

Unlocking large industry through collaborative research: Diversification of the unconventional critical minerals and materials supply chain

共同研究による新たな産業展開－非在来型
資源由来の重要鉱物・素材サプライチェーンの多様化

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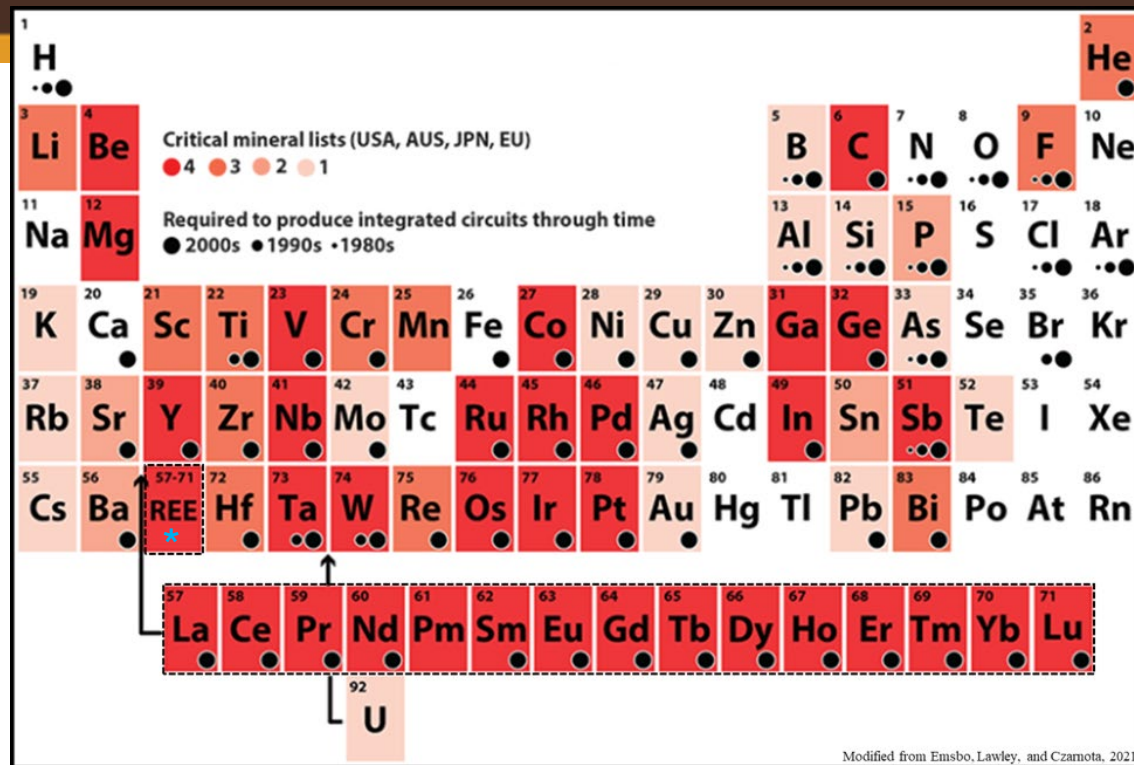


資源の安定供給と脱炭素化シンポジウム2026
Energy Security with Decarbonization Symposium 2026
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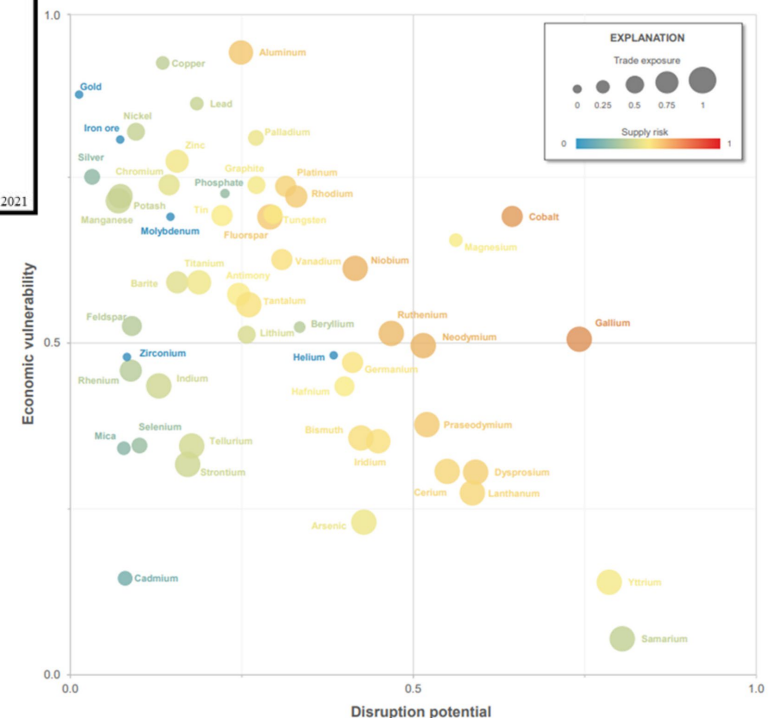
Critical Minerals and Materials (CMM)



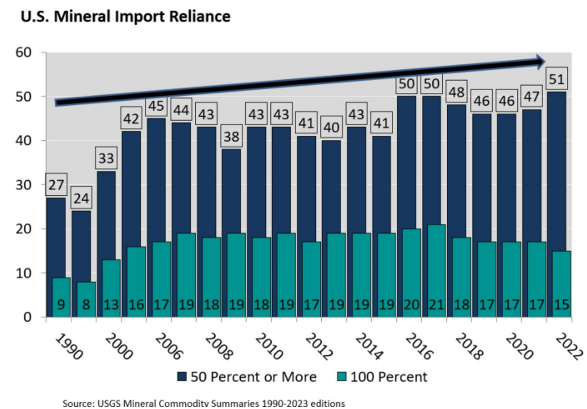
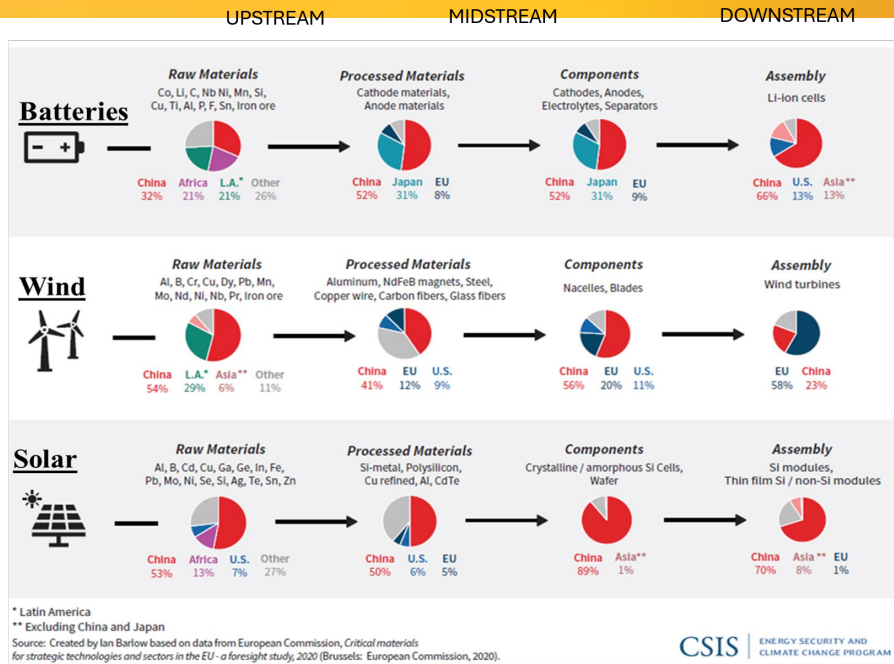
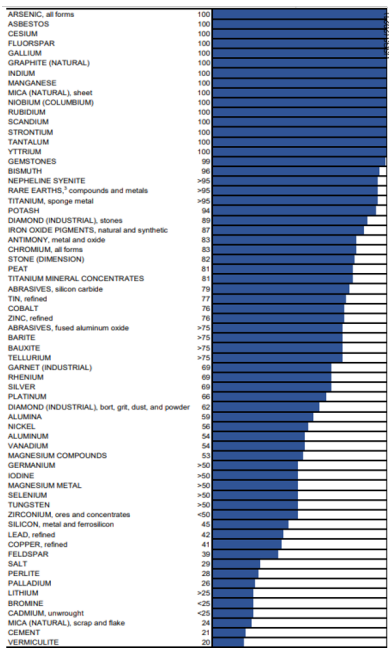
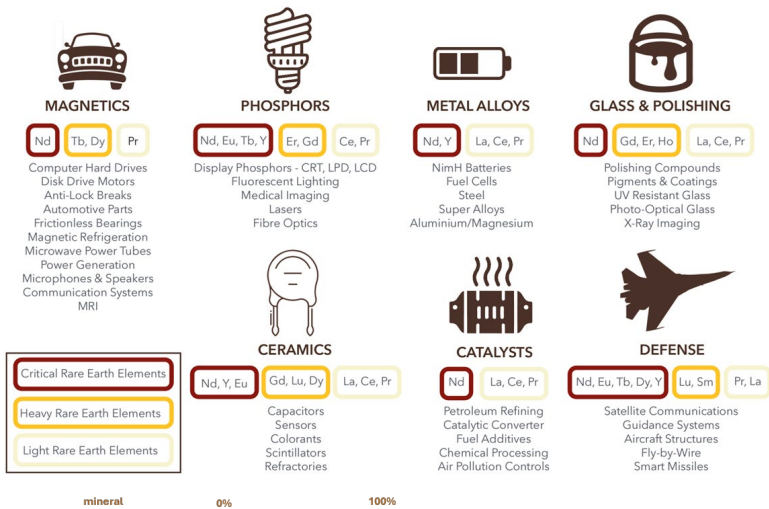
US Geological Survey finalized a revised list of 50 critical minerals in 2022 & 60 in 2025

Australia, Japan and European Union
also identify CMM lists

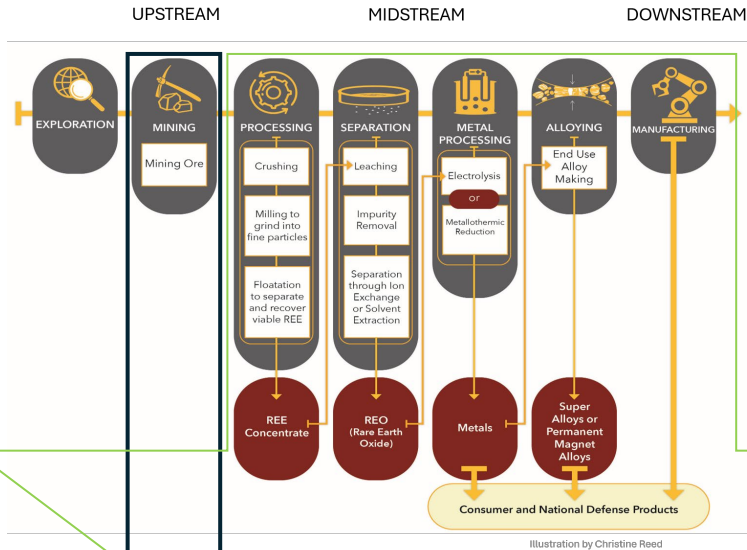
*Rare Earth Elements (REE) compose 15 elements of the U.S. 60



The CMM Supply Chain



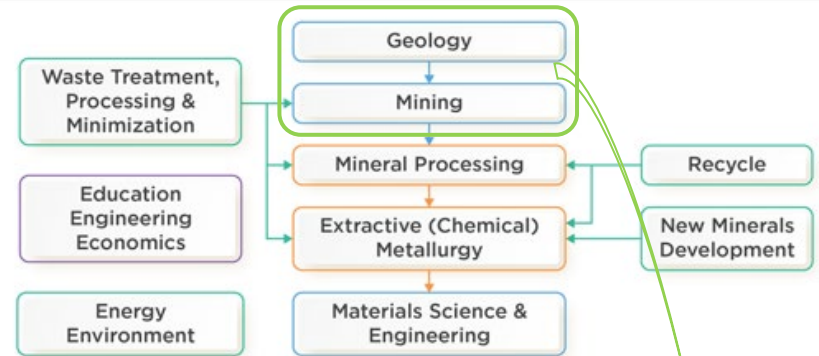
Identifying Priority



Conventional and Unconventional from existing industry

Reuse Repurpose (Re)utilize as new feedstocks

Potential Innovations



Geology
In place XRF and LIBS chemical analysis to identify enriched zones. On mine walls, down hole or core. Development of relationships between certain major elements and CM.

Mineral Processing
Application of ore sortation to upgrade before extraction. More energy efficient fine grinding to liberate small particles. Fine particle separations technology.

Extractive Metallurgy
New bio heap leach technology. In situ leaching. New selective lixiviants. New dissolved metal separations technology (SX or IX).

Mining
Development of selective mining technology.

[Acknowledgment: Prof. Pat Taylor, Colorado School of Mines, (CSM)]

Geology and Mining dictate unconventional priority for a region

Emerging Unconventional CMM Supply Chain

Prospective Feedstocks

Primary (A)

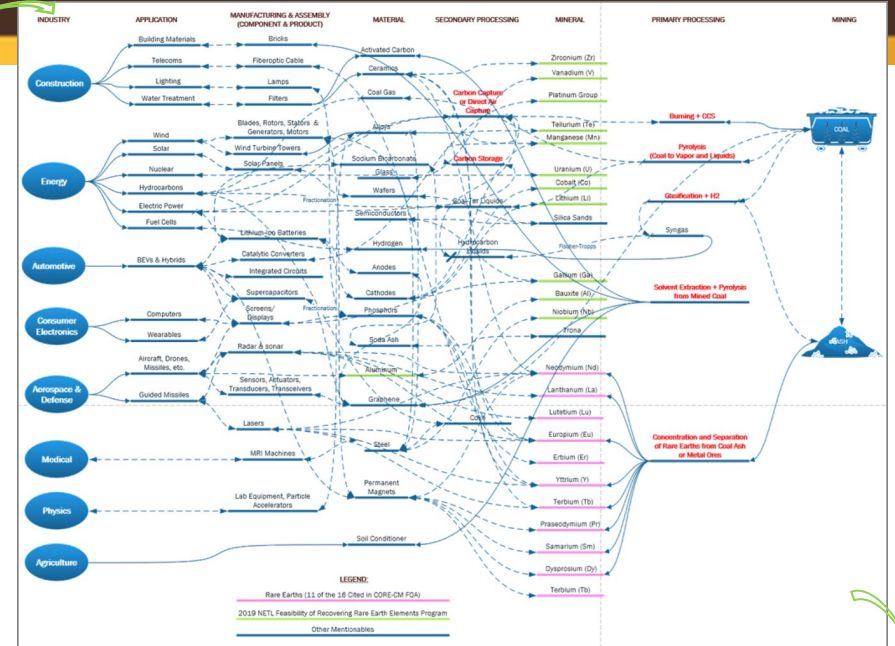
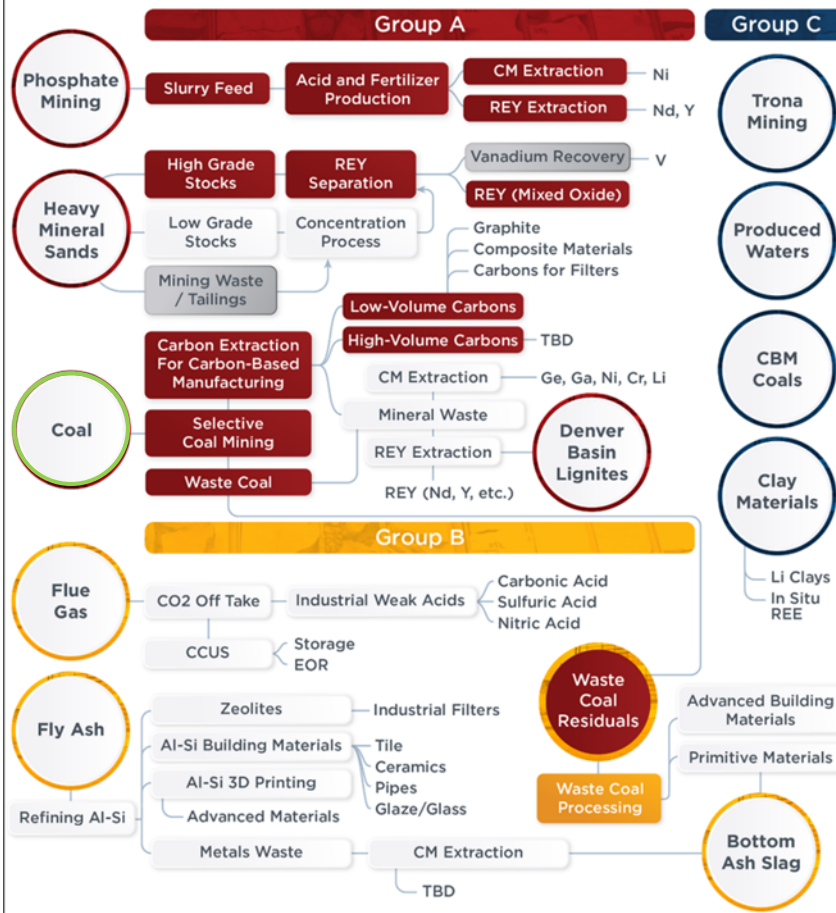
Explore feedstock for carbon-ore potential while developing a CM supply chain nucleus around long-term existing industries.

Secondary (B)

Manage carbon-ore feedstock residuals to recover REE's and Critical Materials of specific interest.

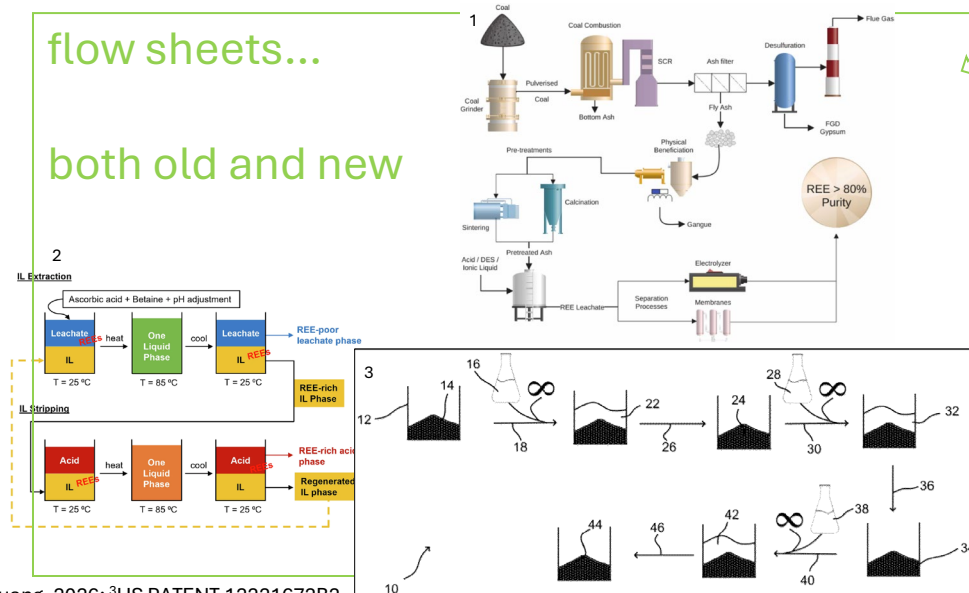
Tertiary (C)

Use remaining mineral matter & study gaps.

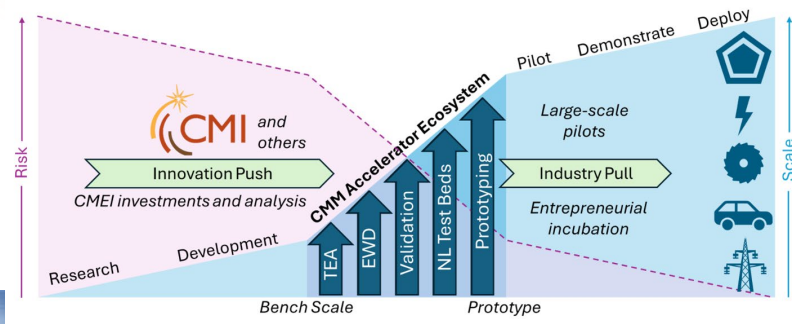
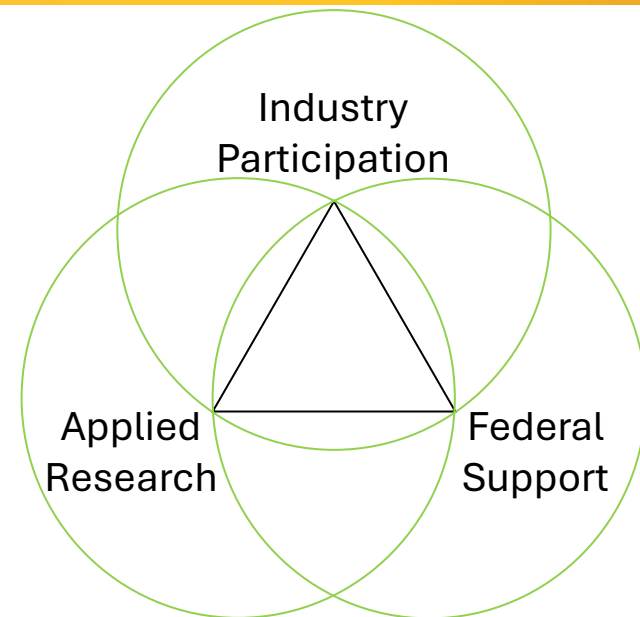
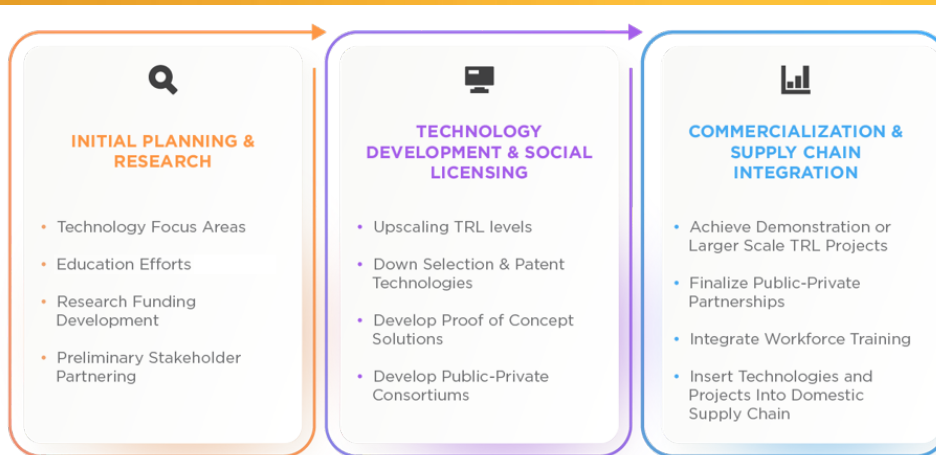


flow sheets...

both old and new



Utilizing Collaboration



US DOE - Notice of Funding Opportunity Number: DE-FOA-0003589



Working Examples

REE Extraction from Powder River Basin Coal Byproducts and Mining Waste, in response to DOE's Technology Commercialization Fund (TCF)

Year 1

Assessment of PRB feedstocks and REE extraction technology testing/optimization per each feedstock tested.

Year 2

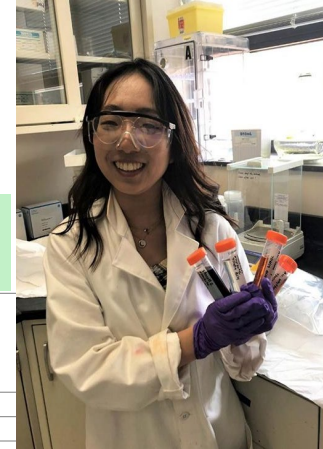
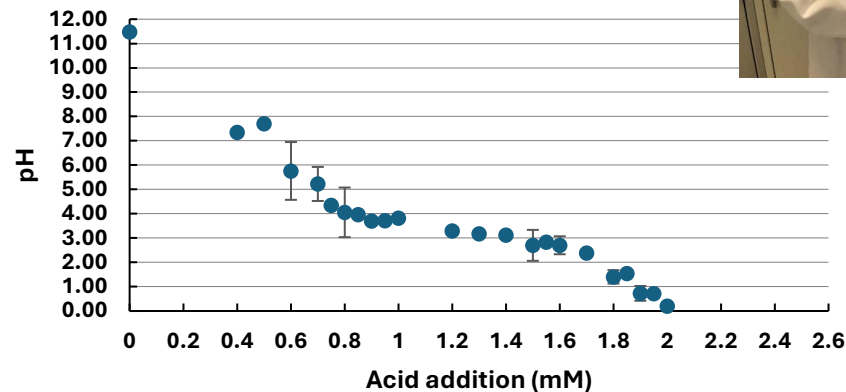
Feedstock(s) down select paired with optimized technology selection for that feedstock(s) demonstration.

Year 3 and 4

Technology upscaling to achieve pilot-scale REE extraction on site. Pilot-scale facility to be located in the PRB by project end date.

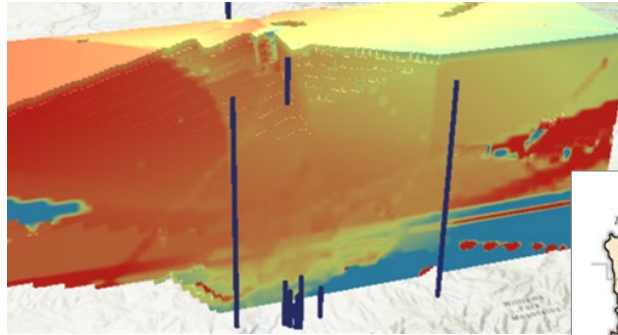
~4 year project: December 2020 – March 2025

pH titration to guide step leaching



Working Examples

A Machine Learning Screening Tool for Rare Earth Elements and Critical Minerals at the Mine Scale

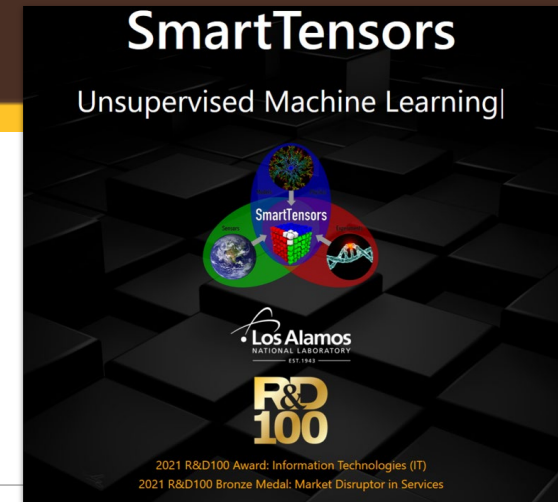


Task 1.0 – Characterization

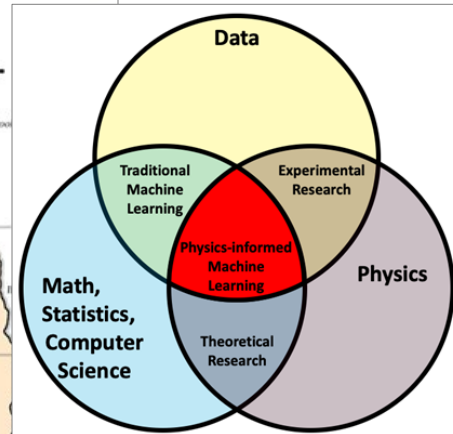
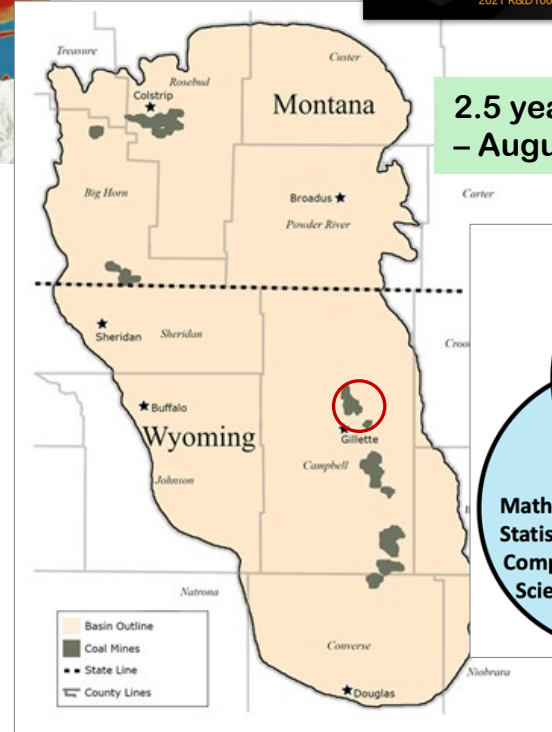
- catalog the existing data from core and well-logs
- add new samples from outcrop and core
- add new chemical and mineralogical data
- utilize advanced analytical techniques
 - ICP-MS, microprobe, elemental mapping (XRF), Raman spectroscopy, XRD, etc...

Task 2.0 – ML model development

- training of unsupervised ML model to extract REE/CM signatures
- construct high-resolution 3D geological framework model using Task 1 outputs and signatures learned with ML model



2.5 year project: March 2023
– August 2025

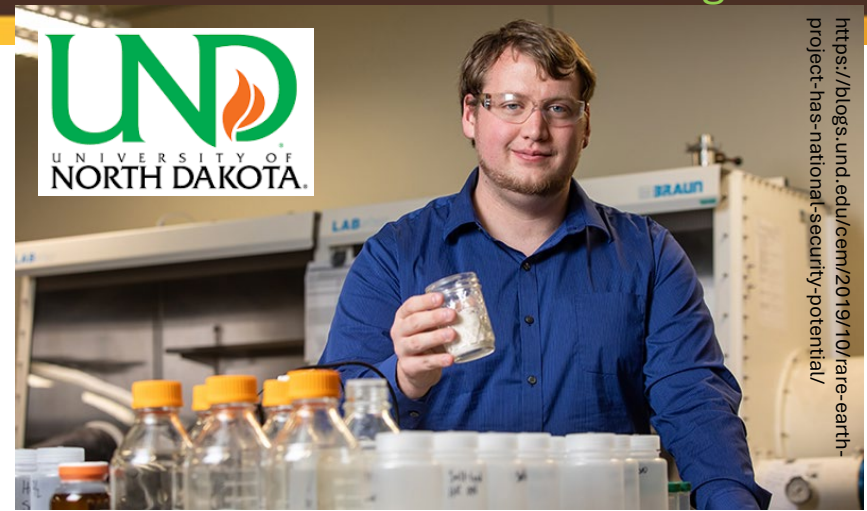


Examples at Scale

Direct Lithium Extraction



REE Extraction from Lignite



AMD - REE
Extraction



Waste is Now a
Strategic
National
Resource

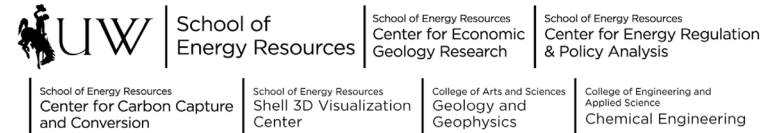
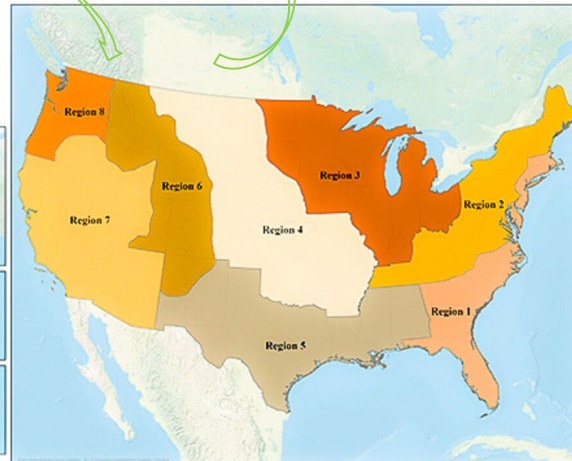
Alumina Waste Ge +
REE Extraction

Expertise Across Institutions

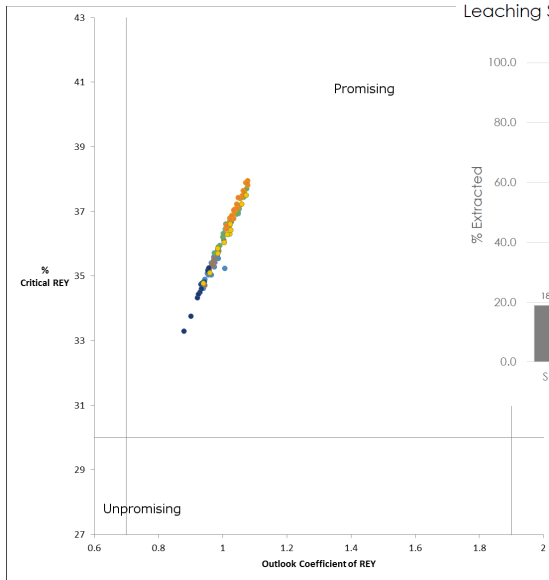
We must fully understand the resource to realize a meaningful supply chain



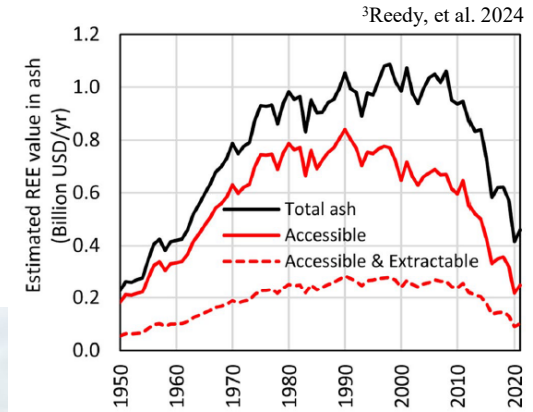
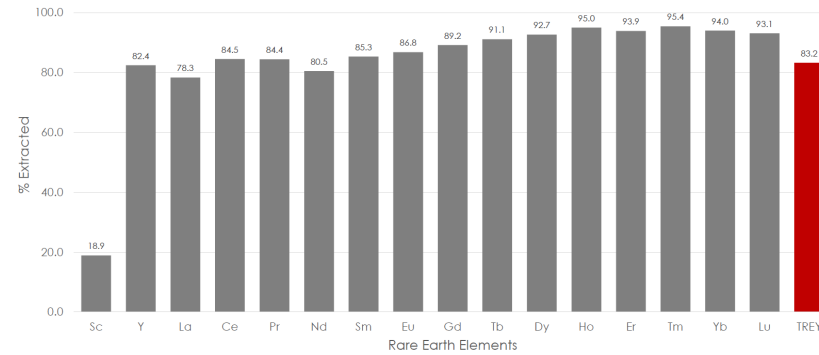
CORE-CM INITIATIVE



Future Work



Leaching Stage



SER Advances Coal Refinery Field Demonstration



Success = pathway to
commercialization

Thank You



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¹Bennet Sam Thomas, Piet Dimitriadis, Chandan Kundu, Sai Sree Varsha Vuppaladadiyam, R.K. Singh Raman, Sankar Bhattacharya, Extraction and separation of rare earth elements from coal and coal fly ash: A review on fundamental understanding and on-going engineering advancements, Journal of Environmental Chemical Engineering, Volume 12, Issue 3, 2024, 112769, ISSN 2213-3437, <https://doi.org/10.1016/j.jece.2024.112769>.

²Liu, T., Huang, CH. Sustainable extraction of rare earth elements from coal fly ash leachates using a recyclable ionic liquid. npj Mater. Sustain. 4, 2 (2026). <https://doi.org/10.1038/s44296-025-00088-2>

³Reedy, Robert & Scanlon, Bridget & Bagdonas, Davin & Hower, James & James, Dennis & Kyle, J. & Uhlman, Kristine. (2024). Coal ash resources and potential for rare earth element production in the United States. International Journal of Coal Science & Technology. 11. 10.1007/s40789-024-00710-z.