MINER— Mining Innovations for Negative Emissions Resource Recovery

PROJECT DESCRIPTIONS

University of Texas at Arlington – Arlington, TX

RECLAIM: Electrochemical Lithium and Nickel Extraction with Concurrent Carbon Dioxide Mineralization - $2,999,997

The University of Texas at Arlington will develop acoustic stimulation and electrolytic proton production to produce lithium (Li) and nickel (Ni) from CO_2-reactive minerals and rocks that contain calcium (Ca) and magnesium (Mg), while sequestering CO_2 in the form of carbonate solids. The technologies use electricity to extract valuable metal ions from the surrounding mineral matrix at sub-boiling temperatures. Feedstocks will include Li/Ni/Ca/Mg-rich igneous and sedimentary minerals. First, an electric potential will be applied to water to simultaneously produce acidity and alkalinity. The solid feedstocks will be dissolved in the acidic anolyte under acoustic stimulation. Exposure of calcium hydroxide and magnesium hydroxide to CO_2 will result in CO_2 sequestration.

Columbia University – New York, NY

Hydrometallurgical Production of Domestic Metals for Energy Transition - $2,949,395

Columbia University (Columbia) will develop new processes with lower environmental impact to obtain energy relevant metals from mines that are olivine rich at lower cost than state of the art processes. Olivine is a CO_2-reactive waste product that can be returned as tailings after capture carbon from the air. Columbia will improve the yield of nickel (Ni) and copper (Cu) from its partner mining operation, simultaneously increasing the amount of carbon captured per kg of metal. Innovations are based on a recent discovery of rapid mineral-leach kinetics with reagents that can be regenerated by an electrochemical process inspired by flow-battery technologies. The chemistry and process may enable the replacement of smelters for processing sulfide minerals. The technology has been proved for copper-sulfide minerals, which will improve the yields of Cu and ultimately Ni.

Travertine Technologies – Boulder, CO

Ex Situ Tailings Leaching and Lateritization with Electrolytic Acid Recycling for Critical Metal Concentration and Mineral Carbon Sequestration - $2,000,000

Travertine will launch a transformative process that integrates strong acid treatment of mining waste or tailings with electrolytic acid recycling. Leached critical elements are recovered as oxides, while carbonate minerals are precipitated using carbon dioxide (CO_2) from the air. Travertine will develop the design basis for a 1 ton/day CO_2 removal system to demonstrate the technical feasibility and commercial viability of this concept, taking it from proof-of-concept to field-ready. If successful, the project will offer a commercially viable approach that will maximize critical element yield from domestic resources while minimizing environmental impacts and potentially sequestering hundreds of millions of tons of carbon dioxide every year.

Harvard University – Cambridge, MA

Developing Advanced NMR Techniques to Predict And Monitor CO_2 Storage and Mineralization for Enhanced Mining Exploration and Operation - $1,889,308

Harvard University (Harvard) will develop advanced nuclear magnetic resonance (NMR) methods for evaluating the chemistry of CO_2 mineralization in CO_2 reactive rocks. Reactions with these rocks enables the permanent sequestration of CO_2, and promotes enhanced mineral extraction. Mineralization reactions occur only in pores occupied by CO_2; thus, understanding CO_2 transport and distribution in rock porosities is key to efficient mineralization and sequestration. NMR well-logging allows accurate evaluation of CO_2 reactive rock formations to optimize field development for the economical deployment of mining and carbon storage. Harvard will expand the productive fields for CO_2 injection and enhanced mining by 100%.

Pacific Northwest National Laboratory – Richland, WA

Re-Mining Red Mud Waste for CO_2 Capture and Storage and Critical Element Recovery (RMCCS-CER) - $1,000,000

Pacific Northwest National Laboratory (PNNL) will advance in-situ and ex-situ techniques to determine the solubility and thermodynamic properties of various sodium rare earth element (REE) carbonates, REE (hydroxy)carbonates, REE phosphate, and REE (oxy)hydroxides in various solutions and pressures and temperature conditions, with or without the presence of carbon dioxide (CO_2). The team will use the results to construct a database for optimizing conditions that efficiently recover energy-relevant minerals in red mud waste.

University of Nevada, Reno – Reno, NV

Accelerated Reactive Carbonation Process (ARCP) for Energy Efficient Separation of Rare Earth Minerals – $3,300,000

The University of Nevada, Reno, will develop and test an accelerated reactive carbonation process to enable improved mineral liberation, energy-efficient comminution (grinding), and enhanced separation of rare earth elements from low-grade bastnaesite-bearing ores. High-pressure grinding rolls will pre-crush the ores to generate internal micro-cracks that will facilitate the subsequent carbonation and grinding process. The carbonation reaction will convert REE-bearing silicate minerals to REE-bearing carbonate minerals. The carbonation reaction from silicate to carbonate will soften the minerals, therefore reduce the comminution energy by 50% and increasing the total REEs yield by at least 20%.

Missouri University of Science and Technology – Rolla, MO

Reduce Comminution Energy and Improve Energy Relevant Mineral Yield using Carbon-Negative Oxalatization Reactions - $2,045,715

Missouri University of Science and Technology aims to establish a novel pathway to extract energy-relevant minerals, such as nickel and cobalt, from CO_2-reactive and low-grade silicate feedstock (e.g., lean ore, mine waste, and geologic formations) via a novel pretreatment using a CO_2- or biomass-derived organic acid that can dissolve silicates efficiently and liberate metals. The progressive dissolution will be followed by the precipitation of oxalate products, turning the bulky silicate rocks into micron-sized crystal particles and amorphous silica. The micron-sized crystal particles reduce the need for energy-intensive comminution during mineral beneficiation, and the separated crystalline oxalates will be further processed using hydrometallurgical approaches to separate the desired energy-relevant minerals.

The University of Texas at Austin – Austin, TX

Carbon Negative Reaction-Driven Cracking for Enhanced Mineral Recovery: In-Situ Test at a Ni-Co-PGE Deposit-$4,997,015

The University of Texas, Austin, will conduct an in-situ injection of CO_2 dissolved in water to (1) permanently sequester CO_2 via carbon-negative reactions (carbon mineralization), (2) chemically fracture the rock via reaction-driven cracking before mining to reduce extraction and comminution energy by at least 50%, (3) replace the CO_2-reactive rock waste with carbonate to reduce energy needed for separation, improve concentrate grade, and increase ore recovery, and (4) expand the lifespan of the mine as a CO_2 sink once the ore is exhausted. The methodology applies to ultramafic rock-hosted mining operations worldwide, is easily scalable, and can be combined with chemical enhancement and subsequent ex-situ carbonation steps to maximize CO_2 sequestration and critical mineral yield to combat climate change and secure the U. S. critical mineral supply.

Idaho National Laboratory – Idaho Falls, ID

Integrated Electro-Hydraulic Fracturing and Real-Time Monitoring for Carbon Negative In-Situ Mining - $3,143,000

Idaho National Laboratory (INL) will develop a novel mineral extraction technology to transform CO2-reactive, impermeable, low-grade ores for in-situ mining, recovery of energy-relevant minerals, and CO2 storage. Once the technology achieves maturity, it could potentially replace costly, energy-intensive, high-carbon footprint underground/open-pit mining. INL will stimulate mafic-ultramafic ore bodies using an innovative electric hydraulic fracturing method followed by in-situ circulating of optimized metal leachate charged with CO_2 for energy-relevant mineral leaching and CO_2 mineralization. The joint in-situ mining and carbonation concept can provide up to 80% recovery of targeted energy-relevant minerals and mineralize up to 60wt% CO_2.

Colorado School of Mines – Golden, CO

Block Modeling of the Carbonation Potential of Ore Deposits Using Cutting-Edge Core Scanning Technology and Advanced Machine Learning Algorithms - $1,159,337

The Colorado School of Mines will develop a novel technological solution to enable mining companies to quantitatively model the carbonation potential of CO_2-reactive copper-nickel-platinum-group element ore deposits using cutting-edge X-ray fluorescence core scanning technology and advanced machine learning techniques. The quantitative models will allow the first of its kind cost-benefit analysis of the total carbonation potential of ore deposits to demonstrate that adapting negative emission technologies will become an integral part of mine feasibility studies.

Michigan Technological University – Houghton, MI

Energy Reduction and Improved Critical Mineral Recovery from Low-Grade Disseminated Sulphide Deposits and Mine Tailings - $2,467,817

Michigan Technological University (MTU) will achieve a decrease of 10 wt% CO_2 equivalent per tonne of ore processed compared with the current methods for primary nickel extraction by storing CO_2 in CO_2-reactive minerals and recovering 80% of energy-relevant minerals from both sulfide and nickel-bearing silicate minerals in mine tailings. MTU will demonstrate (1) 200 kg of CO_2 storage per tonne of magnesium-rich and iron-rich silicate minerals in mine tailings within 4 hours after processing with 10% energy reduction compared with state-of-the-art, and (2) a recovery of 50-80% yield of nickel from domestic low-grade disseminated sulfide ores. An estimated 2.2 million tonnes of CO_2 per year will be sequestered in mine tailings that are permanently and safely stored with a decrease of 100 kg of CO_2 equivalent per tonne of ore processed.

Virginia Polytechnic Institute and State University – Blacksburg, VA

Energy-Relevant Elements Recovery from CO_2-Reactive Minerals During Carbon Mineralization - $2,200,000

Virginia Polytechnic Institute and State University (Virginia Tech) will develop an innovative carbon mineralization/metal extraction technology (CMME) that enables the recovery of energy-relevant elements during direct and indirect carbon mineralization processes. Virginia Tech will introduce an organic phase during the direct carbon mineralization process and in the mineral dissolution step of indirect carbon mineralization process. Energy-relevant elements are extracted into the organic phase immediately after being dissolved, while alkaline-earth and other major elements remain in the aqueous solution for carbon mineralization. Energy-relevant elements in the organic phase can be further purified and separated through advanced separation technologies. Virginia Tech will test the CMME technology on low-grade mafic/ultramafic rocks and allanite ore, which could supply huge reserves of nickel, copper, and rare earth elements.

Johns Hopkins University – Baltimore, MD

Carbon-Negative Mining from Gangue Minerals Enabled by Energy-Efficient Electrosynthesis of Acid and Base - $2,000,000

Johns Hopkins University will develop sustainable mining of critical elements, such as manganese (Mn), cobalt (Co), nickel (Ni), copper (Cu), etc., from gangue minerals. The technology is based on robust acid-base chemistries and renewable electricity as the power source. It will enable the use of unconventional mineral sources for mining of energy-relevant critical metals. It will also avoid high-temperature thermochemical processing, minimize the discharge of hazardous chemical wastes and substantially reduce the carbon emission of mining industries. The proposed process represents a sustainable approach toward increasing domestic supplies of critical materials required for the transition to clean energy.

Columbia University – New York, NY

Innovative Stirred Media Mill Reactor with Integrated Carbon Mineralization and Electrochemical Separation of Critical Metals (critical SMM-e) - $2,500,000

Columbia University will develop a more energy efficient, highly integrated renewable-energy-driven carbon mineralization and metal recovery technology from low-grade ores. The concept will enable concurrent metal valorization and CO_2 sequestration via an autogenous, reactive comminution reactor system that can simultaneously provide high specific surface area mineral particles and accelerate mineral dissolution by removing silicon-rich passivation layers. This approach reduces comminution energy consumption and can be coupled with sustainable carbon mineralization and electrochemical recovery of key energy minerals using selective oxidation and reduction pathways.

University of Kentucky Research Foundation – Lexington, KY

Development of a Carbon-Negative Process for Comminution Energy Reduction and Energy-Relevant Mineral Extraction through Carbon Mineralization and Biological Carbon Fixation - $3,500,000

The University of Kentucky's proposed technology will use CO_2 emitted at or near operating mines and processing operations to reduce the energy consumed during grinding by more than 50% while improving the recovery of critical energy relevant minerals by 20% or greater. In this approach, CO_2 will be mixed with ore containing the valuable minerals, especially copper (Cu) and rare earth elements (REE), to improve the efficiency of grinding and separation. Additionally, biological fixation of CO_2 will be studied and employed in producing acid that can be used to recover Cu from low grade feedstocks. If successful, the project will provide a novel carbon-negative process using waste CO_2 to increase the amount of recoverable valuable energy-relevant minerals.

Phoenix Tailings – Woburn, MA

CO_2 GONE – CO_2 Gasification of Ore for Nickel Extraction - $1,275,000

Phoenix Tailing's CO_2 GONE process uses and recycles carbon dioxide (CO_2) to extract energy-relevant minerals, primarily nickel (Ni) and magnesium (Mg), from iron- and aluminum-rich ore through carbonation with CO_2. Using CO_2 with high pressures, temperatures and mixing breaks the rock structure and allows for greater extraction of energy relevant elements like Ni and Mg, which are then converted to metal carbonates ($NiCO_3$, $MgCO_3$). The resulting $NiCO_3$ and $MgCO_3$ are chemically separated by ammonia (NH_3) and refined to generate high-purity nickel oxide (NiO) and magnesium carbonate. The process is carbon negative, sequesters CO_2, and recycles CO_2 and NH_3 to keep the system operating efficiently.