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.