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ELECTRIC BATTERY PRODUCTION AND WASTE: OPPORTUNITIES AND
CHALLENGES

Wednesday, July 17, 2019

United States Senate

Committee on Environment and Public Works

Washington, D.C.

The committee met, pursuant to notice, at 10:05 a.m. in room 406, Dirksen Senate Office Building, the Honorable John Barrasso [chairman of the committee] presiding.

Present: Senators Barrasso, Carper, Inhofe, Capito, Braun, Rounds, Sullivan, Boozman, Ernst, Cardin, Whitehouse, Merkley, Markey, Duckworth, Van Hollen.

STATEMENT OF THE HONORABLE JOHN BARRASSO, A UNITED STATES
SENATOR FROM THE STATE OF WYOMING

Senator Barrasso. Good morning. I call this hearing to order.

The purpose of today's hearing is to evaluate the environmental challenges and opportunities associated with increased battery demand as well as disposal. The global market for electric vehicles is expected to rise in the coming years.

By 2025, up to 90 percent of the global market for lithium ion batteries will come from electric vehicles. This increase in demand, left unaddressed, will exacerbate current challenges associated with battery production and waste.

Lithium ion batteries use a number of critical minerals. They include lithium, cobalt, graphite and rare earth elements as well. The United States and the rest of the world have allowed China to dominate control over the production of these minerals. China exerts substantial control over mining operations in countries with vast reserves, including the Democratic Republic of the Congo and Chile.

In May, Foreign Policy published a report entitled, I will hold it up here, Mining the Future: How China is Set to Dominate the Next Industrial Revolution. So I would like to enter this report into the record, without objection.

[The referenced information follows:]

Senator Barrasso. The Secretary General for Amnesty International has stated that, "Every stage of battery life cycle, from mineral extraction to disposal, carries human rights and environmental risks. Approximately 60 percent of the world's cobalt is currently mined in the Democratic Republic of the Congo. This photograph shows a child cleaning cobalt there. It is a child in the Congo. Jim, you take a look, I know you have been in that country.

In Chile, lithium production is affecting the local water supplies. The evaporation process to produce lithium requires pumping brine into pools like the one pictured here.

China also has a hold on battery manufacturing. Chinese battery production also has significant environmental impacts. As we all know, China's environmental regulations are not on a par with ours. China uses less advanced manufacturing techniques than the United States. One study found that producing a lithium ion battery in China emits about three times as much carbon dioxide as producing the battery in the United States.

Environmental challenges continue once a battery reaches the end of its life. Lithium ion batteries are recycled at a rate of less than 5 percent. Between 2018 and 2030, over 11 million tons of spent lithium ion batteries will be discarded across the world.

Now is the time for this committee to evaluate the looming waste challenge as well as the opportunity that it presents. I say opportunity, because we have had past successes with other types of battery recycling in this Country. About 99 percent of lead acid batteries from cars and trucks are recycled today, 99 percent.

In the case of lithium-ion batteries, recycling could have multiple benefits. First, it could cut down on the waste that goes into landfills, and in landfills, if not carefully managed, lithium ion batteries pose fire risks as well as electrocution risks.

Recycling also could cut down on emissions and other environmental impacts. From its creation to its disposal, an electric vehicle can have higher environmental impacts in some areas than a standard automobile. For example, an electric vehicle over its full life scale consumes more water resources than your average car. Emissions of sulfur oxides are also higher.

In addition to enhancing environmental sustainability goals, recycling can also address broader economic and security risks. If we recycle more, we can rely less on overseas production of the raw materials. Recycling should be part of a broader discussion that also includes more raw material production and battery manufacturing here in the United States.

If the pace of electric vehicle demand continues, recycling alone will not be enough. My home State of Wyoming contains substantial reserves of critical minerals, including rare earth elements.

I am a co-sponsor of S. 1317, the American Mineral Security Act, which is sponsored by the Energy and Natural Resources Committee, with Chairman Murkowski and Ranking Member Manchin, so it is bipartisan. That bill passed the committee yesterday. The bill recognizes we must improve the permitting process to produce more critical minerals in the United States.

Before we move to our witnesses, I would like to turn to my friend, colleague, and ranking member, Senator Carper, for his remarks.

[The prepared statement of Senator Barrasso follows:]

STATEMENT OF THE HONORABLE THOMAS R. CARPER, A UNITED STATES
SENATOR FROM THE STATE OF DELAWARE

Senator Carper. Thanks, Mr. Chairman. Again to our witnesses, welcome. There is a very young son, 10-year old son sitting behind one of our witnesses, who is going to keep an eye on his dad. We are going to watch and see if his lips move when you speak. We will see how that goes.

[Laughter.]

Senator Carper. I also would like to ask a couple of unanimous consent requests to submit for the record three documents. One is by McKenzie and Company that highlights the uncapped opportunities of recycling electric vehicle batteries to meet our future electric vehicle battery mineral needs. The second is a recent article by OilPrice.com. That article highlights the tens of millions of dollars being invested by folks like Toyota, Tesla, and some U.S. start-up companies in more sustainable batteries.

And the third is a study by the Institute for Sustainable Futures, which found policies that encourage recycling and responsible electric battery sourcing can promote global environmental stewardship and help address the human rights concerns raised by our chairman, with battery recycling being the most important policy. I would ask unanimous consent to submit those.

Senator Barrasso. Without objection.

[The referenced information follows:]

Senator Carper. I would also add that I appreciate very much our chairman's concern for human rights in the context of mining conduct overseas. As we know, issues related to labor practices and the treatment of workers go well beyond just the extraction of minerals currently needed to produce electric vehicle batteries. I am confident that our chairman's comments, and I hope mine as well, we will join together in crafting, with our colleagues, and passing legislation that makes major investments in all electric waste recycling infrastructure to recover critical minerals, but also provide real investments in research, development, and deployment of the next generation batteries that don't need any of the mined materials that are causing the concern that he has spoken to.

As the chairman knows, my colleagues may know, I have been eager for our committee to foster meaningful dialogue about the importance of recycling. I want to thank him for holding today's hearing. It is what I hope will be the first of any number of conversations about what our Country can do to improve recycling education and infrastructure, and producer responsibility.

I have said in this committee many, many times, in adversity lies opportunity. There is plenty of adversity here on this front, but there is also a lot of opportunity.

Today, we get to focus on a couple of my favorite issues, that is electric vehicles and recycling. I expect we will learn more today about how investments in each of these areas can support the other. Our Country's transportation sector is currently the single largest source of greenhouse gas emissions in America. It wasn't always that way, but it is today.

We know that promoting zero-emission vehicles, such as electric vehicles, including them, but also, I would add hydrogen-powered vehicles using fuel cells and others as well, it is one of the best ways we can modernize and clean up our transportation sector. More electric vehicles on our roads means easier air, better climate, and less reliance on foreign oil.

We also know that while electric vehicles are already one of the cleanest vehicles available today, over time, they are only getting cleaner as the power sector that charges the electric vehicles gets cleaner. I am certainly not the only one who sees the vast environmental and economic benefits of cleaner cars. Cities across the Country and countries like China and Norway are investing significantly to transition to electric vehicles. I have seen it with my own eyes in my visits to those

countries.

Today, you could ask almost every car manufacturer where the global vehicle market is heading, and they will tell us that electric vehicles are the future. That doesn't mean we are going to have every car, truck, and van on the roads in 10 years to be an electric vehicle, that is not true, or a hydrogen-powered, or powered by natural gas. But a lot of them will be. We will still have vehicles powered by diesel, still have vehicles powered by gasoline as well. But given the challenges we face on climate change, it is important that we move away from those over time. I think we will.

But as the global market for electric vehicles grows, so will the demand for the raw materials needed to make the batteries that power them. Production of electric vehicle batteries, just like the production of smart phone batteries, requires critical minerals, such as lithium and cobalt, many of which are not mined in the USA.

Some of our colleagues believe we must eliminate or lower mining and environmental standards to keep up with the increasing demand. I just don't agree with that. I would remind us that the damage we have seen incurred by cutting corners in hard rock mining regulations, local communities pay the price in many cases, in environmental and health effects, sometimes for generations.

I am confident that the critical mineral mining industry can meet the new demands of the market forces and produce more here at home without endangering human health and our environment. It is important that we do that.

Some of our colleagues will also say that we need to wait to make real investments in electric vehicles until we have made investments in domestic critical mineral mining . I think that is a little bit like saying, we need every American to use a rotary phone until we mine more for cell phone batteries. It is what is called a logical fallacy. I don't know that it is realistic.

For auto makers to be competitive in the global market, we can no longer delay investments in electric vehicles in this Country. Fortunately, more mining isn't the only solution. Manufacturers are hard at work to create a more sustainable electric vehicle battery, one that needs fewer critical minerals. And of course, technology is rapidly evolving. Just as the cell phones used five years ago are significantly different than the ones we use now, the kind of vehicle batteries we use today will not be the same batteries we used 5, 10, or 15 years ago.

We don't, however, need to wait for better battery technology to have a more sustainable electric vehicle battery. Using today's technology, we can recycle critical minerals and

other materials found in electric batteries that fuel our vehicles and our gadgets. Electric waste, or e-waste, was once destined of the landfill, but now can live a new life as another product, if recycled properly.

In fact, critical minerals can be infinitely recycled without losing any of their properties. Imagine that. Battery recycling also reduces our need for new critical minerals, reduces the carbon footprint of an electric battery and creates economic opportunities through good-paying recycling jobs.

China and the European Union have, or will soon have, laws in place that require auto makers to take on the responsibility of recycling spent batteries. This incentivizes auto makers to find a new purpose for these batteries and recover the minerals in them.

Clearly, other countries are stepping up to the plate when it comes to investments in electric vehicle battery recycling. It is time for the U.S. to get into the game.

The last thing I would say is, I read in the media this past week that Ford Motor Company has joined with a major European auto company to develop a new generation of electric vehicles. Does anybody know who the partner is in Europe?

Mr. Sanders. Volkswagen.

Senator Carper. Volkswagen, there you go. That is an interesting partnership, but frankly, I think, a very

encouraging development. We look forward to hearing more about what the U.S. can do to ensure that we reap the environmental and economic benefits of e-waste recycling and how we can help enhance recycling infrastructure and technologies. We are delighted that you are here. Thank you so much for joining us.

Mr. Chairman, thank you so much for calling this hearing.

[The prepared statement of Senator Carper follows:]

Senator Barrasso. Thank you, Senator Carper.

I now look forward to welcoming our distinguished panel of witnesses and experts. The committee today welcomes Michael Sanders, who is the Senior Advisor of Avicenne Energy. Additionally, we have James Greenberger, who is the Executive Director of the National Alliance for Advanced Technology Batteries International, known as NAATBat, and Ajay Chawan, who is the Associate director of Navigant Consulting, Inc.

We welcome all of you . I would like to remind the witnesses that your full written testimony will be made part of the official record, so I ask that you try to keep your statements to five minutes, so we will have plenty of time for questions.

Senator Carper . Could we ask our third witness to introduce the family member that is the audience?

Senator Barrasso. We will do that when we get to him. Let me start first with Michael Sanders. Thank you.

STATEMENT OF MICHAEL SANDERS, SENIOR ADVISOR, AVICENNE ENERGY US

Mr. Sanders. Chairman Barrasso, Ranking Member Carper and members of the committee, thank you for the opportunity to provide testimony concerning the environmental issues and opportunities in the use of electric batteries.

I am a senior analyst at Avicenne Energy, which is a premier market research and consulting firm, focused on rechargeable battery markets and their opportunities. I have nearly 16 years' experience in the battery market, and I am now advising many companies in this space.

Electric vehicle demand is growing very rapidly, being led by China, both for full electric vehicles and buses. China led with clear direction, along with substantial support and vehicle subsidies. But most of these are expiring. However, the mandates for electrification remain in place.

Many of the EU countries and cities have also established dates for full conversion to electric vehicles. A large group of U.S. mayors recently released a target to purchase a large number of electric buses, and the charts in the deck basically highlight a lot of the data that is behind the testimony. You see in the charts the growth of electric vehicles worldwide.

From a U.S. perspective, the number of electric vehicles that are forecast are for a half million vehicles in 2020, a million five by 2025, and 3.7 million vehicles by 2030. This

demand projection is based on current global regulations, supply chain development, known vehicle launches, expected cost improvements reaching cost parity, and the growth in transit and utility vehicles.

The second market that you asked questions on was the energy storage system market. Demands are much lower in that market, but it is still starting to grow fairly rapidly.

The cell production is continuing to expand in China. Many announcements and constructions have begun in the EU, and the U.S. only has one major announcement for additional manufacturing.

In the EU, the plants are mainly by the current industry leaders. Some OEMs have done investment with some of the startups, and there are two pending government consortiums, one in Germany and one in France.

Lithium ions are made up of many different types of components to produce the cell. The value chain map starts basically with the main components of the battery and ends with the OEMs. This is a very well-established value chain and cell plants have been established in the U.S. But most of the raw materials still come from Asia. We are seeing major expansion in cell plants in the EU and that is leading to raw material suppliers also expanding in the EU.

The industry is very risk-averse, which provides only

limited opportunities for new companies to enter this space. The U.S. has industry leaders that produce metals raw materials in many different areas. They go into cathode and salt such as lithium.

There have been many announcements on lithium investments in the U.S., but for these investments to become a supplier, these companies will need to demonstrate products that meet the quality requirements for batteries and also are cost competitive.

In cathodes, cobalt is a major component, and the U.S. does not have a significant position. Significant development has been progressing well for low cobalt or no cobalt-containing cathode systems. OEMs have gone to significant efforts for materials traceability to ensure that the supply is responsibly sourced.

Nickel is much more abundant . The U.S. is in a better position to provide nickel precursors and the advanced types of nickel that are required for batteries. Aluminum is also used in cathodes, current collectors, cell casing and structural components. The U.S. is in a very good position in aluminum, with major producers like Alcoa, Novelis and Granges.

Recycling of lithium ion batteries and establishing the complex value chain is being led by China. They began with guidance documents in the 1990s, moved to requirements for

recycling for electric vehicles and consumer electronics. Substantial development has been completed in spent battery collection, centers to prepare batteries for recycling and transportation hubs.

The industry leaders in recycling have established processes that can recover metal precursors. The piloting facilities have not reached profitability yet, but with larger scale facilities we are projecting them to become profitable shortly. Korea is gaining ground rapidly on China to support their large cell producers. The EU has established battery recycling mandates that require 50 percent of the materials to be recycled into -- and there is a major meeting this week in the EU to discuss raising that to a normal level.

The US could play an ever-increasing role in the value chain. The first major change is for additional cell plants to be built locally and also materials demand. Second is for local components manufacturing, and finally to establish meaningful recycling. This should offer significant opportunities for the U.S. to become more relevant while managing the environmental and supply concerns. I think the "China-like" model of starting the process by establishing targets, assisting facilities for collecting and recycling could go a long way in demonstrating commitment and the focus on getting results.

I thank you for the opportunity today to provide my

testimony. I look forward to answering additional questions and supporting the committee's work in the future.

[The prepared statement of Mr. Sanders follows:]

Senator Barrasso. Thank you very much, Mr. Sanders.
Mr. Greenberger.

STATEMENT OF JAMES J. GREENBERGER, EXECUTIVE DIRECTOR, NAATBATT
INTERNATIONAL

Mr. Greenberger. Good morning Chairman Barrasso, Ranking Member Carper, and members of the Committee.

My name is James Greenberger. I am the Executive Director of NAATBatt International, a trade association of about 120 corporations and research institutions working to promote advanced battery technology and the industries it will power in North America.

The subject of my testimony this morning is the important role that recycling of lithium-ion batteries can play in developing new industry and supporting reduction of greenhouse gas emissions. Advanced battery technology will be one of the most important technologies of the 21st century. Lithium-ion battery chemistry, which was invented in the United States, represents the most powerful new battery technology widely used in commerce today.

Lithium-ion batteries not only power but enable electric vehicles, wearable and implantable medical devices, mobile robotics, consumer electronic devices, drones, the Internet of Things, high energy weapons, and a variety of other new electric devices. Several new technologies will shape human society in the 21st century. Advanced battery technology will be but one of them.

But advanced battery technology is unique in that it will enable many of those other technologies. Nations wanting leadership in those technologies will need a vibrant, advanced battery industry within their borders.

For the United States to have a vibrant lithium-ion battery industry, it needs to ensure that U.S.-based manufacturers have access to the energy materials and compounds needed to manufacture batteries. Few of those energy materials, such as lithium, nickel and cobalt, are found in great quantities in the United States, and almost none of the chemicals into which those energy materials must be processed to make batteries are manufactured here currently.

Recycling lithium-ion batteries used in the United States offers a partial solution to this supply chain problem. Recycling batteries can create a strategic reserve of battery materials which can provide supply and some assurance of price stability to domestic manufacturers.

Building a strong lithium-ion industry in the United States is critically important. Few other industries have the potential to create more jobs, both upstream and downstream of their immediate products, than advanced battery manufacturing. As we have long pointed out at NAATBatt, who makes the batteries will one day make the cars.

Recycling high voltage lithium-ion batteries is also

important for the environment and for public safety. Making lithium-ion battery cathode materials from recycled batteries can use as little as 18 percent as much energy, 23 percent as much water, and produce only 9 percent as much SOX emissions as producing those compounds from virgin materials.

Recycling high voltage lithium-ion batteries at the end of their useful lives also removes them from potential contact with incautious adults and curious children. A high voltage battery, no longer powerful enough to power a car, is still powerful enough to electrocute a human being.

Recycling lithium-ion batteries is a matter of public safety, as well as good environmental stewardship. But recycling lithium-ion batteries in the United States is a major problem. It is impossible, using current recycling technology, to make money from recycling most lithium-ion batteries.

The cost of shipping, storing and recycling those batteries is simply greater than the revenues to be made from selling the recycled materials. As a consequence, fewer than 5 percent of lithium-ion batteries reaching the end of useful life are recycled in the United States today.

New recycling technology, such as the direct recycling technology being developed at the Department of Energy's new ReCell Center may in time change this dynamic. But unless and until it does, the only way to recycle lithium-ion batteries

will be to require consumers, directly or indirectly, to pay for the cost of that recycling.

Electric vehicles and stationary energy storage of renewably generated electricity are powerful tools in the fight against greenhouse gas emissions. Imposing recycling costs on consumers on top of the still-expensive cost of lithium-ion batteries will inevitably impact market demand and greenhouse gas mitigation efforts. It is essential that recycling costs be kept as low as possible.

I would respectfully recommend that the committee consider four actions to protect U.S. economic competitiveness and greenhouse gas reduction efforts. First, ensure that any program requiring the recycling of high voltage lithium-ion batteries be implemented on a consistent, nationwide basis.

Second, encourage environmental and transportation regulations that differentiate between sophisticated, high voltage lithium-ion batteries, the kind used in electric vehicles, and the smaller, far less consistent lithium-ion batteries used in consumer devices.

Third, limit the export of used lithium-ion batteries in order to ensure a steady supply of battery materials to U.S. battery manufacturers. And fourth, fund more research into next generation technologies that may make recycling lithium-ion batteries safer, cheaper, and in time, hopefully profitable.

Thank you very much for your attention.

[The prepared statement of Mr. Greenberger follows:]

Senator Barrasso. Thank you very much, Mr. Greenberger.

And now, Mr. Chawan, and if you would, introduce your son as well.

STATEMENT OF AJAY CHAWAN, ASSOCIATE DIRECTOR, NAVIGANT
CONSULTING, INC.

Mr. Chawan. Thank you very much for having me here today. Good morning, Chairman Barrasso, Ranking Member Carper, members of the committee.

My name is Ajay Chawan, and I will introduce my 10-year old son, J.D. Chawan, who is here to cheer me on. I am glad you recognized him, as he is growing up in a world where plugging in an EV is as natural as plugging in an iPad. When I would come home from work, when he was three years old, he would come in to put the plugger in the car. Now for people like him and his cohort, an EV is another thing you plug in.

I really appreciate the opportunity to be here with you today to provide testimony regarding the benefits, challenges and opportunities associated with electrified transportation . I have worked in the EV space since 2012, and have led the effort to bring three electrified vehicles to market, with two different auto makers. Currently, I am a member of the Transportation and Grid Team at Navigant Consulting, where I help organizations, including municipalities and utilities, transition to using electric vehicles.

The movement toward the development and introduction of electric vehicles represents a revolution in how goods and people will move, and has the potential to impact numerous

portions of our lives. Three areas I would like to touch on today include energy security, jobs, and health.

Electric vehicles provide a significant opportunity to reduce our dependence on foreign oil. The U.S. is a net importer of about 854 million barrels of oil annually. For each consumer EV that gets put on the road, we can reduce our oil consumption by 25 barrels per year. The same EVs can be powered by electricity produced by a variety of domestic energy sources that employ American workers.

The transportation sector is a significant source of employment in America. The consumer automotive segment alone directly employs over 7 million people and indirectly impacts millions of others who live in those communities. As the transportation technology advances, the nature of these jobs will continue to evolve. The need for workers who are skilled in computer programming, advanced manufacturing and chemistry will continue to increase. American students who have benefitted from emphasis on science, technology, engineering, and math, or STEM curriculums, will be well-equipped to enter these technology focused spaces.

Finally, eliminating the tailpipes on cars and trucks will result in cleaner air due to a reduction in particulates, including carbon monoxide and nitrogen oxide from engine exhaust. These and other exhaust components are known to

contribute to costly diseases, including asthma, heart disease, and cancer. On 2010 study found that if clean air standards were met in California, 30,000 emergency room visits would have been avoided, saving \$193 million in hospital expenses for that State alone. EVs will achieve those clean air standards nationally.

EVs have been growing in popularity since they entered the market on a mass scale at the beginning of this decade. In 2012, there were approximately 14,000 EVs sold across six models. In 2018, more than 225,000 vehicles were sold across 16 models, an increase of 1,500 percentage points. Next year, consumers will have at least 40 models of EVs to choose from.

For reference, total annual vehicle sales in the U.S. is somewhere between \$15 million and \$17 million, depending on how the economy is doing . That is across 500 units . In 2030, Navigant projects that there will be about 3 million vehicle EVs sold that year, and that 13 million EVs will be on the road in that year as well.

One of the key opportunities to address with the increase in EV proliferation is what to do when the vehicle goes off the road, what do you do with that battery? I think my fellow panelists have addressed that point. The average life of a car or truck in the U.S. is about 11 years. After this time, the EV battery still has about 70 percent of its storage capacity left.

One option receiving significant consideration today is using these batteries to provide backup power at critical locations, such as military facilities, hospitals and data centers. Finding uses to give second life batteries a new home is an area my team is very much focused on today.

As research and development dollars continue to flow into the EV battery space, their characteristics will continue to evolve. This includes the very elements used to make batteries and the methods by which they can be redeployed and later recycled. Our research and data shows that there are social, domestic energy security, economic and societal benefits from electric transportation that are poised to increase in the coming years.

Again, I would like to thank you for the opportunity to be here today. I look forward to our discussion.

[The prepared statement of Mr. Chawan follows:]

Senator Barrasso. Thank you very much to all three of you. You can tell how much interest there is in this topic by the number of Senators who have already arrived to listen to you.

Mr. Sanders, relatively little critical mineral mining occurs in the United States, even though we do have some mineral resources. Just last week, CNBC had an article out and it discussed opportunities for Wyoming to increase our domestic supply of minerals. I am going to enter this article into the record, without objection.

[The referenced information follows:]

Senator Barrasso. In your testimony, you highlighted interest in producing critical minerals domestically. Could you discuss what is driving the interest, and how can we do more of these activities in the U.S. in an environmentally responsible way?

Mr. Sanders. The interest comes from really a couple of different areas. Most of these materials have extremely long supply chains. Take cobalt, for instance. Most of it is mined in the Congo. It then goes to Asia for production of cathodes, and then back to wherever the country is that the battery is being produced.

So it would be a much more efficient supply chain, if a cell is being produced here in the U.S., if the minerals and raw materials also came from the U.S. So that is the easiest one. That is a tremendous cost to the industry, of relocating these materials from these various areas.

The second thing is, just from an environmental perspective, if the U.S. can become competitive in supplying these materials, it then reduces our reliance on China and other areas basically being the leaders in this space. Your article on Wyoming was focused in on rare earth type materials. Those are very critical to electric vehicles, mostly in the motor and the magnet side of the equation, a little bit in lithium-ion. But there has also been reports of lithium reserves in western

States, Wyoming and Nevada and others.

So there is the potential of the U.S. becoming competitive and supplying the critical material.

Senator Barrasso. Can we do it in an environmentally responsible way?

Mr. Sanders. I think all of these materials and mining can be done in a responsible way, as long as it has the right guidance and establishment of processes. My prior career was with Dupont, and we had lots of chemical processes and so forth that could be operated in a lot of different areas. So that type of thing can be set up responsibly, it just needs to have the right systems put in place.

Senator Barrasso. Mr. Greenberger, in your testimony, you talk about the need to manage spent batteries because of the public safety concerns. You said if we do not properly dispose of high voltage lithium-ion batteries, it is not a question of if a child wandering through a field or a junk yard would be electrocuted, but how many, and long it would be before we decide to do something about it.

How do spent batteries pose electrocution or fire risks, and what should we do about it?

Mr. Greenberger. As spent batteries are high voltage electric equipment, just like any high voltage electric equipment, someone who opens one up and touches the wrong part

of it is likely to have a very bad outcome. So we have to do something to make sure that at the end of useful life, those batteries are removed from the environment, are decommissioned, disassembled and hopefully recycled. There is a real public need to make sure that that happens. I know members of my organization very much look forward to working with this committee and the Congress in trying to figure out exactly how best to do that.

Senator Barrasso. Mr. Sanders, you may know about how much it would cost to recycle a lithium-ion battery from an electric vehicle. Do we see that cost decreasing for new and innovative recycling techniques?

Mr. Sanders. The best place to look for economics on recycling is today is looking at what China did. They basically established collection facilities to basically collect the battery packs into a reasonable location, prepared those for recycling, and ship those then to a recycling center. The processes that have been established in China, though they are only in piloting level, appear to be able to, once they get to full commercial scale, to recover enough metals to basically recover the cost of the recycling piece.

The piece that still remains a cost to the overall system is that collection piece. Those batteries that are collected and then sold in China to the recycling centers are done at the

metals cost. So that cost piece still has to be managed in the value chain. That is still something that has to be worked out as to how exactly that manages to go forward.

Somebody mentioned earlier the lead acid being 99 percent here in the U.S. That is true. But the processes established and the procedure there that basically got to where there were collection facilities in place, and also as we buy, as consumers, batteries in the marketplace, we also pay a recycling fee when we buy a battery at the local supply chain. So there are ways of managing those types of things, they just have to be figured out, what is the best way to manage that economically.

Senator Barrasso. Do you have an estimate of the current cost to recycle a lithium-ion battery from an electric vehicle?

Mr. Sanders. From raw material all the way, or from basically collecting it from the spent vehicle, to the total reproduction, probably in the neighborhood of \$5,000, depending on size of vehicle and so forth. The metals value is probably in the \$3,500 range. So a substantial portion of that can be recovered from the metals piece of it.

Senator Barrasso. Senator Carper.

Senator Carper. Again, thank you all. This is fascinating and I believe encouraging. Some of our colleagues arrived mercifully after the Chairman and I gave our opening statements, but I just want to go back and reiterate one of the things I

said.

It was just announced last week, a joint venture between Ford and Volkswagen, to develop the next generation electric vehicle. These vehicles are coming, and there are going to be a lot more of them on the road, which I think is a good thing. Hopefully a lot of those vehicles are going to be made here in America, with components, including batteries, that are American.

I have reminded my colleagues a time or two in the past that the Detroit Auto Show, which I go to just about every year, 11 or 12 years ago, the car of the year was Chevrolet Volt, V-O-L-T, an electric hybrid, 38 miles on a charge. A year or two ago, the Chevrolet Bolt, B-O-L-T, all electric, 240 miles on a charge. Next year at the Detroit Auto Show, we will see Tesla vehicles and others getting 300 miles on a charge. This is coming.

We can either be part of it and very much invested and enjoined in the creation of these manufacturing jobs, the research and manufacturing, recycling, or not, or let somebody else do it. We have to be smart enough to take full advantage of it. As we say in Delaware, Carper Diem, also known as carpe diem.

I would ask this question, if I can, I want to make sure I pronounce your name right. Is it Chawan?

Mr. Chawan. Chawan, yes, sir.

Senator Carper. Thank you. In your written testimony, you mentioned that between 2012 and 2018, electric vehicle sales in our Country grew by 1,500 percent. You go on to say that during the same time period, electric vehicle sales in China increased by almost 8,000 percent. The growth trend isn't expected to slow down any time soon.

It is my understanding that if current trends continue, China would account for half of the global electric vehicle market share by 2025. Other countries are also adopting electric vehicles at a faster rate than the U.S.

Should the elected government support the deployment of electric vehicles in the U.S. to ensure that China and the rest of the world do not dominate the future of transportation electrification? In your answer would you discuss how federal investments in electric vehicle charging infrastructure in this Country would help our car manufacturers to be competitive?

Mr. Chawan. Thank you for your question, sir. In order to promote EV adoption in the U.S., there are three pillars that we typically look at. We look at infrastructure, we look at the product cost, and we look at awareness. So awareness generation has been taking place through many activities, including activities by the auto makers, by other third parties such as network operators.

The network operators are also building infrastructure. There are several national network operators out there today. There are also network infrastructures being built by electric utilities, which is an area that we spend a lot of time focusing on as well.

Lastly is the cost piece. As the proliferation of EVs continues, the cost per unit will continue to go down. We are kind of in the \$6,000 per flat panel TV stage of the technology development curve. As more and more volume comes online, the cognitive scale will kick in and new manufacturing techniques and advances in production will enable us to bring the cost per unit down. That will help with the affordability factor of electric vehicles.

Senator Carper. Good, thanks. Just one follow-up question to that, if I could. Based on what you know today, do we have sufficient critical minerals available to be able to produce enough batteries to support the projected electric vehicle growth in our Country?

Mr. Chawan. In our Country? I do not have that information, sir. The last, the only reference point I have is from a USGS report on some of the critical elements that were talked about today for battery production. USGS shows that the U.S. has less than 1 percent of global reserves of nickel, cobalt, and lithium.

Senator Carper. All right. A follow-up question to you, Mr. Chawan. In your testimony, you stated that battery research is happening today that if successful, would dramatically reduce the quantity of critical minerals needed to build and run an electric vehicle battery. My question is, how far along is this research in the U.S.? Do you see auto makers switching from a more traditional lithium-ion battery to a more sustainable battery? Do you agree with what I said in my statement that electric vehicle batteries we are using today are most likely not the battery technologies we are going to be using five or ten years from now?

Mr. Chawan. I think there are three answers to each point individually. Question one was about how far battery research is coming along. There are numerous reports out there for what is the next generation of batteries commonly referred to as solid state, where the liquid portion of the battery is changed to a solid material.

Toyota has stated it is going to have that out by 2022, and some reports say it could be even sooner than that. That would represent a major shift in battery technology.

The question about what our batteries will look like several years from now versus today, the chemistry will very likely be different. As far as what that chemistry looks like, I don't know for sure. And I am sorry, could you repeat the

other question?

Senator Carper. Do you agree with what I said earlier in my statement, that the electric vehicle batteries that we are going to be using in five or ten years are going to be different? That was my last part, I think you responded to that.

Mr. Chawan. Thank you.

Senator Carper. I am going to slip out for a little bit. We all have other committees that are meeting right now. In the Homeland Security committee, we are having an important roundtable discussion on push and pull factors leading to all the surge of people coming to our borders. So I will be going to that, and I will be back. I am very much interested in everything you have to say.

Mr. Chairman, I am delighted that we are having this hearing. Thank you.

Senator Barrasso. Thank you, Senator Carper. Senator Inhofe.

Senator Inhofe. Thank you, Mr. Chairman. First, I want to get into the record this article in Fortune Magazine, it talks about some of the child labor problems.

Senator Barrasso. Without objection.

[The referenced information follows:]

Senator Inhofe. Mr. Chawan, I have spent a lot of time in Africa. I know some of the problems that are there. We know that most of this mining we are talking about is in Congo. We know of some of the problems that were pointed out by the chairman, the picture up here of some of the problems that I am very familiar with.

We know that children are used in cobalt mining, primarily in the Congo, and some of the companies are taking initiatives to better ensure that batteries are ethically mined. What is your thought about that? What have we accomplished and what can we do that we are not doing now?

Mr. Chawan. The traceability of materials I think would be potentially another way to describe what you are referring to. It is definitely possible. It is done in other industries today. For example, the food industry does that very well. The auto industry does that very well for manufacturing, so we know precisely --

Senator Inhofe. So you would be doing it just as well as it is being done right now?

Mr. Chawan. It is being done in these other industries for sure. I do not have familiarity with the mining industry, so I cannot speak to the traceability there. I can simply state that there are best practices from other industries that could potentially be adopted for the mining industry.

I think one of the challenges that we would see is what happens when you mix raw materials from multiple sources at a processing facility.

Senator Inhofe. Okay, it sounds like if you have any problems, just consult your son.

[Laughter.]

Senator Inhofe. Well, I actually do that. I have 20 kids and grandkids. I fly airplanes, and every time I get a new instrument for an airplane, I have my grandkids read the manual and explain it to me. So I am serious when I make that suggestion.

[Laughter.]

Mr. Chawan. I am happy to chat separately about this with your office.

Senator Inhofe. All right. I have another article, Daily Caller article, to be made part of the record.

Senator Barrasso. Without objection.

[The referenced information follows:]

Senator Inhofe. This covers some of the problems with the labor problems that are in there. I would like to, Mr. Sanders, this article talks about how California is contributing to the increased demand on cobalt. We know that is the case. Environmentalists claim that electric cars are the solution to many of the problems that we have. I would also suggest that maybe they are the problem than other solutions.

For example, what is happening with the Highway Trust Fund right now, the reason it is in trouble, is primarily due to electric cars. Then we have the human rights concerns. Earlier this year, the State of California debated a bill that would require the State to ensure zero emission vehicles that they are free from materials using child labor. Now, that bill failed, and the reason is very simple: a prohibition of this kind would get in the way of maintaining the radical electric vehicle mandate.

Unfortunately, California turned a blind eye to the human rights abuses. Mr. Sanders, could you talk about these human rights concerns in the remaining time?

Mr. Sanders. Well, I think the human rights concerns are real. The traceability is also becoming real. Multiple OEMs, global OEMs have established traceability programs from the mines in the Congo, all the way through their supply chain. So it is something that can be executed. And it is being executed

by some of the major OEMs.

The other point that is starting to happen, Senator Carper pointed it out and asked, are batteries today going to be the same as they five years and ten years from now. There are substantial programs to reduce the amount of cobalt that is contained in batteries, and potentially to go to zero cobalt batteries in the very near future. Lots of universities and OEMs have claimed significant breakthroughs. So I think the percentage of cobalt per battery is likely to go down dramatically, which will also further improve the situation.

Senator Inhofe. Thank you, Mr. Sanders. Thank you, Mr. Chairman.

Senator Barrasso. Thanks, Senator Inhofe. Senator Cardin.

Senator Cardin. Thank you, Mr. Chairman. I very much appreciate your leadership, and Senator Carper's leadership, on this issue. It is clear that consumer choice for electric vehicles is there. We have seen the increase in demand. Consumers like it. It is an imperative on our environment to reduce carbon emissions.

So this is clearly not only the future, it is the present. And we need to encourage this.

The supply chain issues are real. I just really want to underscore the concerns that have been raised by my colleagues. We cannot allow that vulnerability for our consumers rewarding

labor practices which are totally unacceptable, and the security issues of our own supply chain. So that is an issue that I fully support the leadership of this committee, to look at alternative ways. You have mentioned legislation, Mr. Chairman, I think we all need to look at ways to be more secure in that regard.

I want to get to the recycling issue for one moment. To me, that seems like low-hanging fruit. As I understand it, we are very dependent on recycling outside the United States. We do not have the domestic industries here to handle the demand that is clearly here today, and will grow tomorrow. That reduces the need for a lot of these critical materials. It also is much friendlier toward our environment generally. And it economically makes sense.

Mr. Greenberger, let me start with you. What do we do as Congress to encourage the robust development of domestic recycling for these batteries?

Mr. Greenberger. Ultimately, what you need to do, what we need to do as a Nation is really encourage the development of a market for these products in the United States. Just to go back to the human rights issue that was earlier talked about, it really is a problem, that human rights abuses are going on in the Congo, and there is really nothing we can do about it, if China is buying 80 percent of cobalt, which is what is going on

today. Because the Chinese don't have the same concerns that we do about human rights issues.

If we built a vibrant battery industry in the United States, by building a vibrant industry for electric vehicles, suddenly we have some control over our future, or over human rights violations abroad, over how we recycle batteries and use the materials here in the United States.

So it really does come down, for me, to the issue of, if we are going to be serious about competing in this new technology, we have to do essentially what China did, and that is build a domestic demand for the products. It is really important, and not just for cars and not even just for greenhouse gas emission issues, it is really important because it is the technology of the future, and it is going to impact a number of industries that are important to this Country and that are going to be the source of jobs.

Senator Cardin. I agree with that point. I am proud of Maryland; we have companies that are on the cutting edge of battery technology. You are right, it is well beyond just transportation. But it is an area where the United States should excel, and we are not as competitive as we need to be. So I completely agree with you.

This committee, of course, needs to look at the transportation infrastructure. It seems to me that by

recycling, we not only are doing things that are smart economically, but we are reducing our demand on the supply chain. I couldn't agree with you more, we should be able to have control of our supply chain, and we don't. China right now is the dominant player on it.

So we need to develop an entire industry. But it seems to me, low-hanging fruit is the recycling of the batteries. What do we need to do to get that moving? Mr. Sanders?

Mr. Sanders. One of the biggest areas that is probably the first challenge that we are facing is, how do we get these used batteries back into the supply chain. If you look at how China set up their model to begin with, the first step that they took was establishing a mandate that basically a certain percentage needed to be recycled. Then they established basically a protocol to get these things to collection centers.

We all have probably a dozen of these things sitting in our house that are waste batteries and waste electronics that have value. If we got to having a robust collection facility approach, that then goes a long way. Because then you have a supply chain of materials that then can go into recycling, can go into the value chain.

But until you get these things collected, they are scattered throughout the U.S. and around the world, and that is a huge challenge for everybody. The EU is meeting this week

regarding these and how many of these are used in each different country. So they actually have data to then go, how big is the problem, or how big is the opportunity.

I think that is the first step, is kind of understanding where these challenges are, and putting together a directive that basically says, here is where we are going. We may not know all the answers of how to get there. But until we basically say, we are going in this direction, it is really hard to get everybody motivated into one organized direction.

Senator Cardin. I would just conclude by saying, I agree with you. The supply today is huge, just in order to get this started. But think about where we are going to be tomorrow. I mean, it is just going to continue to grow. And you can't put these policies into effect overnight. It is going to take time. We are already well behind where we need to be, and when we look at the future, it is imperative that we act quickly.

Thank you, Mr. Chairman.

Senator Barrasso. Thank you, Senator Cardin. Senator Capito.

Senator Capito. Thank you, Mr. Chairman, and thank all of you.

We talked a lot about the core materials that are needed for the batteries. But we do have rare earth elements that are essential to some of that. You all have alluded to some of this

in some of your testimony. It is a particular source of interest to me, because of what we see happening in our State of West Virginia. We know that the last rare earth mine closed, but then reopened, but they are having difficulty with their profitability.

Even though they were able to mine some of the materials, they had to send it, my understanding is, to China to have it refined. That is an issue and an expense at the same time.

So I think we need to guard ourselves against the shocks, the global supplies, of these rare earth elements. At West Virginia University, led by, I am going to call him Dr. Z, because that is what we call him, has been exploring technology to clean up the waste and generate concentrated rare earth elements in our coal, our fly ash and our acid mine drainage. So for me, this hold great promise to solve a domestic supply problem for us in rare earth, but also has the environmental benefit of going into prior acid mine damage or fly ash, to be able to get some benefit out of this and clean it up at the same time.

They are working with a Pennsylvania company called NOH2O solutions, and I have a letter for the record that I would like to submit, without objection, Mr. Chairman.

Senator Whitehouse. Without objection, so ordered.

[The referenced material follows:]

Senator Capito. Thank you, thank you, Mr. Chairman --

Senator Barrasso. In-waiting.

[Laughter.]

Senator Capito. That is a good one. So anyway, I have three questions around this in particular. I am interested in the recycling issue as well, but I am going to concentrate on the rare earth. Can you speak to the importance of rare earth elements in building EVs, batteries and drive trains? Are the costs of these rare earth elements disproportionate to the small volume that they're used in? Put another way, are they expensive inputs? How vulnerable do you think we are as Americans to have access to rare earth elements to be able to threaten this industry?

I will just start with you, Mr. Sanders.

Mr. Sanders. They are very expensive. That is probably the easiest one of the questions. We are very vulnerable to the supply chains of these materials. As you said, most of the refining of these, and most of the mining of these is done in China.

Senator Capito. Right.

Mr. Sanders. So that creates a significant challenge. Where they are really critical is in the motors and the drive train side of this. In the battery side, less so.

A significant opportunity that we have not talked about

today for the U.S. would also be natural graphite, the anode side of the equation here. For those States that produce coal, that could be an option to basically get to a natural graphite solution. So there are opportunities for the U.S. to participate here in both the battery and the EV space.

Senator Capito. Mr. Greenberger?

Mr. Greenberger. Again, I believe the problem with rare earths and our production of rare earths in the United States is that the market for rare earths in the United States is relatively small. So we have not been willing, businesses can't make investments in those types of projects and hope for a reasonable rate of return.

The Chinese, because they have done so much to promote their markets for vehicle electrification and for the other types of technologies that use rare earths materials, are really in the catbird seat when it comes to producing and supporting their own domestic industries. So there is no reason why we cannot produce rare earths in the United States, and we should. But the best, fastest and most direct way to do that is to build up demand for products that actually will require rare earth materials and stand back and see what American businesses will do.

Senator Capito. Right. And that seems to be sort of a universal thing, certainly with you, but with the panel as well.

The market needs to develop to catch up. But for this particular, my particular interest on the environmental side, I think, is the Department of Energy has been very helpful in terms of helping us to develop that technology.

Mr. Chawan?

Mr. Chawan. Yes, I think I would echo everything the panelists have said. The other topic I would add is, as technology develops, the demand for rare earth is declining. So there is a new technology called asynchronous motors, it is a motor that in short, allows for better current flow into the battery for better torque control on your motor which provides better driving dynamics. It will also reduce the need for these materials.

Senator Capito. But the materials, as far as my knowledge is here, the materials are used in a vast other array. It is just creating a bigger market, better market in this Country. Because if China has cornered the market, there is obviously something there, yes. Thank you.

Senator Barrasso. Senator Markey.

Senator Markey. Thank you, Mr. Chairman. Thank you for this hearing.

Some members of the committee have expressed concerns about the sources of raw materials used to make electric vehicle batteries. As has been pointed out today, mining practices

associated with some of the raw materials in batteries, particularly cobalt, raise legitimate reason for concern. Exploiting child labor and using unregulated mining practices is unacceptable. We must work to avoid these sources.

Mr. Chawan, do all electric vehicle batteries require the use of cobalt?

Mr. Chawan. For most of the technologies that are popular today, yes.

Senator Markey. New alternatives, however, are being developed?

Mr. Chawan. Yes, sir, they are being developed. Tesla, for example, has already done a great job of reducing the amount of cobalt that it requires. I believe it is called an 811 configuration. I can follow up with your office with more details on that.

A lot of research has been put into reducing the need for cobalt in EV batteries today. It was simply found that that was an effective solution in the beginning of this decade, when we were trying to develop EV batteries for the market.

Senator Markey. So these new alternatives are very important, because we could focus, perhaps, on the ethical sourcing?

Mr. Chawan. Precisely. If we can take away the economic demand for these problematically sourced materials, we can

definitely have a positive impact that way.

Senator Markey. So a coalition of major car manufacturers has committed to source cobalt ethically, Ford, LG Chem, IBM, Huayou Cobalt, have undertaken a blockchain project to address the problem in the Democratic Republic of the Congo. Potential applications like this are why I think we should try to promote the use of blockchain technology. I am the co-sponsor of a bill which has already passed out of the Commerce Committee last week. We have to find solutions here, because they will encourage avoiding mining in vulnerable, marginalized communities, not only around the world, but even here in the United States.

So it is important for us to ensure that the notion that the only choice we have is to trade one harmed in the world for a child harmed here. It is just not acceptable. Yes, sir, Mr. Sanders.

Mr. Sanders. In addition to block chain, standard traceability techniques that have been used in the food industry and other areas are being put in place in the Congo. Only about 20 percent of the mining in the Congo has the concern of child labor and those issues. The three major producers in eth Congo have responsibly produced cobalt for quite some time.

Multiple OEMs have established relationships with their mining partners and their supply chain to basically put

traceability in place. So blockchain is an option. But standard traceability of shipments and understanding where it is coming from and ensuring that it is coming through that value chain has also been put in place by both U.S. OEMs and some German OEMs that I am aware of.

Mr. Markey. And I want to highlight one other issue, which is, instead of expanding mining, we should be looking to other resolutions, like recycling. The minerals used in these EV batteries are used in many electronic products, in military applications. I am glad to hear from our witnesses today that recycling can be a bipartisan solution and they would look forward to working together with all of us on a bipartisan basis in order to expand efforts in that direction.

When Congress was faced with the environmental impacts of disposing of lead acid batteries, we took action to create the necessary incentives to recycle. We should do the same for the recycling of electric vehicle batteries and all of the materials that would be central to advancing that goal. Researchers in my home State of Massachusetts are advancing the state of lithium-ion battery recycling. Companies like Battery Resources are finding ways to process and re-use these materials.

Can you give us your insight on that issue as well? Mr. Chawan.

Mr. Chawan. Yes, on the recycling?

Senator Markey. Yes.

Mr. Chawan. I think what we are really focusing on is extending the life of the battery. Once it is built, we want to use that battery for as long as it is humanly possible. So what we are doing is focusing on, what can we do when the battery comes out of the vehicle, and finding homes for it in other applications, for demand response.

So if you can provide backup power for important facilities such as medical centers and data centers, you can use that battery for a longer period of time and delay the time that you need to spend time, energy and money to break down the battery into its constituent components. We are hopeful, as more vehicles come into the market, more batteries come into the market, we will build up a larger bank of vehicles or batteries that you will hopefully start to get the economies of scale better needed to have a robust recycling program.

Senator Markey. Thank you. Mr. Chairman, thank you.

Senator Barrasso. Thank you very much. Senator Braun.

Senator Braun. Thank you, Mr. Chair.

I am interested in the carbon footprint. Reading that, to produce an electric vehicle currently, give or take, it produces maybe twice the carbon impact versus an internal combustion engine vehicle. I want to know if that is true or not, or if that is roughly the dynamic. Then it begs the question of what

the useful life is, and of course, the battery and so forth.

Has there been any study, and anyone can answer this, to where you look at what the CAFE standards would have to go to in terms of miles per gallon before it would make the whole argument of an electric vehicle more of a moot point? Normally, that would seem to be something, especially if I was making a regular vehicle, I would want to know, well, how good would we need to make the mileage before it would make the whole argument for electric vehicles maybe less relevant, and addressing the fact that produce one, it has twice the carbon footprint, just to get it on the road.

Mr. Greenberger. I will try that. I have heard this statistic, about twice the amount of greenhouse emissions.

Senator Braun. Yes.

Mr. Greenberger. I have no idea where that comes from. That seems a little bit odd to me. I think certainly recycling is one of the ways that we can reduce the carbon footprint that it takes to produce an electric vehicle. But I think that we are also, it is important to pay another issue in terms of what is really driving the move to vehicle electrification. Part of it is greenhouse gas emissions. But part of it is also is that everything is just electrifying. When we start putting automatic locks and heated seats in cars, you are moving to things like autonomous drive, which are huge draws of

electricity on the vehicle, our vehicles are going to become electric regardless of what fuel prices do. That is just the way that technology is going. We are going to be riding around in computers on wheels. And computers don't tend to run on gasoline very well.

So I think the vehicle electrification is coming for a number of different reasons. I don't know that just increases in fuel economy in the internal combustion engine are really going to, in the long term, significantly slow down that trend.

Senator Braun. Fair point. Mr. Sanders, you had mentioned earlier roughly \$5,000, was that the cost to rehabilitate a worn battery, or what is the cost of a new battery in the average EV currently, and what does it cost to recycle one? Is its life as long as the original battery once it is recycled?

Mr. Sanders. The \$5,000 was a typical battery that is in China now that is basically for an electric vehicle, so what would be here a mid-size type vehicle. There is such a range on each one of those pieces of data that it is hard to quote a given number. But the bottom line in China is, they have put together a collection organization, basically, that allows the folks doing collection and collecting the battery and readying for recycling to make money. Then it appears now that the companies that are doing the recycling, because of the metals value that they can recover out of the recycling process, once

they get to commercial scale, which we are projecting at about 20,000 units, which is not terribly big, they should be able to make money themselves.

So there appears to be financially viable ways of doing this. But it is going to take basically that same type of commitment that China did to basically establish that directive, establish the collection process and drive it through the value chain. Whether it ends up being a hybrid of something like we did for lead acid, where there was support for the recycling through the value chain, or whether it is totally done in a different economic model here, I think is still to be determined.

Senator Braun. And is the projected cost of that recycled battery, once you got to economy of scale, going to be less than the original cost of a new one? Is there any data on that? Because I think that would be a strong case for not only building the infrastructure for recycling, but it would be a cost savings, as long as the life of the recycled battery is close to what the new one would be.

Mr. Sanders. There certainly is that opportunity for profitability, basically, beyond where they are taking recycling today. Where they are taking recycling today is to the metals precursors only. But there is the conversion, then, to the cathode, there is the conversion into the battery itself that

basically can be done at a profitable level through the value chain.

But there is also significant companies, an IP that has been established for conversion of those precursors into a battery material and into the batteries themselves. So I am not exactly sure how that is going to play out. That is still to be determined.

But there are large organizations that have been established, that are battery manufacturers, that have established themselves as the leaders in establishing that value chain and establishing the recycling. So they certainly think that there is the opportunity there to make money through this value chain, and to improve profitability and sustainability by doing it themselves.

Senator Braun. Thank you.

Senator Barrasso. Senator Whitehouse.

Senator Whitehouse. Thanks, Chairman, and thank you for this hearing. The electric vehicle battery recycling problem falls into a larger context of electronics recycling generally. As you all know, the United Nations found that out of 45 million metric tons of e-waste generated globally, 20 percent gets properly recycled, and the rest just goes off into whatever kind of junk operation there is.

A lot of that junk operation is overseas. Do any of you

have anything nice to say about the quality, capability, integrity, cleanliness, effectiveness of a lot of these off-the-books overseas electronic waste disposal operations?

Mr. Greenberger. If I may, yes. Let's make sure that doesn't happen.

Senator Whitehouse. It is pretty poisonous.

Mr. Greenberger. It is bad stuff.

Senator Whitehouse. And it is badly handled in most of these overseas operations.

Mr. Greenberger. And the good news is, if we can keep our waste here and turn it into products that we can use in domestic manufacturing, it is a double win.

Senator Whitehouse. So let me tell you one quick story, which is that I have a bill just on the electronic waste that comes out of these things, our consumer electronics, not refrigerators and washing machines. And there is a group called the Institute of Scrap Recycling Industries, which is the trade association for this group. My bill would do exactly what you have proposed, require it to stay here, so that Americans get the jobs in the recycling and disassembly, so that it does not contribute to the poisoning of wherever this is done on the cheap overseas.

ISRI has been opposing the legislation because ISRI members -- guess what? -- are invested in overseas operations. So they

have a big conflict of interest in this. We are still working with them. But we have a real problem with the fact that some of the groups that are active in Congress on this subject actually are invested in some of these overseas operations.

So if we are going to do this, we are going to have to address that fact head-on. I am with you, and I hope we can do this.

What is each of your best estimates on how many EVs will be on the road by 2040? By that, I mean cars, trucks, and buses. Mr. Sanders?

Mr. Sanders. Twenty forty is a long way out there, but we are projecting 3.7 million by 2030. If you stay on that same ballpark curve of where that is by 2030, that should put it somewhere in the range of 6 million.

Senator Whitehouse. Okay.

Mr. Sanders. So at that point we would be at 56 million vehicles per year sold. So in addition, basically if you look at that --

Senator Whitehouse. So you stack it up year over year.

Mr. Sanders. Yes, if you stack that up basically from today, you would be sitting probably in the range of 50 million vehicles.

Mr. Greenberger. So I am going to defer to my two witnesses that are in the business of collecting this data.

Mr. Chawan. Senator Whitehouse, I have data through 2030 in front of me from our latest forecast. U.S. EV sales in 2030 are about 3 million. And the U.S. EV population in that same year, so total light duty vehicles on the road is about 14 million.

Senator Whitehouse. U.S.?

Mr. Chawan. U.S.

Senator Whitehouse. How about globally?

Mr. Chawan. Globally I don't have those figures. I can follow up with you.

Senator Whitehouse. I will do a request for the record, a QFR, so you can follow up.

Mr. Sanders. Globally, you have through 2030 in my testimony. There is one chart. And basically by 2030, we are projecting, I think it is around 11 million vehicles to be sold in 2030. So the cumulative, basically, if you looked at that from a 2040 basis, in addition to the 50 here, there would probably be close to 50 in Europe, and probably close to 100 million in Asia. So 200 million vehicles, roughly.

Senator Whitehouse. And as people who look at this market, I think there was an expectation that when electric vehicles came into the market, they would be basically glorified golf carts and kind of cheesy and people would laugh at them. In fact, they are coming in through Audi, Jaguar, Mercedes, Bentley

has even started displaying its concept EV.

Mr. Sanders. Porsche.

Senator Whitehouse. Porsche has a huge car that is actually coming to market right now. They are coming in, not at the bottom of the market like glorified golf carts, they are coming in at the top of the market as vehicles that compete on performance with Lamborghinis and cost a quarter, or a third or a tenth as much. What does it say to you about adoption, that these vehicles are coming in at the top of the market as market-leading, aspirational purposes, rather than as glorified golf carts creeping into the bottom of the market?

Mr. Sanders. I don't know whether you all have had the opportunity or the fun driving experience of driving an electric vehicle.

Senator Whitehouse. We have two Bolts, which is probably the cheapest and least exciting of all these electric vehicles. And it is great, it is amazing, it is a wonderful vehicle.

Mr. Sanders. Right. The torque is incredible. The amount of noise is just next to nothing. And the only cost of maintenance, basically, that is demonstrating that it is going up versus going down, is tires. That is because we are all going a little too fast in the electric vehicles. But they are a hoot.

And the breadth of vehicles that are starting to be offered

now, you are right, there are certainly the premier vehicles and so forth. But if you look at some of the launches now by General Motors and by Volkswagen and some of the others, they are hitting the midstream, main focus of vehicles. We are projecting cost parity now for electric vehicles to happen by 2023 to 2025.

So when these things actually start costing equal to or less than internal combustion engine vehicles, that is when we really start hitting the curve for these things taking off.

Senator Whitehouse. And I have overdone my time, so let me just ask unanimous consent to put into the record a report on electric vehicles being cleaner from cradle to grave.

Senator Barrasso. Without objection.

[The referenced information follows:]

Senator Barrasso. Senator Van Hollen.

Senator Van Hollen. Thank you, Mr. Chairman. Thank all of you for your testimony.

I want to thank the chairman and the ranking member for having this hearing. I think it is a really important and timely hearing. I was listening in by TV before I came here. Mr. Greenberger, I thought I heard you say he who makes the battery will ultimately make the car. Is that right?

Mr. Greenberger. That is correct. And we also know just by looking at where we are today in the United States compared to China, for example, we are way behind. We just have a couple recent headlines: China is building the batteries of the future; electric cars, China powers the battery supply. We had mentioned the fact that they have a lot of natural resources in China.

But they also are doing the recycling. They are doing a major recycling program. They have also been much more strategic about overseas supply operations.

Senator Van Hollen. So my question is this, because we are talking about the future market for electric cars, we are also talking about the fact that China has a huge head start. If you look at their investment in clean energy overall from 2005 to 2018, it has gone up like a rocket ship. We were essentially a little bit ahead of them in 2005, the United States, if you

looked at both public and private investment in clean energy. They are now way ahead of us and it has been a steady incline.

So what does that mean to all of you in terms of who is going to be making the cars around the world when it comes to the electric car industry. What would you do, if you were czar, if you were king for a day here in the United States, what are the three things that you would do, that we could do, to help change this?

Mr. Greenberger, you talked about how we need to induce the market, you need more demand, get more people to invest. But it is a little bit of a chicken and egg situation, right? So Senator Markey and I and others have bills that would create more of a financing authority, kind of a green bank, a climate bank, to help more U.S. investment go into clean energy.

But what are the three things each of you would do, here for the United States, to address the challenge that you see before us? If you could just give me the top three. I am looking for anything that also requires Congressional action.

Mr. Greenberger. Sir, first of all, I think we should look at history to some extent. We have seen this movie before. Ten year ago, we wanted the United States to get into the electric vehicle business, and the ARA devoted \$2 billion to battery manufacturing in the United States and to promote electric vehicles.

Those investments were not particularly successful, because it was sort of build it and they will come type of investment. It didn't really pan out. Most of those projects turned out not to be commercially successful, and many ended up being bought by Chinese companies.

China took a somewhat different approach. They decided to incent demand. There are 400,000 electric buses in China, there are 2,000 electric buses, about, in the United States. There were huge incentives put into electric vehicles. There was a market created for vehicle electrification. If you take a look at a lot of the things we hear about China, that we don't like about China, about them promoting a technology transfer, it is all by companies trying to access this consumer market in China.

So the lesson to be learned from the last 10 years, from my perspective, is pay attention to market demand rather than technology push. That is really where the Chinese have gained their leverage. If you can create that market demand, however you are going to do it, whether that is by additional vehicle subsidies, whether that is by purchasing electric buses or heavy duty trucks for municipalities or government organizations, however you want to do it, if you can do that, you are going to be far better along than you will be of just trying to build a supply chain for a demand that doesn't yet exist on a real basis.

Senator Van Hollen. Got it, thank you.

Mr. Sanders. I guess the guidance that I would give us, don't invent the process. There are multiple examples today by China of establishing very clear direction and sticking with it. We have a tendency here of wandering in direction. And when you wander in direction, you get poor results. Jim mentioned the facilities that were built in 2008. Great intentions at the time.

But the market wasn't there. And then we didn't stay with the program. We then went off to some other different direction.

If you look at how China established clear guidance that we are going to electrify, now their problem for pollution was substantially worse than ours. So they had to do something. They had no choice.

But if you look at what is happening in Europe now, you are getting very clear direction. Norway set deadlines, England set deadlines, Germany has set deadlines for when they are going to convert from internal combustion engines to electrified vehicles.

And now the overall business infrastructure is getting behind that. And it gives them a clear path to basically then execute to do what business does well, see the opportunity and say, okay, the game is going to change, how am I going to

participate in that game and win. We have the opportunity to win here. It is just a matter of, it has to be a clear direction in where we are going.

Senator Van Hollen. Got it. Thank you.

Mr. Chawan. What I will add to this is, continuing to support legislation that promotes electric vehicles, so the Drive American Forward Act that Senators Stabenow and Alexander have co-sponsored, which includes increasing the federal tax credit for electric vehicles from \$200,000 to \$600,000 per manufacturer. That allows consumers to help make up that difference in true cost between an EV and a conventional vehicle, and other tax credits to that effect.

That is what you need when you have a nascent market. As I said earlier in my testimony, we are still in the age of \$6,000 flat panels, we are at that early state of the technology curve.

The second thing I would do from a Congressional level is to continue to support advanced research. So the advanced battery research technology that is being done is done by many of our national labs, including Oak Ridge and NREL. That work will help to create these new battery technologies that will have different chemistries than they have today, and that will enable us to bring down the overall price of the vehicle. And the battery is the largest component of that price today.

Senator Van Hollen. I appreciate that. Mr. Chairman, I

think all three have indicated you need national incentives and push and guidance, if I was able to get unanimous agreement on that.

I do worry, we have to make sure that the politics doesn't get in our way up here. Because right now we are, in my view, losing this importance race. We got behind on 5G, and we are getting behind really fast. We are already behind; we have to catch up on this. Thank you.

Senator Barrasso. Senator Carper.

Senator Carper. Again, thank you all for your testimony. It has been enormously encouraging and important.

Senator Inhofe mentioned earlier in his questioning that electric vehicles -- I have two unanimous consent requests. But I think Jim in his question mentioned that vehicles are the primary reason, electric vehicles are the primary reason we face a shortfall in our Highway Trust Fund.

While I believe we must find -- I know the Chairman agrees -- we must find a way for electric vehicles to pay their fair share for using the roads, I would ask unanimous consent to insert into the record a Business Journal article on the purchasing power of the Highway Trust Fund. It states basically the 18-cent gas tax provides about 90 percent of the funds we need that we are using in the Trust Fund.

That tax was set in 1993. If it had been modified for

inflation over the last X number of years, it would be not 18 cents, but 32 cents.

Senator Barrasso. Without objection.

[The referenced information follows:]

Senator Carper. Finally, I would just ask unanimous consent to submit for the record, Mr. Chairman, other materials relevant to today's discussion. Thank you.

Senator Barrasso. Without objection.

[The referenced information follows:]

Senator Barrasso. We are sorry to run off. We are in the final seconds of a vote. Fifteen Senators attended today, which shows how much interest there is in what you had to say and the questions, in asking those. Others may submit questions for the record. We would ask for your written answers to those. The hearing is going to remain open for two weeks.

I want to thank all of you for being here. Thank you for bringing your son, and thank you for discussing such an important issue.

The hearing is adjourned.

[Whereupon, at 11:29 a.m., the committee was adjourned.]