



US critical materials strategy: The importance of innovation in obtaining supply chain security

December 2024

Changing the World's Energy Future

Paul Slezak



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US critical materials strategy: The importance of innovation in obtaining supply chain security

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December 2024

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US critical materials strategy:

The importance of innovation in obtaining supply chain security

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy



Idaho National Laboratory

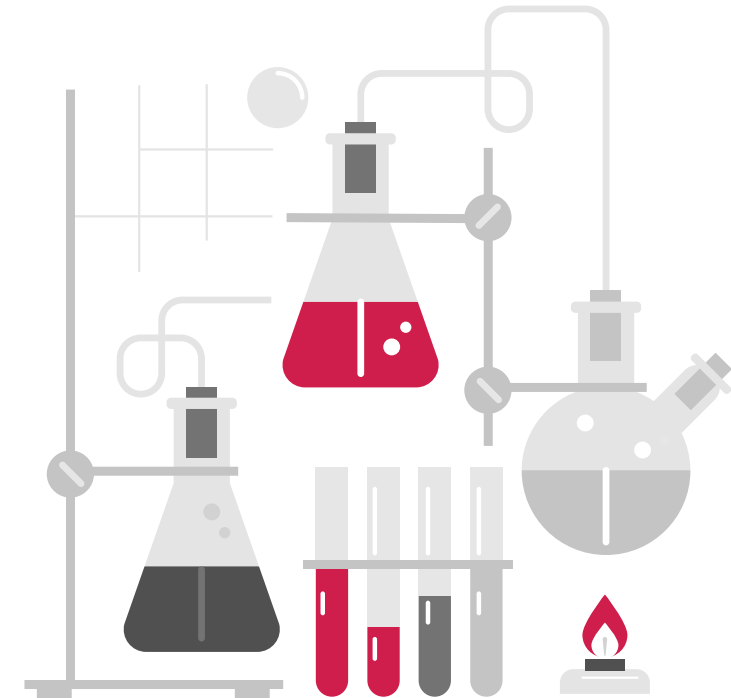


Overview

- The problem at hand
- Review of EU Critical Raw Materials Act (CRMA)
- DOE Critical Minerals & Materials (CMM) policy
- INL projects
- Future landscape for geoscientists

An overly simple mineral path

1. Mineral exploration and mining
 - Find, study, delineate & develop deposit
2. Geometallurgy
 - Characterise, crush & concentrate
3. Metal liberation
 - Crack (e.g. REE), leach and/or smelt
4. Separation/purification
 - REE need to be separated
 - Electroplating, etc.
5. Manufacturing onwards
 - Refine materials further, make alloys, etc.



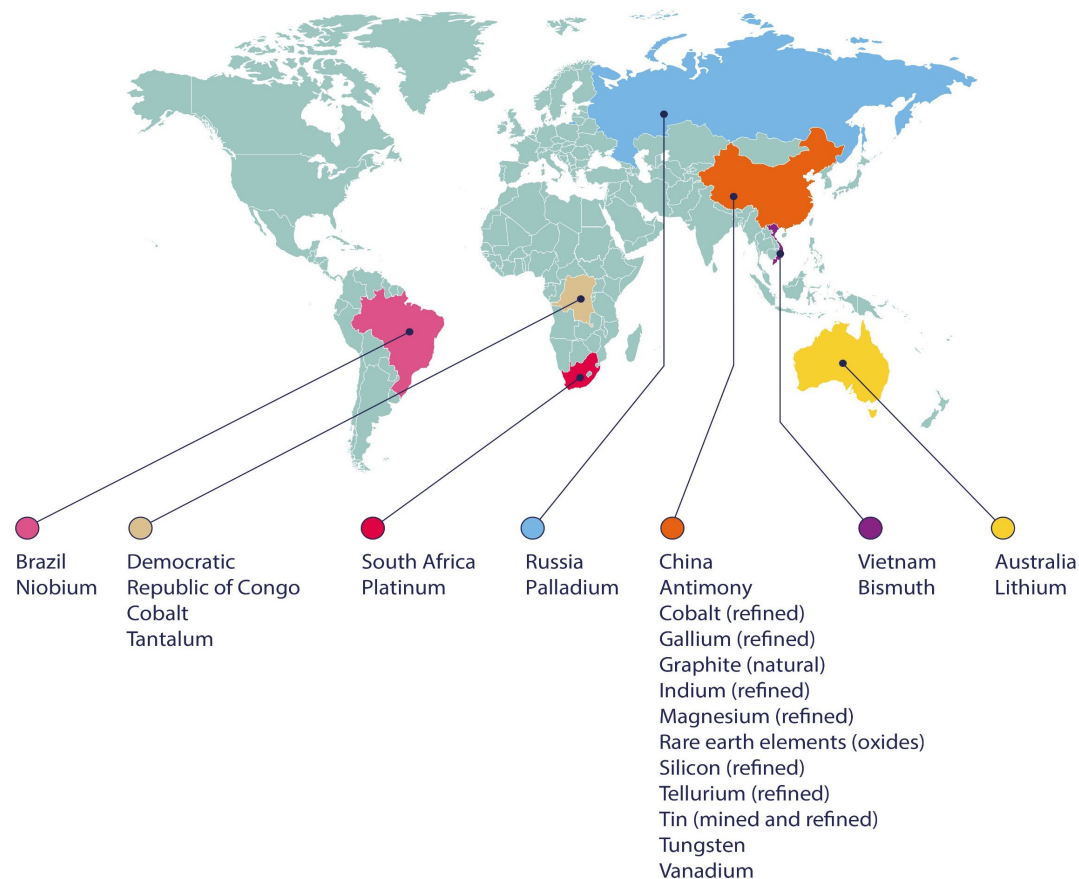
**Mining is an
economy of **scale**,
not an economy of
efficiency**



Geology isn't fair and neither is commodity production

Top producers globally of the 18 critical minerals

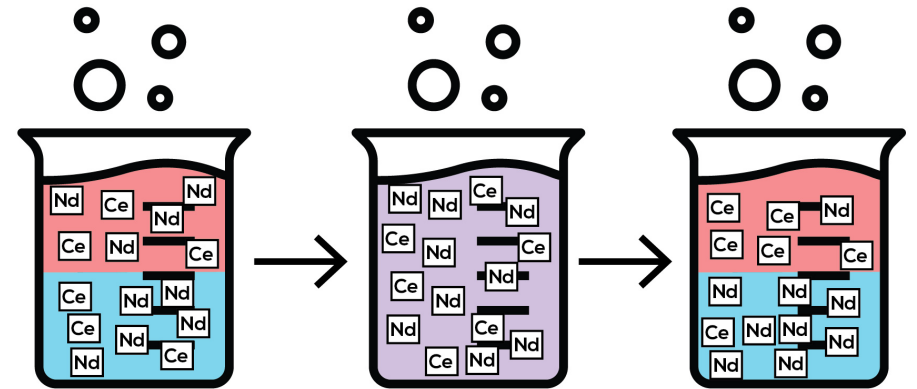
Country with the highest production of each critical mineral; refers to mined production, unless otherwise stated. 5-year average production 2016–2020.



Source: Data from the UK Critical Minerals Intelligence Centre, 2022

Processing not always great

- China is effectively the only country that processes REE
- Solvent extraction (aka liquid-liquid extraction)
 - Method to separate compounds based on their relative solubilities in two different immiscible liquids
 - Difficult to separate REE from each other
 - Not very efficient – multiple passes needed
 - Mixture of chloride solution and kerosene!



Environmental considerations

Satellite imagery of expansion of Baotou, Inner Mongolia, China



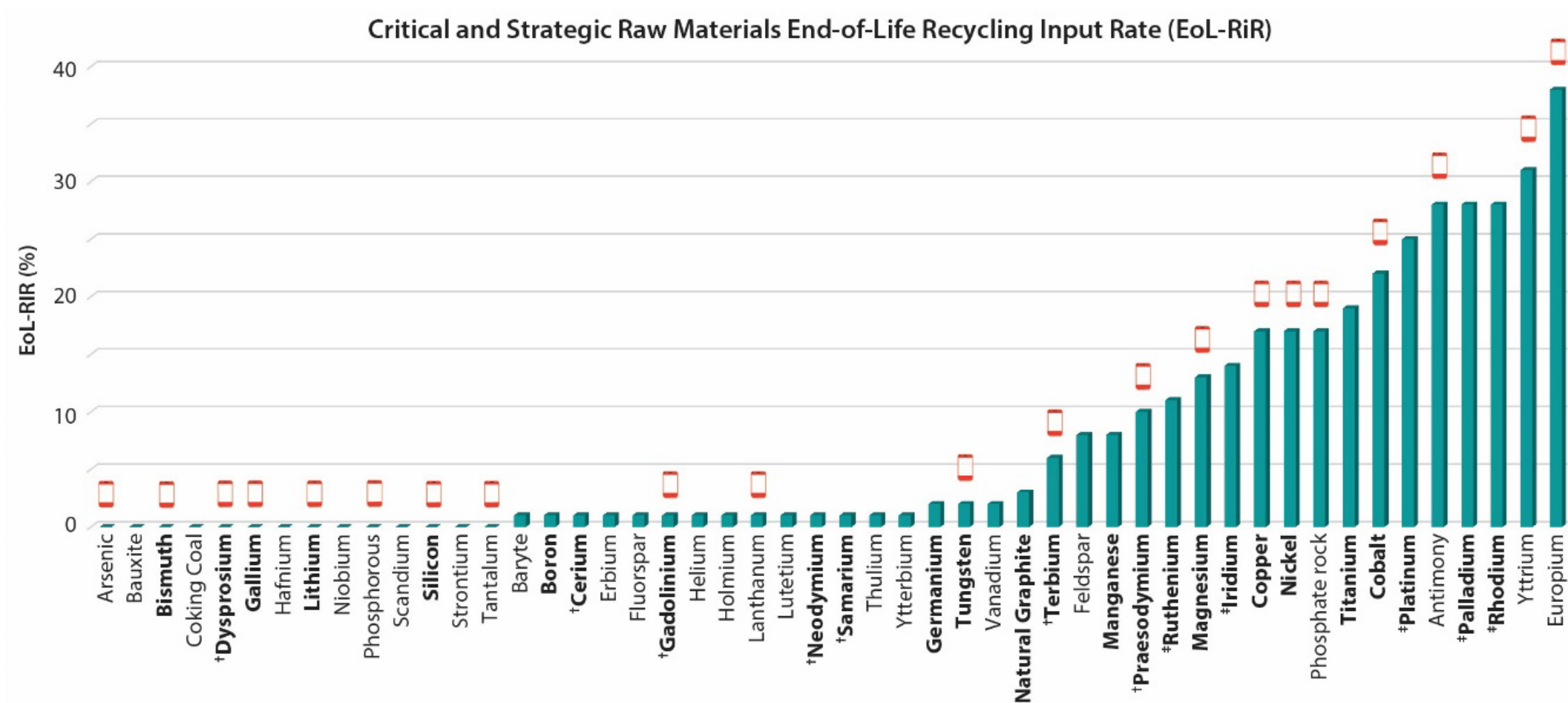
Environmental considerations

- Tailings ponds take up space
- Heavy metal run off, soil contamination, water contamination
- Radioactivity
 - ^{232}Th is low-level radioactive
 - ~35x more Th concentrated in tailings than in the rest of Bayan Obo district
- Dust
 - 1.35x ^{232}Th in dust in district



Weikuang tailings pond near Baotou, Inner Mongolia, China

Recycling



Non-functional recycling

- When a material/metal/mineral is a part of something that is recycled, but is not, in and of itself recovered
 - Antimony (Sb) in lead-acid batteries
 - Boron (B) in borosilicate glass
 - REE in most e-waste (but good progress on permanent magnets)





Critical Raw Materials (CRM)/ Critical Minerals & Materials (CMM) policy

Evolution of CRM list in Europe

1A	2A																				8A
1 H Hydrogen																					2 He Helium
3 *	4																				
Li Lithium	Be Beryllium																				
11	12 *																				
Na Sodium	Mg Magnesium																				
		3B	4B	5B	6B	7B		8B		1B	2B		3A	4A	5A	6A	7A				
19	20	21	22 *	23	24	25 *	26	27	28 *	29	30	31	32	33	34	35	36				
K Potassium	Ca Calcium	Sc Scandium	Ti Titanium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron	Co Cobalt	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Ge Germanium	As Arsenic	Se Selenium	Br Bromine	Kr Krypton				
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54				
Rb Rubidium	Sr Strontium	Y Yttrium	Zr Zirconium	Nb Niobium	Mo Molybdenum	Tc Technetium	Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag Silver	Cd Cadmium	In Indium	Sn Tin	Sb Antimony	Te Tellurium	I Iodine	Xe Xenon				
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86				
Cs Cesium	Ba Barium	Lanthanides	Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	Ir Iridium	Pt Platinum	Au Gold	Hg Mercury	Tl Thallium	Pb Lead	Bi Bismuth	Po Polonium	At Astatine	Rn Radon				
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118				
Fr Francium	Ra Radium	Actinides	Rf Rutherfordium	Db Dubnium	Sg Seaborgium	Bh Bohrium	Hs Hassium	Mt Meitnerium	Ds Darmstadtium	Rg Roentgenium	Cn Copernicium	Uut Ununtrium	Fl Flerovium	Uup Ununpentium	Lv Livermorium	Uus Ununseptium	Uuo Ununoctium				

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La Lanthanum	Ce Cerium	Pr Praseodymium	Nd Neodymium	Pm Promethium	Sm Samarium	Eu Europium	Gd Gadolinium	Tb Terbium	Dy Dysprosium	Ho Holmium	Er Erbium	Tm Thulium	Yb Ytterbium	Lu Lutetium
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac Actinium	Th Thorium	Pa Protactinium	U Uranium	Np Neptunium	Pu Plutonium	Am Americium	Cm Curium	Bk Berkelium	Cf Californium	Es Einsteinium	Fm Fermium	Md Mendelevium	No Nobelium	Lr Lawrencium

*Additional materials

Baryte	Coking Coal	Feldspar	Fluorspar	Natural Graphite	Phosphate Rock
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- 14 CRMs in 2011
- 20 in 2014
- 27 in 2017
- 30 in 2020
- 33 (really 52) in 2023
– 22 “SRMs”

Regulation (EU) 2024/1252 of the European Parliament - *the Critical Raw Materials Act (CRMA)*

Ch. 3. By 2030...

- **≥10%** of annual CRM consumption should be **extracted** in EU
- **≥40%** of annual CRM consumed should be **processed/produced** in EU
- **≥25%** of annual CRM consumption should be **produced via recycling** in EU
- No third country can account for more than **65%** of total EU's CRM annual consumption

Regulation (EU) 2024/1252 of the European Parliament - *the Critical Raw Materials Act (CRMA)*

Ch. 4. Strategic Projects

Ch. 5. Sustainability

- Incentivise resource efficiency
 - *Waste prevention, more re-use, repair*
 - *Increase collection sorting of products*
 - *Increase use of CRMs obtained from secondary processes*
 - *Promote circular design*
- Make list of CRMs in many products and what's recoverable (e.g. permanent magnets)
- Redefine waste streams
- Re-evaluate laws/gaps in legislation

Regulation (EU) 2024/1252 of the European Parliament - *the Critical Raw Materials Act (CRMA)*

Ch. 6. Governance

- Establish European Critical Raw Materials Board

Ch. 7. Delegated powers and committee procedure

Ch. 8. Amendments to previous acts and regulations

Ch. 9. Monitoring progress

- Establishment of penalties by 24 Nov. 2026
- 24 May 2027 and every 3 years Board reports and updates advice

US critical minerals List

1 IA																		2 IIA																		13 IIIA																		14 IVA																		15 VA																		16 VIA																		17 VIIA																		18 VIIIA																																																																																																																																																																																																					
1 H Hydrogen 1.008																		2 He Helium 4.003																																																																																																																																																																																																																																																																																																																	
3 Li Lithium 6.941																		4 Be Beryllium 9.012																																				5 B Boron 10.811																		6 C Carbon 12.011																		7 N Nitrogen 14.007																		8 O Oxygen 15.999																		9 F Fluorine 18.998																		10 Ne Neon 20.180																																																																																																																																																																																			
11 Na Sodium 22.990																		12 Mg Magnesium 24.305																																				13 Al Aluminum 26.982																		14 Si Silicon 28.086																		15 P Phosphorus 30.974																		16 S Sulfur 32.066																		17 Cl Chlorine 35.453																		18 Ar Argon 39.948																																																																																																																																																																																			
19 K Potassium 39.098																		20 Ca Calcium 40.078																		21 Sc Scandium 44.956																		22 Ti Titanium 47.867																		23 V Vanadium 50.942																		24 Cr Chromium 51.996																		25 Mn Manganese 54.938																		26 Fe Iron 55.845																		27 Co Cobalt 58.933																		28 Ni Nickel 58.693																		29 Cu Copper 63.546																		30 Zn Zinc 65.38																		31 Ga Gallium 69.723																		32 Ge Germanium 72.631																		33 As Arsenic 74.922																		34 Se Selenium 78.971																		35 Br Bromine 79.904																		36 Kr Krypton 83.798																	
37 Rb Rubidium 85.468																		38 Sr Strontium 87.62																		39 Y Yttrium 88.906																		40 Zr Zirconium 91.224																		41 Nb Niobium 92.906																		42 Mo Molybdenum 95.95																		43 Tc Technetium 98.907																		44 Ru Ruthenium 101.07																		45 Rh Rhodium 102.906																		46 Pd Palladium 106.42																		47 Ag Silver 107.868																		48 Cd Cadmium 112.414																		49 In Indium 114.818																		50 Sn Tin 118.711																		51 Sb Antimony 121.760																		52 Te Tellurium 127.6																		53 I Iodine 126.904																		54 Xe Xenon 131.294																	
55 Cs Cesium 132.905																		56 Ba Barium 137.328																		57-71																		72 Hf Hafnium 178.49																		73 Ta Tantalum 180.948																		74 W Tungsten 183.84																		75 Re Rhenium 186.207																		76 Os Osmium 190.23																		77 Ir Iridium 192.217																		78 Pt Platinum 195.085																		79 Au Gold 196.967																		80 Hg Mercury 200.592																		81 Tl Thallium 204.383																		82 Pb Lead 207.2																		83 Bi Bismuth 208.980																		84 Po Polonium [208.982]																		85 At Astatine 209.987																		86 Rn Radon 222.018																	
87 Fr Francium 223.020																		88 Ra Radium 226.025																		89-103																		104 Rf Rutherfordium [261]																		105 Db Dubnium [262]																		106 Sg Seaborgium [266]																		107 Bh Bohrium [264]																		108 Hs Hassium [269]																		109 Mt Meitnerium [278]																		110 Ds Darmstadtium [281]																		111 Rg Roentgenium [280]																		112 Cn Copernicium [285]																		113 Nh Nihonium [286]																		114 Fl Flerovium [289]																		115 Mc Moscovium [289]																		116 Lv Livermorium [293]																		117 Ts Tennessine [294]																		118 Og Oganesson [294]																	
57 La Lanthanum 138.905																		58 Ce Cerium 140.116																		59 Pr Praseodymium 140.908																		60 Nd Neodymium 144.243																		61 Pm Promethium 144.913																		62 Sm Samarium 150.36																		63 Eu Europium 151.964																		64 Gd Gadolinium 157.25																		65 Tb Terbium 158.925																		66 Dy Dysprosium 162.500																		67 Ho Holmium 164.930																		68 Er Erbium 167.259																		69 Tm Thulium 168.934																		70 Yb Ytterbium 173.055																		71 Lu Lutetium 174.967																																																																							
89 Ac Actinium 227.028																		90 Th Thorium 232.038																		91 Pa Protactinium 231.036																		92 U Uranium 238.029																		93 Np Neptunium 237.048																		94 Pu Plutonium 244.064																		95 Am Americium 243.061																		96 Cm Curium 247.070																		97 Bk Berkelium 247.070																		98 Cf Californium 251.080																		99 Es Einsteinium [254]																		100 Fm Fermium 257.095																		101 Md Mendelevium 258.1																		102 No Nobelium 259.101																		103 Lr Lawrencium [262]																																																																							

- USGS Critical Minerals
- DOE+USGS Critical Minerals
- DOE Nearly Critical+USGS Critical Minerals
- DOE Nearly Critical

Department of Energy (DOE) critical minerals & materials strategy



DOE goals & objectives

1. Drive supply chain security

- Coordinate existing R&D
- Develop roadmap for new R&D
- Identify opportunities with public-private partnerships
- Collaborate with interagency and international partners

2. Support private sector for domestic CRM production

- Coordinate technology transition and transfer activities/capabilities among research organisations and national lab system
- Develop future opportunities for improved adoption and capacity
- Engage stakeholders
- Enable technology transfer mechanism

DOE goals & objectives

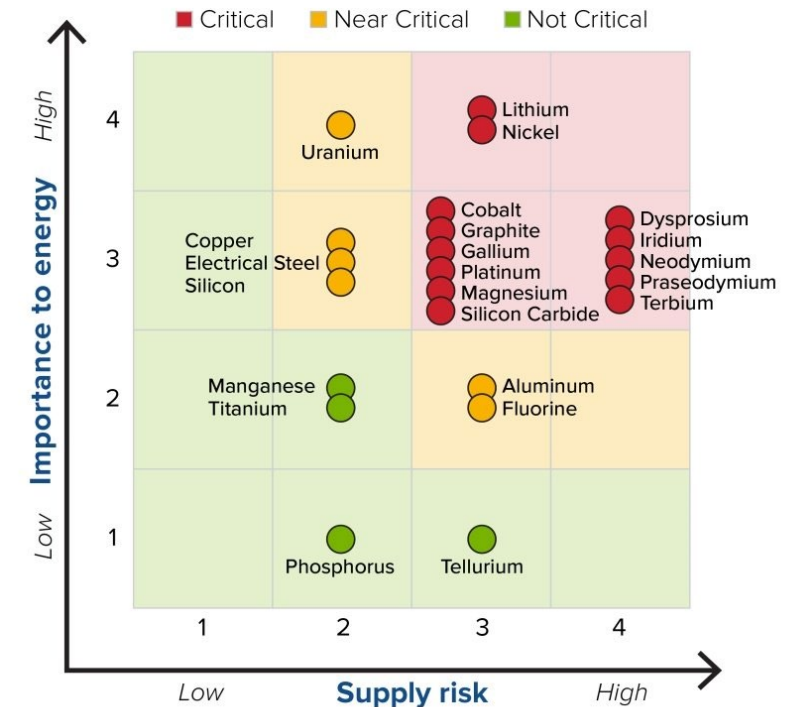
3. Build long-term ecosystem to meet current demands and mitigate future issues

- Build criticality analysis framework
- Improve and enable mapping of critical mineral/material deposits
- Grow US critical materials workforce

4. Coordinate with international partners/allies and other US agencies to diversify supply chains

- Increase international exchanges
- Coordinate across US federal agencies
- Collaborate with international partners and establish global industry standards

MEDIUM TERM 2025-2035



Many organizations work to meet these goals & objectives

Critical Minerals Innovation Hub

- Lead by Ames Nat. Lab
- Mineral processing, manufacturing, substitution, recycling, etc.

Critical Minerals Collaborative

- Group to improve communication/coordination amongst DOE, other gov't agencies and stakeholders

DOE Office of Fossil Energy and Carbon Management (FECM)

- Work to minimise environmental/climatic impacts of fossil energy
- R&D at extracting critical minerals from fossil energy-related sources (e.g., coal, petroleum-related brines, etc.)

Advanced Research Projects Agency-Energy (ARPA-E)

- Funds R&D for advanced applied science/engineering projects related to energy



Critical Materials Innovation Hub



Resulting from these organisations...

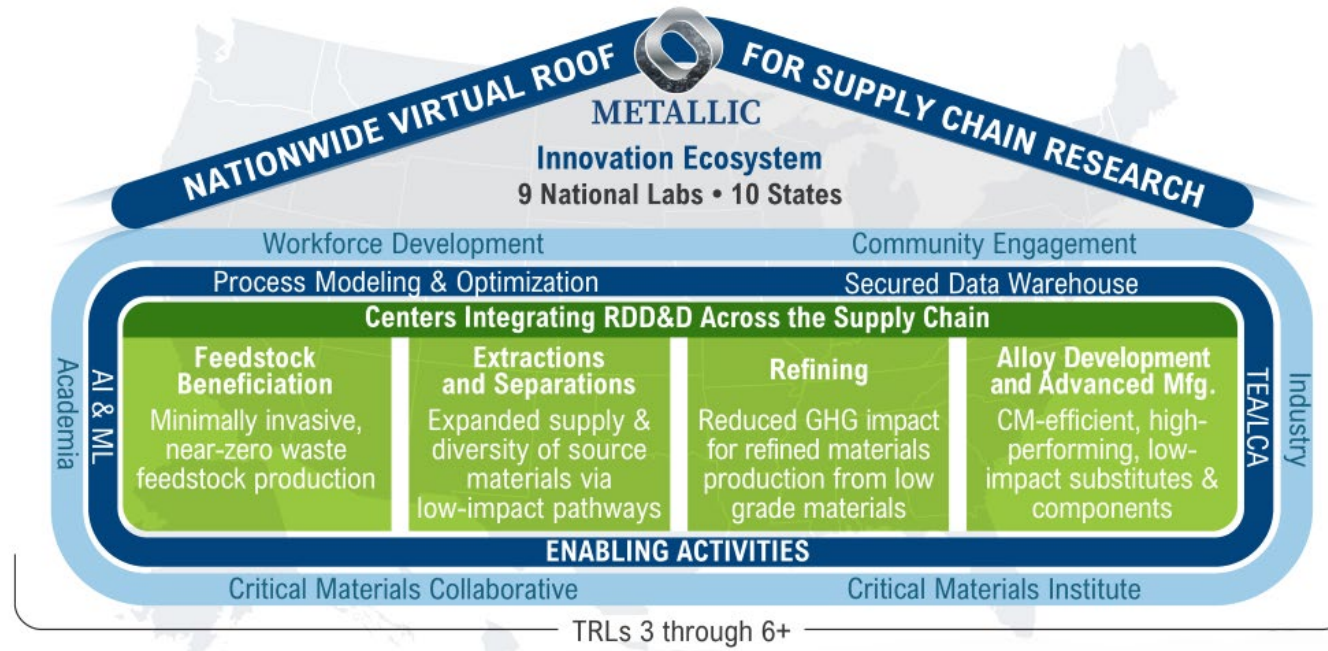
Process for Optimization and Modelling for Minerals Sustainability (PROMMIS)

- Multi-lab, multi-university collaboration to improve existing REE (and other CMM) processes via existing technologies
- Techno-economic analyses
- Minimise waste



Resulting from these organisations...

MinEral to MaTeriALs Supply Chain Research FaCility (METALLIC)



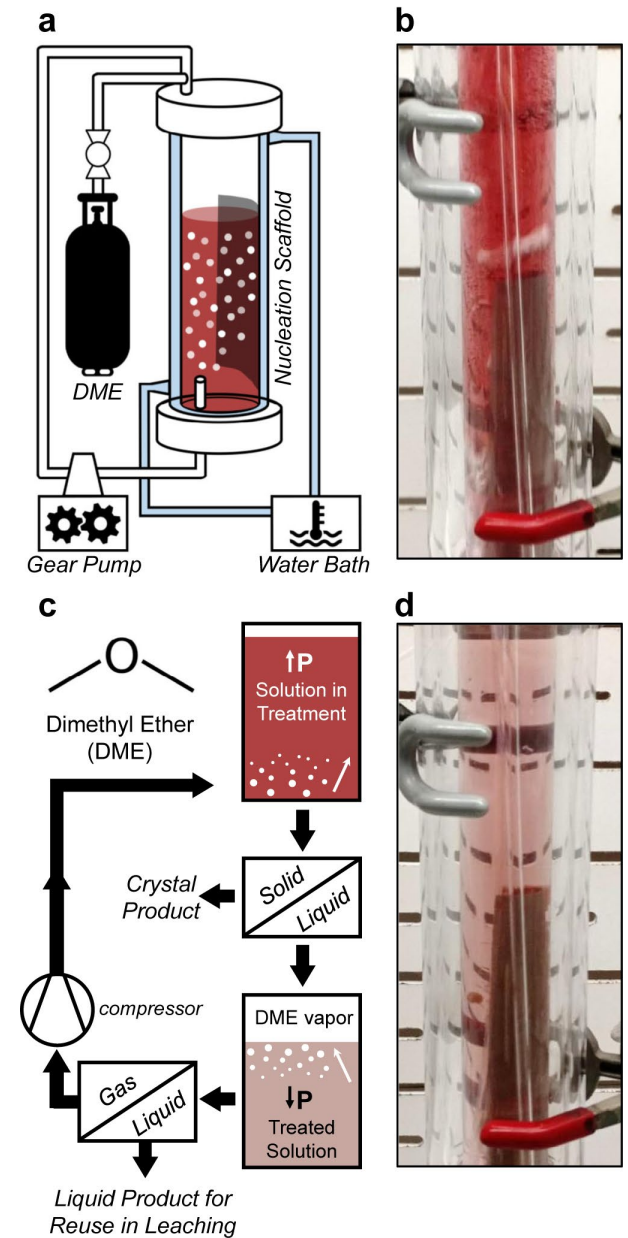
Examples of current work at INL



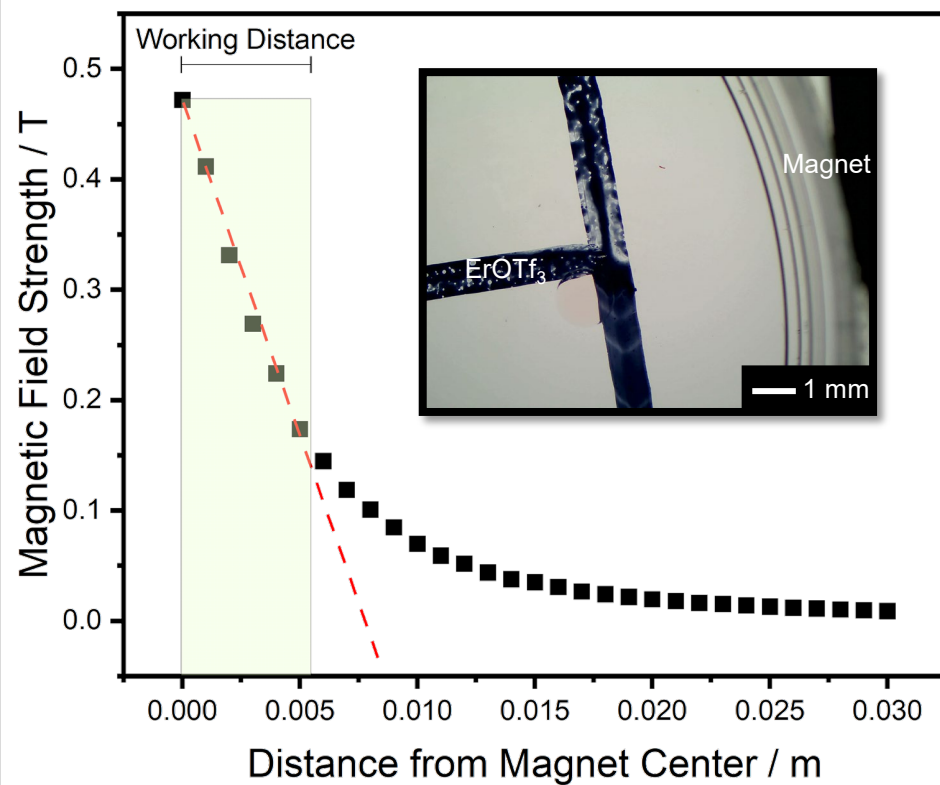
*Electrophoresis unit,
Energy Innovation Laboratory*

Work so far...

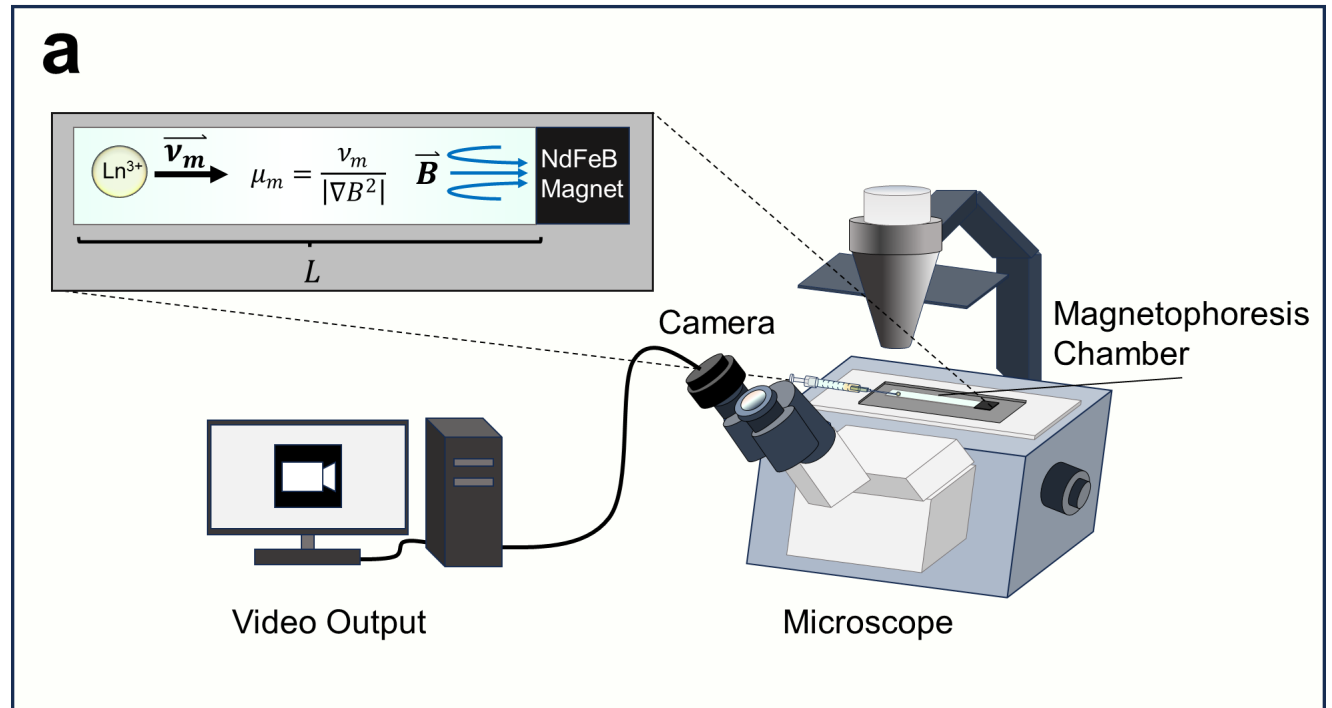
- CMI work on separations chemistry
 - INL work on electro/magneto-phoretics on REE
 - Dimethyl ether separations on Co + Sm



Work so far...



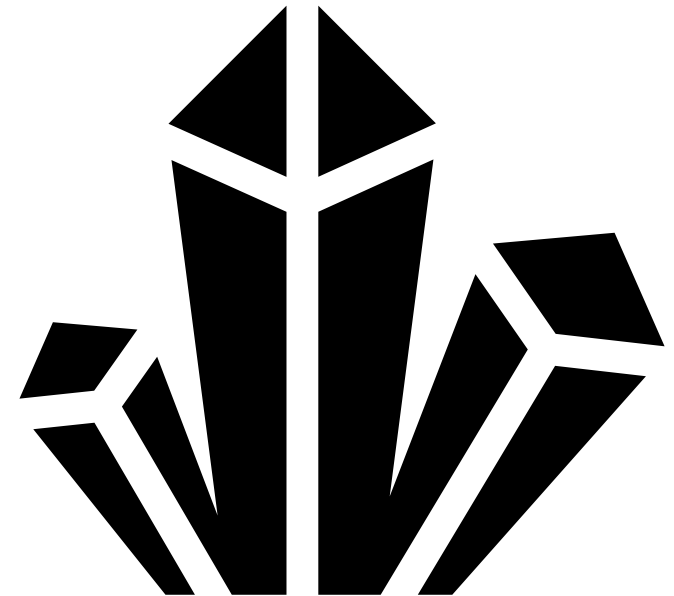
Magnetic field strength measurements used in field gradient calculations for a small cylindrical NdFeB magnet with operational region indicated.



Schematic of the magnetophoretic assembly.

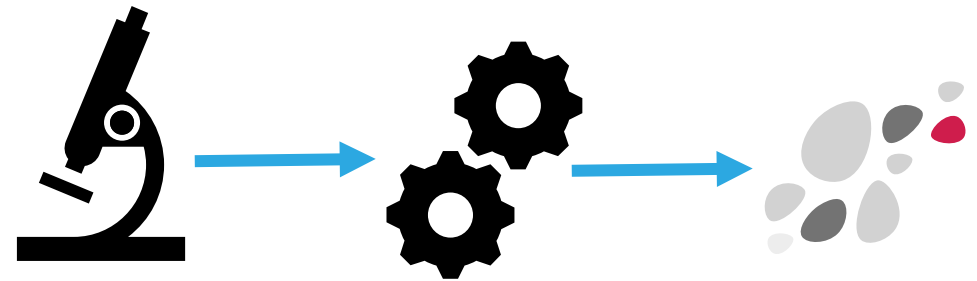
INL work going forward

1. Mineral exploration and mining
 - Find, study, delineate & develop deposit
2. Geometallurgy
 - Characterise, crush & concentrate
3. Metal liberation
 - Crack (e.g. REE), leach and/or smelt
4. Separation/purification
 - REE need to be separated
 - Electroplating, etc.
5. Manufacturing onwards
 - Refine materials further, make alloys, etc.



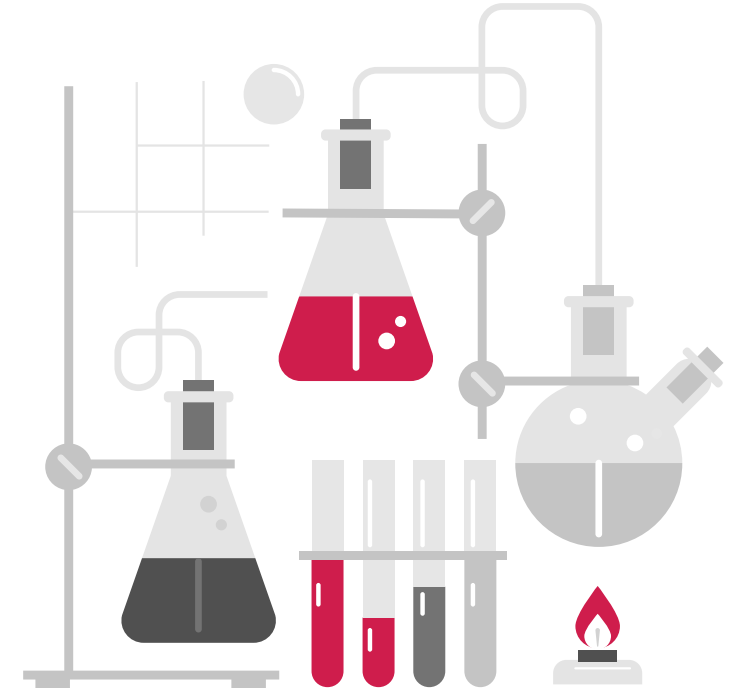
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**Mining is an
economy of **scale**,
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So what should geoscientists/minex companies focus on?

Individuals

- Characterise minerals with a purpose
 - Favourable elements, issues with processing, etc.?
- Elemental deportment
 - Mineral & system
- Consider downstream processes
 - Geometallurgy, separations, waste, etc.
- Think beyond a history and a description!
- Consider alternative resources

Companies

- Think about what's useful information (outside of finding an ore deposit)
- Know what information universities, gov't orgs, consultants are going to actually provide!
- Need investing in mining R&D
- Consider investment in alternative ores/methods/pathways (i.e. mines of the future)

Who wants to collaborate?

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China Bans Rare Mineral Exports to the U.S.

The move escalates supply chain warfare and comes a day after the Biden administration expanded curbs on the sale of advanced American technology to China.

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China, which produces almost all the world's supply of critical minerals, has been tightening its grip on the materials. Wu Changqing/VCG, via Getty Images



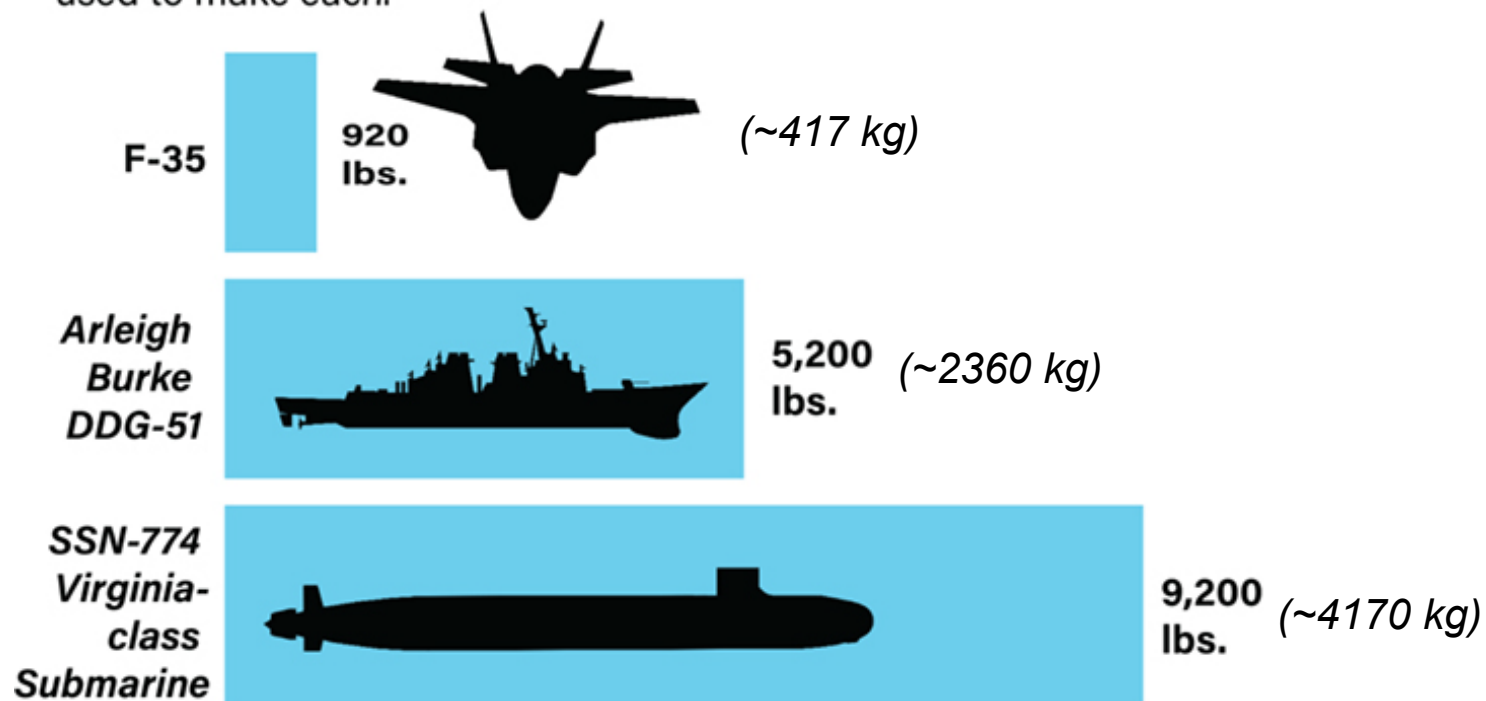
Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

WWW.INL.GOV

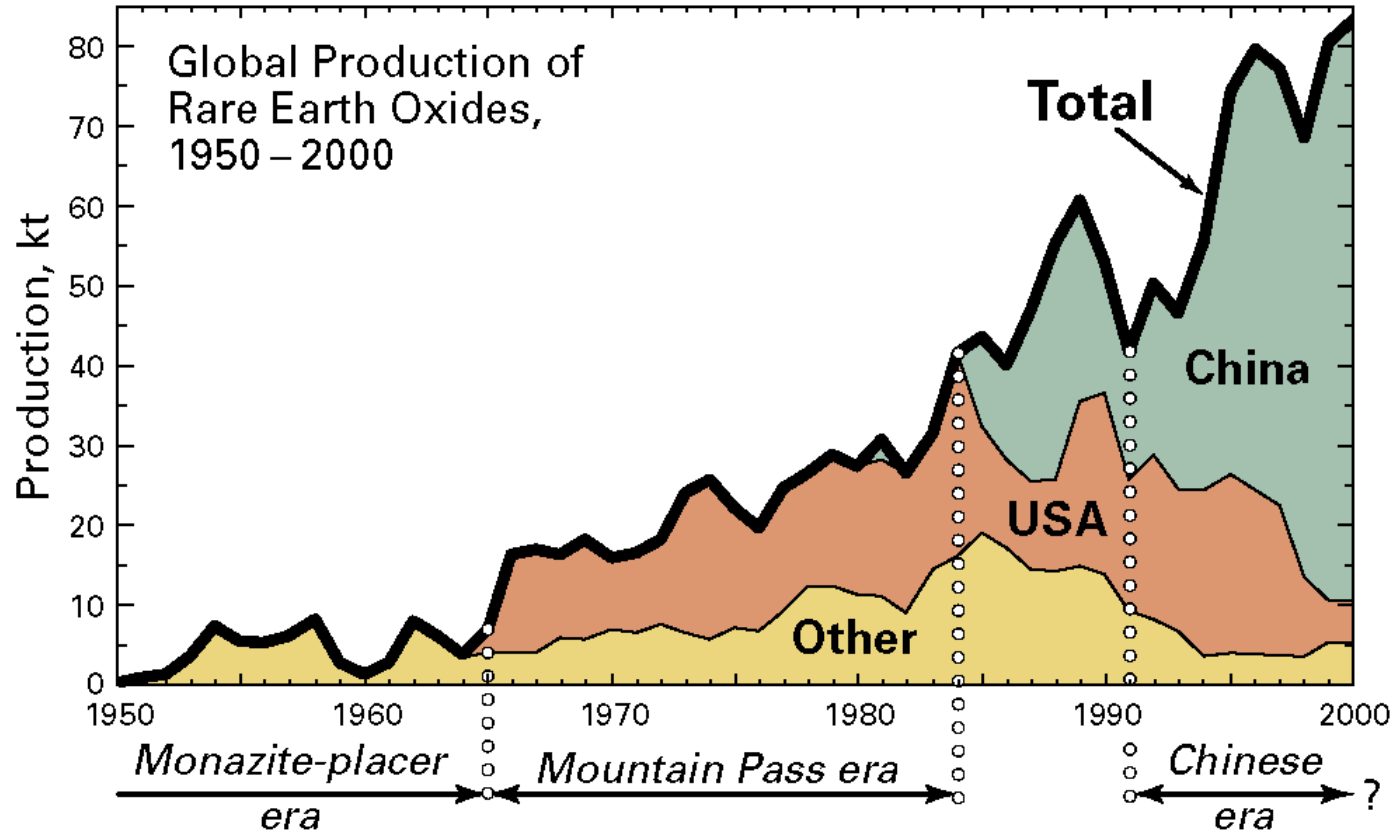
Rare Ingredients

Here is the breakdown of rare-earth materials used to make each.

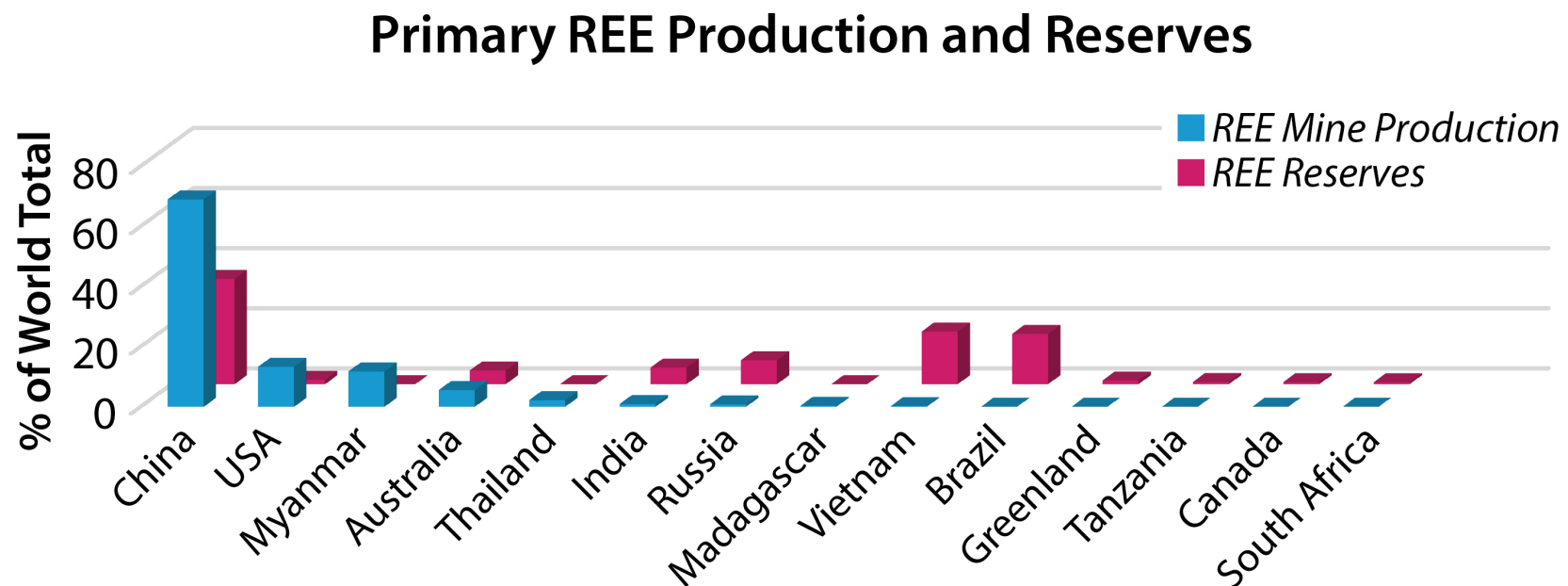


Source: Congressional Research Service

The problem is more complex than “more mines”



Geology isn't fair and neither is commodity production



(data from USGS, 2024)