Hearing of the House Committee on Natural Resources
Subcommittee on Oversight and Investigations

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Statement for the Record

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Chairman Gosar, Ranking Member Stansbury, and distinguished members of the Subcommittee. Thank you for the opportunity to appear before you today for this important hearing, "Dependence on Foreign Adversaries: America's Critical Minerals Crisis."

My name is Michael Moats, and I am a professor of metallurgical engineering and chair of the Materials Science and Engineering department at Missouri University of Science and Technology. I have dedicated my career to the production of metals, developing technology to improve these processes and educating engineers. I offer my insights gained over 30 years in industry and academia. I have worked in industry for public and private corporations that serve the mining and metal production industries. In academia, I have worked for the University of Utah and now am a faculty/administrator at Missouri University Science and Technology. Today, I offer my own opinion and views, and not those of past or current employers.

Importance of Critical Minerals

Critical minerals are elements or compounds that have been deemed by the United States government to pose a significant risk in terms of supply and impact on our country. The United States Geological Survey (USGS) has been tasked with maintaining the critical mineral list which was last published in 2022.[1] The critical mineral list is created through an analysis of three criteria: (1) the likelihood of a supply disruption, (2) the impact to the nation's economy and defense if a supply disruption occurs, and (3) if there is a significant supply risk existing. **Of the 87 elements that are used for manufacturing, 50 are on the list!** This fact alone reveals the dire situation that our country faces in terms of raw material supply as we are dependent on foreign countries, some of which are adversaries.

The importance of critical minerals can be seen in the modern devices that are important to all Americans. Gallium in the form of gallium arsenide phosphide and gallium nitride are essential for integrated circuits (semiconductor chips), laser diodes, light emitting diodes (LED)s, and radio frequency (RF) cellular used in smartphones. Tellurium is used in cadmium telluride, which is a high-efficiency solar collector utilized on 50% of the grid scale solar arrays in the United States and is combined with bismuth to produce thermal imaging night vision optics for civilian and military use. Indium is principally used as indium tin oxide in most flat panel displays and is growing in use in 5th generation (5G) fiber optic communications. Each of these critical minerals is captured during the processing of base metals. They are not mined and produced for their value alone. Therefore, the country that dominates base metal production controls the market for these minor tonnage elements.

[1] "2022 Final List of Critical Minerals", Federal Register, pp. 10381-10382, 02/24/2022.

Chinese Dominance in Base Metal Production

I was born in 1970. In that year, the United States was a mining and metal producing powerhouse. The nation produced the majority of its metal needs. We produced 31% of the world's alumina, 35% of the lead, 23% of the copper, and 17% of the world's zinc.[2] While the 1970s was a time of energy crises and concerns over foreign oil dependence, metal production did not worry our nation. A snapshot of U.S. non-ferrous mining and metal production is provided in Figure 1.

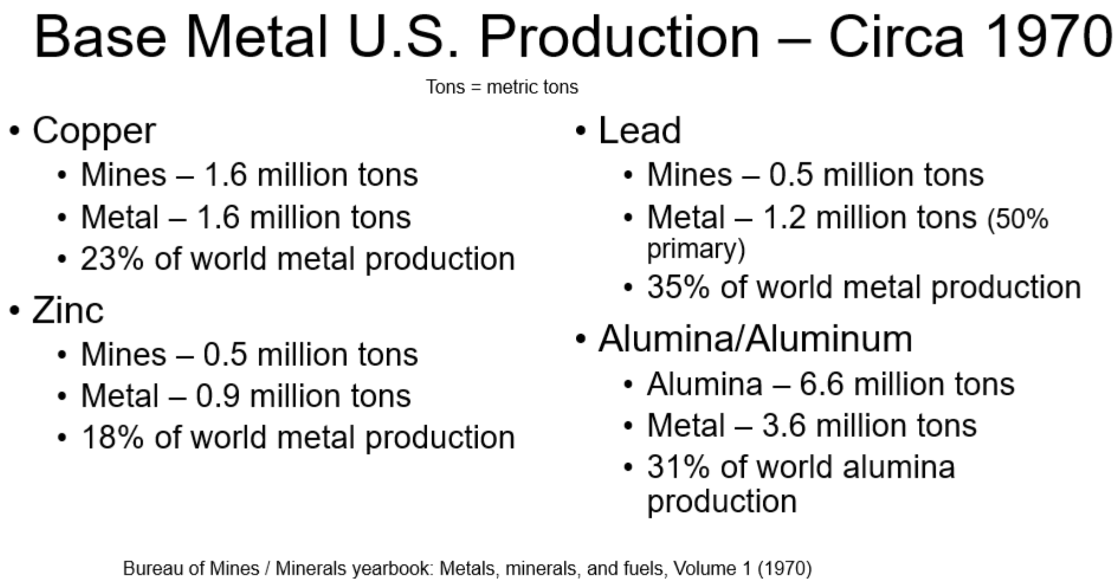

Figure 1. U.S. copper, zinc, lead and alumina/aluminum production in 1970.

However, the seeds of decline were sown during that decade which would impact domestic metal production for years to come and eventually result in American dependence on the world to supply many of the metals needed for modern living. Many countries invested in new or upgraded metal production facilities that met heightened environmental standards. This did not occur in the United States. Many U.S. smelters and refiners could not compete economically against these newer facilities due to pressures to upgrade their plants to meet tighter environmental standards and declining ore grades at local mines. The 1980s and 1990s witnessed the closure of primary and secondary smelters leading to consolidation within the industry, which resulted in few companies willing to invest in their operations to potentially meet domestic demand. By 1995, the U.S. was producing 33% less alumina and 33% less zinc as compared to 1970. Due to a significant technology advancement pioneered in Arizona, copper production increased by 44% from 1970 to 1995[3]. That advancement was an outcome of research on separation processes developed for uranium production with funding from the Department of Energy.

While the United States seemed content to outsource its metal production, China executed a different plan. This resulted in significantly different outcomes between 1995 and 2022. Figures 2-6 offer visual comparisons of mining and metal production for copper, zinc, lead, aluminum and steel in 1995 and 2022 for the United States and China.[4]

Over the past 27 years, the United States lost 30% of its copper mining capacity and 57% of its copper metal production (Figure 2). Meanwhile, China built 40 copper smelters and is presently planning to build

[2] Bureau of Mines / Minerals yearbook: Metals, minerals, and fuels, Volume 1 (1970)
[3] USGS National Minerals Information Center's Mineral Commodity 1996 Yearbook
[4] USGS National Minerals Information Center's Mineral Commodity Summaries and Yearbooks, 1995 and 2023.

four more to meet its internal demand.[5] **This resulted in Chinese copper production increasing by 1570%!** While Chinese copper mining has increased, most of China's copper is mined elsewhere (e.g., Chile and Peru) and shipped as mineral concentrate. The Chinese mineral demand to feed its smelters and refineries occurs in several metal supply chains resulting in a "Mine for China" phenomenon that has swept through developing countries with mineral resources. China now produces 42% of the world's refined copper, while the United States produces only 4%.

In 1995, the United States and China mined and smelted similar tonnages of zinc (Figure 3). During the past 27 years, China has increased its zinc production by 580% and now produces 45% of the world's zinc. Meanwhile, U.S. production has declined 63% and only accounts for 2% of the world's zinc. Zinc was added to the 2022 Critical Mineral list by the USGS.

Lead mining and metal production declined in the United States by 28% and 21% from 1995 to 2022 (Figure 4). Domestic lead metal production has shifted completely to recycling with the last primary smelter in Herculaneum, Missouri, closing in 2013. Lead mining, smelting and battery production provides a $2.3 billion impact on the Missouri economy[6] and is still critical for all automobiles including EVs[7]. Again, while the U.S. lead production declined, Chinese production expanded dramatically. **Between 1995 and 2022, China expanded in lead mine and metal production by 465% and 1210%, respectively!** China now produces 44% of the world's lead.

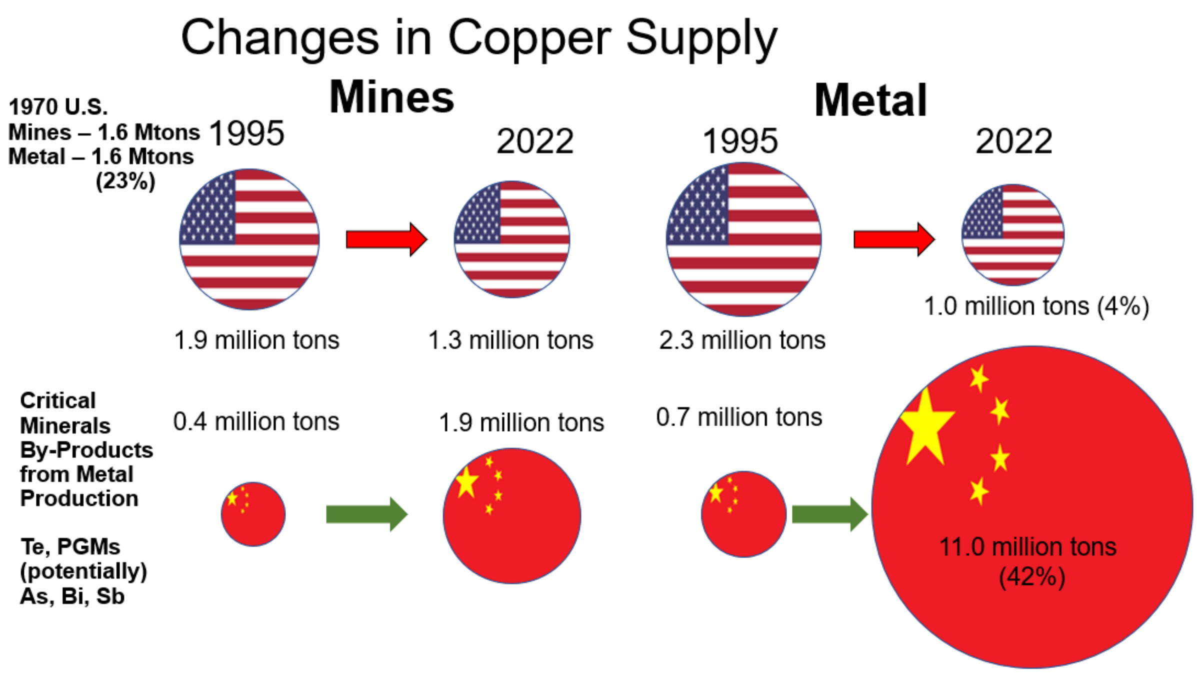

Figure 2. Changes in copper mine and metal production from 1995 to 2022 for the United States and China.

[5] Based on information made by Wang Wei (NFSoc) during his presentation "Development of copper metallurgy technology in China" on November 16, 2022, at the Copper 2022 Conference in Santiago, Chile.
[6] Doe Run Company Fact Sheet. Downloaded on 1/31/2023 from https://doerun.com/wp-content/uploads/2021/03/2021_Doe_Run-Economic_Impact-Fact_Sheet-08.pdf
[7] "How lead batteries could make EVs safer", World Economic Forum, Aug 9, 2021.

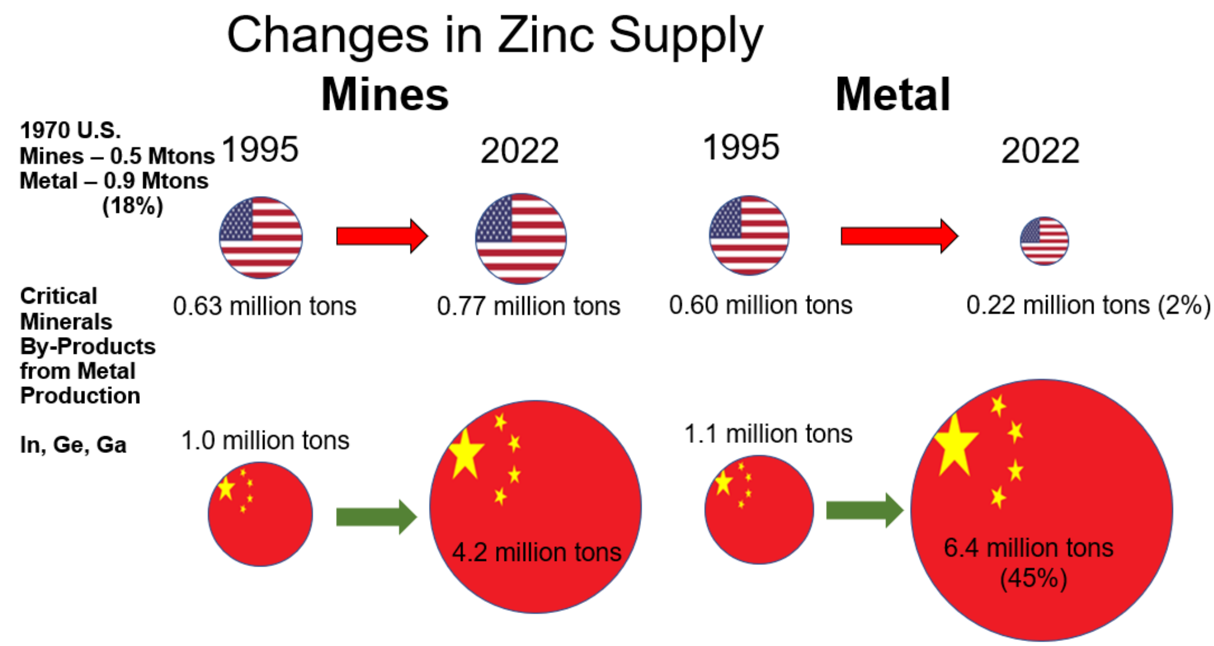

Figure 3. Changes in zinc mine and metal production from 1995 to 2022 for the United States and China.

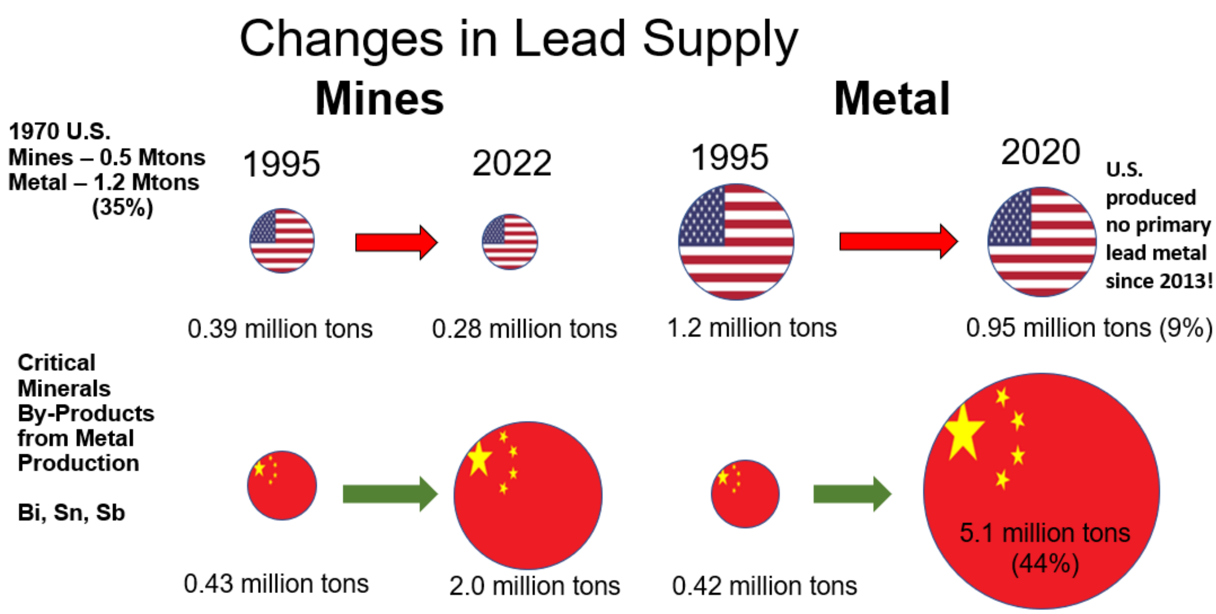

Figure 4. Changes in lead mine and metal production from 1995 to 2022 for the United States and China.

Similar expansions and dominance in Chinese production of aluminum and steel also occurred (Figures 5 and 6). Steel and aluminum are two of the major building materials for human civilization. They are critical for infrastructure, transportation, and defense. While "critical minerals" like rare-earths and battery metals have garnered headlines and grabbed the attention of many, the astonishing production increases by the Chinese in alumina, aluminum and steel have completely re-shaped the world's metal markets.

In alumina and aluminum, the Chinese have increased their production by 3450% and 2100% in the past 27 years! They now produce 54% and 58% of these materials needed for lightweight transportation, construction, consumer goods and military applications. At the same time, the U.S. production has decreased by 74% in both alumina and aluminum. Aluminum is considered a critical mineral by the United States.

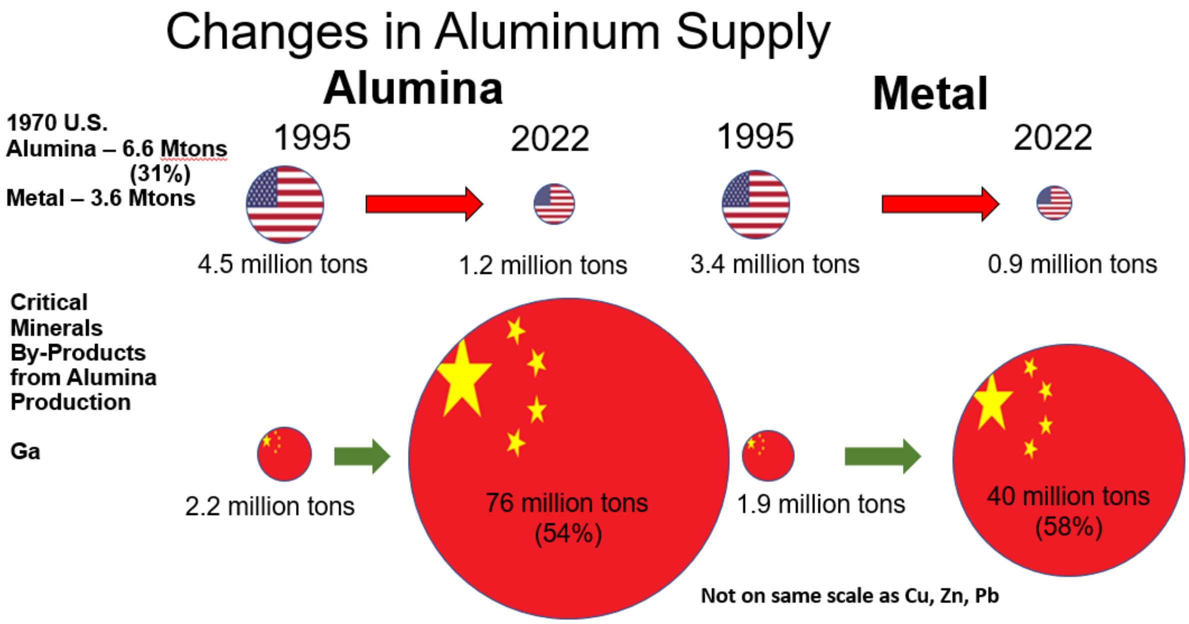

Figure 5. Changes in alumina and aluminum production from 1995 to 2022 for the United States and China.

China dominates the world's steel production with a staggering 990 million metric tons produced in 2022 (54% of the world's total). **China's steelmakers have increased their outputs by 1100% from 1995 to 2022**. China now produces enough steel each year to produce 14,000 Nimitz class aircraft carriers. Again, while China expanded, the United States struggled to maintain its steel mills and declined by 14% over the same period.

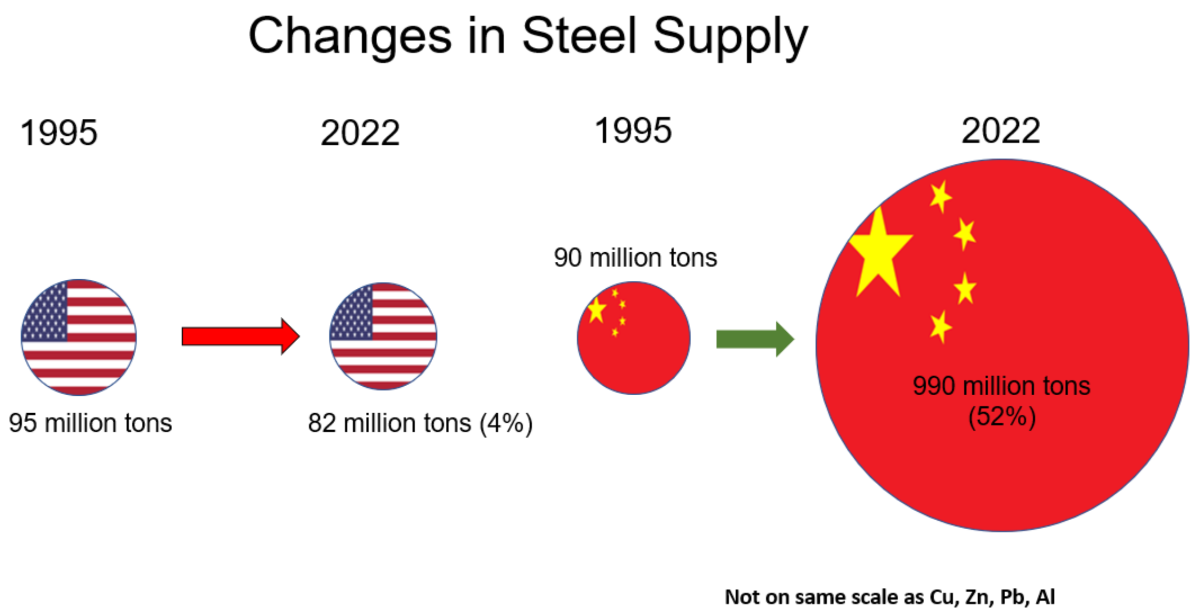

Figure 6. Changes in steel production from 1995 to 2022 for the United States and China.

Chinese Dominance in Critical Minerals from Base Metal Production

A consequence of Chinese base metal dominance is its control of minor by-products that are captured during refining. Many of these by-products populate the U.S. Critical Mineral list.[8] Gallium, needed for advanced electronics, is recovered from alumina production. Tellurium, used in high efficiency solar panels and military grade night vision optics, is collected during copper refining. Indium, used in touch screens, is produced from zinc refining. Chinese dominance in several non-rare earth critical elements captured during base metal processing and refining are summarized in Table 1.

Table 1. Chinese Percentage of the World's Primary Production for Gallium, Tellurium, Indium and Germanium.

Critical Mineral	Chinese Portion of World Production, 2022
Gallium (Ga)	98%
Tellurium (Te)	53%
Indium (In)	59%
Antimony (Sb)	55%
Bismuth (Bi)	80%

United States Metal Needs Examined

Inherent to analyses and discussions related to metal production is what are the needs of the United States. Using data from the USGS (2018-2021), a comparison of mining and metal production that occurs in United States, Canada and Mexico to U.S. Consumption for aluminum, copper, zinc, lead and nickel is presented in Table 2.

[8] "2022 Final List of Critical Minerals", Federal Register, pp. 10381-10382, 02/24/2022.

Table 2. Mining and metal production of five metals compared to U.S. consumption (1000's metric tons).

Base Metal	Mining			Smelting – Primary (Secondary)				U.S. Consumption
	U.S.	Canada	Mexico	U.S.	Canada	Mexico	N.A.	
Aluminum	0	0	0	880 (3160)	3100	0	3980	4300
Copper	1200	590	720	950 (50)	300	470	1720	2000
Zinc	740	260	720	240	680	110 (170)	1283	960
Lead	300	20	270	0 (990)	110 (140)	140 (330)	(1710)	1600
Nickel	18	130	0	0	133	0	133	210

Values are 1000's metric tons. Data are values reported by USGS (2018-2021).
Nickel is undefined product. Zinc data modified based on author knowledge.

These data indicate that through recycling (secondary), the U.S. can produce most of the aluminum it consumes and Canada with its "aluminum valley" can supply higher purity metal as needed. The United States is completely dependent on mining of bauxite (aluminum ore) that occurs in other countries. There appears to be a deficit in copper, zinc and lead metal production in the United States as compared to our mining. The country exports mineral concentrates of copper, zinc and lead and then imports refined metal. This results in losses in jobs and critical mineral production. Existing smelters could be expanded, or new ones constructed. The United States relies on its allies for copper, zinc, and lead metal production.

I have tried to avoid a discussion of battery metals and rare earths to this point because these elements seem to dominate the news and government focus. In short, the data shown in Table 2 reveal that the U.S. produces zero tons of primary nickel metal. The same is true for cobalt metal and rare earths. The U.S. is entirely dependent on other countries for these refined metals. Rare-earth, nickel and cobalt mining does occur in the United States, but not to the level needed for our consumption. Rare-earth mining and production including magnets is controlled by China and the U.S. has no refining capacity. Chinese companies have acquired many of the cobalt mines in Central Africa and refined the materials in China, so they control this critical element as well.

Closing Remarks

When I chose to pursue a Ph.D. in extractive metallurgy in 1995, I was warned by senior colleagues to select a different field of study. They warned I would chase ever decreasing research budgets and opportunities. For most of the past 27 years, this has been true. In the past few years, the U.S. federal government has awoken to the problems we face in metal production. The difficulties caused by the global pandemic and heightened geopolitical tensions have only increased federal concerns.

Federal funding is needed to overcome the uneven playing field caused by China's massive build-up of its metal producing capacity. Funding is also needed to ensure all existing smelters, refineries and mills are updated to maintain their international competitiveness. If the United States does not reverse the trends in metal production, we will continue to depend on others for our economy and defense which has increasing become controlled by current or potential adversaries.

In the past few years, I have studied critical minerals in base metal supply chains and have been helping domestic metal producers to develop processes to capture critical minerals. Projects to recover more tellurium, gallium, germanium, indium, nickel, and cobalt from U.S. resources are on-going. I have provided input into federal policy discussions and project selection. I have participated in the annual critical minerals workshop at Missouri S&T sponsored by the National Science Foundation to connect and engage researchers and industry. There is still significant work to be done to create process to recover critical minerals from domestic sources.

Universities focused on mining and metallurgy are doing our part, but we have suffered from underfunding for decades like the U.S. metal production facilities. As the country looks to onshore mining and metal production, highly trained personnel will be needed to design, build and operate these mines, smelters and refineries. Federal assistance to support the remaining mining and metallurgy schools is much needed.

In closing, I wish to thank the subcommittee for this opportunity to present information on the implications of depending on our foreign adversaries for critical minerals, and why it is imperative that we work to solve America's critical minerals crisis. I hope the data and analysis that I presented before you today will help to inform policy discussions regarding the importance of critical minerals. Thank you for the opportunity to testify and I look forward to any questions you may have.