U.S. Department of Energy
Office of Fossil Energy and Carbon Management
DE-FE0032051

Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Assessment of San Juan River-Raton Coal Basin

4th Quarterly Research Performance Progress Report
Reporting Period: July 1, 2022-September 30, 2022
Project Performance Period: 10/01/2021 – 09/30/2023

Principal Investigator
Navid Mojtabai
Email: Navid.Mojtabai@nmt.edu
Telephone: 575-517-5836

Submitting Institution
New Mexico Institute of Mining and Technology
801 Leroy Place
Socorro, NM 87801
DUNS # 041358904

Submitted by:
Virginia T. McLemore
Principal Senior Economic Geologist/Minerals Outreach Liaison,
New Mexico Bureau of Geology and Mineral Resources
Email: virginia.mclemore@nmt.edu
October 20, 2022

TABLE OF CONTENTS

1. ACCOMPLISHMENTS

The objective of this project is to determine the rare earth elements (REE) and critical minerals (CM) resource potential in coal and related stratigraphic units in the San Juan and Raton basins, New Mexico. We will conduct the following tasks: (1) a basinal assessment for CM and REE potential, using state-of-the-art technologies to estimate basin-wide CM and REE resources in coal and related stratigraphic units; (2) identify, sample, and characterize coal waste stream products; (3) conduct bench tests to develop a basinal reuse of waste strategy; (4) illustrate the current status of the feedstock supply of REE and CM to understand the basinal REE industry's capital expenditures and obstacles to expanding REE-related business development; (5) develop a life-cycle analysis to establish pathways, process engineering, and design requirements to upgrade REE processing industry, (6) evaluate technology gaps, (7) establish a Center of Excellence and Training Center (COE) for coal ash beneficiation at San Juan County; and (8) create REE research-based activities that can be shared during the NMBGMR summer geology teacher workshop and assemble REE research-related articles for an REE-centered issue of Lite. This project will delineate favorable geologic terranes and priority areas containing potential REE and CM deposits for the DOE mandate, which is also a priority of the NMBGMR and state of NM.

A. Major goals and objectives

The following are the major goals of this project as described in the approved Statement of Project Objectives (SOPO):

1. Identify and quantify the distribution of critical minerals (CM), including rare earth elements (REE), in coal beds and related stratigraphic units in the San Juan and Raton basins in New Mexico (including coal, coal refuse, ash, coal seam, interstitial clays/shales, volcanic ash beds, acid mine drainage, associated sludge samples, mine dumps, other nonfuel carbon-based products, process waters, etc.).
2. Identify possible sources of CM and REE in the basins.
3. Identify the coal mine and nonfuel carbon-based waste products that could contain CM and REE.
4. Characterize the CM and REE in these materials.
5. Determine the economic viability of extracting CM and REE from these materials
6. Test and develop new technologies in identifying and quantifying CM and REE in high-fidelity geologic models.

Table 1 describes the tasks and subtasks that will be undertaken to accomplish these goals and Table 2 provides a listing of the revised project milestones, along with anticipated delivery dates.

TABLE 1. List of tasks and subtasks

Task 1.0 Project Management and Planning
Task 2.0 Basinal Assessment of CM and REE in the San Juan and Raton Basins Subtask 2.1 Identification of Sampling Sites Subtask 2.2 Collection and Review of Existing Data Subtask 2.3 Develop a Sampling Plan Subtask 2.4 Collect Samples Subtask 2.5 Sample Characterization Subtask 2.5.1 Bulk Rock Characterization Subtask 2.5.2 Micro-scale Characterization Subtask 2.5.3 3D Multiscale Petrography Subtask 2.5.4 In situ LIBS/RAMAN Analyses Subtask 2.6 Application of Machine Learning techniques for basin-wide resource assessment
Task 3.0 Basinal Strategies for Reuse of Waste Streams Subtask 3.1 Waste Streams Sampling and Characterization Subtask 3.2 Coal Ash Subtask 3.3 Technology Development of Basinal Reuse Strategy
Task 4.0 Basinal Strategies for Infrastructure, Industries and Businesses Subtask 4.1 Infrastructure Investigation Subtask 4.2 Competitiveness and Challenge Subtask 4.3 Life-Cycle Analysis
Task 5.0 Technology Assessment, Development and Field Testing Subtask 5.1 Identify and Assess Existing and Novel Technologies Specific to the Resource Subtask 5.2 Develop Plan for Field Testing
Task 6.0 Technology Innovation Centers Subtask 6.1 SonoAsh Center of Excellence
Task 7.0 Stakeholder Outreach and Education Subtask 7.1 New Mexico State and Regional Education Subtask 7.2 Lessons Learned and Narratives Constructed Subtask 7.3 Publications Subtask 7.4 Training and Conferencing with SJC and Sonoash COE

TABLE 2. Revised List of Milestones **(bold=completed)**

Task/ Subtask	Milestone Title	Planned Completion	Verification method	Status
	Quarterly reports	Quarterly	Report every quarter	**4th quarter 10/20/2022 completed**
1.0	**A: Project Kick-off meeting**	**10/15/21**	**Attend, report**	**Completed** (see https://geoinfo.nmt.edu/staff/mclemore/documents/CORE-CMprojectNMfinal.pdf)
2.1	B: Identification of Sampling Sites	Quarterly	Reports every quarter	Ongoing, planned in 2 phases
2.2	C: Collection and Review of Existing Data	2nd quarter	Map, description	Report in progress, ongoing activity, **REE in produced waters**

				(https://geoinfo.nmt.edu/staff/mclemore/ree_produced_waters_for_GIS.xlsx) and **USGS coal chemistry** (https://geoinfo.nmt.edu/staff/mclemore/REEcoal.mpk) are on the project web site
2.3	D: **Sampling Plan** Database	10/31/2021, progress report 2nd quarter. 3/31/2022	**Sampling plan** Database, web forms, reports.	**Sampling plan is completed** (https://geoinfo.nmt.edu/staff/mclemore/documents/samplingplan_v3.pdf). Database and data entry web pages are being developed; initial availability 3/31/2022.
2.4	E: Collect Samples	Quarterly	Report, database	Started sampling in April 2022 **(see Table 3)**
2.5	F: Characterization	Quarterly	Progress report quarterly, database	Ongoing once samples are collected, **samples submitted to laboratories for chemical analyses, chemical analyses received in August 2022 (see Attachment 3)**
2.6	G: Application of Machine Learning techniques for Basin-wide Assessment	12/31/2022	Progress report quarterly, database	Future activity
3.0	H: Sampling and Characterization of Waste Streams	Quarterly	Progress report quarterly, database	Ongoing, see 2.5, future activity
4.0	I: Results of Basinal Infrastructure, Industries and Business Assessment	03/31/2023	Progress report quarterly, database, publications	Future activity; 4.3 **Life cycle analysis completed (see below)**

B. Accomplishments during 4th quarter

Task 1.0 Project Management and Planning

Project management activities during this quarter included the implementation of regular procedures including regular management and biweekly working group meetings. The team also has regular meetings of the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) database group to develop the project database.

Task 2.0 Basinal Assessment of CM and REE in the San Juan and Raton Basins

Status:

Subtask 2.1 Identification of Sampling Sites (COMPLETED)

Sample sites include the coal fields and mines in the San Juan and Raton basins, shown in Figure 1. Samples from each coal field (Table 3) will be collected. Sampling began in April 2022.

Subtask 2.2 Collection and Review of Existing Data

Legacy chemistry data have been collected and a report evaluating that data is in progress. See preliminary results in Geological Society of America presentation by McLemore (https://geoinfo.nmt.edu/staff/mclemore/documents/McLemoreGSA22Wed10-12-22.pdf).

Subtask 2.3 Develop a Sampling Plan (COMPLETED)
The field sampling plan is completed and revised (https://geoinfo.nmt.edu/staff/mclemore/documents/samplingplan_v5.pdf). Figure 1 shows the coal fields and mines in the area. Table 3 is a list of the coal fields.

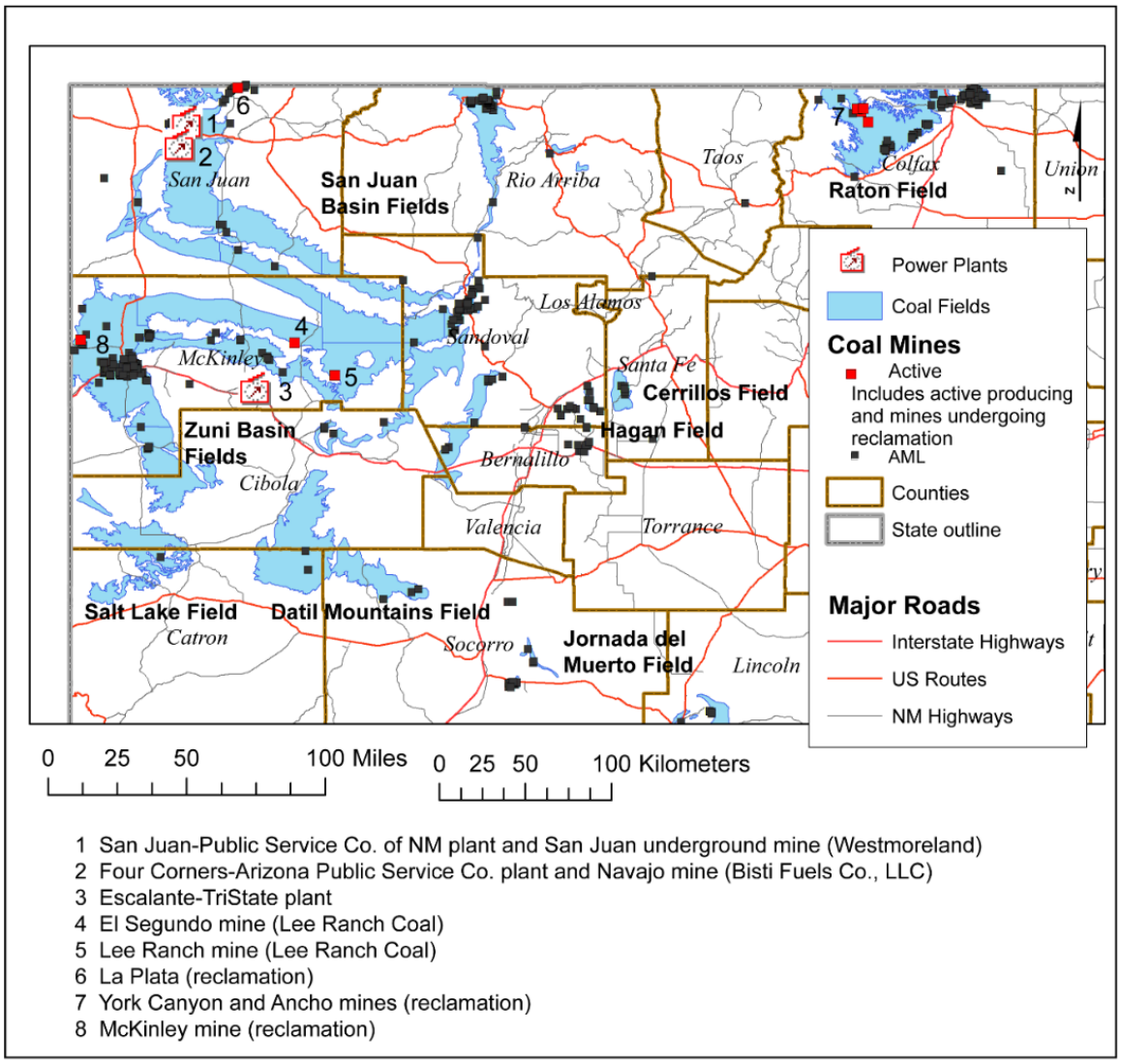

FIGURE 1. Coal fields, active mines, AML (abandoned mine lands) sites, and power plants in the San Juan and Raton Basins.

TABLE 3. Coal fields in the San Juan and Raton basins, studied in this project, delineated by Hoffman (1996, 2017). District Id is from the New Mexico Mines Database (McLemore, 2010a, 2017). Representative samples will be collected from each coal field. Each field sample will be prefixed with an abbreviation representing each coal district. Each drill core sample will be

identified by the hole number and depth. At least 3 samples will be collected from each coal field. Approximately 130 samples will be collected each year.

District id	Coal Field	Year of Discovery	Year of Initial Production	Year of Last Production	Estimated Cumulative Production	Formation	No of samples collected
DIS257	Barker Creek	1882		1905		Menefee	
DIS150	Bisti	1961	1980	1988	$40,075,148.00	Fruitland	2
DIS259	Chaco Canyon	1905	1905			Menefee	
DIS260	Chacra Mesa	1922		1945		Menefee	
DIS174	La Ventana	1884	1904	1983		Menefee	4
DIS118	Crownpoint	1905	1914	1951	$20,758.00	Crevasse Canyon	
DIS155	Fruitland	1889	1889	2001	$3,137,957,050	Fruitland	
DIS119	Gallup	1881	1882	2001	$121,522,629,885	Crevasse Canyon	
DIS156	Hogback	1907	1907	1971	$301,237.00	Menefee	
DIS146	Monero	1882	1882	1970	$5,277,552.00	Menefee	
DIS016	Mount Taylor	1936	1952	1953	$69,948.00	Crevasse Canyon	
DIS157	Navajo	1933	1963	9999	$4,714,689,147	Fruitland	2
DIS258	Newcomb	1955				Menefee	
DIS021	Raton	1820	1898	2002	$954,470,032.00	Vermejo, Raton	23
DIS003	Rio Puerco	1901	1937	1944	$139,555.00	Crevasse Canyon	
DIS009	Salt Lake	1980	1987	1987	$100,000.00	Moreno Hill	2
DIS121	San Mateo	1905	1983	2001	$1,678,742,326	Menefee	
DIS261	Standing Rock	1934	1952	1958		Menefee	
DIS158	Star Lake	1907			$0.00	Fruitland	32
DIS263	Tierra Amarilla	1935	1955	1955		Menefee	
DIS159	Toadlena	1950			$0.00	Menefee	
DIS124	Zuni	1916	1908	1926	$16,010.00	Crevasse Canyon	
	Other areas					Popotosa Formation	7
	Ash						2
Total samples	October 17, 2022						80

Health and safety plan (COMPLETED)
HASP is complete (https://geoinfo.nmt.edu/staff/mclemore/documents/HASP_v2.pdf).

Subtask 2.4 Collect Samples
Sampling was delayed due to poor weather, vacation schedules, closures of Federal land because of fire danger, and students not available because of school schedule. We started sampling in April.

We have logged 3162 ft of core (33 holes). We have collected 80 samples (Table 3; Attachment 3, https://geoinfo.nmt.edu/staff/mclemore/Attachment3-NETLREE-SEDSampleDataNM.xlsx).
Additional samples will be collected.

Subtask 2.5 Sample Characterization
Attended the DOE CORE-CM Characterization Working Group - Planning Meetings on April 11, 19, May 9, June 13, 2022
Chemical analyses have been delayed due to obtaining quotes and proper paperwork required by NM Tech (completed August 2022)
Six samples have been analyzed for major and trace elements (see Attachment 3, https://geoinfo.nmt.edu/staff/mclemore/Attachment3-NETLREE-SEDSampleDataNM.xlsx)

Subtask 2.6 Application of Machine Learning techniques for basin-wide resource assessment
There is no update on this subtask.

Task 3.0 Basinal Strategies for Reuse of Waste Streams
Subtask 3.1 Waste Streams Sampling and Characterization
There is no update on this subtask.

Subtask 3.2 Coal Ash
We have collected 2 coal ash samples from San Juan Generating Plant prior to closure.

Subtask 3.3 Technology Development of Basinal Reuse Strategy
There is no update on this subtask.

Task 4.0 Basinal Strategies for Infrastructure, Industries and Businesses
Subtask 4.1 Infrastructure Investigation
There is no update on this subtask.

Subtask 4.2 Competitiveness and Challenge
There is no update on this subtask.

Subtask 4.3 Life-Cycle Analysis (UPDATED AND COMPLETED)
The project team is utilizing the cradle-to-grave concept, which would be adopted to set the boundary of energy and material flows for all the processes involved in the REE industry. Life-cycle analysis including energy and material analysis, environmental impact assessment, scalability assessment and detailed economic analysis shall be conducted to the current REE and CM supply chain and investigate the potential upgrading of the REE and CM process industry, in order to establish pathways toward net neutral carbon emission and the process engineering and design requirements to accomplish this. Typical REE production route is describe in Figure 2:

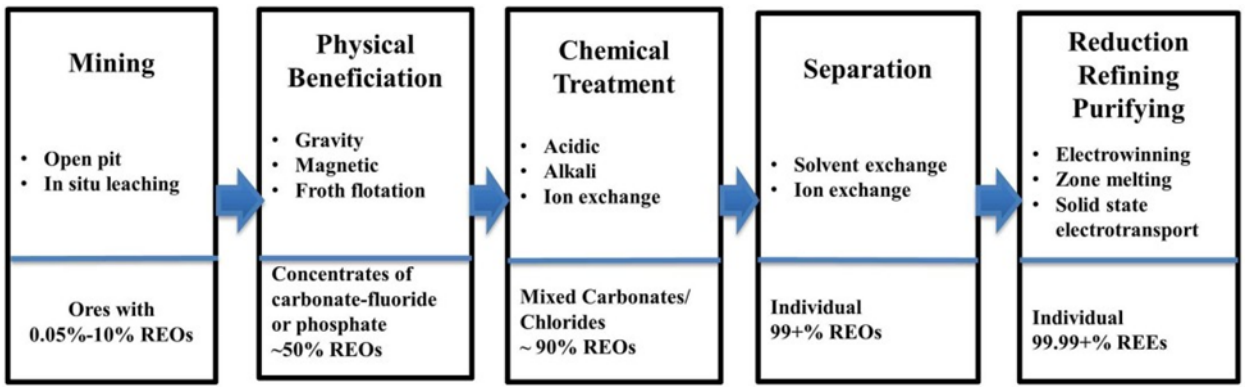

Figure 2. Generalize REE production flow chart

Proposed boundary for this task would be simplified as Figure 3.

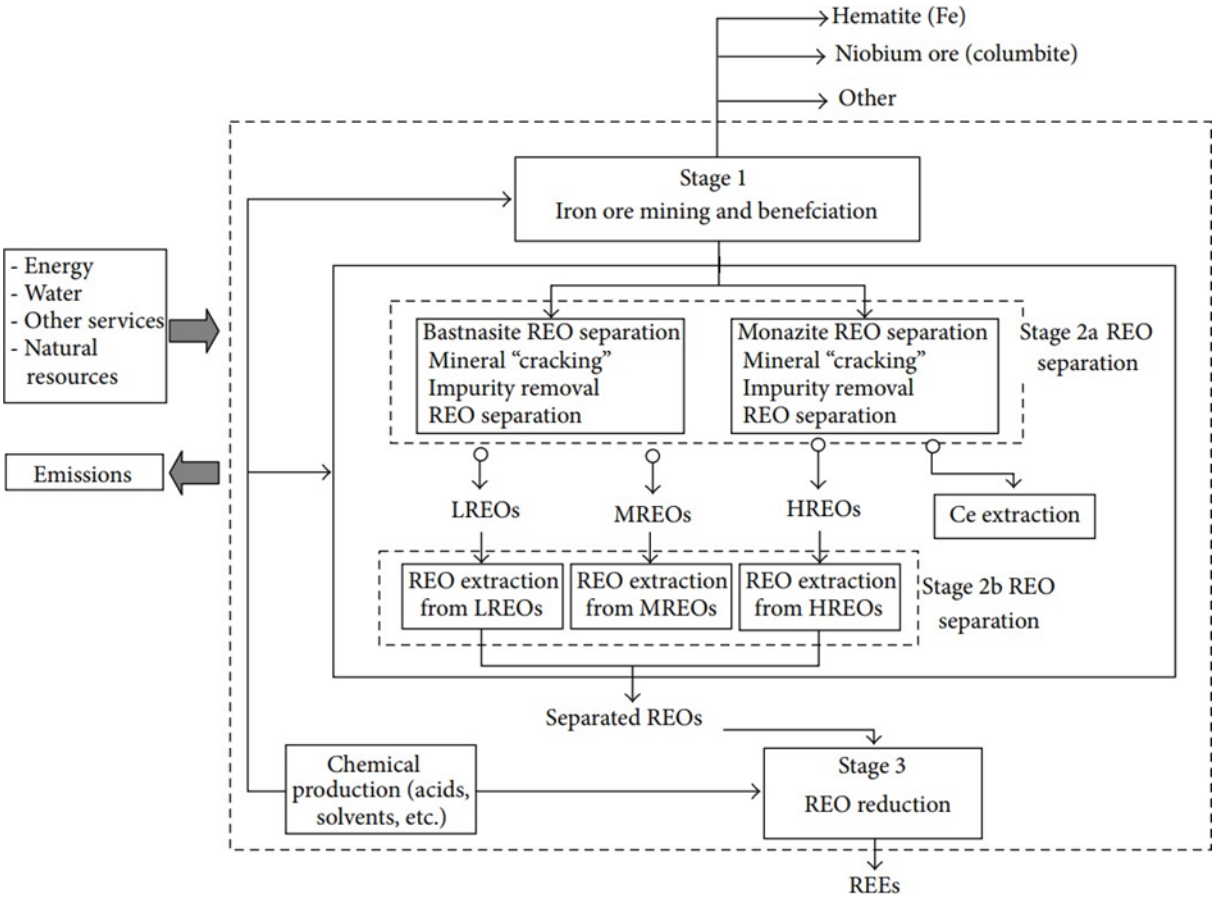

Figure 3. Simplified boundary. (To be modified with details of each unit processes for LCI)

Real Earth Element (REE)/Critical Mineral (CM) Extraction Technique

The focus extraction technology is the utilization of supercritical CO_2 Chelator fluids to mine these minerals (Sandia National Laboratories). In this approach, the solvent dissolves CM and extracted selectively. Also the solvent enhances solution mining by being used to fracture ores

(Mark J. et al). A detail assessment of the processes involved in this technique with respect to its green or carbon neutral importance in comparison to current techniques ought to be conducted.

Overview of Life Cycle Assessment (LCA)

Calculating and evaluating all inputs and outputs of environmental stressors and products' potential impact on the environment, from raw material extraction and acquisition, manufacturing, transportation and distribution, use and maintenance, reuse and recycle, and all the way to disposal and waste management describes LCA. This study follows the ISO 14000 and frame work (Fig. 4).

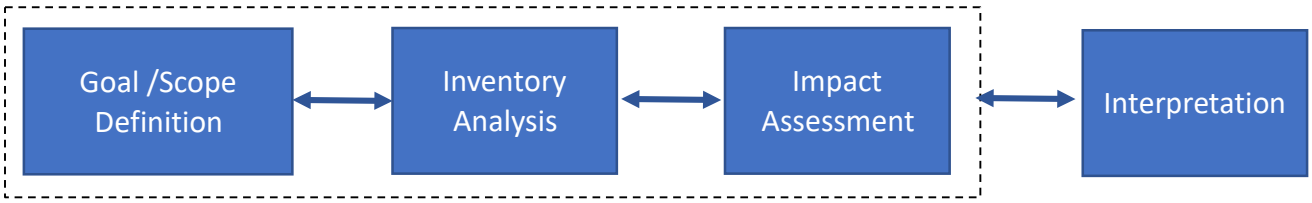

Figure 4. Life Cycle Assessment framework

Goal and scope

Life-Cycle Analysis: Life-cycle analysis including energy and material analysis, environmental impact assessment, scalability assessment and detailed economic analysis shall be conducted to the current REE and CM supply chain and investigate the potential upgrading of the REE and CM process industry, in order to establish pathways toward net neutral carbon emission and the process engineering and design requirements to accomplish this.

Lifecycle Inventory Analysis (LCI)

The LCI is a critical component as it is the data foundation of the LCA study. The approach adopted by ISO 14044 is to compile the inventory based on the inputs and outputs from each of the processes (referred to as unit processes) involved in a product's life cycle.

Figure 5, presents the key processes involved and hence a summary of the project boundary. Inventory of key units to be collected are based on this boundary.

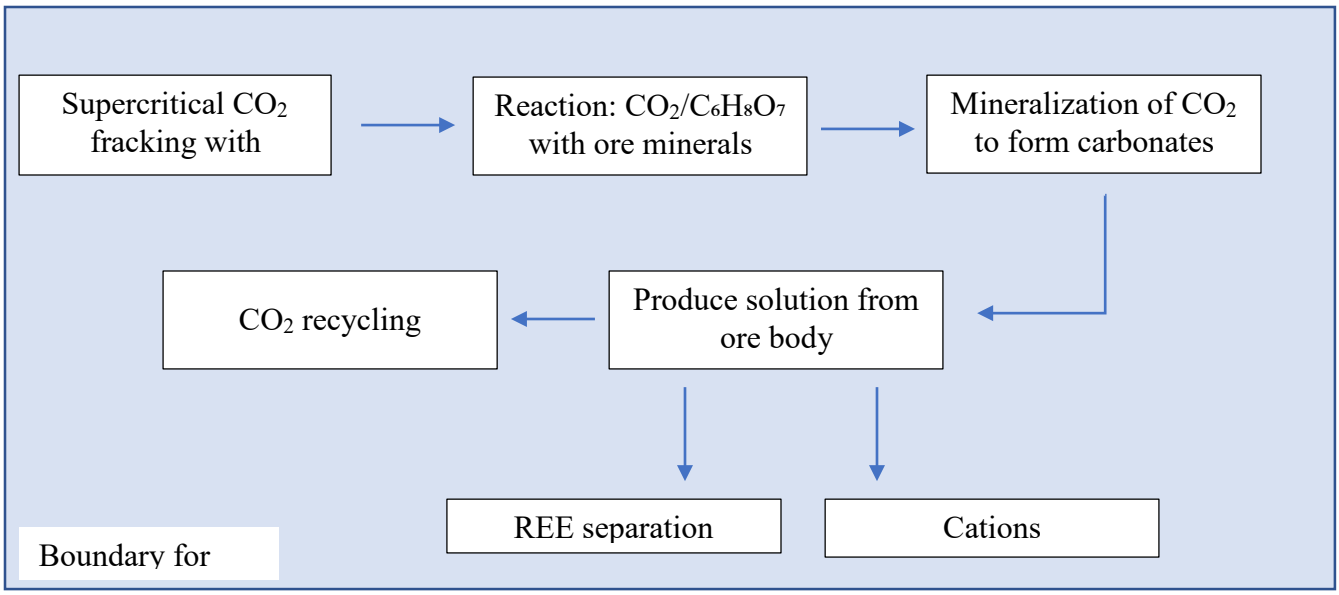

Figure 5. Summary of Key process steps involved/Boundary for LCA

Life Cycle Impact assessment (LCIA)

The LCIA step of an LCA study is used to evaluate the significance of potential environmental impacts using inventory data, and providing information for the interpretation step. This study will focus on evaluating the impact of global warming through a midpoint assessment of measuring global warming potential. Hence the relative potency of different greenhouse gases such as CO_2, N_2O and methane and the results in $kgCO_2$ equivalent (Equations 1 and 2) and other environmental impacts.

$$Impact = \sum_{p \epsilon P} CF_{ip} \,.\, MassEmittedp \qquad \text{Equ. 1}$$

$$GWP[kgCO_{2eq}] = \sum_{p \epsilon P} GWP_p \left[\frac{kgCO_{2e}}{kg\ p}\right] .\, MassEmittedp\ [kg\ p] \qquad \text{Equ. 2}$$

Interpretation of Results

The last step in an LCA study is the interpretation of results. The findings from the LCI and LCIA are considered together. The results will be discussed and summarized in the form of conclusions and recommendations, and presented to decision makers. And this will be in line with the goals of the analysis.

Other Environmental Impacts

TRACI Global Warming Air, Acidification Air, Eutrophication Water, Smog Air, all Ecotoxicity categories, and all Human Health categories. m3 water consumed/ton ore produced. Extractability of toxins per EPA Method 1311.

Selected References

Mark J. Rigali, Yifeng Wang, Yongliang Xiong, Green Mining of Critical Metals Using Supercritical CO2-H2O-Chelator Fluids Sandia National Laboratories (Albuquerque, NM); Guangping Xu

N. A. Azzolina, J. A. Hamling, W. D. Peck, C. D. Gorecki, D. V Nakles, and L. S. Melzer, "A Life Cycle Analysis of Incremental Oil Produced via CO2 EOR," *Energy Procedia*, vol. 114, pp. 6588–6596, 2017.

ISO 14041: Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis. 199

Navarro J and Zhao F (2014) Life-cycle assessment of the production of rare-earth elements for energy applications: a review. Front. Energy Res. 2:45. doi: 10.3389/fenrg.2014.00045

Task 5.0 Technology Assessment, Development and Field Testing

Subtask 5.1 Identify and Assess Existing and Novel Technologies Specific to the Resource

There is no update on this subtask.

Subtask 5.2 Develop Plan for Field Testing

There is no update on this subtask.

Task 6.0 Technology Innovation Centers

Subtask 6.1 SonoAsh Center of Excellence

There is no update on this subtask.

Task 7.0 Stakeholder Outreach and Education

Subtask 7.1 New Mexico State and Regional Education

A short summary of the project was written for Gold Pan (https://nmt.edu/advancement/goldpan_archives/2022_Summer_GoldPan_Digital2.pdf), NMIMT Alumni Newsletter.

Another short summary of the project written for Lite Geology.

The NMBGMR Rockin' Around New Mexico was in Farmington, NM July 6-8, 2022 (https://geoinfo.nmt.edu/education/rockin/home.html). Lectures on critical minerals and a tour of the Navajo coal mine were included (https://geoinfo.nmt.edu/staff/mclemore/home.html) .

Attended CORE-CM Environmental Justice and Social Responsibility Working Group meeting July 12, 2022

Subtask 7.2 Lessons Learned and Narratives Constructed

There is no update on this subtask.

Subtask 7.3 Publications and presentations

See Section 2 below

Subtask 7.4 Training and Conferencing with SJC and Sonoash COE

There is no update on this subtask.

2. PRODUCTS

A. Publications, conference papers, and presentations

1st quarter

Kickoff presentation October 15, 2021
(https://geoinfo.nmt.edu/staff/mclemore/documents/CORE-CMprojectNMfinal.pdf)
DOE Division of Critical Minerals Program Plan Rollout on December 8, 2021
(https://geoinfo.nmt.edu/staff/mclemore/documents/CORE-CMprojectNMDOEsummary12_21.pdf)

2nd quarter
New Mexico Geological Society abstract: Badonie, M.N. and McLemore, V.T., 2022, REE in coalbeds in the San Juan-Raton coal basins (abstr.): New Mexico Geological Society, Spring Meeting, https://nmgs.nmt.edu/meeting/abstracts/view.cfm?aid=2838. Poster at https://geoinfo.nmt.edu/staff/mclemore/documents/NMSG.Poster2022COPY2.pdf.

3rd quarter
Rockin' 22 Critical Minerals presentation
(https://geoinfo.nmt.edu/staff/mclemore/documents/McLemoreRockinCM22.pdf)
Rockin' 22 Critical Minerals activities
(https://geoinfo.nmt.edu/staff/mclemore/documents/Rockin22.pdf)

4th quarter
New Mexico Mining Association abstract and presentation: REE in the coal and associated strata in the San Juan and Raton Basins, New Mexico, 2022, Megan Badonie, Jakob Newcomer, Devlon Shaver Advised by: Dr. Virginia T. McLemore, https://geoinfo.nmt.edu/staff/mclemore/documents/NMAAPresentationNMMAFINAL2022.pdf
McLemore, V.T., 2022, Rare Earth Elements (REE) in Late Cretaceous coal and beach-placer sandstone deposits in the San Juan Basin, New Mexico: Preliminary Observations (abstr.): Geological Society of America, Annual Conference, October, https://gsa.confex.com/gsa/2022AM/meetingapp.cgi/Paper/378264, presentation https://geoinfo.nmt.edu/staff/mclemore/documents/McLemoreGSA22Wed10-12-22.pdf

B. Website(s) or other Internet site(s)
See project web page at https://geoinfo.nmt.edu/staff/mclemore/REEinCoalWeb.html

C. Technologies or techniques
No update

D. Inventions, patent applications, and/or licenses
No update

E. Other products
1st quarter
Sampling plan
Health and safety plan (https://geoinfo.nmt.edu/staff/mclemore/documents/HASP_v2.pdf)
SOP17 Drillhole logging
https://geoinfo.nmt.edu/staff/mclemore/documents/SOP17DrillholeLoggingupdated.pdf

3rd quarter

Revised sampling plan (https://geoinfo.nmt.edu/staff/mclemore/documents/samplingplan_v5.pdf)

REE in produced waters (https://geoinfo.nmt.edu/staff/mclemore/ree_produced_waters_for_GIS.xlsx) and USGS coal chemistry (https://geoinfo.nmt.edu/staff/mclemore/REEcoal.mpk)

McLemore attended Mining and Metallurgical Society of America AML summit in Phoenix April 6-7, 2022

Rockin' was held in Farmington July 5-8, 2022

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A. Individuals involved in project

New Mexico Tech

Dr. Navid Mojtabai (PI) is a professor and department chair in the Mineral Engineering Department at New Mexico Tech - Tasks 1, 3, 5, and 7.

Dr. Virginia McLemore (Co-PI) is the Principal Senior Economic Geologist for the NMBGMR - Tasks 1, 2, 3, 5 and 7.

Dr. Robert Balch (PM) is the Project manager for this project and is the Director of the PRRC – Task 1, 2, 4 and 7.

Dr. William Ampomah (Co-PI) is a Research Engineer and Section Head at PRRC – Task 1, 4, 5 and 7.

Dr. Sai Wang is a Research Associate at PRRC - Tasks 4.

Dr. William Chavez is a professor in the Mineral Engineering department at New Mexico Tech – Task 2 and 3.

Mr. Mark Leo-Russell is the NMBGMR database specialist - Task 2 and 3.

Mr. Mark Mansell: is the NMBGMR GIS specialist - Task 2.

Ms. Cynthia Connolly is the Education Outreach Manager at the NMBGMR – Task 7.

Dr. Shari Kelley is a senior field geologist and geophysicist at the NMBGMR – Task 2 and 7.

Mr. Christopher Armijo is the NMBGMR computer specialist - Task 1 and 2.

Mr. Brian Wheeler is the NMBGMR fleet manager - Tasks 2 and 3.

Ms. Gretchen Hoffman is the NMBGMR emeritus coal geologist - Task 2 and 3.

Sandia National Laboratories(SANL)

Dr. Jason Heath is a hydrogeologist at SANL. –Task 2 and 5.

Dr. Guangpring Xu is an experimental geochemist at SANL - Tasks 2, 3 and 5.

Dr. Mark J Rigali

San Juan College

Dr. John Burris: is a Professor of Geology and Department Chair at San Juan College - Tasks 7.

Summer Begay

Craig J. Williams

Los Alamos National Laboratory (LANL)

Dr. Kirsten Sauer is a Scientist at LANL - Task 5.

Dr. Hakim Boukhalfa is a Senior Scientist at LANL – Task 5

Dr. Sam Clegg is Senior Scientist st LANL – Task 2

Dr. Brent Goehring

SonoAsh

Mr. Claudio Arato is the CTO of SonoAsh company - Task 3, 4, 5, 6 and 7.

Mr. Brad MacKenzie is the VP of SonoAsh company – Task 4 and 6
Bruce Sifton

B. Change in support levels of key persons
Dr. Rajesh Pawar had shifted his responsibilities on this project to Dr. Kirsten Sauer.
Craig Williams and Summer Begay are now representing San Juan College.

4. SPECIAL REPORTING REQUIREMENTS: Mandatory
No update

5. BUDGETARY INFORMATION: MANDATORY

Spend Plan by Fiscal Year Format

	FY 2022		FY 2023		Total	
	DOE funds	Cost Share	DOE funds	Cost Share	DOE	Cost Share
NMIMT	564,432	101,114	544,856	104,147	1,109,287	205,261
Los Alamos National Laboratory	93,750	-	93,750	-	187,500	-
Sandia National Laboratories	99,946	-	87,054	-	187,000	-
SonoAsh LLC	-	115,000	-	115,000	-	230,000
Total ($)	758,128	216,114	725,660	219,147	1,483,787	435,261
Total Cost Share %		22.2%		23.2%		22.7%

Table for Actual Incurred Costs

Table for Remaining Balance

6. REFERENCES

7. APPENDICES

APPENDIX 1. List of SOPs and plans (see https://geoinfo.nmt.edu/staff/mclemore/REEinCoalWeb.html for copies as they are completed)

Number	Name	Description
HASP	Health and Safety Plan (HASP)	Health and safety plan for field and laboratory work (https://geoinfo.nmt.edu/staff/mclemore/documents/HASP_v2.pdf)
FSP	Field Sampling Plan (FSP)	Field sampling plan (https://geoinfo.nmt.edu/staff/mclemore/documents/samplingplan_v3.pdf)
SOP 1	Data management	entering, reporting, verification, and validation of data to the database
SOP 2	Photography	procedures taking photographs in the field and laboratory
SOP 3	GPS surveying	Procedures for use of handheld GPS surveying
SOP 4	Sampling outcrops, rock piles, and drill core	field procedures for taking surface solid samples
SOP 17	Drillhole logging	procedures for drilling, logging, and sampling of subsurface samples (solids) (https://geoinfo.nmt.edu/staff/mclemore/documents/SOP17DrillholeLoggingupdated.pdf)
SOP 6	Soil paste pH and paste conductivity	laboratory procedures for soil paste pH and paste conductivity
SOP 7	Field measurements of water	field procedures for measuring water flow, pH, conductivity, alkalinity, temperature when collecting water samples
SOP 8	Surface water and seep sampling	field procedures for collecting samples of surface and seep water samples
SOP 9	Petrographic analysis	laboratory procedures for describing petrographic samples
SOP 10	Electron microprobe analyses	laboratory procedures use for analyses using the electron microprobe
SOP 12	X-ray diffraction (XRD) analyses	laboratory procedures for mineralogical analyses by x-ray diffraction (XRD)