Lignite Research, Development and Marketing Program

North Dakota Industrial Commission

Application

Project Title: Efficient Refining of Germanium Metal from Fly Ash-Derived Concentrates

Applicant: Microbeam Technologies Incorporated

Date of Application: October 1, 2025

Amount of Request: $400,000

Total Amount of Proposed Project: $1,200,000

Duration of Project: 24 months

Point of Contact (POC): Alex Benson

POC Telephone: 701-330-0308

POC Email: abenson@microbeam.com

POC Address:

4200 James Ray Drive, Ste 193
Grand Forks ND 58202-6090

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ABSTRACT

Objective:

The objective of this project is to demonstrate the ability to efficiently refine germanium–rich concentrates derived from lignite fly ash materials. This project builds on Microbeam's demonstrated ability to produce >60% Ge concentrates from lignite-derived fly ash. To achieve the project objective, Ge concentrate will be exposed to a direct reduction process to produce Ge metal (>90% purity). The Ge metal will be further refined to 99.999% pure Ge metal (5N Ge) using zone refining. This process significantly decreases the cost of the production of 5N Ge and reduces the environmental impact by bypassing extensive hydrometallurgical steps.

Expected Results:

The testing results will provide information on the ability to produce 5N Ge from lignite-derived Ge concentrates at a lower cost and environmental impact. The project will involve the production of concentrates using Microbeam's pyrometallurgical process for use in the direct reduction process. Efforts will focus on the following: 1) production of concentrates while acquiring and setting up the direct reduction equipment, 2) assessment/management of the impacts of the impurities on the properties of the direct reduction Ge metal, 3) identification of all impurities in process streams and evaluation of any environmental issues associated with disposal, and 4) technical and economic evaluation of the integration production of 5N Ge. The project will determine the feasibility of the direct reduction process for scale-up.

Duration:

The duration of the project will be 24 months.

Total Project Cost:

$1,200,000 including $400,000 from NDIC and $800,000 from AmeriCOM.

Participants:

Funding support will come from AmeriCOM who provides support to the optics industry that supplies optical components for commercial and government entities through AmeriCOM's Defense Precision Optics Consortium (DPOC). AmeriCOM released a Request for Proposal # ACOM-25-01 for laboratory-scale projects to recover and refine germanium. This proposed effort is submitted in response to the RFP and builds on past projects with the Army to develop a domestic source of high purity germanium.

Subrecipient includes: IR Power Systems, LLC.

Stakeholders include: North American Coal and Great River Energy.

PROJECT DESCRIPTION

Objectives:

The overall objective of this project is to demonstrate the ability to efficiently refine germanium–rich concentrates derived from lignite fly ash materials. To achieve the project objective, Ge concentrates will be exposed to a direct reduction process to produce Ge metal (>90% purity). The Ge metal will be further refined to 99.999% pure Ge metal (5N Ge) using zone refining. This process significantly decreases the cost of the production of 5N Ge and reduces the environmental impact by bypassing extensive hydrometallurgical steps.

This project builds on Microbeam's demonstrated ability to produce >60% Ge concentrates from lignite fly ash. The specific project objectives include: 1) production of gram quantities of >60% purity concentrates from lignite-derived fly ash; 2) determination of impurity profiles in the concentrate and adjust concentrate production operation to minimize the incorporation of unwanted impurities, 3) design, procure, and assemble equipment required to perform direct reduction of the Ge concentrates; 4) conduct direct reduction testing of Ge concentrates to produce >90% pure Ge metal compatible for zone-refining, characterize all process streams and determine types and abundance of impurities; and 5) perform technical and economic assessment of the overall integrated process.

Figure 1 illustrates the overall process to produce Ge metal as well as other products using Microbeam's pyrometallurgical process. The process produces two product streams shown as A and B. Stream A is the dominant stream used to produce Ge products. However, lesser amounts have lower concentrations and can be processed by the conventional process shown in Stream B. The process is designed to enhance the recovery of materials in Stream A.

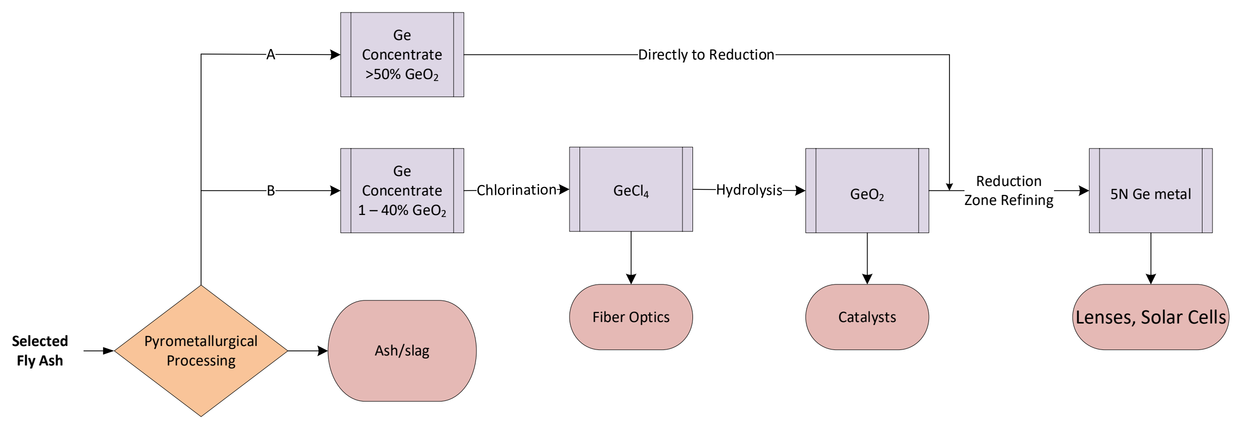


Figure 1. Overall Simplified Flow Diagram of the Germanium Purification Process and Products.

In the past, germanium was produced commercially in the US as a by-product of zinc and lead ore processing[1]. Today most of the Ge metal is produced outside of the US via hydrometallurgical processes using zinc ore and coal-derived feedstocks. These hydrometallurgical methods require managing waste

[1] Piedmont, J.R. and Riordan, R.J., The supply of Germanium for Future United States Demands, SPEI, Vol. 131, Practical Infrared Optics (1978), p 113.

streams that are challenging and costly due to the presence of toxic impurities such as those found in zinc and lead ores. Figure 2 shows the conventional processes used to recover and refine Ge from zinc ore overlain with Microbeam's pyrometallurgical processes (shown in the blue outlined boxes) to produce Ge concentrate combined with a direct reduction process.

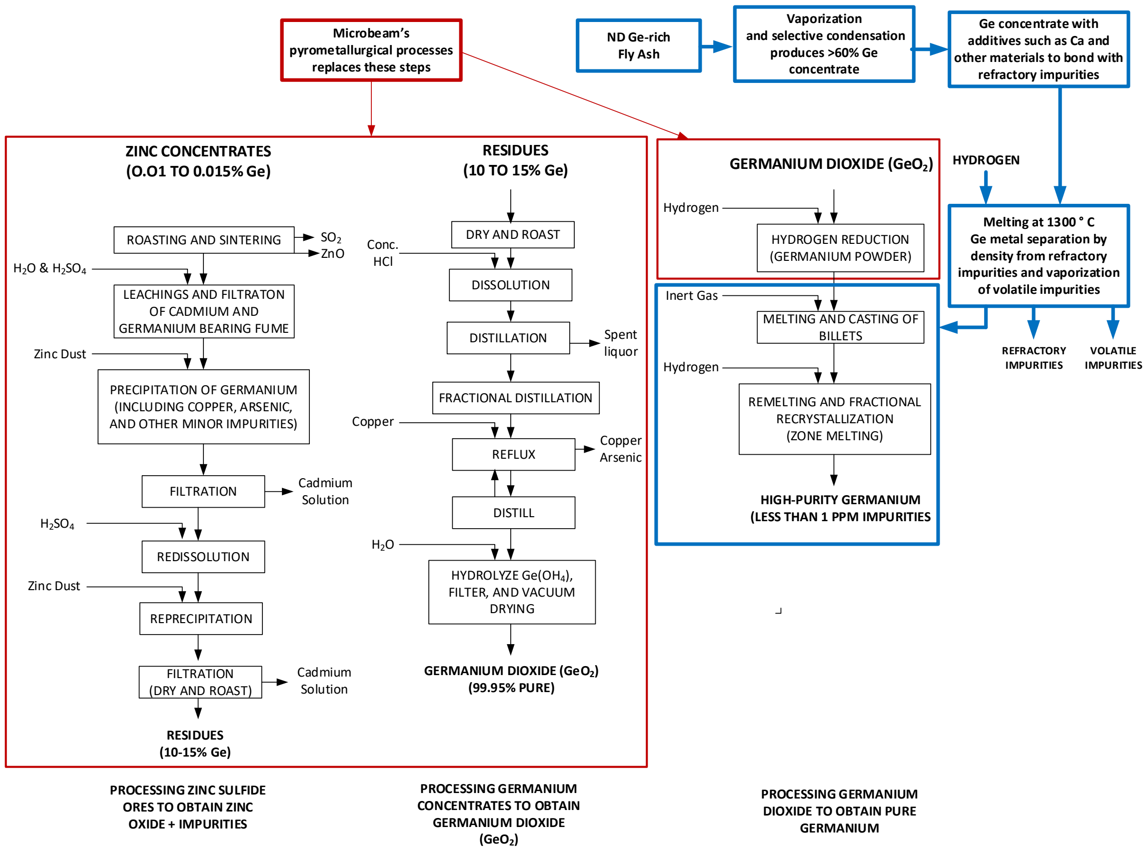


Figure 2. Comparison of an example of Ge metal production using mainly hydrometallurgical processes with Microbeam's pyrometallurgical processes combined with concentrate direct reduction.

Methodology:

The scope of work is designed to meet the project objectives.

Scope of Work

Task 1. Management and Reporting

The project will be managed and directed by the PI to meet all technical, schedule and budget objectives. Regular internal project status meetings will be held to coordinate activities to accomplish the work. In addition, the PI will ensure that project plans, results, and decisions are documented, and project reporting requirements are met.

Task 2. Production of Ge Concentrates for Testing

Subtask 2.1 Fly Ash Selection and Concentrate Production

Lignite samples of high Ge content (>250 ppm (ash basis)) will be combusted to produce fly ash for Ge concentrate production. The fly ash will be processed to produce an enriched fraction that can contain Ge levels as high as 3,500 ppm. Microbeam will work with the project partners to obtain coal and fly ash samples. The goal is to use Microbeam's pyrometallurgical process to produce gram quantities of >60% purity concentrates from lignite-derived fly ash under conditions that optimize Ge content and minimize incorporation of impurities. This will be accomplished by increasing the temperature and ash throughput of Microbeam's online metalloid recovery (OMR). The OMR is a prototype Ge recovery system from coal ash designed and constructed as part of a National Science Foundation Phase II SBIR[2]. The OMR operates in a batch mode and has performed over 300 tests to produce condensed metal concentrates. The OMR system will be upgraded with a higher temperature vaporization system with continuous feed, processed ash discharge system, and a higher capacity product recovery system. In addition, the process control system, data acquisition, and gas analysis will also be improved.

The OMR will be used to process up to 50 g/min of enriched fly ash that will produce up to 300 mg/min of 60% Ge concentrate. Past efforts have shown that the efficiency of releasing the Ge from the fly ash ranged from 77 to 86%. A conservative estimate to produce 10 grams of pure Ge metal would require the OMR to process about 7 kg of enriched ash. This would produce about 20 grams of 60% concentrate. The target quantity of concentrate to be produced for this project is 300 grams. This would require about 100 kg of enriched fly ash. In a worst-case scenario, it would require about a month and a half to produce the 300 grams of concentrate.

Subtask 2.2 Concentrate Characterization

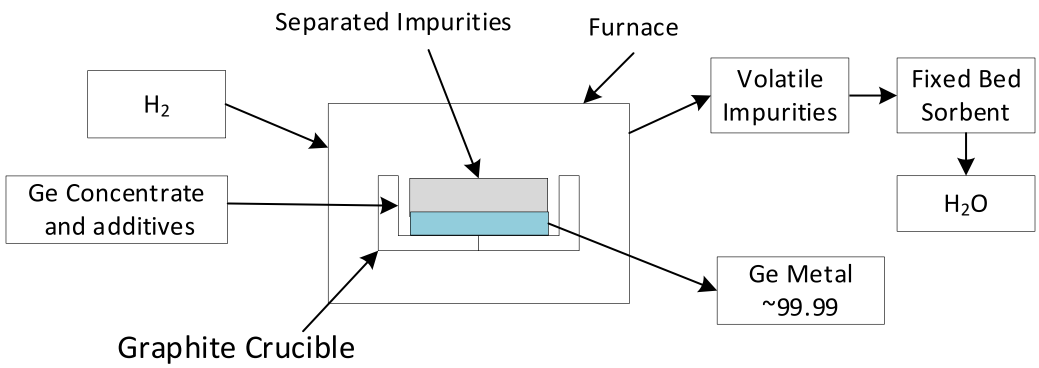
The operating condition of the OMR will be varied to optimize the conditions to selectively condense and capture primarily Ge phases. The abundance of impurities in the concentrate will be determined and adjustments to OMR operation will be made to minimize the incorporation of unwanted impurities. Once conditions are optimized, Ge concentrate production runs will be performed to produce enough concentrate for direct reduction and zone refining. The Ge concentration and abundance, type, and form of the impurities in the concentrate will be determined in samples collected from the OMR. The samples will be analyzed using x-ray fluorescence (XRF) and a scanning electron microscope equipped with an energy dispersive system for x-ray microanalysis (SEM-EDS). In addition, inductively coupled plasma-mass spectrometry (ICP-MS) will be used to determine the abundance of trace elements. Efforts will also track the behavior and fate of specific elements that can be co-produced including antimony, gallium, zinc, and tin. The team will also measure components such as arsenic and lead that can cause environmental impacts.

[2] Microbeam Technologies Inc, NSF SBIR Phase II: Feasibility of On-line Metalloid Recovery in Gasification Systems, NSF Award Number: 0422050, Final Report, July 31, 2007

Task 3. Direct Reduction

Subtask 3.1 Reduction Reactor System

A reduction furnace system will be designed to expose 10 to 50-gram batches of Ge concentrate along with selected additives to a reducing environment at temperatures ranging from 1000 to 1300°C. Additives will be used to bond with selected impurities allowing for their separation from the Ge melt phase. The system requires an oxygen free environment during heating and cooling. The system is illustrated in Figure 3. Equipment components and supplies will be purchased, and the system will be set up in Microbeam's laboratory. The components include a high temperature furnace, graphite crucibles, stirring paddles, viscometer, and a temperature control system.



$GeO_2 + 2H_2 = Ge + 2H_2O$
Requires high temperature
1000 ° C in an oxygen free environment

Figure 3. Simplified batch direct reduction system.

Subtask 3.2 Direct Reduction Testing of Ge-Concentrate

Selected Ge-concentrates will be tested to determine the ability to separate the Ge metal from the impurities in the concentrate. The operating conditions and the additives will be selected in order to bond with impurities and separate from the Ge melt. Certain additives will be combined with refractory elements to allow for separation. The operating conditions will be optimized to vaporize the volatile impurities and will be captured using a fixed bed filter containing active sorbent materials. The cooled Ge metal and slag portion will be physically separated.

Subtask 3.3 Analysis of Ge Metal and Impurities

The concentrate samples will be analyzed using XRF, SEM-EDS, ICP-MS, SEM phase mapping (SEM-PM), and x-ray diffraction (XRD) to evaluate the products and impurities produced. Bulk compositions (major, minor, and trace elements) will be measured using the XRF and ICP-MS. Phase analysis to determine crystalline components will be quantified using XRD and amorphous/crystalline phase microstructural composition/phase distributions will be determined using the SEM-PM procedure. These analyses will provide information on the purity of the Ge metal as well as the ability to separate and capture impurities associated with the Ge concentrate.

Task 4. Micro-scale Zone Refining

Subtask 4.1 Procurement of Micro - Zone Refining Equipment

Microbeam will procure and construct micro-scale zone refining equipment similar to the equipment used in the micro-electronics industry. The system is illustrated in Figure 4 and will have the capability to process milligram to gram size samples. The system consists of a quartz tube enclosure for inert atmosphere, a micro induction coil/power supply capable of heating to 1100 °C, motorized translation stage for controlled movement of the coil, and a thermal camera for real time monitoring.

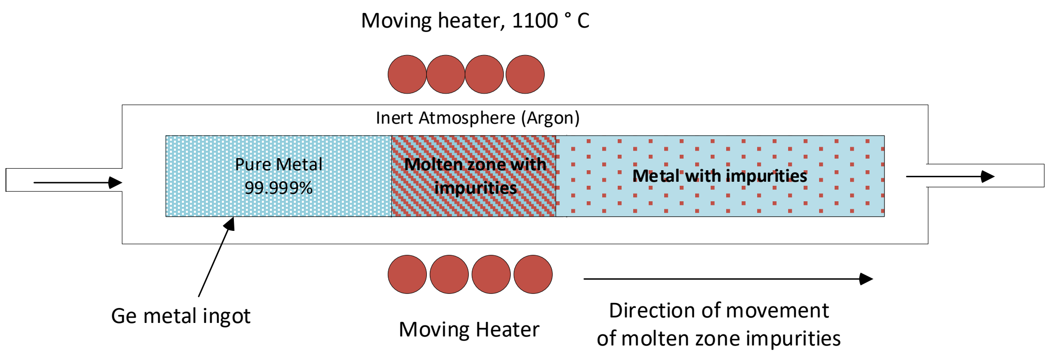


Figure 4. Simplified diagram of the zone refining system.

Subtask 4.2 Testing of Zone-refining of produced metals

The ability to remove the impurities using zone refining of the Ge metal produced as part of the direct reduction and phase separation process will be determined. The goal of the processing is to achieve 99.999% purity Ge metal. The methods of analysis will include ICP-MS to determine the abundance of any impurities present. In addition, the microstructure properties (phase distribution and homogeneity) of the product materials will be determined using SEM-EDS analysis.

Task 5. Technical and Economic Assessment

MTI will update the technical and economic feasibility assessment (TEA) from the Phase I Army project based on the optimized processing and the concentrate processing results. The capital and operational expense estimates will be equivalent to a Class 5 cost analysis by the American Association for Costing Engineers (AACE) and is expected to have a +100%/-50% accuracy.

Anticipated Results:

The primary result is the demonstration of a more environmentally benign and efficient process to refine Ge concentrates derived from ND lignite coal to produce high purity Ge for the optics industry. In addition, the team expects to show that the process is an improvement over conventional extraction from zinc ore.

The TEA work will look to provide information on the economic advantages of the technology and the viability of the overall technology to provide a domestic supply on the order of 15,000 kg/yr.

Facilities and Resources:

Microbeam has two locations, one in Grand Forks, ND, and one in Minnetonka, MN. The Grand Forks location focuses on computer modeling and data processing. The Minnetonka location has about 7,000 square feet of office, shop, and laboratory/testing space. The facility houses high temperature furnaces, two advanced computer-controlled scanning electron microscopes equipped with x-ray microanalysis (CCSEM), chemical fractionation equipment, an x-ray fluorescence spectrometer, a laser-based particle sizer, an ash fusion/slag surface tension system, and associated sample preparation equipment. In addition, the shop/laboratory testing area has a shop area for fabrication, assembly, construction and modification of testing equipment as well as an area for a fluidized bed reactor, metals recovery system, sample preparation and field test staging area. The metals recovery system was designed to be used to study the vaporization, condensation, and capture of critical minerals such as germanium, gallium, and antimony.

Techniques to Be Used, Their Availability and Capability:

Techniques available at Microbeam:

- Metalloid/metal concentrating facilities – Metals recovery facilities (OMR) will be used to produce up to 300 grams of concentrate from Ge-rich fly ash.
- High temperature furnace systems – The furnace systems will be used to perform controlled temperature and atmosphere melting and phase separation testing.
- Advanced analysis methods - Automated scanning electron microscopes with x-ray microanalysis capabilities are available to characterize the microstructure of direct reduction products using phase mapping procedures. Phase mapping allows for visualization of separated phases such as the pure Ge component and the separated crystallized calcium iron phases from the melt.
- Bulk chemical analysis - X-ray fluorescence will be used to track the abundance of germanium and impurities in the fly ash, concentrate, reduction products, and zone refined materials.
- Phase distribution predictions -Thermochemical equilibrium modeling of the distribution of gas, liquid and solid species associated with Ge and impurities will be performed using FactSAGE.

Techniques procured and assembled as part of the project:

- A direct reduction system will be designed and constructed to reduce and purify Ge concentrate.
- A micro-zone refining system will be constructed to produce high purity Ge metal from the direct reduction system.

Techniques available as a service:

- Purity of Ge intermediate and product materials will be determined using ICP-MS analysis. Analysis of the Ge-concentrate, direct reduction Ge product, and zone-refined metal (99.999% Ge metal product) will be performed.
- X-ray diffraction analysis will be performed to determine the crystalline phases present in the Ge metal intermediate and final products.

Environmental and Economic Impacts while Project is Underway:

The project will be performed on a laboratory-scale and will not have an environmental impact. The project will not impact power plant or mining operations. Requests will be made to obtain coal and fly ash samples from coal mines and power plants.

Ultimate Technological and Economic Impacts:

Currently, Ge is not available in sufficient quantities to support defense and commercial needs. The production of Ge from the abundant North Dakota lignite resources has the potential to meet the US Department of Defense (DoD) needs as well as commercial uses for Ge. Ge is an essential component in production of infrared optics, fiber optics, solar cells and other electronics critical to the Army and other Defense applications. In addition, as part of the modernization efforts ongoing at DoD, the availability of Ge is critical to programs such as C5ISR (Command, Control, Communications, Computers, Combat Systems, Intelligence, Surveillance, and Reconnaissance). The C5ISR Center is part of the US Army Combat Capabilities Development Command (DEVCOM).[3] The technology the project team aims to demonstrate has the potential to provide a stable source of Ge that can play a role in the mission of the C5ISR Center. All these platforms and systems are dependent upon Ge-based components that provide reliable high performance, as well as allow for miniaturization. These Ge components also play a key role in high-frequency RF and electronic warfare systems (SiGe alloys for use in devices to detect, jam, spoof, and intercept enemy signals), infrared optics (forward looking IR, search and tracking sensors, and missile guidance systems), space-based ISR and communications (high efficiency solar cells and sensors), and signal processing and spectrum sensing (high electron mobility (high speed)) (allows for real time spectrum monitoring, adaptive jamming, and electronic warfare). Ge is critical for both offensive and defensive spectrum operations requiring a secure and stable supply.

This request for cost share is to support the submission of this project for funding in response to the AmeriCOM RFP ACOM-25-01. The aim of the AmeriCOM RFP is to fund projects to develop sources of Ge for the optics industry that supports DoD needs quickly. Microbeam believes that this technology has the ability to scale to a pilot facility with relatively quick success. The benefits of this technology and the feedstock do not require a large facility to produce significant Ge materials. In the Phase I Army funded SBIR project, the project team determined that a pilot-scale facility could be constructed for approximately $11-12 million with an annual operating cost of $5 million to produce 1,000 kg to 8,000 kg per year. However, current Ge concentrations in the ash at the project partner's facilities is enough to

[3] Home - Combat Capabilities Development Command C5ISR Center

support the production of at least 1,000 kg/yr. Given the current high Ge costs (~$4,000/kg), this facility would be close to supporting itself within the first year of operation (approximately $4M in revenue compared to $5M operating costs). As operations continue and the supporting processes mature, the Ge concentrations in the feedstock will increase and the process will operate more efficiently, increasing revenue while decreasing operating costs. The optimal production rate for this pilot facility is 5,000 kg/yr but will have the capacity to produce 8,000 kg/yr. This could result in revenues ranging from $6.5 million to $24 million depending on the cost of Ge and the production output of the pilot facility - $1,300/kg to $3,000/kg and 5,000 kg/yr to 8,000 kg/yr.

A commercial scale facility that could produce 15,000 kg/yr is estimated to cost approximately $15 million in capital and $7 million in annual operating costs with additional costs related to engineering, business/marketing, and permitting costs associated with this effort. The technology is intended to be collocated with an ash producing facility (power plant or coal-based ash producing facility) to reduce the operational, waste management, and emissions costs.

Why the Project is Needed:

The Ge supply chain is dominated by foreign countries. In addition, China banned shipments to the US as well as trans-shipment through other countries[4]. The lack of readily available Ge is limiting the ability to produce infrared optics, thermal imaging systems, satellite solar panels, and emerging quantum and photonics platforms. The Army is estimating it will require levels as high as 10,000 kg/yr for at least a 5-year duration to upgrade Ge windows and lenses in tanks. This does not include the needs of the Air Force, Space Force and other DoD applications. Based on a USGS commodities report, the US imported 38,000 kg of Ge in 2023, up 20% from 2022. The US has been over 50% reliant on imports. Worldwide demand was 130,000 kg/yr with a compound annual growth rate (CAGR) of 3.3% since 2001.

STANDARDS OF SUCCESS

The standards of success include the ability to produce high purity Ge for DoD and commercial applications with reduced environmental impacts and lower costs. The uses for the Ge products improve the efficiency of electrical components as described in the earlier section of this proposal. The lignite resource contains Ge and during the utilization of the lignite the Ge is concentrated in selected fractions of the fly ash. The plant that will produce Ge is anticipated to be collocated at a mine and power plant in North Dakota and will provide new high paying jobs to operate the plant to produce the Ge concentrates and refine the concentrate.

BACKGROUND/QUALIFICATIONS

Technical Background

Microbeam is a small business that conducts a combination of research, development, and service projects for industry and government clients related to the form, fate, and behavior of inorganic

[4] Asia Financial. (2025, July 21). China stops most antimony exports but rare earth sales to US soar. Asia Financial. https://www.asiafinancial.com/china-stops-most-antimony-exports-but-rare-earth-sales-to-us-soar.

components in coal and other feedstocks in energy conversion and critical mineral recovery systems. Microbeam has conducted over 1700 projects for clients worldwide associated with diagnosing problematic fuel property impacts and developing solutions to improve energy conversion plant performance. This experience has provided Microbeam with a deep understanding of the behavior of fuel associated inorganic components that have provided key insights into novel methods to recover and concentrate critical minerals derived from coal.

Microbeam began working on projects associated with germanium fate and behavior in high temperature processes in service analysis work for commercial coal gasification technology developers. Accumulations of Ge deposits on heat exchangers and gas filters created operational problems in 260 MWe integrated gasification combined cycle (IGCC)[5]. Analysis of the deposits found Ge levels in layered syngas cooler deposits that cause plugging were as high as 54%. The forms of Ge in the deposit included GeS, Ge, and GeO_2. The level of Ge in the feed coal fired at this facility was less than 10 ppm (dry coal-basis) on average. Microbeam received an SBIR research project from the US Department of Energy (DOE) to identify measures to minimize the accumulations[6] through managing process conditions and the use of Ge sorbents.

Based on an understanding of the Ge accumulation processes, MTI was awarded National Science Foundation (NSF) Phase I and II SBIR projects[7] to recover Ge on-line from a coal gasification process through selective condensation of Ge to produce a Ge concentrate. The NSF Phase II SBIR project involved the design and construction of a laboratory-scale prototype system called the Online Metalloid Recovery Unit (OMR) to recover Ge-rich materials from coal-fired gasifiers and gasification ash materials. The prototype system demonstrated the ability to revaporize Ge from ash materials and selectively condense vaporized Ge. The conditions for selective condensation of Ge are dependent upon gas temperature, probe surface temperature, gas composition, and pressure.

In a project funded by DOE, NDIC, and the ND lignite industry, led by University of North Dakota (UND), it was discovered that Ge and Ga were co-extracted with rare earth elements from ND lignite and were present in mixed REE concentrate. However, in the calcining of the MREC the Ge and Ga would vaporize and be lost. In order to recover the Ge and Ga, Microbeam teamed with UND and proposed that the pyrometallurgical technology developed as part of the NSF funded projects to recover Ge from ash could replace the calcining step and recover both Ge and Ga from the UND's MREC. The project was awarded by DOE to first develop the concept and now in the second phase of the project a bench-scale process is being tested to recover Ge and Ga from MREC.

In 2024 Microbeam was awarded a DoD Army SBIR Phase I project to assess the technical and economic feasibility of producing > 60% Ge concentrates from lignite coal-derived fly ash. Coal fly ash samples

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[5] Benson, S.A., Katrinak, K.A., Characterization of a Germanium-rich Gasifier Deposits, MTI Report 344, 1997.

[6] Benson, S.A., Katrinak, K.A., and Laumb, J., Abatement of Filter Corrosion and Plugging in IGCC Systems, Phase I Final Report, SBIR, DE-GE03-99ER82829, June 2000.

[7] Microbeam Technologies Inc, NSF SBIR Phase II: Feasibility of On-line Metalloid Recovery in Gasification Systems, NSF Award Number: 0422050, Final Report, July 31, 2007.

received from project partners were tested along with ash produced in the laboratory using the OMR. The Ge level in Ge-concentrates produced was as high as 69% GeO_2. The OMR tests conducted with syngas performed significantly better with respect to the % of total Ge released from the ash was 77 to 86%.

The following is a short discussion of work conducted by others related to the ability to vaporize and condense Ge and Ga. Pyrometallurgical processes have been utilized to vaporize and condense Ge from ash-related materials and Ga-related materials from nuclear waste materials. Zhang and Xu[8] examined the feasibility of recovering germanium from coal fly ash using a vacuum reduction pyrometallurgical process. They used a pilot scale reactor to produce a reducing environment at high temperatures combined with vacuum to vaporize and condense Ge. The recovery of germanium through the pilot scale testing was 94.64%. The thermal vaporization and deposition of gallium oxide in hydrogen was studied by Butt and others[9]. The work was associated with removing gallium from PuO_{2-x} associated with dismantling and declassifying nuclear weapons. They developed a thermal method that involved heating the Ge_2O_3 in an Ar-H_2 at temperatures in excess of 1000 °C to vaporize the gallium oxide as Ga_2O (g) and separate it from PuO_{2-x}. During the gas cooling in the furnace, the Ga_2O (g) condenses out as Ga(l) and Ga_2O_3 (s). They were able to condense the materials out on copper and SiO_2 substrates and demonstrated the deposited materials consisted of Ga_2O_3 and metallic Ga. They utilized equilibrium thermodynamics to determine the vaporization and condensation process temperatures and atmospheres.

The state of the art for the extraction and recovery of Ge from zinc production[10] is a solvent extraction using an acid such as sulfuric acid to produce a leach solution that is reprecipitated to form a 1-15 percent Ge concentrate. The Ge concentrate is extracted with HCl followed by distillation to produce $GeCl_4$ followed by hydrolysis to produce GeO_2, metallization through reduction reactions to produce Ge metal, and zone refining to remove impurities.

This project builds on Microbeam's demonstrated ability to produce >60% Ge concentrates from lignite fly ash. The >60% Ge concentrate allows for direct reduction/purification and zone refining skipping the environmentally challenging chlorination processes.

Key Personnel

Alex Benson, Mr. Benson will be Principal Investigator for this project. Mr. Benson is currently the Chief Operating Officer at Microbeam. He has a B.S. degree in Mechanical Engineering from the University of St. Thomas. Mr. Benson has over 6 years of experience conducting projects associated with critical minerals. Currently he leads multiple commercial projects associated with REE/CM resource evaluation, detection, measurement, and extraction from carbon-ore and associated waste materials. He was the project PI (DE-SC0021837) and is one of the inventors on a US patent held by Microbeam for algorithms

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[8] Zhang, L. and Xu, Z., An environmentally-friendly vacuum reduction metallurgical process to recover germanium from coal fly ash, Journal of Hazardous Materials 312 (2016) 28–36

[9] Butt, D.P., Park Y., and Taylor, T.N., Thermal vaporization and deposition of gallium oxide in hydrogen, Journal of Nuclear Materials, 264, January (1999) 71-77.

[10] Curtolo, D.C., Friedrich, S. and Friedrich, B. (2017) High Purity Germanium, a Review on Principle Theories and Technical Production Methodologies. Journal of Crystallization Process and Technology, 7, 65-84.

used with handheld XRF and PGNAA-DGA for REE/CM measurements and of a US patent for Ge and Ga separation from ash materials and mixed rare earth element concentrates. He is currently the lead Project Manager on the DOE and Industry funded project (DE-FE0032522) to produce germanium and gallium from REE concentrates. Mr. Benson has over seven years of manufacturing engineering, project management and commercialization in the medical device manufacturing industry. He led engineering activities for new product launches and capacity expansion projects.

Dr. Ari Campanaro, Dr. Campanaro, Research Scientist, has PhD and MS degrees in Chemistry from the University of Minnesota and BA in Chemistry and Mathematics from Gustavus Adolphus College. Dr. Campanaro conducts research on the fate and behavior of rare earth elements, germanium, and gallium in pyro and hydrometallurgical processes. This includes developing methods for determining the abundance of Ge and Ga in feedstocks and products, producing Ge concentrates using laboratory-scale equipment, and performing thermochemical equilibrium predictions of the partitioning of germanium and gallium in pyrometallurgical processes. She also participates in performance of technical and economic assessments of Ge and Ga production technologies. Dr. Campanaro was the technical lead for the recent DoD Army SBIR project entitled "Production of Germanium Concentrates from Coal Ash" coordinating all analysis, testing, data interpretation, and reporting.

Eric Kolb, Mr. Kolb, Research Engineer and Shop Manager, has a B.S. degree from UND in Mechanical Engineering. Mr. Kolb worked with UND on the design, construction, and operation of UND's pilot-scale REE and CM processing plant (DE-FE0031835). His experience associated with the UND system will provide important information that will facilitate integrating the Ge and Ga recovery process into the UND MREC production process. Mr. Kolb has experience in performing analysis using electron microscopes as well as performing tests using the metals recovery unit and other high temperature equipment at Microbeam. Mr. Kolb will coordinate equipment assembly and shakedown efforts associated with the Ge concentrate production, direct reduction, and zone refining.

Dr. Steve Benson, Dr. Benson, Microbeam President, has a BS in Chemistry from Minnesota State University and a Ph.D. in Fuel Science from Pennsylvania State University. Dr. Benson's role in this project will be to assist and advise the Principal Investigator and Technical Lead. Prior to joining Microbeam full time in 2017 he held faculty and research positions at the UND. He was PI on the DOE and industry funded project (FOA 1202, DE-FE0027006) to develop technologies to recover REE from coal and coal byproducts as well as the current DOE and industry funded project (DE-FE0032522) to produce germanium and gallium from REE concentrates. He has 45 years of experience in fuel analysis, fuel properties, combustion, gasification, ash transformations, pollution control, and critical mineral recovery. In addition, Dr. Benson has developed and managed numerous complex multidisciplinary research, development and commercialization projects associated with the utilization of coal funded by US DOE and industry. Dr. Benson is one of the inventors on a US patent held by UND for the extraction of REE/CM from lignite and associated materials, one of the inventors on a US patent held by MTI for algorithms used with handheld XRF and PGNAA-DGA for measuring REE-CM, and one of the inventors of a patent for the process of producing separated Ge and Ga concentrates from ash materials and mixed rare earth element concentrates.

Michael Hulen, Mr. Hulen, IR Power Systems' Chief Executive Officer, has extensive experience in materials science related to production of infrared crystals such as Czochralski (CZ) growth of germanium crystals for night vision optics. He has experience in sourcing feedstock materials from coal ash, as well as knowledge of the process steps to upgrade and refine germanium into its useable forms. The forms include germanium tetrachloride $GeCl_4$ (primarily for fiber optics), germanium dioxide GeO_2 (for PET plastics), germanium 5N+ zone refined metal ingots (feedstock for crystal growth), and CZ optical crystals (for thermal imaging). Mr. Hulen will use this experience to assist in the design and operation of the refinement processes outlined in this proposal.

MANAGEMENT

Microbeam will lead this project and will be responsible for communication with project team members (IR Power Systems) and all project stakeholders (NDIC, NACoal, and GRE). Microbeam shall manage and direct the project in accordance with the proposal task structure and project contract to meet all technical, schedule, and budget objectives and requirements. Microbeam will ensure that project plans, results, and decisions are appropriately documented, and project reporting and briefing requirements are satisfied. Alex Benson, the project PI, will lead the project management efforts for Microbeam.

The project organizational structure illustrated in Figure 5 is designed to provide support for the PI, Alex Benson, in conducting the project on time and within budget.

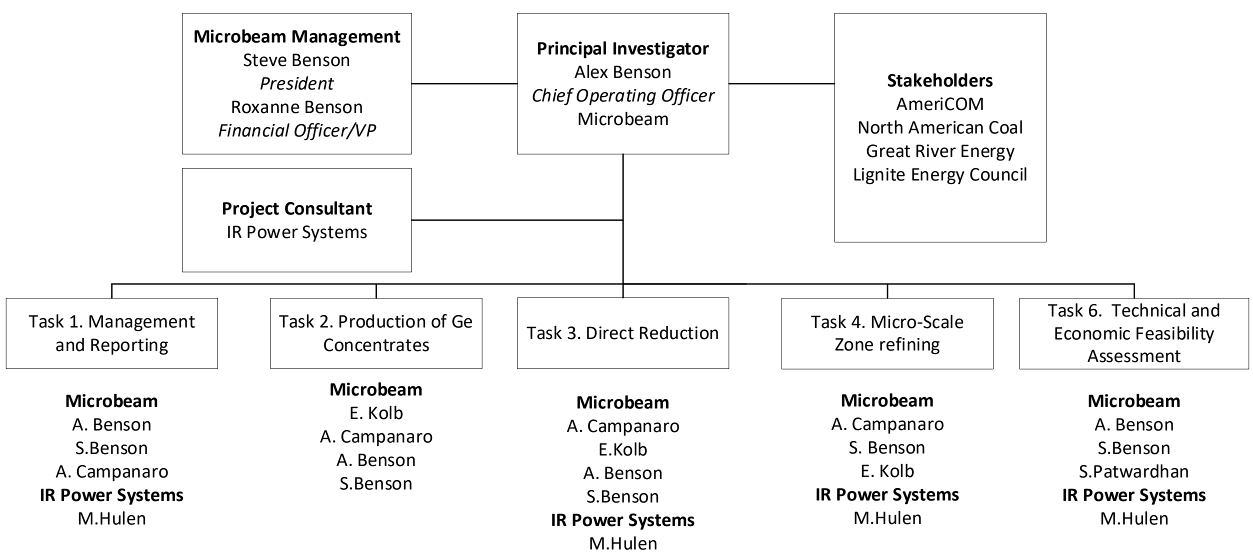

Figure 5. Project organizational management chart.

A project timeline, further discussed in the next section, has been put together and highlights milestones throughout the project. These milestones are evaluation points throughout the project to ensure the project is on track to meet the goals and objectives laid out in this proposal. A summary of those milestones is shown in Table 1.

Table 1. Project milestones.

Task/ Subtask	Milestone Title/Description	Planned Completion Date	Verification Method
1	Final Report	11/26/2027	Final Report
2.1	Ge Concentrate Available For Direct Reduction	10/5/2026	Analytical Characterization of Ge Concentrate; Sufficient Quantity Produced for Direct Reduction Shakedown Testing; Quarterly Report
3.1	Reduction Reactor System Operational	11/30/2026	Shakedown testing complete; Quarterly Report
3.3	Evaluation of Direct Reduction Process	9/6/2027	Analytical Characterization of Direct Reduction Product; Quarterly Report
4.1	Micro-Zone Refinement Equipment Operational	5/17/2027	Shakedown testing complete; Quarterly Report
4.2	Evaluation of Final Ge Product	11/1/2027	Analytical Characterization of Final Ge Product; Final Report
5	Technical and Economic Assessment	11/26/2027	Final Report

TIMETABLE

The proposed project has a two-year timeline with an anticipated start date of December 1st, 2025. Figure 6 shows the project timeline by task, including milestones.

Figure 6. Project timeline.

BUDGET

Table 2 details the overall project costs, separating the portion of the project supported by AmeriCOM and NDIC. The NDIC portion of the budget primarily supports the selection and procurement of coal and ash samples, the direct reduction equipment, the micro-zone refining equipment, and the characterization of samples collected and produced throughout the project.

Table 2. Project budget.

	Total Budget	AmeriCom	NDIC Cash
Budget Category	Incl. Cost Share	Share	Cash Share
Personnel	$ 307,509.00	$202,786.00	$ 104,723.00
Fringe Benefits	$ 105,937.00	$ 69,860.00	$ 36,077.00
Total Personnel & Fringe Benefits	$ 413,446.00	$272,646.00	$ 140,800.00
Travel	$ 5,613.00	$ -	$ 5,613.00
Equipment	$ 219,002.00	$162,810.00	$ 56,192.00
Supplies	$ 13,810.00	$ -	$ 13,810.00
Consultants	$ 80,000.00	$ 80,000.00	$ -
Analysis	$ 77,448.00	$ 38,065.00	$ 39,383.00
Total Direct Costs	$ 809,319.00	$553,521.00	$ 255,798.00
Indirect Costs:	$ 170,174.00	$112,221.00	$ 57,953.00
G&A Costs	$ 220,507.00	$134,258.00	$ 86,249.00
Total Overhead & G&A Costs	$ 390,681.00	$246,479.00	$ 144,202.00
Total Direct and Indirect Costs	$ 1,200,000.00	$800,000.00	$ 400,000.00

The Personnel costs are associated with the selection, procurement, and characterization of samples along with the construction and operation of the micro-zone refining process.

The Travel costs are associated with traveling to ND to meet with project stakeholders, select Ge-rich coal and ash samples, and procuring those samples for use in this project as well as attendance at the 2026 or 2027 Society for Mining, Metallurgy & Exploration (SME) MineXchange conference to present on this technology.

The Supplies costs are associated with materials required for the construction and operation of the direct reduction and micro-zone refining process.

The Equipment costs are associated with equipment required for the direct reduction and micro-zone refining processes.

The Analysis costs are associated with the characterization of coal and ash feedstocks and the Ge products throughout the refinement process.

This project supports the overall Ge extraction, separation, and refinement efforts that Microbeam has been developing that the NDIC has supported. In the past 3 to 4 years, the NDIC has provided or committed $396,000 for completed or active projects with a total of $3.2 million in non-NDIC funds supporting these efforts.

CONFIDENTIAL INFORMATION

Information considered confidential in this project is limited to the composition (including Ge concentrations) of the coal and ash utilized as feedstock and the extraction/separation technology for creating the Ge concentrate. However, the focus of this project is the evaluation of the direct reduction process to refine the Ge concentrate to GeO_2 or Ge metal so that information doesn't impact the ability to provide updates on the progress of this project. Therefore, Microbeam will not be filing a confidentiality request.

PATENTS/RIGHTS TO TECHNICAL DATA

Microbeam reserves the rights to new methods developed as part of this project related to the extraction, separation, or refinement of Ge from coal ash and coal byproducts.

STATE PROGRAMS AND INCENTIVES

Microbeam has received funding from the NDIC on 5 projects in the past five years. Table 3 shows the summary of that funding.

Table 3. State programs Microbeam has participated in within the last five years.

Project Name	NDIC Funding	Matching Funds	Timeframe
North Dakota Rare Earth and Critical Element Resource Evaluation – Contract No. FY21-XCV-235	$504,871.20	$504,871.20 (Industry)	3/2021-12/2024
Development of Novel Sintered Carbon-Ore Building Materials – Contract No. FY22-XCVII-242	$62,500	$586,907 (DOE, Industry)	10/2021-2/2024
Production of Ge and Ga Concentrates for Industrial Processes (Phase I) – Contract No. FY22-XCVII-240	$20,000	$256,329.93 (DOE, Industry)	1/2022-12/2023
Lignite Resource Evaluation for Advanced Utilization Opportunities – Contract No. FY22-101-247	$1,238,994.18	$1,239,000 (Industry)	1/2023-12/2025 (active)
Production of Ge and Ga Concentrates for Industrial Processes (Phase II) – Contract No. FY24-105-259	$376,000	$2,758,978 (DOE, Industry)	11/2024-1/2028 (active)