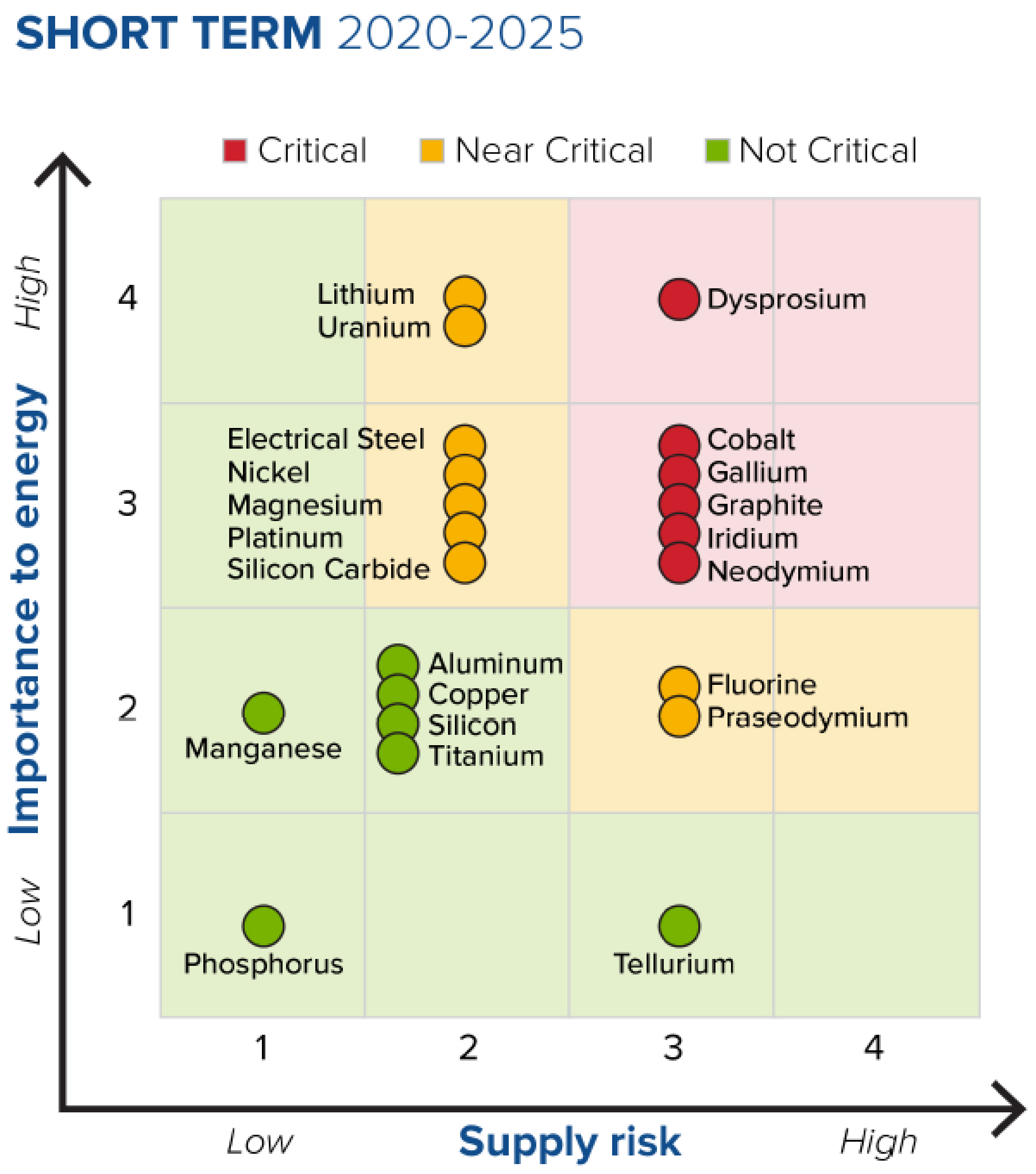
R&D Enabling Domestic Critical Mineral Abundance

Burt Thomas
US DOE's Only
Government operated
Government Owned
National Energy Technology Lab

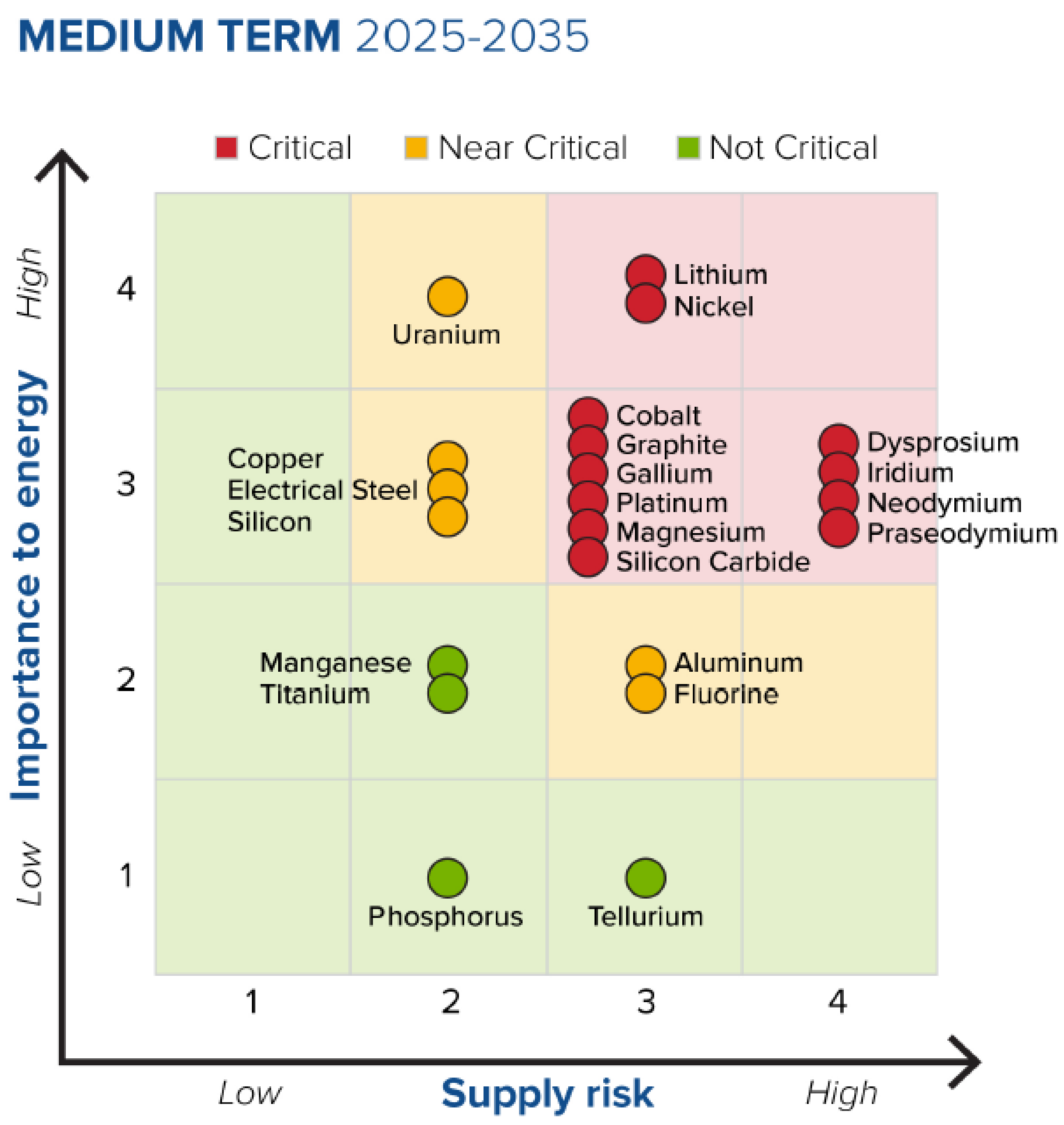
U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

These minerals are critical in the short term



2023 Critical Material Assessment, DOE

These minerals are critical in the medium term



2023 Critical Material Assessment, DOE

There are three ways to think about the US Critical Materials Dilemma

1. Us vs. Them

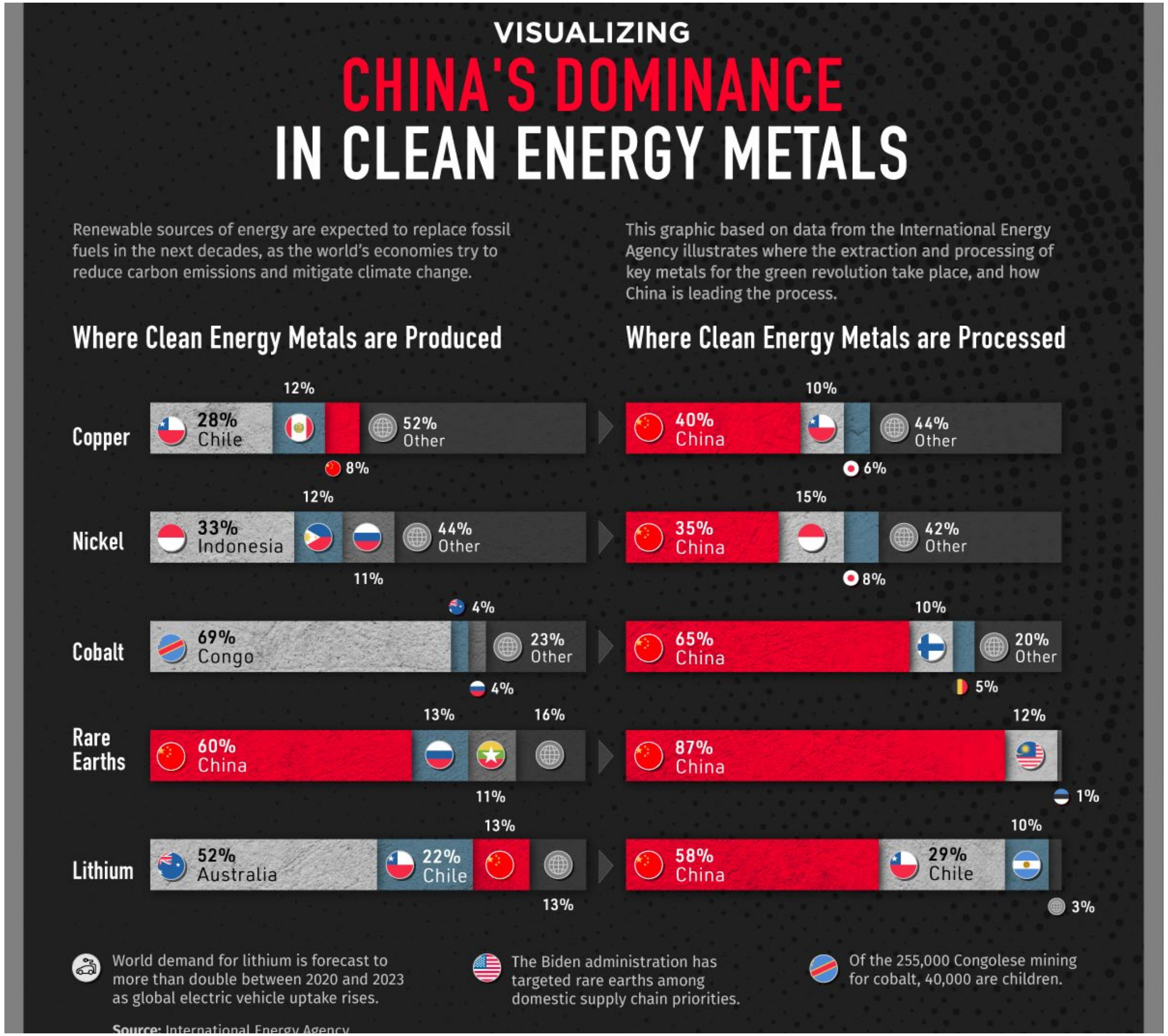
The rules of competition don't apply to monopolies

Monopolies cease innovation and grow by acquisition.

Monopolies manipulate the supply chains to maintain the monopoly.

Incremental domestic improvements in conventional processes will be offshored.

Investment booms and busts primarily serve to solidify the monopoly.

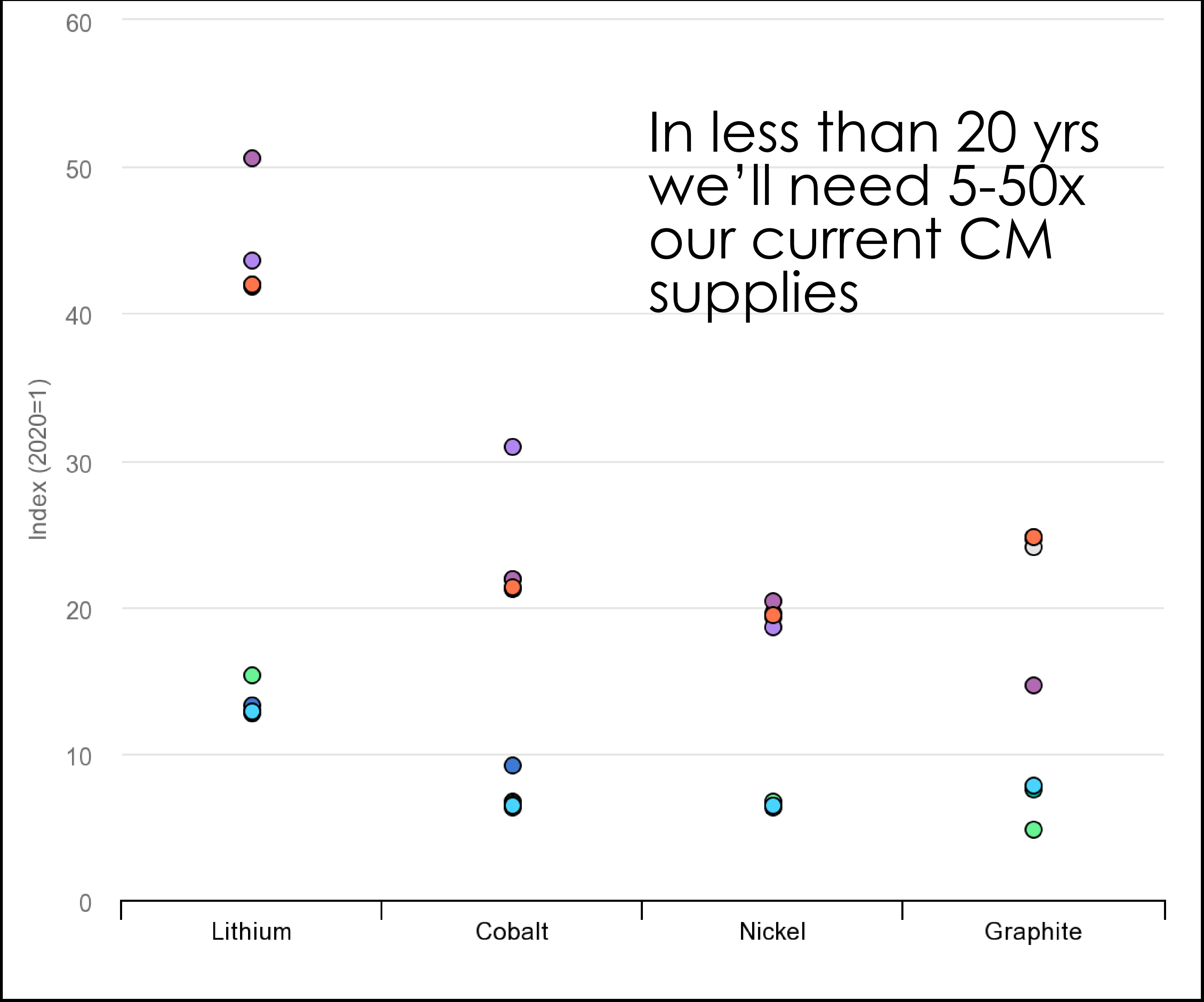


Source: Visual Capitalist using IEA data

There are three ways to think about the US Critical Materials Dilemma

2. It is a race!

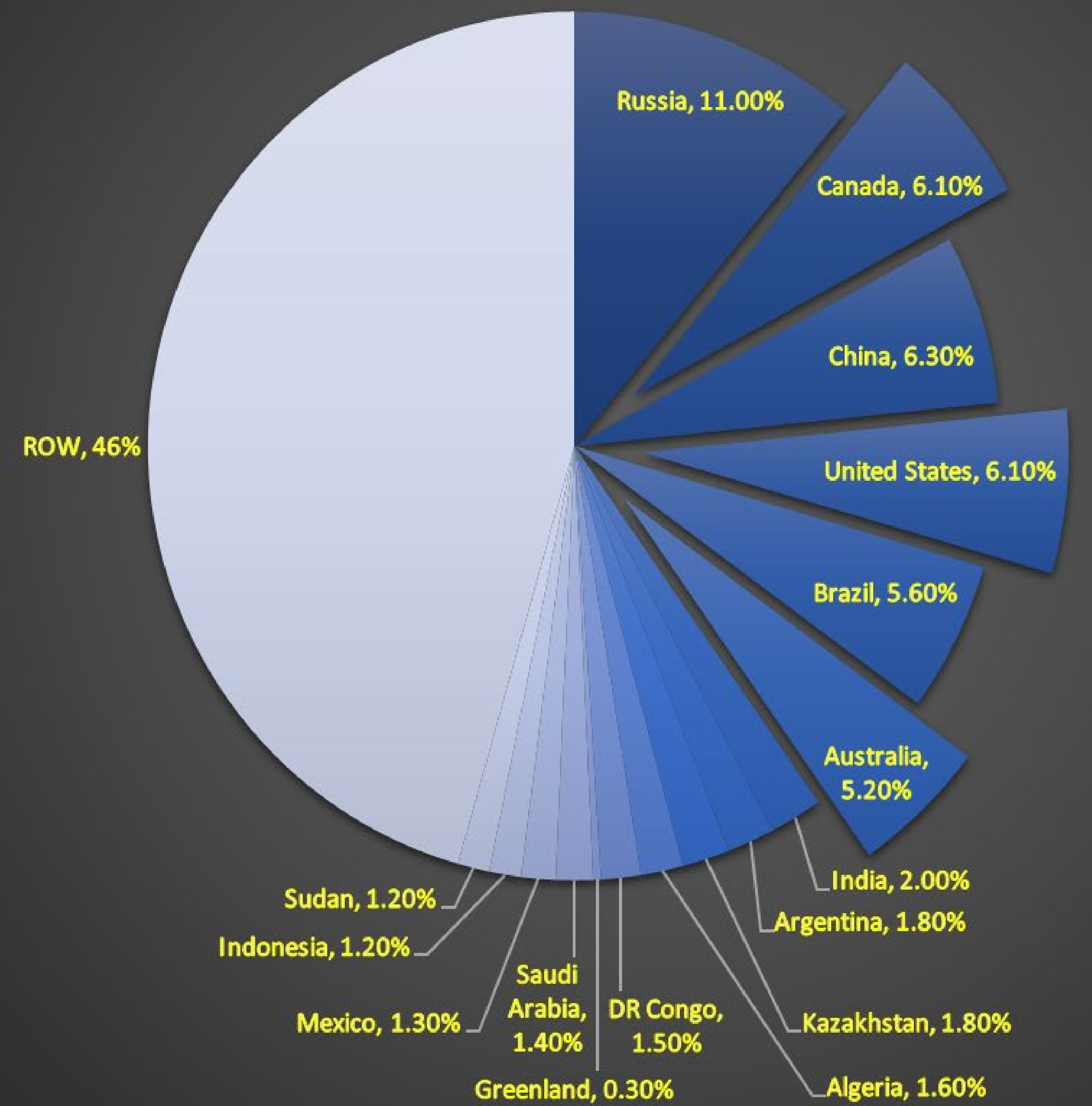
IEA 2040 Demand Scenarios



There are three ways to think about the US Critical Materials Dilemma

3. We’re in this together

% of World Land Mass



If We FOCUS on an Adversary's Approach, We're Playing the Wrong Game

For the World to Decarbonize, we need Critical Mineral Abundance

We Must Innovate Ways to Gain Public Acceptance and Approval

Leading the Way looks like:

- Green Mining Principles
- Community Benefits
- Driving Down the Cost Curve

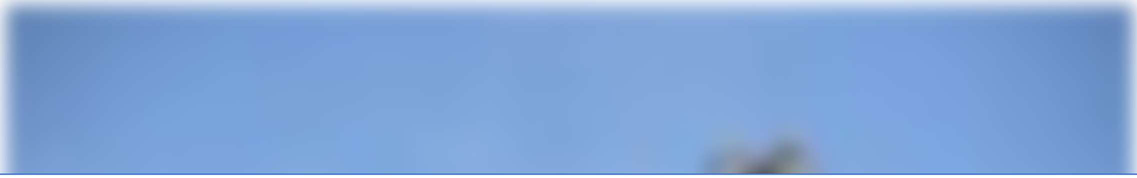
There are three ways to think about the US Critical Materials Dilemma

Give up, let markets fix it

Politics

Breaking China's Grip on Rare-Earths Markets a 'Pipe Dream,' Australia Says

- Resources minister says Australia can be a China alternative
- Australia has big reserves of critical minerals like lithium



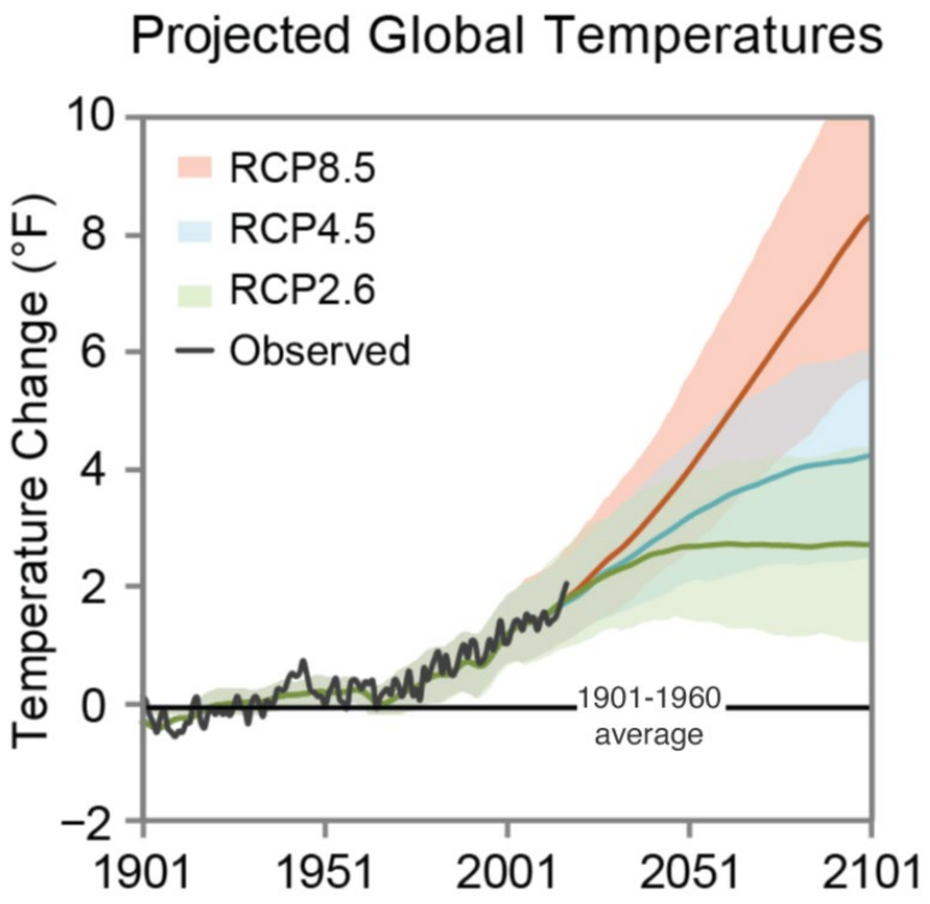
If we let the Monopoly persist:

Monopoly leadership causes:

- Slower adaptation
- Slower growth
- Higher material costs
- Insecure supplies
- Perpetual Dependence
- Failure to Mitigate Climate Risks

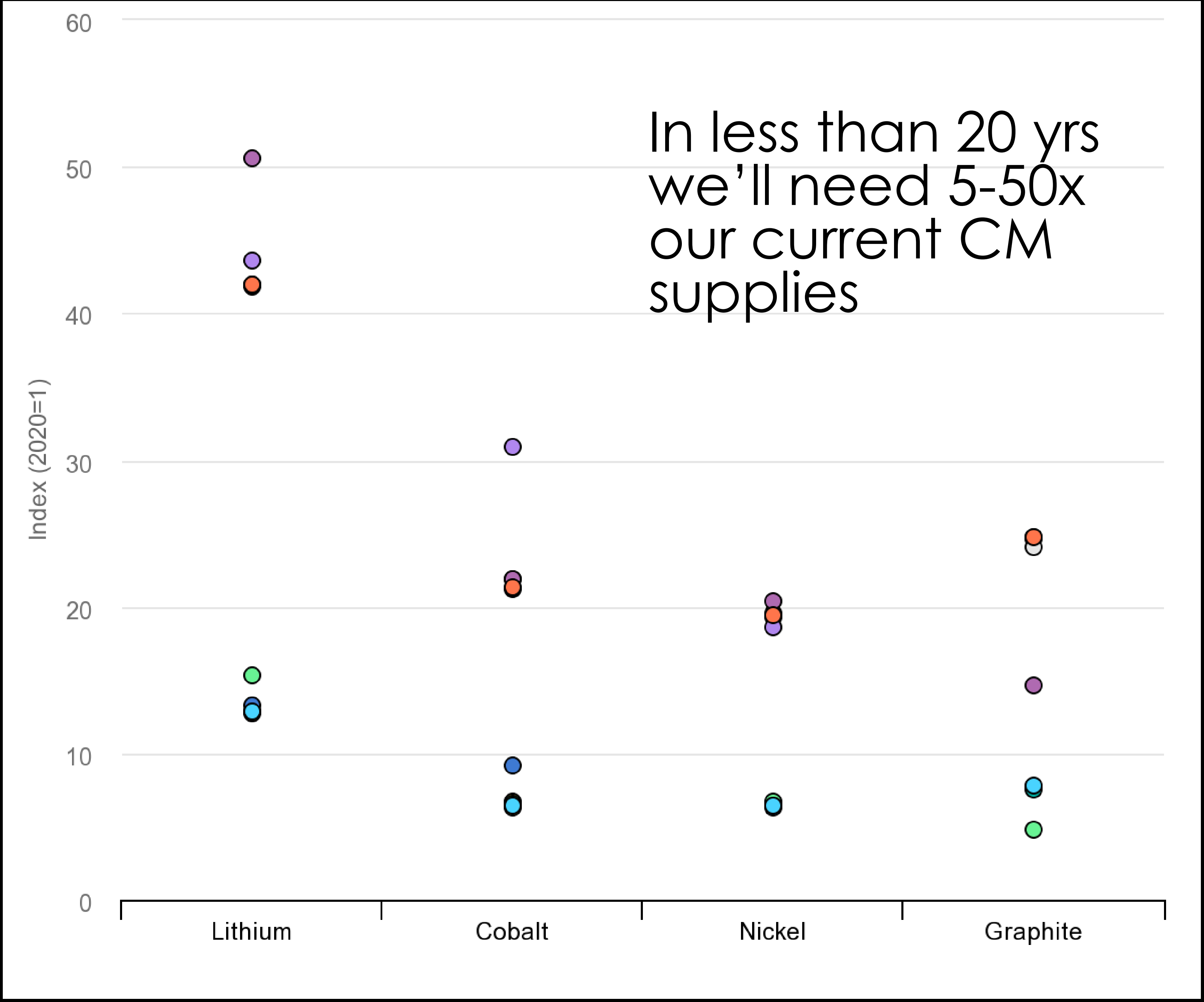
There is no low international co-operation route to limit warming to 1.5 °C and no slow route either

IEA- NetZero Roadmap



2017 Climate Science Special Report, Figure ES-3

IEA 2040 Demand Scenarios



The Clean Energy Future Requires jumping to lower grades

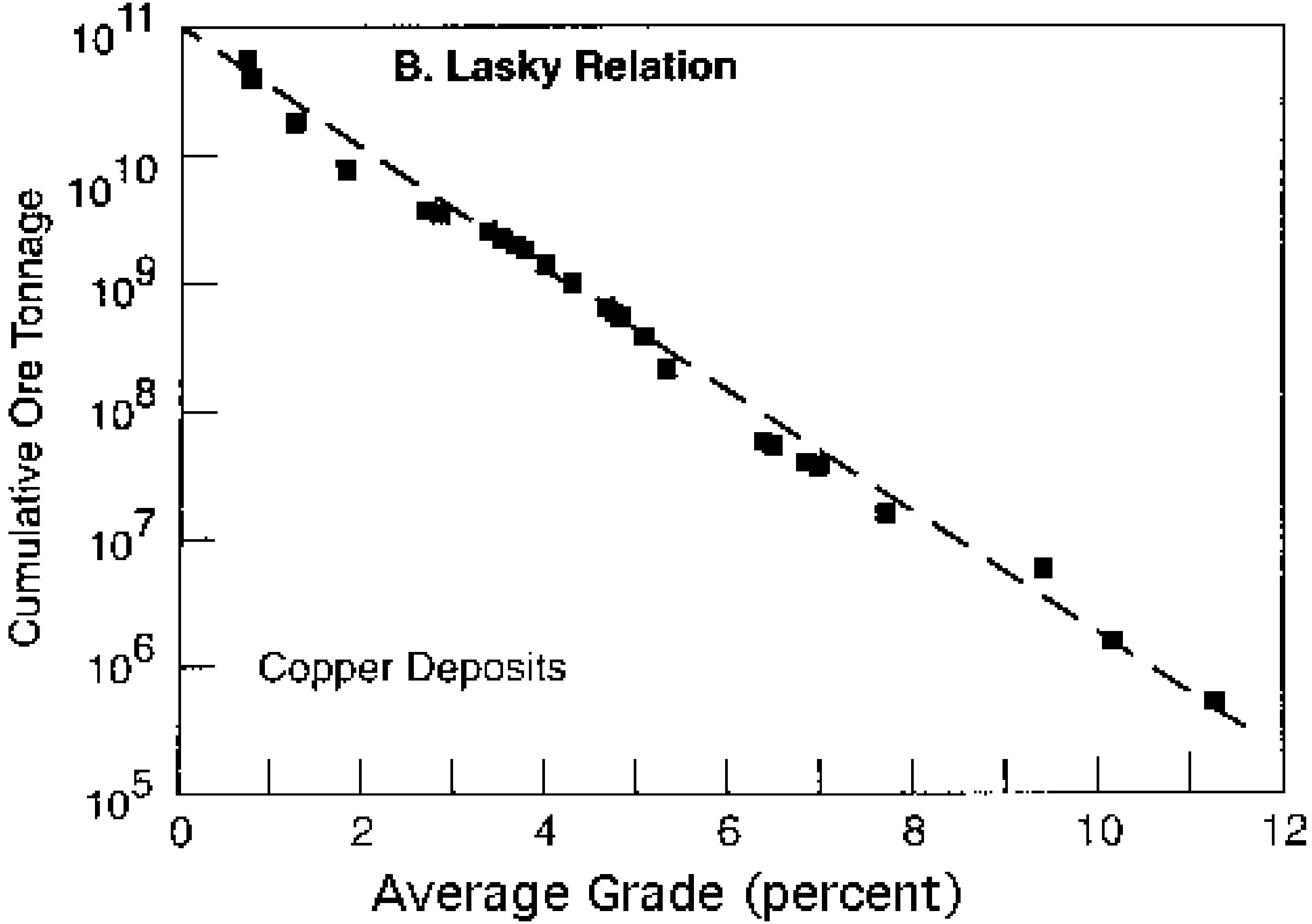
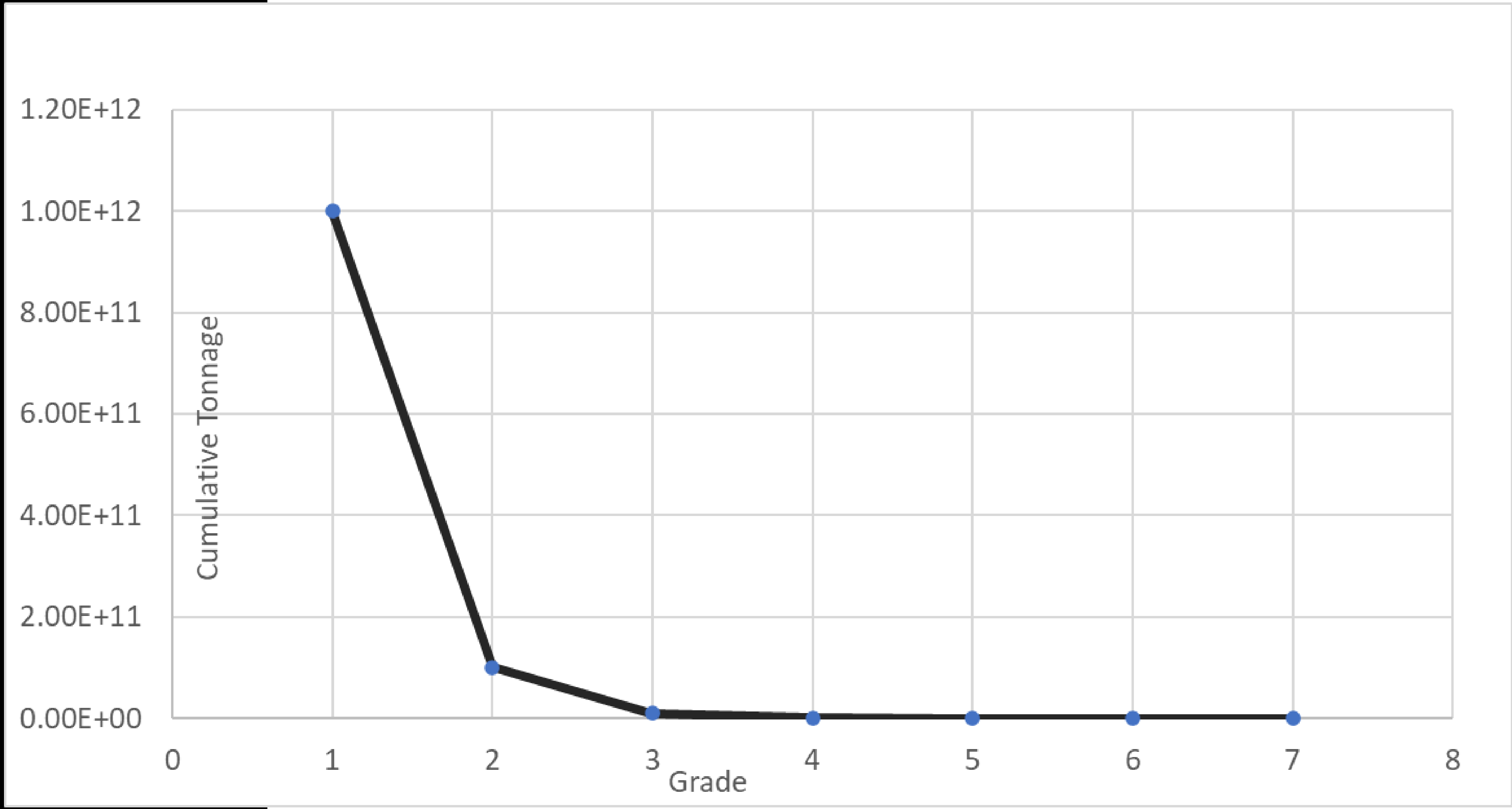


Figure 13-1 B, Mineral Resources, Economics and the Environment, S.E. Kesler, Macmillan

The Clean Energy Future Requires jumping to lower grades



MISSION

To support the U.S. transition to a carbon-free economy and a domestic clean energy manufacturing industry by leading the federal government's efforts to:

1. Characterize and assess domestic critical mineral and carbon ore resourses from fossil energy-related byproducts and related resources;
2. Develop advanced resource extraction, processing, and extractive metallurgical technologies; and
3. Evaluate the co-production potential of critical minerals and carbon ore for high-value products.

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- NETL is the DOE's Applied Energy Research Lab for Fossil Energy and Carbon Management
- NETL is also the heir of the US Bureau of Mines R&D operations following closure in 1996.

The 1996 Division of functions of the USBM to USGS and to DOE

Government organization.
43 USC 1782 note.

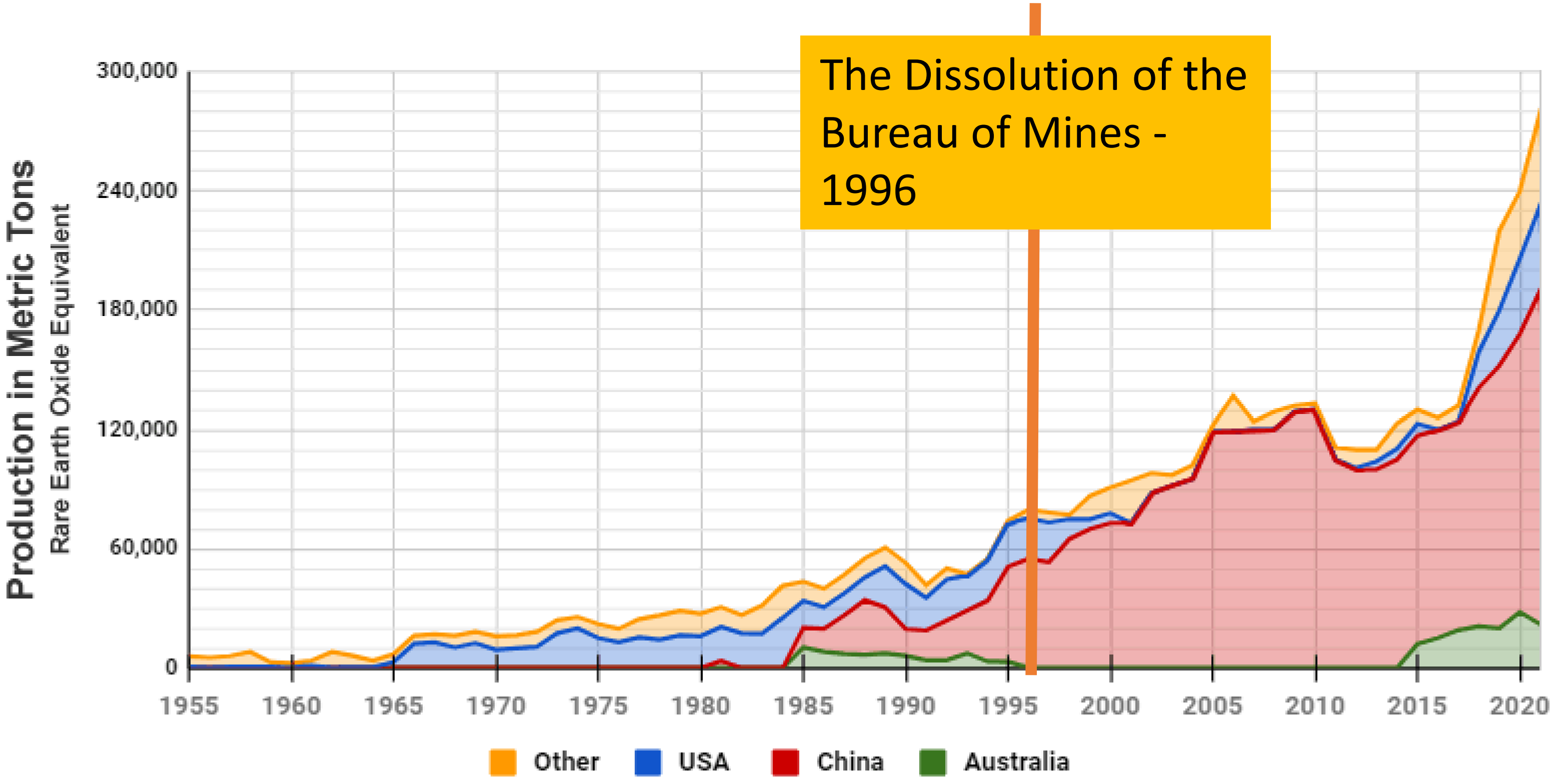
30, 1996: *Provided further*, That the authority granted to the United States Bureau of Mines to conduct mineral surveys and to determine mineral values by section 603 of Public Law 94–579 is hereby transferred to, and vested in, the Director of the United States Geological Survey.

110 STAT. 1321–165 PUBLIC LAW 104–134—APR. 26, 1996

this Act: *Provided*, That there hereby are transferred to, and vested in, the Secretary of Energy: (1) the functions pertaining to the promotion of health and safety in mines and the mineral industry through research vested by law in the Secretary of the Interior or the United States Bureau of Mines and performed in fiscal year 1995 by the United States Bureau of Mines at its Pittsburgh Research Center in Pennsylvania, and at its Spokane Research Center in Washington; (2) the functions pertaining to the conduct of inquiries, technological investigations and research concerning the extraction, processing, use and disposal of mineral substances vested by law in the Secretary of the Interior or the United States Bureau of Mines and performed in fiscal year 1995 by the United States Bureau of Mines under the minerals and materials science programs at its Pittsburgh Research Center in Pennsylvania, and at its Albany Research Center in Oregon; and (3) the functions

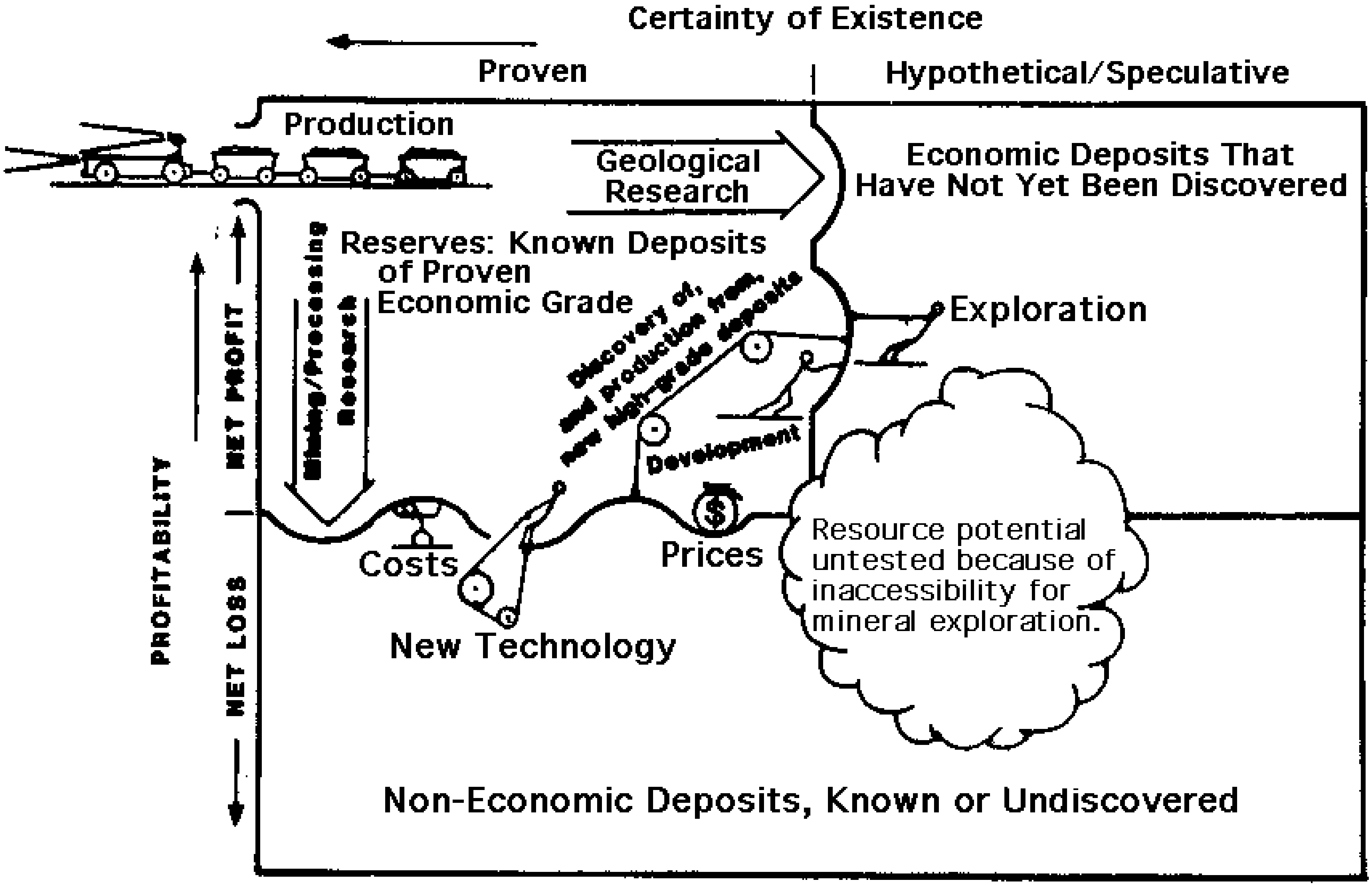
NETL is the government operated, government owned laboratory for:

"research on mineral extraction, processing, use, and conservation of America's mineral resources"



The Bureau of Mines is NETL’s History

The Mines of the Future are NETL’s Business



Certainty of Existence
Proven
Hypothetical/Speculative
Production
Geological Research
Economic Deposits That Have Not Yet Been Discovered
Reserves: Known Deposits of Proven Economic Grade
Mining/Processing Research
NET PROFIT
PROFITABILITY
NET LOSS
Discovery of, and production from, new high-grade deposits
Exploration
Development
Costs
Prices
New Technology
Resource potential untested because of inaccessibility for mineral exploration.
Non-Economic Deposits, Known or Undiscovered

The industry we need will be built from the industry we have

- Robust integrated markets and supply chains can be built from CM sources tied to US energy production.
- The energy sector will benefit from solutions that target their waste materials and contribute to a clean energy future.

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The US should seek to build new partners that benefit from successful solutions

- Major multinational miners benefit from the status quo
- Question the profit motive to solve the CM supply chain issues the US faces.

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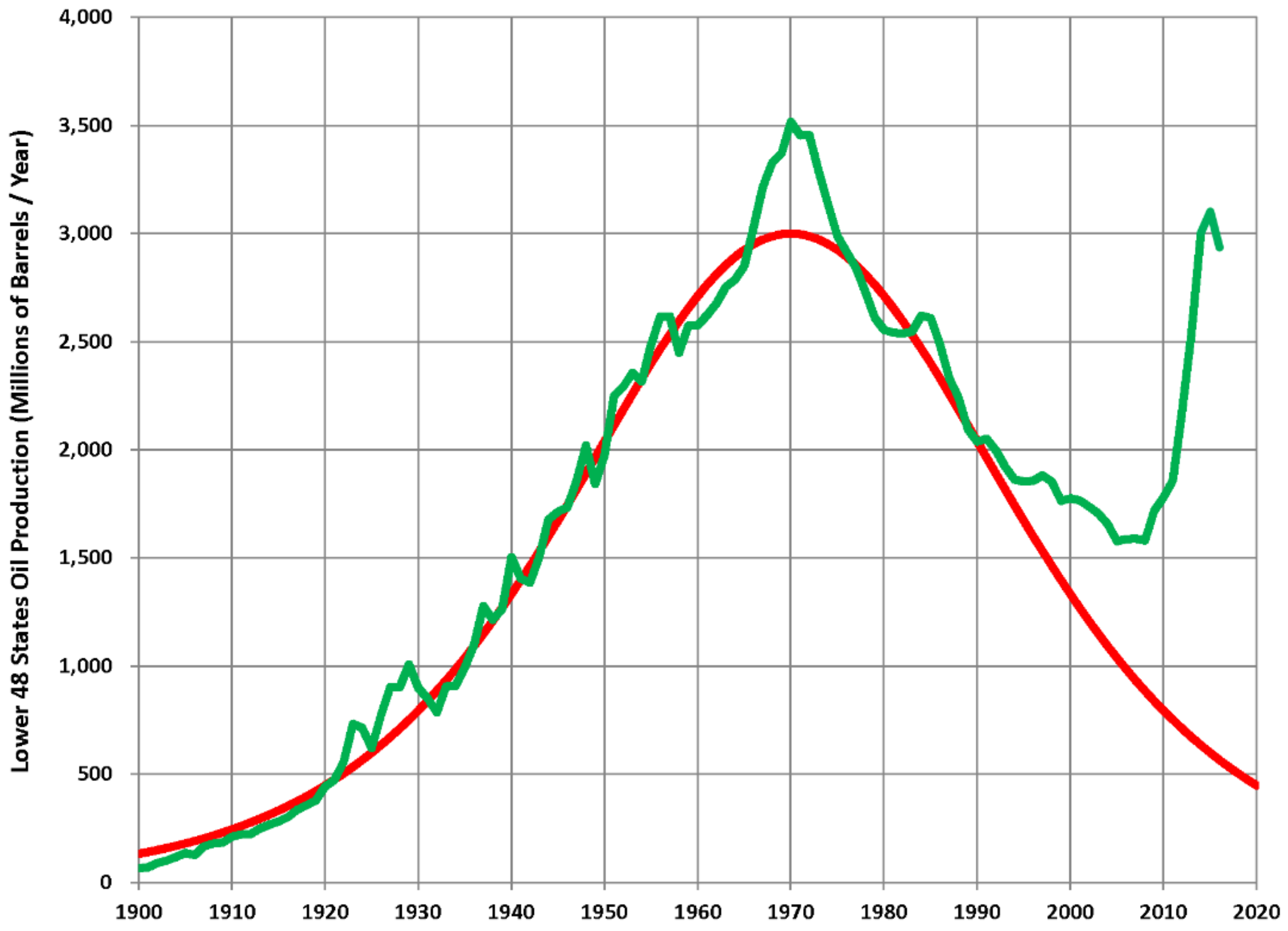
Domestic Abundance

History Rhymes

Peak Oil - averted by Unconventional Sources



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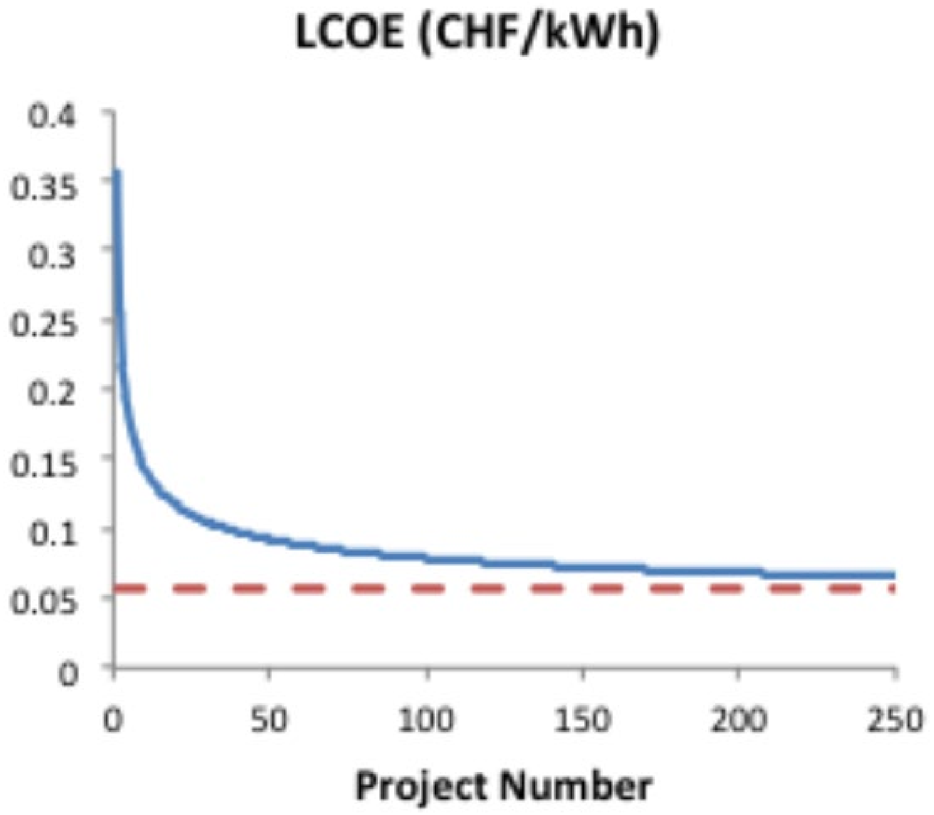
Domestic Abundance

Requires technologies that can hop on the learning curve

- Get Better, Cheaper, Quicker
- Resource Extraction become Resource Manufacturing



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Domestic Abundance

Requires community permission

- Bake-In community benefits
- Minimize Waste
- Clean up Legacy Harms
- Life Cycle Assessments
- Environmental responsibility

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NETL Critical Minerals Research

Transformative Technology
Focused on American Advantages

Unrealized Environmental Benefits

AMD,
Coal Ash,
Mine and Drilling Waste

Resources That Will Grow into the Future

Produced Water
Mineral Carbonation
Wastes

Legacy of Fossil Energy Leadership

Repurpose FE Infrastructure
World's Largest Coal Mines
World Leader in Drilling

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NETL Critical Minerals Research

- CM Resource Data
- CM Systems Analysis
- Emerging Resources R&D
- Enabling Sensing and Processing Technology

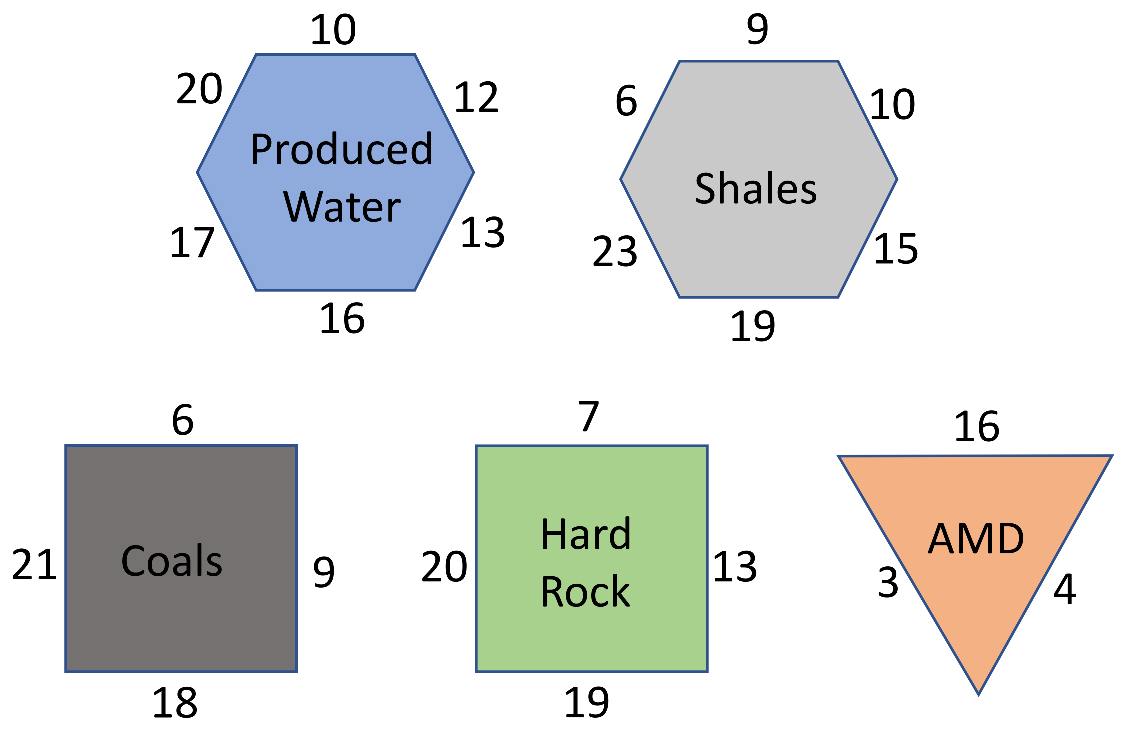
NETL PI	Task #	CM Resource Data
Rose	9.1	URC – CM Resource Prediction Methodology
Rose	9.2	Improve Prediction of REEs in Sedimentary/Coal Lithofacies
Rose	9.4	Developing a CM Data Framework for CORE-CM Data, Waste and By-Products
Kutchko	10	Lithium Brine Resource Characterization in US Sh[illegible]

NETL PI	Task #	Emerging CM Resources R&D
Lopano	18	Ca-Ash Extraction Technology
Lopano	3	CM Recovery from AMD Solids using Adv. Characterization
Gulliver	4	Biologically Enhanced Redox for CM in AMD solids
Verba	5	[illegible] leaching of underclay resources
Thomas	6	In situ extraction from unconventional systems
Verba	7	CM Recovery from Mineral Carbonation (CDR) waste streams

NETL PI	Task #	Enabling Technologies
Gray	12	MUS[illegible] for Produced Water
Gray	13	CHEFS Functionalized hollow fiber sorbents for critical mineral recovery
Dogan	11	Novel Alloy Materials From Domestically Abundant - REE
Baltrus	14	Novel Fiberoptic Sensors for Critical Minerals
McIntyre	15	LIBS downhole and in AMD streams
Lopano	16	Sorbent for Li recovery derived from AMD treatm[illegible]
Thomas	17	Li Carbonation of Produced Water

NETL PI	Task #	Critical Minerals Systems Analysis
Summers	8.1	LCA Baseline for Conventional REE and Framework for Evaluating Others
Summers	8.2	CM Embedded Demand Database
Summers	8.3	Cost and Env. Perf. Optimization of CM Extraction using TEA and CORE CM
Summers	8.4	Process Flowsheet Modeling

Multi-faceted approaches to feedstock barriers



Coal/Sedimentary Resources Recovery

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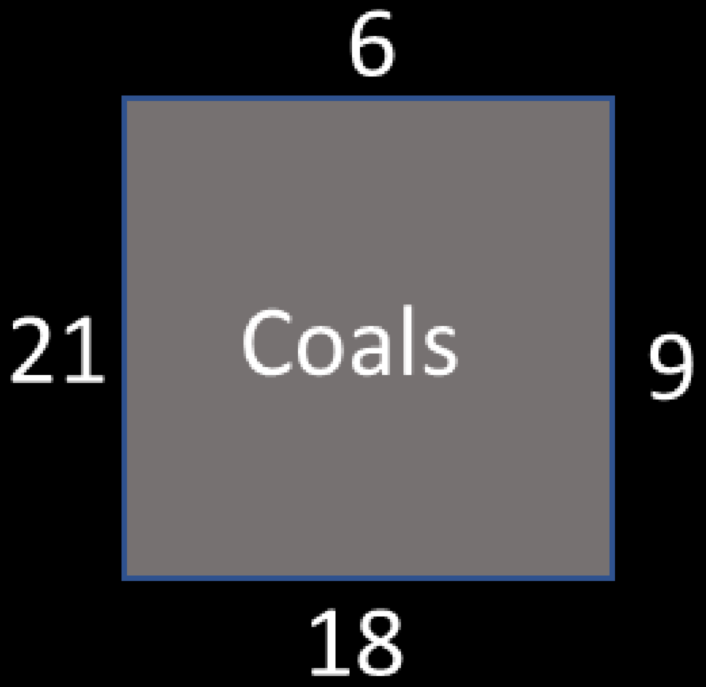
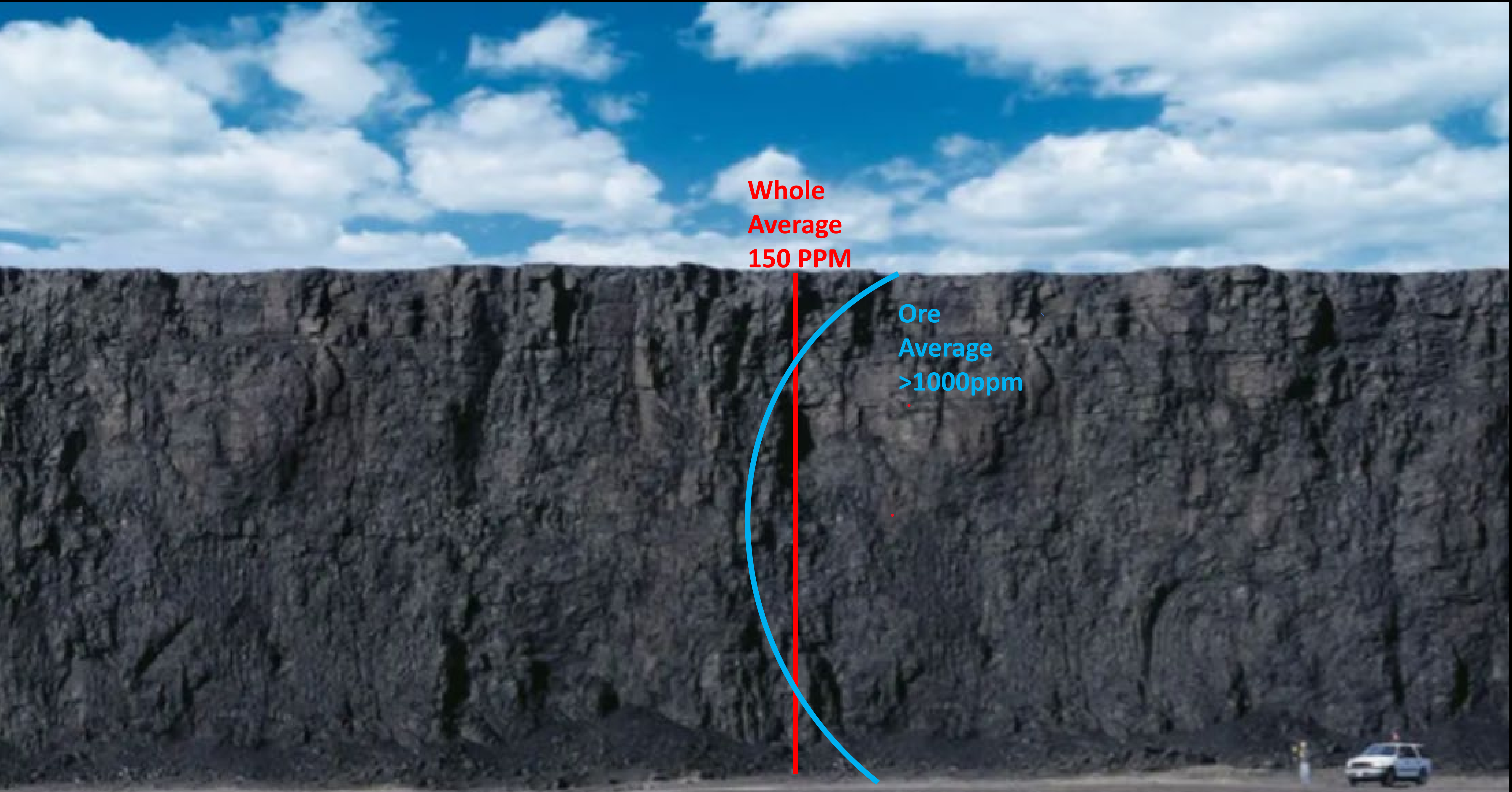
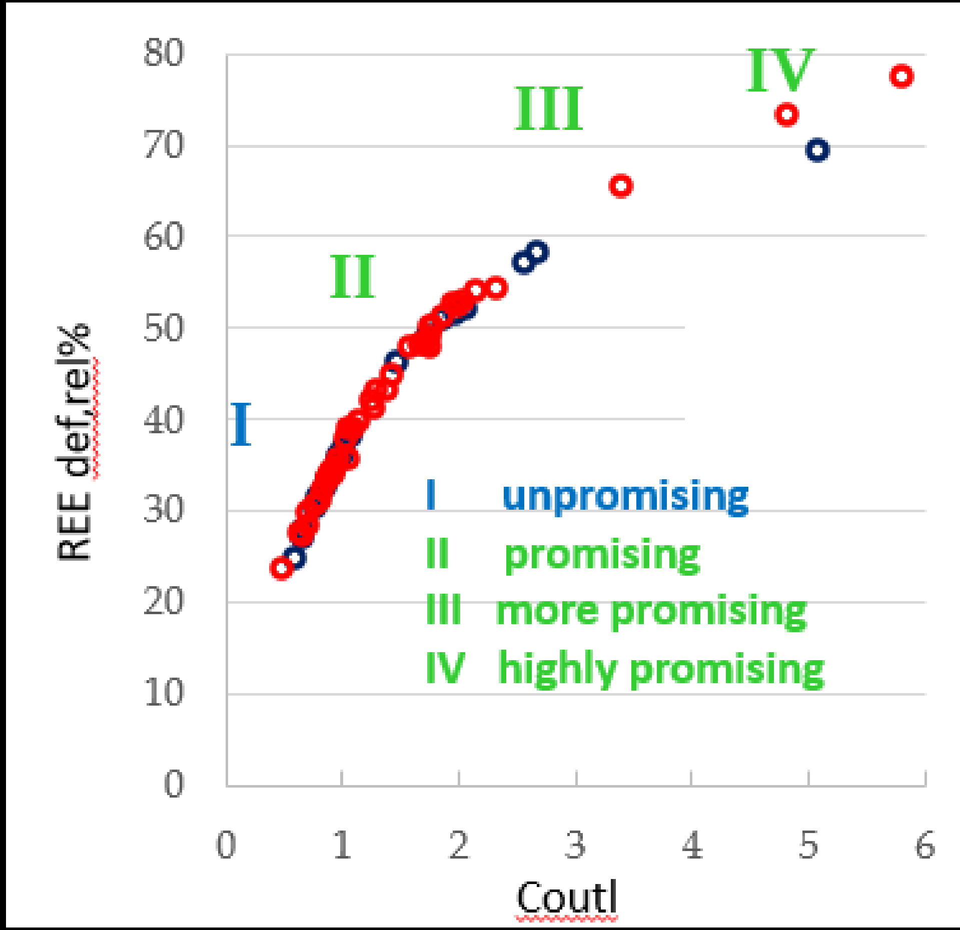
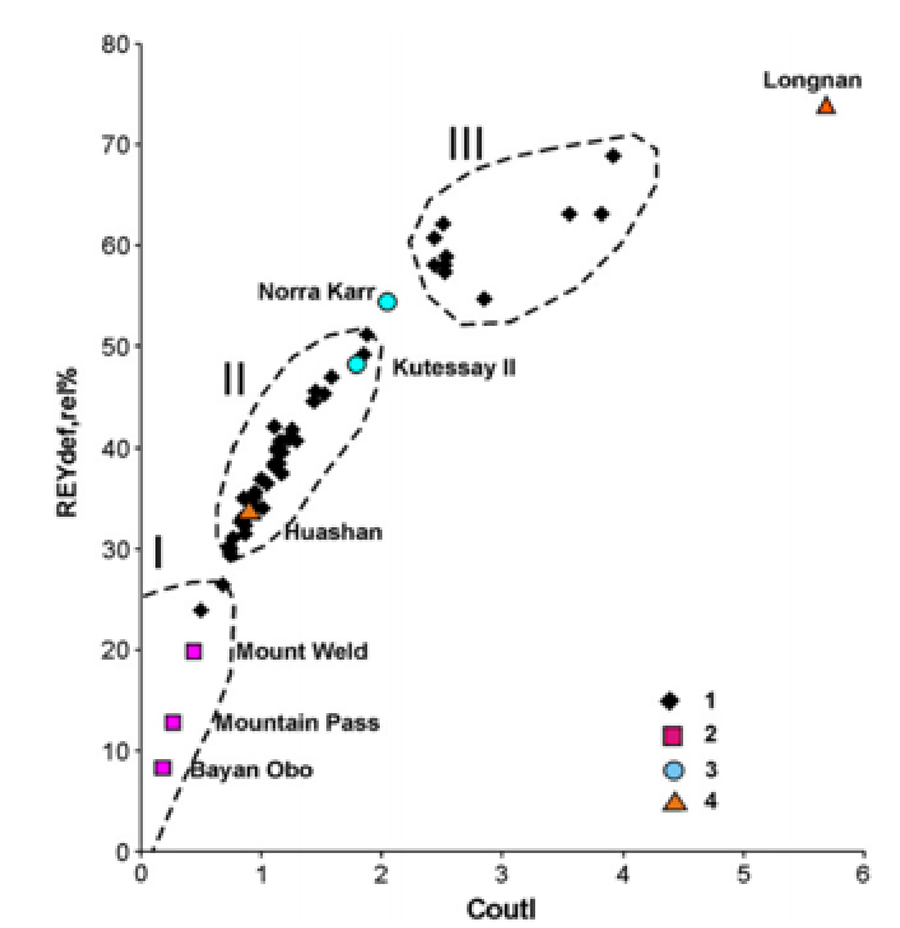



Whole
Average
150 PPM
Ore
Average
>1000ppm

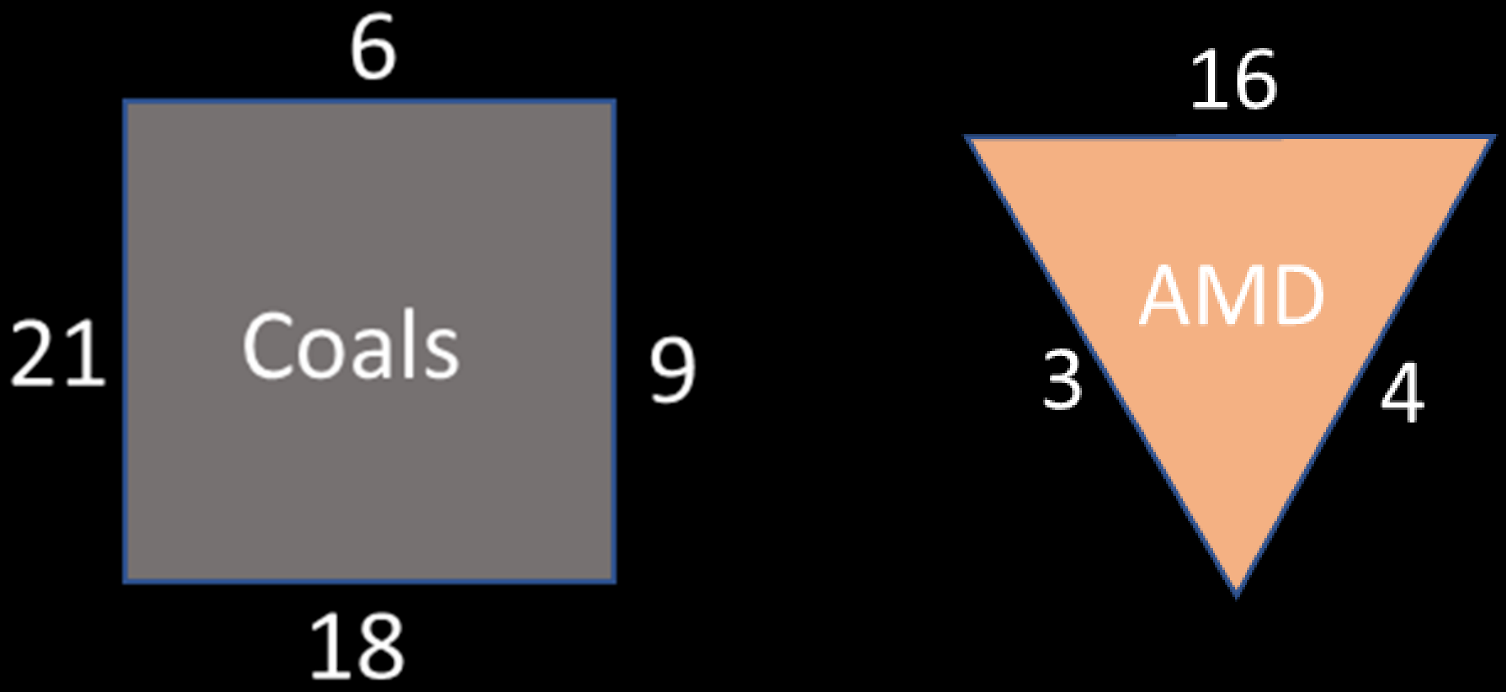
$$C_{outl} = \frac{\frac{Nd + Eu + Tb + Dy + Er + Y}{\Sigma REE}}{\frac{Ce + Ho + Tm + Yb + Lu}{\Sigma REE}}$$

Ore Classification (REE def, rel% = critical elements)

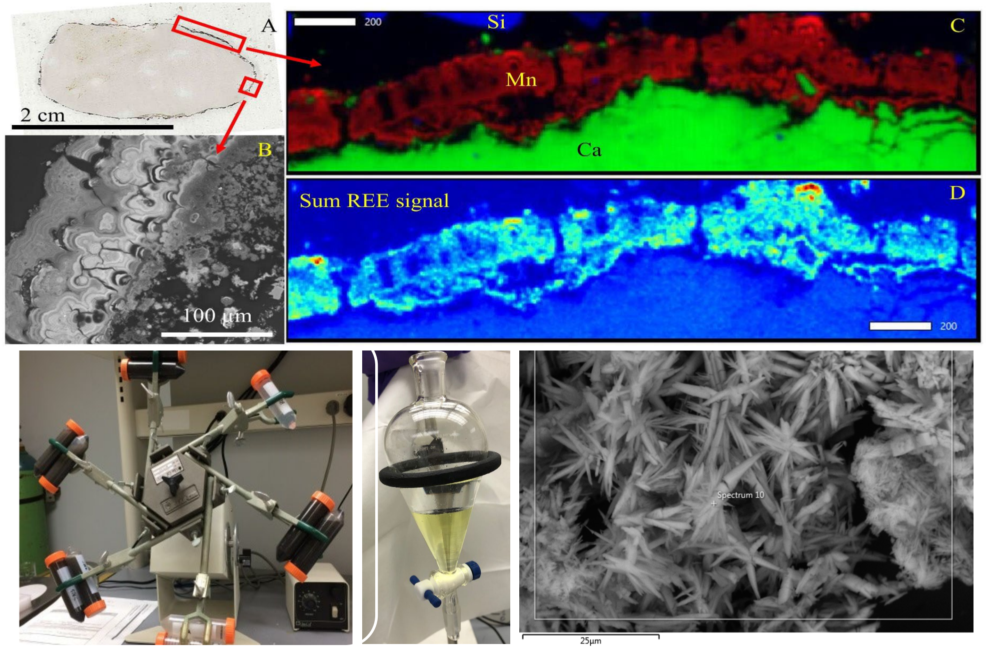




Recovery from Ash and AMD

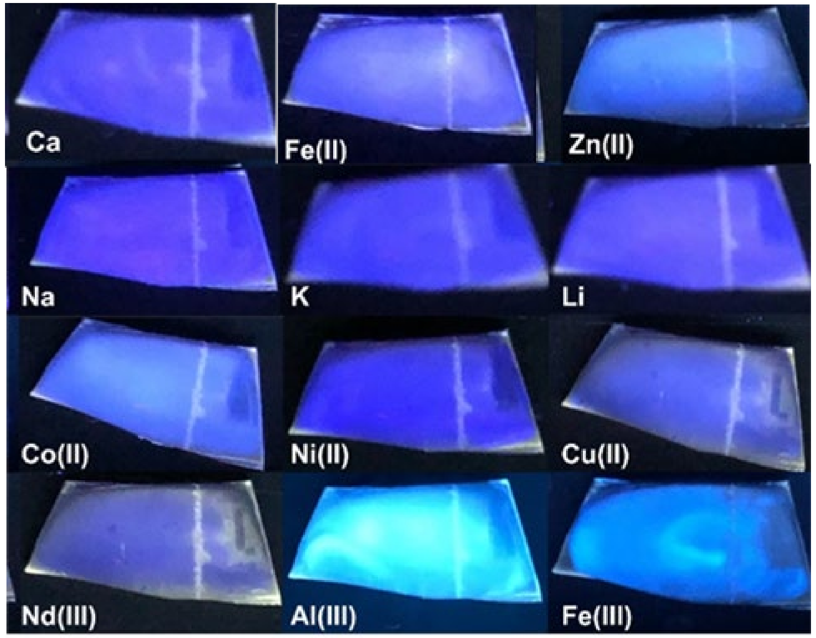


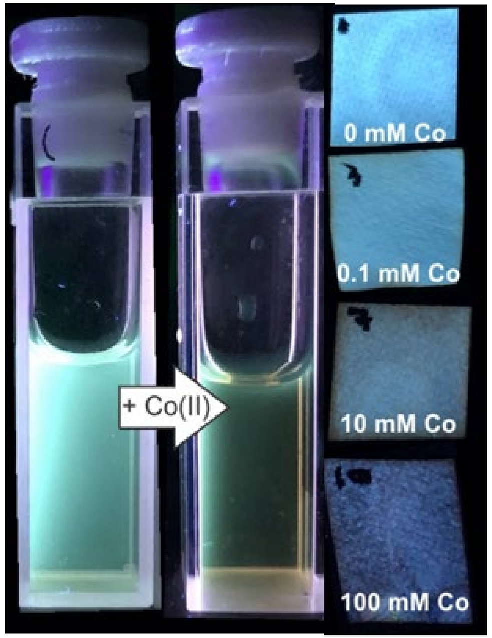
Characterization Informed Recovery of Critical Minerals in Acid Mine Drainage Treatment Systems

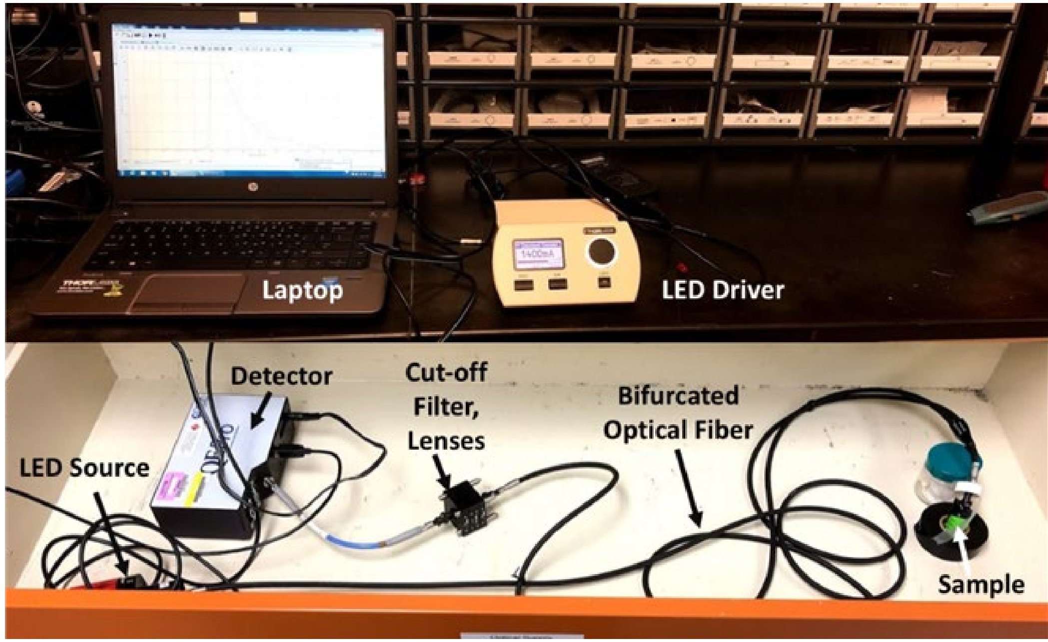


Technical Challenges: Characterization informed extraction methodologies for acid mine drainage, a coal byproduct.

Novel Fiber Optic Sensors for Critical Minerals

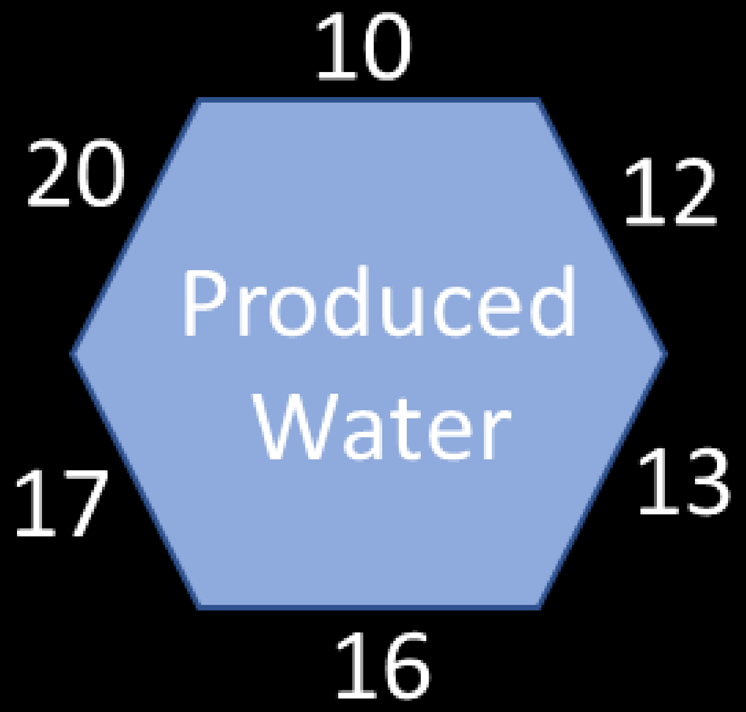




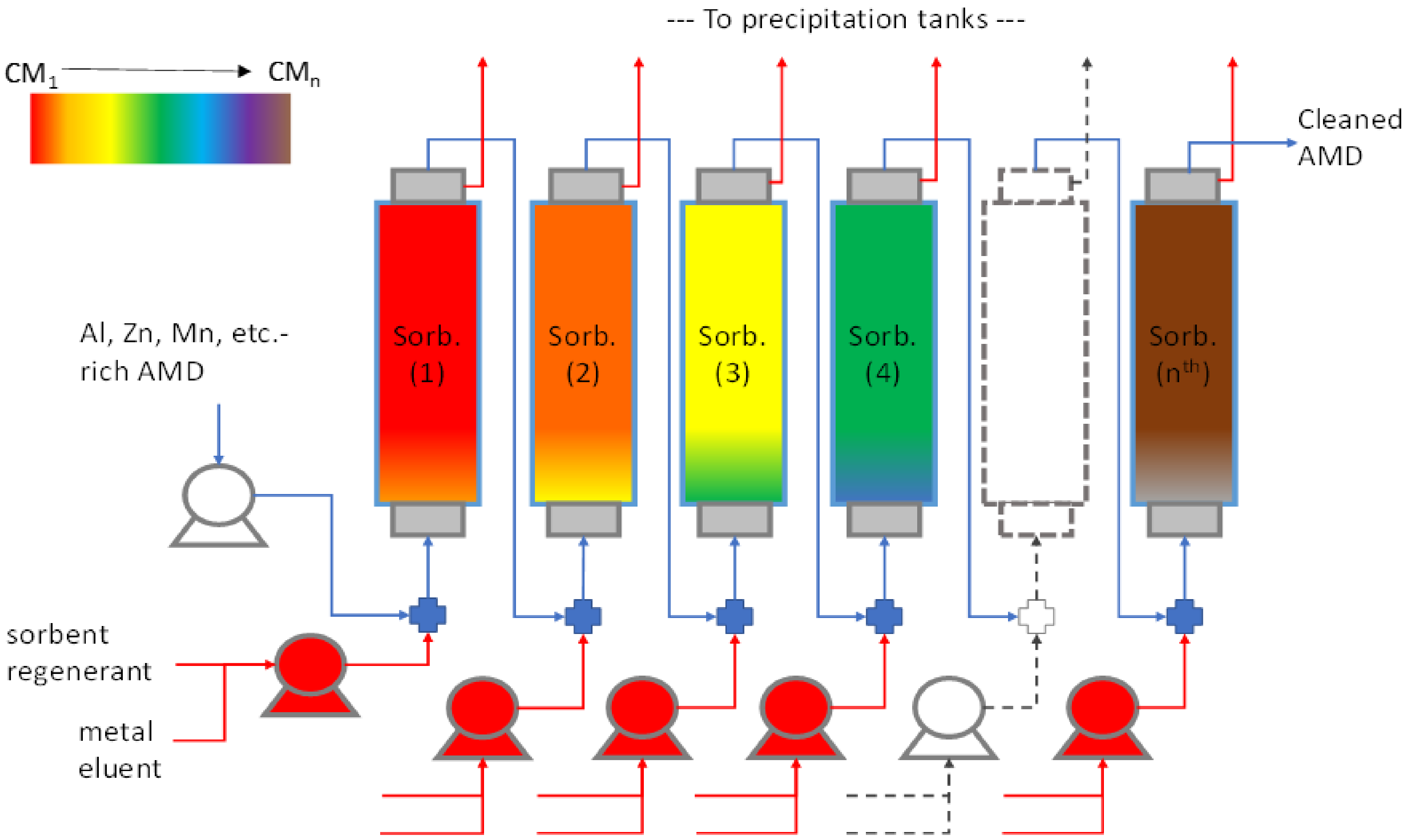


Technical Challenges: Low-cost optical-based detection of low ppm or ppb levels of critical elements in process streams.

Produced Water Recovery



Sorbent Development for Produced Waters



End Product:
Precipitated solids enriched with one or a mixture of critical minerals.

Technical Challenges: The presence of eluted trace Si reduces the purity of CM collected.

Conventional Feedstock Recovery

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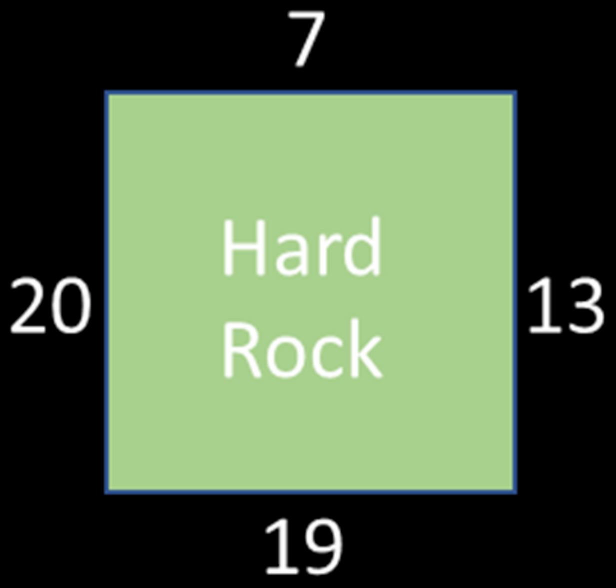


CM Task 7: CM Recovery from Mineral Carbonation (CDR) waste streams

Platinum Group Metal (PGM) potential in Twin Sisters olivine (TSO)

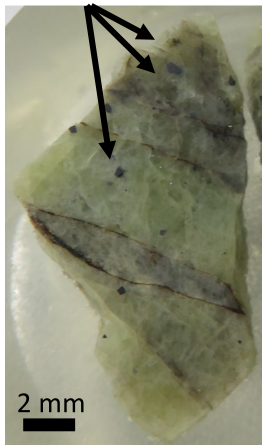
Chromite accessory minerals in dunite rocks

- Typically disseminated occurrences of chromite
- E.g., TSO contains ~1 wt% chromite average

from TSO -1/4" crushed material:

- chromite liberation in 500x300 µm size fraction

Chromite



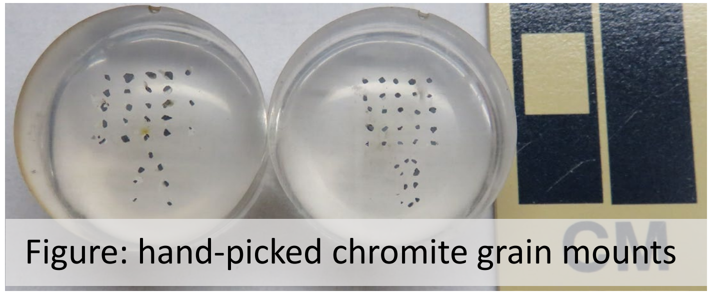
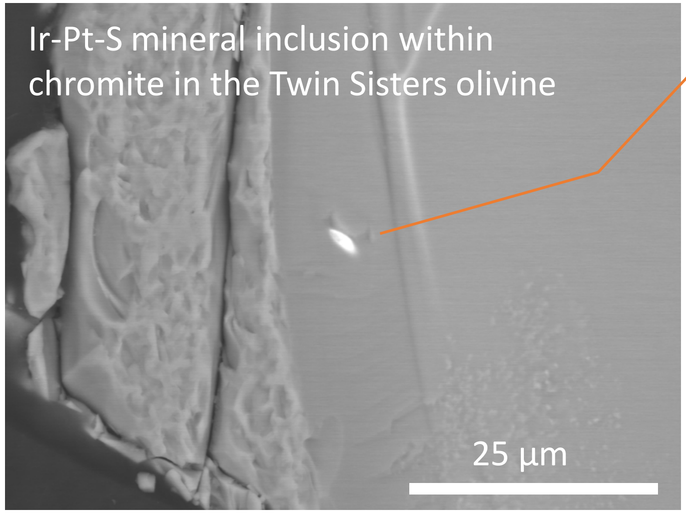
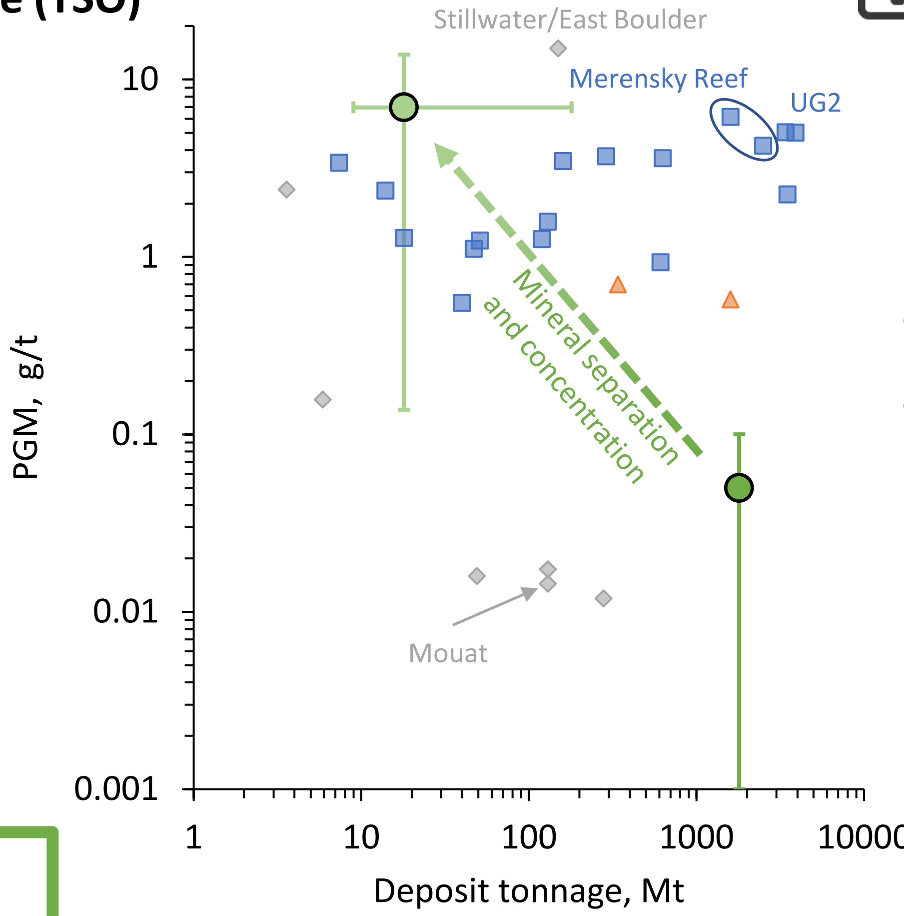


Figure: hand-picked chromite grain mounts



3.5 µm grain
~ 35wt% Ir, 6 wt% Pt
(by EDS)



*assuming ability to be separated

(all data except TSO from Zientek et al, 2017 and references therein)

Next Steps:

- Produce chromite concentrate from TSO and fully determine PGM potential

TSO actively mined for foundry sand and enhanced weathering (CDR) products – **opportunity for PGM byproducts**

Insitu Recovery from Unmineable Resources

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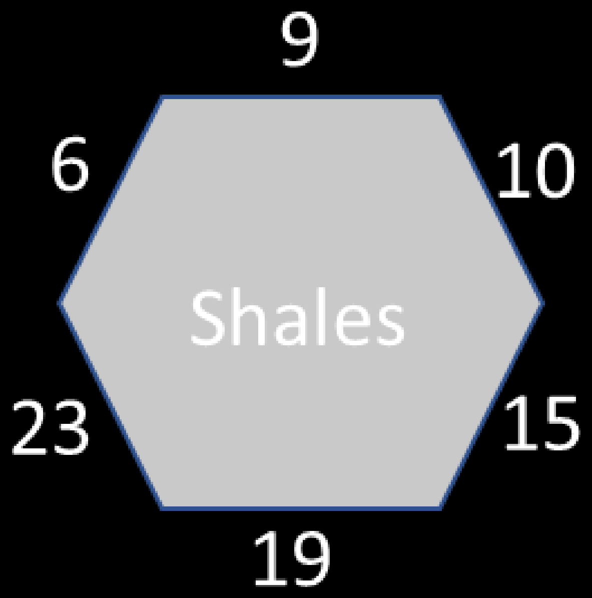

NETL's Vision for the Mines of the Future

An R&D Thrust to unlock America's hidden mineral resources

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- Tap Unmineable Mineral Wealth
  - Improving Prediction and Targeting
  - R&D for Bespoke Feedstock Leaching
- Subsurface Engineering
  - R&D for Subsurface Containerization/ Env. Protection
  - Enable Closed-System Leaching, Recovery, and Disposal
- Surface-based Processing
  - Recovery
  - Water Reuse

Formation	Core	V	Zn	Ni
		mg/kg	mg/kg	mg/kg
Bakken	Bedwell	3,000	13,000	1,000
Marcellus	Armstrong*	20,000	<100	<500
	Dunham*	90,000	5,000	<200
	MIP	90,000	30,000	<500