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Investigating Industrial Mine Waste and Byproduct Streams as Potential Alternative Sources of Critical Minerals in Alberta

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Summary

Global demand for critical minerals is accelerating, motivating the evaluation of unconventional domestic sources in Alberta. This study, a collaboration between the Alberta Geological Survey (AGS) and the Northern Alberta Institute of Technology's (NAIT) Centre for Energy and Environmental Sustainability (CEES) under the AGS Mineral Mapping Program, investigates the potential of coal and oil sand mine waste and byproducts to host critical minerals. Seven coal sites (five active or legacy surface coal mines and two former coal-fired power stations) were selected for sampling. Samples of coal, fly ash, bottom ash, coarse rejects, plant waste, and tailings were collected across multiple locations and depths (0–20 m) using auger and grab sampling techniques. A comprehensive suite of analyses was used to characterize representative samples in terms of their physical, mineralogical, and geochemical properties, and included particle size distribution (PSD) analysis, loss on ignition (LOI), methylene blue index (MBI), bulk and clay-fraction X-ray diffraction (XRD), wavelength-dispersive X-ray fluorescence (WDXRF), inductively-coupled plasma optical emission spectroscopy (ICP-OES) and mass spectroscopy (ICP-MS), CHNS, optical microscopy, and scanning electron microscopy (SEM) techniques. The coal ash samples exhibited an average total REE concentration (303 ppm) slightly above the economic cutoff grade of 300 ppm for coal and coal by-product proposed by the U.S. Department of Energy and are relatively enriched in light rare earth elements (LREE), particularly La, Ce, and Nd. Multiple ash and coarse-reject samples show high proportions of critical REE and favorable outlook coefficients (critical REE/excessive REE), suggesting they could be promising sources of REE. Discrepancies between the REE concentrations measured by WDXRF and ICP-MS can be feasibly explained by the relatively low precision for REE by WDXRF, which in turn results from spectral interference caused by transition metals. Consistent with previous studies, critical mineral concentrations tend to be higher in the finer ash samples relative to the coarser tailings samples. Although the concentrations of some critical minerals (e.g., Mn, Ti, Ga, and V) are significantly enriched relative to values measured in typical coals, they remain below their respective economic cutoff grades. While these results highlight coal ash and select coarse-reject materials as potential targets for further REE exploration, the variability observed between sites indicates the need for more localized characterization to inform resource assessments and development decisions.

Similar characterization is ongoing for oil sands mine waste and byproduct steams.

Introduction

Global demand for critical minerals has increased significantly in recent years, and the identification and development of domestic sources of these valuable commodities is a priority at the federal and provincial levels. In 2017, the Government of Canada released the Critical Minerals List, which has since been updated to include a total of 34 minerals and metals of

strategic importance (Government of Canada, 2026). These minerals and metals are essential for energy, technology, infrastructure, and defense, among other applications. Rare earth elements (REE) are a subset of critical minerals consisting of 15 elements of the lanthanide series, scandium (Sc), and yttrium (Y). Based on the classification scheme outlined in the International Union of Pure and Applied Chemistry (IUPAC), REE have been categorized into the light REE (LREE; La, Ce, Pr, Nd, Sm, Eu, Gd) and heavy REE (HREE; Tb, Dy, Ho, Er, Tm, Yb, Lu, Y). Seredin and Dai (2012) subdivided the REE into critical (CREE; Nd, Eu, Tb, Dy, Y, Er), uncritical (UREE; La, Pr, Sm, Gd), and excessive REE (EREE; Ce, Ho, Tm, Yb, Lu). Decreasing ore grades worldwide has generated interest in alternative sources of critical minerals, such as waste materials from mining and other industries. Waste and byproducts are attractive sources of critical minerals due to their accessibility, well-quantified volumes, tendency to host multiple elements of interest, and potential environmental benefits of development.

As part of the Government of Alberta's Minerals Strategy (Government of Alberta, 2021) the Ministry of Energy and Minerals funded the Alberta Geological Survey's (AGS) Mineral Mapping Program, aiming to increase public geoscience knowledge of Alberta's mineral resources. This work has resulted in a growing collection of data, maps, reports, and other information on a wide array of critical mineral commodities, all available to the public on the AGS website (ags.aer.ca). As part of the Mineral Mapping Program, the AGS has partnered with the Centre for Energy and Environmental Sustainability (CEES) at the Northern Alberta Institute of Technology (NAIT) to investigate the potential of coal and oil sands mine waste and byproduct materials to host critical minerals.

The scope of the coal investigation includes evaluating and characterizing critical minerals in mine waste from Alberta's coal industry. The main objectives were to identify and quantify sources of critical minerals in coal, coal combustion byproducts (i.e., fly ash and bottom ash), coarse rejects, and mine tailings. Previous work (e.g., Bishop et al., 2023; Burkus et al., 2023; Gupta et al., 2019; Hower et al., 2016; Huang et al., 2018; Kuppusamy et al., 2024; Mastalerz et al., 2022; Seredin and Dai, 2012) has yielded preliminary findings that demonstrate the potential for various coal mine and power generation waste products to host valuable commodities such as REE, lithium (Li), and titanium (Ti). Research on the potential in Alberta has been limited in scope and in many cases, samples are not geolocated. This project takes an integrative approach, analyzing a broad range of samples for a wide variety of potential commodities using consistent methodology for multiple sites. The results will be compiled and presented in an accessible format to enhance public understanding of the critical mineral potential in coal mine wastes in Alberta.

Rationale

Alberta contains abundant coal deposits throughout the central and southern regions of the province, generally grading from lignite or sub-bituminous coal in the eastern Plains to high-grade, thermal or metallurgical (bituminous) coal in the Foothills (Beaton, 2003). Significant volumes of coal ash have been produced from past power generation, with recent estimates suggesting more than 5.5 megatonnes (Mt) of ash produced in 2014 and 3.0 Mt of ash produced as recently as 2019 (Burkus and Belosevic, *in preparation*). Coal-associated REE are retained in coal ash, and the combustion process concentrates these elements, thereby increasing their

relative abundance and the potential of these resources (Ardakani et al., 2022; Bishop et al., 2023; Fu et al., 2021).

Coal seams occur associated and interbedded with shale, clay, and paleosol horizons, which have also generated research interest as potential sources of REE (e.g., Flynn, 2023, Gilbert and Marsh, 2025). These strata tend to be discarded in coarse reject piles during mining, and therefore this waste stream could be a potentially important source of REE. Previous studies have found that REE can be more abundant in coal mine waste than in the mined coal itself (e.g., Freiburg et al., 2022).
REE content in coal mine waste depends on feed coal composition, processing, and storage conditions (Fu et al., 2021). Thus, REE anomalies and occurrences vary by region and mine, and location-specific data collection is required to understand the extent and potential of these resources in Alberta.

Methodology

Five surface coal mines and two former coal-fired power generation sites were sampled for this study. Various waste materials were sampled at each site, and included coal, fly ash, bottom ash, coarse rejects, plant waste, and tailings, dependent on the availability of these materials at each site. Each waste disposal area was sampled at multiple geospatial locations and different depths to better capture the compositional variability of these materials. Samples were collected using a combination of solid-stem auger and grab sampling techniques, at depths ranging from 0 to 20 metres below the ground surface.

A subset of these samples was analyzed by the CEES laboratory at NAIT using a comprehensive suite of analyses to fully characterize the samples in terms of their physical, mineralogical, and geochemical properties. All samples were homogenized and oven-dried prior to analysis. Particle size distribution (PSD) analyses were conducted to quantify the range of particle sizes in each sample. Methylene Blue Index (MBI) tests were conducted to determine the clay activity of the samples. Mineral identification and clay quantification were conducted using X-ray diffraction (XRD) techniques, whereas microstructural characterization and elemental mapping were performed using optical microscopy and scanning electron microscopy (SEM) on selected samples. The elemental compositions of the samples were quantified using a complementary set of analytical techniques: wavelength-dispersive X-ray fluorescence (WDXRF) for major and trace elements; loss on ignition (LOI) and CHNS analysis for volatile residues and organic content; inductively-coupled plasma optical emission spectroscopy and mass spectroscopy (ICP-OES and ICP-MS) for critical minerals and REE, respectively.

Results and Discussion

The coal ash samples analyzed in this study have an average total REE concentration of 303 ppm, slightly above the 300 ppm threshold considered the minimum for economic interest by the U.S. Department of Energy (e.g., Bagdonas et al., 2022; Yesenchak et al., 2022; Kolker et al., 2024). These coal waste samples are enriched in LREE, especially La, Ce, and Nd. Previous work has demonstrated a negative correlation between coal ash particle size and critical mineral concentrations (e.g., Lin et al., 2017), and the results of this study show a similar trend, with higher concentrations of several critical minerals (e.g., Co, Cu, Mn, Ga, V, and Ti) observed in relatively

fine-grained coal ash samples compared to coarse-grained coal tailings samples based on PSD and ICP-OES results. Several coal ash and coarse reject samples have a relatively high proportion of critical REE relative to total REE and high outlook coefficients, as defined by Seredin and Dai (2012), suggesting that these materials could be promising REE sources (Figure 1). While the concentrations of manganese (Mn), titanium (Ti), gallium (Ga), and vanadium (V) measured in the analyzed samples were significantly enriched relative to typical coals, they were still consistently below common economic cutoff grades (e.g., Manganese X Energy Corp., 2022; Woodruff et al., 2017; Rudnik et al., 2024; Lopez et al., 2020). The new data from this work may be used to refine future processing strategies such as the selection of processing techniques, the potential for adverse chemical reactions or side-effects of processing, and the feasibility of co-producing multiple commodities.

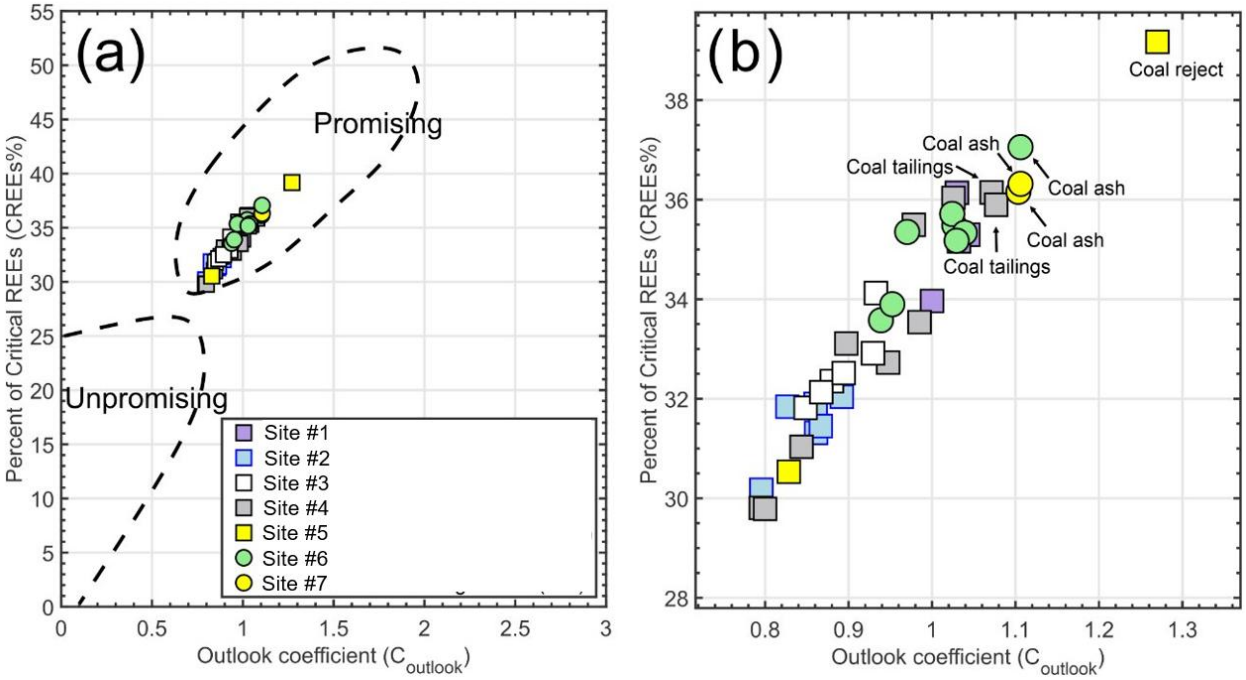


Figure 1: (a) Cross-plot of the percent of critical REE against the outlook coefficient for the samples analyzed in this study, annotated with “Promising” and “Unpromising” fields from Seredin and Dai (2012). (b) Detailed view of the sample points shown in (a); the most promising sample points are annotated with the type of sample material. The percentages of critical REE were calculated as CREE% = (Nd+Eu+Tb+Dy+Y+Er)/REE*100, and the outlook coefficients were calculated as C_outlook = (Nd+Eu+Tb+Dy+Y+Er)/(Ce+Ho+Tm+Yb+Lu), as in Seredin and Dai (2012).

It should be noted that the concentrations of critical minerals reported in these coal-related materials are significantly lower than those previously reported for oil sands mine waste and byproducts. For example, vanadium concentrations have been reported in petroleum coke at 1100-1900 ppm (Abdolahnezhad and Lindsay, 2022; Har, 1981; Jack et al., 1979; Nesbitt et al., 2017; Zubot et al., 2012), and in froth treatment tailings at 490 ppm (Roth et al., 2017). Previous work by Gupta et al. (2019) suggests that Alberta oil sands petroleum coke ash could contain 647 ppm Mo, 4,037 ppm Ni, 10,568 ppm V, and 1,547 ppm REEs. The AGS and NAIT are currently applying similar methodology to investigate the critical mineral potential of coke, ash, froth

treatment tailings, and other waste/byproduct streams related to oil sands mining and processing in Alberta.

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References

Abdolahnezhad, M. and Lindsay, M.B.J. (2022). Geochemical conditions influence vanadium, nickel, and molybdenum release from oil sands fluid petroleum coke; Journal of Contaminant Hydrology, v. 245, art. 103955.

Ardakani, O.H., Biggart, K., Dewing, K.E. (2022). Rare earth element (REE) content of shale, coal, and coal byproducts, and potential for Canadian REE supply – a literature review and initial assessment. Geological Survey of Canada Open File 8914, 61 p. Retrieved 17 April 2024 from https://ostrnrcan-dostrncan.canada.ca/entities/publication/835651a6-0df1-495f-b985-48a427d3c64d

Bagdonas, D. A., Enriquez, A. J., Coddington, K. A., Finnoff, D. C., McLaughlin, J. F., Bazilian, M. D., et al. (2022). Rare earth element resource evaluation of coal byproducts: a case study from the Powder River Basin, Wyoming. Renew. Sustain. Energy Rev. 158,112148. doi:10.1016/j.rser.2022.112148

Beaton, A. (2003). Coal-Bearing Formations and Coalbed-Methane Potential in the Alberta Plains and Foothills. Canadian Society of Exploration Geophysicists Recorder, Vol. 28, No. 09, 10 pp.

Bishop, B. A., Shivakumar, K. R., Alessi, D. S., & Robbins, L. J. (2023). Insights into the rare earth element potential of coal combustion by-products from western Canada. *Environmental Science: Advances, 2*(3), 529-542. Retrieved 29 April 2024 from https://pubs.rsc.org/en/content/articlelanding/2023/va/d2va00310d

Burkus, Z. and Belosevic, M. (*in preparation*). Critical Metals in Alberta: Preliminary Evaluation of Rare Earth Element Potential in Alberta Oil Sands and Bedrock. Alberta Environment and Protected Areas and Alberta Geological Survey.

Burkus, Z., Lopez, G.P., Rokosh, C.D., White, G.V. (2023). Critical Metals in Alberta: Preliminary Evaluation of Vanadium and Nickel Potential in Alberta Bitumen and Bedrock. AER/AGS Special Report 113. Alberta Geological Survey.

Flynn, J. (2023): A preliminary investigation into rare earth element distribution in the organic-rich Upper Cretaceous Colorado Group mudstones in east-central Saskatchewan; in Summary of Investigations 2023, Volume 1, Saskatchewan Geological Survey, Saskatchewan Ministry of Energy and Resources, Miscellaneous Report 2023-4.1, Paper A-1, 19p. and 1 Microsoft® Excel® file.

Freiburg, J., Elrick, S., & Delpomdor, F. (2022). The Illinois Basin Carbon Core, Rare Earth, and Critical Mineral Initiative (IB CORE-CM). In *Geological Society of America, North-Central Section, 56th annual meeting; Geological Society of America, Southeastern Section, 71st annual meeting.*

Fu, B., Hower, J. C., Zhang, W., Luo, G., Hu, H., & Yao, H. (2022). A review of rare earth elements and yttrium in coal ash: Content, modes of occurrences, combustion behavior, and extraction methods. *Progress in Energy and Combustion Science, 88, 100954.* Retrieved 18 April 2024 from https://www.sciencedirect.com/science/article/pii/S0360128521000526

Gilbert, M.M., Marsh, A. (2025). Investigating the critical mineral potential of Upper Cretaceous to Paleogene coals and carbonaceous shales in southwestern Saskatchewan, Canada. GeoConvention 2025, Calgary, Alberta, May 2025. https://geoconvention.com/wp-content/uploads/abstracts/2025/115664-investigating-the-critical-mineral-poten.pdf

Government of Alberta. (2021). Renewing Alberta's mineral future: A strategy to re-energize Alberta's minerals sector. Ministry of Energy. Retrieved January 11, 2026, from https://www.alberta.ca/minerals-strategy-and-action-plan

Government of Canada. (2026). Critical minerals: an opportunity for Canada. Natural Resources Canada. Retrieved January 11, 2026, from https://www.canada.ca/en/campaign/critical-minerals-in-canada/critical-minerals-an-opportunity-for-canada.html

Gupta, R., Pudasainee, D., and Khan M. (2019): Advanced Processing of Froth Treatment Tailings - Proof of Principle. Submitted to Alberta Environment and Parks as a result of Grant No 19GRPOL09.

Har, S.H-k. (1981). Characterization of oil sands fluid coke; M.Sc. thesis, University of Alberta.

Hower, J. C., Eble, C. F., Dai, S., & Belkin, H. E. (2016). Distribution of rare earth elements in eastern Kentucky coals: indicators of multiple modes of enrichment? *International Journal of Coal Geology, 160*, 73-81. Retrieved 15 January 2024 from https://doi.org/10.1016/j.coal.2016.04.009

Huang, Z., Fan, M., & Tiand, H. (2018). Coal and coal byproducts: A large and developable unconventional resource for critical materials–Rare earth elements. *Journal of Rare Earths, 36*(4), 337-338. Retrieved 6 November 2023 from https://www.sciencedirect.com/science/article/pii/S1002072118300139

Jack, T.R., Sullivan, E.A. and Zajic, J.E. (1979). Comparison of the structure and composition of cokes from the thermal cracking of Athabasca oil sands bitumen; Fuel, v. 58, no. 8, p. 585–588.

Kolker, A., Lefticariu, L., and Anderson, S. T. (2024). "Energy-Related rare earth element sources," in Rare earth metals and minerals industries (Cham: Springer). doi:10.1007/978-3-031-31867-2_3

Kuppusamy, V.K., Mackay, M.L., Aboagye, P., Holuszko, M.E. (2024). Characterization and Bench Scale Testing of Rare Earth Elements from East Kootenay Coalfields. Geoscience BC Publication 2024-07.

Lin, R., Howard, B., Roth, E., Bank, T., Granite, E., Soong, Y. (2017) Enrichment of rare earth elements fromcoal and coal by-products by physical separations. Fuel, 200, 506-520.

Lopez, G.P., Budney, H.E., Weiss, J.A. and Pawlowicz, J.G. (2020): Minerals of Alberta; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Map 590, scale 1:1 250 000.

Manganese X Energy Corp. (2022). Mining the Future. https://www.manganesexenergycorp.com/wp-content/uploads/2022/02/ManganeseX-Investor-Jan2022-V7_compressed.pdf (accessed June 12, 2025).

Mastalerz, M., Drobniak, A. J., & Branam, T. (2022). Coal and Coal Byproducts as Potential Sources of Rare Earth Elements (REE) in Indiana. Indiana Geological and Water Survey, *Indiana Journal of Earth Sciences, 4*. doi: 10.14434/ijes.v4i1.35307

Nesbitt, J.A., Lindsay, M.B.J. and Chen, N. (2017). Geochemical characteristics of oil sands fluid petroleum coke; Applied Geochemistry, v. 76, p. 148–158, doi:10.1016/j.apgeochem.2016.11.023.

Roth, E., Bank, T., Howard, B. and Granite, E. (2017): Rare earth elements in Alberta oil sand process streams; Energy Fuels, v. 31, p. 4714–4720, doi:10.1021/acs.energyfuels.6b03184.

Rudnik, E. (2024). Review on gallium in coal and coal waste materials: Exploring strategies for hydrometallurgical metal recovery. *Molecules*, *29*(24), 5919.

Seredin, V.V., Dai, S. (2012). Coal deposits as potential alternative sources for lanthanides and yttrium. International Journal of Coal Geology 94, 67-93.

Woodruff, L. G., Bedinger, G. M., & Piatak, N. M. (2017). *Titanium* (Professional Paper 1802–T). In Schulz, K.J., DeYoung, Jr., J.H., Seal II, R.R., Bradley, D.C. (Eds.*), Critical Mineral Resources of the United States – Economic and Environmental Geology and Prospects for Future Supply*. U.S. Geological Survey. https://pubs.usgs.gov/pp/1802/t/pp1802t.pdf

Yesenchak, R., Sharma, S., and Maxwell, A. E. (2022). Modes of occurrence, elemental relationships, and economic viability of rare earth elements in West Virginia coals: a statistical approach. Minerals 12 (8), 1060. doi:10.3390/min12081060

Zubot, W., MacKinnon, M.D., Chelme-Ayala, P., Smith, D.W. and Gamal El-Din, M. (2012): Petroleum coke adsorption as a water management option for oil sands process-affected water; Science of the Total Environment, v. 427–428, p. 364–372, doi:10.1016/j.scitotenv.2012.04.024.