate on funding for basic science research and the importance of that. I think the market, an individual company, you're not going to fund basic science research at the level it needs to be funded, and government has a crucial role there.

And he also spoke -- one of the things I -- there are about a half a dozen things I'd like to follow up with Dr. Isaacs from his very interesting remarks on, but one of them he mentioned a study about comparative capital costs for production in different countries in scaling of technology. And as I said right now, as I said, this is an industry that's scaling up around the world. U.S. leadership in this industry promises tremendous benefits for Americans, and that's going to require companies and the government working together to create those opportunities for Americans.

MR. EBINGER: Yes, sir?

MR. MINUTE: Larry Minute from Congresswoman Gifford's office. There's increasing concern about the availability of materials such as lithium or earth elements, et cetera, as a supply problem somewhat akin to petroleum. You mentioned the materials cost being roughly equal for everybody, but that assumes infinite availability of those materials. Could you address both that concept and just how much lithium and manganese is in a typical volt battery? What are we talking about?

DR. ISAACS: So I think from the point of view of availability of lithium, it's like many minerals and elements we mine; when the value for mining them goes up, then people will mine them. It is true in this country, and you've heard this a lot with other elements like the rare earths, we have plenty of rare earths in this country, for example, but we haven't mined them in a long time. We now buy them from China, and it's probably pretty similar right now with lithium. We do -- a lot of other countries do lithium. We have plenty of lithium. Lithium is a light element. There's a lot of it. There's probably hundreds of years of lithium -- and I should say batteries. Lithium is actually very easy to recycle, so it's easy to pull back out again. For the same reason it's good in a battery, it's also easy to get back from the battery.

So there are estimates, and they're all over the map. But there's -- I can't tell you there's plenty of lithium for 10,000 years, but there's certainly plenty of lithium for hundreds of years based on what we know exists in existing mines, et cetera. But there's also a strong belief that once we start really driving the full economy based on lithium, that we'll also expand our mining capabilities as well. So in terms of availability of lithium, it's not a big deal.

Jeff, do you want to comment on exactly how much lithium is in a -- do you know how much lithium actually is in a battery in terms of grams?

MR. CHAMBERLAIN: No, I don't know. You're talking about sub-kilogram quantities.

MR. SANDALOW: I'll just jump in to say I told Charlie I need to go in a minute, which I do and we're over time, but this is a question I could talk on for a long time. So maybe privately we could do that. We've done a fair amount of work on this at the Department of Energy in the past year, and I'd direct you to a report we did in December we call our Critical Materials Strategy. It's a 200-page report, a lot of good research in there, and we assessed the criticality of different elements. We assessed lithium as not being in a critical situation over the course of the next decade or two. There's lots of lithium out there.

MR. EBINGER: We have a few minutes left on our questions, but Mr. Sandalow needs to go. Please -- and let's give him applause.

MR. SANDALOW: Thank you.

MR. EBINGER: Okay. Yes, ma'am?

SPEAKER: (inaudible) even though we actually do mine lithium, we send it overseas to extract it because the labor is much cheaper, and we haven't gotten an efficient process so it becomes very labor intensive.

And the other thing is that I think there's other projects; one is beyond rare earth minerals that we're actually looking at -- I'm not the expert in it -- but aren't there other projects that are looking at beyond other minerals that have -- that are not rare earth minerals? So two things: that there are processes now being at least looked at for being much more efficient so that we can actually do a lot -- some of the extraction here, and two, that there are other mineral sources that are being looked at for the future.

DR. ISAACS: I would just comment, certainly rare earths, replacing rare earths, they're good for magnets. We use them often in motors, right? So there is a project actually DOE is sponsoring now which is focused on what are the replacements? I mean, rare earths are very good -- I won't get into the details -- but are very good for permanent magnets with long lifetimes, et cetera. So in that case we're looking for potential alternatives just from a materials point of view. What are the new materials that we can replace rare earths with? But rare earths just like lithium, there's a lot of it in the ground. You know, you never know exactly how much, and I defer you again to the DOE's and David Sandalow's report. But there's a lot of it in the ground. The questions is, you know, when does it become worth our while to mine it? The question of whether we refine it in the U.S. or whether we refine it in Russia or China is another question that I'm not qualified to really answer, the economic arguments behind it.

MR. EBINGER: Yes, sir?

MR. GALE: Sir, my name is Alexander Gale. I'm actually a student with the National Defense University. I'm a captain in the U.S. Army Special Operations. For those of us who like a little bit of power in our vehicles, what's the outlook on the battery-run vehicles given the fact especially that you have natural gas vehicles now pretty much being considered equal when it comes to power in a vehicle? And what's to stop automakers from investing more into natural gas-run vehicles as opposed to battery-run vehicles?

DR. ISAACS: So you're asking the question about power in lithium batteries? Certainly, there are two axes when you think about what a battery can do. There are two components to it. One is the power, which is how fast you can accelerate and like you pointed out, Americans love to accelerate. And the other is range, which is what we're mostly talking about range in this discussion today, how far can you go on a single charge? And they're not necessarily mutually exclusive, right? And so a lot of the details about whether you get power out of a battery depend on the chemistries and how fast you can pull the lithium out or whatever the energy-carrying capacity is.

And certainly when we talk about things like lithium air today, one of the issues that lithium air has is that it's not powerful enough, right to your point. You can't pull the lithium out fast enough and so it comes out slowly and, therefore, it's got large range -- it can be charged once -- but it doesn't get you the acceleration, you know, like the Tesla car has, right? And the Tesla is amazing, to repeat what David said. I've driven one, and they can take your head off when you try to accelerate those things.

But it's a good question, and it's a balance that always has to occur as to whether -- so batteries are now designed with both of those components in mind. And like everything, it's a tradeoff. Nature is a tradeoff. So if you want lots and lots of range, often you have to give up some of the power. But the batteries we're talking about, these lithium batteries are pretty good actually. They're sort of on a straight line towards gasoline, which has both power and range. So we work very carefully and think about chemistries that do both because you do need acceleration for safety reasons even, right, to get on a highway. So we think about those things.

In terms of natural gas, I guess I'm not really qualified to answer your question, why the auto industry isn't moving toward natural gas powered. But anytime you have gases, right, unless you can liquefy them, the volume issues become unbearable. So, you know, liquid gas is one thing. A natural gas, which is often in a liquid form when you go -- in a gaseous form. When you go to a solid or a liquid form, it becomes -- I mean, you can do that, but then you have other challenges of high-pressure containers, et cetera, on an automobile.

MR. EBINGER: Well, I want to -- I'm sorry we didn't get all the questions, but to keep us on track, we better take our break now. I'd like to thank Dr. Isaacs for a very exciting presentation. (Applause)

(Recess)