S. HRG. 116–336

THE SOURCING AND USE OF MINERALS NEEDED FOR CLEAN ENERGY TECHNOLOGIES

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

SEPTEMBER 17, 2019

Printed for the use of the
Committee on Energy and Natural Resources

Available via the World Wide Web: http://www.govinfo.gov

U.S. GOVERNMENT PUBLISHING OFFICE
37–816 WASHINGTON : 2021

COMMITTEE ON ENERGY AND NATURAL RESOURCES

LISA MURKOWSKI, Alaska, *Chairman*

JOHN BARRASSO, Wyoming
JAMES E. RISCH, Idaho
MIKE LEE, Utah
STEVE DAINES, Montana
BILL CASSIDY, Louisiana
CORY GARDNER, Colorado
CINDY HYDE-SMITH, Mississippi
MARTHA McSALLY, Arizona
LAMAR ALEXANDER, Tennessee
JOHN HOEVEN, North Dakota

JOE MANCHIN III, West Virginia
RON WYDEN, Oregon
MARIA CANTWELL, Washington
BERNARD SANDERS, Vermont
DEBBIE STABENOW, Michigan
MARTIN HEINRICH, New Mexico
MAZIE K. HIRONO, Hawaii
ANGUS S. KING, JR., Maine
CATHERINE CORTEZ MASTO, Nevada

BRIAN HUGHES, *Staff Director*
KELLIE DONNELLY, *Chief Counsel*
LANE DICKSON, *Senior Professional Staff Member*
ANNIE HOEFLER, *Professional Staff Member*
SARAH VENUTO, *Democratic Staff Director*
SAM E. FOWLER, *Democratic Chief Counsel*
ELLIOT HOWARD, *Democratic Professional Staff Member*

CONTENTS

OPENING STATEMENTS

WITNESSES

ALPHABETICAL LISTING AND APPENDIX MATERIAL SUBMITTED

THE SOURCING AND USE OF MINERALS NEEDED FOR CLEAN ENERGY TECHNOLOGIES

TUESDAY, SEPTEMBER 17, 2019

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 9:41 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Lisa Murkowski, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

The CHAIRMAN. Good morning, everyone. The Committee will come to order.

I would like to start this morning not with the topic of our hearing, but certainly the topic of the day, the topic that has been dominating our headlines and that is the attacks over the weekend on the Saudi oil infrastructure which have threatened Middle East security and rattled global oil markets.

I certainly condemn these attacks, I think all of us do, and those that perpetrated them. I have read the classified briefing that is available to all Members. I spoke last night with the Deputy Secretary of Energy. And while the details and impacts are still publicly emerging, it is clear our intelligence and national security teams certainly have a lot of work to do in concert with our partners in the region.

I think we all recognize that this is a difficult situation, and that is putting it mildly. But as I look to where we are today, I think we also recognize that the impact that we are seeing could be worse. Over the weekend we saw 5.7 million barrels of oil go offline. Yesterday the WTI closed at less than $62 a barrel. I think we will likely see higher gasoline prices in the days and weeks ahead. It is never a good thing. But I would urge the Committee, urge all of us, to just kind of think about how much worse the situation could have been were it 10 or 12 years ago.

These attacks, in my mind, are a reminder that there is no substitute for American energy production, which has grown into a stabilizing force for world markets. They are a reminder of the importance of good policy that recognizes the global nature of modern energy. When you think about how the markets would have reacted and what our allies would be asking, if we had not lifted the crude export ban back in 2015.

These attacks are also a reminder that we need to maintain a robust and functional Strategic Petroleum Reserve and not simply treat our emergency stockpile as an ATM to pay for unrelated spending. You hear me talk about that all the time. Again, I think this is just a reminder of why we want to make sure that we have reserves at the ready.

I am certainly going to be paying close attention to this situation in the days and the weeks ahead. But for anyone wondering why so many of us believe that supply matters, American supply, from places like my State of Alaska, now you know. Our production creates jobs, generates revenues, helps keep energy affordable, and strengthens our national security.

Now, unfortunately, these attacks are also relevant to our subject this morning, which is minerals. We are heavily or entirely dependent on foreign suppliers for dozens of these commodities. We don't have guaranteed supplies, much less stockpiles or even strategic reserves, to cover ourselves in the event of a shortage.

We are here this morning to discuss the minerals needed for clean energy technologies, particularly renewable energy. I will just make a simple observation here. If we do not address our domestic mineral supply chains, we will dramatically lower the chances that America can lead the world on renewable energy and other key industries of the future.

Minerals are the fundamental building blocks for any modern technology, whether they are light bulbs or computers or airplanes. In the energy world, batteries don't work without lithium, without graphite, cobalt and nickel. Solar panels require silver, gallium, indium and tellurium, and wind turbines are built not just from steel, but also from aluminum, from copper and rare earth elements. We all know that these minerals just don't appear out of thin air. They are mined from the ground. They are processed. They are refined into materials that can be manufactured into an end product.

You have heard me refer to the "immaculate conception" theory of energy where many people think you can just flip a switch and the lights come on, or you pull up to a gas station and miraculously there is fuel there, but this is also applicable and equally wrong on the minerals side. Sometimes I think it is hard for people to acknowledge that the products that we rely so heavily on, whether it is your cell phone or otherwise, are built from things that come from the ground.

Right now, the United States is falling further behind in the global race to control supply chains for new technologies. Allowing that to happen is a massive strategic mistake, impacting everything from our ability to create high-paying jobs to our national security and influence on the global stage. We are already behind the curve.

We will hear today how China is consolidating control of the entire supply chain for clean technologies, from raw minerals mined out of the ground to manufacturing solar panels and recycling batteries. Chinese companies are going into countries like the Congo, Chile, and Argentina to control cobalt and lithium mines. They are even taking the small amounts of rare earths that are produced in California, processing them in China and then they export it back to the U.S. because we don't have the domestic capability to do it ourselves.

I have been calling attention to this issue for almost a decade now. I feel like we have gained some traction in these past couple years. I commend the Administration for its attention to this issue, including its recent report with dozens of recommendations to increase America's mineral security.

Yet the fact remains that so many countries are doing a lot more. For example, Australia has also released a critical minerals strategy. Theirs is much more aggressive than ours. Countries like Canada are far more efficient in permitting than the U.S., giving them a distinct advantage in the global competition for investment dollars.

The other piece of this discussion is the national and global push to transition our energy systems to renewable energy. As we have those discussions, we need to take a holistic approach and keep in mind the increases in mineral demand that these technologies will inevitably lead to.

This morning, I am releasing a short report from the Congressional Research Service that summarizes three different analyses of the quantity of materials needed to meet various renewable and greenhouse gas emission goals.

[The CRS Report entitled "Projected Demand for Critical Minerals Used in Solar and Wind Energy Systems and Battery Storage Technology" follows:]

Congressional Research Service
Informing the legislative debate since 1914

MEMORANDUM September 10, 2019

To: Senate Committee on Energy and Natural Resources
Attention: Tristan Abbey

From: [redacted]

Subject: **Projected Demand for Critical Minerals Used in Solar and Wind Energy Systems and Battery Storage Technology**

This memorandum is in response to your request for a list of critical minerals used in renewable energy technologies,[1] and for demand projections for those critical minerals needed for wind, solar, and battery storage technology. This memo provides the results of three global forecasting studies on the subject.[2] These were the only three forecasting studies CRS located in the time available. The three studies use a number of variables that impact mineral demand, including: market penetration of renewable energy technologies, global economic growth, demand for electricity, and public policy, among other variables.

This memo is organized to provide a discussion of critical minerals demand in general, a brief materials analysis of renewable energy systems, and demand projections for critical minerals used in wind, solar, and battery storage systems.

If you have additional research needs, please contact me at the extension above.

Background

Demand for Critical Minerals

The demand for mineral commodities is a derived demand which differs from consumer goods demand. Minerals are used as inputs for the production of goods and services. For example, the demand for rare earth elements (REEs) is derived from the production of their end-use products or use, such as flat panel displays, automobiles, or catalysts. As a result, the demand for critical minerals depends on the strength of the demand of the final products for which they are inputs. An increase in the demand for the final product will lead to an increase in demand for critical minerals (or their substitutes).

[1] For a complete listing of minerals deemed to be critical by the Trump Administration, see *83 Federal Register, Final List of Critical Minerals*, 23295, May 18, 2018.

[2] U.S. Department of Energy, *Critical Materials Strategy*, 2011; World Bank Group, *The Growing Role of Minerals and Metals for a Low Carbon Future*, June 2017; and Kohmei Halada, et al., *Forecasting of the Consumption of Metals up to 2050*, Materials Transaction, Vol. 49, No. 3 pp. 402-410, 2008.

U.S. and Global Demand

Some of the demand drivers in recent decades for critical minerals include permanent magnets using REEs, batteries using cobalt and lithium, automobiles and electronics using tantalum and niobium, and vanadium for steel production.

Many critical minerals (e.g., manganese, tungsten, and vanadium) are used for steelmaking and infrastructure projects, such as roads, housing, rail lines, and electric power grids. Others (e.g., REEs, lithium, indium, tantalum, gallium, and germanium) are used in the manufacturing of high-value electronic products, such as laptops and batteries, renewable energy systems, and other consumer goods, such as automobiles and appliances.

Materials Analysis of Critical Minerals Content in Finished Products and Systems

Materials analysis can be a useful tool to better understand various aspects of mineral demand. For example, such analyses can provide information on how material inputs are used in component parts and how components are used in larger systems such as solar arrays, wind turbines, and automobiles. Below are simplified examples of material requirements for wind and solar systems and battery storage technology.

Materials for Wind Energy

Based on the Department of Energy (DOE) Report *20% Wind Energy by 2030*, wind power installations consist of four major parts: wind tower, rotor, electrical system, and drivetrain (e.g., generator, gearbox, and motor).[3] Most of the common large wind turbines have tower heights over 200 feet and rotor blades as long as 150 feet. The average rated capacity of an onshore wind turbine is between 2.5 megawatts (MW) and 3 MW.[4] DOE lists the following as the most important materials for large-scale manufacturing of wind turbines: steel, fiberglass, resins (for composites and adhesives), core materials, permanent magnets, and copper. Some aluminum and concrete is also required. DOE considers the raw materials for large-scale wind turbines to generally be in ample supply. Turbine manufacturing, however, would be 100% dependent on permanent magnet imports, primarily from China, as that country produces 75% of the world's permanent magnets which contain REEs (assuming certain drivetrains are used).

Recent analysis indicates that the offshore wind industry could be a major driver for increasing REE demand. There are indications that the larger turbines that are better suited for offshore locations, which also contain REEs, may be more reliable and require less maintenance than onshore turbines.[5]

Materials for Solar Energy

There are two major types of photovoltaic (PV) cells: crystalline silicon cells (most widely used) and thin film solar cells. The silicon based PV cells are combined into modules (containing about 40 cells) then

[3] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *20% Wind Energy by 2030, Increasing Wind Energy's Contribution to U.S. Electricity Supply*, July 2008. (www.energy.gov/eere)

[4] Offshore wind farms are deploying much taller structures, with longer blades and greater MW capacity.

[5] T Fishman and T.E. Graedel, "Impact of the Establishment of U.S. Offshore Wind Power on Neodymium Flows," *Nature Sustainability*, vol. 2, April 2019; Dodd, Jan, "Rethinking the Use of Rare Earth Elements," *WindPower Monthly*, November 30, 2019, https://www.windpowermonthly.com/article/1519221/rethinkingtheuseofrare-earthelements.

mounted in an array of about 10 modules. Ethylene-vinyl acetate and glass sheets typically frame the PV module, with additional aluminum frames for added protection.[6] Thin-film solar cells use layers of ultra-thin semi-conductor materials that can serve directly in rooftop shingles, roof tiles, and building facades. Thin-film PV cells have been noted to use cadmium-telluride or copper-indium-gallium-diselenide. A separate category of solar technology is concentrating solar power; these systems use mirrors to convert the sun's energy into heat and then into electricity.

Permanent Magnets

The use of REEs in permanent magnets are another example of how materials analysis for end uses may inform an understanding of critical minerals vulnerability. For example, some of the pertinent questions that might be raised with respect to permanent magnets include: How much dysprosium, neodymium, terbium, and Praseodymium go into a neodymium-iron-boron (NdFeB) permanent magnet and what fraction of the total cost is each element? What are permanent magnet unit production costs and what portion of the total costs of a wind turbine do the permanent magnets represent? And what is the likelihood and the economics of substitution?

Lithium-Ion Batteries

The use of lithium-ion batteries for the rapidly growing electric vehicle market is expected to transform the material requirements for battery technology. Material analysis of lithium-ion batteries would bring to light useful insights on materials composition, cost, technologies, and supply chains. In the case of the lithium-ion (li-ion) battery[7] for electric vehicles, what is the material composition of the battery?[8] In other words, how much cobalt, lithium, nickel, and other materials are needed per battery, how much are the material costs for each battery, and what percent of the total battery manufacturing cost do the materials represent? Then, further, what is the battery cost per electric vehicle? Analysts would want to know the point at which material price increases would warrant a shift in the use of those materials. Other useful insights in materials analysis would be to understand the suite of battery technologies being developed, their manufacturing capacity, and the ownership structure of the supply chain for the materials and the batteries.

---

[6] Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema, "Emissions from Photovoltaic Life Cycles," *Environment Science and Technology*, vol. 42, no. 6, 2008.

[7] Helbig, et al., "Supply Risks Associated with Lithium-ion Battery Materials," *Journal of Cleaner Production*, October 12, 2017 (hereinafter referred to as Helbig 2017).

[8] Material composition of a product (MCP) is a unit of measurement used to study the impact of metal/minerals on demand for a product. MCP measures the efficiency of converting raw materials into final end use products. The greater the efficiency, the less demand for the material per unit of output.

Critical Minerals Used in Renewable Energy Systems and Demand Projections

Selected Critical Minerals used for Wind Energy:

- Rare earth elements (neodymium, dysprosium, terbium and praseodymium) used in permanent magnets
- Aluminum

Selected Critical Minerals Used for Solar Photovoltaics and Concentrated Solar Power:

- Aluminum
- Indium
- Gallium
- Tellurium

Selected Critical Minerals Used in Battery Storage Technology:

- Aluminum
- Lithium
- Manganese
- Natural graphite (projected demand not available)
- Vanadium (projected demand not available)

DOE Critical Minerals Demand Projections

One study by DOE presents its results out to 2025 for some of the REEs used in permanent magnets for direct drive wind turbines and also used in general consumer goods. The DOE study also provides demand projections for critical minerals used in solar and battery storage systems. DOE's findings on projected demand for selected rare earths (neodymium, dysprosium, and terbium) show a more than doubling in demand for neodymium and dysprosium, and a 35% increase in demand for terbium from 2010 to 2025. All three rare earth minerals are used in permanent magnets for wind energy turbines, electric vehicles, and consumer electronics. The DOE study, based on a "high penetration" for renewable technology, illustrates an increase in demand for critical minerals used in solar energy systems; more than doubling for tellurium and gallium by 2025. DOE also projects mineral demand for battery storage technology such as manganese dioxide, cobalt, and lithium (all used in the lithium-ion battery storage technology). Graphite is also used widely in most battery storage technologies but projection data was not available at the time of this writing. **Table 1** below shows a four-fold increase in demand for lithium, and a 50% increase in demand for manganese dioxide and cobalt that are used in the lithiumi-ion battery.

Table 1. DOE Selected Critical Minerals Projections

Renewable Energy System	2010	2025
Wind Energy		
Neodymium oxide	~20 kilotons (kt) per year	~59 kt/year
Dysprosium oxide	~1,500 metric tons (mt) /year	~4,000 mt/year
Terbium oxide	~400 mt/year	~650 mt/year
Solar Energy		
Tellurium	~600 mt/year	~1,300 mt/year
Gallium	~230 mt/year	~550 mt /year.
Indium	~1,450 mt/year	~2,500 mt/year.
Battery Storage		
Manganese dioxide	~800 kt/year	~1,200 kt/year
Cobalt	~60 kt/year	~90 kt/year
Lithium	~100 kt/year	~400 kt/year

Source: DOE, ***Critical Materials Strategy***, 2011.

Notes: ~ = approximately

World Bank Group Critical Minerals Demand Projections

The World Bank Group (WB) study projected several minerals used in wind, solar, and battery technology and describes the projections as the percentage of increased demand under a scenario that is based on the 2 degree Celsius (2DS) commitment under the Paris Climate Agreement. They also present projections under a 4 degree Celsius scenario (4DS); both scenarios show a greater increase in demand compared to an increase over a 6 degree Celsius (6DS) scenario. The 6DS scenario is described as an expansion of current policy and practices under the 2DS scenario. Compared to the 6DS scenario, the WB results show a more than doubling of demand from 2013 to 2050 for aluminum, neodymium, and manganese used in wind energy systems, and a 300% increase in aluminum and 325% rise in indium demand used in solar energy systems. WB results also show a 1,200% increase in demand for all four critical minerals used in battery storage technology discussed in the study (i.e., aluminum, cobalt, lithium, and manganese); see **Table 2** below.

Table 2. The World Bank Study — Selected Critical Minerals, Percentage Increases between 2013 to 2050 (under its 2 degrees Celsius (2DS) and 4 degrees Celsius (4DS) Scenarios)

(% Increase)

Renewable Energy Technology	2DS	4DS
Wind Energy		
Aluminum	250	160
Neodymium	240	150
Manganese	250	150
Solar Energy		

Renewable Energy Technology	2DS	4DS
Aluminum	300	160
Indium	325	170
Battery Storage Technology (lithium-ion)		
Aluminum	1,200	100
Cobalt	1,200	100
Lithium	1,200	100
Manganese	1,200	100

Source: World Bank Group, *The Growing Role of Minerals and Metals for a Low Carbon Future, June 2017.*

Halada, et al. Selected Critical Mineral Demand Projections

A third study, by Halada et al., highlights the following critical minerals: aluminum, manganese, lithium cobalt, indium, and gallium, among other non-critical minerals. The study bases its projections on global gross domestic product (GDP), population growth, and the relation between per capita metal consumption and per capita GDP, among other variables such as electricity demand. Their results predict a nearly fourfold increase (or higher) in demand for aluminum, lithium, cobalt, and gallium and a five-fold increase in indium and rare earth demand from 2010 to 2050. Manganese would increase by three-fold.

Table 3. Selected Critical Mineral Projections for 2010 and 2050 by Halada, et al., Study

Renewable Energy Technology	2010	2050
Wind Energy		
Rare Earth Elements	190 kilotons (kt) /year	800 kt/year
Solar Energy		
Aluminum	20,000 kt/year	75,000 kt/year
Indium	2 kt/year	10 kt/year
Gallium	1 kt/year	4.5 kt/year
Battery Storage		
Manganese	12,500 kt/year	40,000 kt/year
Lithium	100 kt/year	425 kt/year
Cobalt	90 kt/year	390 kt/year

Source: Kohmei Halada, et al., *Forecasting of the Consumption of Metals up to 2050*, 2008.

One comes from the World Bank, which forecasts that demand for certain minerals will increase by more than 1,000 percent under an aggressive scenario to limit warming.

I think that the United States is certainly capable of being a leader in this area. We have incredible, high-grade mineral deposits and we have the highest labor and environmental standards in the world, but we have to find the political will to advance policies that will allow us to rebuild a robust domestic supply chain.

I am hopeful that by highlighting the direct link between minerals and clean energy technologies we can gain additional support for our legislative efforts which are designed to help us avoid future shortages and strengthen our manufacturers.

So as we begin this morning, I would like to thank our witnesses for joining us. I understand that most of you changed travel plans to be here, which we greatly appreciate, as we focus on this critical issue this morning so thank you for that.

I will now turn to my Ranking Member, Senator Manchin.

STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

Senator MANCHIN. Thank you, Madam Chairman.

I concur with you on all of our concerns about the attack on Saudi Arabia, the attack on energy supplies around the world. I don't think Saudi is going to be the exception. I think there is going to be a lot more that we are going to see, strategic strikes.

I want to thank you for holding the hearing today. I want to thank the panel for being here. This is the most expertise panel. I think we are going to learn an awful lot from you all and look forward to that.

As our Committee rightly focuses our attention on the whole portfolio of clean energy technologies, we must also pay attention to the mineral commodities that make these technologies possible. It is important for us to know where and how these minerals are sourced and to fully understand the challenges and opportunities that they play in the deployment of clean energy technologies.

Renewable energy sources and storage play growing and crucial roles in the energy sector. In fact, according to a recent report, renewable energy investments will likely exceed $2.6 trillion in this decade—$2.6 trillion in this decade. Electric vehicles are also expected to be a growing part of our energy future.

The common denominator between all of these clean energy technologies is a handful of minerals that either occur in limited abundance or only in certain countries around the world—so it is not accessible any place that you may live.

According to a March 2017 article in Nature magazine, mineral resourcing and climate change are inextricably linked, not only because the mining requires a large amount of energy but also because the world cannot tackle climate change without an adequate supply of raw materials to manufacture clean technologies. I would add, at the same time we must also not become so desperate for these minerals that we throw our bedrock environmental laws out the window which we see happening every day.

Mining companies today are finding it harder and harder to obtain and maintain their social license to operate. It only takes one or two accidents to put a stain on the entire industry. And when you lose buy-in from the local communities, you experience delays which only puts increased stress on mineral supplies. There is a balance to be had between extraction and environmental protection, and I think that is in every segment, every segment.

However, looking at what China is doing in places like the Democratic Republic of the Congo (DRC) and other central African countries, I worry about the global state of play, and I think there is cause for concern. China has a long-term strategy to establish major stakes in global markets for a handful of key elements for renewable energy or storage technologies. A few large upstream Chinese companies will source and export these minerals and through a complex, a very complex, supply chain they will be refined and smelted in China and sold to downstream companies. For example, cobalt is often mined by artisanal miners which are children, amateurs, people who have never done it, no experience at all, and they are not often authorized or regulated by the DRC.

Unfortunately, as much——

[Cell Phone Rings.]

I am sorry. That is usually a fine where I come from.

[Laughter.]

The CHAIRMAN. It is reminding you about critical minerals.

Senator MANCHIN. I know.

[Laughter.]

And it works.

Unfortunately, as much as 20 percent of the cobalt exported from the DRC to China for processing is done by these amateur miners. Children, as young as seven, have been documented working brutal hours in unsafe conditions, mining for cobalt in the DRC, or the Republic of the Congo. And that same unregulated, unauthorized cobalt ends up in some of the products we use for clean energy technologies right here in the United States.

Let me be clear. I support mining. I come from a mining state, an extraction state, but I believe that we need to be doing it right, responsibly and safe. The United States has an obligation to be developing the best mining standards and processes to be used as a model for the rest of the world, and that means we need to have updated laws on the books that match the current needs of our society. That includes both responsible mining and recycling, and on that front I am encouraged by innovative examples that our witnesses, that all of you, are going to speak to today.

I understand that Mr. Kang's company, for example, recycles end-of-life minerals to be used in new technologies. There is a large number of electric vehicles reaching the end of the useful lives here in the United States, and I am curious to hear more from our panel today about how we can improve our national recycling policies in these areas.

The DOE, of course, has a big role to play in this space, and I appreciate Mr. Simmons being here today to tell us about how research investment at DOE is helping to solve these challenges, and how they plan to do more.

With that, I welcome all of our witnesses. I thank you all for being here today as we help get a better understanding of the complexities of these supply chains and energy critical minerals and I look forward to hearing from you.

Thank you, Madam Chairman.

The CHAIRMAN. Thank you, Senator.

I think we all appreciate the need for the balance there. While we recognize that we have a very clear need and a growing and accelerated need for these minerals, we also want to do it responsibly. That is why, I say, we want to do it here because we are doing it safely with environmental regulations that, I think, we can be proud of.

Let's turn to our panel this morning, a strong panel. Again, we appreciate you all being here.

We are going to be led off this morning by the Honorable Daniel Simmons, who is the Assistant Secretary for the Office of Energy Efficiency and Renewable Energy, EERE, at the Department of Energy (DOE). We welcome you.

Ms. Allison Carlson is the Managing Director for Foreign Policy (FP) Analytics. We welcome you.

Mr. Robert Kang is the CEO for Blue Whales Materials. We are glad to have you here this morning.

Dr. Morgan Bazilian is the Director of the Payne Institute and Professor of Public Policy out at the Colorado School of Mines. We welcome you.

And Mr. Mark Mills has been before the Committee on numerous occasions. He is a Senior Fellow for the Manhattan Institute for Policy Research.

We welcome you all.

Assistant Secretary, if you would like to lead off?

We would ask you all to try to limit your comments to about five minutes. Your full statements will be included as part of the record, and then we will have an opportunity for the back and forth.

So, welcome, Mr. Simmons.

STATEMENT OF HON. DANIEL SIMMONS, ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY

Mr. SIMMONS. Thank you, Madam Chairman, Ranking Member Manchin and members of the Committee. Thank you for the opportunity to testify today on behalf of the Department of Energy.

My name is Daniel Simmons. I'm the Assistant Secretary for the Office of Energy Efficiency and Renewable Energy at the Department of Energy.

Critical minerals are used in many products important to the U.S. economy, energy and national security. The manufacturing and deployment of these products provides Americans with additional employment as well as contributes to overall economic growth. Where the production occurs in the United States it is at higher environmental standards than almost anywhere else in the world.

For the Department of Energy, critical minerals play a crucial role in a number of different energy technologies across the Department's research and development portfolios. For the U.S. clean energy industry, access to critical minerals assures that it can continue to innovate, increase output and efficiency and stay ahead in globally competitive markets.

For example, some of the minerals that DOE considers most critical in terms of supply risk include gallium for LEDs, rare earth dysprosium and neodymium for permanent magnets and wind turbines and electric vehicle battery—or electric vehicle motors and cobalt and lithium for electric vehicle and other batteries.

According to a 2017 World Bank report on critical minerals, "The technologies assumed to populate the clean energy shift—wind, solar, hydrogen, and electricity systems—are in fact significantly more material intensive in their composition than current traditional fossil-fuel-based energy supply systems."

Material intensity and potential global demand is illustrated by a recent report, by a recent analysis, by the Head of Earth Sciences at the Natural History Museum in the UK. Using the most current technologies, for the UK to meet their 2050 electric car targets it would require just under two times the current annual world cobalt production, nearly the entire world production of neodymium, three-quarters of the world's lithium production and at least half of the world's copper production. And to put that in perspective, the UK, the population of the UK is only 66 million currently, while the population of the United States is 327 million. That is a massive amount of these critical minerals that is required.

Cobalt makes up 20 percent of the weight of the cathode of lithium-ion electric vehicle batteries. Today, cobalt is considered one of the highest material supply risks for electric vehicles in the short- and medium-term. Cobalt is mined as a secondary material from mixed nickel and copper ore with the majority of the global supply mined in the Democratic Republic of Congo, as Senator Manchin mentioned, a place with poor environmental and labor conditions. The dependency of the U.S. on foreign sources of critical minerals creates a strategic vulnerability for both our economy and our military with respect to adverse foreign government actions, natural disasters and other events that could disrupt supply.

Within the Department of Energy, research and development investments are coordinated around three main pillars to address supply chain disruption risk. Number one, diversifying supply of critical minerals, including increasing domestic production, processing all throughout the supply chain; number two, developing substitutes; and number three, driving recycling, reuse and more efficient use of critical materials overall.

The Administration believes that we need to do more to secure a reliable supply of critical minerals and products made from critical minerals. We have made progress in reducing the need for some critical materials in some applications, and we have made progress in recycling critical minerals; however, we need to increase domestic exploration, production, recycling and reprocessing of critical minerals.

The Federal Government needs to do more to expedite and enable exploration, mining, concentration, separation, alloying, recycling and reprocessing of critical minerals. We need to enable the entire supply chain here in the United States. We will continue to partner with industry, academia and other federal agencies to forge paths toward greater critical mineral security while also working with Congress to assure appropriate stewardship of taxpayer dollars.

I appreciate the opportunity to appear before this Committee to discuss the Department's efforts to increase critical mineral security this morning.

Thank you very much.

[The prepared statement of Mr. Simmons follows:]

Testimony of

Daniel Simmons

Assistant Secretary for Energy Efficiency and Renewable Energy, U.S. Department of Energy

Before the

U.S. Senate Committee on Energy & Natural Resources

September 17, 2019

Introduction

Chairman Murkowski, Ranking Member Manchin, and Members of the Senate Committee on Energy and Natural Resources, thank you for the opportunity to testify today on behalf of the Department of Energy.

Critical minerals are used in many products important to the U.S. economy, energy, and national security. The manufacturing and deployment of these products provides employment for American workers and contributes to U.S. economic growth. For the Department of Energy, critical minerals play a crucial role in a number of different energy technologies across the Department's research and development portfolios. For the U.S. clean energy industry, access to critical minerals assures that it can continue to innovate to increase the productivity, output, and efficiency to stay ahead in a globally competitive marketplace. For example, some of the minerals that DOE considers most critical in terms of supply risk include gallium for LEDs, the rare earths dysprosium and neodymium for permanent magnets in wind turbines and electric vehicles, and cobalt and lithium for electric vehicle and grid batteries.

This Administration is very concerned about strategic vulnerabilities related to critical minerals. President Trump's Executive Order 13817 explained:

> The United States is heavily reliant on imports of certain mineral commodities that are vital to the Nation's security and economic prosperity. This dependency of the United States on foreign sources creates a strategic vulnerability for both its economy and military to adverse foreign government action, natural disaster, and other events that can disrupt supply of these key minerals. Despite the presence of significant deposits of some of these minerals across the United States, our miners and producers are currently limited by a lack of comprehensive, machine-readable data concerning topographical, geological, and geophysical surveys; permitting delays; and the potential for protracted litigation regarding permits that are issued. An increase in private-sector domestic exploration, production, recycling, and reprocessing of critical minerals, and support for efforts to identify more commonly available technological alternatives to these minerals, will reduce our dependence on imports, preserve our leadership in technological innovation, support job creation, improve our national security and balance of trade, and enhance the technological superiority and readiness of our Armed Forces, which are among the Nation's most significant consumers of critical minerals.[1]

The Administration believes we need to do more to secure a reliable supply of critical minerals and products made from critical minerals. We have made progress in reducing the need for some critical minerals in some applications and we have made progress in recycling critical minerals, however, as the Executive Order explained, we need an increase in private-sector domestic exploration, production, recycling, and reprocessing of critical minerals. The federal government needs to do more to expedite and enable exploration, mining, concentration, separation, alloying, recycling, and reprocessing critical minerals.

---

[1] Executive Order 13817, https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals.

In response to President Trump's Executive Order 13817, the Department of Interior published a list of 35 mineral commodities considered critical to the economic and national security of the United States.[2]

Additionally, in response to EO 13817, the Department of Commerce issued "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," on June 4, 2019.[3] The Federal Strategy has six Calls to Action:

1. Advance Transformational Research, Development, and Deployment Across Critical Mineral Supply Chains
2. Strengthen America's Critical Mineral Supply Chains and Defense Industrial Base
3. Enhance International Trade and Cooperation Related to Critical Minerals
4. Improve Understanding of Domestic Critical Mineral Resources
5. Improve Access to Domestic Critical Mineral Resources on Federal Lands and Reduce Federal Permitting Timeframes
6. Grow the American Critical Minerals Workforce

The Department of Energy, in coordination with other federal agencies, including Department of Defense, Department of Commerce, and Department of the Interior, is in full support of the Federal Strategy. The Department is co-chair of the National Science and Technology Council (NSTC) Subcommittee on Critical Minerals, which is responsible for implementation of the Federal Strategy, and provides leadership among the federal agencies to address critical minerals across the entire supply chain. Specifically, DOE is in the lead on Call to Action 1 and contributes to other Calls to Action.

The U.S. is dependent on foreign sources of critical minerals. Of the 35 mineral commodities identified as critical in the list published in the Federal Register by the Secretary of the Interior in response to EO 13817, the U.S. lacks domestic production of 14[4] and is more than 50 percent

[2] Department of Interior, *Interior Releases 2018's Final List of 35 Minerals Deemed Critical to U.S. National Security and the Economy*, May 18, 2018, https://www.usgs.gov/news/interior-releases-2018-s-final-list-35-minerals-deemed-critical-us-national-security-and.

[3] Department of Commerce, *Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, June 4, 2019, https://www.commerce.gov/sites/default/files/2019-06/Critical%20minerals%20strategy%20final.docx.

[4] U.S. Geological Survey, *Mineral Commodity Summaries 2018*, 2018, https://doi.org/10.3133/70194932. Of these 14 elements, six have not been produced domestically since 1985. The quality of U.S. reserves for three of these elements (Manganese, Niobium, and Tantalum) were reported by the Department of the Interior as being low grade, subeconomic at 2018 prices, and either not commercially recoverable, or as having potentially high extraction costs. *See* U.S. Department of Interior, *Mineral Commodity Summaries 2019*, https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf.

import-reliant for 31.[5] For example, some mineral commodities important to energy from those identified include gallium (imported from China, the United Kingdom, Germany and the Ukraine); rare earths including dysprosium and neodymium (imported from China, Estonia, France, and Japan); lithium (imported from Argentina, Chile, China, and Russia); and cobalt (imported from Norway, China, Japan, Finland, and the Democratic Republic of Congo).[6] This import dependence is a problem when it puts supply chains and U.S. companies and mineral users at risk. The dependency of the U.S. on foreign sources of critical minerals creates a strategic vulnerability for both our economy and our military with respect to adverse foreign government actions, natural disasters, and other events that could disrupt supply.

Many of the mineral commodities identified by the Department of the Interior are vital to the energy technologies of today and the future. The Department of Energy's approach to mitigate risk is in alignment with the President's Executive Order 13817 to ensure secure and reliable supplies of critical minerals. The Department's three priorities for decreasing U.S. dependence on foreign sources of critical minerals is first, to increase domestic production across the entire supply chain, second, to develop substitutes, and third, to improve reuse and recycling.

We believe that DOE needs to now focus on improving innovations through research and development across the entire supply chain including, mining, concentration, separation, and alloying in addition to our current work on recycling and reprocessing.

To illustrate the challenge, the United States currently has some rare earth mining. The United States, however, lacks the domestic capability to extract and separate the useful elements from the bastnasite ore, which can contain more than ten different rare earth elements depending on the deposit. The separation and purification of rare earth elements from bastnasite ore must instead be handled at overseas processing facilities.

The U.S. also lacks the domestic capability to manufacture magnets containing neodymium and relies on imported magnets crucial for both civilian and defense applications. This reliance creates potential price and supply vulnerabilities and jeopardizes U.S. jobs and national security. Addressing the full critical mineral supply chain through increasing domestic production, separation and processing, recycling, reuse and remanufacturing, and identifying commonly available alternatives will reduce our dependence on imports, preserve our leadership in technological innovation, support job creation, and improve our national security and balance of trade. In addition, addressing the full supply chain through responsible domestic production and processing brings environmental outcomes under American regulatory oversight, which may provide more environmental protection than other foreign producers.

Many of the mineral commodities identified by the Department of the Interior are vital to the energy technologies of today and the future. The Department of Energy's approach to mitigate risk is in alignment with the President's Executive Order 13817 to ensure secure and reliable supplies of critical minerals.

[5] Department of the Interior, *Final List of Critical Minerals 2018*, 83 Fed. Reg. 23295; 2018, https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018

[6] U.S. Geological Survey, *Mineral Commodity Summaries 2018*, 2018, https://doi.org/10.3133/70194932

Department of Energy's Approach to Critical Minerals and Materials

The Department has led several studies assessing material criticality across a range of energy technologies based on importance to energy and potential for supply risk. Early and on-going assessment is required to adapt the Department's priorities to changing material and energy technology markets. Over the years, some criticality levels have decreased (e.g., terbium and europium in florescent lighting phosphors); some have increased (e.g., lithium and cobalt in batteries); and some have remained prominent (e.g., neodymium and dysprosium in magnets). In addition, the Office of Policy has led several studies examining potential supply chain vulnerabilities related to market dynamics and volatility across each stage of the supply chain from mining to final product production and demand.

Within the Department, research and development (R&D) investments are coordinated among the program offices agency-wide around **three pillars** to address supply chain disruption risks: **(1) diversifying supply of critical materials—including increasing domestic production and processing, (2) developing substitutes, and (3) driving recycling, reuse, and more efficient use of critical materials**. For example, working with world-class researchers at the Department of Energy's National Laboratories, the Department has made significant strategic investments to address rare earth permanent magnets for motors and generators. The Office of Energy Efficiency and Renewable Energy (EERE), through the Advanced Manufacturing Office (AMO), Vehicle Technologies Office (VTO) and the Wind Energy Technologies Office (WETO), and ARPA-E have made significant and complementary efforts to reduce or eliminate potential dependences on critical materials (such as rare-earth metals) that are essential to modern and clean energy technologies. The Office of Electricity (OE) is working on grid-scale battery storage technologies that use domestically sourced earth-abundant materials, and EERE, through our Building Technologies Office, is working on thermal energy storage and advanced phase change materials (PCMs) that use earth-abundant materials (including water) for advanced energy storage. The Office of International Affairs is focused on countering attempts to control or distort the critical materials markets. The Office of Fossil Energy (FE) is focused on production of rare earth elements (REEs) and critical materials from coal and coal-based resources. Currently FE has one domestic bench-scale and two domestic pilot-scale facilities producing small quantities of REEs from coal refuse, power generation ash and acid mine drainage sources, with the potential to simultaneously assist in mitigating coal waste legacy environmental liabilities .

The Department is engaged across nearly all Calls to Action of the Federal Strategy. DOE has strong interagency leadership in R&D, investing in R&D across the three pillars, as is described below (Call to Action 1). The Department is also developing activities to support increased domestic production and recycling of critical materials.

Use of Critical Materials in Energy Technologies:

Critical minerals and materials play a significant role in a number of different energy technologies across the Department's R&D portfolio. The availability and cost of critical minerals and materials has a direct impact on many of these technologies especially in regard to those associated with clean energy. In fact, according to a 2017 World Bank report on critical minerals, "The technologies assumed to populate the clean energy shift – wind, solar, hydrogen, and electricity systems – are in fact significantly more material intensive in their composition than current traditional fossil-fuel-based energy supply systems."[7] Examples in the Department's Office of Energy Efficiency and Renewable Energy include:

- *Vehicle Technologies*: Lithium and cobalt for lithium-ion batteries for electric vehicles, along with other critical minerals such as graphite, aluminum, rare earth elements, and magnesium, for light-weighting vehicles, motor magnets for electric vehicles, and higher strength materials for vehicle structures. For internal combustion engine powered vehicles, platinum group metals (PGM) catalysts are critical for meeting more stringent emissions standards for light- and heavy-duty vehicles. Demand for PGM is beginning to exceed supply and price is expected to dramatically increase. Currently over 9 million ounces of palladium are used annually for automotive catalyst. Research is being conducted to reduce PGM content and develop lower cost alternative materials.

- *Building Technologies*: Building technologies use some critical materials such as: europium, terbium, neodymium and yttrium as well as gallium and indium. Oxides of rare earths—europium, yttrium, lanthanum, and terbium—make up the red and green phosphors that illuminate fluorescent lighting tubes. China controls 90 percent of the world's supply of rare earths and periodic market pricing fluctuations affect U.S. productivity.[8]

  Critical materials are also used in light-emitting diodes (LEDs). LEDs and organic light emitting diodes (OLEDs) employ key materials such as gallium and indium for LED compound semiconductor materials. White LED designs eliminate the need for lanthanum and terbium phosphors, but may still use cerium and europium phosphors to convert blue LEDs to useful white light. Gallium and indium are used in the formation of the LED compound semiconductor material.[9]

  There is also great potential in magnetic refrigeration for improving the energy efficiency of the refrigeration process using rare earth materials. Some experts believe this technology could be commercialized and capture a significant share of the refrigeration market in the medium term.[10] This process relies on very powerful magnets. Magnets that use the critical material neodymium are the most powerful known permanent

---

[7] World Bank Group, *The Growing Role of Minerals and Metals for a Low Carbon Future*, June 2017, http://documents.worldbank.org/curated/en/207371500386458722/pdf/117581-WP-P159838-PUBLIC-ClimateSmartMiningJuly.pdf.

[8] Critical Materials Institute: Shining new and better light on research and industry collaborations, Aug. 2, 2019, https://www.ameslab.gov/news/news-releases/critical-materials-institute-shining-new-and-better-light-research-and-industry.

[9] U.S. Department of Energy, *Critical Materials Strategy*, Dec. 2010, https://www.energy.gov/sites/prod/files/piprod/documents/cms_dec_17_full_web.pdf.

[10] *Id.*

magnets. These magnets are about 10 times more powerful than your average refrigerator magnet.[11]

- *Solar Energy Technologies:* Thin film solar cells, which compose less than 5 percent of today's market, utilize tellurium to make CdTe. This does not pose a significant critical minerals risk since the majority of the solar market relies on silicon for the solar cell, which is not a critical material. Very high efficiency solar cells used in space applications use antimony, arsenic, beryllium, gallium, germanium, and indium. There are not good alternatives for these materials, however we are funding the development of higher efficiency, tandem silicon solar cells, which would provide alternatives. If there were supply issues before those technologies were ready, silicon could also provide an option for the space industry; however it is a less attractive one due to its lower power and higher weight. Aluminum is used for many solar cell electrical contacts, but there are alternatives available.

- *Wind Energy Technologies:*
  Five rare earth elements (REE) - dysprosium, terbium, europium, neodymium and yttrium - are used in magnets for wind turbines. Of these, neodymium and dysprosium availability and their cost represent the most significant risk to wind turbines using high-performance NdFeB magnets.

  Concerns over rare earth supply drove reductions in the material intensity of permanent magnet generators in wind turbines. Hybrid generator designs can reduce the weight of the magnet material from 600 kilograms (kg)/MW to 200 kg/MW. Improvements in magnet technology have reduced the amount of dysprosium required from 3 percent–6 percent to as little as 1 percent dysprosium (by weight). This was largely achieved by using strategies such as optimizing placement of dysprosium in the magnet's crystal structure, or by redesigning generators to reduce the operating temperatures and thus the need for dysprosium to maintain coercivity. Some manufacturers are developing turbine models with dysprosium-free magnets. Although similar reductions in material intensity for neodymium have not been achieved, current research is targeting 20 percent neodymium content by 2030, which is significantly lower than the current state of the art (29 percent–32 percent). Currently, energy demand for neodymium and dysprosium is dominated by its use in wind turbine magnets.

  In order to reduce the dependence on rare earth elements even further, WETO is funding the development of advanced technology, such as high- and low-temperature superconducting generators, which would significantly reduce or eliminate the need for REEs in wind turbines.

- *Fuel Cell Technologies:* At present, PGM-based catalysts are essential to the function of fuel cell electric vehicles and comprise over 40 percent of fuel cell stack cost. Today's technology for hydrogen fuel cells in the market, as well as emerging electrolyzers, rely on PGM catalysts to achieve the performance and durability needed for commercial

[11] Critical Materials Institute, *10 Things You Didn't Know About Critical Materials*, https://cmi.ameslab.gov/materials/ten-things

viability. As we see the development of heavy duty fuel cell trucks, we recognize that even more PGM catalysts may be needed to meet 30,000 hour durability targets, compared to the target of 8,000 hours for light duty vehicles. Therefore, we are focusing on research to lower the content of PGM catalysts in fuel cells and electrolyzers and even potentially eliminate them, which would mitigate U.S. dependence on South Africa, Russia, China and other countries for PGM imports.

- *Advanced Manufacturing:* Arsenic and gallium are used in wide-bandgap semiconductors for power electronics. Wide bandgap semiconductor materials are much more favorable for power electronic applications than conventional silicon material — wide bandgap semiconductors are faster, capable of higher voltages, and higher temperatures, all of which leads to increased energy efficiency in power electronics. Silicon carbide and gallium nitride are the two wide bandgap power electronic material candidates for the foreseeable future. For high voltage applications (above 600 volts) Silicon carbide, which does not use any critical materials, is the only current option and has experienced rapid manufacturing expansion in the United States. For low voltage applications (below 600 volts) gallium nitride has the performance advantage and therefore has gained recent commercial acceptance offering higher energy efficiency than standard Silicon semiconductors. Although gallium is used in small quantities in gallium nitride semiconductors, if gallium supplies were no longer available, it is uncertain whether silicon carbide or other materials could be improved to match the high efficiency of gallium nitride semiconductors in low voltage power electronics.

The nuclear energy industry is also significantly impacted by critical minerals, including uranium. According to the Energy Information Administration, nearly 10 percent of the 40 million pounds U3O8 equivalent delivered in 2018 was U.S.-origin uranium, with foreign-origin uranium accounting for the remaining 90 percent of deliveries.[12] Uranium in fuel assemblies loaded into U.S. civilian nuclear power reactors during 2018 contained 50.2 million pounds U3O8 equivalent, with 11 percent of the uranium loaded during 2018 of U.S.-origin uranium and 89 percent of foreign-origin uranium.

Primary uranium production in 2018 was ~ 700,000 pounds U3O8, the lowest level since 1949. Licensed and permitted uranium production capacity in the United States is approximately 25 million pounds U3O8 and would not be capable of meeting U.S. demand.[13] In addition, some of this capacity is not currently operational and would take some time to ramp up production.

Within the electricity sector, aluminum is one of the major materials that enable the transmission and distribution of electricity, by providing increased conductivity, enhanced strength, and high temperature tolerance. Aluminum is also among the materials that can be used to fabricate devices such as transistors and diodes that enable advanced functions such as high power control, conversion, and switching.

---

[12] Energy Information Administration, *Uranium Marketing Annual Report,* May 30, 2019, https://www.eia.gov/uranium/marketing/.

[13] Energy Information Administration, *Domestic Uranium Production Report – Annual*, Table 5, https://www.eia.gov/uranium/production/annual/uisl.php.

DOE has been proactive in developing new tools and technologies to accelerate energy storage development, including energy storage with lower critical mineral content, such as through the Grid Modernization Initiative, the Advanced Energy Storage Initiative, and the Grid Storage Launchpad (GSL). The Office of Electricity's proposed GSL will extend U.S. R&D leadership in energy storage through validation, collaboration, and acceleration. By validating new technologies at earlier maturity stages, the GSL will lower the time and expense of storage chemistry innovations.

Critical Minerals R&D Activities Across the Department

Critical Materials Institute

The Critical Materials Institute (CMI), an Energy Innovation Hub currently managed by EERE (through the Advanced Manufacturing Office), is a multi-institutional, multi-disciplinary consortium of U.S. national laboratories, universities, and companies led by the Ames Laboratory. CMI's mission is to accelerate the development of technological options that assure supply chains of materials essential to clean energy technologies—enabling innovation in US manufacturing and enhancing energy security. CMI carries out early-stage applied research in three areas: diversifying supply, developing substitutes, and reuse and recycling. These research areas are linked to industrial needs and are enabled with fundamental scientific research and cross-cutting analysis. As a result, technologies developed by the CMI span the entire supply chain and lifecycle of materials, except geoscience and mining. While congressional report language has continued to insist upon funding the CMI, the FY2020 Budget Request favors a transition away from the hub model because the mortgaging of future appropriations reduces budgetary flexibility. Instead, the Budget Request proposes a set of smaller and more directly managed, early-stage, R&D consortia activities.

CMI is currently in its seventh year of operation. CMI has issued 120 invention disclosures, filed 56 patent applications, received ten patents, created two open-source software packages and won four R&D 100 awards. It licensed eight technologies to U.S. companies. Examples of these technologies include:

- Membrane solvent extraction for rare-earth separations, relevant for both primary production and recycling,
- 3D printing of rare-earth magnets to reduce manufacturing wastes,
- A cerium-aluminum alloy for creating lightweight, strong components for advanced vehicles and airplanes, and
- A cost-effective, high-throughput system for recycling rare-earth magnets from computer hard drives, and Formulation of low rare earth containing phosphors for lighting.

CMI developed capabilities to include machine learning materials design and predicted and synthesized critical material-free permanent magnets that have the potential to reduce the demand for rare earth containing neodymium-iron-boron magnets in a number of applications. CMI researchers won an R&D 100 Award and Gold Award for Special Recognition in Green Technology for development of an acid-free magnet recycling process.

Addressing Critical Lithium-Ion Battery Materials and Electric Drive Systems
As electric vehicles sales grow, so does the increased focus on abundant and affordable materials for lithium ion batteries and electric drive motors. Current high-energy lithium-ion batteries contain cathodes with lithium nickel-manganese-cobalt (NMC) or nickel-cobalt-aluminum (NCA), graphite anodes, and aluminum & copper current collectors. Of these materials, cobalt, lithium, and graphite are of concern due to price fluctuations and material availability.

The demand for the critical materials cobalt and lithium is driven by the growth in demand for lithium-ion batteries. Industry forecasts are that 85 percent of these lithium-ion batteries will be for electrified vehicles by 2030.[14]

Cobalt makes up to 20 percent of the weight of the cathode in lithium-ion electric vehicle batteries. Cobalt is considered the highest material supply risk for EVs in the short and medium term. Cobalt is mined as a secondary material from mixed nickel and copper ore with the majority of the global supply mined in the Democratic Republic of Congo.

Lithium is the integral intercalating material for lithium-ion and lithium metal batteries due to its high energy and power density and low cost. Lithium is critical to long term sustainability of EVs. Most lithium is mined through a salt brining process in South America that takes years to yield, so unexpected increases in demand can yield price spikes.

Graphite is a key material for the anodes within lithium-ion batteries and the potential growth in electric vehicles could place stress on supply. Lithium-ion battery manufacturers currently use a blend of natural graphite and the more expensive synthetic graphite in battery anodes. In 2014, China constituted 66 percent of the supply of natural graphite, and has closed or consolidated several graphite mines in an effort to reduce environmental and human health impacts and instituted export restrictions to support its domestic industries. Other primary sources include India (14 percent) and Brazil (7 percent), and new mines are under development in African countries. However, processing capacity resides almost exclusively in China.

To mitigate critical materials supply risks for lithium-ion batteries, EERE (through VTO) aims to reduce the cost of electric vehicle battery packs to less than $100/kWh by September 2028 (from a baseline of $197/kWh in 2018)[15] with technologies that significantly reduce or eliminate the dependency on critical materials (such as cobalt and lithium) and utilize recycled material feedstocks.

Cells in EV batteries contain 10-20 percent weight in cobalt and it plays a critical role in stabilizing the crystal structure of the NMC/NCA cathodes. DOE is pursuing several R&D paths to mitigate the potential issues associated with the supply of cobalt including (1) funding R&D to reduce cobalt content in the battery cathode to less than 5 percent by weight in the mid-term by increasing nickel content or substituting manganese, aluminum, or other earth abundant metals

[14] Bloomberg New Energy Finance, *Electric Vehicle Outlook – 2019: Annual Lithium Ian Battery Demand.*

[15] Steven Boyd, *Vehicle Electrification*, Presented at DOE Vehicle Technologies, Annual Merit Review, June 2018, Washington, D.C.

and (2) funding high risk research to completely eliminate the need for cobalt in the long term, such as lithium sulfur, solid state, and lithium metal battery technology.

DOE is pursuing several R&D paths to mitigate the potential issues associated with the supply of natural graphite including (1) developing anode technology that utilizes a higher percentage of synthetic graphite, (2) exploring anode alternatives such as silicon based composite materials or lithium metal, and (3) producing graphite from other sources, such as carbon dioxide, is being explored.

EERE is also funding efforts to address the challenges of recycling lithium-ion batteries, which have more than 15 different cathode chemistries across end-use applications. EERE's VTO has established the ReCell Lithium Battery Recycling R&D Center to develop innovative, efficient recycling technologies for current and future battery chemistries. ReCell funds R&D across four research areas: design for recycling, recovery of other materials, direct recycling or cathode-to-cathode recovery, and reintroduction of recycled materials.

Getting end-of-life lithium-ion batteries to recycling centers is also a challenge to the reuse, recycling and recovery of critical materials. ReCell reports that lithium-ion batteries are currently recycling at a rate of less than 5 percent. In January 2019, the Department (through EERE's VTO and AMO) announced the launch of a Lithium-Ion Battery Recycling Prize to incentive American entrepreneurs to create cost-effective, disruptive solutions to collect, sort, store, and transport 90 percent of spent or discarded lithium-ion batteries for eventual recycling.

Electric Drive Motors, Rare Earth Materials

Rare earth-based magnets containing neodymium, iron, boron, and dysprosium are the dominant magnet type used in electric drive motors used in today's electric vehicles, due to overall superior magnet properties. Dysprosium is required in these magnets for stable performance characteristics at higher temperatures. Low naturally-occurring concentrations strain the supply for high temperature magnets. There are no domestic active mines producing dysprosium, but there are potential projects in places such as Alaska and Texas. Neodymium is less of a concern, but prices remain volatile and the vast majority of supply remains contained to China. While the Mountain Pass mine in California does produce neodymium, it is currently shipped to China for processing.

To mitigate critical materials supply risks for electric drive systems, EERE (through VTO) aims to reduce the cost of electric drive systems to less than $7/kW by 2022 (a 30 percent reduction from 2017) with technologies that significantly reduce or eliminate the dependency on critical materials (such as rare earth magnet materials) and utilize recycled material feedstocks.

Materials to Reduce Vehicle Weight

Key materials in vehicle light-weighting to improve fuel efficiency of light, medium, and heavy duty vehicles are high-strength steel, aluminum alloys, and magnesium alloys. Aluminum alloys are a prevalent light-weighting material and now make up roughly 10 percent of the weight of light-duty vehicles in the United States. Magnesium's high strength-to-weight ratio makes it an attractive material for reducing the vehicle structural weight commonly used in the gearbox, steering column, and seat frames.

The supply risk for aluminum and magnesium is moderate in the short term, but projected demand for magnesium in transportation sector has the potential to significantly increase supply risk in the medium term if a more geographically diverse portfolio of additional production capacity does not come online. High/medium strength steel is the most common light-weighting material and can include as much as 24 percent manganese to increase strength and stretchability, adding to the supply risk for manganese.

Research is ongoing to make other lightweight materials, such as carbon fiber reinforced plastics, more cost competitive; however, they are unlikely to significantly displace aluminum, magnesium, and high strength steels in the short or medium terms.

Platinum Group Metal Use in Fuel Cells

The growth in demand for hydrogen fuel cells for transportation and other industrial applications necessitates additional use of critical PGM. At present, PGM-based catalysts are essential to the function of fuel cell electric vehicles and comprise over 40 percent of fuel cell stack cost. Decreasing the PGM content decreases the fuel cell system cost, while also reducing the reliance on critical materials.

EERE's Fuel Cell Technologies Office (FCTO) is pursuing two approaches to this challenge: First, to increase the performance and durability of fuel cell catalysts with low PGM content; and second, to develop PGM-free catalysts that could substitute without compromising performance. Both approaches aim to reduce fuel cell system cost from current status of $120/kW to the DOE ultimate target of $30/kW.

While on-road fuel cell stacks today contain about 30 grams of PGM per vehicle, FCTO-funded R&D to lower PGM content has demonstrated improved catalysts requiring less than 10 grams of PGM per vehicle. Ongoing R&D addresses further reduction needed to meet the cost target. The PGM-free approach is being pursued through ElectroCat, FCTO's research consortium dedicated to the rapid advancement of next-generation fuel cell catalysts. Progress since 2016 has included a 65 percent improvement in PGM-free catalyst activity, though significant R&D is necessary to match PGM-based catalyst performance.

Office of Electricity

The Department's Office of Electricity is funding efforts to develop non-lithium energy storage technologies for use on the grid. The program supports fundamental research to advance the development of batteries based on earth-abundant materials such as sodium and zinc, with a cell-level cost target below $100/kWh.

At present, electrochemical storage technology offers some of the most flexible solutions that allow bidirectional flow of the electric energy and can be strategically placed throughout the electric grid. However, the cost of high-energy high-capacity batteries remains relatively high in large part due to the cost of the materials used by the existing technologies. Much of the electrochemical storage R&D proposed efforts are focused on utilizing earth-abundant materials (such as carbon-based organics, sodium, and zinc) to enable the next generation of low-cost storage technologies with U.S. sourced materials.

For grid-scale electrochemical storage, R&D efforts include advanced flow batteries using water-soluble organics to store the electricity enables tremendous opportunity for highly flexible storage systems that can serve not only short-duration power quality applications, but also longer-term energy applications including time shifting of renewable generation. Sodium, as the seventh most abundant element in the earth's crust, has the potential to be a lower-cost alternative to today's lithium-ion batteries while eliminating supply-chain constraints from sensitive nations. Finally, reversible zinc-based storage technologies—based on the alkaline batteries found in every household—could allow very low cost grid storage solutions to be developed that utilize an already existing U.S. manufacturing base. Other electrochemical technologies are also in development for grid-scale storage—the most promising candidates need to similarly possess both low-cost starting materials and a pathway to high-volume manufacturing.

Unconventional Resources
The Office of Fossil Energy (FE), through the National Energy Technology Laboratory (NETL) *Feasibility of Recovery Rare Earth Elements Program*, is currently focused on developing technologies for the recovery of rare earth elements and critical materials from coal and coal-based resources. Three overarching goals of the FE-NETL's *Feasibility of Recovering Rare Earth Elements* program include:

- Development of technologies that can be economically deployed, enabling domestic supply of REEs and critical materials
- Reducing the environmental impact of coal and REE/critical materials production
- Delivering advanced technologies that can be developed and manufactured within the U.S.

FE-NETL's REE RD&D program which began in 2014, currently has over 25 active projects which span from (1) prospecting of domestic field materials and their geological and analytical characterization, to (2) utilization of conventional and advanced separation and extraction technologies to process coal-based feedstocks, to (3) production of individually separated, high purity rare earths in the form of oxides, salts or metals. R&D projects are focused on process system efficiency improvements and optimization to assure cost competitive recovery of REEs and critical materials from coal-based materials. In addition, the program will validate the technical and economic feasibility of small, domestic, pilot-scale, prototype facilities to generate, in an environmentally benign manner, high purity 90-99 wt% (900,000-990,000 ppm), salable, rare earth element oxides (REOs) from 300+ ppm coal-based resources.

Major accomplishments of FE-NETL's REE program are that in FY19-Q4/FY20-Q1 – merely three and one-half years from the start of their initial contract efforts with FE-NETL – DOE's third, first-of-a-kind, domestic extraction, separation and recovery pilot facility in Pennsylvania under the direction of Physical Science Inc. Winner Water, will be producing small quantities of rare earth elements from power plant fly ash, in addition to the REEs being produced at the University of Kentucky and West Virginia University extraction sites which utilize coal refuse and acid mine drainage, respectively, as their feedstock materials. Notably, the rare earths produced at each of these facilities are/will be in the form of oxides that could be further

converted into rare earth metals (REMs) for use in alloying and production of intermediate and/or domestic end-use clean energy, commodity, and national defense products.
To further diversify critical materials supplies, EERE has invested and continues to invest in the recovery of critical materials, such as lithium, from geothermal brines (through the Geothermal Technologies Office (GTO) and AMO) and development of seawater mineral mining technologies (through the Water Power Technologies Office (WPTO)). The latter technology has the potential to use marine and hydrokinetic power to support the extraction of uranium, lithium, precious metals, and rare earths from seawater.[16] In addition, GTO, AMO, and VTO recently started a techno-economic analysis project of the state of lithium production from geothermal brines and its potential place in a domestic supply and manufacturing chain.

Fundamental Science
In order to drive technological change, fundamental science is considered an essential input. Much of the progress by the Department's applied energy offices is underpinned by investments made by the Office of Science. These investments support fundamental research to advance understanding of critical materials at the atomic level. This research includes the development of novel synthesis techniques that control properties at the atomic level to develop unique capabilities for the preparation, purification, processing, and fabrication of well-characterized materials. The Office of Science also supports the development, validation, and application of models to theoretically and computationally identify compounds that are promising critical material substitutes. This research includes projects aimed at identifying replacements for rare earths in electronic and magnetic applications as well as alternatives to materials such as lithium and cobalt in batteries, and platinum in catalytic reactions.

Conclusion
The U.S. must continue to make improvements across the critical minerals supply chain because they are vital to continuing growth and deployment of clean energy technologies. The Department's efforts help enable the U.S. to maintain our edge in innovation. The Department and our national lab researchers and experts are committed to working in a holistic and strategic approach across all three pillars of responsible critical materials management in the energy sector—diversifying supplies and activity at all levels of the supply chain, developing substitutes, and driving recycling, reuse, and efficient use. Executive Order 13817 and the "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals" illustrate that we have a significant task to secure domestic supplies of critical mineral resources.

We will continue to do this in partnership with industry, academia, and other federal agencies to forge paths to critical mineral security, while also working with Congress to ensure appropriate stewardship of taxpayer investments. I appreciate the opportunity to appear before this Committee to discuss the Department's efforts to increase critical mineral security.

[16] U.S. Department of Energy, *Potential Maritime Markets for Marine and Hydrokinetic Technologies: Draft Report*, Apr. 2018, https://eere-exchange.energy.gov/FileContent.aspx?FileID=fcf63beb-3f9d-4e8b-9c35-aa1d746fef6d.

The CHAIRMAN. Thank you, Mr. Simmons.
Ms. Carlson, welcome.

STATEMENT OF ALLISON CARLSON, ACTING MANAGING DIRECTOR, FP (FOREIGN POLICY) ANALYTICS

Ms. CARLSON. Good morning, Madam Chairman, Ranking Member Manchin and members of the Committee. Thank you for the invitation and for your attention to this very important topic.

My name is Allison Carlson. I'm Managing Director at Foreign Policy Analytics, a member of the Foreign Policy Group.

As countries around the world ramp up renewable energy goals and focus on clean technology development, relatively scant attention is being paid to the raw materials required to achieve these ambitions and China's increasing control over the inputs vital to our clean energy economy and competitiveness. Batteries, wind turbines, solar panels and the digital technologies upon which our clean energy future depends require critical minerals and metals that are located in a surprisingly small number of countries and which few commonly found substitutes are available.

China is already the number one producer and processor of at least ten critical minerals and metals that are essential to clean energy and high-tech industries including rare earth elements and several of the other critical minerals that have already been mentioned. Its hallmark initiative, "Made in China 2025," aims to establish global leadership in these industries and is driving the systematic acquisition of those and other critical minerals around the world. To achieve these objectives, in October 2016 the government announced an action plan for its metals industry to achieve world power status by deploying state-owned enterprises (SOEs) and state-linked firms to resource rich hot spots around the globe. China would develop and secure other country's mineral reserves, including minerals in which China already holds a dominant position, giving that country both an economic edge in the next industrial revolution and increasing geopolitical power.

The timing could not have been better. The fall in metal commodity prices in 2011 to 2015 left many mining companies around the world desperate for capital. By directly acquiring mines, accumulating equity stakes in natural resource companies and making long-term purchase agreements for current and future output, Chinese firms have traded much needed capital for control or influence over large shares of global production of these resources.

China's steady accumulation of cobalt in the Democratic Republic of Congo, as was mentioned, which is essential for battery and energy storage technologies, is illustrative of this strategy. The DRC is home to nearly two-thirds of the world's cobalt production and half of its known reserves. For over a decade, China's SOEs and private firms have targeted debt-stressed mining companies and secured equity shares and influence over a majority of mines and over 52 percent of the country's cobalt production.

Chinese SOEs driven strategy remains dominant throughout Africa where adverse market sentiment and financial hardship in the mining industry have opened the door for SOE investment across the region. Notably, SOEs have partnered with the China-Africa Development Fund to expand in Africa's Bushveld Complex. Bushveld is a mineral rich, geological formation that contains the world's largest reserves of platinum group metals which are key to making catalytic converters that reduce automobile emissions. The Complex also holds the world's highest grade and third largest deposit of vanadium, a resource integral to the broad range of high-tech industries from renewable energy storage to aerospace and defense.

Though China is already a global leader in vanadium, tapping into the resource rich Complex will give China an edge in the development of redux flow batteries and support its plan roll out of a 100-megawatt energy storage stations to manage its wind and solar output.

China's position is even stronger in graphite, an element carbon whose high conductivity makes it a major component in electrodes, batteries and solar panels. Rapidly growing demand for batteries and other end uses, coupled with environmental restrictions in China, are driving prices higher and stimulating investment in new projects concentrated in Mozambique where the largest graphite mine and fourth largest known reserves are located.

Increasing volumes of graphite are being channeled toward China's booming domestic battery and new electric vehicle industries. Stockpiling domestic production and restricting graphite exports could result in a supply crunch for other end users.

China is also proving agile at adapting to conditions in market-oriented, democratic countries using privately-owned companies that are backed by state capital. Nowhere is this privately-driven resource strategy more evident than in the three countries where nearly 90 percent of global lithium production and more than three-quarters of the world's known lithium reserves are located: Chile, Argentina and Australia. By incrementally acquiring equity stakes in major local resource companies and financing junior developers, Chinese firms are strengthening their market presence. More than 59 percent of the world's lithium resources are now under Chinese firms' control or influence through equity stakes.

While China's resource accumulation is vast, that country's control over clean energy technology and their supply chains is not a forgone conclusion. It will, however, require us to fundamentally rethink how we understand strategic industries and the long-term investments that are needed to support U.S. clean energy manufacturing. While sustainable resource development will be part of the analysis, intensified focus on industrial and post-consumer minerals recycling, robust investments in material science and research and development could help reduce dependence on extraction, mitigate supply chain vulnerabilities and provide alternative resources of supply that will be critical to U.S. competitiveness in the next industrial revolution.

Thank you so much again for the invitation. I appreciate being here.

[The prepared statement of Ms. Carlson follows:]

Written Testimony of Ms. Allison Carlson, Acting Managing Director, FP Analytics

For: U.S. Senate Committee on Energy and Natural Resources

Hearing : Tuesday, September 17, 2019 – 9:30 a.m. Room 366, Dirksen Senate Office Building, Washington, D.C.

Focus: *The Sourcing and Use of Minerals Needed for Clean Energy Technologies*

As tensions between the United States and China brew over 5G and the question of who can be trusted to control the world's wireless infrastructure, relatively scant attention is being paid to an issue of arguably greater importance to the future of the world's economy and security: China's control of the raw materials necessary to the digital economy.

No new phone, tablet, car, or satellite can be made without certain minerals and metals that are located in a surprisingly small number of countries, and for which few commonly found substitutes are available. Operating in niche markets with limited transparency and often in politically unstable countries, Chinese firms have locked up supplies of these minerals and metals with a combination of state-directed investment and state-backed capital, making long-term strategic plays, sometimes at a financial loss.

Through in-depth analysis of company reports and disclosures, mapping of deal flows, quantification of direct and indirect equity stakes, and other primary research, FP Analytics produced the first consolidated review of this unprecedented concentration of market power. The fact-based analysis details how rapidly and effectively China's state-owned enterprises (SOEs) and state-linked private firms have executed its national ambitions, with far-reaching implications for the U.S. and the rest of the world. A summary of the report's findings is below.

"Going Out and Bringing In"

China's hallmark initiative, "Made in China 2025," aims to build strategic industries in national defense, science, and technology. To meet these objectives, in October 2016, the Ministry of Industry and Information Technology announced an action plan[1] for its metals industry to achieve world-power status: By deploying state-owned enterprises and private

[1] Ministry of Industry and Information Technology of the People's Republic of China, "Nonferrous Metal Industry Development Plan 2016-2020," October 2016, http://www.miit.gov.cn/n1146290/n4388791/c5288773/content.html.

firms to resource-rich hot spots around the globe, China would develop and secure other countries' mineral reserves—including minerals in which China already holds a dominant position.

The timing could not have been better. The fall in metal commodities prices from 2011 to 2015 left many mining companies around the world desperate for capital. By directly acquiring mines, accumulating equity stakes in natural-resource companies, making long-term agreements to buy mines' current or future production (known as "off-take agreements"), and investing in new projects under development, Chinese firms traded much-needed capital for control or influence over large shares of the global production of these resources. Despite China's slowing growth and a major pullback in its foreign direct investment in other sectors, the government has maintained robust financial support for resource acquisition; mergers and acquisitions in metals and chemicals hit a record high in 2018.[2]

Though it boasts a rich endowment of natural resources at home, China lacks significant reserves of three resources vital to its technology ambitions: cobalt, platinum-group metals, and lithium. It has successfully employed two strategies to secure global control of them. The first is driven by China's state-owned enterprises, which use development finance and infrastructure investment in higher-risk countries to establish close ties with government leaders. The second is investment by state-linked private firms in market-based economies. Both strategies have shown an ability to effectively adapt to local circumstances to achieve the same end.

SOE Strategy, Cobalt, and the Case of the Democratic Republic of Congo

With few governments having articulated, let alone implemented, an explicit resource strategy, China is more than a decade ahead in the game. In the Democratic Republic of Congo (DRC), which is home to nearly two-thirds of the world's cobalt production and half of its known reserves,[3] China's SOEs and private firms have targeted debt-stressed mining companies and secured equity shares and influence over a majority of its mines - over 52 percent of the country's production.[4] China's deep investment in copper and cobalt mining—which constitutes 80 percent of the DRC's export revenue[5] and thousands of jobs—has conferred an ability to influence the future of the DRC's economy.

Replicating the State-Owned Enterprise Model

China's SOE-driven strategy remains dominant throughout Africa, where adverse market sentiment and financial hardship in the mining industry have opened the door for SOE

[2] "PwC M&A 2018 Mid-Year Review and Outlook," PricewaterhouseCoopers, https://www.pwccn.com/en/deals/publications/ma-2018-mid-year-review-and-outlook.pdf.
[3] "BP Statistical Review of World Energy," BP, June 2018, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.
[4] FP Analytics analysis.
[5] "The World Bank in DRC," The World Bank, May 16, 2018, https://www.worldbank.org/en/country/drc/overview.

investment across the region. Notably, SOEs have partnered with the Chinese state-funded China-Africa Development Fund to expand in South Africa's Bushveld Complex. Bushveld is a mineral-rich geological formation that contains the world's largest reserves of platinum-group metals, which are key to making catalytic converters that reduce automobile emissions. The Complex also holds the world's highest-grade and third-largest deposit of vanadium - a resource integral to a broad range of high-tech industries, from renewable-energy storage to aerospace and defense. Such investments in South Africa's highly concentrated and strategic resource deposits have helped make metals the country's leading source of export growth,[6] with nearly 50 percent of its metal exports going to China[7]—tying South Africa's economic welfare directly to Chinese investment.

Private Firms and the Extension of State Strategy Abroad

China is also proving agile at adapting to conditions in market-oriented, democratic countries, using privately owned companies that are backed by state capital. By incrementally acquiring equity stakes in major local resource companies and financing junior developers, Chinese firms are strengthening their market presence. Nowhere is this privately driven resource strategy more evident than in the three countries where nearly 90 percent of global lithium production and more than three-quarters of the world's known lithium reserves are located: Chile, Argentina, and Australia.[8] By acquiring a major stake in the leading producer in Chile, financing new development in Argentina, and acquiring mines and building up processing capacity in Australia, Chinese firms are dominating the global market: More than 59 percent of the world's lithium resources are now under their control or influence.[9]

China Reinforcing Its Resource Dominance

Already the dominant producer in a range of critical minerals and metals, China is investing in additional supplies in foreign markets thereby strengthening its global position. Natural resources are abundant in China; it is the No. 1 producer and processor of at least ten critical minerals and metals[10,11] that are essential to high-tech industries and upon which China's commercial and strategic competitors depend. To reinforce its dominant position,

[6] "Statistical Release P0441: Gross Domestic Product, Fourth quarter 2017," Statistics South Africa, June 5, 2018, http://www.dmr.gov.za/Portals/0/files/P04414thQuarter2017(1).pdf?ver=2018-03-09-063718-170.
[7] "South Africa Minerals Exports By Country 2017," World Integrated Trade Solution (WITS), The World Bank, https://wits.worldbank.org/CountryProfile/en/Country/ZAF/Year/LTST/TradeFlow/Export/Partner/by-country/Product/25-26_Minerals.
[8] "BP Statistical Review of World Energy," BP, June 2018, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.
[9] FP Analytics analysis.
[10] "Mineral Commodities Summaries," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/mcs/.
[11] The definition of "critical" or "strategic" and the exact list of minerals, metals, or materials varies by jurisdiction, but a literature review of major studies assessing "criticality" identifies the resources most commonly categorized and cited in official documents. China is the leading global producer of the majority of those listed, including natural graphite, rare-earth elements, vanadium, indium, tungsten, gallium, antimony, tellurium, cadmium, and molybdenum. Also see: https://www.sciencedirect.com/science/article/pii/S0301420718301296?via%3Dihub.

Chinese firms are acquiring mines and output from the next-largest producers and reserves, giving China both an economic edge in the next high-tech industrial revolution and increasing geopolitical power.

Perhaps the best-known example both of China's natural-resource dominance and its willingness to exploit it is rare-earth elements. Rare earths are a group of 17 elements that (despite their name) are commonly found, but rarely in concentrations that can be economically extracted. They are important materials for the defense, aerospace, electronics, and renewable energy industries. Over the past two decades China has produced more than 80 percent of the world's rare-earth elements and processed chemicals. Six state-owned enterprises control the industry.[12] In 2010 China cut off exports to Japan[13] amid rising tensions over the East China Sea - demonstrating China's ability and willingness to exert control over critical minerals for commercial and geopolitical ends. With global demand for rare-earth elements projected at a compound average growth rate of more than 17 percent to 2025,[14] a supply crunch is likely approaching—and China is already securing other nations' supplies, including in the U.S., Australia, and Greenland.

China is also expanding its dominant market position in vanadium and graphite, securing additional supplies and building integrated supply chains. Vanadium is a transition metal that is used in flow batteries, superconducting magnets, and high-strength alloys for jet engines and high-speed aircraft. Chinese firms already produce 56 percent of the world's vanadium domestically, and China is home to 48 percent of the world's reserves.[15] Now, they are targeting South Africa - ranked third in vanadium production and reserves behind China and Russia[16] - and tapping into local companies' plans to develop an integrated platform to produce vanadium redox flow batteries for distributed energy across South Africa.[17] The vanadium resources will also flow toward China, feeding its battery industry and the National Development and Reform Commission's planned rollout of 100-megawatt stationary energy storage stations to manage its wind and solar energy.[18]

China's position is even stronger in graphite, a crystalline form of the element carbon whose high conductivity makes it a major component in electrodes, batteries, and solar

[12] "Barbara Lewis and Ernest Scheyder, "China cutting rare earth output, unnerving global manufacturers," *Reuters*, Oct. 24, 2018, https://www.reuters.com/article/us-china-rareearths/china-cutting-rare-earth-output-unnerving-global-manufacturers-idUSKCN1MY2GZ.

[13] Keith Bradsher, "Amid Tension, China Blocks Vital Exports to Japan," *The New York Times*, Sep. 22, 2010, https://www.nytimes.com/2010/09/23/business/global/23rare.html.

[14] "United States Securities and Exchange Commission Form 10-K: Rare Element Resources Ltd.," fiscal year ended Dec. 31, 2017, http://www.rareelementresources.com/docs/default-source/financial-reports/p05218_rare-element-resources_2018_10k_v2.pdf?sfvrsn=0.

[15] "Mineral Commodities Summaries 2019," U.S. Geological Survey, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf.

[16] Ibid.

[17] "Bushveld Minerals: Right commodity, right asset, right time," Alternate Resource Capital, March 1, 2018, http://www.bushveldminerals.com/wp-content/uploads/2018/03/BMN_010318.pdf

[18] "Bushveld Minerals acquisition of Bushveld Vametco Limited," Bushveld Minerals, December 2017, http://www.bushveldminerals.com/wp-content/uploads/2017/12/Bushveld-Minerals-acquisition-of-Bushveld-Vametco-Limited_Final.pdf

panels, as well as industrial products such as steel and composites. Rapidly growing demand for batteries and other end uses, coupled with environmental restrictions in China, are driving prices higher and stimulating investment in new projects concentrated in Mozambique, where the world's largest graphite mine and fourth-largest known reserves are located.[19]

Controlling most of the world's graphite, China has expanded down the supply chain, becoming the world's leading producer of anodes, positively charged electrodes that are essential for making lithium-ion batteries. Increasing volumes of graphite are being channeled toward China's booming domestic battery and new electric-vehicle industries. Stockpiling domestic production and restricting graphite exports could result in a supply crunch for other end users.

Controlling the Fuel of the Future

This resource consolidation could determine whether China is able to overcome the last major hurdle to achieving its ambitions: a competitive semiconductor industry. The lifeblood of high-tech industries, semiconductors are made of the very minerals and metals over which China is securing control. Several materials are now being used to improve speed and performance, including rare-earth elements, graphite, indium, gallium, tantalum, and cadmium. China is the dominant producer of five out of the six, controls more than 75 percent of the world's supply of three,[20] and is consolidating control over them all.

However, China still lacks the technological capability to produce semiconductors on par with the industry's leading companies and remains highly dependent on imports, at a cost of roughly $260 billion per year.[21] Should China succeed technologically, its capacity to scale production and flood markets has serious implications not only for leading semiconductor producers, but also for national security. The ramifications for U.S. national security could be severe if Chinese-manufactured chips are embedded in the devices upon which our data-driven lives, our economies, and our defense systems increasingly depend.

This is not a foregone conclusion. It will, however, require us to fundamentally rethink how we understand strategic industries and the long-term investments needed to ensure economic prosperity and national security in the digital age. While sustainable resource development will be part of that analysis, intensified focus on industrial and post-consumer minerals recycling and robust investments in materials science R&D could help reduce dependence on extraction, mitigate supply chain vulnerabilities, and provide alternative sources of supply that are critical to high-tech industries' competitiveness and security.

[19] Mozambique has the fourth highest reserves at 17 million tons, tied with Tanzania which also as 17 million tons of estimated reserves. "Mineral Commodities Summaries: Graphite (Natural)," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/commodity/graphite/mcs-2019-graph.pdf.

[20] "Mineral Commodities Summaries 2019" U.S. Geological Survey, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf.

[21] Shunsuke Tabeta, "Chinese companies rush to make own chips as trade war bites," *Nikkei Asian Review*, Nov. 7, 2018, https://asia.nikkei.com/Business/China-tech/Chinese-companies-rush-to-make-own-chips-as-trade-war-bites.

FP ANALYTICS

FP Analytics is the research and advisory division of The Foreign Policy Group. Allison Carlson is FP Analytics' Acting Managing Director, overseeing all global research and analysis. She counsels clients on current and prospective market, policy, and security developments. Prior to this role, Carlson led FP Analytics' energy and technology team for over a decade. Carlson received her master's degree from the Johns Hopkins School of Advanced International Studies (SAIS) in international relations and international economics.

The CHAIRMAN. Thank you, Ms. Carlson.

Mr. Kang, welcome.

STATEMENT OF W. ROBERT KANG, CHIEF EXECUTIVE OFFICER, BLUE WHALE MATERIALS LLC

Mr. KANG. Madam Chairman Murkowski, Ranking Member Manchin, honored Committee members, thank you for the opportunity to appear before you today to discuss the sourcing and use of minerals needed for lithium-ion batteries, a rapidly growing sector that is leading the electrification of transportation and energy storage for a variety of applications.

My name is Robert Kang, and I am CEO of Blue Whale Materials, a leading lithium-ion battery recycling company in the United States.

As we sit here today, I suspect every one of the people in this room is carrying a lithium-ion battery powered device, preferably on silent, and news is coming out almost daily——

Senator MANCHIN. Sorry.

[Laughter.]

Mr. KANG. ——about new commitments from auto manufacturers to move to electric vehicle production powered by lithium-ion battery technology. The question is no longer if, but when, those lithium-ion batteries will become the dominant energy storage devices in the world.

Behind the growth of lithium-ion batteries lies a battle for the materials critical to their production. Demand for cobalt, nickel, lithium, and graphite is projected to rise dramatically to meet the future demand for lithium-ion batteries. The U.S. has fallen behind in this global race to secure access to these critical minerals including cobalt and lithium.

As a result of these supply constraints and the increased projected demand for these minerals, manufacturers of lithium-ion batteries and products reliant on lithium-ion batteries are seeking new and alternative sources of these minerals at earlier points in the supply chain.

The lithium-ion battery recycling industry provides one answer to meet the demand for U.S. sources of critical minerals. The lithium-ion recycling industry operates in three categories.

First, collectors gather spent batteries from consumers, industrial sites, and manufacturers and sorts them into different chemistries for further recycling. Next, processors take those sorted batteries and discharge them to eliminate the risk of thermal events and then process them to create intermediate metal products. Processing methods range from very crude shredding to a more sophisticated process that isolates the higher value metals such as cobalt and nickel and produces a more concentrated intermediate product. Finally, processors sell the intermediate metal material to refiners that produce pure metal to battery precursor manufacturers to be used in new lithium-ion batteries.

As this Committee considers measures to strengthen access to critical minerals in the United States, a number of measures could help spur the U.S. lithium-ion recycling industry.

First, we need to collect far more of the spent batteries for recycling. The U.S. currently collects less than 5 percent while Europe collects approximately 40 percent or more.

Secondly, we need to expand the United States' capacity to process batteries. Today we ship most of our collected lithium-ion batteries for recycling to China, South Korea and Europe. Increasing U.S. processing capacity will allow U.S. businesses to control the flow of these metals earlier in the supply chain.

Lastly, we should encourage refining capabilities here in the U.S. A market for recycled metals will support investments to strengthen the entire lithium-ion battery industry in the U.S.

As this Committee evaluates possible approaches to increase U.S. access to critical materials, we commend the Committee for including recycling provisions in the American Mineral Security Act. We see several possible ways to increase investment and innovation in this space.

First, there are significant opportunities for innovation with the individual states, which can and should explore policies to increase the recycling of lithium-ion batteries. For example, California and Maryland are seeking policy proposals for effective lithium-ion battery recycling that have the potential to serve as models for national adoption. We are encouraged by the progress these initiatives might offer, but funding these programs is an obstacle for many states. We recommend this Committee consider federal matching funds for state programs or investments in collection, processing and refining projects to spur lithium-ion battery recycling here in the U.S.

In addition, we encourage this Committee to consider other creative ways to spur investment in this sector. The Opportunity Zone credit has been effective at generating investment in specific geographic zones, and we recommend a similar approach that targets specific industries, including collection, processing and refining of lithium-ion batteries. Such investments will not only provide access to critical minerals here in the U.S., but will create manufacturing jobs, solve important safety concerns, and help support a more developed lithium-ion battery industry in the United States.

If the U.S. is going to lead the next generation of technology transformation brought by the advent of the lithium-ion battery, we must have access to a reliable and sustainable source of these critical minerals. Recycling is one solution to this challenge, and the policy of this government should be designed to stimulate the industry.

Thank you so much for your time, and I appreciate and look forward to your questions.

[The prepared statement of Mr. Kang follows:]

Testimony of W. Robert Kang
Chief Executive Officer
Blue Whale Materials LLC

Before the
U.S. Senate Committee on Energy and Natural Resources

September 17, 2019

Introduction

Chairman Murkowski, Ranking Member Manchin, honored Committee Members, thank you for the opportunity to appear before you today to discuss the sourcing and use of minerals needed for li-ion batteries, a rapidly growing sector that is leading the electrification of transportation and energy storage for a variety of applications. My name is Robert Kang, and I am CEO of Blue Whale Materials LLC, a leading lithium-ion battery recycling company in the United States.

Market for Minerals Needed for Li-Ion Batteries

The advances in energy storage and the advent of the li-ion battery are fueling a new technology revolution – in our consumer products, the automotive industry, energy storage, grid management, and the internet of things. As we sit here today, I suspect every one of the people in this room is carrying a li-ion battery powered device (preferably on silent) and news is coming out almost daily about new commitments from auto manufacturers to move to electric vehicle production powered by li-ion battery technology. The question is no longer if, but when those li-ion batteries will become the dominant energy storage devices in the world.

Behind the growth of li-ion batteries lies a battle for the materials critical to their production. Demand for cobalt, nickel, lithium, and graphite is projected to rise dramatically to meet the future demand for li-ion batteries. As other witnesess before this Committee have testified, the U.S. has fallen behind in the global race to secure access to these critical minerals including cobalt and lithium. China has established a near-stranglehold on the cobalt market, refining an estimated 70 percent of the world's cobalt chemical products. Further, most cobalt is mined in the Democratic Republic of Congo, a weak state in which the mining industry has had difficulty keeping children and other laborers from hazardous "artisanal mining" — i.e., mining and washing the ore by hand. The DRC is projected to supply nearly 70 percent of the world's cobalt for the foreseeable future. China also produces over half of the world's refined lithium and its dominance is expected to continue.

As a result of these supply constraints and the increased projected demand for these minerals, manufacturers of li-ion batteries and products reliant on li-ion batteries, such as smartphones and electric vehicles, are seeking new and alternative sources of these minerals at earlier points in the supply chain.

Li-Ion Battery Recycling Is A Solution

The li-ion battery recycling industry provides one answer to meet the demand for U.S. sources of critical minerals. We are sitting on a goldmine of discarded phones and gadgets with spent li-ion batteries in our desk drawers and junk heaps waiting to be recycled. The electric vehicles that will soon proliferate will have batteries with valuable minerals in need of recycling. And we will need to ensure that the batteries we do collect in the U.S. are recycled here, so we do not lose control of this feedstock of critical minerals. Investment in the li-ion recycling industry will create manufacturing jobs here in the U.S. and solve important safety problems associated with transportation and improper dispossal of potentially volatile spent li-ion batteries. We applaud the Committee for including recycling provisions in the American Mineral Security Act in an effort to turn the country's current deficit in recycling into an advantage.

The li-ion recycling industry operates in three categories. First, collectors gather spent batteries from consumers, industrial sites, and manfuacturers. Those collectors may be electronic waste collectors or entities focused specifically on batteries and often provide a role in sorting batteries into different chemistries for further recycling. Next, processors take those sorted batteries and discharge them (to eliminate the risk of thermal events) and then process them to create intermediate metal products. Processing methods range from very crude shredding to a more sophisticated process that isolates the higher value metals such as cobalt and nickel and produces a more concentrated intermediate product. The most efficient processors can recycle close to 98% of the constituent metals in a li-ion battery. Finally, processors sell the intermediate metal material to refiners that produce pure metal to battery precursor manufacturers to be used in new li-ion batteries.

Improving the Li-Ion Battery Recycling Ecosystem

As this Committee considers measures to strengthen access to critical minerals in the United States, a number of measures could help spur the U.S. li-ion recycling industry to provide a reliable and sustainable source of cobalt, nickel and lithium for U.S. manufacturers.

First, we need to collect far more of the batteries we currently throw out. While the United States is one of the world's largest consumers of li-ion batteries, it's estimated that fewer than one in 20 is returned for recycling — significantly less than the 40 percent collected in Europe, where collection infrastructure is more established. Battery manufacturers fund the leading collector of batteries in the U.S., the non-profit Call2Recycle, but more can be done to change consumer recycling behavior and create a stronger infrastructure for li-ion battery collection. New programs are needed to deal with the volume of electric vehicle and large format li-ion batteries that will be coming off line in the near future.

Secondly, we need to expand the United States' capacity to process batteries. Today we ship most of our collected li-ion batteries for recycling to South Korea, Europe, or China. Increasing U.S. processing capacity will allow U.S. customers to control the flow of these metals earlier in the supply chain.

Lastly, we should encourage refining capabilities in the U.S. to produce cobalt and nickel from spent li-ion batteries. A market for those recovered metals will support investments to strengthen the entire li-ion battery industry in the U.S., including active cathode material manufacturing, precursor manufacturing and cell manufacturing that requires these metals. Those industries are currently established in Asia and expanding in Europe.

Recommended Steps to Encourage Investments in U.S. Recycling

The U.S. government has already taken some positive steps to secure access to these minerals. The Trump administration's Executive Order to "Ensure Secure and Reliable Supplies of Critical Minerals" and the follow on work by the administration have been productive. In January, the Department of Energy announced a Lithium-Ion Battery Recycling Prize and the establishment of an associated Battery Recycling R&D Center aimed at recycling and reclaiming critical materials like cobalt and lithium. And this Committee's work on the American Mineral Security Act is a positive move in the right direction.

There are significant opportunities for innovation with the individual states, which can and should explore policies to increase recycling of li-ion batteries. California and Maryland are seeking policy proposals for effective li-ion battery recycling that have the potential to serve as models for national adoption. We are encouraged by the progress these initiatives might offer, but funding these programs is an obstacle for many states. We recommend this Committee consider federal matching funds for state programs or investments in collection, processing and refining projects to spur li-ion battery recycling here in the U.S.

In addition, we encourage this Committee to consider other creative ways to spur investment in this sector. The Opportunity Zone tax credit has been effective at generating investment in specific geographic zones, and we recommend a similar approach that targets specific industries, including collection, processing and refining of li-ion batteries. Such investments will not only provide access to critical minerals here in the U.S., but will create manufacturing jobs, solve important safety concerns, and help support a more developed li-ion battery industry in the United States.

Conclusion

If the U.S. is going to lead the next generation of technology transformation brought by the advent of the li-ion battery, we must have access to a reliable and sustainable source of these critical materials. Recycling is one solution to this challenge and the policy of this government should be designed to stimulate the industry.

Thank you very much for your time today. I look forward to answering your questions.

The CHAIRMAN. Thank you, Mr. Kang, we appreciate your very specific recommendations there.

Dr. Bazilian.

STATEMENT OF DR. MORGAN D. BAZILIAN, PROFESSOR AND DIRECTOR, PAYNE INSTITUTE FOR PUBLIC POLICY, THE COLORADO SCHOOL OF MINES

Dr. BAZILIAN. Good morning, Chairman Murkowski, Ranking Member Manchin, and members of the Committee. It's an honor to be here to talk to you about the topic of the mineral foundations of the energy transition.

My name is Morgan Bazilian. I am a Professor and Director of the Payne Institute for Public Policy at the Colorado School of Mines. The Colorado School of Mines is one of the finest universities in the world on the topics being discussed today.

For my testimony today I have five points.

First, the future energy system will be mineral intensive. We can be confident that the tremendous growth and innovation in clean energy technologies will continue. Each of these clean energy technologies relies on significant quantities of a diverse group of critical minerals and metals. And while the focus is rightly on the minor metals, space metals are also being affected by this change.

As noted, my former employer, the World Bank, has quantified the scale of this demand growth and subsequently they've launched something called the Climate Smart Mining Initiative which helps developing countries engage on these issues.

Second, this is a tremendous opportunity for the mining industry, an industry that has experienced enormous public pressure and critique accompanied by offshoring of production can now evolve into one fundamental to supporting a shift to a low-carbon and sustainable energy system based on domestic natural resources. Crafting this positive narrative is critical to creating a vibrant and sustainable mining sector in the U.S. and abroad. And as Senator Manchin said, it's also critical to supporting issues of social license to operate.

Third, the sector is diverse. The set of minerals required for clean energy technologies is heterogeneous and have their own set of supply chain conditions. Each will thus require individual examination and policy prescriptions. Most of these markets are not liquid, nor transparent. They also do not provide clear price signals and thus, investment decisions are exceedingly difficult to make. Complicating this further, some of these minerals are secondary or tertiary. Humility is required. While it's immediately attractive to focus on mineral supply, there's only one place to stimulate activity. From exploration through to mining, refining, manufacturing and recycling, each part of the supply chain offers opportunities and challenges for U.S. company entry. And as you're aware, currently China has become the dominant world player in many parts of that chain.

Fourth, we have useful precedent for security and policy from the energy sector. Chairman Murkowski, you've said that energy and mineral security are the building blocks of a robust economy. It's clear to me from my research and the literature and current indicators that that is correct. These issues of supply threats, international relations, security and the related analysis have been well considered in energy policy. And as you note, that's been demonstrated in some of the responses to the attacks in Saudi Arabia. What has become clear over decades of energy security analysis is the goal of independence or even dominance is not useful. Rather, a focus on diversity of supply and demand as well as better understanding of resilience across the supply chain will lead to a more sophisticated and robust approach. Recall that the British Navy under Winston Churchill between 1912 and 1914 shifted from domestic coal to imported oil. It was a vital decision to the success of their military operations. One lesson from that is that domestic resources alone are not always the key to success.

Fifth, this is a global issue. The 2019 Department of Commerce Federal Strategy for Critical Minerals has acknowledged this clearly in its six action areas. And while withdrawing from the extractive industry's transparency initiative was short-sighted, the State Department's new Energy Resource Governance Initiative has been launched with the aim to engage countries to advance governance principles, share best practice and encourage a level playing field.

Domestic interventions, such as strategic reserves, resource mapping, R&D funding, targeted industrial policy, workforce development, and improved permitting processes are all worth exploring. Still, policy design should not be done with domestic blinders on.

As you've noted, Senator Murkowski, other regions and countries like the European Union, Australia, Japan and others have all come up with their own critical minerals list.

Finally, I applaud the Committee for robustly and persistently considering these issues and doing so in a bipartisan manner. Your deliberations and actions can lay the foundation for a productive engagement by the United States on these critical issues.

[The prepared statement of Dr. Bazilian follows:]

The Payne Institute for Public Policy
COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

September 17, 2019

"The Mineral and Metal Foundations of the Energy Transition"

Congressional Testimony of
Dr. Morgan D. Bazilian
Professor and Director, Payne Institute for Public Policy
The Colorado School of Mines

Before the
Committee on Energy and Natural Resources
United States Senate
116th Congress

Chairman Murkowski, Ranking Member Manchin, and Members of the Committee, thank you kindly for inviting me to testify on the minerals needed for clean energy technologies. I appreciate the bipartisan spirit that this Committee brings to the energy issues of the United States. It is an honor to appear before this Committee on the critical topic of the mineral foundations of the energy transition.

My name is Morgan Bazilian, and I am a Professor and Director of the Payne Institute for Public Policy at the Colorado School of Mines. The Colorado School of Mines is a public research university, where students and faculty together address the great challenges society faces—particularly those related to the Earth, energy, and the environment. The Payne Institute was established to bring the cutting-edge science, mathematics, and engineering at Mines to bear in helping to inform policy.

Minerals and metals are central to the energy transition, but the economic, security, and geostrategic implications are all in play, depending how the U.S. policy responds.

The principal impetus for the 2017 Executive Order (13817) provides a useful framing for this hearing: "The United States is heavily reliant on imports of certain mineral commodities that are vital to the Nation's security and economic prosperity. This dependency of the United States on foreign sources creates a strategic vulnerability…"

We can be confident that the tremendous growth and innovation in technologies such as batteries for electric vehicles and grid-electricity storage, fuel cells, wind turbines, and solar photovoltaics (PV) will continue. Each of these clean energy technologies relies on significant quantities of a diverse group of critical minerals and metals.

The future energy system will be far more mineral and metal-intensive than it is today. [1] Many of these advanced technologies require minerals and metals with particular properties that have few to no current substitutes.

The opportunity for the mining industry is tremendous. An industry that has experienced enormous public pressure and critique, accompanied by offshoring production overseas, can now evolve into one fundamental to supporting a shift to a low-carbon and sustainable energy system based on domestic natural resources.

The issues related to the mineral foundations of the energy transition go well-beyond the energy and extractives sectors. There will be implications for geopolitical dynamics, defense, consumer technology, water security, industrial growth, innovation in high-tech sectors, responsible consumption and production, decent work, and equality.

My testimony will begin with some historical context and then move to future scenarios. The following sections will consider issues of security and criticality, and conclude with some thoughts on domestic energy and natural resources policy.

I applaud the Committee for robustly and persistently considering these issues. This Committee most recently held a hearing on similar matters on May 14 of this year, making this the 8th in the genre.

The continued focus on supply chains, as well as a building robust domestic industry with the "highest environmental and labor standards in the world," is appropriate and important. Your deliberations and actions can lay the foundation for a productive engagement by the U.S. on issues of global importance.

---

[1] See e.g., André Månberger, Björn Stenqvist, Global metal flows in the renewable energy transition: Exploring the effects of substitutes, technological mix and development, Energy Policy, Volume 119, 2018, Pages 226-241; Anna Stamp, Patrick A. Wäger, Stefanie Hellweg, Linking energy scenarios with metal demand modeling–The case of indium in CIGS solar cells, Resources, Conservation and Recycling, Volume 93, 2014, Pages 156-167; Jan de Koning, René Kleijn, Gjalt Huppes, Benjamin Sprecher, Guus van Engelen, Arnold Tukker, Metal supply constraints for a low-carbon economy, Resources, Conservation and Recycling, Volume 129, 2018, Pages 202-208.

PAST AND FUTURE

We are seeing rapidly increasing mineral intensity in the energy sector. Figure 1 helps us better understand the historical development of the energy system in terms of both energy sources and end uses. Society moved from agrarian communities using biomass, to the industrial revolution and coal, to a modern area of services and a portfolio of energy sources including petroleum, natural gas, nuclear, and renewables.

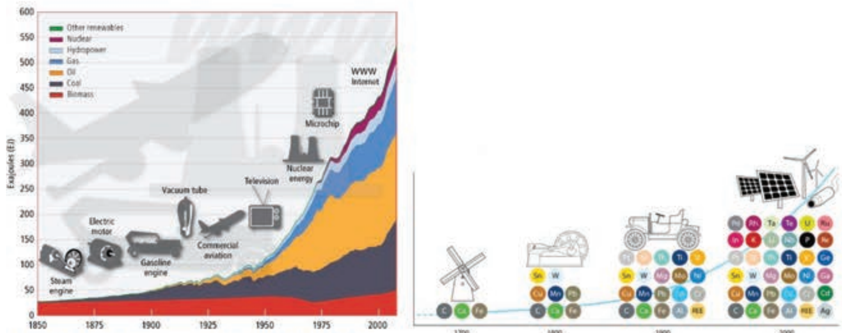


Figure 1: Left, Nakicenovic, IIASA; Right, Zepf, 2014

The current set of minerals required for clean energy technologies such as PVs, wind turbines, LEDs, and vehicle batteries is diverse (Figure 2). Each of the individual minerals have their own set of supply chain conditions, and will thus require individual examination and policy prescriptions.

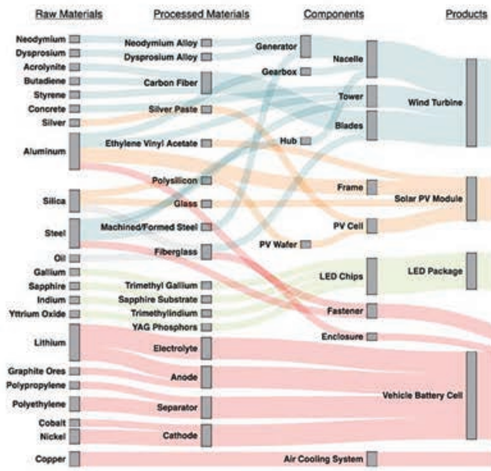


Figure 2: Mineral flows to technologies, CEMAC, NREL, 2018

My former employer, The World Bank, undertook important work in analyzing the mineral-intensity of future energy portfolios with a focus on clean energy technologies. The work shows enormous demand growth estimates for certain minerals such as lithium, cobalt, graphite, vanadium, nickel, and silver (Figure 3).

Figure 3: Scenarios of mineral demand, World Bank, 2018

This type of scenario exercise helps us better consider the effects of different policy responses. One important example comes from lithium for electric vehicle (EV) batteries. While the growth in EVs is projected to be spectacular, the price signals, and uncertainty in which minerals and metals will comprise battery chemistries going forward, are not providing clear investment signals (Figure 4).

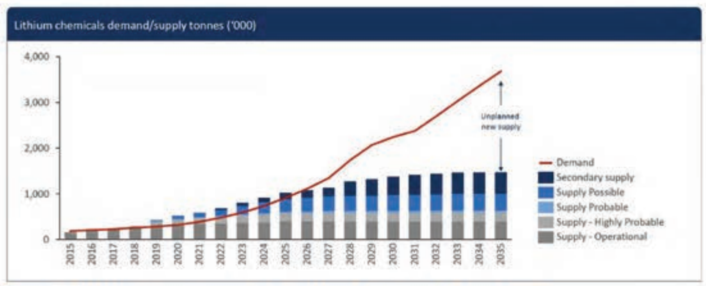


Figure 4: Supply and demand projections for lithium, Benchmark Minerals, 2019.

And while lithium may have the most pronounced risk in terms of possible supply-demand imbalances, gaps could also occur for nickel, cobalt, manganese, and even copper and bauxite. It should be emphasized that cobalt, by far, is the largest concern today, and the most uncertain.

While there may be some bottlenecks to supply, along with price implications for markets, the resource base on a geological basis for most of these minerals is large and unlikely to be a significant constraint.

MINERAL SECURITY AND CRITICALITY

In May, 2018, the Department of the Interior produced a draft list of 35 critical minerals.[2] Many of the minerals are essential for the defense or aerospace sectors, and of course, many for energy. Additional analysis is required to evaluate the criticality of specific minerals to U.S. interests, and the resilience of each supply chain to price shocks.

The U.S. is not the only country, or region, to consider mineral criticality. Japan, the EU, and Australia have all produced critical minerals lists. (Interestingly, Australia's list is not focused so much on their domestic needs, but how to provide strong export markets. The European Commission's list started in 2011, and has been updated three times since.

[2] https://www.usgs.gov/news/interior-releases-2018-s-final-list-35-minerals-deemed-critical-us-national-security-and

As is well known to this Committee, China has become the dominant world player in many critical mineral supply chains (Figure 5).

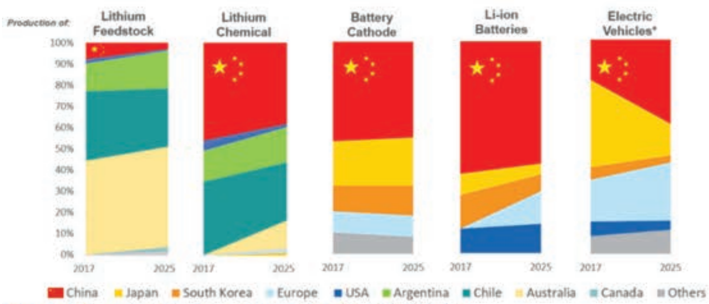


Figure 5: Who controls the Li-ion battery supply chain, IHS Markit

In response to these trends, on May 2, 2019, Chairman Murkowski introduced the bipartisan American Mineral Security Act (S. 1317).

Earlier this year, Senator Manchin proposed the bipartisan Rare Earth Element Advanced Coal Technologies Act (S. 1052). The legislation frames the issue as one with national security and geopolitical implications, particularly given Chinese dominance of the sector.

Related, the RE-Coop 21st Century Manufacturing Act (S. 2093) acknowledges the need to consider an integrated rare earth value chain to serve U.S. security interests.

In the spring of this year, China state media issued some pieces indicating a ramp-up of confrontational language around using rare earths supply as a strategic counter to the Trump administration's latest tariffs. The "tools" China has (according to their articles) include, "cutting the number of rare-earth mining licenses, raising market access standards for miners, reducing exports of primary rare earth products, and restricting outbound and inbound investment in related industries."

These issues of supply threats, international relations, security, and the related analysis is well-covered in energy policy—especially in relation to oil. The big recent change in energy security has been due to the shale revolution. The U.S. has become the largest producer of crude oil in the world, and one of the largest exporters of natural gas, through a combination of Federally-supported and private technology development as well as supportive regulations and policy. That precedent has not gone unnoticed in the mining sector.

What has become clear over decades of energy security analysis is that a reliance solely on import dependence does not account for the economic impacts of energy supply, nor many other factors, and thus is only one of many elements that need be considered for robust decisionmaking in issues of security and resilience.

The future will likely bring more globally interdependent markets and systems. As a result, it is useful to further encourage new quantitative and qualitative approaches to the issues of security and criticality—in both minerals and energy.

Additionally, some of the tools developed during the early oil shocks, such as the development of the Strategic Petroleum Reserve, are now being considered to protect access to critical materials.

DOMESTIC ACTION

The Department of Commerce released the Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals in June, 2019.[3] The six "Calls to Action" range from an improved workforce, to speeding up permitting, to acknowledging the importance of supply chains and trade, and better understanding the domestic resource base.

The Strategy provides a useful multi-pronged framework for domestic action. As each of these minerals has a very different supply chain and market structure, they will need to be individually considered for where the U.S. might best strategically focus.

The other categories of required interventions range from: resource mapping and minerals-specific scenario analytics; to technological constraints and advances in technology design and engineering; to market development and other economic approaches; to governance improvements along the value chain; to social protection and environmental management.

While it is immediately attractive to focus on mining, it is only one place to stimulate activity. From exploration, through to mining, refining, manufacturing, and recycling, each part of the supply chain offers opportunities and challenges for U.S. entry (Figure 6—battery example).

[3] https://www.commerce.gov/news/reports/2019/06/federal-strategy-ensure-secure-and-reliable-supplies-critical-minerals

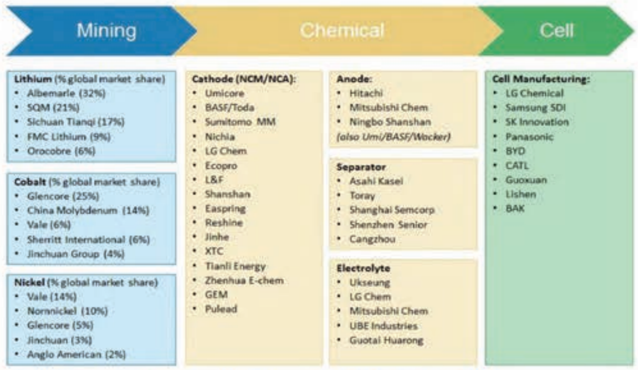


Figure 6: Battery supply chain companies, Morgan Stanley and DCDB, 2019.

At the same time, the global nature of these issues must be acknowledged, as it has been in the Commerce Strategy. Withdrawing from the Extractive Industries Transparency Initiative, as an example, does not send the right signals, and was a strategic mistake.

On a positive note, the State Department's new Energy Resource Governance Initiative has been launched with the aim to, "engage countries to advance governance principles, share best practices, and encourage a level playing field. It will also promote resilient and secure energy resource mineral supply chains."

The trade policies, including tariff-setting mechanisms and dispute mechanisms in place through the World Trade Organization will need to be dramatically improved to tackle the new patterns and scale in trade for certain of the minerals. Related, in 2016, the EU reached a deal on legislation related to the sustainable provision of minerals and metals into the bloc.

As a Professor at one of the finest technical universities in the world on these topics, I can confirm that educational training and workforce development should be foundational elements of a domestic plan.

Efforts by the Department of Energy in creating the Critical Materials Institute (originally created after the 2010 price spikes for rare earths) remain essential in maintaining the U.S. technological advantage.

Chairman Murkowski has said that, "energy and mineral security are the building blocks of a robust economy." It is clear from the literature and current indicators that this is correct.

****

The CHAIRMAN. Thank you, Dr. Bazilian, we appreciate that.
Mr. Mills, welcome.

STATEMENT OF MARK P. MILLS, SENIOR FELLOW, MANHATTAN INSTITUTE

Mr. MILLS. Thank you, Madam Chairman, and thank you to the Committee for the opportunity to testify on this matter.

As this Committee knows, there are those who claim that the wind and sun could or should provide 100 percent of America's energy needs compared to today's 3 percent share. Setting aside whether such a jump in the share of wind and solar is necessary or even feasible, the fact is that a massive increase in clean energy use by the United States, especially in concert with other nations, will lead to the biggest expansion in global mining and chemical processing that the world has ever seen. And given the realities of America's apparent antipathy to mining, it would also mean a radical increase in the quantities and sources of import dependencies and new geopolitical risks.

To understand why this is inevitable, we need to step back, perhaps, to dissect two common and misleading tropes in this energy debate we're having these days: the idea that wind and solar are free and the idea that there are renewable energy machines.

First, the air and sun are no more free than our oil and gas. Mankind had nothing to do with creating either. In order to deliver useful energy to society, it's perhaps obvious, that all sources require access to and the use of land and all require construction of physical hardware that, in turn, comes from mined minerals. So derivatively there's no such thing as a renewable energy machine because all machines are built from non-renewable minerals and all machines wear out and must be replaced, creating a continual need for further mining.

These realities are at the nub of the challenge for all policies that would radically increase the use of wind and solar machines and batteries. The path means that things people claim are "dirty" are just done elsewhere. And it means an astounding increase in materials use and dependencies, as this panel has noted.

These realities don't come from design flaws in human engineering. It's important to note that they're inherent in the physics of energy in our universe. Per unit of useful energy delivered to society, whether you measure it in miles of travel or tons of products or gigabytes of data, the wind to solar battery path increases both land and material use by something like 500 to 1,000 percent.

Rather than do big numbers for the globe, it's helpful to look at an illustrated example. The battery in a single electric car weighs about 1,000 pounds. Fabricating that single battery involves digging up, moving, processing more than 500,000 pounds of materials somewhere on the planet.

To deliver the same vehicle miles using oil counted over the same seven-year life span of a battery, that would entail one-tenth as much in cumulative materials extracted from the earth.

It's this kind of reality, of course, that creates the global challenge. And we've heard from every witness in the introductory remarks the clean energy plans that are being contemplated by many nations will create demand for a wide range of minerals that will explode by some 200 to over 2,000 percent.

And as the Committee notes and as you, Madam Chairman, pointed out at the introduction, the United States is a minor, if not—and no pun intended, minor, m-i-n-o-r—or non-existent player in most of the materials necessary for clean energy. The U.S. depends on imports for over half of more than four dozen minerals and 20 of which we're 100 percent dependent on imports. The bottom line is that the kinds of global expansion commonly proposed for clean energy aren't sustainable and, in fact, might not even be possible. But to the extent that the train has left the station, as they say, and our nation, along with others, has embarked on a path to expand clean energy use, permit me to suggest four actions Congress might consider with apologies that they're all perhaps obvious because one can reach no other conclusions.

At first, Congress should direct an examination and a full accounting of the full fuel cycle materials impacts but not focus so much on the impacts from using more materials for clean energy but, in particular, on the sources and, specifically, the changing structure and nature of the geopolitical risks. If there were a war in the Democratic Republic of Congo, the loss of cobalt to the world would be a far greater impact in that energy supply chain than the current attack on Saudi Arabia's oil field, in relative terms.

Second, Congress should direct a study at the state and the limits of recycling in the face of such a massive increase in clean energy materials and flow.

And third, Congress should consider exploring, advancing the funding areas of basic material science research, a historically and egregiously underfunded area of basic science where we can find new efficiencies and, in fact, where we are likely to find magic new alloys and new materials through supercomputing algorithms based on the materials genome project.

And fourth, and perhaps most obviously, Congress should enact policies that will encourage and not impede the investment in development of mining in America.

Madam Chairman, you like to use the analogy of immaculate conception for energy. If I might say that until engineers invent an element that one might call unobtanium, you know, a magical energy producing element that appears out of nowhere, requires no land, weighs nothing and emits nothing, we will always need mining.

And if we're going to mine, like I think all the witnesses, we probably all agree that we should do it here where we can do it the most environmentally responsible way and where we can minimize geopolitical risks.

Thank you.

[The prepared statement of Mr. Mills follows:]

Testimony of
Mark P. Mills, Senior Fellow, Manhattan Institute
Before
U.S. Senate Committee on Energy and Natural Resources
On
Sources And Uses Of Minerals For A Clean Energy Economy

September 17, 2019
Dirksen Senate Office Building, Washington D.C.

Good morning. Thank you for the opportunity to testify before this Committee. I'm a Senior Fellow at the Manhattan Institute where I focus on the policy implications of technologies, especially at the intersections with energy, and where I have advocated for years that America's energy policies should emerge from both the realities of the underlying physics of technologies, as well the unavoidable realities of geopolitics.

I am also a Faculty Fellow at the McCormick School of Engineering at Northwestern University where my focus is on the technology and the future of manufacturing. And, for the record, I'm a strategic partner in a venture fund dedicated to startup companies in digital oilfield technologies.

Permit me to start by noting an obvious fact, but one that deserves restating in the context of this hearing. Every product and service that exists requires extracting minerals from the earth. And all those minerals must be refined, transported and converted into materials, then fabricated into products and ultimately disposed of or recycled. All of that activity entails the use of land and energy somewhere. Thus all environmental, economic, social and geopolitical consequences derive from the quantities of materials needed and where it all comes from.

As this committee well knows, the issue of America's strategic dependencies on a small set of "critical minerals" is not a new subject. However, the issue on the table now is the potential for "clean energy" policies to inadvertently create entirely new mineral dependencies.

And, as the Committee also knows, there are advocates who claim that the wind and sun could provide 100% of America's energy needs, compared to today's 3% share. While the credibility of this claim is not our focus today, it bears noting that achieving that goal is simply not possible, any more than it's possible to use airplanes to fly to the moon. And the often-used analogy, that an ostensible energy tech revolution will echo the characteristics and velocity of the information revolution is, to put it diplomatically, fallacious.

Set aside for now whether such a huge jump in the share of wind and solar is desirable or even feasible. The fact is, a more vigorous pursuit of clean energy by the U.S., especially in concert with other nations, would lead to an unprecedented expansion in global mining and chemical processing, and collaterally a radical increase in the quantities and sources of import dependencies and geopolitical risks for the United States -- and it would produce astonishing quantities of waste. And this says nothing about the demonstrably destructive economic impacts.

To understand why, we must first dissect two deeply misleading tropes used in our national debate about America's energy future: the idea that wind and solar are "free" and that the machines access those energy sources are "renewable."

There is no such thing as free energy, at least not delivered in a way that matters to survival. The seductive idea that the air and sun are free is no more true than is the case for oil and gas. Mankind had nothing to do with creating either. In order to deliver useful energy to society, all sources require access to and use of land, and all require construction of physical hardware, all of which has costs.

Thus, there's no such thing as a renewable energy machine. All energy machines must be built from non-renewable minerals and all machines wear out and must be disposed of and replaced. This is, not to wax philosophical, society's central Sisyphean struggle.

More practically, these two points are the nub of the challenge for policies that propose to radically increase America's use of energy from wind and solar machines. The clean energy path leads to astounding increases in materials use and dependencies.

These consequences do not derive from design flaws in the green machines, in effect from a failure in human engineering or imagination. The consequences, regardless of policies or aspirations, arise from the inherent nature of the physics of energy in our universe. Per unit of useful energy delivered to society, whether measured in miles of travel, tons of products, or gigabytes of data, the wind and solar path increases both land and material uses by something like 500 to 1,000 percent.

Of course we find elements like iron, chromium, silver and neodymium used to build frack pumps in the shale fields as well as in wind turbines. But the physics difference between the quantities needed is literally visible: A wind or solar farm stretching to the horizon can be replaced by a handful of gas-fired turbines, each no bigger than a tractor-trailer.

For example, to replace the lifetime energy output from a single shale rig producing gas requires building a 6-fold greater quantity of similar-sized wind turbines. Of course, the shale rig 'disappears' from that shale field, and is re-used to produce more energy, while the field of wind turbines stays in sight for decades, until they wear out. And consider, because wind and solar are nearly useless without storage, it takes 60 pounds of battery to store the energy equivalent of just one pound of oil. Such realities are what leads to the 'invisible' amplification in the quantities of materials mined upstream, somewhere.

That amplification is made particularly clear if we examine a few specific examples in terms of total fuel-cycle mineral requirements. The battery for a single electric-car weighs about 1,000 pounds. About 50 pounds of oil can provide the same vehicle range. Fabricating that single battery involves digging up, moving and processing more than 500,000 pounds of raw materials somewhere on the planet. Meanwhile, measured over the lifespan of the battery (seven years), using oil involves one-tenth as much in cumulative material weight extracted from the earth to deliver the same vehicle-miles.

Or consider one more example. Building one wind turbine requires 1,500 tons of iron ore, 2,500 tons of concrete and 45 tons of non-recyclable plastic. For an equal amount of energy production, solar power requires even more cement, steel and glass—not to mention other metals. Increasing the wind and solar share to, say, just a one-third share of America's energy arithmetically requires a 1,000% increase in the materials already consumed to produce such machines.

The resource realities of clean energy have not escaped the attention of international organizations including the World Bank and the International Energy Agency (IEA). But it is remarkable how little attention has been afforded to the implications for U.S. energy policymaking.

It's worth highlighting just some of the conclusions. According to IEA analyses, in order to meet current solar forecasts, for example, global silver and indium mining will jump 250% and 1,200% respectively over the next couple of decades. Similarly, world demand for rare-earth elements—which, I note, aren't rare but are rarely mined in America—would rise 300% to 1,000% by 2050 just to achieve the Paris Accord goals.

Or, as numerous similar analyses have shown, replacing conventional cars with EVs would drive up global demand for cobalt and lithium by more than 2,000%. We'd also see a 200% jump in copper mining, along with at least a 500% rise in graphite demand. EVs, typically, use more aluminum too in order to offset the enormous weight penalty from the battery. And none of this counts the materials demand if batteries are scaled to back up wind and solar grids.

Last year a Dutch government-sponsored study concluded that the green ambitions of the Netherlands alone would consume a major share of global minerals. Considering that the U.S., never mind the world, consumes 30-fold more energy than the Netherlands, it's unsurprising that the study also concluded: "Exponential growth in [global] renewable energy production capacity is not possible with present-day technologies and annual metal production."

Nonetheless, many nations including the U.S. government, and numerous states, are incentivizing, if not requiring, greater use of these co-called clean energy technologies. The implications of all this are obvious in terms of environmental, social justice and geopolitical fallout.

It's not just the need to responsibly address the environmental challenges of mining in and of itself, as you Chairman Murkowski are painfully aware vis-à-vis Alaska's Pebble Mine fiasco. One must also consider the astounding quantity of green machines that will wear out and all that old equipment that must be decommissioned, all generating millions of tons of waste. The IEA has calculated that solar goals for 2050 consistent with the Paris Accords – which it bears remembering are a mere shadow of green ambitions now being proposed -- will require disposing of solar panels that will constitute more than double the tonnage of all today's global plastic waste.

There are collateral issues. The Sydney-based Institute for a Sustainable Future, for one, cautions that in a global "gold" rush for clean-energy minerals, mining will be pushed into "some remote wilderness areas [that] have maintained high biodiversity because they haven't yet been disturbed."

Then there's the staggering increase in materials production that will lead, necessarily, to a comparably radical rise in the physical transport of energy materials on global sea-lanes, both increasing and changing the locus of geopolitical supply-chain risks. We note that those who propose to allocate a share of the U.S. Navy's budget to the cost of protecting oil supply-chains should consider a similar calculation for green supply chains.

With respect to America's security and import dependence, it bears noting the U.S. is a minor or non-existent player in most of the materials necessary for clean energy. As this Committee knows, today the U.S. imports over half of more than four-dozen minerals that are commonly used, and 20 of the minerals must be entirely imported.

It is extremely unlikely that any increased mineral production will come from mines in Europe or the U.S. Instead, much of the necessary additional mining will take place in nations with significant geopolitical consequence, and where in many cases labor practices are oppressive and generally not transparent. The Democratic Republic of the Congo produces 70% of the world's raw cobalt, and China controls 90% of cobalt refining.

The desire expressed by many citizens and corporations to ensure ethical supply chains is a particularly thorny one in general, and especially so when it comes to green energy tech. For example, the World Economic Forum's Global Battery Alliance (and numerous pieces of investigative journalism) has observed that the "raw materials needed for batteries are extracted at a high human and environmental toll." The London Metal Exchange proposed last year to ban the sale of "tainted" cobalt. But a broad consortium of NGOs opposed that move, worried that it would simply lead to less transparency and would just increase the amount of trade conducted in "underground" transactions.

The mineral supply chain can sometimes be rendered invisible by other means. Instead of importing minerals, America imports the finished products such as solar panels and batteries. China already has nearly 60 lithium battery manufacturers accounting for over half of the world's production, and is on track to two-thirds dominance by 2030. As a relevant aside, all that production occurs on an electric grid that's nearly two-thirds coal-powered. And, relevant to that fact: it takes the energy-equivalent of 100 barrels of oil to fabricate a battery that can store the energy-equivalent of one barrel.

Setting aside the ethical quagmire of sourcing more of America's, and the world's energy materials from places like China, Bolivia, Russia, and the Congo, one might reasonably observe, as the world bank has, that greater mineral demand would be a huge "opportunity" for citizens in such nations as Chile, Canada, Australia, Brazil, Argentina, and Peru.

But that also presents for the United States at least, another ethical question: Replacing oil, gas and coal with wind, solar and batteries takes jobs and economic output away from our citizens and adds jobs and economic benefits to other nations. Some may see this as a good outcome, but we should be honest about the realities.

More than $300 billion per year of economic output comes from America's oil and gas production. And now our nation is not merely essentially self-sufficient in energy production, but on track to becoming a net overall energy exporter. By contrast, the clean energy materials path both increases the cost of energy and radically increase the share of those costs that comes from imports. And it would of course, reverse the recent historic gains of energy independence.

Some have proposed that the massive gap in materials disparities between hydrocarbons and green energy could be closed by spending more money on improving clean technologies. Of course useful improvements are possible for creating more efficient green machines that thus use fewer materials per unit of energy produced. But we know that those gains are limited by the fact that wind, solar and battery technologies are approaching the physics limits of performance. This means that throwing more money and subsidies at these technologies won't lead to radical improvements in material-use efficiency. Ironically, for hydrocarbon technologies, the distance to physics limits is further away, which means greater efficiency gains are still possible for oil and gas than for green tech.

However, to the extent that 'the train has left the station' and our nation is embarked on a path to expand clean energy, permit me to suggest four actions Congress should consider.

First, Congress should direct an examination and accounting of the full fuel-cycle upstream materials impacts of greater use of clean energy. This will improve the transparency associated with environmental, social, economic and geopolitical impacts.

Second, Congress should direct an examination of the state of recycling clean energy minerals. Notably, only three minerals in general have achieved a 50% level of recycling, according the International Union of Geological Sciences. And rather than institute economically or operationally punitive requirements for greater recycling, efforts should be directed towards research that could yield more economically efficient recycling technologies.

Third, Congress should examine the state of basic research funding associated with the development of both more efficient and new ways to use existing minerals and even the creation of new classes of products that can replace critical minerals. This research should center on the materials genome program that targets the use of supercomputers to invent new classes of alloys that can enhance mineral flexibility and minimize the use of rare elements.

Fourth, and finally, Congress should enact policies that will encourage, not impede, the investment in and development of U.S. mines.

Geological data show that the United States has a vast untapped abundance of mineral wealth. Until engineers invent an element that one might call "unobtanium" -- a magical energy-producing element that appears out of nowhere, requires no land, weighs nothing, and emits nothing – we will need more mining. We should do it here if we want to enjoy the benefits and if we want to ensure the most environmentally sound approaches.
<>

The CHAIRMAN. Thank you, Mr. Mills, you have given me a new word for the morning, unobtanium. I am going to ponder that one.

Thank you all for your comments this morning.

I wanted to start off by probably directing this to you, Dr. Bazilian.

When you were talking about the supply chain, you were basically saying all aspects of the supply chain are key when we think about our mineral security here in this country. I wanted to ask, kind of, an open, generic question. Which piece of the supply chain do we worry most about?

I think you suggested that it is, and I am reading my own notes that are probably not an accurate reflection of your comments, but you said it is not necessarily the dominance in the production but the diversity that we would have, the diversity of the supply and demand that creates that resilience. So it is not just about making sure that we are dominating the field but that we have greater diversity.

In terms of the supply chain and recognizing the key aspects there, is there one part of the supply chain that you are worried most about now and does that change going forward as you think about the need for diversity within the supply chain?

Dr. BAZILIAN. Thank you, Senator, for the easy question.

You know, if you look at China's dominance which has been brought up several times here this morning about across the supply chain in terms of a value add to their economy, you'll see that the added value in the manufacturing sector from processing to advanced manufacturing is larger than the funds that they're getting from mining itself, so, on the direct supply side. And so, they've put some effort into making sure that they're very strong on parts of the supply chain further down from processing to advanced manufacturing. So I think that that gives us one clue that that's one way to highlight which parts of that supply chain are important.

The aspects of diversity make this, as you know, a very difficult task. We can look at oil and gas as a precedent for how to think about diversity of supplies and functioning markets, but if we're trying to do that across 10 or 20, or 30, or 50 different minerals it becomes very difficult.

And so, I think we have to keep that in mind that each one of these has very different context, very different supply chain, very different markets and most of those markets don't function in the way we understand them to function. Say, like the oil market is apparently functioning today. So the diversity is important but the complexity of this area makes it such that it's hard to draw specific lessons like that.

The CHAIRMAN. Let me go to you, Mr. Kang, because when we think about what we have all acknowledged is going to be just an ever increasing demand and a recognition that we are going to be looking at significant additional mining whether it is here in this country or around the world, your focus on the recycling aspect of it, most of the global recycling taking place in Asia. Your very constructive suggestions that what we need to be doing here, one of the first steps is we need to be collecting more. We need to be expanding our capacity rather than doing the reprocessing elsewhere.

What is it here in this country that we can't seem to be recycling much of anything? I mean, we are all in a panic now because China is no longer accepting the recycled product, everything from cardboard to, you know, pretty basic things, to more high-tech and certainly more critical initiatives. Do we just want to make it here and we don't care about the back end of it? What more can we be doing on this?

Again, I think you have given us a couple of specifics. I like the Opportunity Zone idea in terms of encouraging more. But what can we be doing there, because I think that is going to be a critical part of how we move forward here?

Mr. KANG. Senator, that's a great question, and I think something that we think about constantly as we are looking to grow our supply to recycle and produce these minerals.

I think, you know, what's interesting is, as you mentioned, recycling. Most of the world's recycling of lithium-ion batteries resides in Asia where most of the batteries are manufactured. I think those two are tied together.

When you have, you know, one aspect of recycling that I think is very important is that manufacturing scrap can also be recycled. The manufacturers that produce the batteries produce scrap which is very high and rich in these minerals. And so, when you put that back into the refining process, that helps this process be very economically viable.

And then, when you have access to the raw materials you have other aspects of the battery manufacturing, precursor manufacturing or cathode material that will naturally just locate next to the recycling.

So, a couple things. One, I believe that if we can promote our recycling here in the United States by really emphasizing and focusing on collection, creating the supply of batteries. You know, one way we have been working on is to create a curbside collection. You know, minimize the difficulty in taking your batteries and taking them to locations, drop-off centers.

I sheepishly will admit, I have many phones and gadgets in my drawers at home that I have not thought of or don't have the time to prepare to take to these drop-off locations.

The CHAIRMAN. But if we have these drop-off locations, and my time is expired, we still are sending them overseas.

Mr. KANG. That's correct.

The CHAIRMAN. We are collecting them. We need to do a better job of collecting them, but at the end of the day we are still sending them to others.

Mr. KANG. Well, if you create that supply, yes. And then we can create this recycling industry here. I think that will be a first step in the problem.

The CHAIRMAN. Thank you.

Senator Manchin.

Senator MANCHIN. Madam Chairman, my dear friend from Maine has to go to another committee meeting and I want to go ahead and defer to him at this time.

The CHAIRMAN. Very good.

Senator King.

Senator KING. Thank you, Senator. Ironically, the hearing I have to go to is on China, so it seems to be a constant refrain.

Mr. Simmons, in the Department are there specific programs, offices, personnel assigned to deal with this problem in terms of recycling and mining and those kinds of things? In other words, you expressed general support, which I appreciate, but is there somebody who wakes up every morning thinking this is something we have to deal with?

Mr. SIMMONS. Yes, there are.

One, first of all, there are multiple people that are in the Office of Energy Efficiency and Renewable Energy that work on critical minerals. It's not a very big team, but we do have multiple people.

You also have the Critical Materials Institute and much of that focus, well, really that focus for, you know, funding of $25 million a year is exactly on this issue.

So the Office of Science, I just found this out recently, they're going to have a new initiative on critical minerals starting in FY20. They have been doing research for a long time but a renewed focus on some of the basic science of, as Mr. Mills mentioned, to advance what is possible, so.

Senator KING. I would urge you to think about how to structure that so that it really does have a serious focus. One of my principles is structure, is policy, and if you have a messy, confused structure, you are going to have a messy, confused policy. So I commend the work that is being done, but let's see if we can focus it more precisely.

Mr. SIMMONS. We are working on that exact issue because this issue is difficult, it is complex. It is far reaching and we need to figure out a nice, cohesive strategy that makes sense. So we're working on that.

Senator KING. Thank you very much.

Ms. Carlson, have we already lost? Have we already lost this fight? Have the Chinese already cornered the market?

I mean, I think you said 50 percent of cobalt in Africa and some other areas. What do we do?

And none of you have testified specifically about which of these—are there cobalt deposits here? There has been some allusion to how hard it is to mine here, but let's assume that mining had a better reputation. Are the minerals here? Do they exist here, these various minerals?

Ms. CARLSON. Thank you for the question.

No, I would not say that we've lost the race, and I do think there are a number of avenues for additional, sustainable production of resources, but as well as the supply chain, the recycling and investment in materials, R&D, that I believe each one of the panelists mentioned.

I think one of the tricky aspects of cobalt, in particular, is that it's a byproduct of copper and nickel mining. And so, it's subject——

Senator KING. We have plenty of copper mining or there used to be anyway in the U.S. So, does that mean we have cobalt?

Ms. CARLSON. And so——

Senator KING. In Jerome, Arizona?

Ms. CARLSON. And so, it depends on whether or not it's economically extractable.

And so, given the fact that it's a byproduct, there are fluctuations in the market and cobalt is subject to those fluctuations.

And so, and as a consequence as well, cobalt, more so lithium, isn't traded as widely on global commodity markets, and in the case of lithium, it is a specialty chemical and ends up being contracted more directly.

There are opportunities and resources in this country, but largely speaking, they tend to be highly, highly concentrated in countries around the world. I think, given that concentration, it's important to evaluate partnerships and investment.

Senator KING. One of the problems, it seems to me, not to interrupt, but one of the problems—I guess I did interrupt——

[Laughter.]

——is that China is China, Inc. We talk about mining companies whether they can get investments and whether it pays back and what the rate of return is. China has decided, apparently as a matter of national governmental policy, that this is important.

And so, the normal rules of the road of capitalism are not necessarily applying here if it is a government-owned entity and that is something we really need to think about. If we are assuming the private sector is going to open a mine in the Congo that may or may not be sustainable, economically, China doesn't necessarily care about that. I think that is a problem we need to identify.

One more question before my time runs out.

Mr. Kang, what percentage of the need could be met by recycling if we had a much stronger and more thorough going recycling program? We have an awful lot of batteries in this country.

Mr. KANG. Absolutely.

When you look at the projections of production of batteries in the future, they are outrageously enormous. And so, and then when you take it to the collection rates now and recycling, you know, I've heard estimates that anywhere from about 20 to 30 percent of the world's mineral needs can be met by recycling.

Senator KING. Well, that is not insignificant. I mean, that is a big number.

Mr. KANG. That's not insignificant, absolutely.

And actually, it's reclaiming value from our waste stream.

Senator KING. Right.

Mr. KANG. You know, one way to think about this is if you could change your perspective, I believe, you know, one of the next new mines of the future are urban cities, our homes. We have these, this material, locked away in our drawers and in boxes that we don't look at too often.

So if we can promote collection, if we can take these, kind of, you know, spent batteries away from or bring them back to this industry, I think we can claim a significant amount of minerals.

Senator KING. One way to incent, I mean, the classic way we incent things is by a bounty or by a payment of some kind. If it is worth a few bucks that would be, maybe it would be enough to stimulate somebody to bring them in?

Mr. KANG. Absolutely, absolutely, Senator.

One other thing I'll add, I think that we should be very mindful of is it's not only this Committee or those who are interested in recycling that see the value of recycling, but we are well aware of foreign entities now that are coming into the U.S. and setting up recycling facilities here because they see these minerals and it's widely known that the U.S. is one of the largest producers of spent lithium-ion batteries.

Senator KING. They are mining under our very noses.

Mr. KANG. Yes, sir.

Senator KING. And a domestic resource.

Mr. KANG. Yes, sir.

Senator KING. Ridiculous.

Thank you.

The CHAIRMAN. Who is it?

Mr. KANG. Well, I do know that there is a Korean company that is coming in. There's a Canadian company that's setting up facilities here as well as we are aware of conversations and research by Chinese firms, recyclers, who are coming into this market.

The CHAIRMAN. Senator McSally.

Senator MCSALLY. Thank you, Chairman Murkowski, Ranking Member Manchin, for holding this really important hearing as we talk about the link between green energy technology and mining.

In Arizona, actually I was just recently in Jerome a few weeks ago, but in Arizona we are a mining state, especially copper. We are known—it is one of our five Cs—known as the Copper State. We produce 65 percent of America's copper, far more than any other state. Mining across Arizona generates $4 billion and 44,000 jobs.

So generating, transmitting, and storing electricity from any source requires literally tons of raw and refined material, as you all know. For example, there are 5.5 tons of copper used per megawatt-hour inside photovoltaic systems.

The rising demand for clean energy technologies like wind and solar combined with the continued electrification of our transportation sector means that there is going to be a surging demand for copper and other minerals as well.

Despite this clear link though between rapid deployment of clean energy and responsible sourced raw materials, we still see extreme environmental groups continuing to try and kill off the American mining industry through litigation and organized opposition. But just because there is an activist judge or an environmental group that gets an American mine shut down doesn't mean the demand for raw material decreases. Instead, the void is filled by other countries, often those with dismal records like China and the DRC.

So, just for others, remember if you oppose American mining, you are likely to just be making the rest of the planet and environmental problems even worse. If you care about clean energy, you should care about mining. In fact, I don't see a mining plan anywhere in the "Green Bad Deal" that has been proposed. If you really care about moving toward green energy, then it needs to include mining.

Anyway, so any serious plan should have been part of the conversation that we have had today. I am glad I joined the Chairman and the Ranking Member and Senator Sullivan in introducing the

American Mineral Security Act of 2019 which addresses this core issue that we are talking about here today.

I want to start off with Dr. Bazilian. For clean energy technologies, there is a lot of discussion here about rare earth elements, but can you also share why we should be concerned about the supply of base metals, especially copper?

Dr. BAZILIAN. Thank you very much, Senator.

My second point was that this narrative is a very powerful one for the mining industry which you have also said and in the mining industry the most sophisticated approach to it has come from the Copper Alliance, the International Copper Alliance and the domestic.

And of course, as you said, they have a good reason to be excited about this clean energy future, not only for the reasons you stated, but also if you want to have an air conditioner or a motor, you roughly need copper. So they have a very positive outlook on this. And what they're doing in their approach is not only going out with the positive optics and the good narrative, but also discussing the recyclability of copper. And so I think the base metals such as copper have a great role to play.

The other ones in photovoltaics, you need a lot of silver so there's likely to be a growth in the silver market. That market is better than some of these minor metals, and so it's probably able to handle that growth better than some of the small ones.

But it's just to say that while we focus on these specific minor metals and the conversation is dominating by cathode material for batteries, there are quite a lot of other minerals and some of those secondary and tertiary ones are really hard to get to from an investment perspective. But I do think we have to look across all of them, but I really appreciate your comment.

Senator MCSALLY. Great, thank you.

I want to turn to the national security implications.

My last assignment in the military was standing up U.S. Africa command. And what we saw, this was 2007 to 2010, was China systematically going into African countries in order to just steal their resources and with no benefit to the country. Certainly no environmental concerns or concerns for the well-being of those who live in the countries.

They are doing what they said they were going to do. If you look at their "Made in China 2025" and what their plan is, specifically, in this sector, this is no surprise. There is no, sort of, top secret. China is doing exactly what they said they were going to do in this area.

In fact, it was reported earlier this year that the Chinese government was considering restricting refined rare earth elements to the United States which should wake people up that they look at this also, not just economically but as a geopolitical tool or a geopolitical weapon.

Ms. Carlson, can you share more perspective on the national security implications of what we are talking about today?

Ms. CARLSON. Thank you for the question.

I think it is certainly an issue of rare earth elements but it also applies to other critical minerals and metals as well, not only in Africa but other regions of the world and their efforts ongoing as countries recognize the strategic nature of those metals for their countries and interest in developing their local economy and understanding how critical those sectors are to the development of their local industry, to the number of jobs provided, and there's increased restriction on the export of those minerals as well as changing taxing structures, et cetera. And so, even within a couple days ago there were discussions of export restrictions for nickel from Indonesia, both primary and refined nickel coming out of Indonesia, which is also very important.

So I think that just underscores the importance of the need for both diversification of materials and investment in supply chains for alternatives, research and development upstream and then the recycling networks and systems that we've been talking about.

Senator MCSALLY. Great, thanks.

In summary, my view is if we care about national security, if we care about green technologies, if we care about American jobs, then we should be pro-mining in America.

Thank you, Ms. Chairman.

The CHAIRMAN. Senator McSally, thank you.

Senator Manchin.

Senator MANCHIN. Thank you, Madam Chairman.

I am trying to break this down to understand this as Americans. We recycle about 90 percent of the car batteries that we use. And it makes sense, I mean, you get $10.00, usually, a core charge. You bring it back and it is big and heavy and bulky. You don't want it laying around your house.

And then when I grew up, we used to recycle pop bottles at $0.02 apiece.

The CHAIRMAN. $0.10?

[Laughter.]

Senator MANCHIN. Well, it was $0.02 when I got started. Anyway, we did pretty good on that. I keep thinking about that. We have three billion a year of the disposable batteries we use in our flashlights or our little, you know, and we don't do anything with them. We just throw them away.

And then now, all the new age we have coming in with cars and wind power and solar power, home to big storage batteries. We are not doing any of that, like throw away cars now. Is that the way they look at it? I mean, can an average person that owns an electric car change that battery?

There has to be something that we do here because I keep thinking of all my environmental friends who are rightfully right on top and looking at everything that we do, and coal mining is something that is scrutinized every minute of every day of how it is done. The energy that it has produced, the steel that it has produced. The ability for us to win every war we have been in because of our own energy supply.

But when we talk about clean energy, you are telling me that clean energy is the dirtiest form of energy we have, right now what it takes to produce what we look at as clean. So I guess, out of sight, out of mind for Americans. We are happy with that as long as someone else is using child labor and doing the dirty work.

Sooner or later our environmental friends have to step to the front and push this. It won't be pushed unless we pass some legislation on mandatory recycling. If you make that battery, you are responsible for it if you are a car manufacturer that has to be using it. Would that cut down a great deal on the amount of mining that is needed to be done for these rare earth minerals? Is there enough that we can extract from recycling to really change a whole boom?

And I would think that you have a little bit of an incentive. A financial incentive goes a long way in Americans habits.

So Mr. Kang, you might want to respond since you are in this business.

Mr. KANG. Sir, again, I would say that recycling is one answer to meet the demands that we see in the future. I believe that by having a robust collection system and a vibrant recycling industry, we not only will meet the national security issues that we're discussing here today, but we'll also be, as you mentioned, taking care of a hazardous problem where these——

Senator MANCHIN. Who changes the car batteries right now? If I have an electric car—I know my good friend, the Senator from New Mexico here, Senator Heinrich, has a beautiful little electric car and so does Senator King. Who is going to change their battery?

Mr. KANG. It is the automobile manufacturer, when it's under warranty.

Senator MANCHIN. So.

Mr. KANG. When it's under warranty.

So let's think about——

Senator MANCHIN. How about when it is not under warranty or it goes dead?

Mr. KANG. Well, then you have mechanics and, you know, automobile shops that would——

Senator MANCHIN. It would be hard for Senator Heinrich to do it himself.

Mr. KANG. Absolutely, that's correct.

Senator MANCHIN. Okay.

How about in the house if I have solar panels—and those are pretty good, heavy-sized batteries—would I, am I capable of doing the replacement or do I usually have a contract with the company that services that?

Mr. KANG. Correct, I would believe, sir.

Senator MANCHIN. So you already have a built-in mechanism for those people to have 100 percent recycling, correct?

Mr. KANG. If we can utilize the infrastructures that are in place today, the service contractors that install and can remove.

Senator MANCHIN. Yes.

Mr. KANG. Also, the waste management.

Senator MANCHIN. But there are no laws whatsoever that mandate that we recycle these?

Mr. KANG. I'm sorry?

Senator MANCHIN. How are they disposing of this? In landfills?

Mr. KANG. Currently, yes.

Senator MANCHIN. Does the car go the landfill or just the battery in the car?

Mr. KANG. Well, there are conversations today from automobile manufacturers looking at the end of life of these electric vehicle batteries. I think they are coming together, again, because it's also a collection issue and how to streamline these.

But again, we need to invest into the recycling industry to create a solution for these batteries to be taken care of. And so, if we can, if this Committee can work on incentivizing this industry, I will tell you, it's, for the past several years the conversation has definitely changed in terms of investing into the recycling of lithium-ion batteries. But it has been difficult.

I do know, I watched the testimony in a hearing prior to this one and I believe it was, there was some information that recycling of lithium-ion batteries is not an economically viable industry. And I would say that it is, actually, for our company. And we see the value there, and we can find value.

So the technology is there. The industry can thrive and we need it, we need the industry.

Senator MANCHIN. Mr. Mills, very quickly.

You made some comments earlier I was interested in as far as where we are getting, how we are sourcing what we are doing, what our mineral state may be.

Do you have anything you want to add to that?

Mr. MILLS. Well, I think I would just remind the Committee of the scale issue we're talking about.

So recycling cell phone batteries, you know, it's 400 million cell phones, a billion, I think, now a year sold but the scale involved in storing energy in automobiles and grids is, to use the overused word, astronomically greater. So the challenge is not just that one could recycle. Recycling has limits. They're economic. They're practical. They're physical. We should do more.

Senator MANCHIN. Let me ask this question.

Is the environmental community and really—and I have some great friends and they bring it to our attention, they come and see our office and tell us what is going on. This is the first time I have heard of the amount of social changes and basically things that we thought we eliminated 50 years or more ago, child labor.

Mr. MILLS. Sure.

Senator MANCHIN. Environmental laws, you know, and we are letting the Congo and everybody else just run rampant on this. Has it not been brought to their attention? Do they not see it along those lines?

Mr. MILLS. Sure. There's a lot of—the Washington Post did an outstanding exposé on the cobalt issue.

There are some good investigative journalists still in the world, despite the shallots of the industry. And when you look at the supply chain, both in environmental terms and in labor terms, most countries are not as sensitive to doing it right, as we are. Most of the mining is migrating there. A lot of the nickel in the world is produced in Russia.

I worked for a mining company in Canada earlier in my career. I may be the only person in this room, perhaps, that's been at the bottom of a 5,000-foot, vertical, hard rock shaft. We mined silver, gold and uranium. And it was very much involved in the reclamation and the, you know, environmental processes.

But we don't, in the West and in Europe in particular, want to mine anymore. I mean, when I said there's an antipathy to it, that's what I find, not just in the environmental community, but among my colleagues, both conservative and liberal. They don't think we should mine in America.

Well, my position is that the world, with or without more clean energy, is going to need a lot more mined materials.

To the Senator from Arizona's point, it doesn't matter whether it's an air conditioner or motor, you need copper. You're going to need nickel, steel, aluminum. Electric cars use more aluminum because you have to get them lighter because the batteries are heavy. They use more nickel. They use more common materials. Windmills use steel. We want iron ore to come from someplace other than Minnesota.

I think these challenges of bringing it back here are addressable, but we have to mount a campaign that says, look, we could use automation, modern technologies and monitoring to do mining very safely. The automation reduces the labor but it actually increases the labor here because it will bring the mining back here.

Senator MANCHIN. Thank you, Madam Chairman.

The CHAIRMAN. Senator Cassidy.

Senator CASSIDY. I am not sure to whom to address this, but I will open it up.

It is a different form of recycling. I was speaking to some folks in Louisiana who have a lot of bauxite that has been used to create aluminum. They say they can extract rare earth from this bauxite. It is just sitting there and tons of it.

Now on one, maybe two occasions they have come up with a business plan where somebody would come in and take this and get maybe scandium or something. And both times, or at least the one time for sure, that they were about to go, the week before the Chinese cut their price dramatically and the business model was destroyed. Clearly a market manipulation.

So I guess, this is just a wasted resource. It is not breaking new ground. It is taking that which is there. But it would require us to somehow give a price support in case the Chinese did that once more.

I am not quite sure how that would work, but I open that up because it does seem to be, if there is a lot of residue from copper mining in New Mexico, it seems like you could concentrate rare earth or not so rare earth out of that residue. But then again, it would still be susceptible to people coming in and cutting the price.

Any thoughts from anybody as to how to approach this issue?

Mr. Kang, you seem to——

Mr. KANG. Yes, sir.

Senator, I'm not familiar deeply with rare earth materials but I can share with you, from a lithium-ion battery perspective that manufacturers of consumer products today are very interested in closing their loop. So, you know, they've spent their time before just selling their products. Now, because of the supply chain issue, they are trying to reclaim their products, to bring them back so that they can ensure their own supply of raw materials for their future production. So in my thinking, I believe that it is, again, this solves another issue, a supply chain issue for manufacturers.

Senator CASSIDY. But I guess my specific question is, if it is susceptible to market manipulation by somebody cutting the price?

Dr. Bazilian.

Dr. BAZILIAN. Yes, as I said, Senator, these markets are not markets in the way we conceive of them. They are opaque and there's no price discovery in the way we would say, use an analogy for something like oil or natural gas. And if you think of rare earths, there's on the order of 15 of them, each one of them is supposed to have a specific pricing. That price that you see or you can find somehow is garbage.

Senator CASSIDY. So what you're really telling us is that we perhaps need an industrial policy or at least some sort of price support for that to have a domestic production from used bauxite we're going to guarantee a price. If it goes above it, you get it, but if not, we will smooth out the valley, if you will.

Dr. BAZILIAN. I think there's every reason to consider industrial policy. Whether or not you want to put collars and caps on to pricing for commodities is a different story.

Senator CASSIDY. Except you could not support, you cannot support the harvesting, if you will, of a rare earth from residue unless you have some sort of business model which guarantees a return.

Dr. BAZILIAN. That's correct.

So, if we're in a private sector situation as we are in the United States with markets, it's very difficult without some sort of pricing instrument to give the signal to invest in these things, keeping in mind that bauxite is just one opportunity.

Senator CASSIDY. Yes.

Dr. BAZILIAN. There's a mine open today with light rare earths in Mountain Pass, California, and there's, to the other Senator's point, there's cobalt all over. There's cobalt in Idaho, et cetera, and then in Wyoming and West Virginia.

Senator CASSIDY. Well, this sidesteps what Mr. Mills talks about. People don't want mining here.

Dr. BAZILIAN. Right.

Senator CASSIDY. This is just sitting by the side of the Mississippi River. And so, it has been mined.

Mr. Mills?

Mr. MILLS. Well, we should be clear that people don't want mining or, particularly, the processing, the chemical processing associated with mining. So there's two parts to this. And I'm sure you're intimately familiar.

Senator CASSIDY. But on the other hand, is if we are already processing the bauxite to make alumina, we actually have the processing which is currently occurring. So it is co-located, if you will.

Mr. MILLS. Well, no, but the problem is, rare earths in particular, are chemically similar, very difficult to separate. So they involve much more difficult environmental processes that are difficult to permit here. So there's two sides to this. If you're a private sector investor and you look at the hurdles you have to go through to get state and federal permits to do that kind of chemical process——

Senator CASSIDY. So, let me just move on.

Mr. MILLS. It's a huge barrier.

Senator CASSIDY. It is not so much I am concerned about that. Let's assume you can get the permits but it does seem as if you would have to have some sort of price support in case a market manipulator attempted to cut your feet out from beneath you.

Mr. MILLS. The challenge is proving to Morgan's point, to Dr. Bazilian's point, the challenge of this market is that it's quite opaque. I doubt you can prove market manipulation because there's so few players, with so little market transparency and almost, probably half of the minerals that are traded.

Senator CASSIDY. Thank you all.

The CHAIRMAN. Interesting, thank you.

Senator Heinrich.

And before we turn to Senator Heinrich, Senator Risch had to be called away, but he asked that his statement be included as part of today's Committee record.

[The prepared statement of Senator Risch follows.]

Senate Energy and Natural Resources Committee Hearing
"Minerals and Clean Energy Technologies"
September 17, 2019
Statement for the Record by Sen. James E. Risch

Thank you Chairwoman Murkowski and Ranking Member Manchin for holding this important hearing.

Many technologies have become an indispensable part of our daily lives – cell phones, batteries, laptops, and other consumer goods, to name a few. Others products and technologies have become critical to our safety, because our military relies on them every day. Yet, the average consumer is generally unaware of the numerous minerals needed for these products, and the global supply chain that influences their production.

Currently, the United States is completely reliant on imports for more than a dozen critical minerals. As demand for mineral-intensive technologies grows, it is crucial that the United States have a secure and stable supply. Attaining that goal requires a three-pronged approach: first, that the United States reduce dependence on potentially unreliable sources, particularly China; second, that we shore up our domestic capacity across the supply chain; and third, that we collaborate with steadfast partners who share our interests and values.

In 2010, China embargoed export of rare earth minerals to Japan following the latter's detention of a Chinese fishing boat captain. Markets adjusted reasonably quickly to China's attempt at economic coercion – other nations ramped up production, companies reduced their dependence on certain rare earths, and nations like Japan invested in recycling technologies to repurpose existing supplies. That said, this incident alerted the United States and its allies and partners to the potential economic and national security risks of overreliance on nations willing to cut off supply for geopolitical or other purposes.

In 2018, the Department of the Interior published a list of 35 critical minerals. The list includes everything from aluminum (used in most economic sectors) to lithium (important for batteries powering electronics and other emerging technologies) to arsenic (crucial for the semi-conductor industry) to beryllium (used primarily in the aerospace and defense industries).

The United States relies on China to obtain 20 critical minerals. These critical minerals (including rare earths) figure prominently in China's development and industrial plans. China published two separate action plans for mineral resources and rare earths in 2016. Minerals will be crucial to advancing many of the strategic technologies identified in China's "Made in 2025" initiative, such as electric vehicles, batteries, and high performance computers. As one witness testified at the hearing, to support these plans both Chinese state-owned enterprises and private firms are "acquiring mines and output" in resource-rich nations – both established market economies and higher-risk developing countries alike. In addition, China is seeking to strengthen its position in the downstream portions of mineral supply chains, such as processing and refining. Even companies whose mines have no Chinese ownership have to send their raw or semi-processed materials to China for processing.

In light of China's more dominant position across the supply chain, now more than ever the U.S. needs a clear policy that prioritizes a secure supply of critical minerals. In 2017, the President put forward an Executive Order on critical minerals, and pursuant to that order the Department of

Senate Energy and Natural Resources Committee Hearing
"Minerals and Clean Energy Technologies"
September 17, 2019
Statement for the Record by Sen. James E. Risch

Commerce published a strategy earlier this year. Importantly, the Department of Commerce strategy highlights that "increasing the rate of mining without increasing corresponding processing and manufacturing capabilities will simply move the source of economic and national security risk further down the supply chain and create dependence on foreign sources for these capabilities." To bolster the entire U.S. supply chain, the strategy advocates for advancing research and development, improving understanding of U.S. domestic critical mineral resources, and growing the American workforce.

Cobalt is one example of a vitally important critical mineral. The demand for cobalt is growing dramatically as new energy technologies that rely on the mineral are being developed. As this demand grows, China is well positioned to control the flow of cobalt unless an alternative source is developed. Idaho is home to the largest deposit of cobalt in North America, and the mining industry is actively working to mine this resource domestically. These are important first steps, but we need to do more. In particular, we need to reform our outdated mining laws and make it easier to produce these critical minerals. The Chairwoman's American Mineral Security Act would do just that, and I hope that we can enact these meaningful improvements.

In addition to these domestically focused steps, cooperating with our allies and partners is key to a secure supply chain. Putting together a coalition is good for the free market – it allows all countries involved to focus on their comparative advantages. The Department of State recently announced several partnerships with nations like Australia and Canada. This includes an Energy Resource Governance Initiative, which "promotes sound governance and resilient supply chains in the energy minerals sector." As the U.S. government turns greater attention to this issue, our efforts should be aimed towards supporting and enhancing collaboration between the American private sector and companies in partner countries.

Thank you again for holding this important hearing.

The CHAIRMAN. Senator Heinrich.

Senator HEINRICH. Thank you, and I want to thank you for holding this hearing. I think it's very important policy questions and, as somebody who grew up visiting my grandfather at mines across Nevada, places like Battle Mountain and others, where he worked and whose father worked for Anaconda Copper in exploration.

I think one of the challenges we have is, as a first world nation we set a pretty good standard for mining labor because we had strong labor unions in this country, we didn't look at the other policies along the way. And we have a pretty strong hangover in this country from not addressing the other policies around mining.

We have a proposed mine right now outside of Santa Fe in an area that provides an enormous amount of recreational outdoor economic activity. And because it is permissive, there is no consideration for that in the policy whatsoever. We have a 150-year-old law. I think if we are going to create an environment where more mines can move forward, it is going to need to be as part of updating our mining law.

Today, and Senator Manchin knows this very well, if you want to mine federal hard rock minerals, unlike coal, you pay no royalties to the American people, even though those hard rock minerals are, theoretically, owned by the American people.

A bigger concern to many of my constituents is the incredible legacy of uncleaned-up mines across the West. There are thousands of them.

A few years ago, during the Gold King Mine spill irrigators had to close off their ditches, not water their crops, not water their livestock. There were municipal and tribal impacts as huge amounts of released heavy metals came downstream because of the uncleaned-up legacy of 150 years of abandoned mines all across the mountain West.

So I think if we are going to create a path forward, one of the things we need to do is really think about reforming the 1872 Mining Law if we are going to create the environment where some of these other things can move forward in a first world country.

I want to go back to recycling real quick. I will start with you, Secretary Simmons.

One of the things I am interested in is even before you do what Mr. Kang is doing in terms of recycling lithium-ion, there is a process of repurposing a number of the EV cells, in particular, who don't have the juice, forgive me, to necessarily be used in the transportation sector but they still have enough life to be used in a stationary form, either providing grid services like frequency regulation or voltage support. What is DOE doing to look at that business model and find ways to do a two-step recycle where you do EV batteries, to stationary applications, to the kind of recycling that Mr. Kang does?

Mr. SIMMONS. So we are looking at exactly that and to understand what is required and what the values are for some of these secondary uses so that we understand, so that we don't need to necessarily recycle if that product has a useful life.

Some of the research that we have funded has found that, I believe, it's about $25 per kilowatt-hour. If it is worth that, then it makes sense to turn it into these, like, these secondary uses such as stationary sources.

So this is an important area for us because those batteries can be very inexpensive. And then from there we are working on the recycling technologies to be able to recycle them very efficiently as well as collection technologies to make sure that we do a good job collecting these batteries and getting them to, well, so that we're collecting more than five percent which is where we currently are. There's much work to be done there.

Senator HEINRICH. Mr. Kang, if you could write a recycling bill what would it look like? How much would be policy? How much would be incentives? How much would be building the infrastructure of collection that you talked about?

Mr. KANG. My goodness, Senator, I think it would be all of the above. I think we really need to encourage development at every level of the recycling industry, again, the collection, the processing and refining so that the metals can be put back into manufacturing of new batteries.

I think, you know, a lot of the ideas that we've discussed today regarding incentivizing companies to come into this market. I'll tell you, as we've been speaking and trying to create a state-wide collection program, it's the dollars that are getting in the way of making this happen. The state realizes this is a need that we need to address.

One thing that I'm sure all of us have heard about is when batteries are collected, they get into our waste streams. They cause problems for other recyclers and for our waste municipalities. So it's a serious issue that needs development in all areas.

Senator HEINRICH. Thank you.

The CHAIRMAN. Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you. Thank you, also, for this great conversation today.

As somebody who is from Nevada, it is a very proud mining state, I do think that we can find that balance between extraction and environmental protection. Nevada is a perfect example—not only is it a mining state but we really have led in the growth of renewable energy in the State of Nevada from solar, wind and geothermal.

I know there are many mining companies in Nevada now who, and I have visited with them, who literally look at how they can sustain the environment while they are engaging in the extraction at the same time. It can be done. And I think this conversation shows that we have a lot of work ahead of us.

But here is the thing, and I think this is my concern, that I am hearing from you. And I so appreciate the Chairwoman in bringing this forward. If we do not do something about this when it comes to our critical minerals from the extraction to the processing, the manufacturing and the end, all of it and recycling, we are going to be behind when it comes to an economic advantage for not only this country but around the world. And we hear this. This is now our time. This is really our call to action to recognize something is happening here.

The other thing I want to say. There has been this discussion over battery storage and batteries and recycling. I think, and I am curious about the panel, what you think, but we are only at the beginning stages of the technology when it comes to battery storage and what it is going to look like.

I think technology is growing at such an exponential growth that it is going to change what we are talking about today as a car battery. You just have to look at history and as we have seen technology and where it is taking us now.

I think if we don't incentivize it, if we don't start embracing this technology and growing with it, we are going to be left behind. That is what I am hearing from all of you.

But there is one piece that we have not talked about today, and let me jump into that very quickly because let me highlight in Nevada, Lithium America is pursuing the largest known lithium resource in the United States. It is the only lithium mining that I am aware of that is occurring in the United States. But the President and CEO was here. He testified, Thacker Pass, in Northern Nevada, he talked about it has the potential to produce enough lithium to fulfill 25 percent of the world's demand. But the President shared his concerns about the limited pool of technical professionals available to fill the roughly 300 permanent positions a mine the size of Thacker Pass would require.

I know, Mr. Simmons, you noted in your written testimony that the Department of Commerce issued its federal strategy to ensure secure and reliable supplies of critical minerals in response to Executive Order 13817. And among the strategy's six calls to action is growing the American critical minerals workforce.

So I want to open this up to the panel, but I will start with you, Mr. Simmons. What are you hearing? What are the concerns? And what should we be considering? And what do we need to do to be building and working along with everything we've talked about, that building that strong pool of technical professionals to support more domestic critical mineral production?

Mr. SIMMONS. Well, the first thing that I think that we need is for the jobs to be here. Currently, the jobs are not here in many ways. As we have more job opportunities, I think that that then incentivizes more people to look to, you know, people look at mining as technology of the past. And I think that that is incorrect.

The Colorado School of Mines is a great college and I'm sure that Dr. Bazilian will have some additional impact, but the first thing that we need is for the possibility of jobs and for these jobs is to be seen as jobs of tomorrow as opposed to, you know, jobs of the 1860s. And that's the first key. And the Administration is working, well, working across the Administration to provide technical support and training to hopefully move us forward.

Senator CORTEZ MASTO. Please, I open it up to the panel because I think part of it is, yes, creating the jobs. But if we don't have that skilled workforce, and that is what I am hearing is part of the problem as well. The jobs may be there, but if we don't have the people that have the skills necessary for those jobs we are still going to be left behind.

So I am curious if there are any ideas that we should be looking at how we build that skilled workforce.

Dr. BAZILIAN. Thank you, Senator.

Yes, we, as one of the best mining and mining engineering departments in the world, we think about workforce development of our students every day. And that is both the education of undergraduates as well as providing research opportunities at further stages of their career.

And as Secretary Simmons has said, we have the—we partially run the Critical Materials Institute outside of the School of Mines with Ames Laboratory. But inside what we're trying, what we're seeing is if we can tie the education to this attractive new narrative. In other words, if the young people see an attractive narrative, like Foundational for the Clean Energy Future or the Energy Transition as something they will participate in, support and drive forward, then it will be much easier to grow our numbers in the mining department as opposed to things like quantum physics and other areas of the university which are growing even faster.

Senator CORTEZ MASTO. Right. Sure.

Mr. SIMMONS. May I add to what I said previously?

Earlier this year I visited the Colorado School of Mines, and one of the things that I was very excited about when I was there is a new program that the Colorado School of Mines is doing with the National Renewable Energy Laboratory. I mean, they're both in Golden, Colorado.

The teaming up of mines and NREL, I think, is a fantastic opportunity that we are bringing together the expertise of the national labs and in this particular situation, educating students, educating some of these very smart people of tomorrow to advance clean energy technologies and mining technologies at the same time.

Senator CORTEZ MASTO. Thank you.

I notice my time is up. I didn't know if, Mr. Mills, you wanted to say a few words.

Mr. MILLS. Well, I could add a quick comment that I agree with your concern. It's the right one.

And Dr. Bazilian's point about connecting the narratives really relates to my not entirely facetious comment about unobtanium. As people understand the devices they like, computing and the internet and everything that we talked about begins with mining, requires mining. Processing and manufacturing, it's an integrated ecosystem. And it's poorly appreciated, poorly taught from K through college. And so, there are constructive things one can do there. They're not obvious so there's no simple thing.

But the interesting part is that the kinds of technologies that can now be used to mine and the kinds of jobs that can be created and manner of training are all now subject to, essentially, revolutionary transformations because of things like artificial reality, virtual reality, because of new teaching tools and techniques, both for the skilled trades, the so-called, I like Mike Rowes' phrase, "Dirty Jobs." These dirty jobs are not as dirty as they used to be. They're dirty in the sense that they're not, you know, typing at a word processor.

There's a, I think, there's a potential to create excitement about them. If you create excitement by virtue of awareness and we collaterally make it easier and, I say this again, sort of obvious, you have to make it easier without being lax for businesses to decide to invest in mining here.

It is very difficult to open a mine in America. It's just a fact. It's much easier to open a mine in my homeland, where I grew up, in Canada. Canadians are very environmentally conscious, but you can open a mine far more easily there.

Senator CORTEZ MASTO. Okay, thank you.

The CHAIRMAN. Thank you.

Senator Stabenow.

Senator STABENOW. Well, thank you, Madam Chair.

I want to thank you for the hearing and your focus on this which is a really critical issue, and I also really appreciate the discussion on recycling. I think this is an area where we have a lot of opportunity.

Mr. Kang, thank you, as I am thinking of my own house and how many cell phones and things that I have in my own house that——

The CHAIRMAN. I was actually thinking about here in Congress.

Senator STABENOW. Yes. Absolutely.

The CHAIRMAN. I mean, do we recycle any of this stuff? We are working on that so we can have a Committee letter going out.

Senator STABENOW. Yes, good.

Well, please count me in on working with you. I think this is incredibly important.

I also want to reiterate, Senator Cortez Masto, just in the sense, broadly, that we are America and we can do anything we decide to do. Right? If we are focused.

China is getting ahead of us not only on the things we consider dirty energy, but on clean energy now, way ahead of us because they are focused. We know they use different economic models, obviously. But they are laser focused, and we need to be laser focused if we, in fact, are going to do what we need to do which means we have to pay attention to the raw materials.

So there is no question that dependence on foreign sources of critical minerals is a danger to our economy and national security. And we don't have to do that. I mean, it is complicated, sure. But if we are focused on it, we can address this. Also, as all the witnesses have said, support the focus on not only recycling, but manufacturing. We are a great manufacturing state in Michigan. We can really make anything. And so, we welcome that.

And refining of critical minerals that are so key to the renewable energy systems and electric vehicles.

I also support mining done in a smart, environmentally responsible way. We need to be moving forward and using technology and being able to do that.

I also want to make sure that taxpayers and governments are adequately compensated for such activities which Senator Heinrich is working on and I think is a very important piece of the policies.

But I do have to say, Madam Chair, that we are talking about expediting permitting for mining or doing other things to increase the opportunity to get the materials but then, some of my same colleagues, not anyone here in this room, is opposing the ability to spur the technologies that would be using these minerals. And so, I hope that we will be embracing also the electric vehicles, the technologies, all the things that we need to be able, that we want to use these raw materials for. I think this is very, very important.

I am also very concerned that we are not just simply mining the materials and shipping them to China which could happen if we are not, ourselves, developing our own technologies. We have the intellectual property. We have the capacity on manufacturing right now. But the truth is that we could end up in a situation where we are mining it here and shipping it to China which raises another side issue, I would just say that Senator Manchin and I have been working on, which relates to what we are doing with ethane as part of oil and gas exports because ethane is critical to manufacturing in the United States and as that price goes up, we are only hurting ourselves if we are shipping it, you know, exporting it. So I am very concerned about how we are managing these resources.

But I do want to ask Assistant Secretary Dan Simmons. Assistant Secretary, I am concerned, you have described the serious concerns about U.S. strategic vulnerabilities for critical minerals. I agree. The Administration's belief that the Department of Energy should promote R&D across the supply chain. I agree. But your budget in no way reflects what you just said.

I don't know how to square this when your 2020 budget said an 85 percent cut to Energy Efficiency and Renewable Energy Office, 24 percent cut to Fossil Fuel R&D, 178 percent cut to Advanced Research Projects, 16 percent cut to the Office of Science which you have referenced during the testimony today. How do we accomplish this if the Administration is proposing to gut the programs?

Mr. SIMMONS. Well, we, you know, we have the proposed budget to focus on some things that are critical to the Administration but, as you know, the proposed budget is a proposed budget, it is the beginning of the process. It's not the end of the process. And just last week the Senate Appropriators, the mark for my office, the Office of Energy Efficiency and Renewable Energy, was over $2.8 billion.

And so, you know, we—it is a—the proposed budget is a give and take. I will definitely take back your comments, because we are currently working on the FY21 budget. I will take those comments back to the Department of Energy.

And then, but at the end of the day what matters is the monies that get appropriated, and we are working diligently to spend those monies wisely. And as we've seen for the past few years, that is substantially more money that what has been asked for the proposed budget.

Senator STABENOW. Well, and I would just say we are very fortunate to have strong, bipartisan support not to accept those cuts every year. And I would just give a shout out to our Chair, who is an important part of that process because we have not been doing that.

I just have one other quick question, if I might, as the last person speaking?

The CHAIRMAN. Sure, go ahead.

Senator STABENOW. Mr. Mills, I won't go through, you know, everything that you have said. We don't see eye to eye, I think, on a lot of things and I appreciate the support in the folks funding your Manhattan Institute and the perspective that folks bring.

I will say I agree with you on human rights violations, but I also want to just point out that international human rights violations have also been associated with the oil industry, which to be fair, I didn't hear you mentioning that, be it in Nigeria or South Sudan. And the U.N. recently wrote the international oil companies should be well aware of the legacy of unaddressed human rights violations associated with oil exploration. So I support your focus on that, but we need to be focusing on everything.

I would just finally ask one question. Well, actually, two questions.

Do you believe that climate change is a crisis? Do you believe that?

Mr. MILLS. Do you have—that is the one question?

Senator STABENOW. That's your question, yes.

Mr. MILLS. Do I think it's a crisis?

Senator STABENOW. Do you believe that climate change——

Mr. MILLS. I don't believe it's a crisis, no, I don't.

Senator STABENOW. You don't.

Mr. MILLS. I agree with Bill Gates on the matter that it's, that human beings have demonstrable impacts on everything in the environment, including the atmosphere. I think Bill Gates would describe it as a long-term challenge and not a crisis. I would be in his camp.

Senator STABENOW. Do you think it is a challenge? You are saying it's a challenge?

Mr. MILLS. Yes, it is.

Do I think dealing with climate change is a challenge? The climate has always changed. It's going to change whether it changes more radically or a lot, it's always a challenge. Resiliency is the biggest single challenge humanity has with respect to weather and climate.

Senator STABENOW. Okay.

Mr. MILLS. The challenge of doing something about it is unequivocally, scientifically, economically and in engineering terms, the largest, single proposed change in the structure of society that's ever been made anywhere. So, yes, it's a big deal.

Senator STABENOW. I understand.

And one other just quick question because I know the Chair has been very patient.

It sounds like from what you are saying and from your written testimony that the U.S. should simply cede global leadership on renewable energies and advanced vehicles to other countries because fossil fuels have a century head start in developing their industry in the United States.

Mr. MILLS. I'm saying the opposite.

Senator STABENOW. The opposite?

Mr. MILLS. I'm saying that the——

Senator STABENOW. It sounds like you don't believe it is worth it for us to go in that direction on clean energy.

Mr. MILLS. No, I'm not saying—I'm saying the opposite.

I'm saying the fact that we are pursuing greater use of wind, solar, and batteries, which is meritorious in many ways and far greater use that we have today, has implications that are poorly understood and recognized from a physical resource, economic and environmental perspective.

We are exporting the issues that we are unhappy about which are environmental issues, labor issues by being an independent, essentially, an independent oil producer, we have control over those human rights issues here. We don't have control over these issues with respect to the supply chain for green energy.

Senator STABENOW. Thank you.

Well, I am looking forward to having us have more control over our raw materials, Madam Chair. Thank you, again, to you and the Ranking Member, for having what is a very important hearing.

The CHAIRMAN. Thank you.

It is a very important hearing.

Just to follow up on that because I think sometimes, again, we don't know what we don't know and the supply chain is not a very transparent process. I think there are real challenges as you try to trace what goes into this or what goes into the battery of your electronic vehicle. And so, we put ourselves in a position that while we want this, we want to be able to say that what we are using is not only derived in an environmentally sensitive and sound manner, but that from a human rights perspective we have all done right. And in fairness, it is difficult, it is challenging.

Somebody noted the Washington Post article which I, too, had read which I thought was very well done with regards to how lithium is being extracted in the Congo. And you look at that and say, individually we need to be doing something. Collectively, we need to be doing even more.

But in fairness, and I guess I will throw this to you, either Mr. Mills or Assistant Secretary Simmons, what more can we be doing to improve the transparency in the supply chain because I think right now, a lot of folks just don't know. And maybe they don't care, maybe they don't want to know, maybe they just want the product, maybe they just want to believe that there is free energy. But I think that this is a challenge for us when as an issue it is not clearly understood.

So jump in here, Mr. Assistant Secretary.

Mr. SIMMONS. So I'll start on that one. Interesting to hear what Mr. Mills has to say.

I think one of the best things that we can do about the supply, about this supply chain transparency, is to have U.S. supply chains or supply chains that are based in countries like Canada, the United States, Australia.

I had the chance a little while ago to visit the Rio Tinto's Kennecott Bingham Canyon Mine in Utah, and one of the byproducts of producing copper there is gold and silver. And Tiffany's, the jewelry company, buys their gold and silver.

Like, you saw how incredibly transparent that supply chain was. Well, it's because it is a global, one of the largest global miners and a large jewelry company, and they are very cognizant of those challenges. That's one of the most important things.

One, we have to raise the issue of the challenges of supply chains. And two, when it occurs in the United States, it is at another level of transparency.

As has been noted earlier, when it is run by state-owned enterprises, when it's, you know, when it's illegally obtained, there's no transparency there. And so, a place like the United States, like

Canada, like Australia, it is just another level of transparency that you don't get anywhere else.

The CHAIRMAN. Mr. Mills.

Mr. MILLS. I couldn't agree more.

I could elaborate on that. If the transparency comes by having the supply chain in countries where you can't be transparent, and as you, I'm sure, know, the efforts to force more transparency on the African nations' supply chain was opposed by a group of, I think, 20 NGOs because they were worried that that would cause the trade to go underground, figuratively disappear and make the supply chain even more opaque.

Maybe the short answer to how to make the supply chain better is through a very old technique called shaming. And that's a little bit of what's been going on in consumer groups. And I think that might help because shaming can often work in cultures, even in non-Western cultures it works.

The CHAIRMAN. Let me ask you, Ms. Carlson. You have very keenly focused on China and the role that China plays with regards to critical minerals and rare earths. I think we recognize that in addition to not only having the resource, they have worked very aggressively with their own very specific strategy, their "Made in China 2025" initiative. They are clearly looking at the full supply chain. Are there any other countries besides China that you are watching that we should be watching that, again, has a very clear and focused view of this?

I spend a lot of my time in the Arctic looking at the issues of the Arctic and, of course, we know we have considerable resources in the Arctic with very few people. For some, it is cold and dark and out of the way and there aren't a lot of investors that are looking at places like Greenland, for instance, and so China can come in and say, here, we will help you. We will bring in a workforce. We will be able to extract a resource, and we will be able to benefit you. China is very clear about that.

Who else or is there anybody else?

Ms. CARLSON. Thank you for the question.

I think there are other countries. And as you mentioned in the beginning, countries that are focusing on developing their mineral strategy writ large as a matter of their economic competitiveness, Australia being one of them.

So I think it's important to look around the world and see how those policies are being developed, how they're being prioritized and how they're ensuring sustainable production with supply chains that are transparent and seeing what we can learn and how we can partner and move forward with a sustainable strategy ourselves.

I think it's also important to recognize in those countries where minerals are concentrated, other factors that are impacting their availability whether it's labor standards, geopolitical risks and other factors that could really undermine access and supply to those resources. That's absolutely critical.

And also looking into the Arctic, as you say, understanding that there have been investments by China and Greenland toward that end.

I do think that there is a tremendous opportunity here as Senator King asked earlier, has it been lost and has our competitiveness been undermined? And I would say, no. I would say that the situation now in addressing this—and thank you again to your Committee for doing so—presents an incredible opportunity for economic development and competitiveness for the United States and our partners, as was mentioned, but will require full commitment to investment in R&D, really supporting the supply chains that work, that were discussed for recycling, partnering with the private sector to do so, understanding that there are companies that are recognizing those risks to their own supply chain and already starting to do something about it themselves.

So aligning those interests with the public and the private sector can help reduce the risk and create the scale that's needed so there won't be as much focus, necessarily, on price floors or other things that would be challenging to implement, but creating the scale, the network and the resource and the skills and investment in science and technology that will be necessary to really grow that here.

The CHAIRMAN. You speculate about whether or not we are so far behind that we can never catch up. I think we have to remember that one of the advantages that we have, in addition to good environmental laws and standards, good record with labor protections, but we have the resource, not every nation has the resource.

I look to my state, a very, very exciting graphite mine up in the North, and then down in the Southeastern part of the state we have a very favorable opportunity for processing of rare earths down in the Bokan Mountain area. And right now, we have some folks that are looking to establish a processing facility there in Ketchikan, Alaska.

Now in fairness, there are some challenges with getting the investors. But when Senator Stabenow mentioned that we don't want to be in a position where we are mining the resource here and then shipping it to China, I didn't want to interrupt her, but we are doing that now. And it is my understanding that the Mountain Pass operation in California is now reopened, and so we are mining that resource, those critical minerals that we want. But because we don't have any processing facility here in this country, we are sending it to China. And then, I suppose, if we're good, China will send it back to us. It is not just theoretical, what if we have the resources here, but we don't have the processing. It is a true enough situation right now.

Assistant Secretary Simmons, you were kind of challenged by Senator Stabenow with regards to your budget there, and I concurred. I was a little bit disappointed. That is why, as an appropriator, I strongly supported the work that Chairman Alexander, the Chairman of that Subcommittee, did in really plussing up the EERE account. I think that that is significant. I think it is important.

I certainly hope that the Administration gets a very clear message that we feel pretty strongly about this and how we are able to do with minerals what we have demonstrated with regards to our energy dominance that we can be doing more, not only to dominate but to diversify, which I am using as your take away, Dr. Bazilian, because I think that is an important part for us because with as many of these important minerals as we need in today's modern society, I don't think it is possible to dominate, but I do think it is clearly possible to be a significant player with regard to how we cannot only gain access to production but to the processing and to all aspects of that supply chain. But it takes a focus. I think it takes a vision and it takes a political willingness that, I think, that is where we are lacking right now is the willingness to actually move forward with a policy. We have an Executive Order that is in place. Our American Mineral Security Act, I think, is a good step with that.

But in fairness, I think it needs to be a broader view and a broader vision. So that is one of the roles of this Committee is to try to look at things from 30,000 feet and figure out where we go forward. But I think this is an area where there needs to be greater education. There needs to be greater awareness. There needs to be better understanding as to the very, very significant role that minerals play in a modern society—how we extract them safely and responsibly from an environmental perspective, from a human perspective, a social perspective. It is a tall order but it is certainly something that the United States can help lead that charge.

I thank you for contributing to a very valuable conversation here this morning. Know that in addition to all that you have provided us, other members may have questions that they wish to submit and we will include those and your responses as part of the Committee record as well.

With that, we stand adjourned.

[Whereupon, at 11:33 a.m. the hearing was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: *The Sourcing and Use of Minerals Needed for Clean Energy Technologies*
Questions for the Record Submitted to the Honorable Daniel Simmons

QUESTIONS FROM RANKING MEMBER JOE MANCHIN III

Q1. There are plenty of opportunities to harvest minerals from end-of-life products, and not just from electric vehicles. Can you please describe opportunities for innovation that will help improve mineral recycling rates across other high-tech industries?

A1. Research and innovation is needed to improve reusing, remanufacturing, recycling, and recovery of critical materials in end-of-life products. This aligns with DOE's R&D efforts, as well as the Federal Strategy released in response to Executive Order (E.O.) 13817.

The Advanced Manufacturing Office (AMO), within DOE's Office of Energy Efficiency and Renewable Energy (EERE), is engaged in R&D to drive reuse and recycling of critical materials from products at the end of their useful life.

Through competitively selected AMO awards, researchers at Oak Ridge National Laboratory are shifting the paradigm by automating disassembly of hard disk drives. Disassembly allows for reuse of valuable components, such as the magnet-containing voice-coil motor assembly and the printed circuit boards, while preserving the option to shred the data-containing platter to preserve data security. At Ames Laboratory, an acid-free recycling process was developed to recover rare earth oxides from shredded hard disk drive waste. This novel process leaves non-rare earth containing components undissolved, and allows for recovery of copper, which is increasing in value and makes the process economical.

Electronic waste more broadly is another opportunity for recovery of critical materials. The Reducing EMbodied-energy And Decreasing Emissions (REMADE) Institute, a Manufacturing USA Institute funded per guidance in Congressional appropriations report language, funds projects to develop efficient, economical recycling and recovery processes. Researchers are developing low-cost and low-energy leaching technologies to directly recover copper and precious metals from electronic waste.

Scrap metal is another opportunity for recovery of materials. The REMADE Institute also funds R&D work to rapidly sort high-grade aluminum scrap from lower grades of aluminum and other nonferrous metals using electrodynamic sorting. This technology has the potential to increase throughput and enable greater purity and yield of the sorted metals.

While congressional report language has continued to insist upon funding the Critical Materials Institute (CMI), the FY2020 budget request favors a transition away from the hub model because the mortgaging of future appropriations reduces budgetary flexibility. Instead, the budget request proposes a set of smaller and more directly managed, early-stage, R&D consortia activities.

Finally, as part of the implementation of the Federal Strategy in response to E.O.13817 – DOE will be leading an effort to develop a roadmap that identifies key R&D needs across critical mineral supply chains – including more efficient and effective recycling and reuse.

Q2. What can the DOE do to reduce investor risk and increase confidence in the U.S. for rare earths and other minerals that are needed in the clean energy technologies?

A2. A key strategy to increasing the U.S. private sector's investment and engagement in critical mineral supply chains is research and development. This was highlighted in "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," issued on June 4, 2019 by the Department of Commerce. [1] This Federal strategy is in response to E.O. 13817.[2] An organizing principle of the Federal strategy is to address the full supply chain of critical minerals, which spans from securing raw materials to end-uses in both civilian and defense applications.

Call to Action 1 of the Federal strategy is to "*Advance Transformational Research, Development, and Deployment across Critical Minerals Supply Chains.*" One of the goals of Call to Action 1 is to "increase U.S. private industry investment in innovation and improve technology transfer from federally funded science and technology." DOE is the lead agency for Call to Action 1. As such DOE is charged with:

[1] Department of Commerce. https://www.commerce.gov/news/reports/2019/06/federal-strategy-ensure-secure-and-reliable-supplies-critical-minerals
[2] Federal Register. https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals

- Coordinating with other federal agencies to evaluate and provide recommendations to incentivize the development and use of advances in research and development (R&D), science, and technology in private industry; and
- Providing support for small and medium businesses by leveraging and expanding the existing coordination between the DOE's Critical Materials Institute, National Institute of Standards & Technology (NIST)'s Manufacturing Extension Partnership, relevant Manufacturing USA institutes, national laboratories, and universities.

The Federal strategy also calls for development of an R&D strategy to enhance scientific and technical capabilities across critical minerals supply chains. The Department will develop a roadmap that identifies key R&D needs and coordinate on-going activities for source diversification, more efficient use, recycling, and substitution for critical minerals. The roadmap will also identify cross-cutting mining, data science techniques, materials science, manufacturing, computational modeling, and environmental health and safety R&D. To inform the R&D roadmap, DOE will convene stakeholders across the entire domestic rare earths and energy storage supply chains.

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: ***The Sourcing and Use of Minerals Needed for Clean Energy Technologies***
Questions for the Record Submitted to the Honorable Daniel Simmons

QUESTIONS FROM SENATOR BERNARD SANDERS

Q1. On September 4, 2019, the Department of Energy issued a final rule that would allow the continued sale of highly inefficient lightbulbs. This energy efficiency rollback is estimated to cost the average American household more than $100 per year, adding up to a total of $14 billion in additional electricity costs by 2025. What is the rationale for this decision to increase Americans' energy bills? Please describe in detail and provide a list of meetings held with any outside groups on this rulemaking while it was being drafted.

A1. DOE's final rule does not roll back any standards. Rather, after considering new data and public comments, on September 5, 2019, DOE published a final rule withdrawing the revised definitions of general service lamps (GSLs) and general service incandescent lamps (GSILs). The 2019 final rule neither implements nor seeks to enforce any standard. Rather, it merely seeks to maintain the currently effective regulatory definitions, and not amend existing standards for GSL and GSIL, consistent with the clear intent of Congress.

DOE developed this final rule after reevaluating its legal interpretations underlying the rules and considering comments, data, and information from parties that represented a variety of interests.

On September 25, 2018, DOE attended by telephone an E.O. 12866 meeting between the Office of Management and Budget, Earthjustice, and NRDC on DOE's pending proposed rule. On February 5, 2019, one day before DOE issued its proposed GSL definition rule, DOE met with representatives of LEDVANCE. After DOE published the proposed rule on February 11, 2019, the rule was open for public comments for 81 days and DOE hosted a public meeting on February 28, 2019 to gather additional input from the public. The final rule was published on September 5, 2019. All comments and the public meeting transcript were made available.[3]

Q2. The Department of Energy continues to miss energy efficiency rulemaking deadlines. As of June 2019, DOE has missed legal deadlines for eighteen product standards. Please describe in detail your plan, including a timeline, to complete these rulemakings. Please also describe in detail the actions taken by the Department of Energy to reduce delays on future rulemakings.

---

[3] https://www.regulations.gov/docket?D=EERE-2018-BT-STD-0010

A2. DOE's plan for addressing missed statutory deadlines is available in the 2019 Fall Unified Agenda published at RegInfo.gov. This plan indicates that DOE is actively conducting rulemaking on several products with missed appliance standards deadlines.

DOE has taken a number of steps to improve its rulemaking process. DOE has requested information, held public meetings, and published a proposal to improve the 1996 Process Rule. Further, DOE has requested comments on a more targeted evaluation of the potential energy savings, technological feasibility, and economic justification of amended standards, allowing for a streamlined evaluation of those products and equipment for which significant additional energy savings are not likely. DOE has also issued a request for information (RFI) to better understand whether there are provisions in DOE's test procedures that could be improved to produce results that are more representative of average use cycles or periods of use. Additionally, DOE issued an RFI to better understand the emerging market for "smart" appliances and commercial equipment. By improving coordination between energy conservation standards and test procedure rulemakings and streamlining its reviews, in conjunction with a better understanding of energy and consumer use developments, DOE is better positioning itself to meet statutory obligations.

Q3. In FY2018, DOE failed to spend its appropriated funding for research despite clear and strong congressional guidance to invest public dollars in new technologies and innovation for clean energy. Approximately $600 million in FY2018 R&D funding went unused, including $319 million of the Office of Energy Efficiency and Renewable Energy's (EERE) budget (14 percent of EERE's total budget). What is DOE's progress toward using its FY2019 research funds? What did DOE do differently in FY2019, relative to FY2018, to fully use its appropriated research spending? Can you commit to ensuring that this will not be an issue in FY2020? If you cannot make that commitment, why not?

A3. DOE fully intends to utilize its appropriated research funding to invest in new technologies and innovation for clean energy, consistent with both congressional guidance and administration priorities. The majority of funds not obligated by year-end are associated with competitive funding opportunity announcement (FOA) awards that are under review or being actively negotiated. While there are specific plans for these funds, the FOA process typically takes 12-13 months from the date of publication to finalization of awards. Additionally, publication of FOAs are dependent on receiving final appropriations from Congress. In FY 2018 appropriations for the Department of Energy were not finalized until March, 2018 – nearly 6 months into the fiscal year – resulting in substantial delays to FOA publications for that year. To expedite funding of competitive awards in FY 2019, EERE, for example, moved almost exclusively to aggregating its FOAs into larger, multi-topic solicitations to streamline FOA development and issuance processes. EERE award selections not completed by the end of FY 2019 are expected to be finalized by the end of the calendar year. For FY 2020, EERE will continue to use and refine this multi-topic FOA process. Additionally, EERE will post its FOAs as expeditiously as possible – pending finalization of FY 2020 appropriations – in order to obligate its R&D dollars as soon as feasible.

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: *The Sourcing and Use of Minerals Needed for Clean Energy Technologies*
Questions for the Record Submitted to the Honorable Daniel Simmons

QUESTIONS FROM SENATOR MAZIE K. HIRONO

Q1. Hawaii is some of the highest per capita use of electric vehicles as well as using batteries to store electric power from the grid or home solar panels. How much potential does DOE see for reusing old batteries from electric vehicles to help store power from the grid? Your testimony mentions the ReCell Lithium Batter Recycling R&D Center. Is DOE supporting any research on evaluating when it there would be more value in would repurposing used electric vehicle battery for use on the power grid versus recycling the minerals inside?

A1. Electric vehicle (EV) batteries may have substantial energy capacity remaining once they reach the end of their useful life in vehicle applications. Reusing those batteries in an application with a less rigorous duty cycle than EV applications has the potential to create an additional revenue stream for electric vehicles and energy savings. However, market penetration of second use batteries has been challenging due to the lack of available spent lithium-ion batteries and the rapidly decreasing cost of new lithium ion batteries.

DOE's Energy Efficiency and Renewable Energy's Vehicle Technologies Office (VTO) has supported projects in the past with respect to reusing electric vehicle batteries in second use applications. VTO funded the National Renewable Energy Laboratory (NREL) to perform the techno-economic analysis from an economic perspective, the NREL study, completed in 2015, showed the cost to refurbish electric vehicles batteries for second use applications is less than \$50/kWh at scale.[4]

The goal of DOE's Battery Recycling Prize is to encourage American entrepreneurs to find innovative solutions to collecting, storing, and transporting discarded lithium-ion batteries for eventual recycling. Over three progressive funding phases, the prize aims to accelerate the development of solutions from concept to prototype to demonstration. Three of the winning concepts for Phase 1 of the DOE Lithium-Ion Battery Recycling Prize are aimed at evaluating, or "grading," batteries for secondary use applications prior to eventual recycling.

Additionally, DOE's Office of Electricity funded a demonstration project with General Motors, ABB, and Oak Ridge National Laboratory to study real world effects of second use batteries in the field for

[4] https://www.nrel.gov/docs/fy15osti/63332.pdf

grid applications. Research has largely showed second use is feasible from an economic and technical perspective. In fact, EV batteries for second use applications are being used in the United States today. From a technical perspective, cells need to be appropriately "graded" for their state of health in order to properly balance them in the second use application in order to assure safe operation.

Q2. Related to understanding the materials needed for clean energy technologies is understanding the potential future demand for clean energy technologies. On September 12, the Institute for Electrical and Electronics Engineers (IEEE) published an article on its website related to a DOE-funded study on power transmission in the Eastern and Western U.S. power grids, known as the Interconnection Seams Study. The article, titled "China's Grid Architect Proposes a "Made in China" Upgrade to North America's Power System," states: "Last year, political appointees at the U.S. Department of Energy blocked publication of a modeling study exploring integration of the Eastern and Western grids via DC lines. The study, led by the grid modeling group at the National Renewable Energy Lab (NREL) in Boulder, Colo., projected that long DC lines linking the grids would reduce power costs and accelerate renewable energy development." Has DOE reviewed a final written report on the Interconnection Seams Study? If not, why not? If the final report exists, why has DOE not released it or allowed it to be published?

A2. The Department of Energy (DOE) has a specific interest in large-scale (e.g., inter-regional and even continental-scale) transmission planning. The Interconnections Seam Study was funded through DOE's Grid Modernization Initiative and conducted by NREL to use current tools to assess the benefits of increasing connectivity between the Eastern and Western Interconnections. DOE officials reviewed preliminary results from the study and decided to expand the project to model and analyze additional scenarios. This includes refining methods and data parameterization for improved modeling of transmission congestion within capacity planning tools and grid operations models. The improved characterization of congestion will model how this transmission expansion can contribute to reliability and resilience in the future grid.

The expanded scope of work for the study is nearly complete. We expect to have some initial results in FY 2020, with the overall project expected to be complete in the summer of 2022.

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: ***The Sourcing and Use of Minerals Needed for Clean Energy Technologies***
Questions for the Record Submitted to the Honorable Daniel Simmons

QUESTIONS FROM SENATOR JOHN HOEVEN

Q1. The Critical Materials Institute acknowledges the role that both the private sector and government must play to manage risks and facilitate market activities. In your view, how can the public and private sectors effectively work together to ensure an adequate domestic supply of the materials upon which clean energy and technology rely?

A1. DOE utilizes several public-private partnerships mechanisms as powerful tools to accelerate time to market of innovative and disruptive technologies that improve the supply chain for critical minerals. These include prize competitions, R&D partnerships, and transfer of National Laboratory R&D innovations to the private sector for commercialization. An example of prize competitions is the Lithium-Ion Battery Recycling Prize (Prize) launched in 2019 by EERE. It is a $5.5 million multi-phased prize competition. The Prize encourages American entrepreneurs to develop and demonstrate processes that, when scaled, have the potential to capture 90 percent of the discarded or spent lithium-ion batteries in the United States for eventual recycling and recovery of key materials for re-introduction into the U.S. supply chain.

Another mechanism is through R&D partnerships at CMI between the National Laboratories, academia, and industry. While congressional report language has continued to insist upon funding the CMI, the FY2020 Budget Request favors a transition away from the hub model because the mortgaging of future appropriations reduces budgetary flexibility. Instead, the budget request proposes a set of smaller and more directly managed, early-stage, R&D consortia activities. Regardless of the funding profile, these partnerships are de-risking new technologies and processes through R&D. This has resulted in rapid technology adoption by industry, with eight technologies currently being licensed by U.S. companies. One of the technology solutions that has come out of the CMI partnership is a ceramic phosphor for LED lighting, which reduces the Terbium content by 90 percent and eliminates Lanthanum, while the new red phosphor eliminates both Europium and Yttrium and is rare-earth free. It was developed by Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory (ORNL), and General Electric (GE)[5], resulting in LEDs that are more efficient, have a longer lamp lifetime, and reduce dependence on critical materials.

[5] https://www.llnl.gov/news/better-fluorescent-lighting-through-physics

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: ***The Sourcing and Use of Minerals Needed for Clean Energy Technologies***
Questions for the Record Submitted to the Honorable Daniel Simmons

Another example of the public-private partnership mechanisms utilized by DOE is the Technology Commercialization Fund project. In one project initiated through the Technology Commercialization Fund, Momentum Technologies is working with Oak Ridge National Laboratory (ORNL) to commercialize a new method to recover earth elements from electronic waste. This membrane-solvent extraction process, patented by CMI researchers at ORNL and Idaho National Laboratory, recovers rare earth oxides at purities greater than 99.5 percent using a limited amount of energy, labor, and chemical solvents. The recovered earth oxide materials are suitable for manufacturing permanent magnets used in electric vehicle motors, wind turbine generators, and hard disk drives.

Q2. Determining the nature, occurrence, and economic potential of critical minerals in coal combustion byproducts and in oil and gas produced waters would go a long ways toward discovering new synergies within the energy industry. Has DOE studied – or does it have plans to study – the potential of deriving critical minerals from waste or byproducts from domestic energy production?

A2. Yes. DOE's Office of Fossil Energy's (FE) Feasibility of Recovering Rare Earth Elements program is currently focused on developing extraction, separation, and recovery technologies for the production of rare earth elements (REEs) and critical minerals (CMs) from coal and coal-based resources. Our Nation's vast coal reserves contain quantities of REEs that offer the potential to reduce our dependence on others for these CMs and to create new industries in regions where coal plays an important economic role.

FE and the National Energy Technology Laboratory (NETL) lead this RD&D program, which consists of developing process and production technologies, environmental management, and field materials sampling and characterization, along with systems integration, optimization, and efficiency improvements to produce REEs and CMs from coal and coal by-products streams, such as coal and coal refuse, clay/sandstone over/under-burden coal seam materials, power generation ash, and aqueous effluents as acid mine drainage sludge.

Efforts also focus on validating the potential for extracting, separating, and recovering REEs in three of our Nation's first-of-a-kind, domestic, bench- and small pilot-scale coal-based REE-processing plants. In Sharon, PA, a small pilot-scale facility is being built by Physical Sciences Inc., and Winner Water Services, LLC, is targeted to be producing small quantities of rare earth elements by the end of next month, using fly ash as their feedstock material. In addition, under a recent DOE-NETL funding opportunity award (FOA), several pilot-scale systems will begin optimization with efficiency improvements to enhance production of rare earths and initiate generation of critical minerals from coal refuse, lignite, and acid mine drainage materials.

This will reduce U.S. dependence on foreign imports, create new industries, and increase U.S. competitiveness in the global marketplace. The REE-CM program offers a pathway to improve the economics and reduce the environmental impact of a domestic coal-based value chain. The development of an economically competitive supply of REEs and CMs will assist in securing and maintaining our Nation's economic growth and national security.

Q3. The Industrial Commission Lignite Research Program has leveraged DOE National Energy Technology Laboratory Funding to explore what Rare Earth Elements (REEs) could be extracted in North Dakota. The next phase of this research is to demonstrate readily recoverable resources of these elements. How might industry integrate REE recovery into existing mine operations and power plants?

A3. Since 2016, the University of North Dakota (UND) has been working in conjunction with DOE-NETL through several Funding Opportunities Announcements (FOAs) and contract proposals Requests for Proposals (RFPs) to address the location of where high concentrations of rare earth elements may be found in domestic lignitic deposits. In addition, UND has focused their efforts on the development of physical processing and chemical separation techniques to extract and recover the contained rare earths as oxide materials (REOs) which could then be used to produce rare earth metals (REMs) for alloying and ultimately for commodity and national defense product manufacturing and equipment production. UND's research efforts, as well as efforts at the University of Kentucky, West Virginia University, and Physical Sciences, Inc., are being integrated into small pilot-scale rare earth element (REE) and critical minerals (CMs) separation facilities that potentially could be deployed in the near future as modular units to coal mine sites, coal preparation plants, or to power generation or acid mine drainage treatment facilities, to extract the contained critical materials at various locations within the United States.

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: ***The Sourcing and Use of Minerals Needed for Clean Energy Technologies***
Questions for the Record Submitted to Ms. Allison Carlson

Questions from Ranking Member Joe Manchin III

Questions: As you have highlighted in your excellent work on the subject, China has put in place a quota on exports of refined rare earth products in China, and also has its fingerprints on several mines outside of China. This includes the only operating rare earth mine in the United States, which a Chinese company, Shenge Resources, has an ownership stake in. Oxides from that mine are currently sent to China for processing to be used by Chinese customers.

What other metals are the Chinese most interested in besides rare earths and the battery metals? How do they finance these investments?

Response:

Dear Senator Manchin:

Thank you very much for your questions and your interest in our work.

Our research found systematic efforts to increase control and influence over mineral and metals that are critical to realizing China's Made in China 2025 industrial strategy. In addition to rare earth elements and battery metals (such as lithium, cobalt, graphite and nickel), Chinese state-owned enterprises (SOEs) and private firms have invested in the development of a range of minerals and metals that are key inputs for other clean technology and high-tech applications, both domestically and abroad. Most notably these include vanadium, indium, gallium, tantalum, cadmium, tellurium and tungsten.

With respect to financing, China has successfully employed two strategies to secure control and influence over resources. One is driven by China's SOEs, which use development finance and infrastructure investment to establish presence and market influence in locations where minerals/metals are concentrated. The second is investment by state-linked private firms in market-based economies.

By targeting debt-stressed mining companies, China's SOEs and private firms have secured equity shares and influence over mining and resource development companies. As noted in our report, China's SOE-driven strategy remains dominant throughout Africa, where adverse market sentiment and financial hardship in the mining industry have opened the door for SOE investment across the region.

Notably, SOEs have worked with the China-Africa Development Fund, a Chinese state-funded institution, to expand in South Africa's Bushveld Complex.[1] The Bushveld Complex is a mineral-rich geological formation that contains the world's largest reserves of platinum-group metals[2], which are critical for making catalytic converters and for reducing automobile emissions. It is also the world's highest-grade and third-largest deposit of vanadium, a resource integral to a broad range of high-tech industries from renewable-energy

[1] Zhen Han, "China's Current Involvement in Mining in Africa," *Mining Journal*, Jan. 19, 2016, https://s3.amazonaws.com/documents.lexology.com/efec9be3-a177-43e6-97e4-24e64ac6ef41.pdf.
[2] "Mineral Commodities Summaries: Platinum-Group Metals," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/commodity/platinum/mcs-2019-plati.pdf.

storage to aerospace and defense. Chinese firms already produce 56 percent of the world's vanadium domestically and China is home to 48 percent of the world's reserves.[3] Now, they are targeting South Africa, ranked third in vanadium production and reserves behind China and Russia.[4]

By leveraging state resources, China's SOEs and private firms have made multiple mineral plays in the Bushveld Complex, including at least eight major equity and off-take plays in platinum-group metals.[5] Such investments in South Africa's highly concentrated and strategic resource deposits have helped make metals the country's leading source of export growth.[6] With nearly 50 percent of its metal exports going to China,[7] South Africa's economic welfare is tied directly to Chinese investment. The strong influence of Chinese investment on countries' economic welfare can be seen in other major resource-endowed countries in Africa to Latin America.

In addition to direct state-backing, Chinese private companies have raised capital on the public markets, such as the Hong Kong Stock Exchange, for expanded resource-related investments. State-linked cornerstone investors have invested in Chinese firms, conferring influence over those firms' operations as well as their assets should those companies find themselves in financial difficulty. While this practice could apply to a range of critical materials investments, the degree and means by which the Chinese state is investing in other metals and minerals beyond those contained in our research report has yet to be fully investigated.

---

[3] "Mineral Commodities Summaries 2019," U.S. Geological Survey, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf.
[4] Ibid.
[5] FP Analytics analysis.
[6] "Statistical Release P0441: Gross Domestic Product, Fourth quarter 2017," Statistics South Africa, June 5, 2018, http://www.dmr.gov.za/Portals/0/files/P04414thQuarter2017(1).pdf?ver=2018-03-09-063718-170.
[7] "South Africa Minerals Exports By Country 2017," World Integrated Trade Solution (WITS), The World Bank, https://wits.worldbank.org/CountryProfile/en/Country/ZAF/Year/LTST/TradeFlow/Export/Partner/by-country/Product/25-26_Minerals.

FP

FP ANALYTICS SPECIAL REPORT

MAY 2019

MINING THE FUTURE

How China is set to dominate the next Industrial Revolution.

ILLUSTRATION BY GWEN KERAVAL

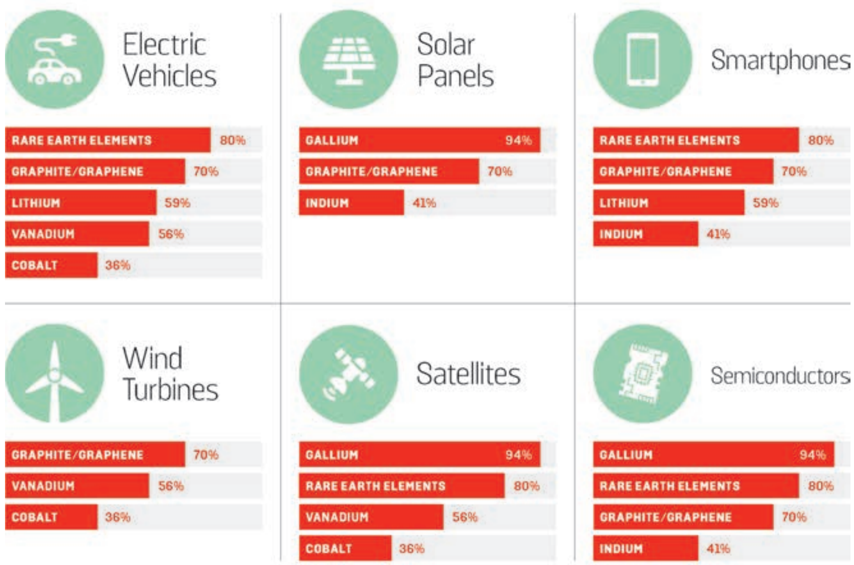
A fight between the United States and China is brewing over 5G and the question of who can be trusted to control the world's wireless infrastructure. But scant attention is being paid to an issue of arguably greater importance to the future of the world's economy and security: China's control of the raw materials necessary to the digital economy.

No new phone, tablet, car, or satellite transferring your data at lightning speed can be made without certain minerals and metals that are buried in a surprisingly small number of countries, and for which few commonly found substitutes are available. Operating in niche markets with limited transparency and often in politically unstable countries, Chinese firms have locked up supplies of these minerals and metals with a combination of state-directed investment and state-backed capital, making long-term strategic plays, sometimes at a loss. Through in-depth analysis of company reports and disclosures, mapping of deal flows, quantification of direct and indirect equity stakes, and other primary research, FP Analytics has produced the first consolidated review of this unprecedented concentration of market power. Without rhetoric or hyperbole, this fact-based analysis reveals how rapidly and effectively China has executed its national ambitions, with far-reaching implications for the rest of the world.

China's 13th Five-Year Plan declared 2016 to 2020 a "decisive battle period" for the nonferrous metal industry and for building a well-off society.[1] Its hallmark initiative, "Made in China 2025," aims to build strategic industries in national defense, science, and technology. To meet these objectives, in October 2016, the Ministry of Industry and Information Technology announced an action plan[2] for its metals industry to achieve world-power status: By deploying state-owned enterprises and private firms to resource-rich hot spots around the globe, China would develop and secure other countries' mineral reserves—including minerals in which China already holds a dominant position.

The timing could not have been better. The fall in metal commodities prices from 2011 to 2015 left many mining companies desperate for capital. Even the largest global players, such as Anglo American, had to slash their workforces and shed assets.[3,4] By directly acquiring mines, accumulating equity stakes in natural-resource companies, making long-term agreements to buy mines' current or future production (known as "off-take agreements"), and investing in new projects under development, Chinese firms traded much-needed capital for outright control or influence over large shares of the global production of these resources. Despite China's slowing growth and a

A Vast Sum of Parts *China's control or influence over critical minerals and metals that power modern technology is unrivaled.*



SOURCES: USGS; FPA ANALYSIS OF COMPANY FILINGS, DEAL FLOWS, EQUITY STAKES AND OFF-TAKE AGREEMENTS

major pullback in its foreign direct investment in other sectors, the government has maintained robust financial support for resource acquisition; mergers and acquisitions in metals and chemicals hit a record high in 2018.[5]

PART I

'Going Out and Bringing In'

Though it boasts a rich endowment of natural resources at home, China lacks significant reserves of three resources vital to its tech ambitions: cobalt, platinum-group metals, and lithium. It has successfully employed two strategies to secure control of them. One is driven by China's state-owned enterprises (SOEs), which use development finance and infrastructure investment to embed themselves in higher-risk countries, establishing close ties with government leaders. The second is investment by state-linked private firms in market-based economies. Both strategies have shown agility and an ability to effectively adapt to local circumstances to achieve the same end.

SOE Strategy, Cobalt, and the Case of the Democratic Republic of the Congo

With few governments having articulated, let alone implemented, an explicit resource strategy, China is more than a decade ahead in the game. At a gathering last June in

Lubumbashi, the mining capital of the Democratic Republic of Congo (DRC), representatives from 35 Chinese mining companies announced the creation of the Union of Mining Companies with Chinese Capital to coordinate communication with the DRC's government.[6] The announcement was less an inauguration than a formalization of the deep, long-term relationships between Chinese industry and DRC government officials that have been cultivated for decades: China now owns or has influence over half of the DRC's cobalt production,[7] and has a massive stake in its mining industry. Six months ahead of the presidential elections, the event also sent a strong message to candidates about China's deep investment in copper and cobalt mining—which constitutes 80 percent of the DRC's export revenue[8] and thousands of jobs—and its capacity to influence the future of the DRC's economy.

China's notably high tolerance for political and security risk and its ability to embed firms in the development of local industry have not only enabled Chinese SOEs to gain footholds in complex natural-resource markets, but given them a competitive edge over their rivals in the industry. Its patient acquisition of the DRC's cobalt resources serves as a case in point.

The DRC is home to nearly two-thirds of the world's cobalt production and half of its known reserves.[9] Those resources are the prime target of investors for the booming battery industry. Over a decade of steady engagement, China has staked out a dominant position by developing strong political ties and investing in production assets and related infrastructure. Using development financing, in 2007, the Export-Import Bank of China issued[10] $6 billion for infrastructure (a figure later reduced to $3 billion) and $3 billion for copper and cobalt mine development.[11] Projects were run by Sinohydro and China Railway Group in exchange for a 68 percent mineral stake in the Sicomines copper and cobalt mine, thought to be one of Africa's largest.[12] China deepened the DRC's reliance on Chinese capital by committing to finance the revitalization of the DRC's state-run company Gécamines,[13] strengthen the country's core industrial sector, and create needed jobs through additional sector investments.[14]

By targeting debt-stressed mining companies already established in the DRC, China's SOEs and private firms have secured equity shares and influence over a majority of its mines, including majority stakes in the Tenke Fungurume mine, which holds one of the world's largest, highest-grade deposits of copper and cobalt. China Molybdenum bought the majority stake (56 percent) from U.S. company Freeport-MacMoRan in 2016, and recently bought an additional 24 percent stake from Chinese private-equity firm BHR Partners.[15,16,17] Over time, China has secured ownership over 10 out of the DRC's 18 major operational mines, six major development projects, and a three-year off-take deal from the DRC's (and the world's) largest cobalt mine,[18] effectively establishing influence over 52 percent of the country's production.[19]

A worker watches a conveyor belt loaded with chunks of raw cobalt at a plant in Lubumbashi, the mining capital of the Democratic Republic of the Congo, on Feb. 16, 2018. SAMIR TOUNSI/AFP/GETTY IMAGES

Recognizing the continued demand from global industry, former President Kabila and DRC officials implemented a 50 percent tax on superprofits in a revised mining code,[20] creating even more uncertainty about the country's future cobalt production. Before leaving office, Kabila declared cobalt a "strategic" metal and tripled the royalty tax, to boost local governments' profit share from the sector.[21] Similar taxes are being considered in neighboring Zambia.

Despite the DRC's recent election and uncertainty about how the new president will engage with the mining industry, China and its local firms continue to reinforce their impact on the local economy and engage collectively with the DRC's political establishment. The recent formalization of the Union of Mining Companies with Chinese Capital has been set up to do just that.

Replicating the State-Owned Enterprise Model

China's SOE-driven strategy remains dominant throughout Africa, where adverse market sentiment and financial hardship in the mining industry have opened the door for SOE investment across the region. Notably, SOEs, in partnership with the China-Africa Development Fund, a Chinese state-funded institution, have expanded in South

Africa's Bushveld Complex,[22] a mineral-rich geological formation that contains the world's largest reserves of platinum-group metals[23]—critical for making catalytic converters, which are essential for reducing automobile emissions—and the world's highest-grade and third-largest deposit of vanadium, a resource integral to a broad range of high-tech industries, from renewable-energy storage to aerospace and defense.

By leveraging state resources, China's SOEs and private firms have made at least eight major equity and off-take plays in platinum-group metals in the Bushveld Complex.[24] Such investments in South Africa's highly concentrated and strategic resource deposits have helped make metals the country's leading source of export growth,[25] with nearly 50 percent of its metal exports going to China[26]—tying South Africa's economic welfare directly to Chinese investment.

Private Firms and the Extension of State Strategy Abroad

China is also proving agile at adapting to conditions in market-oriented, democratic countries, using privately owned companies that are backed by state capital. By incrementally acquiring equity stakes in major local resource companies and financing junior developers, Chinese firms are strengthening their market presence while overcoming local concerns about foreign control over strategic domestic resources, such as niobium in Brazil and tantalum in Australia.Nowhere is this privately driven resource strategy more evident than in the three countries where nearly 90 percent of global lithium production and more than three-quarters of the world's known lithium reserves are located: Chile, Argentina, and Australia.[27] In just six years, China has come to dominate the global market: More than 59 percent of the world's lithium resources are now under its control or influence.[28]

With the backing of state-owned banks, China's industrial chemical giants—Tianqi Lithium and Ganfeng Lithium—have become the world's third-largest producer of lithium[29] and third-largest producer of lithium chemical compounds,[30] respectively. The chairmen of both companies have risen within the ranks of Chinese politics over the past few years, just as China was beginning to prioritize securing supplies of rare metals. In 2013, Tianqi's chairman, Jiang Weiping, became a member of the Standing Committee of the Political Consultative Conference of Sichuan province,[31] and he was made a delegate to the National People's Congress in 2018.[32] Ganfeng's chairman, Li Liangbin, became a member of the Standing Committee of the 12th Political Consultative Conference of Jiangxi province in 2018.[33] These two companies, along with other Chinese firms, have expanded their investments and integrated operations in three distinct markets by acquiring a major stake in the leading producer in Chile, financing new development in Argentina, and acquiring mines and building up processing capacity in Australia.

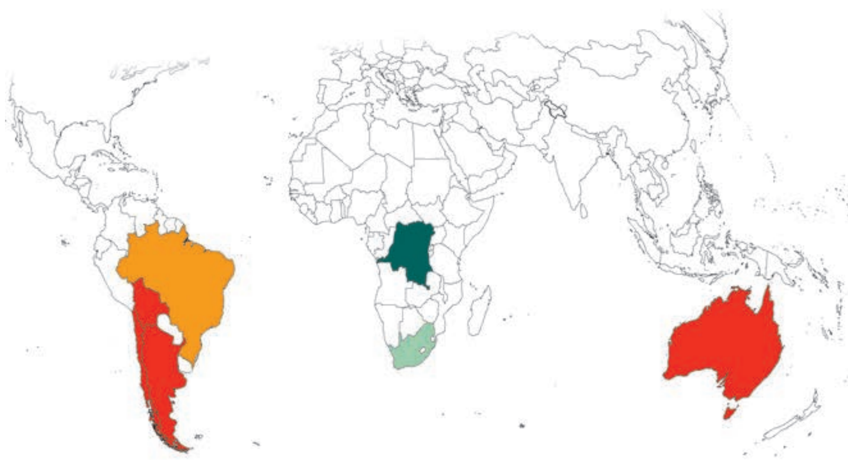
Growing Equity in Latin America's Lithium Leaders

In early 2018, Tianqi Lithium made a bold play to acquire a 24 percent stake in Chilean rival Sociedad Química y Minera (SQM), the world's second-largest lithium producer. Chile is home to 57 percent of the world's known lithium reserves,[34] the world's largest known concentration, and SQM controls roughly half the country's production. In the industry's biggest mergers-and-acquisitions deal to date, Tianqi made a $4.1-billion bid on SQM's shares, $3.5 billion of which was financed by China's CITIC Bank International,[35] whose parent company, CITIC Group, is among China's largest state-owned financial and industrial conglomerates.[36]

The Chilean government has traditionally held a relatively tight rein on its lithium resources, which have long been considered strategic for the nation's nuclear industry. The size of the deal with Tianqi heightened concerns in Chile over a foreign entity controlling those resources, and the potential for a cartel to form—spurring public opposition and antitrust and constitutional court challenges by SQM's majority shareholder. After months of legal battles and debate, the Constitutional Court of Chile dismissed the antitrust claims,[37] allowing Tianqi to secure the deal in December. Though the final agreement[38] included restrictions on Tianqi's board and committee participation and its access to SQM's sensitive data, Tianqi's equity position still confers considerable influence over SQM.

But the SQM deal is just one piece of a deepening economic relationship[39] with Chile, including Chinese investments in the local lithium industrial base, exports of electric buses to Chile, and an upgraded trade agreement between the two countries that just came into force in March 2019.[40] In April 2018, China's ambassador to Chile, Xu Bu, stated to local news outlets that opposition to the sale "could leave negative influences on the development

In just six years, China has come to dominate the global lithium market: More than 59 percent of the world's lithium resources are now under its control or influence.



Chinese Resource Strategy

China is securing minerals and metals for which it is net import reliant.

COBALT

Democratic Republic of the Congo

PRODUCTION: 61%

RESERVES: 49%

CHINA'S INFLUENCE: Influence over 52% of cobalt production with equity stakes and supply agreements

NIOBIUM

Brazil

PRODUCTION: 88%

RESERVES: 80%

CHINA'S INFLUENCE: Stakes in 100% production

PLATINUM GROUP METALS (PGMs)

South Africa

PRODUCTION: 54%

RESERVES: 91%

CHINA'S INFLUENCE: Stakes in ⅔ of all major PGM sites

LITHIUM

Argentina

PRODUCTION: 10%

RESERVES: 14%

CHINA'S INFLUENCE: Stakes in 41% of major planned projects accounting for 37% of reserves

Australia

PRODUCTION: 58%

RESERVES: 19%

CHINA'S INFLUENCE: Stakes in 61% of production

Bolivia

PRODUCTION: None

RESERVES: Believed to be among the world's largest

CHINA'S INFLUENCE: Stakes in 100% of development via an equity agreement

Chile

PRODUCTION: 21%

RESERVES: 57%

CHINA'S INFLUENCE: Stakes in 67% of Chile's output

PRODUCTION AND RESERVES FOR 2017. SOURCES: USGS; FPA ANALYSIS OF COMPANY FILINGS, DEAL FLOWS, EQUITY STAKES AND OFF-TAKE AGREEMENTS of economic and commercial relations between both countries,"[41] and has since reportedly made other economic threats.[42] Tianqi is now seeking permission to develop Salar de La Isla, Chile's second-largest lithium brine deposit,[43] in partnership with U.S.-based lithium company Albemarle, the other major player in Chile's lithium industry. Tianqi has the majority stake in the joint venture.[44]

Leveraging Capital Across Developing and Developed Markets

In a cash-strapped industry, Chinese firms are financing mine expansion and new development in exchange for a guaranteed supply of lithium in both mature and emerging markets. In Argentina, where President Mauricio Macri is eliminating mineral export taxes, reducing corporate tax rates, and allowing profit repatriation, China is establishing a dominant position in the nascent sector with "streaming deals," which provide development capital in exchange for future lithium yields to help projects get off the ground. Chinese firms, led by Ganfeng, have stakes in 41 percent of the country's major planned projects that account for 37 percent of Argentina's reserves.[45] This raw-material strategy is already coming to fruition: Lithium export volumes from Argentina to China rose nearly fourfold from 2015 to 2017,[46] and China has secured access to the country's lithium for the longer term.

This same strategy, combined with asset acquisition, has also been successful in Australia, whose proximity to China, significant lithium reserves, and broad political support for mining investment have attracted Chinese investment. Tianqi and Ganfeng have established stakes in 91 percent of the lithium mining projects underway and 75 percent of the country's reserves, including some of the world's largest.[47] By taking over Talison Lithium, Tianqi captured a majority stake in the Greenbushes mine, which accounts for roughly 40 percent of global lithium production.[48] Together, Chinese firms have secured deals with nine of the 11 major operations and projects in the pipeline in Australia, two-thirds of which are exclusive.[49]

Growing the Global Footprint

Having already consolidated control over global lithium supplies, Tianqi and Ganfeng are just getting started. Both filed for initial public offerings last fall with the intent to raise capital for further expansion. Ganfeng raised $421 million in its October 2018 initial public offering,[50] which included four state-linked cornerstone investors.[51] Last November, Tianqi received the necessary approvals from the China Securities Regulatory Commission to prepare for its Hong Kong listing,[52] the proceeds from which will be deployed in global markets.

PART 2

China Reinforcing Its Resource Dominance

China is also making moves to take an even stronger position in resources it already controls on the global market. Natural resources are abundant in China; it is the No. 1 producer and processor of at least ten critical minerals and metals[53, 54] that are essential to high-tech industries and upon which China's commercial and strategic competitors depend. To reinforce its strength, Chinese firms are acquiring mines and output from the next-largest producers and reserves, giving China both an economic edge in the next high-tech industrial revolution and increasing geopolitical power.

Perhaps the best-known example both of China's natural-resource dominance and its willingness to exploit it is rare-earth elements, a group of 17 elements that (despite their name) are commonly found, but rarely in concentrations that can be economically extracted. They are important materials for the defense, aerospace, electronics, and renewable energy industries. Over the past two decades China has produced more than 80 percent of the world's production of rare-earth elements and processed chemicals.[55] In 2010 it cut off exports to Japan[56] amid rising tensions over the East China Sea, and the following year it imposed export quotas[57] that threw governments and manufacturers into a panic.[58] But with the exception of Japan, the attention to this critical vulnerability was short-lived, and little action was taken by other countries reliant on imports to diversify their resources or develop minerals action plans of their own.

China declared rare-earth elements a strategic resource in 1990 and prohibited foreign investment in the sector.[59] Six state-owned enterprises control the industry, and the government cut production quotas in 2018 by 36 percent.[60] With global demand for rare-earth elements projected at a compound average growth rate of more than 17 percent to 2025,[61] a supply crunch is likely approaching—and China is already securing other nations' supplies.

Chinese firms have been increasing stakes in mines and securing off-take deals from the world's largest deposits of rare-earth elements. While Russia strictly limits foreign participation in rare-earth element development, Chinese firms have accumulated off-take agreements and stakes in rare-earth element mines in Australia and Brazil. Though Australia's Foreign Investment Review Board denied a 2009 takeover of Australian company Lynas' mine at Mount Weld,[62] the second-largest rare-earth element oxide producer outside China, Chinese firms have locked in output from the site.[63] Northern Minerals, owned by Chinese firms,[64] is also developing Australia's other major rare-earth elements site, Browns Range; 100 percent of the mine's dysprosium, an element used in magnets and superalloys, will go to China's Lianyungang Zeyu New Materials Sales Co. Ltd.[65]

And in the United States in 2017, China's Shenghe Resources and two U.S. private equity firms acquired the sole U.S. and North American rare-earth element producer and processor, Molycorp, and its idled mining operations at Mountain Pass, California.[66] The operation went bankrupt in 2015 due in large part to low prices for Chinese supplies of rare-earth elements, and its sale briefly spurred debate over whether the deal posed risks to national security,[67] but opponents could not make the legal case to block it. Shenghe holds rights to the mine's output; meanwhile the United States' rare-earth element imports continue to increase, at a cost of $160 million in 2018 alone.[68] Though President Donald Trump has since called for a defense review and assessment of critical minerals, the Committee on Foreign Investment in the United States has not taken further action on the site. Meanwhile, Shenghe and its subsidiaries are continuing to expand internationally, with a major joint-venture development project in rare-earth elements now underway in Greenland.[69,70] China's decades-long consolidation of strategic resources has only compounded its commercial and geopolitical capabilities, and it shows no sign of slowing down.

Vanadium and Graphite

China is also seeking to expand its dominant market position in vanadium and graphite, securing additional supplies and building integrated supply chains. Vanadium is a transition metal that is used in flow batteries, superconducting magnets, and high-strength alloys for jet engines and high-speed aircraft. Chinese firms already produce 56 percent of the world's vanadium domestically, and China is home to 48 percent of the world's reserves.[71] Now, they are targeting South Africa, ranked third in vanadium production and reserves behind China and Russia.[72]

In 2015, Hong Kong-based International Resources Ltd., a company whose ownership is opaque, executed a takeover of a major vanadium mine from Russia's Evraz Highveld Steel and Vanadium, which was facing bankruptcy.[73] In 2016, China's Yellow Dragon Holdings Ltd. co-invested with Bushveld Minerals, the primary vanadium developer in South Africa's massive Bushveld Complex, to acquire Strategic Minerals, which owned the Vametco vanadium mine and plant.[74] Yellow Dragon subsequently increased its investment in Bushveld Minerals and has become the fifth-largest shareholder.[75] The holdings deepen China's influence over South Africa's vanadium resources and its role in the country's emerging high-tech sector. Bushveld

A worker walks across the Jin Yang graphite factory in the town of Mashan, China, on May 28, 2016. MICHAEL ROBINSON CHAVEZ/THE WASHINGTON POST VIA GETTY IMAGES

Minerals is moving to develop an integrated platform to produce vanadium redox flow batteries for distributed energy across South Africa.[76] The vanadium resources will also flow toward China, feeding its battery industry and the National Development and Reform Commission's planned rollout of 100-megawatt stationary energy storage stations to manage its wind and solar energy.[77]

China's position is even stronger in graphite, a crystalline form of the element carbon whose high conductivity makes it a major component in electrodes, batteries, and solar panels, as well as industrial products such as steel and composites. For the last 20 years, China has been the leading global supplier of graphite, representing nearly 70 percent of the world's production in 2018 and 24 percent of its reserves.[78] While synthetic graphite, which is produced from petroleum coke, is an alternative, unfavorable economics constrain its use.

Rapidly growing demand for batteries and other end uses, coupled with environmental restrictions in China, are driving prices higher and stimulating investment. New projects are concentrated in Mozambique, where the world's largest graphite mine and fourth-largest known reserves are located.[79] Already, Chinese firms have secured off-take agreements with the three major developers in Mozambique for the majority of their graphite production,[80,81] and they are financing new development.[82]

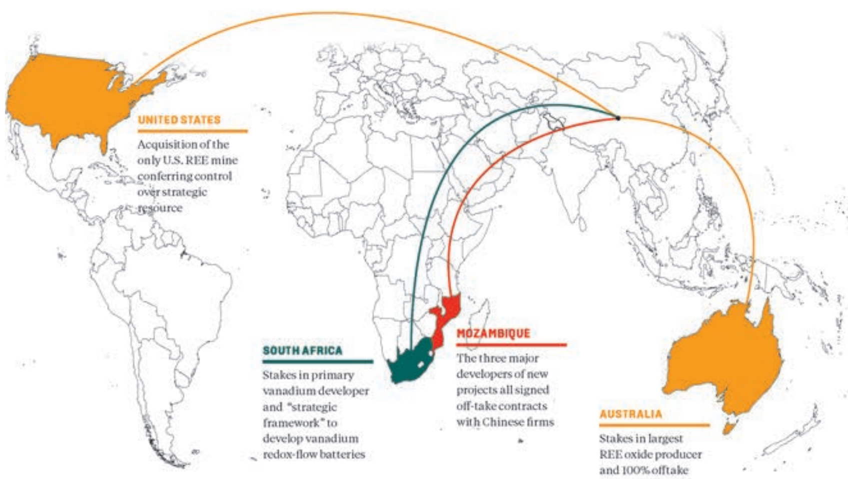
Now that it controls most of the world's graphite, China has expanded down the supply chain, becoming the world's

Building on Domestic Resource Dominance

China is supplementing its own supplies with investments abroad.

DOMESTIC PRODUCTION AND RESERVES

GRAPHITE		RARE EARTH ELEMENTS		VANADIUM	
70%	24%	80%	37%	56%	48%
PRODUCTION	RESERVES	PRODUCTION	RESERVES	PRODUCTION	RESERVES



PRODUCTION AND RESERVES FOR 2017. SOURCES: USGS; FPA ANALYSIS OF COMPANY FILINGS, DEAL FLOWS, EQUITY STAKES AND OFF-TAKE AGREEMENTS leading producer of anodes, positively charged electrodes that are essential for making lithium-ion batteries. That industry is also highly concentrated: China's Shenzhen BTR New Energy Materials accounts for roughly 70 percent of global anode production.[83] The next-largest player is Japan's Hitachi Chemical, at 20 percent;[84] Japan is 90 percent reliant on China for its graphite.[85] China is channeling increasing volumes of graphite toward its booming domestic battery and new electric-vehicle industries, stockpiling domestic production and reducing graphite exports, which could result in a supply crunch for other end users. In 2016, China consumed 35 percent of the world's graphite production.[86]

PART 3

Controlling the Fuel of the Future

This resource consolidation could determine whether China is able to overcome the last major hurdle to achieving its ambitions: a competitive semiconductor industry. The lifeblood of high-tech industries, semiconductors are made of the very minerals and metals over which China is securing control. Semiconductors can be pure elements or compounds and altered with impurities to improve their conductivity. Several materials are now being used to improve speed and performance, including rare-earth elements, graphite, indium, gallium, tantalum, and cadmium. China is the dominant producer of five out of the six, controls more than 75 percent of the world's supply of three,[87] and is consolidating control over them all.

However, China still lacks the technological capability to produce semiconductors on par with the industry's leading companies and remains highly dependent on imports, at a cost of roughly $260 billion per year.[88] The government is keenly focused on ending its dependency by acquiring the technological expertise to surpass its rivals. It poured nearly $20 billion into highly targeted research and development to that end from 2014 to 2017,[89] and it is only intensifying its focus.

Should China succeed technologically, its capacity to scale production and flood markets (as it has already done with solar panels and wind turbines) has serious implications not only for leading semiconductor producers, but also for national security, if Chinese-manufactured chips are embedded in the devices upon which our data-driven lives, our economies, and our defense systems increasingly depend. While government and industry officials have started to restrict semiconductor sales and scrutinize Chinese acquisition of technology firms—e.g., the United States' temporary ban on selling semiconductors to ZTE, or the recent flare-up over Huawei—such moves are strengthening China's resolve to develop its domestic industry. More attention should be paid to its efforts to consolidate critical raw materials and the computing power they confer.

This is not a foregone conclusion. It will, however, require us to fundamentally rethink how we understand strategic industries and the long-term investments needed to ensure economic prosperity and national security in the digital age. Some countries are waking up to these strategic vulnerabilities and starting to act on them. In April, U.S. government officials announced plans to meet with lithium industry leaders and automakers with the intention of developing a national electric-vehicle supply chain strategy. It is a start.

FP ANALYTICS

This report was produced by FP Anayltics, the research division of the FP Group. Access it online at ForeignPolicy.com/miningthefuture (requires subscription).

Endnotes

[1] Ministry of Industry and Information Technology of the People's Republic of China, "Nonferrous Metal Industry Development Plan 2016-2020," October 2016, http://www.miit.gov.cn/n1146290/n4388791/c5288773/content.html.

[2] Ministry of Industry and Information Technology of the People's Republic of China, "Nonferrous Metal Industry Development Plan 2016-2020," October 2016, http://www.miit.gov.cn/n1146290/n4388791/c5288773/content.html.

[3] "Annual Report 2015: Driving Change, Defining our Future," Anglo American, https://www.angloamerican.com/~/media/Files/A/Anglo-American-PLC-V2/documents/aa-ar-15.pdf.

[4] Peter Koven, "Anglo American's massive restructuring involving 85,000 layoffs shows miners bracing for prolonged downturn," Financial Post, Dec. 8, 2015, https://business.financialpost.com/commodities/mining/anglo-american-to-cut-85000-workers-sell-60-of-its-assets-and-suspend-dividend.

[5] "PwC M&A 2018 Mid-Year Review and Outlook," PricewaterhouseCoopers, https://www.pwccn.com/en/deals/publications/ma-2018-mid-year-review-and-outlook.pdf.

[6] William Clowes, "China Marks Cobalt, Copper Ascendancy in Congo With New Group," Bloomberg, June 18, 2018, https://www.bloomberg.com/news/articles/2018-06-18/china-marks-cobalt-copper-ascendancy-in-congo-with-new-group.

[7] FP Analytics analysis.

[8] "The World Bank in DRC," The World Bank, May 16, 2018, https://www.worldbank.org/en/country/drc/overview.

[9] "BP Statistical Review of World Energy," BP, June 2018, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.

[10] "Accord Protocol," Ministry of Infrastructure, Public Works and Reconstruction, Democratic Republic of Congo, Sep. 17, 2007, http://congomines.org/system/attachments/assets/000/000/274/original/B8-Sicomines-2007-ProtocoleDAccordConsortiumEntreprisesChinoises-RDC.pdf?1430928299.

[11] Martyn Davies, "How China is Influencing Africa's Development," OECD Development Centre, April 2010, https://www.oecd.org/dev/pgd/45068325.pdf.

[12] David G. Landry, "Sicomines: A Resource-for-Infrastructure Case Study," China Africa Research Initiative, Johns Hopkins University School of Advanced International Studies, March 1, 2017, https://static1.squarespace.com/static/526eec2ce4b0178a935d2104/t/58bddf5e9f745699f218aa48/1488838500718/NRGI+Blog+-+Sicomines+A+Resource+for+Infrastructure+Case+Study+(David+G.+Landry).pdf.

[13] "Announcement on Investment in PE527 Copper-Cobalt Project in Congo-Kinshasa," Zhejiang Huayou Cobalt, March 15, 2018, http://www.huayou.com/downloadRepository/61e1b228-ac24-4c2d-8a64-494595c3debe.pdf.

[14] "Announcement: Proposed Acquisition of 51% Shareholding in La Compagnie Minière de Musonoie Global SAS," Zijin Mining Group, http://www.zijinmining.com/Portals/1/LTN201411032180.pdf.

[15] "2017 Annual Report," China Molybdenum, http://www.chinamoly.com/06invest/DOC/2018/E_03993_04207.pdf.

[16] Siyamend Al Barazi et al., "Cobalt from the DR Congo – Potential, Risks and Significance for the Global Cobalt Market," July 2017, https://www.researchgate.net/publication/326060301_COBALT_FROM_THE_DR_CONGO_-_POTENTIAL_RISKS_AND_SIGNIFICANCE_FOR_THE_GLOBAL_COBALT_MARKET_1_Commodity_Top_News_53.

[17] Cecilia Jamasmie, "China Moly ups stake in giant Tenke copper mine to 80%," Mining, Jan. 18, 2019, http://www.mining.com/china-moly-ups-stake-giant-tenke-copper-mine-80/.

[18] "GEM Announcement Regarding Strategic Purchase Agreement for Cobalt and Raw Materials for Batteries," Shenzhen Stock Exchange, March 15, 2018, http://www.szse.cn/disclosure/listed/bulletinDetail/index.html?415fcfb8-75e4-4ee8-8283-237d8a31c727.

[19] FP Analytics analysis.

[20] "A new mining code for the DRC," DLA Piper, August 10, 2018, https://www.dlapiper.com/en/morocco/insights/publications/2018/08/democratic-republic-of-congo-mining-code/.

[21] "Congo declares battery metal cobalt 'strategic' in move that triples royalties," Financial Times, Dec. 3, 2018. https://www.ft.com/content/382c3d24-f726-11e8-8b7c-6fa24bd5409c.

[22] Zhen Han, "China's Current Involvement in Mining in Africa," Mining Journal, Jan. 19, 2016, https://s3.amazonaws.com/documents.lexology.com/efec9be3-a177-43e6-97e4-24e64ac6ef41.pdf.

[23] "Mineral Commodities Summaries: Platinum-Group Metals," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/commodity/platinum/mcs-2019-plati.pdf.

[24] FP Analytics analysis.

[25] "Statistical Release P0441: Gross Domestic Product, Fourth quarter 2017," Statistics South Africa, June 5, 2018, http://www.dmr.gov.za/Portals/0/files/P04414thQuarter2017(1).pdf?ver=2018-03-09-063718-170.

[26] "South Africa Minerals Exports By Country 2017," World Integrated Trade Solution (WITS), The World Bank, https://wits.worldbank.org/CountryProfile/en/Country/ZAF/Year/LTST/TradeFlow/Export/Partner/by-country/Product/25-26_Minerals.

[27] "BP Statistical Review of World Energy," BP, June 2018, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.

[28] FP Analytics analysis.

[29] Tianqi Lithium, http://en.tianqilithium.com.

[30] Ganfeng Lithium, http://www.ganfenglithium.com/about_en.html.

[31] "List of members of the Standing Committee of the 11th Political Consultative Conference of Sichuan Province," The People's Government of Sichuan Province, Jan. 9, 2013, http://www.sc.gov.cn/10462/10464/10797/2013/1/9/10243666.shtml.

[32] "Sichuan Province People's Congress Announcement (No. 1)," People.cn, Feb. 1, 2018, http://sc.people.com.cn/n2/2018/0201/c345514-31206075.html.

[33] "The 2018 list of representatives of the 'two sessions' of Jiangxi Province was announced!" Jan. 18, 2018, https://baijiahao.baidu.com/s?id=1589931694452543678&wfr=spider&for=pc.

[34] Mineral Commodities Summaries," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf.

[35] "Tianqi Lithium Industry Co., Ltd.'s Announcement on Its Reply to the Shenzhen Stock Exchange's Restructuring Inquiry, June 20, 2018," http://www.szse.cn/disclosure/listed/bulletinDetail/index.html?0a2b7923-9c60-4893-84b3-2423db4c6549.

[36] CITIC Group Corporation of Beijing was founded by Rong Yiren, vice president of China from 1993 to 1998 and known as "the Red Capitalist."

[37] "Tianqi and Nutrien Comment on Chilean Constitutional Court Ruling," BNamericas, October 26, 2018, https://subscriber.bnamericas.com/en/news/miningandmetals/tianqi-and-nutrien-comment-on-chilean-constitutional-court-ruling?position=1&aut=true&idioma=en.

[38] Fabian Cambero, "China's Tianqi agrees truce in battle over Chilean lithium miner SQM," Reuters, April 11, 2019, https://www.reuters.com/article/us-sqm-tianqi-lithium/chinas-tianqi-agrees-truce-in-battle-over-chilean-lithium-miner-sqm-idUSKCN1RN2B0.

[39] Jeppe Saarinen, "China-Chile FTA Upgraded, New Opportunities for Investors," China Briefing, March 4, 2019, https://www.china-briefing.com/news/china-chile-fta-upgraded-market-opportunities-investors/.

[40] "China-Chile Free Trade Agreement Upgrade Protocol enters into force today," Ministry of Commerce of the People's Republic of China, March 1, 2019, http://www.mofcom.gov.cn/article/ae/ai/201903/20190302839160.shtml.

[41] "China warns Chile against blocking $5bn SQM lithium deal," Financial Times, April 26, 2018, https://www.ft.com/content/238bda20-48b0-11e8-8ee8-cae73aab7ccb.

[42] "The China lobby: How the Asian country deploys its influence in the Chilean Congress," La Tercera, Nov. 7, 2018, https://www.latercera.com/la-tercera-pm/noticia/un-lobby-chino-como-el-pais-asiatico-despliega-su-influencia-en-el-congreso-chileno/391266/.

[43] "Lithium Report 2018," Swiss Resource Capital, http://www.advantagelithium.com/resources/pdf/en_Doppelseite_Lithium_2018.pdf.

[44] Tianqi is seeking permission to develop Salar de La Isla through its joint venture partnership, Talison, with U.S.-based lithium company Albemarle, the other major player in Chile; Tianqi has the majority stake in Talison and the joint venture has a 50 percent stake in the play. The partners are also working with Canada-based Wealth Minerals, which holds the other 50 percent stake.

[45] FP Analytics analysis.

[46] United Nations Comtrade Database, accessed Feb. 6, 2019, https://comtrade.un.org.

[47] FP Analytics analysis.

[48] "Greenbushes project – Western Australia," Lithium Australia, https://lithium-au.com/greenbushes/.

[49] FP Analytics analysis.

[50] Kristian John Dayrit, "Report: Ganfeng Lithium prices Hong Kong IPO at US$421M," S&P Global Market Intelligence, https://www.spglobal.com/marketintelligence/en/news-insights/trending/ijk96vubsklahzczse0lvq2.

[51] Ganfeng IPO Prospectus, p. 266-267, http://www3.hkexnews.hk/listedco/listconews/sehk/2018/0927/ltn20180927025.pdf.

[52] "Tianqi Lithium Gets Securities Regulator Approval To Issue Offshore Shares, List in Hong Kong," Reuters, Nov. 8, 2018, https://www.reuters.com/finance/stocks/002466ta.SZ/key-developments/article/3934258.

[53] "Mineral Commodities Summaries," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/mcs/.

[54] The definition of "critical" or "strategic" and the exact list of minerals, metals, or materials varies by jurisdiction, but a literature review of major studies assessing "criticality" identifies the resources most commonly categorized and cited in official documents. China is the leading global producer of the majority of those listed, including natural graphite, rare-earth elements, vanadium, indium, tungsten, gallium, antimony, tellurium, cadmium, and molybdenum. Also see: https://www.sciencedirect.com/science/article/pii/S0301420718301296?via%3Dihub.

[55] U.S. Geological Survey annual commodity data.

[56] Keith Bradsher, "Amid Tension, China Blocks Vital Exports to Japan," The New York Times, Sep. 22, 2010, https://www.nytimes.com/2010/09/23/business/global/23rare.html.

[57] Nabeel A. Mancheri, "China's export restrictions on rare earths," East Asia Forum, Oct. 6, 2011, https://www.eastasiaforum.org/2011/10/06/china-s-export-restrictions-on-rare-earths/.

[58] "China's cut to rare earth output unnerves global manufacturers," Reuters/The Japan Times, https://www.japantimes.co.jp/news/2018/10/25/business/china-cutting-rare-earth-output-unnerving-global-manufacturers/#.XLDqJetKjGI.

[59] Pui-Kwan Tse, "China's Rare-Earth Industry: Open-File Report 2011-1042," U.S. Geological Survey, https://pubs.usgs.gov/of/2011/1042/of2011-1042.pdf.

[60] "Barbara Lewis and Ernest Scheyder, "China cutting rare earth output, unnerving global manufacturers," Reuters, Oct. 24, 2018, https://www.reuters.com/article/us-china-rareearths/china-cutting-rare-earth-output-unnerving-global-manufacturers-idUSKCN1MY2GZ.

[61] "United States Securities and Exchange Commission Form 10-K: Rare Element Resources Ltd.," fiscal year ended Dec. 31, 2017, http://www.rareelementresources.com/docs/default-source/financial-reports/p05218_rare-element-resources_2018_10k_v2.pdf?sfvrsn=0.

[62] "Australia blocked China investment on supply concerns," The Sydney Morning Herald, Feb. 15, 2011, https://www.smh.com.au/business/australia-blocked-china-investment-on-supply-concerns-20110215-1au8x.html.

[63] "2018 Annual Report," Lynas Corporation, https://www.lynascorp.com/Pages/Reporting-centre-Annual-report.aspx.

[64] Conglin Investment Group, accessed March 2019, http://www.conglingroup.com.au/profile.html.

[65] Christopher Ecclestone, "Northern Minerals Strategy: Long," Hallgarten & Company, Feb. 7, 2018, http://northernminerals.com.au/wp-content/uploads/2018/02/NTU_Hallgarten-Feb2018.pdf.

[66] "Rare Earths: Mountain Pass sold to Chinese-led consortium," Roskill, June 21, 2017, https://roskill.com/news/rare-earths-mountain-pass-sold-chinese-led-consortium/.

[67] "Rare-earth rancor: Feds must stop Chinese purchase of US mine," The Hill, June 26, 2017, https://thehill.com/blogs/pundits-blog/economy-budget/339528-Rare-earth-rancor%3A-Feds-must-stop-Chinese-purchase-of-US-mine.

[68] "Mineral Commodities Summaries: Rare Earths," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/mcs-2019-raree.pdf.

[69] "New Chinese JV for rare earth minerals from Greenland," World Nuclear News, Jan. 23, 2019, http://www.world-nuclear-news.org/Articles/New-Chinese-JV-for-rare-earth-minerals-from.

[70] "2017 Annual Report: Materials for an Energy Efficient Future," Greenland Minerals and Energy, http://www.ggg.gl/assets/Uploads/Annual-Reports/43ab98ed04/2017-Annual-Report.pdf.

[71] "Mineral Commodities Summaries 2019," U.S. Geological Survey, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf.

[72] Ibid.

[73] Terence Creamer, "Hong Kong resources group named as winning Highveld bidder," Mining Weekly, http://www.miningweekly.com/article/hong-kong-resources-group-named-as-winning-highveld-bidder-2015-09-16/rep_id:3650.

[74] "Bushveld Gets USD5.2 Million for Strategic Minerals Acquisition," Morningstar, June 3, 2016, http://www.morningstar.co.uk/uk/news/AN_1464938425301552800/bushveld-gets-usd52-million-for-strategic-minerals-acquisition-(alliss).aspx; In 2017, Bushveld Minerals moved to acquire Yellow Dragon Holding's shares of Bushveld Vametco in exchange for 9.24% of the larger integrated Bushveld Minerals resource platform, with businesses in vanadium, tin, coal and power. "Bushveld Minerals acquisition of Bushveld Vametco Limited," Bushveld Minerals, December 2017, http://www.bushveldminerals.com/wp-content/uploads/2017/12/Bushveld-Minerals-acquisition-of-Bushveld-Vametco-Limited_Final.pdf.

[75] Bushveld Minerals Capital Structure Shareholder Information, March 29, 2019, http://www.bushveldminerals.com/capital-structure-shareholder-information/.

[76] "Bushveld Minerals: Right commodity, right asset, right time," Alternate Resource Capital, March 1, 2018, http://www.bushveldminerals.com/wp-content/uploads/2018/03/BMN_010318.pdf.

[77] "Bushveld Minerals acquisition of Bushveld Vametco Limited," Bushveld Minerals, December 2017, http://www.bushveldminerals.com/wp-content/uploads/2017/12/Bushveld-Minerals-acquisition-of-Bushveld-Vametco-Limited_Final.pdf.

[78] "Mineral Commodities Summaries: Graphite (Natural)," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/commodity/graphite/mcs-2019-graph.pdf.

[79] Mozambique has the fourth highest reserves at 17 million tons, tied with Tanzania which also as 17 million tons of estimated reserves. "Mineral Commodities Summaries: Graphite (Natural)," U.S. Geological Survey, 2019, https://minerals.usgs.gov/minerals/pubs/commodity/graphite/mcs-2019-graph.pdf.

[80] "Battery Minerals secures fourth offtake deal for Mozambique graphite," Small Caps, Jan. 22, 2018, https://smallcaps.com.au/battery-minerals-fourth-offtake-deal-mozambique-graphite/.

[81] "Triton cements second major graphite supply deal with China; shares gain," Stockhead, May 10, 2018, https://stockhead.com.au/special-report/triton-cements-second-major-graphite-supply-deal-with-china/.

[82] "Mozambique: Triton signs MoU for Ancuabe development," The Mozambique Resources Post, March 15, 2019, https://mozambiqueminingpost.com/2019/03/15/mozambique-triton-signs-mou-for-ancuabe-development/.

[83] "Batteries: POSCO begins aggressive lithium-ion battery anode materials expansion," Roskill, Nov. 15, 2018, https://roskill.com/news/batteries-posco-begins-aggressive-lithium-ion-battery-anode-materials-expansion/.

[84] Ibid.

[85] United Nations Comtrade Database, https://comtrade.un.org/data/.

[86] "Mineral Commodities Summaries: Graphite (Natural)," U.S. Geological Survey, 2017, https://minerals.usgs.gov/minerals/pubs/commodity/graphite/mcs-2017-graph.pdf.

[87] "Mineral Commodities Summaries 2019" U.S. Geological Survey, https://minerals.usgs.gov/minerals/pubs/mcs/2019/mcs2019.pdf.

[88] Shunsuke Tabeta, "Chinese companies rush to make own chips as trade war bites," Nikkei Asian Review, Nov. 7, 2018, https://asia.nikkei.com/Business/China-tech/Chinese-companies-rush-to-make-own-chips-as-trade-war-bites.

[89] E. Jan Vardaman, "Semiconductor Industry in China," TechSearch International, 2017, https://forums.ni.com/t5/NI-Test-Leadership-Council-Forum/TLF-2017-Presentation-The-Semiconductor-Industry-in-China-Supply/gpm-p/3785289?profile.language=en.

FP

FOREIGNPOLICY.COM

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: *The Sourcing and Use of Minerals Needed for Clean Energy Technologies*
Questions for the Record Submitted to Mr. W. Robert Kang

Question from Chairman Lisa Murkowski

Question: In your testimony before the Committee, you stated that recycling can meet 20-30 percent of the world's mineral needs. What are the options for meeting the remaining 70 percent?

Answer:
Other than recycling spent li-ion batteries and the waste streams from the li-ion battery manufacturing process, considerable additional sources of cobalt, nickel, and lithium will be needed to meet the demand for new li-ion battery manufacturing worldwide. This demand will likely need to be met from mined material or from existing stockpiles of minerals maintained as strategic reserves.

Question from Ranking Member Joe Manchin III

Question: There are plenty of opportunities to harvest minerals from end-of-life products, and not just from electric vehicles. Can you please speak to opportunities for innovation that will help improve mineral recycling rates across industries?

Answer:
There is significant opportunity to improve collection and recycling of spent li-ion batteries. We offer the following suggestions for opportunities to improve mineral recycling rates.

First, establish financial incentives to create an economically viable market for li-ion battery recycling. Recycling is a nascent industry, with numerous processing technologies used and variability and uncertainty in cost of processing and future transportation costs. Economic viability of recycling li-ion batteries is linked to volatile commodity mineral prices. In addition, there are a number of stages in the recycling process. Consumers or businesses collect spent li-ion batteries for recycling. Collectors obtain the batteries from consumers or businesses. Processors purchase or receive batteries from collectors for recycling and sell mineral products to refineries or other steps in the li-ion battery supply chain. Government or industry incentives provided to each stage of this recycling supply chain would help to secure the economic viability of recycling.

Second, public education regarding the value of recycling li-ion batteries and the ways in which material can be effectively recycled can also play a large role in increasing mineral recycling rates. We encourage this Committee to consider how public campaigns or incentives for state-funded public education campaigns that describe the value of the material available for recycling and provide resources to assist in collecting those batteries may help to grow our collection and recycling rates.

Third, building infrastructure for collection efforts would also improve mineral recycling rates. Curbside recycling programs have proven the most effective yet no reliable curbside collection efforts have been undertaken to recycle electronics and li-ion batteries. Developments in technology for safe transport of li-ion batteries, which have a risk of thermal event, make curbside recycling programs possible today. Further investigation and investment in such programs would likely increase the collection of material for recycling. We are working to explore this option with state and local governments.

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: *The Sourcing and Use of Minerals Needed for Clean Energy Technologies*
Questions for the Record Submitted to Mr. W. Robert Kang

Lastly, providing incentives to increase U.S. processing capability will also spur investment in the li-ion recycling sector and assist in establishing demand for the collection of batteries for collection and recycling.

Questions from Senator Mazie K. Hirono

Questions: Your testimony discusses how recycling is one solution to accessing reliable and sustainable sources of critical minerals and the importance of changing consumer behavior. When a consumer purchases an iPhone or buys an electric car, there is no effort to educate them on the mineral components of that product or opportunities to recycle. What suggestions do you have for educating the public on sourcing and recycling? Is there an opportunity to label products that contain sustainably sourced, recycled minerals, such as a government-backed program like the Energy Star label for energy efficient products?

Answer:
Educating consumers on the mineral content of the electronics they purchase and the benefits of recycling would likely increase collection and recycling of li-ion batteries. Manufacturers are relatively protective of the chemical content of their batteries so publishing detailed information about battery composition may put manufacturers are competitive disadvantages that could have unintended consequences. Labeling batteries with the chemistry and chemical makeup (i.e. content of recyclable metals such as cobalt and nickel), even if provided in broad ranges, would increase the efficiency of the sorting and recycling process and would allow collectors to better value their feedstock. There have been examples of battery manufacturers touting the use of recycled material in their products. The Energizer Eco Advance alkaline battery is one such example. Incentives to manufacturers to identify the use of recycled material in their batteries would be a positive step towards encouraging increase recycling and the reduction of our reliance on minerals mined in places like the Democratic Republic of Congo, where most of the world's cobalt is currently sourced. Government backing for a certifying entity to communicate the level of recycled material in a product is also a positive step towards consumer education regarding the benefits of recycling products. We would support such an effort.

U.S. Senate Committee on Energy and Natural Resources
September 17, 2019 Hearing: *The Sourcing and Use of Minerals Needed for Clean Energy Technologies*
Questions for the Record Submitted to Mr. Mark Mills

Questions from Ranking Member Joe Manchin III

Question 1: In your testimony you noted the amount of material that must be processed to obtain the minerals needed to build a battery for an electric vehicle. Specifically, you said 500,000 pounds of materials need to be mined and processed for one battery.

Please elaborate on the processing requirements needed for the metals that are utilized in electric vehicles batteries.

> **Answer:** Yes, a single battery weighing 1,000 pounds (typical in a Tesla for example) entails by my estimate moving/mining/processing approximately 500,000 pounds of material. This refers specifically to two key factors.
>
> First is the ore grade (pounds of the target mineral per pound of ore) which of course varies widely for different minerals. Thus it is obvious if one is mining copper where the ore grade is 1%, 100 pounds of ore is mined per pound of copper put in a battery. The actual number will be higher than the ore grade suggests because of inefficiencies in ore extraction of course. But I used average ore grades without adjustment for the various minerals in a battery. Others include cobalt, nickel, graphite, aluminum, steel, lithium, etc.
>
> Second, for all mines there is an overburden – material that must be dug up and removed in ore to access the ore body itself. The tonnage of overburden per ton of ore varies widely. I used an average number of 7 tons of overburden per ton of ore accessed.
> The quantities of minerals in a battery are widely reported: for example a 50 kWh battery typically has 40 kg of lithium, and so forth.

Question 2: How does the size of the deposit, the grade or concentration, impact the amount of tonnage that is processed?

> **Answer:** The size of a deposit does not enter into the calculation. The quantity of material is entirely dominated by ore grade and overburden. There are of course other materials that should be added to this equation, notably the tonnage (per unit of ore processed) of chemicals used to dissolve ore and extract/process the minerals. In some case, steel in particular, one should count the tonnage of metallurgical coal used (I did not) – this turns out to be significant since so much coal is electrochemically required (i.e., not used for heat/energy).

AML

1604 S Harbor City Blvd.
Melbourne, FL 32901
321.728.7543
www.AML-Enabled.com

Senator Lisa Murkowski, Chairman
U.S. Senate Committee on Energy and Natural Resources

Topic: **Sourcing and use of minerals for clean energy technologies**

The Advanced Magnet Lab, Inc, (AML) is a recognized leader in the development of magnet-based technologies that address products and solutions for energy, transportation, medical, and research.

Globally, virtually all manufacturers of purely fossil fuel-powered engines, are transitioning to hybrid or fully electric engines. Not only electric cars and trucks, almost all forms of transportation, manned or unmanned - land, air and sea - are going electric. All of these vehicles require electric motors for propulsion. Furthermore, the electricity required to charge these vehicles is more and more dependent on wind turbine generators.

Permanent magnets made from Rare Earth materials are the heart of motors and generators – and they drive energy production and e-mobility. As a result, demand for the type of magnet that allows this, one made of Rare Earth Elements (Rare Earths), will grow exponentially.

Permanent magnets currently represent the largest group in Rare Earths consumption, close to 25% of Rare Earths used worldwide.

Currently, the only practical supply of Rare Earths and permanent magnets is through parts of East Asia, notably China. This dilemma presents an unsustainable solution for the businesses and federally funded agencies (i.e. Department of Energy and Department of Defense) in the United States.

For example, China has time and time again proven that it has no regard for the needs of the consumer of Rare Earths. This is evidenced through a history of market manipulation and control along with an economically adversarial relationship with the U.S. Further, Rare Earths and magnets are a major component of the current of trade war with China.

At the end of July 2019, the White House invoked the Defense Production Act of 1950, a Presidential Determination, for the domestic supply of **Rare Earth materials** and the production capability for **Permanent Magnets** as ESSENTIAL TO NATIONAL DEFENSE. Addressing the threat on U.S. National Security is a focus for AML.

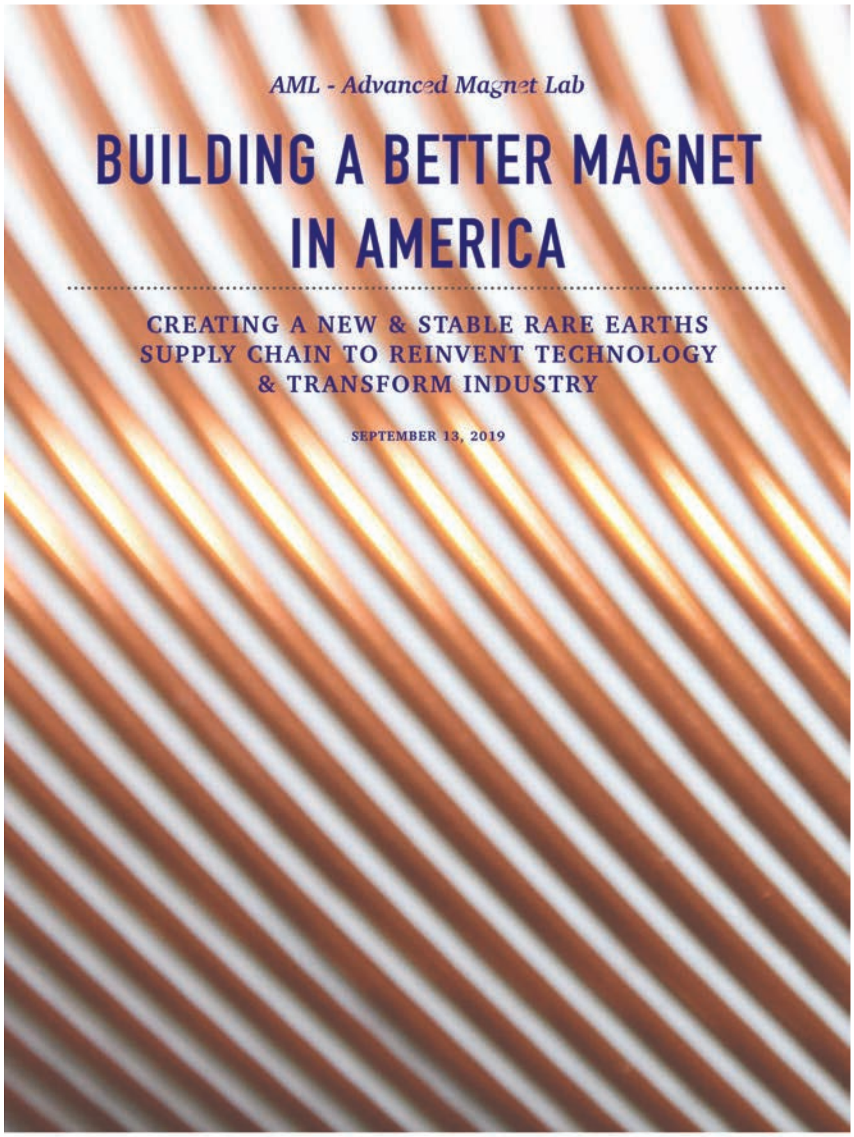
Combining AML's efforts with US and Rare Earth mines worldwide, we have the ability to streamline the supply chain problem to potentially solve this crisis. **Everybody wins with a vertically-integrated solution**. Miners, magnet producers, magnet users and the end-use consumer. With a higher value magnet and end-product, these stakeholders are less impacted by China's Rare Earth subsidies which result in unstable commodity pricing.

Together, this will result in production of a steady supply of new, higher quality, lower cost permanent magnets to power the motors required for military aircraft, ships, submarines, and meeting the coming demand for e-mobility solutions from electric cars, trucks, trains, aerospace, commercial flight, electric turbines, power tools, medical solutions, and more.

The attached white paper explores the future of magnets and their end-use impact and the solutions to the manufacturing challenges, supply of Rare Earth resources, and creation of a stable, thriving, vertically-integrated "mining to magnet to end-use" industry.

Respectively submitted on this 19th day of September 2019.

Mark W. Senti, CEO
Advanced Magnet Lab, Inc.


AML - Advanced Magnet Lab
BUILDING A BETTER MAGNET
IN AMERICA
CREATING A NEW & STABLE RARE EARTHS
SUPPLY CHAIN TO REINVENT TECHNOLOGY
& TRANSFORM INDUSTRY
SEPTEMBER 13, 2019

Building a better magnet

REINVENTING AN INDUSTRY

SUMMARY

Magnets are at the heart of electrically powered machines. As the world evolves away from purely fossil fuel-powered engines, vehicles, and machines, the electric and hybrid-powered machines have to evolve along with it. This need for better, more efficient, more powerful, lighter weight magnets and magnet-powered motors and generators will take over in industries from transportation to wind energy to robotics and more. As a result, demand for the type of magnet that allows this, one made of Rare Earth Elements (Rare Earths), will grow exponentially. Permanent magnets represent the largest group in Rare Earths consumption, close to 25% of Rare Earths used worldwide. Currently, the only practical supply of Rare Earths and permanent magnets manufactured from Rare Earths is through China. This is not a sustainable solution from a country with a history of market manipulation and control along with an economically adversarial relationship with the USA that recently triggered a global crisis. The Advanced Magnet Lab (AML) has developed a novel solution for the optimized design, manufacture and performance of permanent magnets that, combined with efforts from numerous Rare Earth mines worldwide and deep tech Rare Earth processing companies, will streamline the supply chain problem to potentially solve this crisis.

This paper explores the future of magnets and their end-use impact and the solutions to the manufacturing challenges, supply of resources, and creation of a stable, thriving, vertically-integrated "mining to magnet to end-use" industry.

INTRODUCTION

The way the world is powered and propelled is changing. The path is toward fully or hybrid electric transportation, devices, electric machines and other solutions that require electric motors and generators for propulsion and power with optimal performance. At the heart of those motors are magnets.

Self-driving vehicles, flying and hovering vehicles, machines that are cleaner, more efficient and significantly improve the legacy transportation systems of today– these are the machines that will move us into the future. **And the future is now! It is innovation in the field of magnetics that is making it all possible.**

The road to better magnet technology is long and routed through complex territory. It begins in a technological space that hasn't had a major change in more than a century, involving a product that currently requires source materials and natural resources that either come only from China or can only be cost-effectively processed and refined in China at the present time. Not to mention the current conventional wisdom saying that thanks to China's inexpensive labor force and reckless disregard for safety and environmental impact, manufacturing of permanent magnets will only ever only be cost-effectively produced in China.

E-Mobility

The electrification of transportation replaces fossil fuel and carbon-emitting powered vehicles with cleaner, more efficient and quieter electrically driven vehicles.

~

However, it should not be at the expense of human rights trade-offs sponsored by China.

Even still, thanks to emerging technological innovation and its marveling applications, magnet end-users are eager for real, fundamental, and disruptive solutions within the magnet industry.

Breaking the Bottlenecks

The world is moving toward a new form of propulsion, but there are significant bottlenecks in the supply chain. AML's approach for innovative technologies and its business model solve them all.

Today, the Rare Earth materials from which permanent magnets are made come mostly from China.,Currently the most cost-effective supplier, China produces more than 90% of the world's permanent magnets. The reasons for this are simple, China has a system that cares little for the health and well-being of its workers and even less for the health of the environment. Labor is cheap, and Rare Earths are more easily refined when there is no environmental concern. Also, while cheap labor might lessen the concerns of China for the hazards associated with today's permanent magnet manufacturing processes, it also raises the risk of political upheaval.

Protests in Yulin, China in May 2018 at the Chinese company "Chinalco" ended in a batons and shields attack from Chinese police and arrests of several protesting villagers that complained against working conditions at the Rare Earths facility.

Of course, with little care for workers or environment, the quality and performance of the magnets is about what you would expect. Inconsistent. Far from optimal. And not to the standard required for today's revolutionary machines.

The magnets produced in China are adequate for current uses **ONLY**, because there is no alternative. Latent innovation and new approaches that could significantly improve performance and economics of existing and evolving industries, like e-mobility and clean power generation, are lacking.

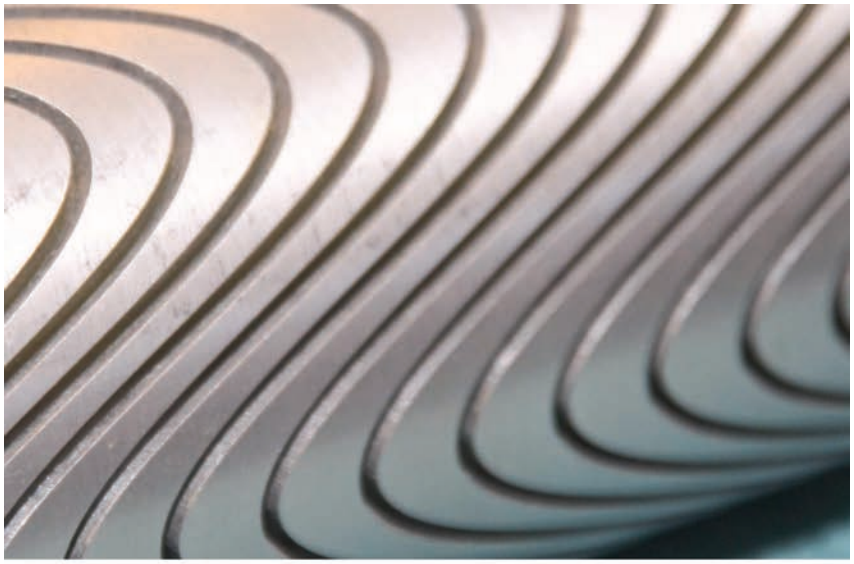
In an industry where the driving mentality of good enough is good enough to be successful, the tide is turning to a truth where good enough will never be good enough again. The only way to succeed will be to make not just a better magnet, but a better-designed and applied, optimally manufactured magnet-based end-product. Like a motor.

The highest performance commercially available gasoline cars to-date can achieve 0-60 mph in 2.3 seconds, with a top speed of 261 mph (420 kmh). They can also wear a price tag of up to 3 million dollars. Todays $80,000 electric car, with a motor powered by arguably inefficient magnet design, can already reach 0-60 mph in 3.2 seconds and a top speed of 162 mph (260 kmh). (Source: caranddriver.com, accessed 09/12/2019)

Take Formula 1 cars, for example, which have a World speed record of 231mph. The Formula E (electric engine) has already reached 174mph (75% of fossil fuel engine speed), surpassing the average speed of F1 competition (164mph) and consistently improving its performance. (Source: Bloomberg Nov. 13, 2018)

Innovation is the solution to that better product; innovation in the way magnets are made; innovation in the way the resources for those magnets are mined and refined; innovation in the way the products that use magnets are designed. And what's more, this type of innovation will only serve to inspire the next generation of engineers and designers bent on making a better world.

End-use manufacturers such as automotive companies, aircraft manufacturers, and other users of electric motors (the demand side), recognize the importance of optimum performance and keeping a clear, consistent, predictable supply chain in place.



Optimizing Power Density

THE KEY TO BETTER MAGNETS

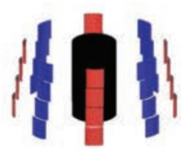
Increasing Power Density, that is, optimizing the ratio of power to weight and cost is the only way to achieve the required performance and price points of the future. Just like for electric vehicles, where battery technology seeks the highest Power Density at the lowest cost, motors using the majority of that energy also need to have the highest Power Density at the lowest cost.

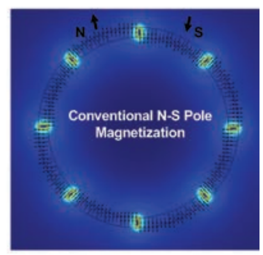
The only way to optimize Power Density in motors–the only way to make a better magnet–is through innovation. The same holds true for the systems generating the electricity to charge the batteries required to support these machines.

For example, Wind Turbines also seek the highest Power Density generators in order to shrink the size and weight of the turbine yielding the lowest levelized cost of energy. The impact is even greater for electrically powered vehicles, where mass drives the power requirements, and consequently, its cost.

These innovations are already in development. Particularly at the juncture of magnet manufacturing for companies that need real solutions for their electrically powered machines and more. The supply chain for Rare Earth materials is the stickiest point, but that, too, is being disrupted by innovation. The inevitable result will be a market expanding away from the controls of China and toward a safer, more responsible, reliable supply chain with higher quality and product design.

Historically and currently, permanent magnets are created as either a batch of piece-part components or substantial chunks of metal, which are then cut and configured into a final physical and magnetic orientation. These individual piece-parts of powerful magnets are assembled through a difficult, dangerous and laborious process for the final end-product, such as a spinning rotor for an electric motor or generator.





The current reality is, product designers dream of having an even more complex assembly, where these magnet piece-parts are arranged in what is called a Halbach array configuration. As compared to a conventional and simple North-South magnetic pole configuration, where a signifiant portion of the field is unusable without adding heavy iron (shown above), a Halbach array directs most of the magnets' available "energy product" to be fully utilized in the end-product without iron, and therefore yield much higher Power Density. This method, however, is process-intensive, work-intensive, expensive, and more than occasionally physically dangerous to workers.

These complicated Halbach arrays, are cost-prohibitive to manufacture, extremely dangerous and challenging to assemble as piece-parts into the end-product. In a practical way, complicated equals expensive and in manufacturing, expensive, while not always impossible, makes production impractical, unprofitable and therefore not a realistic option as a marketable solution.

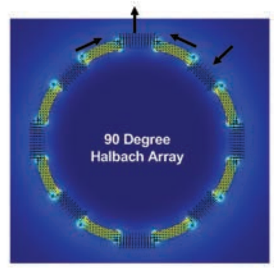
The ability to design and manufacture products with significantly greater performance and cost savings is a game-changer. Beyond motors, other products like magnetic levitation systems, magnetic bearings, magnetic gearboxes, and medical devices, would benefit immensely from lower cost and optimized Power Density. And these are only a few examples of many possibilities. AML has developed a novel solution for the optimized design, manufacturing and end-product assembly of permanent magnets.

What is a Halbach Array?

Named for its inventor, Berkeley Labs physicist Klaus Halbach, a Halbach array is a special arrangement of permanent magnets that directs the magnetic field lines so that the field is augmented on one side of the array and canceled to near zero on the other side.

In laymen's terms, such a configuration channels most of the magnetic flux in one direction, forming magnetic poles with a close to perfect sinusoidal distribution. This leads to generation of the maximum magnetic field from the permanent magnet and directs the field in the optimum configuration for the application. In a motor, that provides higher magnetic fields where it counts and removes the need for iron reducing the total weight and size.

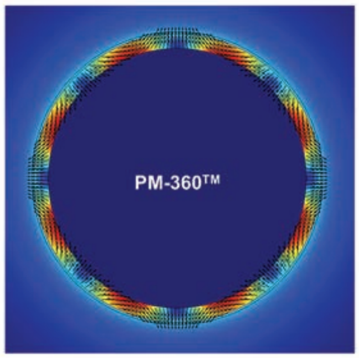
First discovered by John C. Mallinson in 1973 as what he described as a curiosity, the potential was identified and Halbach independently developed his arrays to focus particle accelerator beams in the 1980s.



Called **PM-Wire™**, the technology developed by AML is a uniquely innovative way of manufacturing and configuring permanent magnets. This approach is driven by AML's Technology Platform. A platform which integrates proprietary **MOEM™** electrical machine design software and **CoilCAD™** magnet design software with patented magnet technologies and manufacturing, enabling designers to fully optimize their end-products and applications. Compare that to the way the problem is currently solved–what we call a "me-too" solution–a method using dozens or hundreds of magnet piece-parts to achieve a much less than optimal performance.

And this innovation is just the starting point. For many end-use products like motors, the ideal solution would be a "better than Halbach array" configuration with minimal assembly, lower cost and optimal performance.

AML's **PM-360™** process which optimizes both geometry and magnetic field direction offers unprecedented Power Density, and more, that cannot be matched. Not to mention cost-effectiveness and "better than Halbach array" magnetic fields.



PM-360™ Wins!

Simple, Elegant & Optimized

1. **Higher** Quality
2. **Higher** Yield
3. **Higher** Performance
4. **Easier & Safer** to Use
5. **Lower Cost** to Produce
6. **Lower Cost** End Product

DEFINITION

Deep Tech

A discovery or commercialization of breakthrough deep technology with the potential for world-changing impact and/or a critical milestone in science and technology.

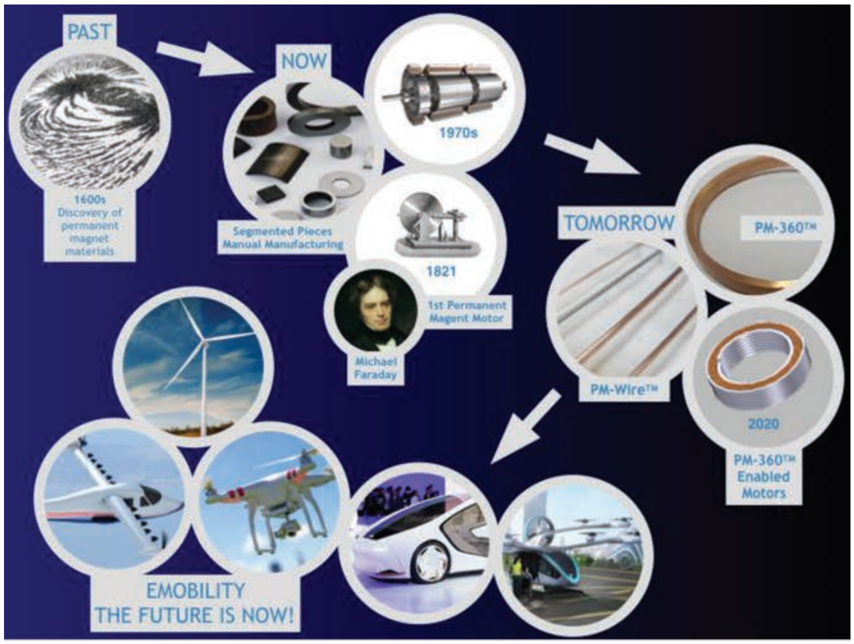
Is AML's solution Deep Tech?

In a word, YES! AML's innovation is a perfect example of Deep Tech. It is tangible and set apart by its profound enabling capabilities, the differentiation it can create, and its potential as a catalyst for change.

AML's Innovation is fundamental, defensible, and distinguished from the existing market; a market built on incremental refinement, that produces a standardized product, and is fragmented.

AML's Innovation includes business model innovation, creating a new and sustainable industry. Not just for magnets, but also to create independence from China for new mining and extraction businesses.

AML's Innovation spans across many diverse applications including energy, transportation, medical and more.



Better Magnets = Better Products

CYCLE OF INNOVATION

In short, innovation that drives an improved magnet product improves the products those magnets go into. That, in turn, creates a cycle of improvement and innovation bound to continue and drive the future of electric machines for more efficient generation and use of energy, which in turn, creates a new cycle of innovation that propels human life into a new stage for our unalienable right of the "pursuit of happiness."

At this point, it is worth noting that no part of this discussion is focused on optimizing petroleum-powered vehicles or machines. It is abundantly clear that the future will be built on higher performing, cleaner running, more energy-efficient machines that utilize electrical energy. At this moment, all of the biggest and best automakers, aircraft manufacturers and hundreds of start-ups are focused on electric or electric hybrid models. Anyone betting on a purely internal combustion future is, quite simply, missing the boat. Or self-propelled trucking line. Or airplane. Or flying car. Or hyperloop.

The History

Magnets have been at the heart of electric motors and all electric machines since the inception of magnetics in the late 1800s. With the exception of scale and the materials used to make them, the technology of magnetics and making magnets hasn't changed in nearly two centuries.

As we've said, today's most powerful, most effective permanent magnets are mostly manufactured in China, purely due to the fact that China offers the cheapest, quickest source of Rare Earth materials, cheapest labor, and lowest consideration for safety and environmental consequence anywhere in the world.

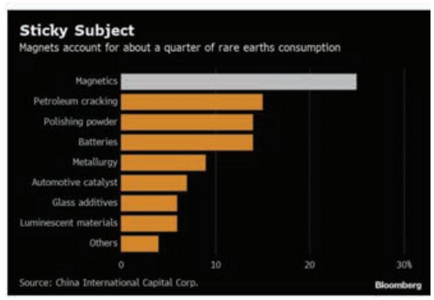
FROM THE EXPERTS ABOUT AML U.S. DEPARTMENT OF ENERGY

"The proposed technology is a novel process that can compact, shape, sinter and magnetize the permanent magnet material in a highly automated and high-rate process and still provide unique flexibility in terms of shape and continuously changing magnetization direction. The PM-Wire™ process for fabricating a continuous flux Halbach array is particularly innovative."

- U.S. Department of Energy Technology Reviewer

This single-source model presents obvious opportunity for companies able to tap into the source, but also a very clear and present danger to disruption of a supply chain where one can only get the source materials for a product from one, occasionally economically hostile place.

What if it didn't need to be this way? What if the supply chain for Rare Earths and even the production of permanent magnets could be done in America or other places where safety and environmental responsibility were a more important concern? What if the supply chain had numerous sources that were not dependent on a single source controlled by a dictatorial government? **What if the complete value stream from mining to magnets to end-product could be sustainable?**



Through the next section, we examine the current state of Rare Earth mining and permanent magnet manufacturing and layer that with new developments in magnet manufacturing to clearly illustrate an industry ripe for disruption. Permanent magnets represent about 25% of current worldwide use of Rare Earths, it is a disruption that is inevitable for the future of electrically powered vehicles, energy production, personal devices, robots, medical solutions and more.

Rare Earths Are Not Really All That Rare

BUSTING THE MYTH

It's said so often that it's easy to believe the claims. China is the ONLY Source for Rare Earth materials. The only affordable route to get the powerful permanent magnets you need is through China.

The Myth: TRUE or FALSE ?

Rare Earth minerals can only be accessed through rich mining deposits within Chinese borders. Beyond that, separating and extracting those materials from Chinese ore cannot be financially feasible outside of China. Furthermore, because of its low cost of labor, manufacturing of permanent magnets can only be financially feasible in China as well. As a result, Rare Earth permanent magnet technology is dependent on China for its existence and if China decides to weaponize access to Rare Earths, the rest of the world is completely at her beck and call.

ANSWER: Mostly false. Or at least it's not completely true.

Historically, manufacturers were attracted to China for the same reason clothing and toy manufacturers are attracted to China. Cheap labor costs and low consideration for worker safety and environmental considerations. China in the mid 80s declared, "the Middle East has oil, we have Rare Earths." Three decades later, China controls the practical supply of Rare Earths around the globe.

Rare Earth materials aren't actually rare at all. They are available in many places around the world. They're called "rare" because it is so difficult to separate and extract the elemental materials from the mined ore. Also because the ore contains dangerous radioactive elements like uranium and thorium that need to be handled carefully and either disposed of or used safely. This is another reason China is a current source for these metals. The Chinese government has little safety or environmental regulation protecting its workers and citizens from the effects associated with handling Rare Earths. This has resulted in the loss of life, destruction of entire communities, and even the creation of Rare Earth cartels not unlike the notorious drug cartels of South America and Mexico.

And China isn't the only country trafficking in Rare Earths in these ways. In fact, Australian mines have been sending their "dirt" or ore to both China and Malaysia in an attempt to realize the same benefit without being held captive to China's economic whims. In other words, Australia is shipping its "pollution" to Malaysia. This kind of action just creates another threat of destabilization in the market.

In 2012, about 3,000 Malaysians staged a protest against a Rare Earth refinery being built by Australian mining company Lynas over fears of radioactive contamination concerned it posed health and environmental risks.

In 1992, a Malaysian refinery operated by Mitsubishi of Japan, was closed after protesters claimed it caused birth defects and leukemia. (Photo - EPA pic, August 23, 2018)

There are alternatives

Rich deposits of Neodymium and Praseodymium, necessary Rare Earth materials for permanent magnets, do exist in other areas of the world. Locations like the Mountain Pass mine in California, Round Top mine in Texas, and Bear Lodge mine in Wyoming, have the added benefit of minimal radioactive elements within the ore. Add to that its stateside location in a politically stable part of the world and it is a tremendously attractive resource for the materials so in demand for magnet manufacture. Along with companies like AML, developing magnet manufacturing technology and processes (**PM-Wire™** and **PM-360™**), cost-effective manufacturing solutions on American soil can be opened up, and suddenly, the market is poised to change dramatically.

The difficulty with the ore from Mountain Pass and other mines like it comes in the separation and extraction process. To date, refining the ore from these mines is so expensive and site-specific that the only cost-effective way of doing it has been to ship the "dirt" to China for extraction. With ore from other parts of the world; Australia, Canada, and others; the dangerous elements are left for China or Malaysia to deal with. Once the Rare Earths are extracted for use, a mining company's only option is to ship it to China to be made into magnets. This is the current case for Mountain Pass, the only U.S. Rare Earth mine in operation at this time.

Brazil is also an alternative latent partner-supplier of rare earths. It has half of China's rare earths reserves and is the single largest niobium ore global producer with more than 90% of global market share. In this case, Rare Earths are actually a by-product of niobium mining production.

Commodity or product?

Rare Earth magnets have been seen from only one side since their inception. Because they are made from mined materials and only a limited amount is available at any given time, they are often seen and understood as commodities. For example, the magnet industry defines magnets as a function of their weight; the amount of raw materials used to manufacture them. A better approach is to recognize the magnets within the end-use product, such as a motor. Because of the inherent reliance on availability of Rare Earth magnets required for the products we use on a daily basis, they should be treated more as an end-use product; for example, the magnet rotor in a motor.

Numerous Rare Earth mines around the globe have been investing significant sums in developing their own separation and extraction processes. Since each lode of ore requires its own specific process, dictated by the elements included in the ore itself, every mine requires its own unique process for extraction.

The demand for Rare Earths today is large and growing steadily. The explosion of new electrically driven products, both military and commercial is poised for a market breakout as production and manufacturing increases over the next decade. Without Rare Earth resources, economies could decline and countries would be unable to produce essential end-products required for national security. **In most cases there are no alternatives.**

The threat has become existential

Combined with the possibility growing over recent years of China "weaponizing" the Rare Earths market; that is, controlling the price and supply and flow of Rare Earth materials to its benefit; it has become a necessity for mines in other countries to develop their own processes and maintain a stable supply chain.

End-use manufacturers such as automotive companies, aircraft manufacturers, and other users of electric motors (the demand side), recognize the importance of optimum performance and keeping a clear, consistent, predictable supply chain in place.

The present technology developments at AML have generated a strong pull from industry participants for **PM-Wire™** and **PM-360™.** Companies ranging from start-ups to fortune 100 and Global 2000 are engaged with AML as part of their new product developments. Products like propulsion motors for drones, flying cars, aircraft, electrical vehicles, and consumer power tools.

RECYCLING FOR RARE EARTHS

Mining existing stores

While the process of mining Rare Earth materials and refining the valuable materials out of the ore from such efforts is the only current process capable of producing these elements at the volume required for industrial use, it is not the only way of skinning the magnetic cat.

Urban Mining Company offers another way in to the Rare Earth minerals required for the production of permanent magnets that doesn't necessitate shipping ore to China to be extracted and produced into permanent magnets.

The Austin-based company commercialized a process for recycling magnets using a patented Magnet-to-Magnet™ process designed to produce recycled neodymium-iron-boron (NdFeB) type magnets.

Recovered "waste" from devices like motors, cell phones, computers, tablets, televisions and more, can be repurposed into new magnets and magnetic devices without relying on a new Rare Earth supply currently only available in a practical way from China.

Because the elements used in the materials being recycled have already been refined, the safety and environmental concerns are limited as the recovered NdFeB is reused into new magnets.

Clearly, the recycled materials are not available in quantities sufficient to meet the supply chain needs of a new and growing industry or large-scale commercial production, but availability through recycling does offer another way of thinking about the issue and another, safer, cleaner way of solving the challenge.

How big of a deal is it?

At the end of July 2019, the White House invoked the Defense Production Act of 1950, a Presidential Determination, for the **domestic supply of Rare Earth materials** and the **production capability for Permanent Magnets** as **ESSENTIAL TO NATIONAL DEFENSE.**

The Defense Production Act is a federal law put in place and headed up by the Truman Administration at the start of the Korean War. The act has been reauthorized some 50 times since then and was designed as a part of a broad civil defense and war mobilization effort at the time in response to the nation's Cold War posture.

Addressing the threat on U.S. National Security is a focus for AML and the current domestic Rare Earth mines. Together, this will result in production of a steady supply of new, higher quality, lower cost permanent magnets to power the motors required for military aircraft, ships, submarines, and meeting the coming demand for e-mobility solutions from electric cars, trucks, trains and even scooters, aerospace, commercial flight, electric turbines, medical solutions, and more.

National Security Cornerstone

RARE EARTHS

The U.S. Military is an important buyer of Rare Earths and products using Rare Earths. Permanent magnets are required for navigation, weaponry and electric propulsion motors for a new generation of vehicles, aircraft, ships and submarines.

The U.S. Navy's newest warship, USS Zumwalt (DDG 1000) is the largest and most technologically advanced surface combatant in the world. Zumwalt is the lead ship of a class of next-generation multi-mission destroyers designed to strengthen naval power from the sea.

The Zumwalt features all-electric propulsion. The electric drive eliminates the need for drive shaft gearing, reduces acoustic signature, and produces an increase in available power for weapon systems while improving the quality of life for the crew.

Everybody wins with a vertically-integrated solution.

Miners, magnet producers, magnet users and the end-use consumer. With a higher value magnet and end-product, these stakeholders are less impacted by China's Rare Earth subsidies which result in unstable commodity pricing.

AML is working together with international mines, industry consultants, and experts in order to streamline the entire value chain from mine-to-magnet-to-end-product. The effort is to form partnerships involving relevant supply-and-demand players prepared to compete with China's market dominance.

As in any business strategy that depends on natural resources, vertical integration is the right answer to the competitiveness question.

The actual scenario is leaning towards coalitions, such as the Pan-American coalition that extends from Canada to Brazil to Chile and has the potential to offset China's grip over "The Americas."

The significance of such an endeavor is not only felt in the economics of the situation but also emerges in the social, human values of freedom enshrined in the American way of life. It is intertwined with other geopolitical issues of global power like the telecommunications debate over 5G technology.

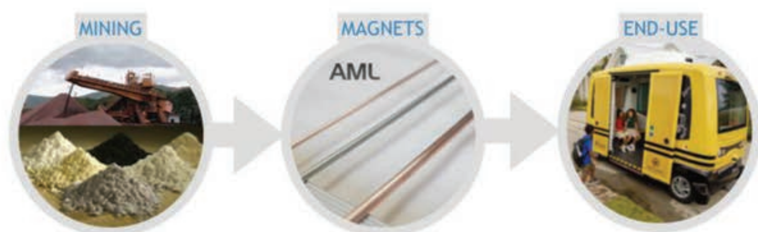
As a result, this endeavor requires support from all federal governments of the participating nations.

China and Russia have been working together toward a common agenda for a social-communist lifestyle since 1991. This effort was amalgamated by a cultural-economic treaty signed in 2001 during the BRIC Summit between Russia's Vladimir Putin and China's Xi Jin Ping with support of former Brazillian social-communist president Luis Inacio Lula da Silva (currently under arrest for corruption).

So, it can be inferred that we are not living in a simple "trade war" with China but in a "social-tech war" with global implications spurred by availability and access to natural resources and innovation. Thus, joining forces among natural resources-rich countries and American deep tech companies is crucial to a successful prevalence of freedom and justice in the near future for the whole of the Western World.

The result is related to sovereignty, human values, and way of life. Therefore, **building a better magnet in America** is essential to our country, our citizens and our allies, too.

The fact that the U.S. Government acknowledges the importance of a clean, supportable, undisrupted domestic supply chain for permanent magnet production just serves to illustrate the way the industry tide **MUST** turn. It **WILL** be a major part of the world economy going forward. As it has at every major technological juncture in its history, the U.S. needs to **LEAD THE WAY**.



What makes magnets important?

MAKING THINGS POSSIBLE

Without permanent magnets, much of today's most advanced technology, or at least the technology that makes life more interesting, profitable, and technologically advanced, would not be possible.

Set aside what's being developed. Many of the devices we carry and work with every day today would not exist without permanent magnets made from Rare Earth materials.

Smart phones. Laptop computers. Speakers and microphones. Drones. Studio and cinema lighting and projection. Heavy industrial uses. Hybrid vehicles. In fact, all transportation—land, air and sea—are going electric or hybrid electric including new modes of transportation such as eVTOLs. Affectionately known as "flying cars," these Jetsons-like electric vertical take-off and landing vehicles will be flying the sky's in less than 5-years for Urban Air Mobility, organ delivery, and emergency services.

Powerful permanent magnets are the beating heart of all of these things. Without access to Rare Earth materials, the permanent magnets that make these things possible, wouldn't be possible either.

AML's comprehensive technology platform enables the efficient production of a new generation of permanent magnets that delivers 10-50%, or even higher, performance increase across a broad variety of end-products and applications. More powerful. More efficient. Less expensive. And significantly safer to produce and use.

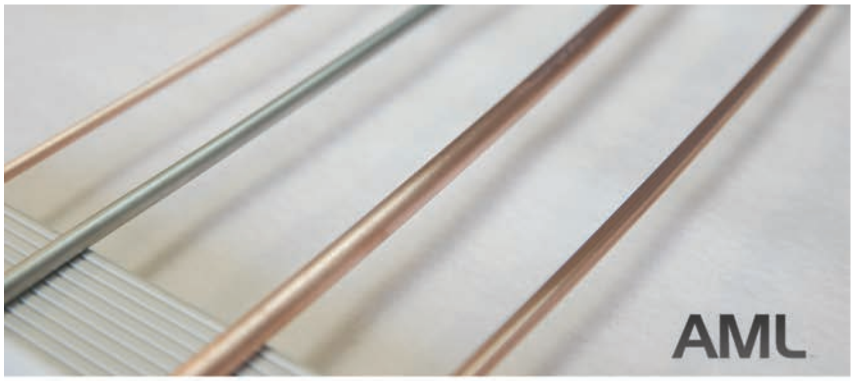
The Old Method of producing permanent magnets, the one that is dependent on China and Chinese labor, produces small piece-parts or often large magnet blocks that need to be cut and placed together into arrays to generate the kind of power required to run electric machines and other magnetic systems.

That process is manual, dangerous for workers, and produces magnets that exhibit low yield, poor quality, inconsistency and are restrained from optimizing end-product performance and capabilities. While some companies outside of China are replacing humans with robots to automate the process, the product is still the same and costs are not competitive. Furthermore, in both cases, the end-product design is constrained to designs made from limited sizes and shapes. It is a "me-too" product designed for a highly fragmented market.

The New Method, AML's novel approach, powered by the innovations of proprietary software and its **PM-Wire™** and **PM-360™** processes will enable safe, streamlined magnet manufacturing, along with unique solutions that will result in more powerful, more efficient, less costly and lighter end-products. It is an entirely new way of thinking about magnets and delivering performance to products powered by magnets.

This New Method does not require the manual element that made China the de facto leader in the industry. **PM-Wire™** and **PM-360™** are not piece-part magnets. They are a fully optimized solution for the end-product. **A solution that does not compete in the fragmented "me-too" market. A solution that is less sensitive to China's Rare Earth commodity price and market manipulation.**

This is an enabling technological solution that brings sustainability to the entire industry. And it is "source agnostic," meaning the Rare Earth materials used can come from the U.S., Australia, Brazil, Canada, Greenland, Africa, China, Vietnam, or even Afghanistan. For the U.S., a supply of domestic Rare Earth materials allows the entire process to become a domestic industry empowering new thinking across a vast array of industries around the world. **It is a complete transformation in the way magnets are produced and used, at the same time, reigniting the American manufacturing sector.** For the Americas, it may ignite a new Occidental coalition of freedom and prosperity as together we become stronger and less dependent on the Orient.



Our Conclusion

WHAT COMES NEXT?

The way we all move around in the world is changing. The engines that built America over the last century and more will be giving way to a new generation of propulsion, power, and energy requiring different materials, a new way of generating movement, and an innovative approach to solving these challenges. **It is an approach with magnet technology at the center of the motors that move us.** And the change is coming quicker than most people can envision.

Electrically powered machines with magnets at their hearts will be replacing virtually every existing type of fossil-fuel powered machine in industries around the globe. And when they do, there needs to be a solution to the Rare Earth materials required to produce magnets outside of China; outside of the traditional commodity market for these resources.

The reasons driving this change are varied and wide ranging; from practical, hard economic, market-driven inevitability; to environmental impact; to responsibilities to the health and safety of the American workforce. These reasons are making it clear that the need for magnets having higher quality, higher performance, easier and safer to use, produced at a lower cost, yield a lower cost, and optimal performance of the end-use product will grow exponentially over a predictably short time horizon.

But in a market where most of the materials required to manufacture the magnets needed to make these machines possible come from only one source, there is an obvious need for an innovative solution to where those materials come from and how those magnetic components are manufactured.

AML has already solved several of the most challenging magnet manufacturing challenges with its own novel approach that is shifting the paradigm and is poised to create what amounts to a new market in magnetics.

This is not incremental improvement. It is transformational. AML is leading a truly revolutionary change taking us from a fragmented, "me-too" market to a streamlined, vertically-integrated market delivering better magnets and enabling better end-use products.

The company is currently leading the charge into the next steps that will lead to a resurgence of the American manufacturing sector in magnetics. Rare Earth mines across the U.S. and around the world are working diligently to solve and streamline the supply chain challenges.

It is true that China is the only practical provider of Rare Earth elements and manufactured permanent magnets in the world at this time. But that time is changing. And changing swiftly. Toward the inevitable creation of a stable, thriving, vertically-integrated "mining to magnet to end-use" industry that will supply a beating heart to the machines of the future.

~ end ~

POISED FOR EXPONENTIAL GROWTH

Disrupting traditional industrial processes

Best-selling author and serial entrepreneur Peter Diamandis talks about his 6-Ds of exponential growth.

"The Six Ds are a chain reaction of technological progression, a road map of rapid development that always leads to enormous upheaval and opportunity."

DIGITIZATION - Does the business utilize or rely on digital technology over manual labor?

DECEPTIVE - Is the business uniquely deceptive because of a unique approach?

DISRUPTIVE - Does it have the potential for massive and disruptive growth?

DEMATERIALIZED - Does it alleviate or significantly change the use of materials?

DEMONETIZE - Does it remove or significantly reduce the cost?

DEMOCRATIZE - Does it make the technology more available for everyone on the planet?

AML's PM-Wire™ and **PM-360™**

Checks all six D's

Everything AML does is anchored in proprietary software processes, **DIGITIZATION**, exploring the optimal approach to solve a challenge.

The name alone makes it seem **DECEPTIVE**. PM refers to permanent magnets, and PM-Wire™ is a completely new solution to an old technology.

AML is doing PMs in a totally revolutionary way, **DISRUPTIVE** to the current Chinese stronghold.

On **DEMATERIALIZED**, it breaks the single source model. It reduces the part count of the final end-product sometimes from 100s to a single part.

It **DEMONETIZES** by removing today's "me-too" magnets with a unique and optimized solution.

And what could be more **DEMOCRATIC** than making better magnets more effective, more affordable and easier to use in a wider variety of products?

CONTACT US

COMPANY

AML is a recognized leader in the development of technologies and solutions for electrical machines and other magnet-based applications.

AML's capabilities are driven by a Technology Platform comprised of a comprehensive portfolio of intellectual property and know-how. This includes proprietary software for the optimization of electrical machines and magnet solutions, magnet and manufacturing technologies.

As a result, AML is a world leader at optimizing magnet-based applications that address products and solutions for energy, transportation, medical, and research.

AUTHOR

Mark Senti
Co-Founder, CEO and Chairman
AML - Advanced Magnetics Lab

More than 30 years of experience at the forefront of innovation and technology solutions including superconducting magnetics and supercomputers, robotics, manufacturing and sustainability. Teamed with world-class scientists and engineers, Mark leads the company's strategic direction including developing technology and product solutions, business strategies, intellectual property strategies, and strategic partnerships.

Email: msenti@amlsm.com
Phone: 321.728.7543
LinkedIn: linkedin.com/in/M-Senti

ACKNOWLEDGEMENT

I want to sincerely thank Lyle Smith, Romulo Queiroz and Max Skuhersky for their awesome input and trusted advice to help tell this story. A real story, which will have tremendous impact. In the U.S. and abroad.

Disclaimer - The information contained in this white paper is for general information purposes only. It describes the general nature of the Rare Earth and Permanent magnet industry, the current crisis and the potential solution for a new and sustainable solution. It is the opinion and vision of the Author and the Advanced Magnet Lab, Inc. (Company).

All information in this paper is provided in good faith, however the Author and Company make no representation or warranty of any kind, expressed or implied, regarding the accuracy, adequacy, validity, reliability, availability or completeness of any information provided.

This paper is NOT meant to replace any specific advice. In no event will the Author or Company be liable for any loss or damage including without limitation, indirect or consequential loss or damage, or any loss or damage whatsoever.

As used in this document, "AML" means Advanced Magnetics Lab, Inc.

Advanced Magnet Lab, Inc.
1604 S Harbor City Blvd
Melbourne, FL 32901

AML

AML-Enabled.com
info@amlsm.com
@AMLInnovation

AMERICAN ELEMENTS
THE ADVANCED MATERIALS MANUFACTURER®

U.S. Senate Committee on Energy & Natural Resources
Hearing on Critical Minerals & Renewables/Solar Energy
September 17, 2019
Testimony of Michael Silver, CEO, American Elements

TESTIMONY

I am Michael Silver, Chairman & CEO of American Elements. American Elements is entering its 25th year as the world's largest catalog of advanced materials. In addition to the catalog, our research programs in the use of advanced materials has led to many key discoveries in green technology and solar energy. We supply essentially all of the critical raw materials for producing photovoltaic cells and solar panels.

American Elements engineers prepared the below table of the basic raw materials necessary for solar panel production showing the countries the materials are mined and the application for each material. As you will see from the table, like the 14 rare earth elements, China is the major supplier of several of the most critical – indium, gallium, silicon, tin, antimony and arsenic. Readily available supplies at global market prices is critical to any nation hoping to compete in solar energy production.

China has shown a willingness to use a two-tiered pricing structure for raw materials for which it is the major producer; charging significantly less for the materials inside of China than outside of China in order to force producers to build their plants in China. This strategy in connection with rare earths was challenged by the US, Japan and the EU in a joint action at the WTO and China was forced to stop. Note China appealed the action and still believes it was in the right. They lost the appeal and our honoring the ruling at present. However, at any time they could choose to reinstitute the policy, particularly if they chose to exit the WTO. This approach to global pricing is the issue that needs to be addressed! I suggest this committee consider requiring the executive branch to include in trade talks with China that China agrees that it will not charge differential pricing on the solar energy raw materials they produce.

Should this committee require further information on the information or advise contained herein, I would be pleased to provide it and could attend a future hearing in person. I will be in Europe on Tuesday and cannot make this hearing.

SUPPORTING INFORMATION

1. **Copper**
    a. Used in: CIGS, CIGSS, CZTS (copper zinc tin sulfide, for thin film cells) and interconnects/cables/etc.
    b. Location:
        i. **Chile** (170,000 MT)
        ii. Australia (88 MT)
        iii. Peru (83 MT)

    iv. Russia (61 MT)
    v. Indonesia (51 MT)
    vi. Mexico (50 MT)
    vii. USA (48 MT)
    viii. China (26 MT)

2. **Indium**
    a. CIGS, CIGSS, Semiconductors like InSb and InGaSb (more experimental)
    b. Locations – No reliable estimates on reserves, data below is for refinery production
        i. China (300)
        ii. Korea (230)
        iii. Canada (70)
        iv. Japan (70)
        v. France (50)
        vi. Belgium (20)
        vii. USA : No domestic production
3. **Gallium**
    a. Gallium Arsenide – 2nd most common type of cell after Silicon
    b. Locations – No reliable estimates on reserves, data for refinery production
        i. **China** (390,000)
        ii. Russia (6,000)
        iii. Ukraine (6,000)
        iv. Japan (3,000)
        v. Korea (3,000)
        vi. USA : No domestic production
4. **Selenium**
    a. CIGS, CIGSS, Cadmium Selenide in thin film/quantum dot cells
    b. Locations
        i. China (26,000)
        ii. Russia (20,000)
        iii. Peru (13,000)
        iv. USA (10,000)
        v. Canada (6,000)
5. **Silicon**
    a. (Industry standard)
    b. Locations – no reserves estimates, supply is ample in relation to demand
        i. China (4,000)
        ii. Russia (670)
        iii. USA (430)

iv. Norway (380)
v. Brazil (190)

6. **Tin**
   a. CZTS, tin-based perovskite solar cells (research phase)
   b. Locations: (Note: recycling is common)
      i. China (1,100,000)
      ii. Indonesia (800,000)
      iii. Brazil (700,000)
      iv. Bolivia (400,000)
      v. USA (370,000)
      vi. Russia (350,000)
      vii. Malaysia (250,000)
      viii. Congo (150,000) ***Conflict mineral
7. **Lead**
   a. Phasing out due to toxicity
8. **Antimony**
   a. Antimony selenide – promising thin film absorber material
   b. **Designated in May 2018 as a critical mineral by the U.S. Department of the Interior
   c. Locations
      i. **China** (480,000) – largest producer
      ii. Russia (350,000)
      iii. Bolivia (310,000)
      iv. Australia (140,000)
      v. Turkey (100,000)
      vi. USA – 60,000 in reserves but no domestic production
9. **Arsenic**
   a. Gallium Arsenide
   b. Locations
      i. **China** (24,000)
      ii. Morocco (6,000)
      iii. Namibia (1,900)
      iv. Russia (1,5000)
      v. USA: no domestic production
10. **Zinc**
   a. CZTS, zinc oxide (dye sensitized solar cells, coatings)
   b. Locations
      i. Australia (64,000)
      ii. China (44,000)

iii. Peru (21,000)
iv. Mexico (20,000)
v. Kazakhstan (13,000)
vi. USA (11,000)
vii. India (10,000)

COEUR MINING®
We pursue a higher standard

Mitchell J. Krebs
President and Chief Executive Officer
Director

Testimony of Mitchell Krebs on behalf of Coeur Mining
Senate Energy and Natural Resources Committee
Full Committee Hearing on Minerals and Clean Energy Technologies
September 17, 2019

I serve as the President and Chief Executive Officer of Coeur Mining. Thank you for the opportunity to submit testimony on the importance of minerals to our nation's growing clean energy technologies and please accept for the official record these comments on behalf of Coeur Mining.

Headquartered in Chicago, IL, Coeur Mining (NYSE:CDE) is the largest U.S. based primary silver producer and a significant gold producer with five precious metals mines in the Americas, employing approximately 2,200 people. Our U.S. mining operations are located in Nevada, South Dakota, and Alaska. Our purpose statement is "We pursue a higher standard." Holding ourselves to a higher standard means we are committed to protecting the environment. Our company prioritizes the need for clean air, clean water, and the protection and enhancement of the land we use or disturb to produce the metals crucial to everyday life.

I thank the Committee for holding this hearing to explore the direct connection between the incredible growth in clean energy technologies and the minerals necessary to develop, construct and implement our current and future energy supplies. In the ever-growing debate over our future energy sources, we can be sure of one thing—technology will continue to improve and there is no doubt that clean energy technologies and renewable energy sources will become common place in the United States and around the globe. According to a 2019 McKinsey report, electricity consumption will double by 2050 and renewable energy sources will provide 50% of the global generation capacity by 2035. Wind and solar are rapidly expanding their role in our generation capacity today and accounted for more than half of the net capacity additions from 2015 to 2017. The infrastructure necessary to meet these future demands is massive. Every component of these technologies is at some point mined from the earth. The old adage of the mining industry that "If it can't be grown, it has to be mined" comes into even clearer focus as clean energy sources emerge as a dominant player in the world's generation capacity.

In order to support the growth of renewable energy capacity, mining of minerals must increase dramatically. For example, according to the World Bank, a single 150-metre 3MW wind turbine requires 4.7 tons of copper, 335 tons of steel, 3 tons of aluminum and 2 tons of rare earth metal along with zinc and molybdenum. Similarly, though silver comprises only a minute portion of a photovoltaic (PV) cell, solar accounts for seven percent of the global silver demand. These technologies as well as new technologies will place ever increasing demands on these minerals and many others.

According to a Dutch Ministry commissioned report, globally our production of key minerals must increase far beyond current supply levels. In order to supply mineral demands for wind and PV energy alone by 2050, the production of indium, a critical mineral, must increase 12 fold. The world's top producer is China. Neodymium production must increase by over 7 times, and silver production must increase by over 2.5 times the current global production. Globally, just over a billion ounces of silver were produced in 2018. Increasing silver production by 2.5 times in the next 30 years will be a monumental task. Increasing the production of critical minerals such as indium 12 times is a daunting challenge.

As the largest U.S. based primary silver producer, Coeur is focused on the demands of what many believe is a fairly common mineral. Yet, the United States imported 194 million ounces of silver in 2018. While Canada and Mexico are the primary suppliers of U.S. silver imports, we also import silver from China, South Korea, South America and Poland. In 2018, the world demand for silver for (PV) production exceeded 80 million ounces. Electronics, brazing alloys and solders account for another 306 million ounces of current demand. Yet, the United States produced just 28 million of 855 million ounces of silver produced globally in 2018. Of course, as this Committee has explored previously, the case for critical minerals is even more severe in terms of U.S. import reliance. U.S. mining policies must consider the realities of ever-increasing demands for minerals to support the transition to clean energy solutions and the electronics that accompany those technologies.

In addition to clean energy infrastructure, new technologies continue to emerge that will create further demands on minerals. The electrification of the automotive industry creates great demands on nickel, lithium, cadmium, cobalt, graphite and silver. In 2015 this industry demanded approximately 50 million ounces of silver. By 2040, the demand for silver for the production of EV, HEV, and hybrid ICE vehicles will triple to 150 million ounces per year. Emerging technologies are sure to place ever increasing demands for a broad array of minerals.

Energy independence has been a focus of many U.S. policies since the United States realized in the 1970's that dependence on foreign sources of oil compromised our position as a world leader and world power. Today, Americans are beginning to realize that our technology driven world is ever dependent on the minerals we produce. Unfortunately, the United States is heavily dependent upon the importation of critical minerals. In fact, the United States is the top producer of only two critical minerals: helium and beryllium. China is the world's top producer of 19 critical minerals and the United States' top supplier of 13 of those critical minerals. If we are going to compete in the technology race of the future and build the clean energy technologies required to improve our environment, we must grow our domestic sources of minerals and secure more favorable import partners.

Despite our vast reserves of mineral resources, the United States only accounts for seven percent of the world-wide spending on mineral exploration and production. We are currently reliant on a population of mature mining projects for our supplies and the pipeline of exploration and new projects is lacking. Unexpected permitting delays and increased risk from the U.S. permitting process discourage investment in U.S. mineral projects. Delays, risk, and higher costs often lead to mining projects becoming financially unviable. Coeur appreciates this factor better than most companies. Our Kensington gold mine in Alaska went into production in 2010 after nearly 20 years of permitting and a trip to the Supreme Court of the United States. These delays increased the capital costs of the mine by 49 percent.

While we are very proud to be a U.S. corporation and proud of our U.S. operations, we also operate in Canada and Mexico and understand how other nations can permit operations more efficiently without compromising strict environmental standards.

The Department of Interior has adopted Rules that significantly streamline the NEPA process for mining and other projects on public lands. This is a welcome change and improves confidence for mine expansion and development. Reducing the page limits of NEPA documents and placing hard deadlines on these processes is making a significant difference for mining projects while continuing to inform the public and insure we protect our environment. The U.S. Forest Service is currently undergoing a rulemaking to bring that agency more in line with the Bureau of Land Management's minerals management rules and is also reviewing their NEPA processes as well. We are hopeful these changes improve the permitting process on Forest Service lands and bring more certainty to the industry.

Coeur is dedicated to the safety of our employees, the safety of the environment and the domestic production of minerals critical to our energy future. We understand our responsibilities to the public and the environment, especially when we produce minerals from their lands, and we look forward to working with this Committee and Congress to build a bright future for the domestic production of minerals.

Sincerely,

Mitchell J. Krebs
CEO and President