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

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Paul Slezak

Changing the World's Energy Future

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

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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

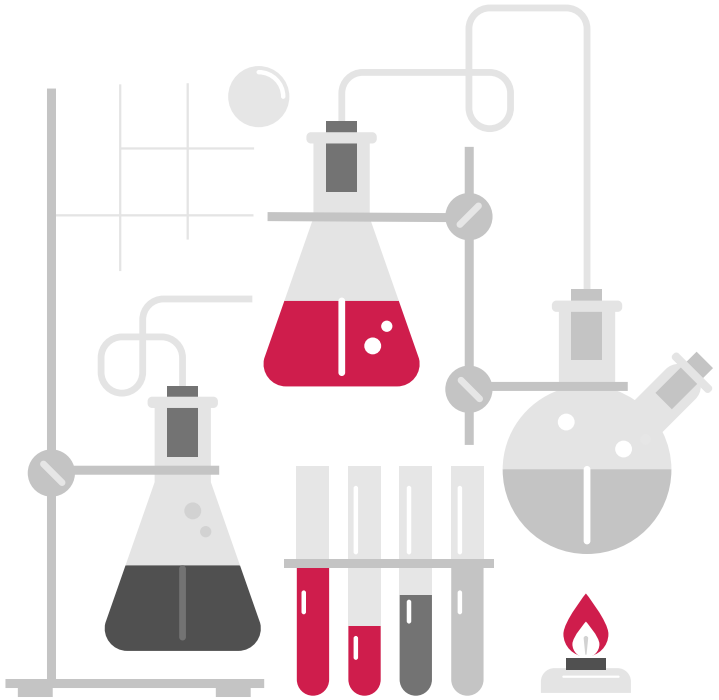
Idaho National Laboratory

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.

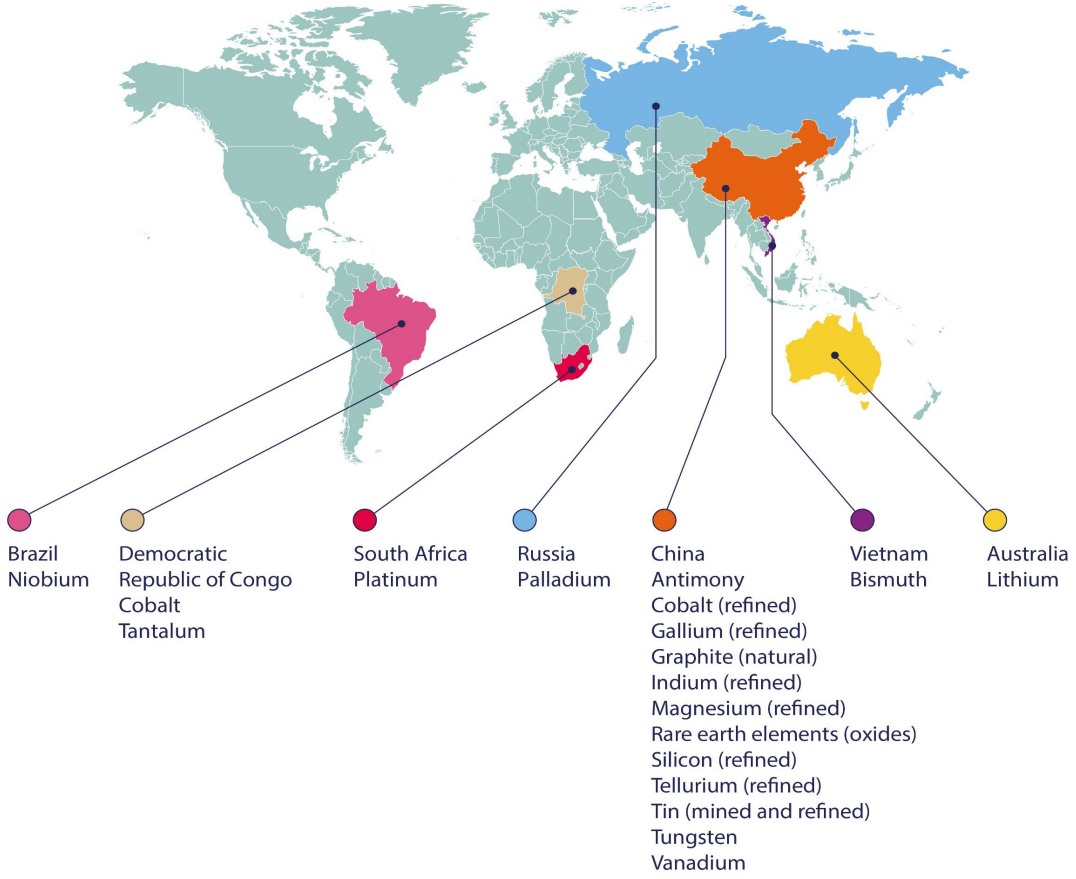


Mining is an economy of scale, not an economy of efficiency

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.

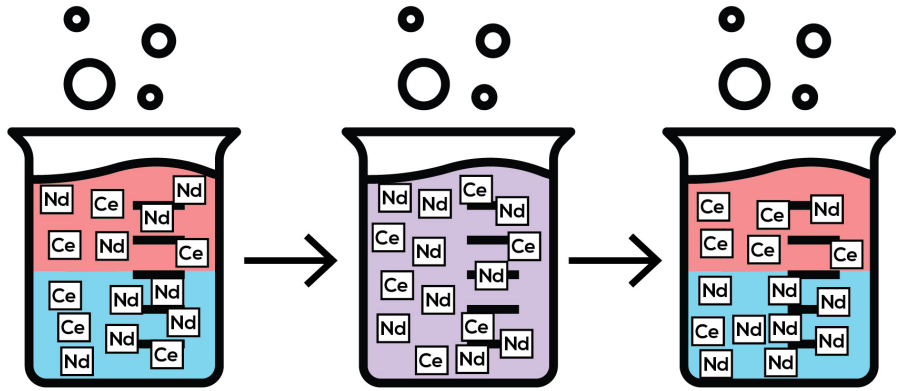


Source: Data from the UK Critical Minerals Intelligence Centre, 2022

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

(Li et al., 2016)

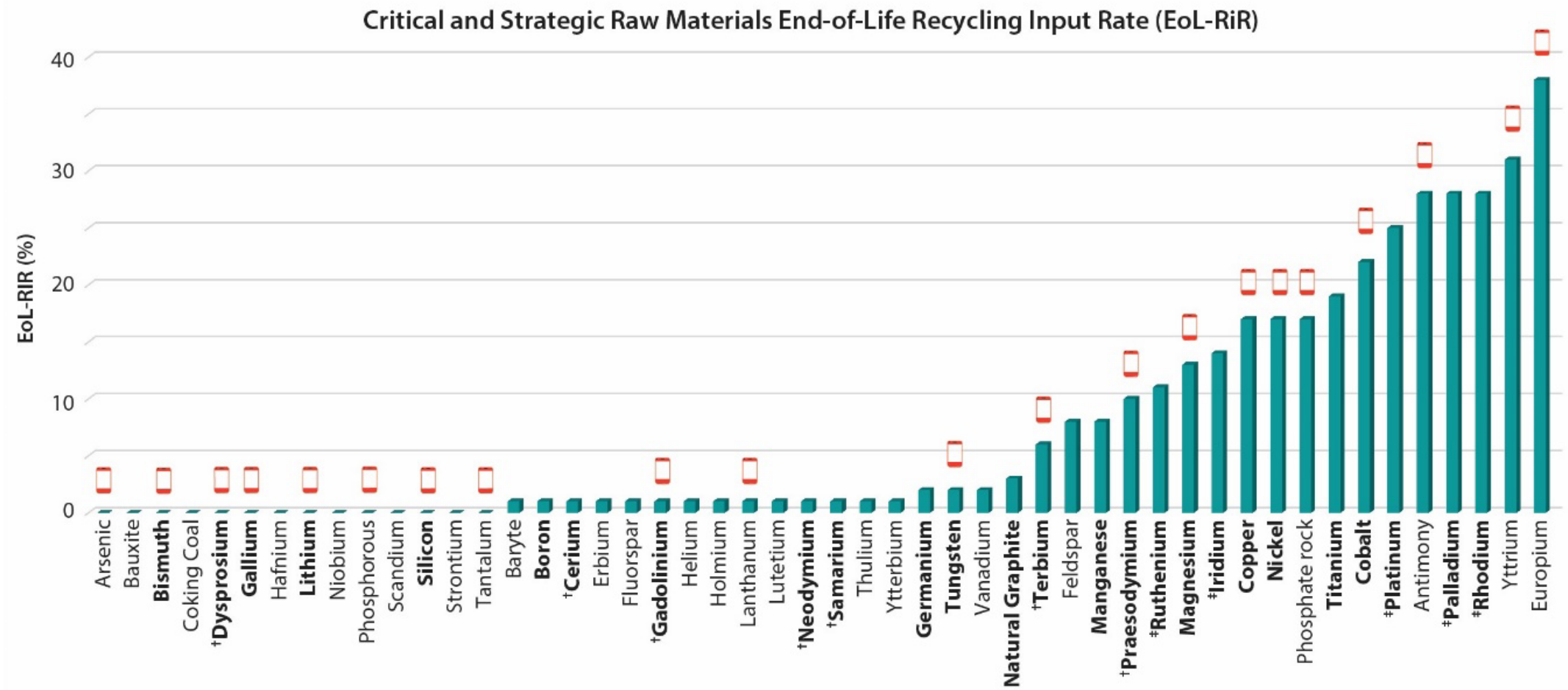
Environmental considerations

- 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

(Li et al., 2016)

Recycling

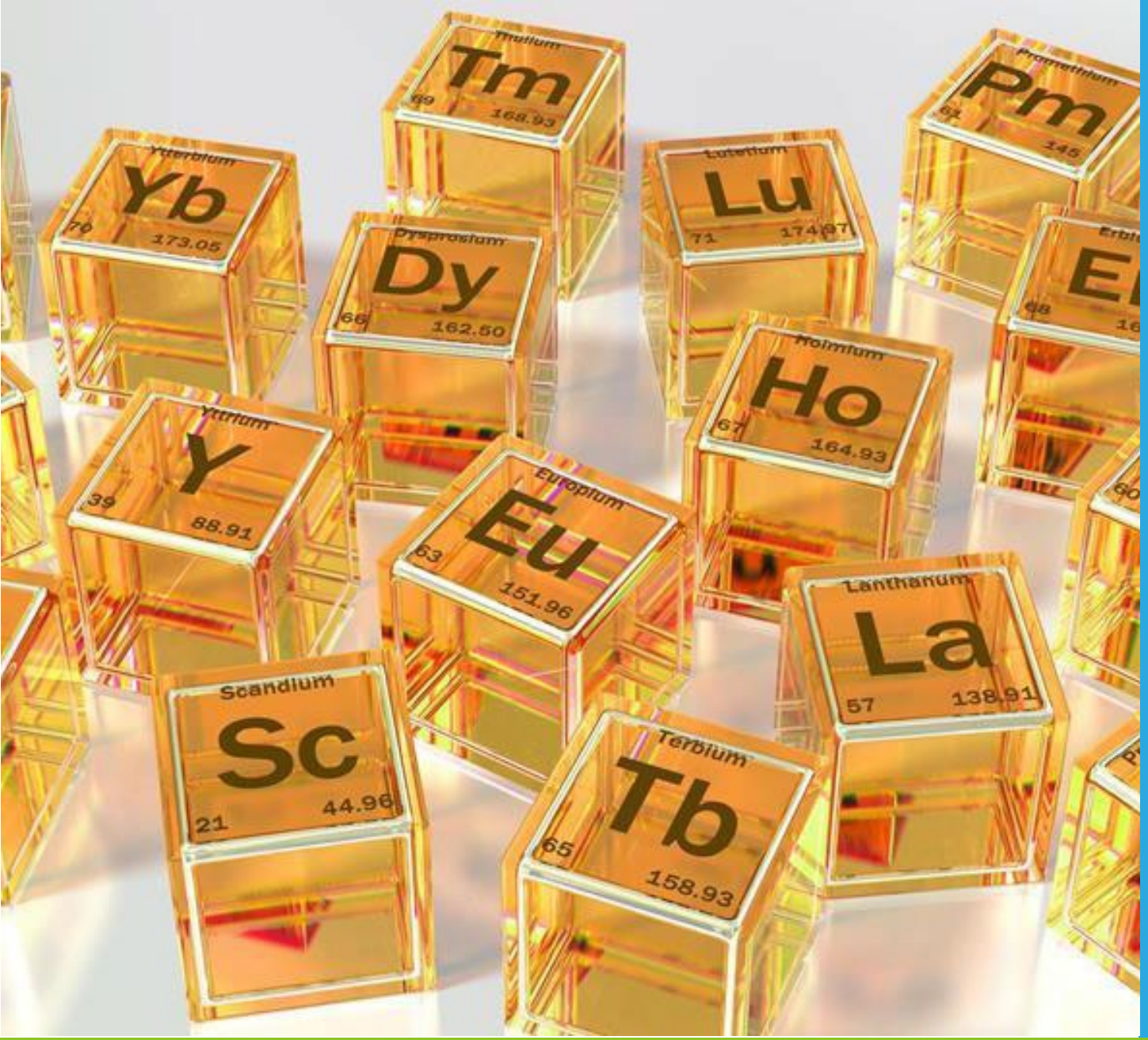


(Vafeas et al., 2024)

Non-functional recycling

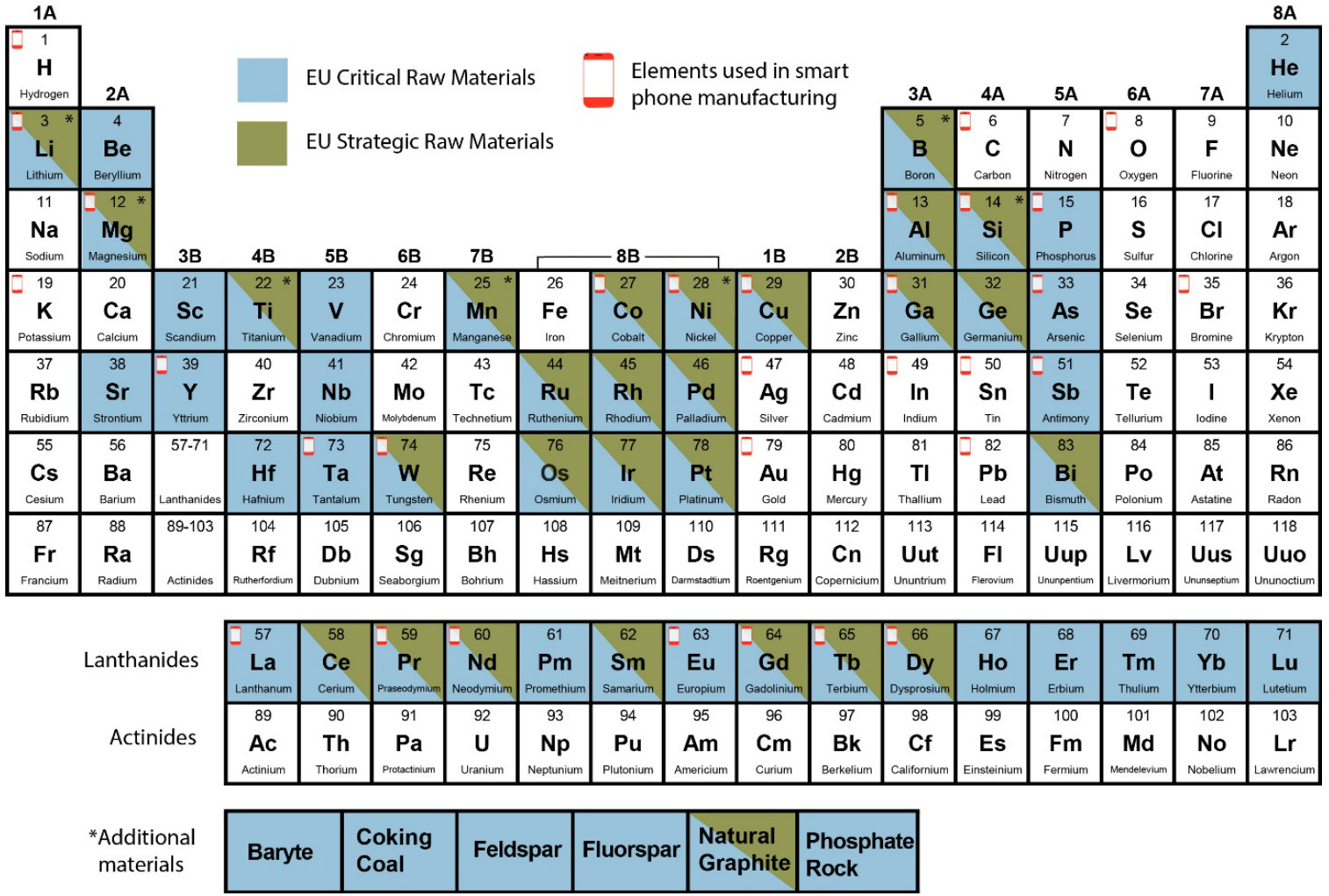
- When a material/metal/mineral is a part of something that is recycled, but is not, in and of itself recovered
  - Antimony (Sb) in lead-acid batteries
  - Boron (B) in borosilicate glass
  - REE in most e-waste (but good progress on permanent magnets)

(BIO Deloitte, 2015)



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

Evolution of CRM list in Europe



- 14 CRMs in 2011
- 20 in 2014
- 27 in 2017
- 30 in 2020
- 33 (really 52) in 2023
  - *22 "SRMs"*

(Vafeas et al., 2024)

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

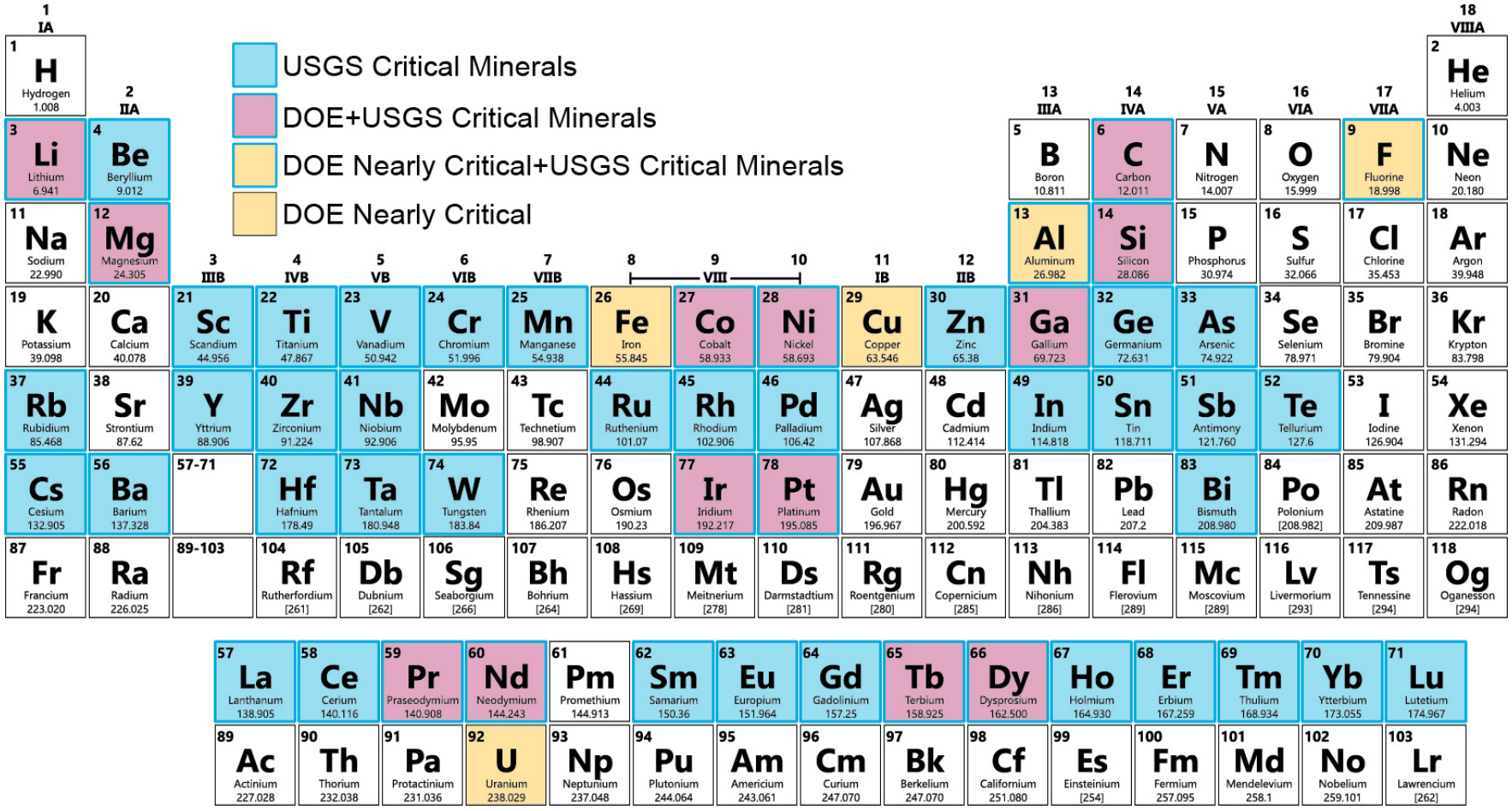
Ch. 7. Delegated powers and committee procedure

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



Department of Energy (DOE) critical minerals & materials strategy

(DOE, 2024a)

DOE goals & objectives

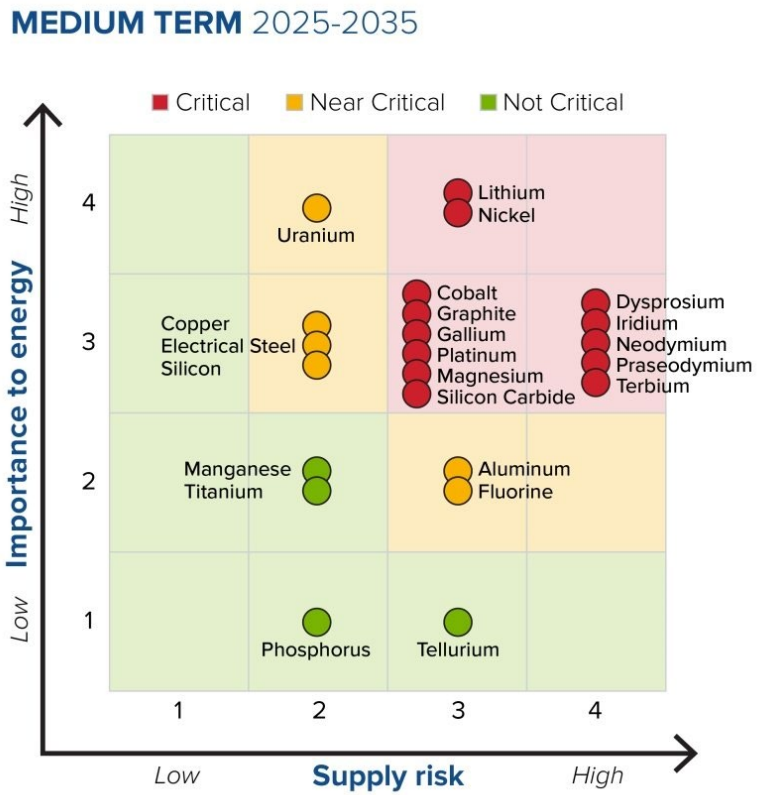
1. **Drive supply chain security**
   - Coordinate existing R&D
   - Develop roadmap for new R&D
   - Identify opportunities with public-private partnerships
   - Collaborate with interagency and international partners

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



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 mininimise 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

CRITICAL MATERIALS COLLABORATIVE

U.S. DEPARTMENT OF ENERGY

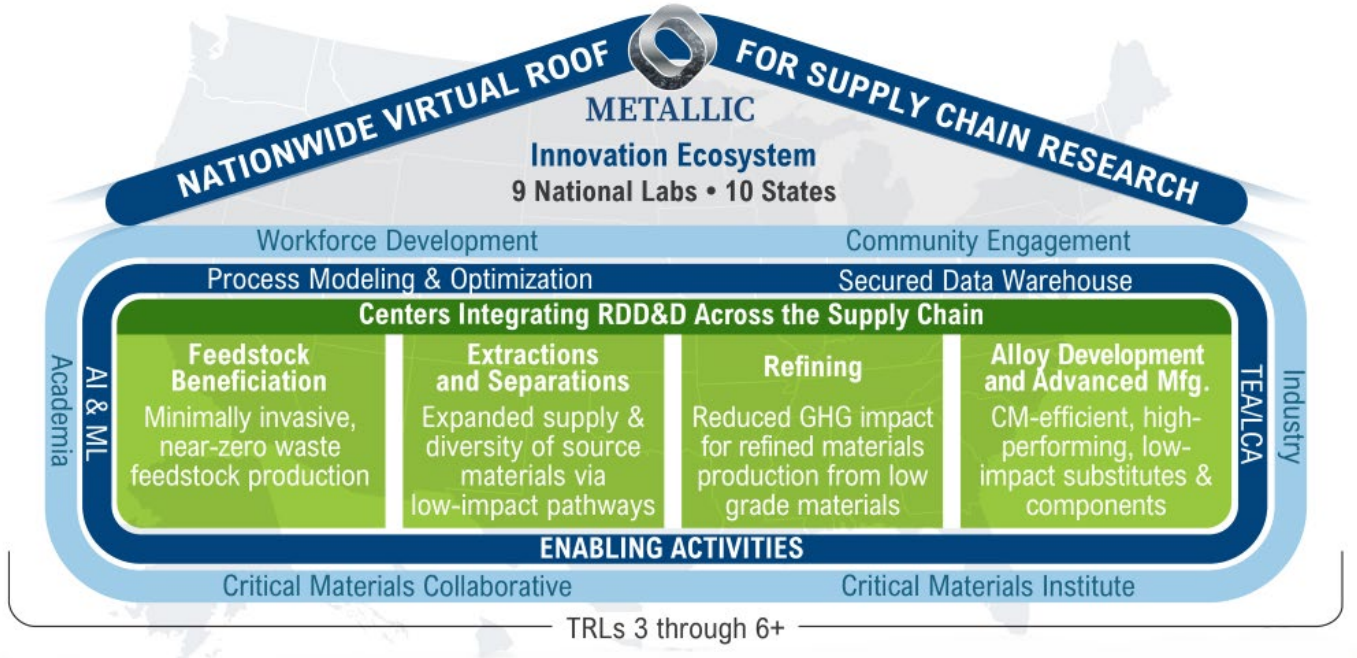
Resulting from these organisations…

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…

Min**E**ral to Ma**T**eri**AL**s Supply Cha**I**n Research Fa**C**ility (METALLIC)

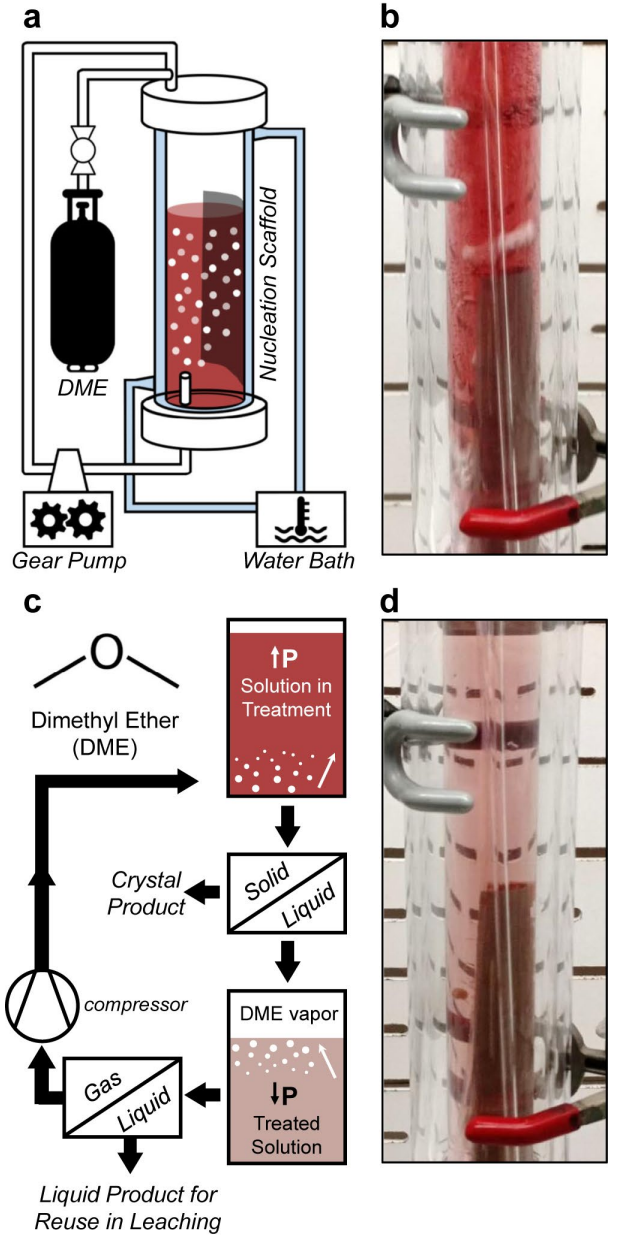


Examples of current work at INL

Electrophoresis unit,
Energy Innovation Laboratory

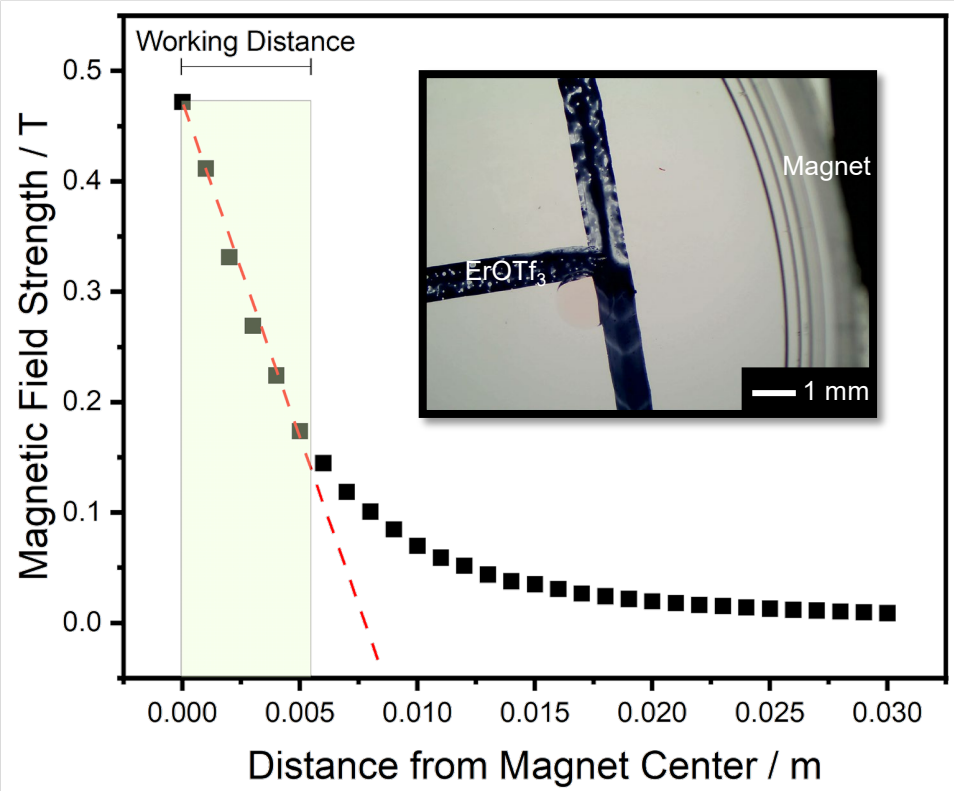
Work so far…

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

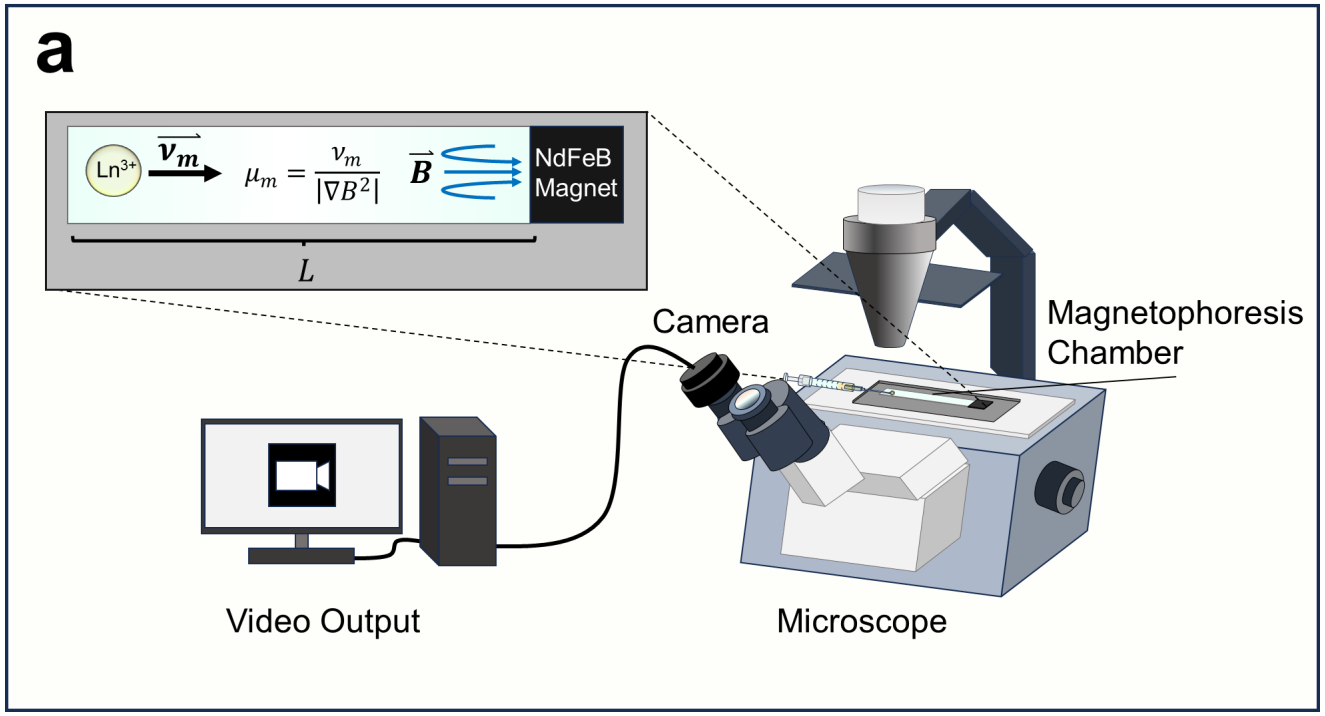


(Stetson et al., 2022)

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

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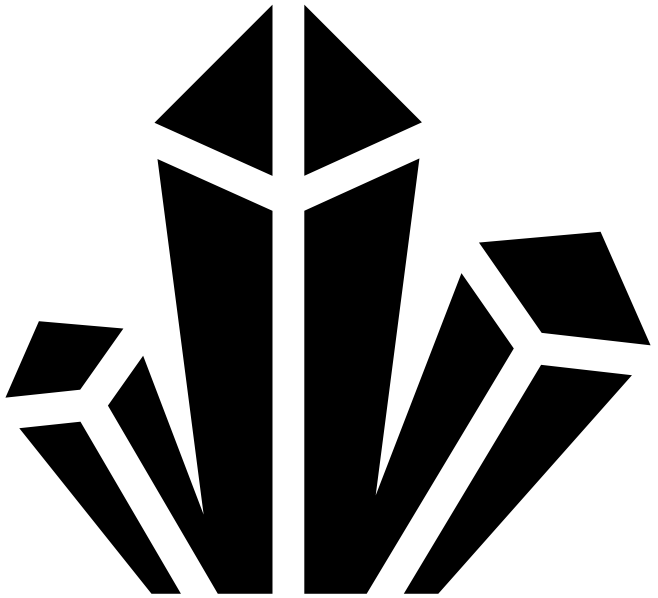

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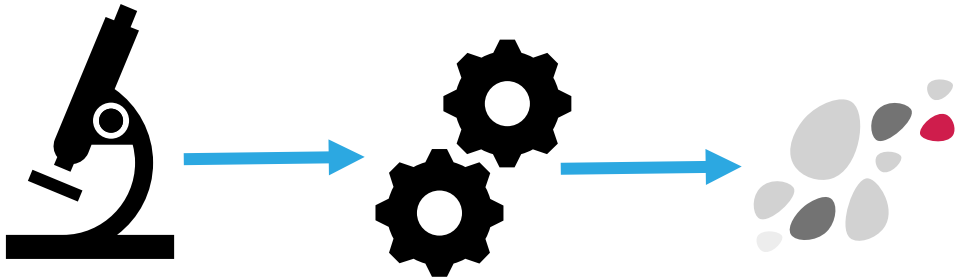

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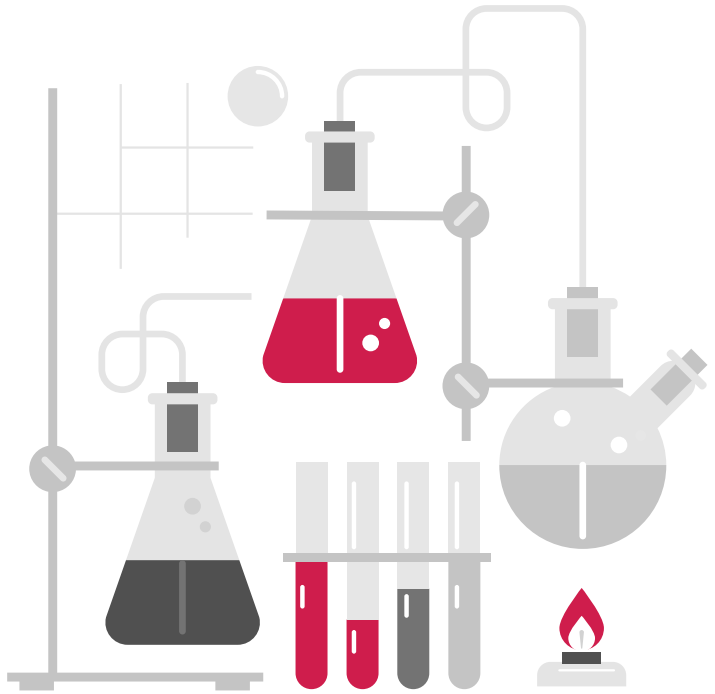

Mining is an economy of scale, not an economy of efficiency

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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The New York Times

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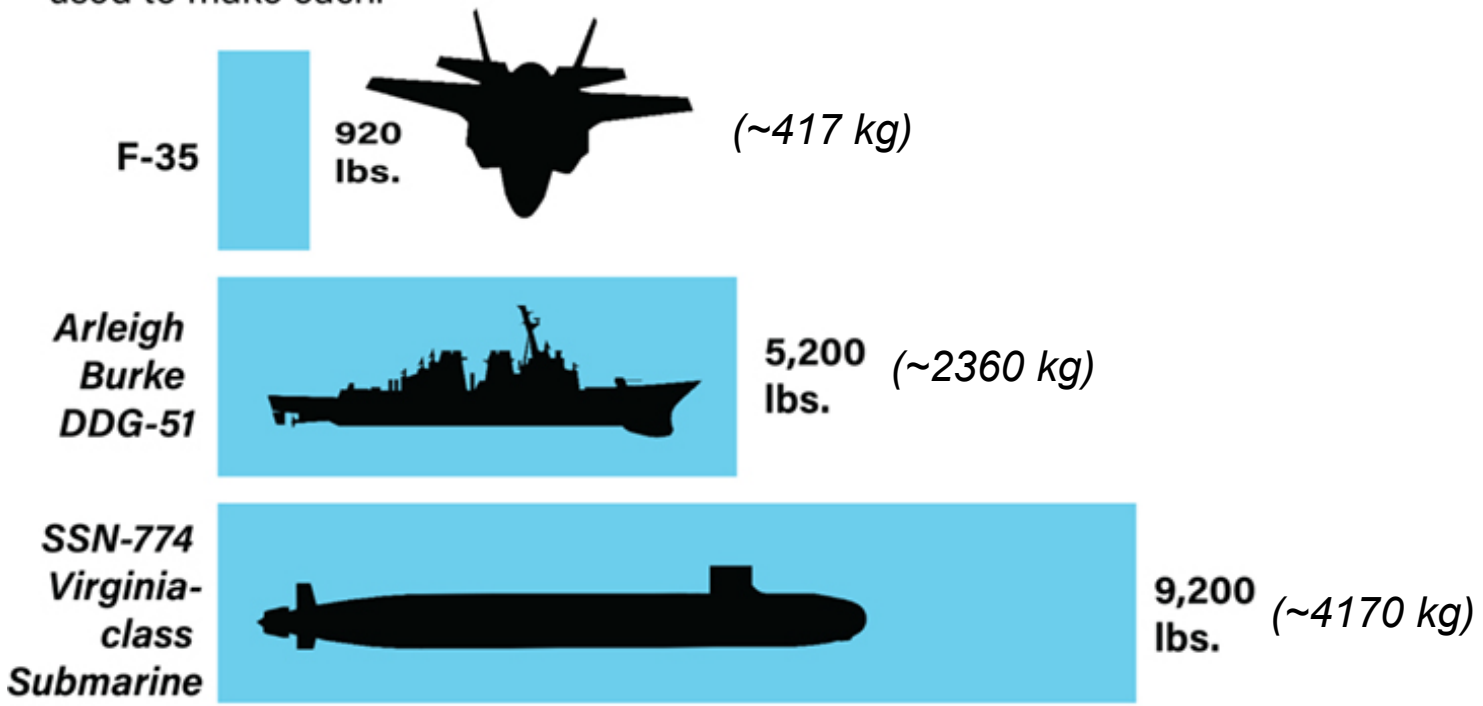
China, which produces almost all the world's supply of critical minerals, has been tightening its grip on the materials. Wu Changqing/VCG, via Getty Images

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.

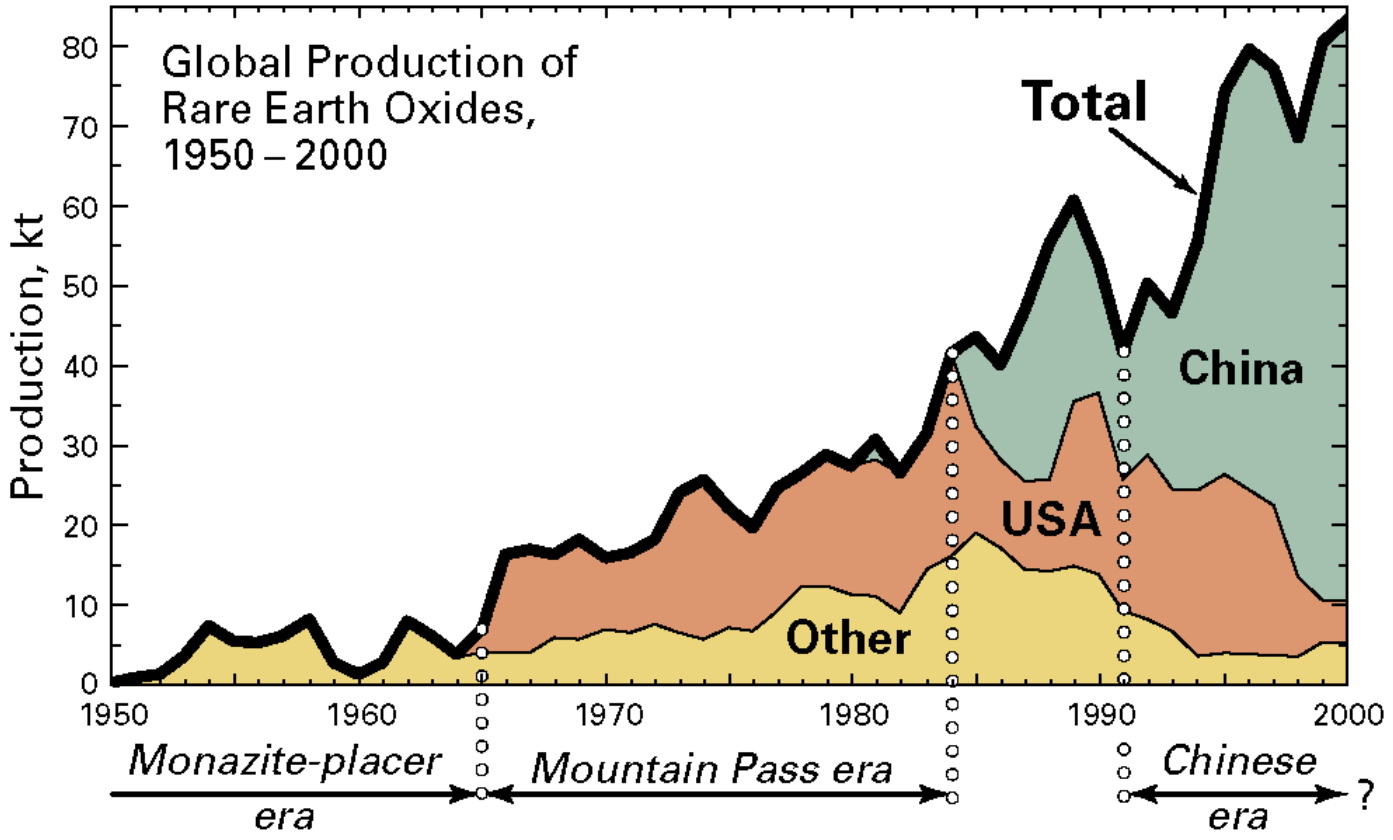
Rare Ingredients

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



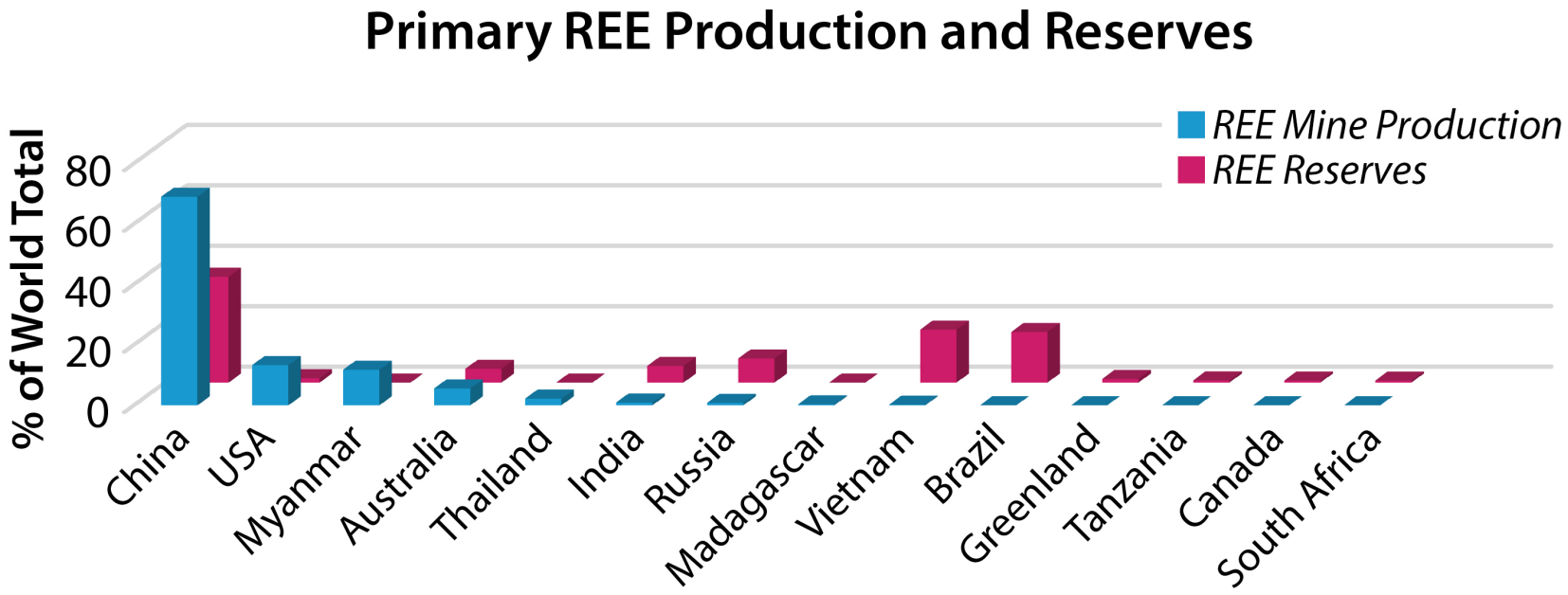
Source: Congressional Research Service

The problem is more complex than “more mines”



(Haxel et al., 2002)

Geology isn’t fair and neither is commodity production



(data from USGS, 2024)