Written testimony of

Chibueze Amanchukwu

Assistant Professor

Pritzker School of Molecular Engineering

University of Chicago

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Pedal to the Metal: Electric Vehicle Batteries and the Critical Minerals Supply Chain

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Representative Foster, Representative Casten, and all distinguished members of the committee, thank you for the invitation to join the hearing today. I am an assistant professor in the Pritzker School of Molecular Engineering at the University of Chicago. I am honored to join the committee at this pivotal moment in the U.S. energy history, a moment that could define the next century.

Summary

The renewable energy revolution is already upon us. As the U.S. ramps up deployment of electric vehicles (EVs), EV charging infrastructure, and battery manufacturing, the battery technology most ready is the lithium-ion battery. However, as these batteries are scaled up in GWh capacities, supply chain deficiencies in cobalt, nickel, graphite, and lithium will impede the ability of the U.S. to catch up to its counterparts in Europe and Asia. The U.S. must become self-sufficient and invest not only in the production of electric vehicles, but at upstream and downstream points in the supply chain. *While continued deployment is critical, it is important that the U.S. continue to invest in fundamental research and basic science to develop alternative battery chemistries with properties that surpass that of current Li-ion*. This alternative battery chemistry strategy – through increased support for the National Science Foundation and the DOE Office of Science – is the pathway for the U.S. to regain its perch as the leader in battery technology and lead the world as it transitions. Finally, by working with universities, the US must actively train a new diverse workforce versatile with battery science and electrochemistry to build and develop the batteries of tomorrow.

In the past, the U.S. innovated in batteries, but didn't manufacture. Now, we need to manufacture <u>and</u> continue innovating.

The previous energy transition

***Key takeaway*: *The U.S. has been through energy transitions in the past and innovated its way through supply chain related challenges*. *It must do so again*.**

Amid an energy revolution, it can often be difficult to place current happenings in context since the energy landscape shifts rapidly. But we can learn from the past with other energy transitions as well as the history of the current Li-ion battery. With the advent of the internal combustion engine in the early 1900s, numerous fuels could power the engine ranging from alcohol to gasoline. There are many suggested reasons for why gasoline (and petroleum) dominated but availability and cost were the most impactful. It was easy to source, especially from the United States. And with greater innovation on crude oil processing, it was cheap. However, as car manufacturing and deployment across all sectors of society soared, the U.S. became an oil importer. Dependence on foreign oil led to the oil shocks of the 1970s that made the U.S. realize how vulnerable it had become. Hence, diversification of the supply chain is paramount. Fortunately, innovation in drilling practices such as horizonal drilling, the ability to refine sour crude (crude with high sulfur content), and the proliferation of natural gas decreased the U.S.'s reliance on foreign oil and set the U.S. on its current path as the worlds' top oil exporter.[1] Innovation allowed the U.S. to regain world dominance. *From this history, it is important to emphasize that innovation, rather than diversification alone, played a primary role in regaining independence.* This history provides a lens with which to view the challenges that will arise in the current energy transition. Innovation and fundamental science discoveries must again play a pivotal role as the U.S. lags behind Asia and Europe in electrified transport.

Learning from the past

Key takeaway: Many Li-ion battery materials have been invented by Americans or in the U.S., but translation of these discoveries to the marketplace took hold in Asia and Europe. The U.S. must remedy this by incentivizing deployment across all parts of the supply chain.

America is ingenious in its continued drive to innovate. Batteries are complex devices but can be broken down into three primary components: anode, cathode, and electrolyte. The anode consists primarily of graphite, while the electrolyte consists of a lithium salt dissolved in a solvent. Many of the current supply chain challenges can be tied to the cathode.

The predecessor for the lithium-ion battery used titanium disulfide (TiS_2) as the cathode. Although sulfur is cheap, this cathode lacked the required energy densities (energy stored per mass and volume). Innovation by American and University of Chicago alumnus John Goodenough of the lithium cobalt oxide ($LiCoO_2$ or LCO) cathode set the Li-ion battery on the trajectory it is on today. Unfortunately, cobalt is the most expensive component of the cathode, and it is geographically limited. Work done in the U.S. at the University of Texas at Austin led to the discovery of $LiFePO_4$, a cathode material consisting of earth abundant and widely available materials. However, it suffered from lower voltages and lower energy densities compared to LCO. And so, innovation and research continued. At Argonne National Lab, the discovery of the lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or NMC) cathode family decreased the cobalt content and increased the energy density. Hence, numerous electric vehicles today use the NMC cathode chemistry. Pivotal battery innovation happened here in the U.S.

Despite the U.S.-based and U.S.-led innovation in battery chemistries, America has lagged in translating these discoveries to the marketplace. Asian and European countries have been able to scale up U.S.-generated intellectual property and dominate the supply chain. Fortunately, the landscape is changing as the Bipartisan Infrastructure Bill seeks to shore up and diversify the supply chain, bringing mining and mineral processing jobs to North America. As value is added up the supply chain, onshoring battery material processing and manufacturing (anode, cathode, and electrolyte), battery cell fabrication and electric vehicle production is critical. Finally, at the end of battery life, onshoring battery recycling and reuse provides additional value-added opportunities. The recently enacted Bipartisan Infrastructure Bill (Infrastructure Investment and Jobs Act) acknowledges these challenges and provides funding and incentives to U.S. companies.

Supporting the present

Key takeaway: Current research efforts to deal with the critical mineral supply chain have focused on replacing cobalt with nickel in the cathode since cobalt is the most expensive component. However, this is only a short-term strategy. Innovation around alternative battery chemistries must continue.

As the U.S. invests in deployment and manufacturing, current innovation must continue. *Innovation focused on alternative battery chemistries beyond current Li-ion batteries is the ultimate disruptor and path to mitigating supply chain concerns and making the U.S. independent.* There are several current short-term and long-term research approaches. Promising short-term research efforts have focused on low cobalt cathodes or high nickel cathodes. While these cathodes now exist, there are no electrolytes to allow for their long-term cycling. Electrolytes are the component in the battery that allow for lithium-ion transport between the anode and the cathode. The interaction and interface between the electrolyte and anode as well as the electrolyte and cathode determine the cycle life, charging rate, and many other battery properties. *My research group at the University of Chicago Pritzker School of Molecular Engineering has invested heavily in designing new electrolytes that can allow these next generation cathodes to be used.* These electrolytes are synthesized, characterized, and studied in lithium-based batteries and my work has been supported by the National Science Foundation as well as fellowships from companies such as 3M and Toyota/Electrochemical Society. However, as the cathode chemistries focus on lowering or eliminating cobalt and increasing nickel, nickel will become an even more critical material. Hence, this strategy works only for the short-term.

Investing in the future

Key takeaway: Future alternate battery chemistries can eliminate critical materials, use earth abundant materials while enabling high energy densities for both applications in transportation and electricity generation. Continued investment in fundamental and basic science through the NSF and DOE Office of Science is critical.

As investment in manufacturing and deployment rise significantly in the U.S., it is paramount that research and development funding for alternative battery chemistries not only continue but also be prioritized. This is because the battery of the future may not yet exist today. ***That is why continued and increased funding appropriation for basic and fundamental research through the DOE Office of Science and the National Science Foundation is key.*** Unfortunately, the Bipartisan Infrastructure Bill does not explicitly fund continued R&D**.** Basic and fundamental research allows researchers to work on the alternative battery chemistry of the future that will allow the U.S. to lead and dominate the future of electric transportation. *During my PhD and postdoctoral experience and in my faculty career, I have worked on some of these experimental battery chemistries that are not ready today. But, with the right level of support and effort, these alternative chemistries hold promise much greater than the Li-ion batteries of today*.

One prominent chemistry involves completely replacing the current nickel and cobalt-containing cathodes with active materials like oxygen and sulfur. These new chemistries – termed Lithium-oxygen and Lithium-sulfur – can double the energy density of current Li-ion batteries, reduce the cost since they use abundant oxygen and sulfur, and de-risk the supply chain since these materials are available worldwide. However, these battery chemistries are plagued by the lack of suitable electrolytes. State-of-the-art electrolytes are unstable upon exposure to reactive oxygen species and lead to continued dissolution of the active sulfur active species. Research must continue on new materials, especially focused on electrolyte design.

Newer battery chemistries exist where the current Li-ion cathode is replaced by graphite. These batteries are termed dual-ion batteries as the salt anion also participates in the electrochemical reaction. While it is exciting that these batteries operate at high voltages, almost no electrolytes are stable at the high voltages they at which they operate. Again, this reinforces the need for continued fundamental understanding of electrochemical battery reactions as well as need for new materials. The afore-mentioned lithium-air, lithium-sulfur, and dual-ion battery chemistries can be deployed for transportation but also for the electric grid.

Beyond supply chain related challenges for the cathode, alternative battery chemistries that use lithium metal as the anode have been termed the 'holy grail.' The country able to solve lithium metal challenges and develop the infrastructure needed will dominate the electric future. However, there is still a dependence on lithium. Although the U.S. used to be a leading producer of lithium, the rise of cheaper extraction processes in South America (lithium brines) have usurped the U.S. position. Hence, innovation in mining – without environmental damage – and recycling/reuse is important. *I want to emphasize that these are fundamental research challenges, and if solved, can be deployed in the U.S. to lead to mining and manufacturing jobs*. Beyond lithium, there are advanced efforts for Sodium-ion (Na-ion) batteries that avoid the potential geopolitical concerns of lithium but do suffer from lower energy densities. Finally, early-stage work on aluminum, magnesium, calcium, and fluoride ion batteries must continue to diversify the battery chemistries relevant for transportation, but also for applications beyond electric vehicles.

Investing in the future through academic research also necessitates a strategy to translate academic discoveries to the marketplace. This can be accomplished by providing capital and grants as well as a supportive regulatory framework for early-stage startups in the battery ecosystem.

Training talent

Key takeaway: A diverse workforce to perform STEM research, build batteries, and manufacture electric vehicles is needed. Here, universities have a pivotal role to play in training the next generation of battery scientists and electrochemists.

Significant effort must be placed on training the talent that will develop next generation batteries, build those batteries, and manufacture electric vehicles (EVs). This is an area where universities have historically shone. To prepare the U.S. workforce and equip them with the skills needed to innovate in battery and EV design will require a targeted collaboration between the government, industry, and universities. *Training women and underrepresented minorities in science, technology, engineering, and math (STEM) is important to ensure that all segments of U.S. society benefit from the energy transitio*n. Chemical engineering, mechanical engineering, materials science, and molecular engineering curricula will have to be modernized. *A curriculum heavily dominated by the thermochemistry of the past century will need to transition to electrochemistry for the next century.*

References

1. https://www.eia.gov/international/overview/world (Accessed April 17, 2022)