Rare Earth Element Recovery from Coal Waste

Opportunities for Saskatchewan

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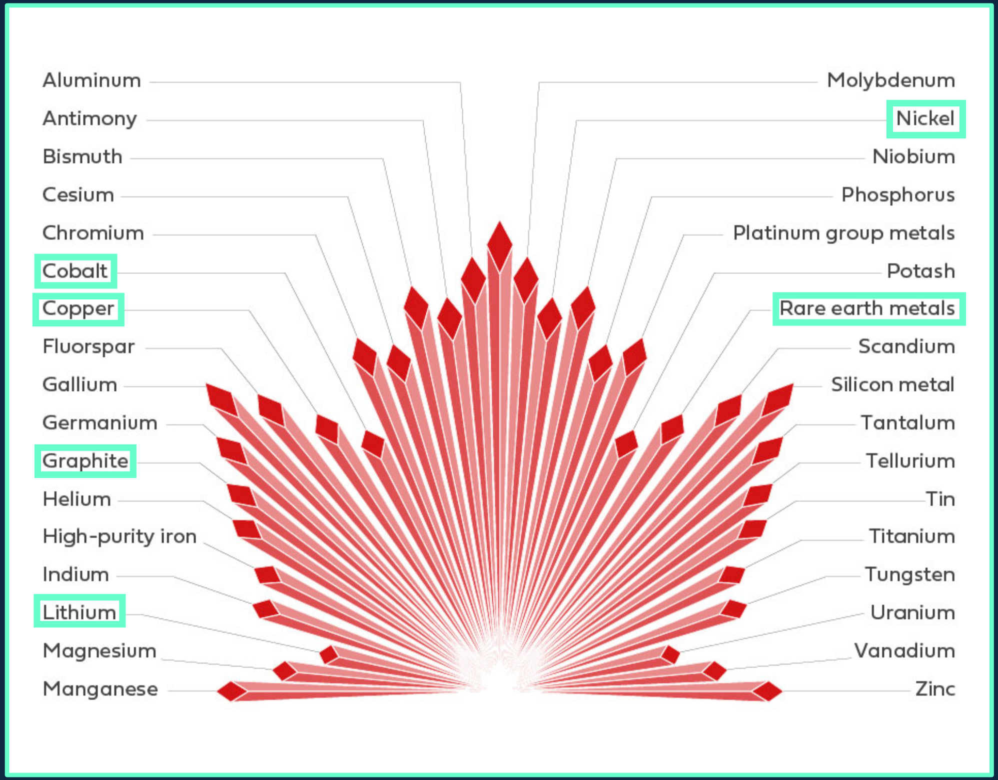
Critical Minerals

- A <u>non-fuel</u> mineral that is important for the economy and renewable energy whose supply may be disrupted
- Shared view that Critical Minerals:
  - Have few or no substitutes
  - Are strategic with limited quantities
  - Concentrated extraction and processing
- Classified on a political and economic basis
- Transient depending on supply and demand

Commodity	Canada	EU	South Korea	USA	Japan	Australia	South Africa	India	UK
Aluminum	x	x	-	x	-	x	-	-	-
Cobalt	x	x	x	x	x	x	x	-	x
Coking Coal	-	x	-	-	-	-	x	-	-
Copper	x	-	-	-	-	-	x	-	-
Graphite	x	x	-	x	x	x	-	x	x
Helium	x	-	-	-	-	x	-	-	-
Iron ore	x	-	-	-	-	-	x	-	-
Lead	-	-	-	-	-	-	x	-	-
Lithium	x	x	x	x	x	x	x	-	x
Nickel	x	-	x	x	x	-	x	-	-
PGM	x	x	x	x	x	x	x	-	x
Potash	x	-	-	-	-	-	-	-	-
REE	x	x	x	x	x	x	x	x	x
Uranium	x	-	-	-	-	-	x	-	-
Zinc	x	-	-	x	-	-	x	-	-

Critical Minerals in Canada

- To be a critical mineral it must have both a:
  - Threatened supply chain
  - Reasonable chance of being produced in Canada
- And either:
  - Be essential to economic or national security
  - Be required for the energy transition
  - Position Canada as a sustainable and strategic partner within global supply chains
- Six metals of high priority

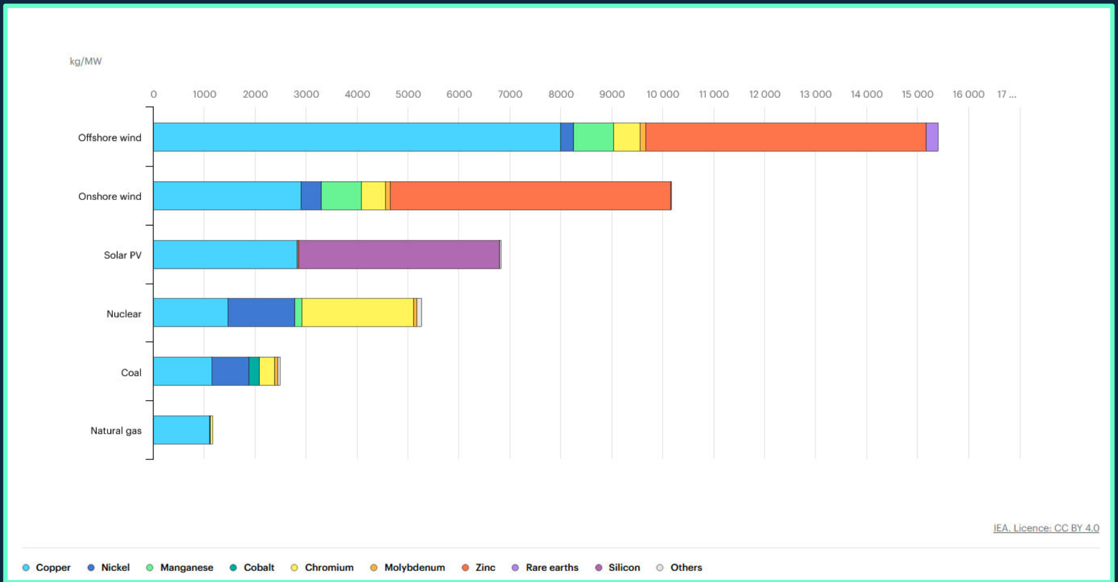


NRCan, 2024

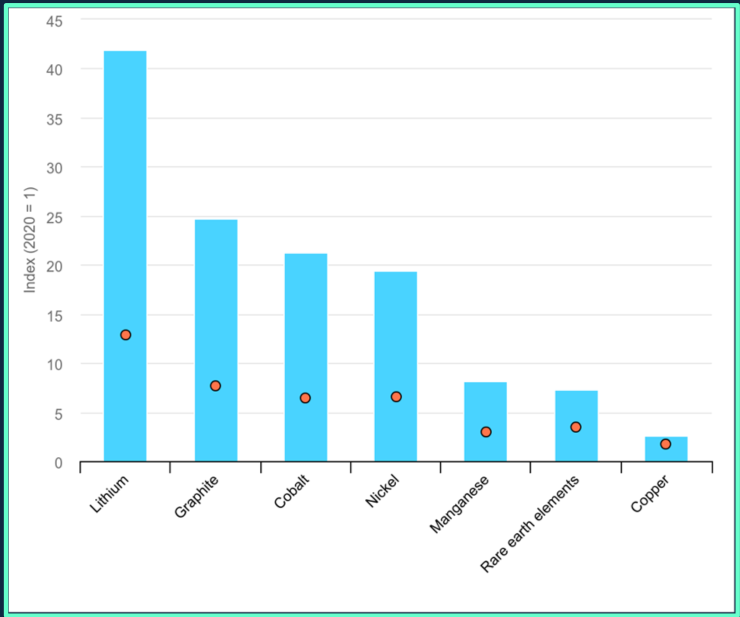
Critical Minerals in Clean Energy

- Renewable energy technologies require more metals than carbon-based energy sources
- Energy transition is very metal intensive

Minerals in Clean Energy Technologies



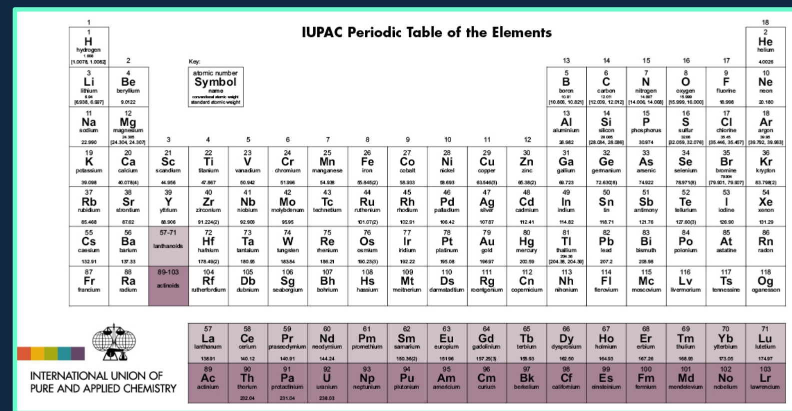
Metal Demand Increase to 2040 Relative to 2020

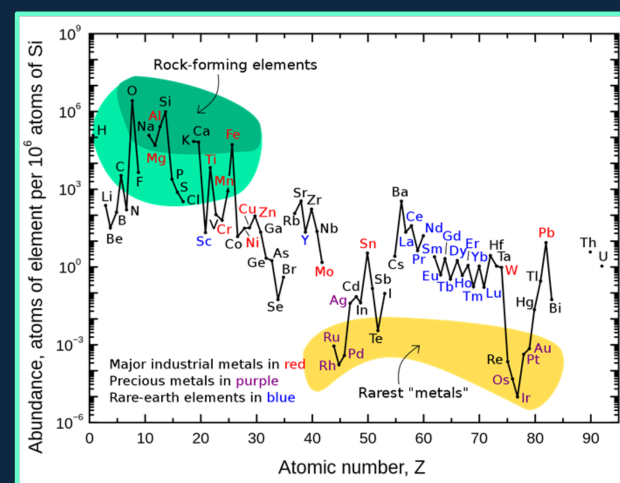


IEA 2021

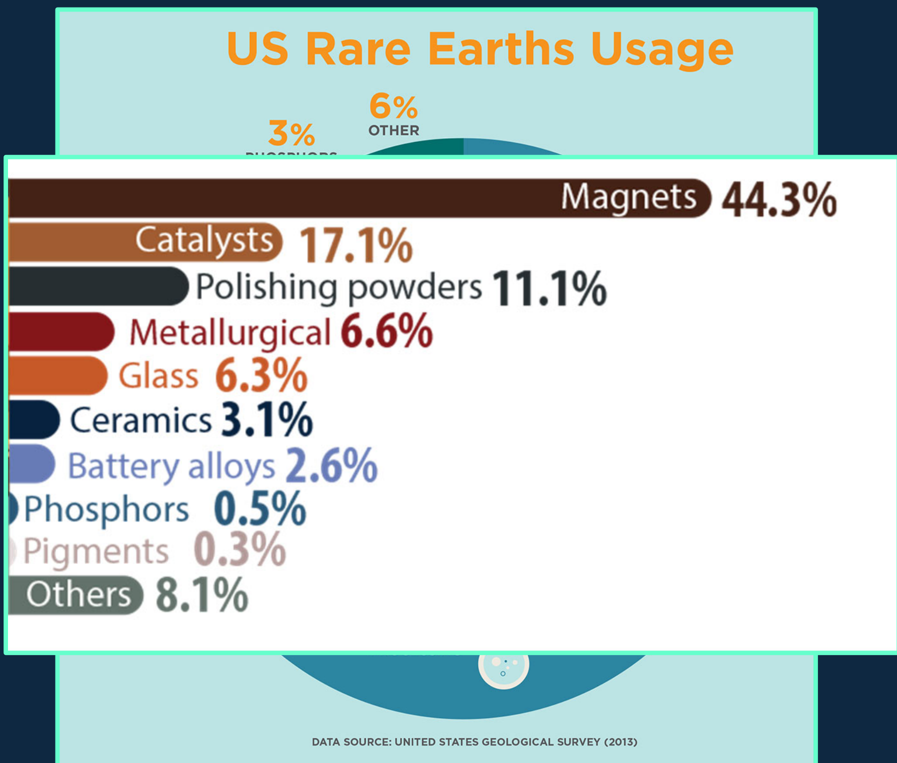
Rare Earth Elements

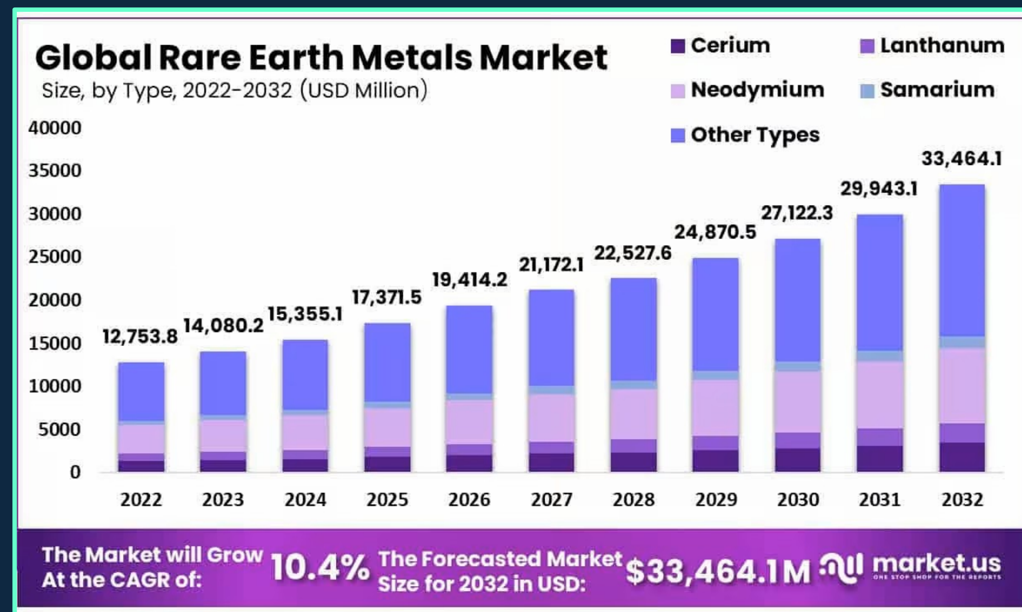
- Group of metals (lanthanides)
- Unique magnetic, optical, electronic properties
- Geologically “incompatible”
- Not “rare” in terms of crustal abundances, but few environments where economic concentrations exist
- Always occur as a group but in different proportions





REE Applications and Demand



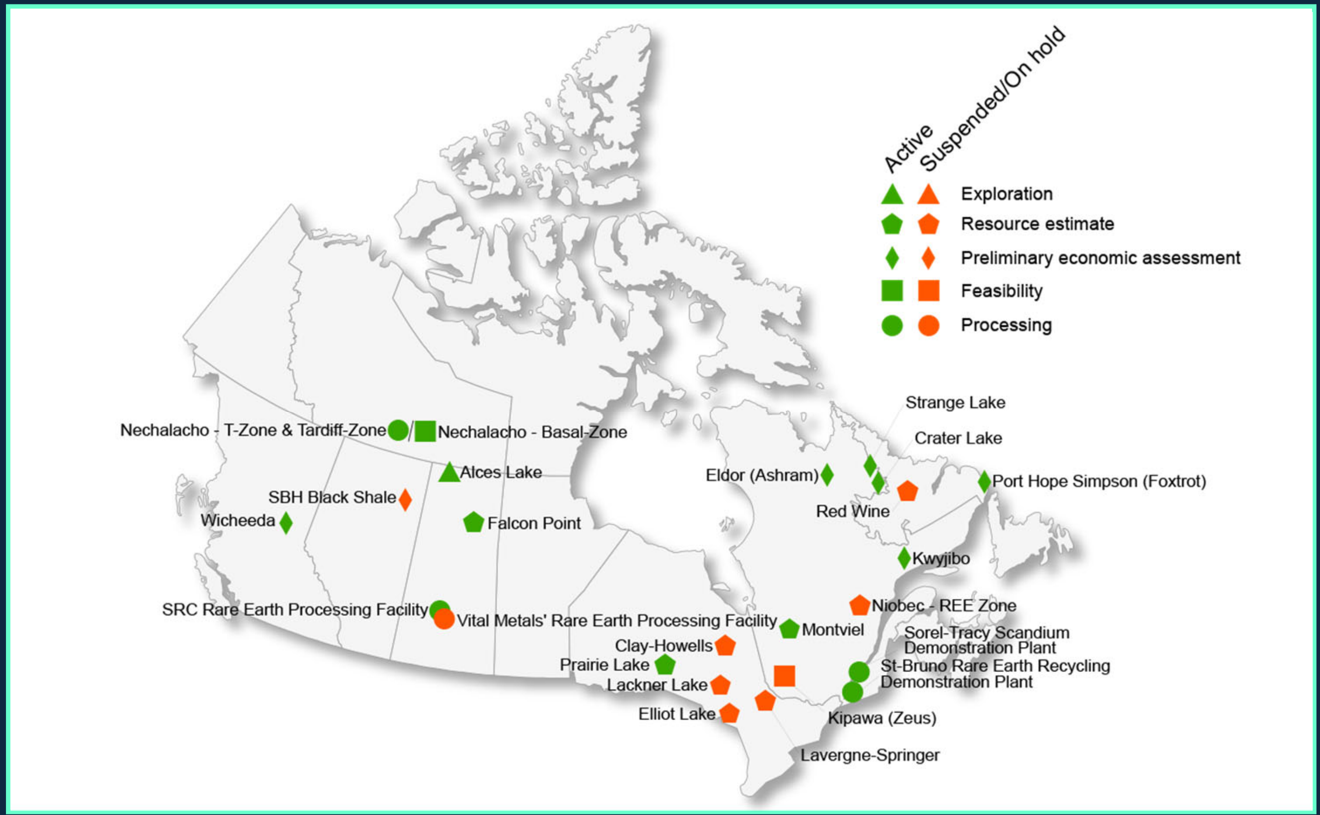


NRCan, 2024

Where do REE come from?

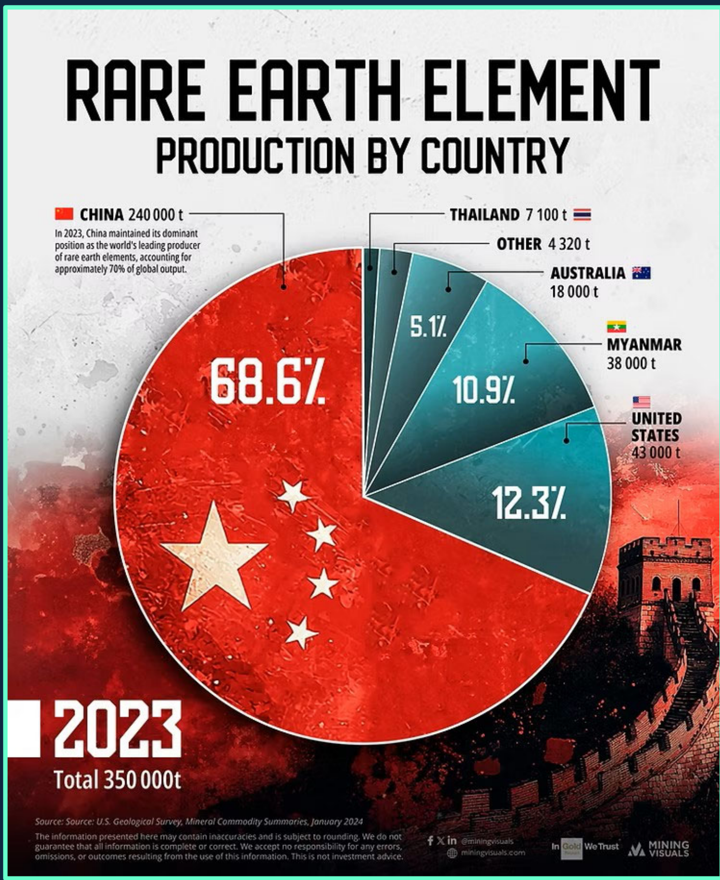
- Primary deposits
  - Monazite
  - Bastnaesite
  - Xenotime
- Secondary deposits
  - Ion-adsorption clays

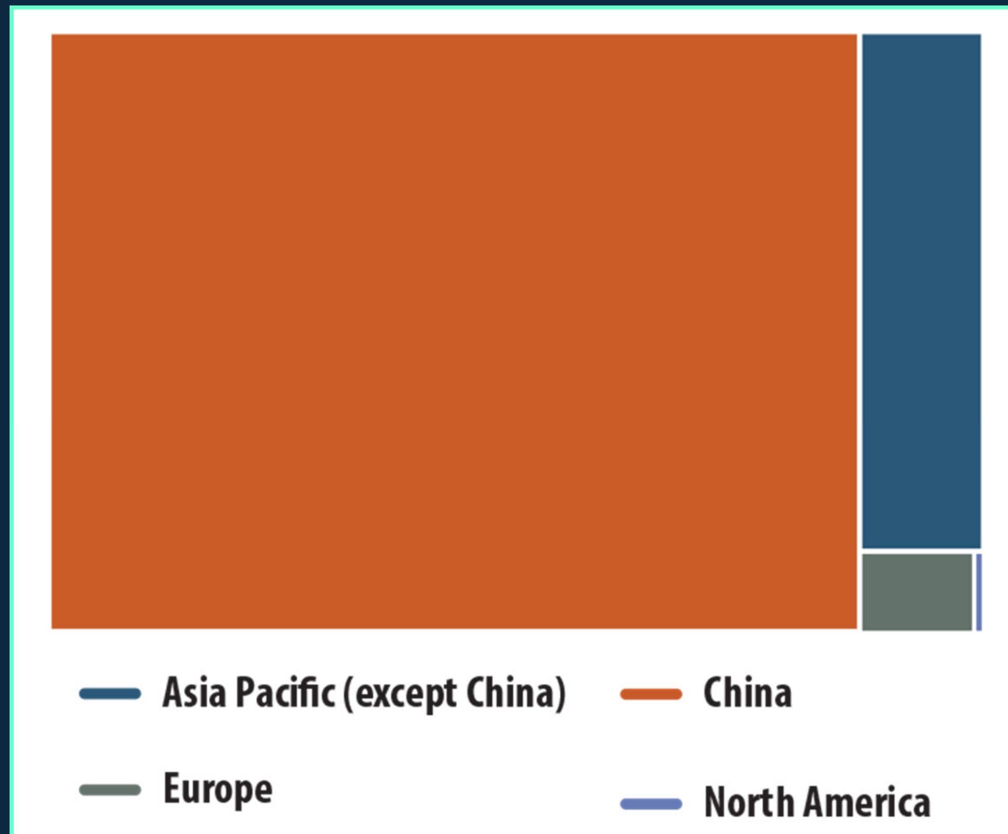
- Canada has advanced exploration projects and large resources/reserves but no production



Chen et al., 2024,
NRCan 2024

Global Production/Processing





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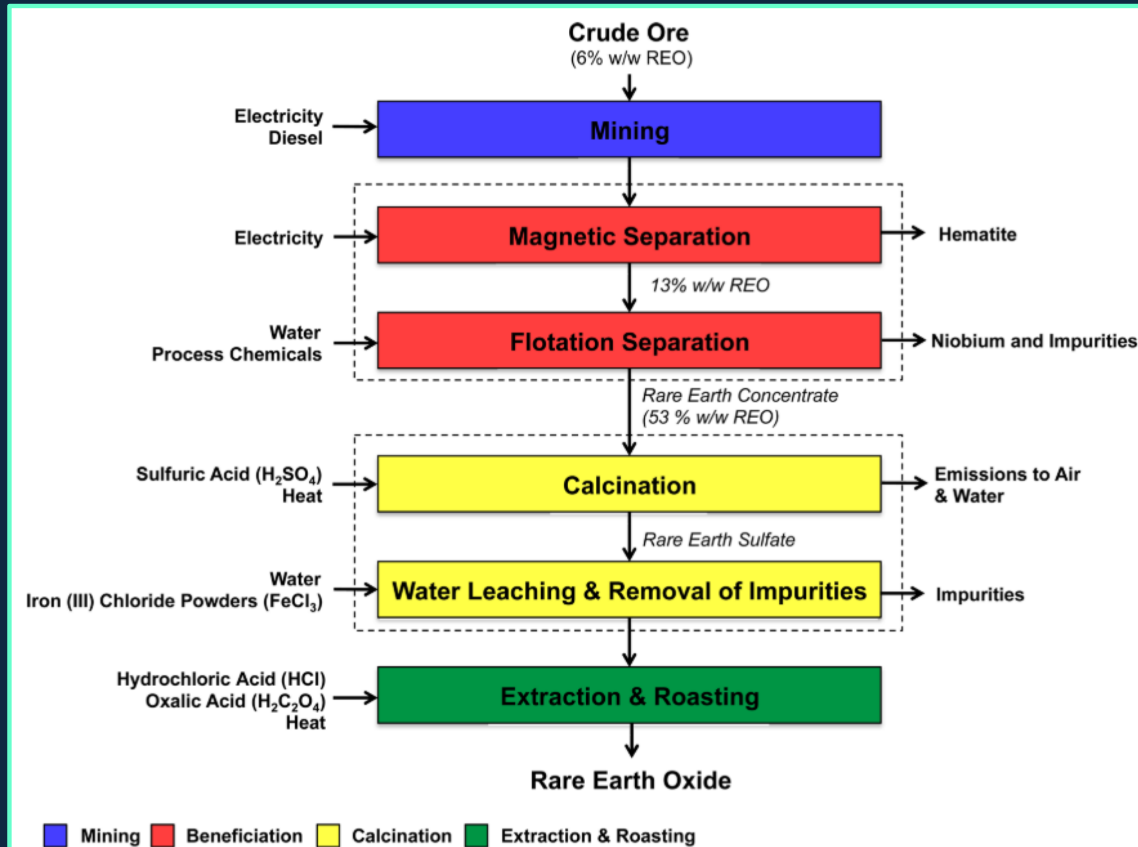
Processing

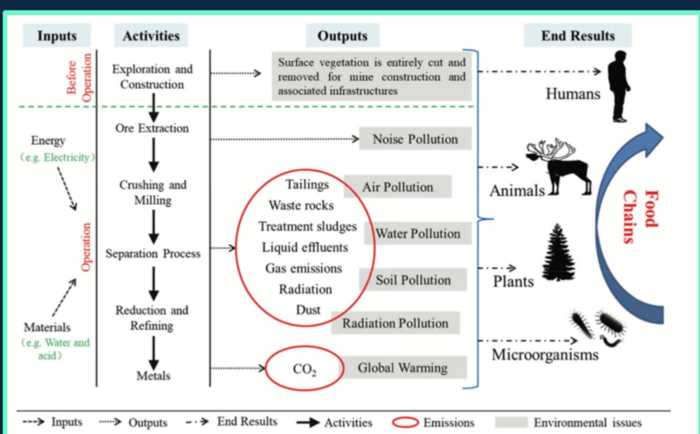
- Ore grades are relatively low (~1-3%) and heterogeneous
- Difficult to separate individual REE
- High energy and chemical requirements



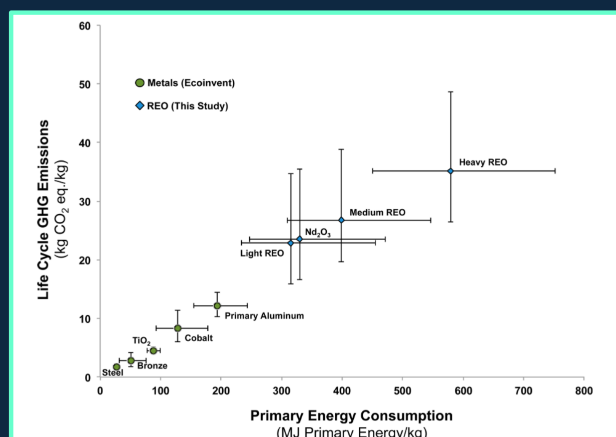
Zaimes et al., 2015

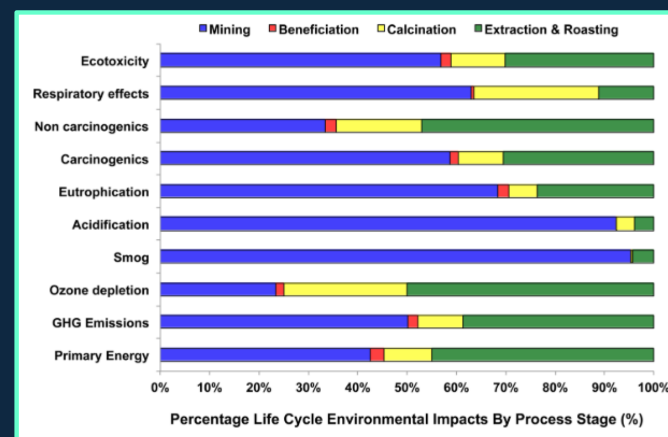
Environmental Concerns

- Large volumes of tailings (can be radioactive)
- Land requirements
- Effects on humans and ecosystems
- Energy intensive mining and processing
- High chemical and water requirements



Yin et al., 2021





Zaimes et al., 2015

Concerns with meeting the material needs of the energy transition

- Extremely mineral intensive – increased demand
- Ore deposits are distributed unevenly
- Domestic supply – production/processing of most critical minerals are dominated by few nations
- Environmental concerns associated with increased mining
- Long lead times for new mines

Secondary/Non-Traditional Sources

Metals from waste

- Mine tailings
- Acid mine drainage waters
- Coal waste

New sources

- Oilfield and geothermal brines
- Deep-sea mud
- Space

Recycling

Advantages

- Utilize a waste-product
- Value-add for remediation
- Lower environmental impacts
- More evenly distributed
- Domestic source
- Simpler permitting?

Exploration and production are in early stages

What is the REE potential of western Canadian coal ash?

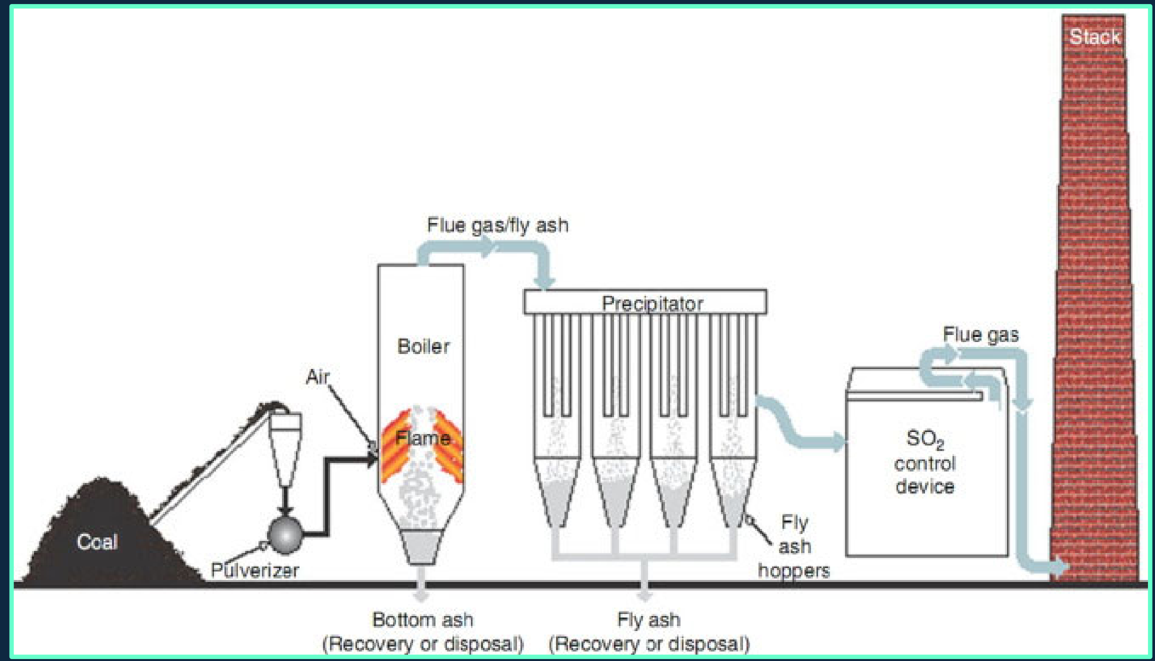
Rare Earth Elements from Saskatchewan Coal Ash

Coal in Saskatchewan

- 1389 MW of coal-fired capacity (24%)
- Lignite is mined from the Paleocene Ravenscrag Formation
- Stratigraphically equivalent to the Fort Union Formation of the Powder River Basin
- Power plants mandated to close…?

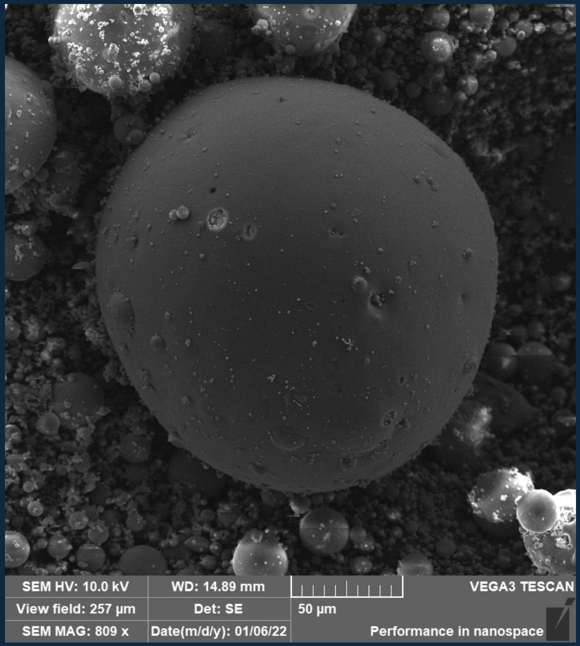
Coal Ash

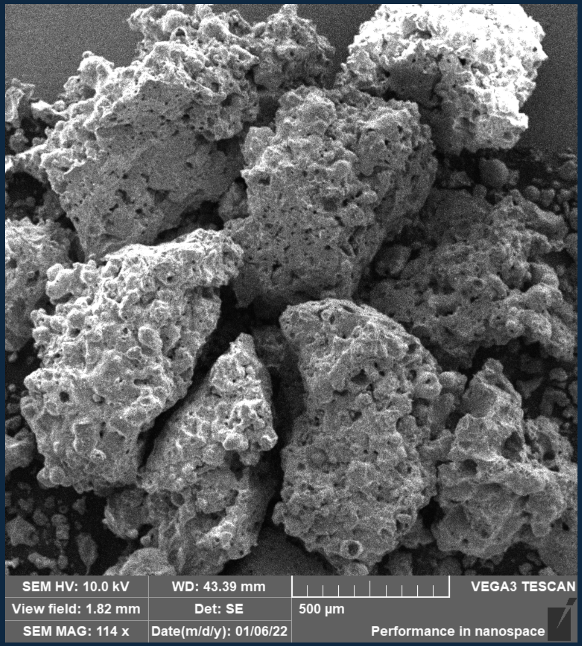
- ~14% of coal remains as ash
- Fly and bottom ash are collected following combustion
- Typically stored in landfills, lagoons, or mounds
- ~60% is reused
- Ash is an environmental liability
  - Can leach metals
  - Kingston coal ash spill



Coal Ash

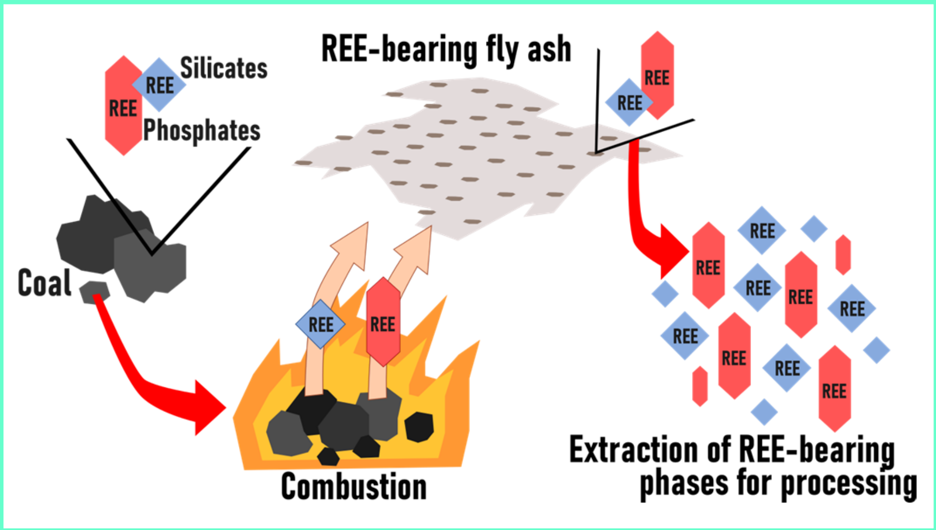
- Variable size
- Composition depends on coal chemistry and boiler conditions
- Dominated by amorphous aluminosilicate phases
- Contains trace metals





REE in Coal Ash

- Coal ash can contain elevated REE concentrations
- Appealing because:
  - Widely available
  - No need for mining/crushing
  - Removes an environmental liability
  - Domestic source
  - Easier permitting/shorter timelines
  - Reduced cost
- No commercial recovery processes
- Canadian ashes have been understudied



Bishop et al., 2024

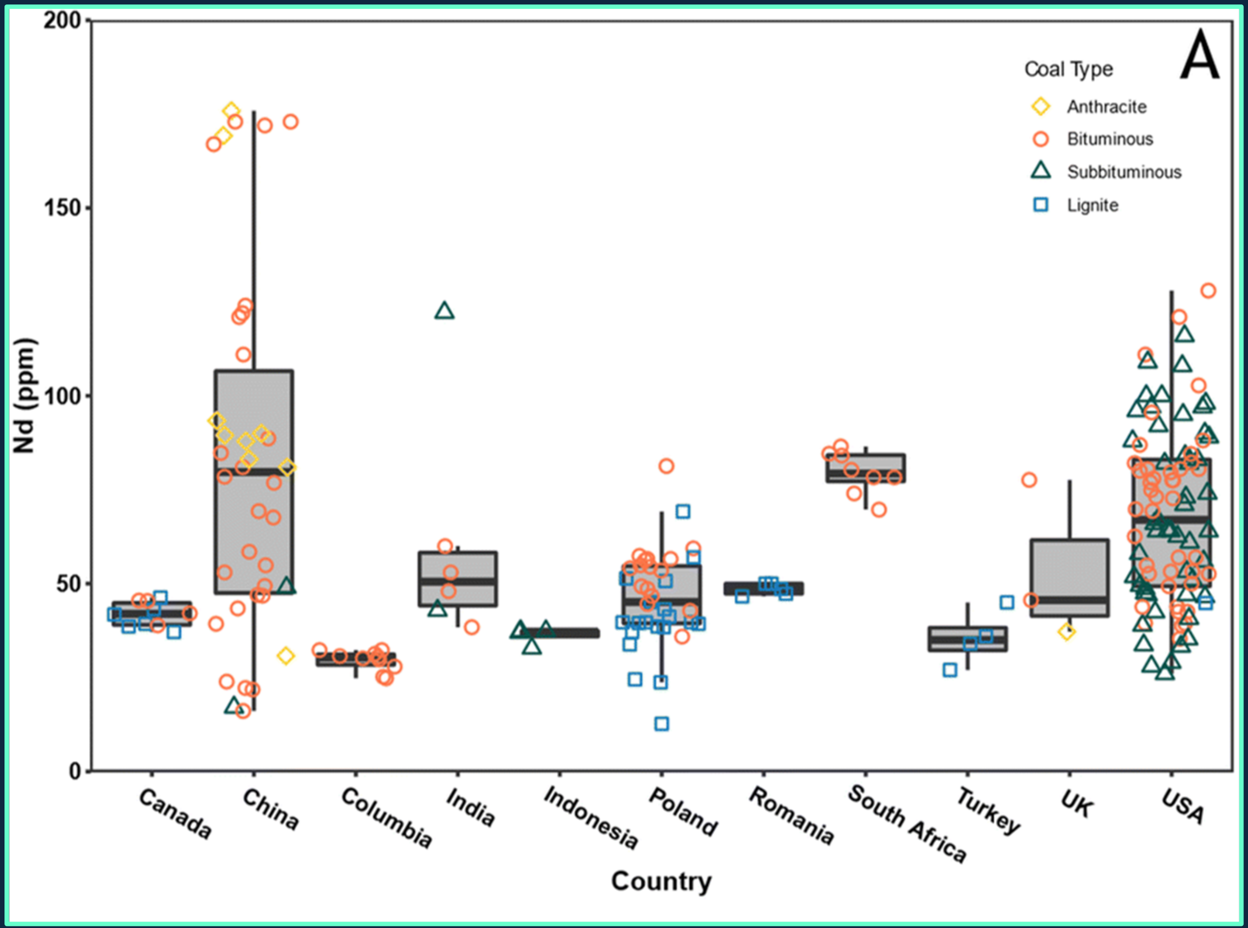
Composition of AB/SK Coal Ash

- Ashes from each plant need to be assessed individually
- Studied the REE potential of ashes from Alberta and Saskatchewan
- Poplar River – high Ca similar to PRB coal
- BD/SND/AB – high Si similar to Appalachian Basin coal
- ~300 ppm is considered promising

Sample	REE (ppm)	SiO_2 (wt%)	CaO (wt%)	Al_2O_3 (wt%)
Alberta 1 BA	259	62.6	5.1	20.4
Alberta 1 FA	294	59.8	6.3	21.2
Alberta 3 BA	277	60.2	6.8	19.8
Alberta 3 FA	299	52.8	13.2	20.6
Boundary Dam BA	311	53.1	11.4	18.7
Boundary Dam FA	268	54.3	8.4	18.9
Poplar River BA	289	39.4	17.2	22.9
Poplar River FA	321	39.6	18.6	26.6
Shand BA	272	53.7	9.1	18.8
Shand FA	262	53.6	8.2	19.3

Bishop et al., 2023

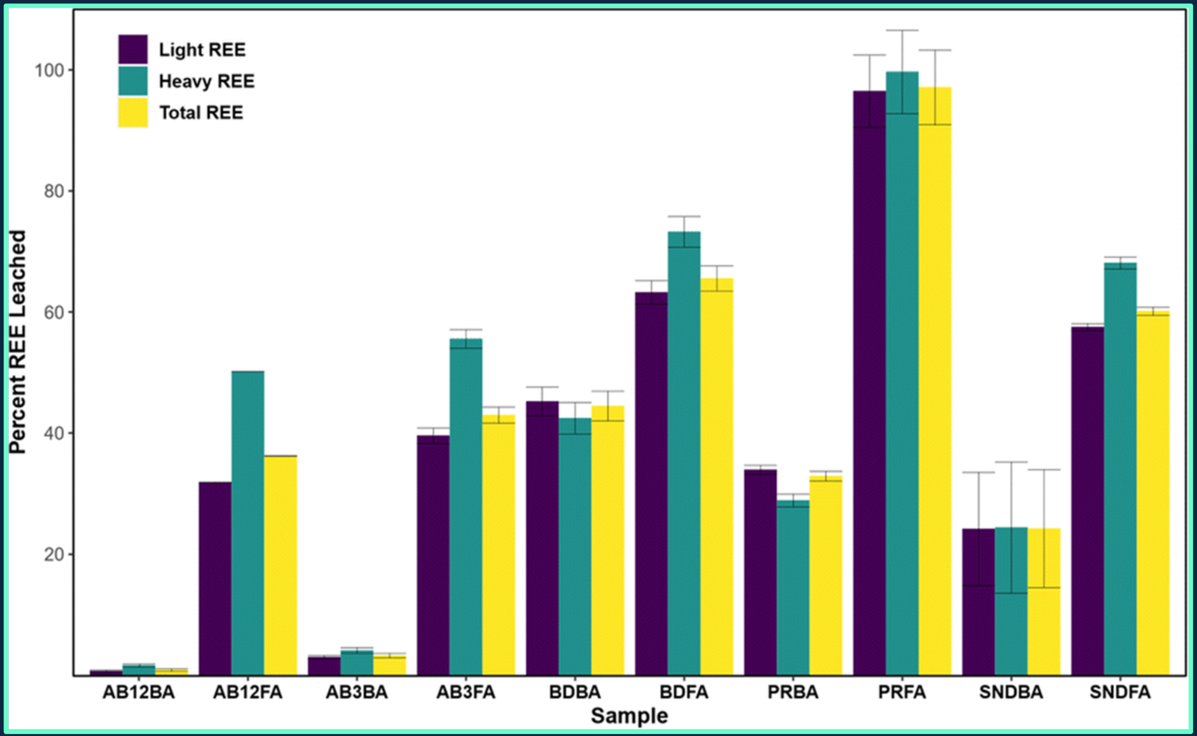
Comparison with Global Ashes



Bishop et al., 2023

Best Ashes for Recovery?

- First step in a recovery process is leaching
- Poplar River ashes have the highest leaching efficiency
- Leaching efficiency can be more important than concentration
- 3 M HCl – room temperature
- Can organic acids or bioleaching be applied?

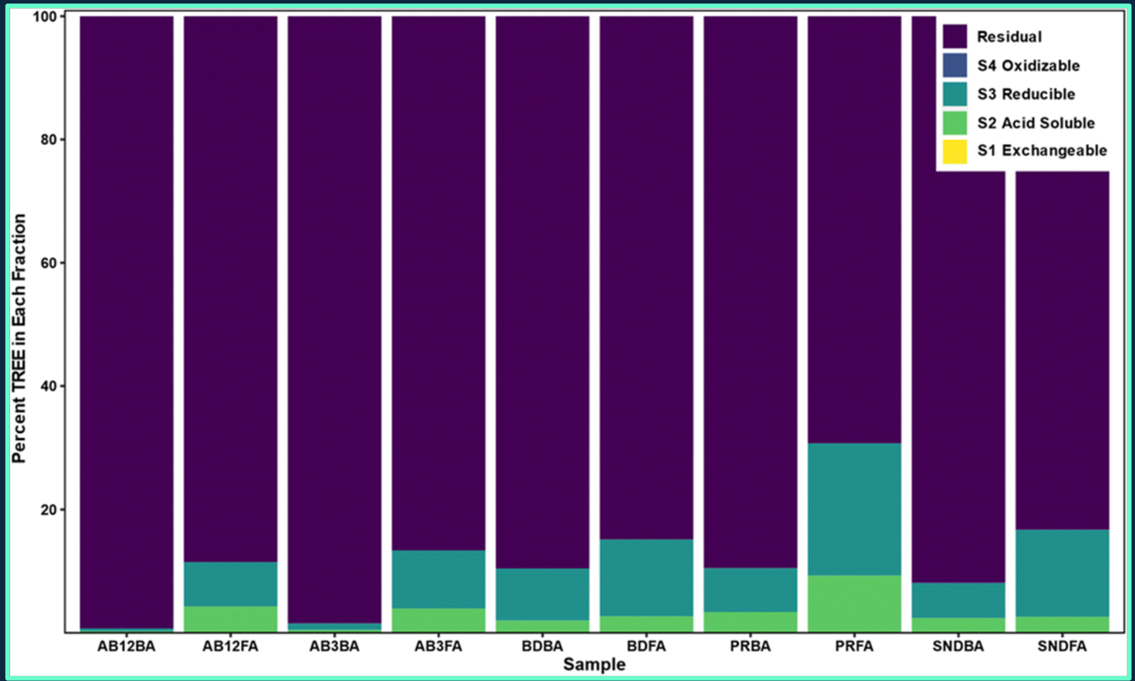


Bishop et al., 2023

How do REE occur in the coal ash?

- Important for:
  - Understanding how coal/coal ash become enriched
  - Developing an extraction process
- Performed sequential extractions
- Primarily occur in the residual phase

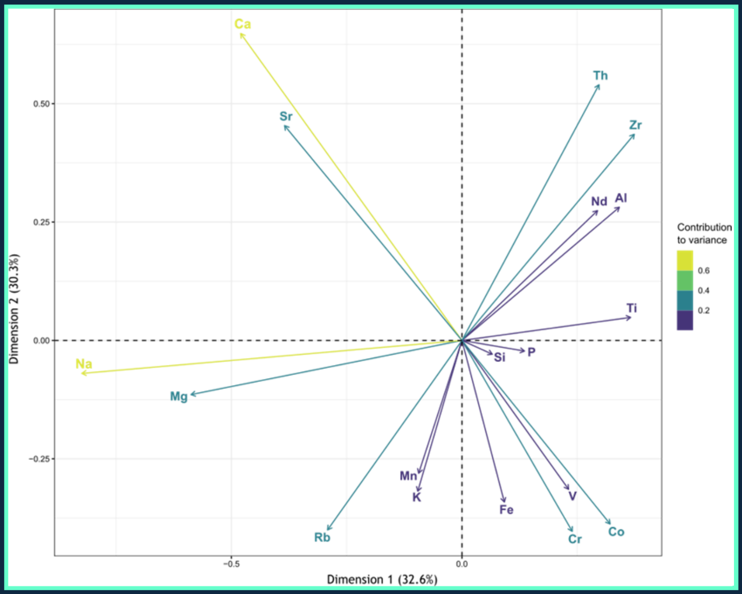
- What is the mineralogical REE host?

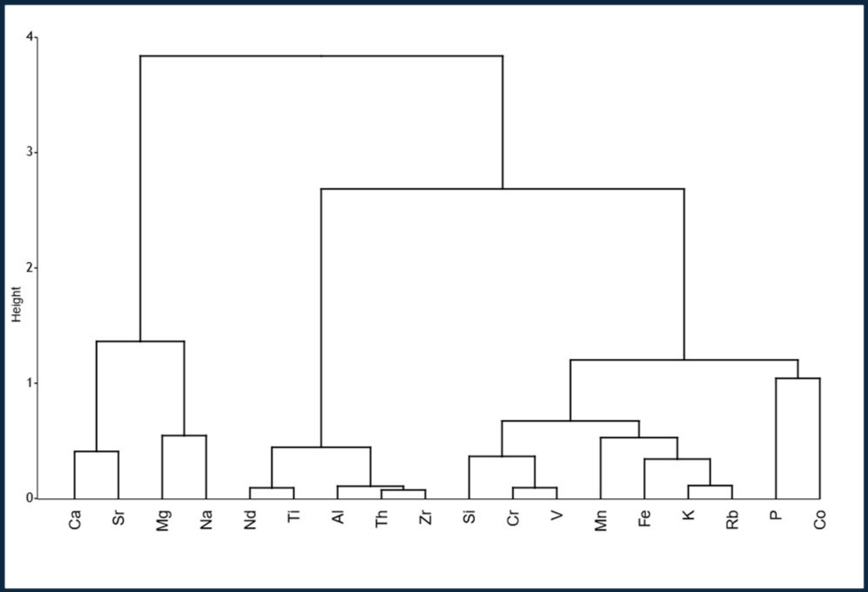


Bishop et al., 2023

Elemental Associations?

- REE are correlated with other incompatible elements
- Indicates REE are associated with clays or aluminosilicate/detrital minerals
- Which minerals?

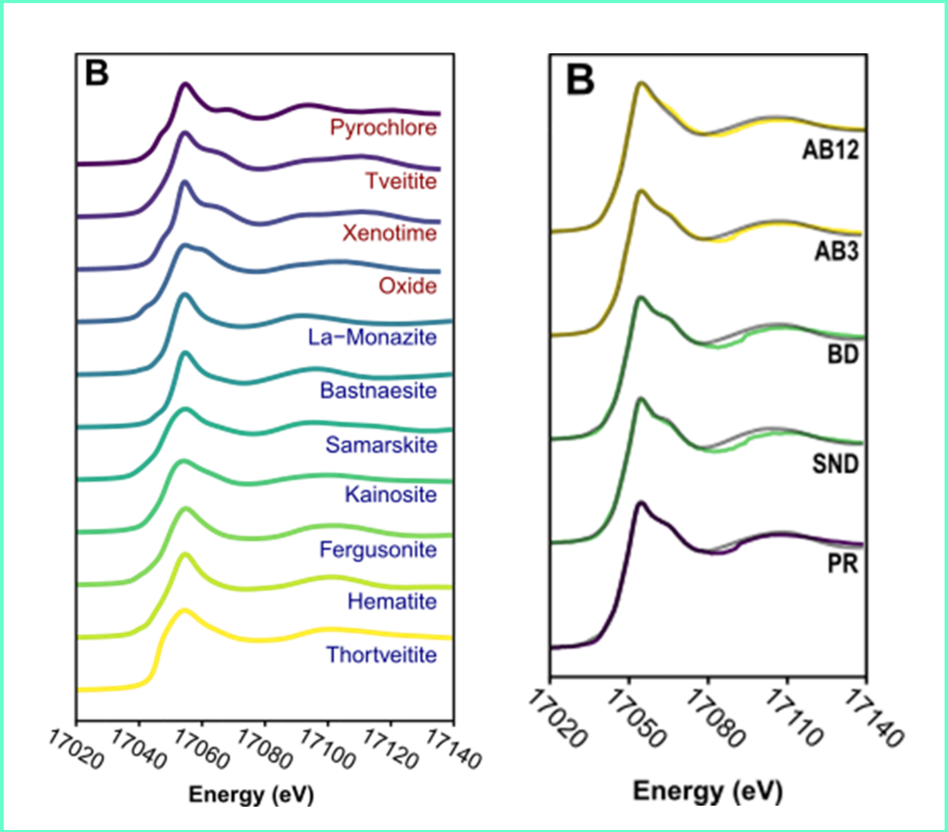




Bishop et al., 2023

Synchrotron XAS to Identify REE Host

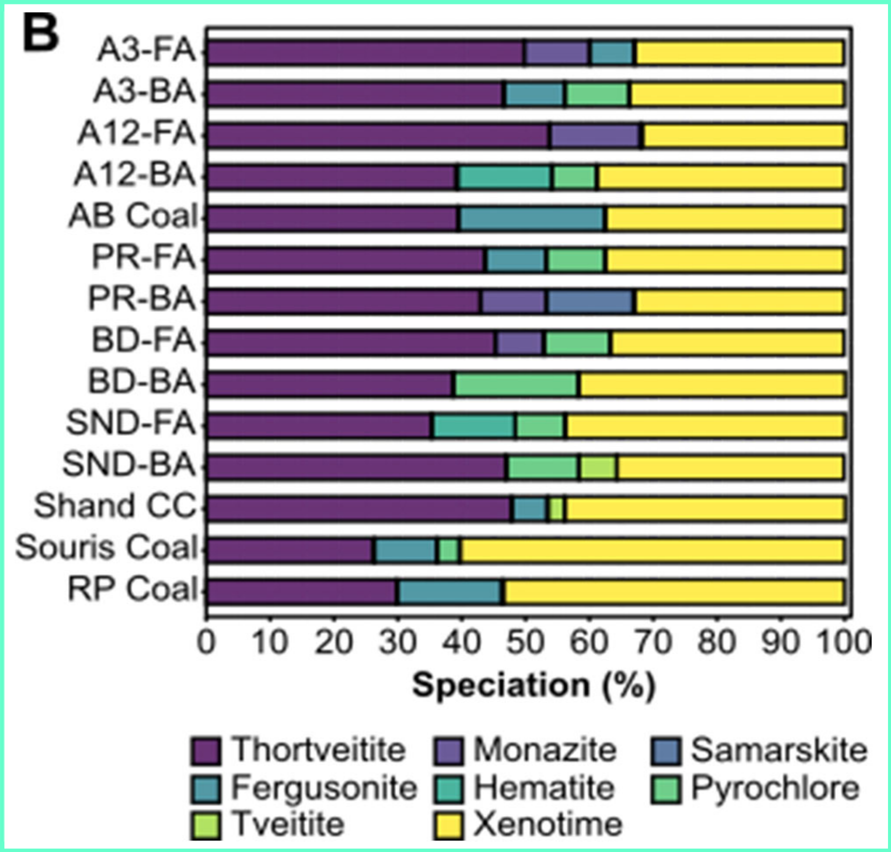
- 2 hypotheses for mode of occurrence
  - REE are distributed throughout the ash particle
  - REE are hosted in discrete mineral phases
- XAS can identify the speciation and mineralogical host
- First time EXAFS has been applied to REE in coal ash



Bishop et al., 2024

REE Mineralogical Host

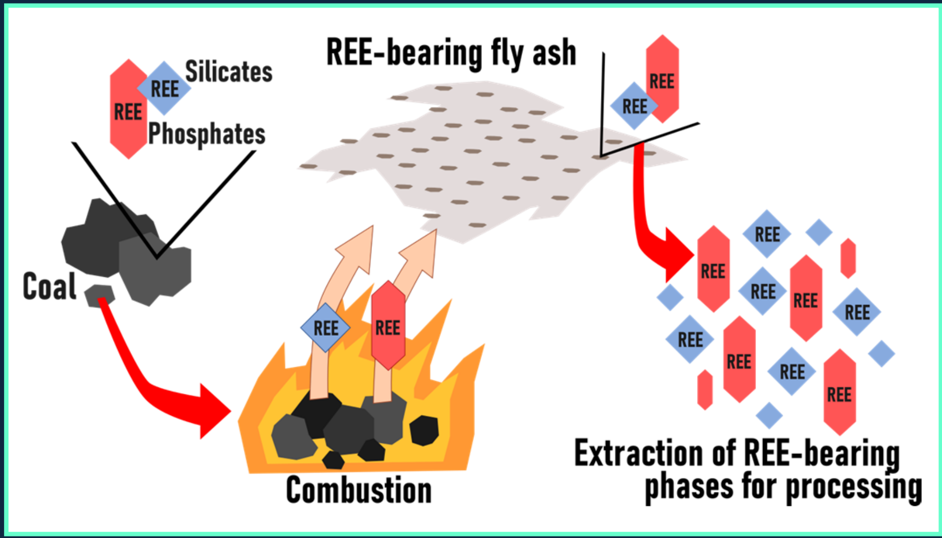
- Hosted in discrete phases consistent with 2nd hypothesis
  - Phosphate - xenotime
  - Silicates – zircons, clays, etc
- Supported by indirect methods
- Similar host in coal and ash
- Implies the host phase is preserved through combustion



Bishop et al., 2024

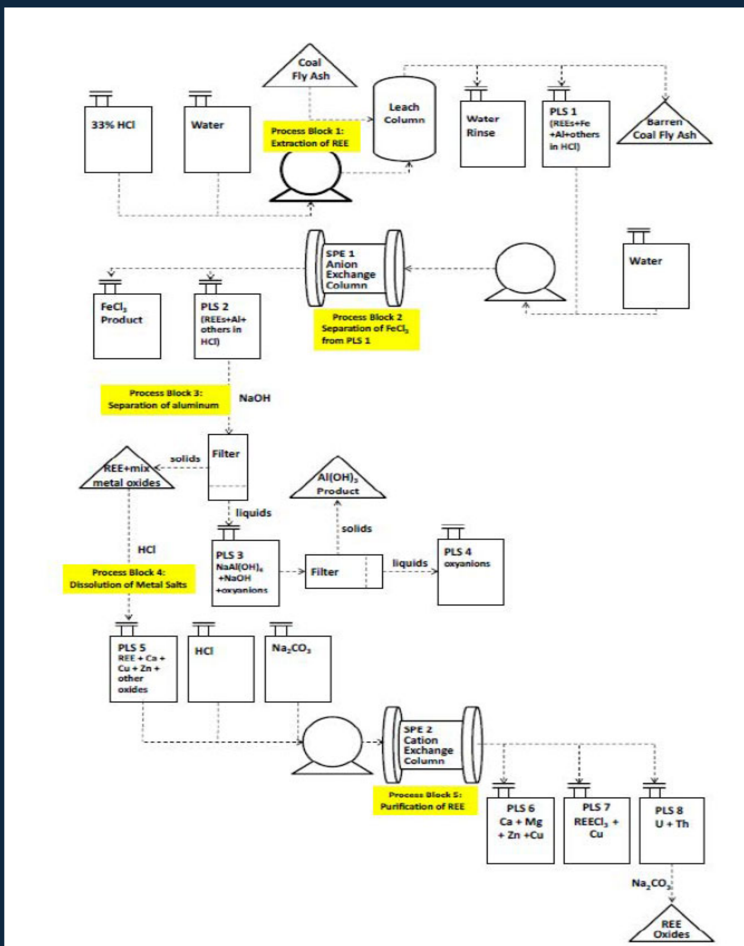
What does this mean for extraction?

- Can these specific mineral phases be targeted for extraction?
- Same minerals in the ash as in ore deposits
- Can a “concentrate” be prepared on site and transported for further refining?



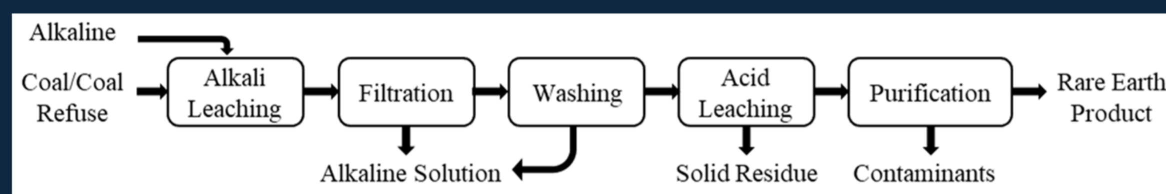
Bishop et al., 2024

Recovering REE from Coal Ash



Neodymia, 2022

- Requires initial characterization of the ash
- Leaching
- Alkali treatment can increase recovery from high silica ashes
- Solvent extraction or ion exchange to separate the REE
- Modifying or incorporate existing processes?

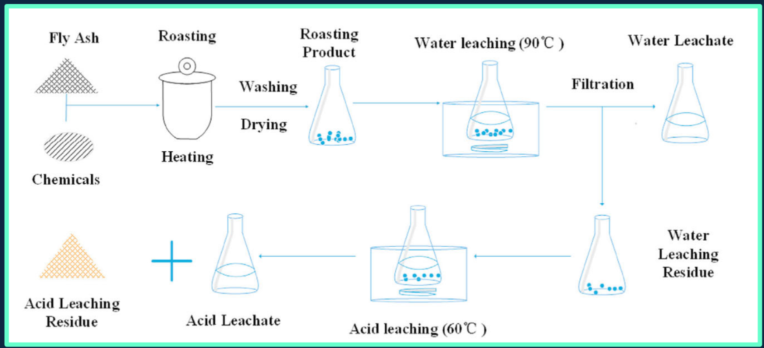


Developing an Extraction Process

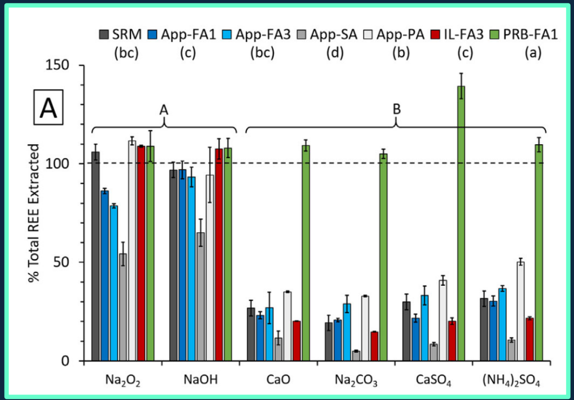
- What is the most efficient and economic process to recover REE?
- What to do with the residue? Soil amendment, remediation, etc?

Different pre-treatment products

XAS



Test different organic acids (bioleaching?)



Taggart et al. (2018) Int J Coal Geol

Pan et al. (2021) J Clean Prod

Opportunities for Saskatchewan

- Poplar River ash is not suitable for concrete
- Est. 22 million tonnes
- Environmental liability
- Further coal-fired power production requires increased land for ash storage

Opportunities for Saskatchewan

- Poplar River ashes are most suitable for REE recovery
- At a concentration of 46.3 ppm there could be ~1,000,000 kg of Nd
- Potential to extract other value
- Saskatchewan will be acutely affected by the energy transition
- Energy transition jobs
- Investment and government support

Considerations for Extraction

- Economics
  - Cost of processing
  - Commodity price
  - Demand
- What else can be extracted & waste managaement?
- How much is actually recoverable?
- Is the “deposit” homogeneous?
- Permitting/regulations
- Environmental impacts
- Social license

Summary

- Poplar River ash is among the most promising for REE recovery in the world
- Rare earths are hosted in discrete mineral grains which can be targeted for extraction
- No process has been developed on a commercial scale
- More research is required – partnership with SRC?
- Government investment similar to the DOE & NETL

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Canadian Light Source / Centre canadien de rayonnement synchrotron

Bishop et al. (2023). Environmental Science: Advances

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