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Chairman Hickenlooper, Ranking Member Braun and distinguished members of the subcommittee, thank you for the opportunity to testify today on the growing importance of our critical minerals workforce.

With over 40 years of experience in the global mining industry, I have seen firsthand the value the minerals industry brings to the economy, local communities and living standards. Critical minerals are the building blocks of medicines, semi-conductors, defense systems, clean energy and more.

I have also seen examples of the damage mining can have on communities and ecosystems in the U.S. and abroad, if not done properly or responsibly. This includes lasting environmental damage, unacceptable labor practices and legacy waste sites which are difficult to repair or remediate. These competing realities complicate perceptions of a mining industry that is vital to our economy, energy future and national security.

My experience has taught me that when it comes to minerals and their role in our modern world, our most critical resource is our people— skilled professionals equipped to responsibly manage our earth's resources and solve complex engineering and social challenges.

It is for this reason that I returned from semi-retirement to mining education—first as a professor of practice. Today, I serve as the Head of the Mining Engineering Department at Colorado School of Mines (Mines), home to the top ranked mineral and mining engineering program in the world.[1] Our world-class faculty support interdisciplinary education and research covering all aspects of the mining and mineral life cycle—from exploration, extraction and processing to recycling, mine closure and reclamation, as well as water management, community engagement, occupational health and safety, mineral economics and supply chains. Our broad scope of study also includes space mining and deep underground mining and construction.

[1] QS Top Universities. (2024). *University subject rankings: Mineral & mining engineering*. https://www.topuniversities.com/university-subject-rankings/mineral-mining-engineering

Mining and Minerals Workforce Challenges

As global demand for critical minerals has surged, largely in response to energy goals, there is a growing recognition that achieving these goals will consume more minerals and require more mining.

The International Energy Agency (IEA) estimates that to meet demand for clean energy technologies by 2040, the world will need 42 times as much lithium compared to 2020—25 times more graphite, 21 times more cobalt and 19 times more nickel.[2] According to Benchmark Mineral Intelligence, at least 284 new mines will need to be built globally to meet electric vehicle demand by 2035.[3] The challenge is compounded both by the scarcity of economically viable deposits and the length of time required to characterize, permit and develop a new mine.

It is well documented that for most critical minerals, the U.S. is heavily reliant on foreign sources for its consumption requirements[4]— many of which are mined and processed in adversarial nations with low or unenforced environmental, labor and human rights standards. While the U.S. was once the global leader in mineral development, we have ceded that leadership position. Nonetheless, there are important and impactful new mineral developments being advanced throughout the country, including for lithium, copper, manganese, nickel and cobalt.

At the same time, it is estimated that half of the U.S. Mining workforce, about 220,000 people, will retire by the end of the decade, and the talent pipeline is not sufficient to replace experienced professionals in mining engineering or other related disciplines.[5] The minerals and mining workforce includes a broad range of skilled professionals including technicians, engineers and scientists trained in geology, hydrology, metallurgy, chemistry, community engagement and social science, business and economics, data science, health and safety, mine closure and reclamation and more.

Today, there are 14 mining engineering programs in the U.S.—down from 25 in 1982. Last year, these mining schools collectively enrolled 590 undergraduate students, graduating just 162

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[2] International Energy Agency. (2021). *The role of critical minerals in clean energy transitions: Executive summary*. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

[3] Hodgson, C. (2023, May 1). *More than 300 new mines required to meet battery demand by 2035*. Benchmark Mineral Intelligence. https://source.benchmarkminerals.com/article/more-than-300-new-mines-required-to-meet-battery-demand-by-2035

[4] U.S. Geological Survey. (2023). *Mineral commodity summaries 2023* (Report No. 2023-3000). U.S. Department of the Interior. https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf

[5] Society for Mining, Metallurgy & Exploration. (n.d.). *Workforce trends in the US mining industry*. https://www.smenet.org/What-We-Do/Technical-Briefings/Workforce-Trends-in-the-US-Mining-Industry

students for an industry demand of 400-600 new mining engineers each year.[6] In comparison, China's 45 mining engineering programs currently enroll about 12,000 students and graduate approximately 3,000 a year—about 16 times the number of graduates in the United States.[7]

Declining enrollments are the result of a combination of factors, including limited knowledge or experience with the industry, the globalization of mining operations, an industry image that associates mining with adverse environmental impacts, as well as a perception of an unsafe workplace.

It is imperative that we—industry, academia and society—thoughtfully address these concerns and demonstrate that careers in mining engineering are rewarding, technology-driven and impactful. Absent a meaningful shift in perceptions, the best and brightest students and leaders will pursue opportunities in other competitive fields.

A New Vision for the Future of Mining

In response to these challenges, Mines is advancing a compelling new vision for the future of mining that aligns with students' passion for environmental stewardship. This vision also integrates advanced technologies and sustainable mining practices to increase productivity, minimize environmental impact, improve safety and optimize resource utilization.

While undergraduate enrollment in Mining Engineering at Mines, like other mining schools, has experienced a decline in enrollment, there are signs of a rebound. In Fall of 2023, Mines' undergraduate Mining Engineering enrollment increased by 22% from the prior year, with just over 100 students enrolled in the Mining Engineering program.

This rebound is attributed, in part, to a focus on first and second-year students who are undecided or not yet strongly committed to their major. With climate change at the forefront of many of our students' concerns, informing students of the world's essential critical mineral applications and the need for innovative leadership appeals to their inherent sense of purpose and desire to solve the most complex challenges. Also, promoting strong stewardship of natural resources to create sustainable development and prosperity for communities, tribes, governments and other stakeholders speaks to students' altruistic desire to positively impact the world. Thus, we teach

[6] Society of Mining Professors and Society for Mining, Metallurgy & Exploration, 2021; data collected by Vlad Kecojevic. National Academies of Sciences, Engineering, and Medicine. 2024. Building Capacity for the U.S. Mineral Resources Workforce: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/27733.

[7] National Academies of Sciences, Engineering, and Medicine. (2024). *Building Capacity for the U.S. Mineral Resources Workforce: Proceedings of a Workshop*. Washington, DC: The National Academies Press. https://doi.org/10.17226/27733.

the essential link between mining, minerals, responsible resource management, sustainable energy, and community and societal benefits.

Informed by regular input and support from industry partners, the Mining Engineering curriculum extends far beyond the basic foundations of geology and mine operations. Students take classes in waste, water and tailings management and social and community engagement. Our Mining Department faculty also includes an anthropologist, highlighting the need for both technical and social awareness to understand projects within the context of the environment, communities and society.

Furthermore, our industry partners consistently share that today's mining operations require talent from various disciplines, including expertise in mechanical, electrical, civil, environmental, chemical, petroleum, and humanitarian engineering—and need to extend to economics, computer science, data science, risk management, statistics and math. We believe promoting a Minor in Mining Engineering to students in these disciplines can also help draw non-mining engineers to the sector.

As a result, Mines graduates are highly sought after by industry, academia and government, serving in roles that range from mine planning, extraction and processing, mine remediation and reclamation, community engagement, business and finance, public policy and regulatory compliance.

Mines is also strengthening diverse pathways into engineering careers by actively working with Colorado's community colleges to expand opportunity and access to all Mines engineering degrees, including Mining Engineering. Mines Academy is a program that puts community college students on a direct pathway to a bachelor's degree from Mines after completing a two-year Associate of Engineering Science degree at a participating community college, which includes minority-serving institutions.[8]

Beyond aligning students' interests with the world's need for critical minerals, Mines also engages in more traditional outreach programs such as career information workshops, highlighting opportunities that include readily available scholarships and internships and near 100% graduate job placements in well compensated positions that offer unique lifestyle opportunities.

[8] Colorado School of Mines. (n.d.). *Mines Academy*. https://www.mines.edu/undergraduate-admissions/mines-academy/

Mining & Minerals Innovation

Mines' vision for the future of mining also recognizes the transformational role that research and innovation can and must have on the future of mining. Research—and strong research funding—is critical to inspire the most talented minds to tackle the most pressing mining-related challenges. It is also necessary to recruit and retain the next generation of mining and mineral faculty and educators that support and sustain mining engineering programs.

The mining industry faces significant changes due to evolving social and environmental conditions, technological advancements, development costs, market fluctuations and the need for sustainable mining practices. For example, future mines will likely need to be self-sufficient in power and water to avoid competing with local communities, relying on renewable energy systems to support decarbonization efforts.

Advanced technologies and techniques—robotics and artificial Intelligence (AI), drilling innovations, brines extraction, advanced separations, coproduction processes, digital subsurface applications, tailings management, recycling and more—will be critical to create an economically viable industry that generates net positive impact for stakeholders.

Specific advances expected to evolve from applied technological innovation include mine design algorithms that will incorporate social license considerations. Advanced analytics, machine learning and AI will enhance operations by reducing costs and improving dispatch systems, ore sorting, recycling, ore control, maintenance and downtime. Safety advancements will focus on operator fatigue, collision avoidance and vehicle intervention systems. Autonomous equipment like trucks, drills, loaders and dozers will improve safety and efficiency, while drones and robots will handle tasks traditionally performed by humans.

The research community, including the Colorado School of Mines, is actively engaged in applied research of semiconductors, clean energy, and advanced technologies—all of which require critical materials. These strategic investments, supported by the CHIPS and Science Act, the Bipartisan Infrastructure Law and the Inflation Reduction Act, have focused on downstream processing and battery manufacturing, but have not included investments in next generation mining innovation and research and development.

Since the dissolution of the Bureau of Mines in 1996, largely for budget reduction purposes, there has been no federal program dedicated to improving mining technology and processes for sourcing critical minerals more efficiently and responsibly at home or abroad. Investments in research not only address the mining industry's most pressing economic, environmental and sustainability challenges, they also support a strong academic community, which is essential for developing a skilled workforce.

Research Centers & Partnerships

Central to Mines' vision for the future of mining is partnerships with industry, national labs, academia, government and communities, and a commitment to listen, innovate and co-create advanced mining technologies and processes.

More broadly, mining innovation is intended to support community engagement and regulatory acceptance, develop a skilled workforce and inform mining and mineral policies that ensure a responsible, sustainable, and economically viable domestic mining industry.

Mines serves as the academic lead of the Department of Energy's Critical Material Innovation Hub (CMI), which carries out scientific and engineering research to facilitate more diverse primary supply chains, more efficient manufacturing, reuse and recycling, as well as the development of new materials. In addition, the Center for Resource, Recovery and Recycling (CR3), affiliated with Mines' Kroll Institute for Extractive Metallurgy both have direct application in the recovery of critical minerals through primary processing or secondary and recycling processes. Mines' Tailings Center is an industry-university consortium focused on applied and basic research in tailings and mine waste management, as is the NSF-supported Center for Advanced Science and Exploration to Remediation of Mining (CASERM), a partnership with our colleagues at Virginia Tech.

Additionally, with the support of the Bipartisan Infrastructure Law, the U.S. Geological Survey (USGS) is constructing the new USGS-Mines Energy and Minerals Research Facility on the Mines campus. The new facility will house the USGS Geology, Geophysics and Geochemistry Science Center, and Central Energy Resources Science Center.[9] More importantly the partnership will strengthen collaboration between USGS scientists and Mines faculty and students to advance research on topics including critical mineral origins, supply chains and markets, as well as educate the next-generation workforce that will support the critical materials sector.

Conclusion

The future of mining vision begins with the workforce—and will require active engagement from industry, academia, communities, and government. This effort will take time, resources, and most importantly a coordinated strategy. In that regard, Mines supports legislative efforts,

[9] U.S. Geological Survey. "Energy and Minerals Research." U.S. Department of the Interior, https://www.usgs.gov/special-topics/bipartisan-infrastructure-law-investments/science/energy-and-minerals-research. Accessed 7 June 2024.

like the bipartisan *Mining Schools Act* (S. 912), which would establish a grant program for mining schools to recruit students and support programs in relevant mining and mineral fields.

A strong minerals workforce will also require a new social relationship with the earth's resources, supported by industry, academia (P-20), and government—a relationship that draws direct connections between the mineral workforce and the economy, energy future, environmental protection and national security.

Mining schools play a crucial role in growing our nation’s critical mineral capabilities through both education and research. The opportunity before us is to engage and inspire the next generation of mining and mineral leaders with a passion for impactful careers in an industry innovating to support a sustainable environment.

Colorado School of Mines is committed to this vision and working with all stakeholders to reestablish our mineral workforce as a critical element of our economic, energy and security future.

Thank you.