Critical Materials Institute

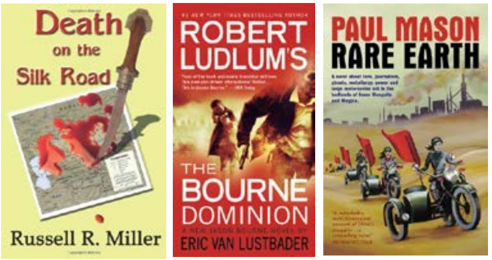
AN ENERGY INNOVATION HUB

Overview of the Hub

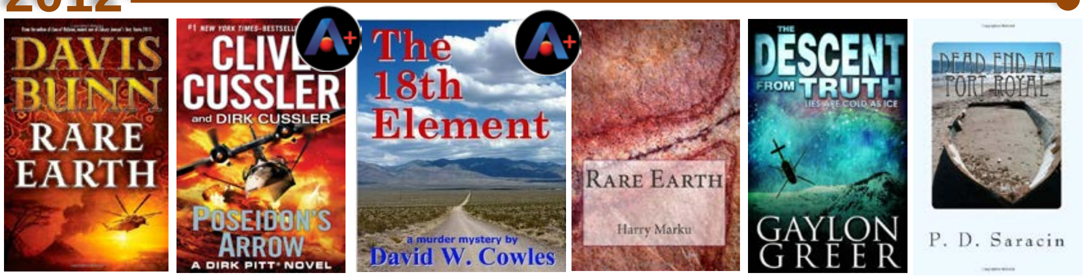
Alex King
CMI Director

How to deal with a materials shortage…

2011



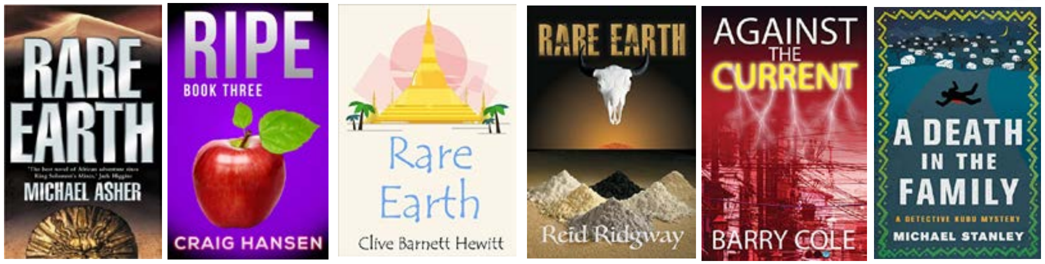
2012



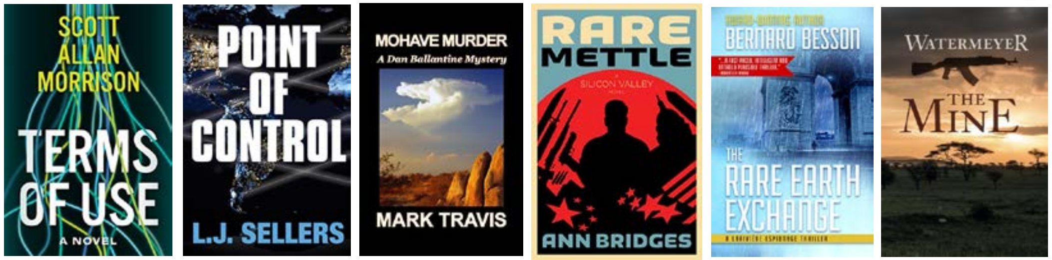
2013

2014

2015



2016



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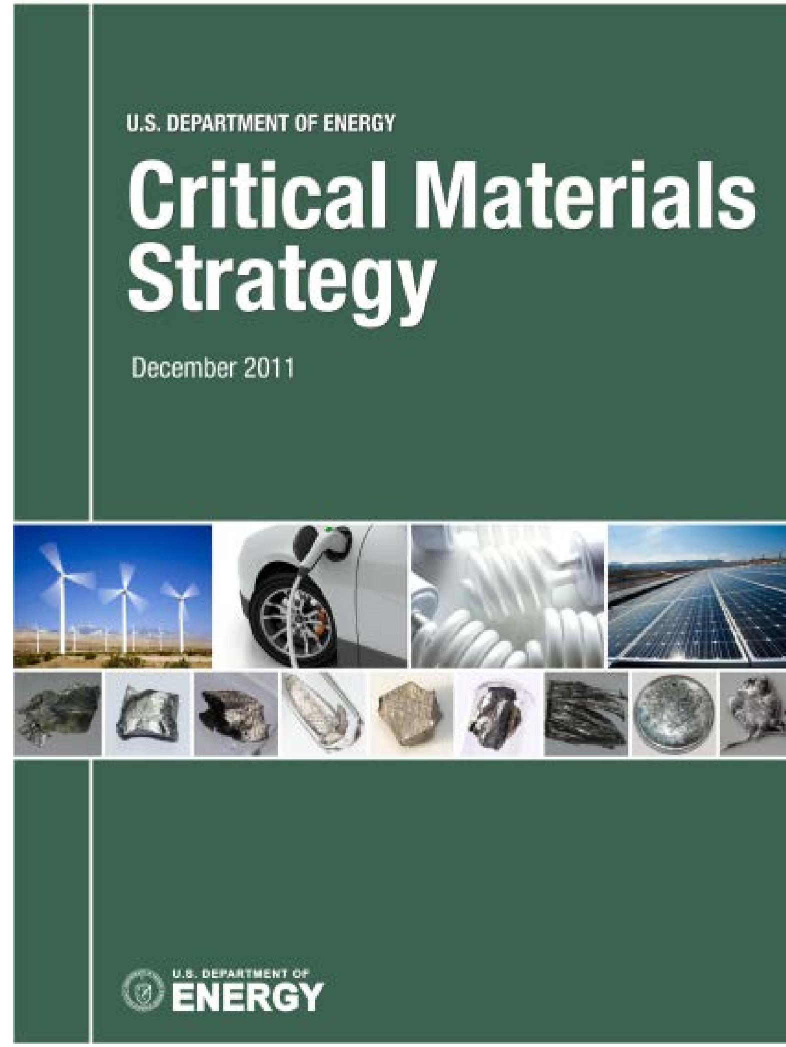
What are we really doing about it?

Finding ways to:

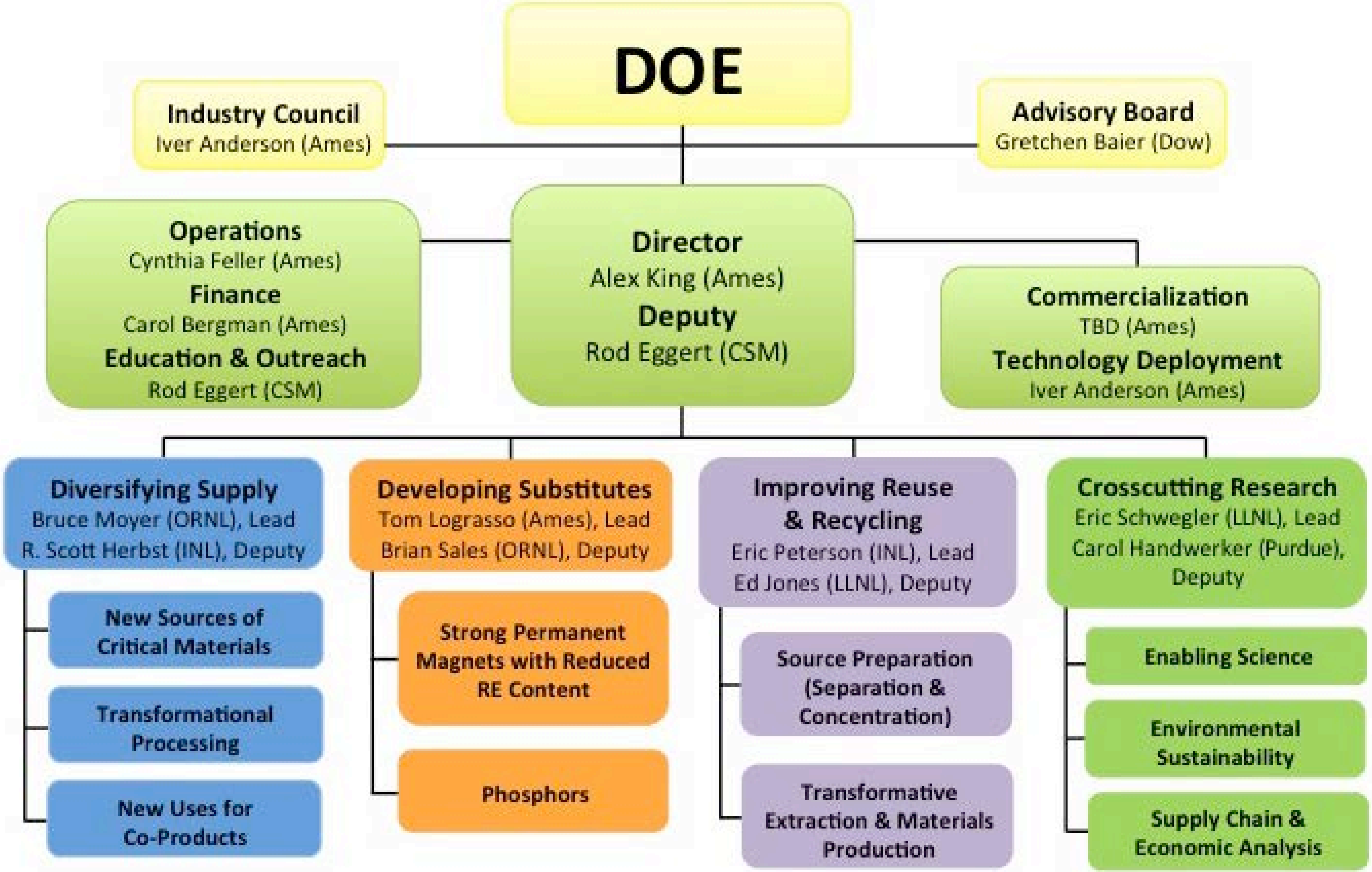
- diversify our sources;
- provide alternatives to the existing materials;
- make better use of the existing supplies through efficient manufacturing, recycling and re-use.

Some of these approaches work better than others for specific materials.

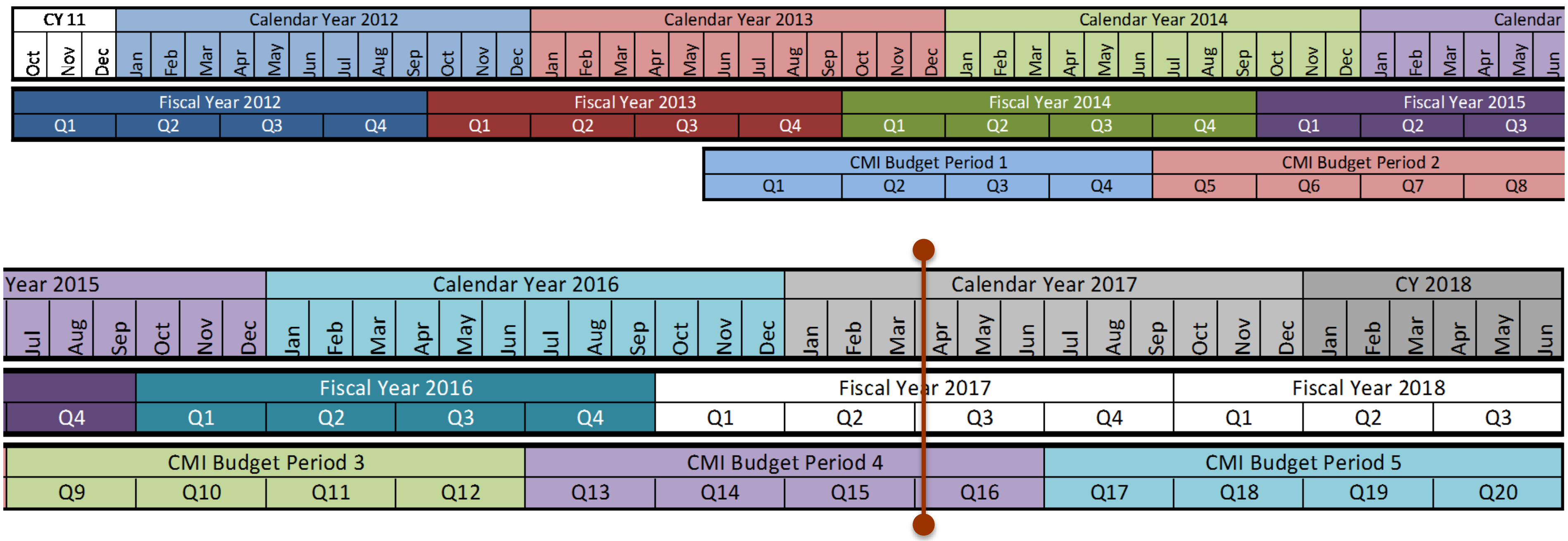


The Critical Materials Institute

- An Energy Innovation Hub
  - Supported by the US DOE, Advanced Manufacturing Office
  - One of only four such Hubs supported by DOE.
- Budget of $120M, over five years
- Led by the Ames Laboratory
  - Four national labs
  - Seven university partners
  - Nine industrial partners – soon to be eleven
  - Approximately 350 researchers
- www.cmi.ameslab.gov


DOE
Industry Council
Iver Anderson (Ames)
Advisory Board
Gretchen Baier (Dow)
Operations
Cynthia Feller (Ames)
Finance
Carol Bergman (Ames)
Education & Outreach
Rod Eggert (CSM)
Director
Alex King (Ames)
Deputy
Rod Eggert (CSM)
Commercialization
TBD (Ames)
Technology Deployment
Iver Anderson (Ames)
Diversifying Supply
Bruce Moyer (ORNL), Lead
R. Scott Herbst (INL), Deputy
New Sources of Critical Materials
Transformational Processing
New Uses for Co-Products
Developing Substitutes
Tom Lograsso (Ames), Lead
Brian Sales (ORNL), Deputy
Strong Permanent Magnets with Reduced RE Content
Phosphors
Improving Reuse & Recycling
Eric Peterson (INL), Lead
Ed Jones (LLNL), Deputy
Source Preparation (Separation & Concentration)
Transformative Extraction & Materials Production
Crosscutting Research
Eric Schwegler (LLNL), Lead
Carol Handwerker (Purdue), Deputy
Enabling Science
Environmental Sustainability
Supply Chain & Economic Analysis

Timeline



First funding cycle ends: **June 30, 2018**

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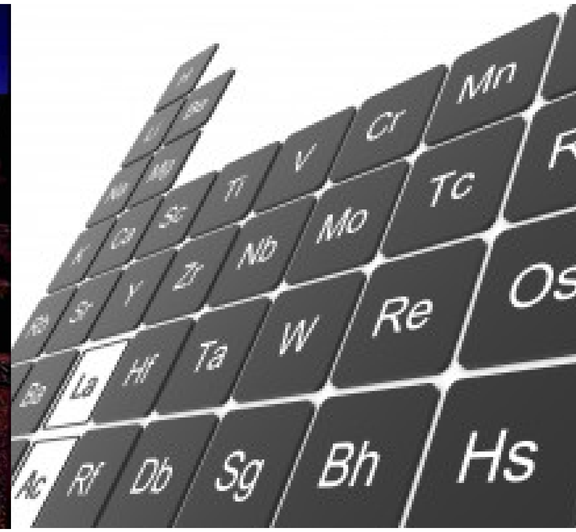
Original Five-Year Goals

Within its first five years, CMI will develop at least one technology, adopted by U.S. companies, in each of three areas:



Diversifying & expanding production

Developing substitutes

Reducing wastes

Materials Genome Initiative

HOME · BLOG

The Materials Genome Initiative: The First Five Years

AUGUST 2, 2016 AT 3:00 PM ET BY THOMAS KALIL, LLOYD WHITMAN

The DOE *Critical Materials Institute* (CMI) relies on the integrated MGI approach to accelerate the discovery and development of rare-earth replacements, such as new phosphors for high-efficiency lighting. The CMI, one of DOE's Energy Innovation Hubs, is a collaboration of researchers from universities, four DOE national laboratories, and members of industry working together to assure the supply chains for materials critical to clean energy technologies. Read more and more.

Today, the White House hosted an event recognizing the fifth anniversary of the Materials Genome Initiative (MGI). On June 24, 2011, President Obama announced "To help businesses discover, develop, and deploy new materials twice as fast, we're launching what we call the Materials Genome Initiative." Over the past five years, Federal agencies, including the Departments of Energy (DOE) and Defense (DoD), the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST), and the National Aeronautics and Space Administration (NASA), have invested more than $500 million in resources and infrastructure in support of this initiative.

In the increasingly competitive world economy, the United States must find ways to get advanced materials into innovative products such as light-weight cars, more efficient solar cells, tougher body armor, and future spacecraft much faster and at a fraction of the cost than it has taken in the

What GAO Found

Selected Strengths and Limitations of Federal Critical Materials Activities

Strengths	Limitations
• Department of Energy's Critical Materials Institute	

Source: GAO analysis of expert survey and information collected from agency officials. | GAO-16-699

for Critical Materials

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GAO-16-699

DRAFT

...concentration of the supply of some critical materials under foreign control has renewed questions about the U.S. government's and industry's ability to address potential supply disruptions.

GAO was asked to examine U.S. efforts to identify and strategically plan for critical material supply issues. Among other objectives, this report (1) describes federal agencies' activities related to the supply of critical materials and (2) evaluates the federal government's approach to addressing critical materials supply issues. GAO reviewed relevant laws, agency documents, industry reports, and academic studies; interviewed federal agency officials; and conducted a two-stage web-based survey of a nongeneralizable sample of critical materials experts selected to cover a range of subject matter areas.

What GAO Recommends

GAO is making six recommendations, including that OSTP take steps to improve interagency collaboration through the Subcommittee by, for example, agreeing on roles and responsibilities and that Commerce engage with industry stakeholders to continually identify and assess critical material needs across a broad range of industrial sectors.

View GAO-16-699. For more information, contact John Neumann at (202) 512-3841 or neumannj@gao.gov.

...diversifying supply, providing alternatives to existing materials, and improving recycling and reuse. In addition, agencies conduct a range of other critical materials related activities, including stockpiling or producing materials, and reviewing and approving resource extraction projects, among other efforts.

The federal approach to addressing critical materials supply has areas of strength, but is not consistent with selected key practices for interagency collaboration, and faces other limitations as shown below.

Selected Strengths and Limitations of Federal Critical Materials Activities

Strengths	Limitations
• Existence of an interagency subcommittee to support interagency collaboration	• Interagency collaboration is not consistent with selected key practices
• U.S. Geological Survey information on mineral resources	• Federal focus on only a subset of materials for assessing critical materials supply issues
• Department of Energy's Critical Materials Institute	• Limited focus on developing domestic resources
	• Limited federal government engagement with industry stakeholders

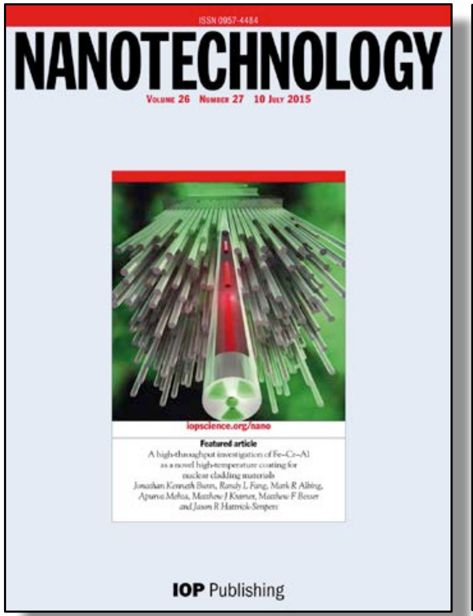
Source: GAO analysis of expert survey and information collected from agency officials. | GAO-16-699

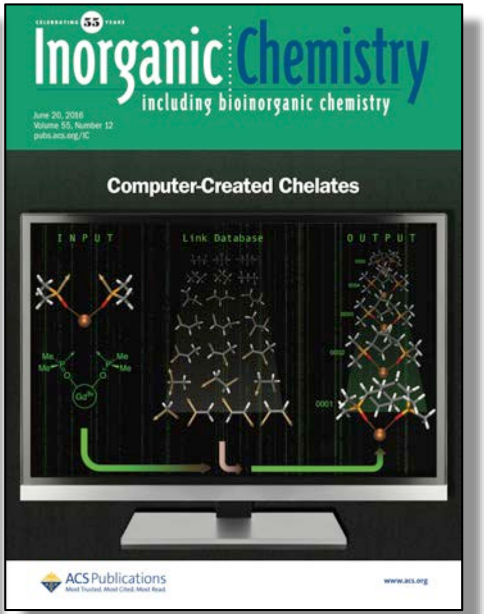
- According to its charter, the Subcommittee on Critical and Strategic Mineral Supply Chains—co-chaired by the Office of Science and Technology Policy (OSTP), DOE, and the Department of the Interior—is to facilitate a strong, coordinated effort across its member agencies on critical materials activities. However, the Subcommittee's efforts have not been consistent with selected key practices for interagency collaboration, including agreeing on roles and responsibilities; establishing mutually reinforcing or joint strategies; and developing mechanisms to monitor, evaluate, and report on results. For example, some member agencies do not have a clear role in the Subcommittee's efforts and have had limited or no involvement in its work. By taking steps to actively engage all member agencies in its efforts and clearly define roles and responsibilities, the Subcommittee would have more reasonable assurance that it can effectively marshal the potential contributions of all member agencies to help identify and mitigate critical materials supply risks.
- Other limitations to the federal approach to addressing critical materials supply include limited engagement with industry and a limited focus on domestic production. For example, the Department of Commerce is required by law to identify and assess cases of materials needs. However, Commerce does not solicit information from stakeholders across a range of industrial sectors. As a result, Commerce may not have comprehensive, current information across a range of industrial sectors to help it identify and assess materials needs.

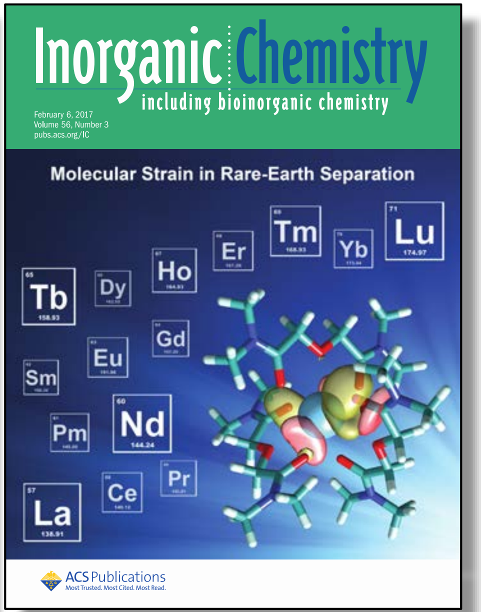
United States Government Accountability Office

DRAFT

Front page news







Invention Disclosures

1. Extraction of rare earth elements from phosphoric acid streams
2. Recovery of neodymium from neodymium iron boride magnets
3. Membrane solvent extraction for rare earth separations ✪ ✪
4. Selective composite membranes for lithium extraction from geothermal brines ✪
5. Methods of separating lithium-chloride from geothermal brine solutions ✪
6. Extraction of rare earths from fly ash
7. Recovery of Dy-enriched Fe alloy from magnet scrap alloy via selective separation of rare earth elements ✪
8. Aluminum nitride phosphors for fluorescent lighting ✪
9. Novel surface coatings to improve the functional properties of permanent magnets
10. Additive manufacturing bonded permanent magnets using novel polymer matrix ✪

INNOVATION

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✪ *Patent application submitted*
✪ *Patent awarded* ✪ *License awarded*

Invention Disclosures

11. Ceria-based catalyst for selective phenol hydrogenation under mild reaction conditions
12. Recycling and conversion of samarium cobalt magnet waste into useful magnet
13. Catalysts for styrene production
14. Task specific ionic liquids extractive metallurgy or rare earth minerals ✪
15. Separation of neodymium from praseodymium
16. High throughput cost effective rare earth magnets recycling system ✪
17. Recycle of Fe Nd B Machine Swarf and Magnets ✪
18. Directly Printing Rare Earth Bonded Magnets
19. Procedure for Concentrating Rare-earth Elements in Neodymium Iron Boron-based Permanent Magnets for Efficient Recycling/Recovery
20. Enhancing Consumer Product Recycling via Rapid Fastener Eradication

✪ *Patent application submitted*
✪ *Patent awarded* ✪ *License awarded*

Invention Disclosures

21. Automated Printed Circuit Board Disassembly by Rapid Heating ✪
22. Electrochemistry Enabled Recovery of Value Metals from Electronics ✪
23. Synthesis of High Surface Area Mesoporous Ceria
24. Self-Assembly of Low Surface Colloidal Nanoparticles into High Surface Area Networks
25. Selective Chemical Separation of Rare-Earth Oxalates (CSEREOX)
26. Carbothermic Preparation of $SmCo_x$ (x=5 to 8.5) Permanent Magnets Directly from Sm_2O_3
27. A One Step Process for the Removal of Nickel/Nickel Copper Surface Coating from the $Nd_2Fe_{14}B$ (neo) Permanent Magnets ✪
28. Engineering Caulobacter Surface Protein for Rare Earth Element Absorption ✪
29. Chemical Separation of Terbium Oxide (SEPTER) ✪
30. Novel Methods towards Selective Surface Modification of $Nd_2Fe_{14}B$ Magnets to Achieve High Performance Permanent Magnets ✪

✪ *Patent application submitted*
✪ *Patent awarded* ✪ *License awarded*

Invention Disclosures

31. Mesoporous Carbon and Methods of Use
32. Castable High-Temperature Ce-Modified Al Alloys ✪
33. High Command Fidelity Electromagnetically Driven Calorimeter (High-CoFi EleDriCal) ✪
34. 3D Printable Liquid Crystalline Elastomers with Tunable Shape Memory Behaviors and Bio-derived Renditions
35. The Separation of Ancylite by Way of Magnetic Separation and Froth Flotation ✪
36. Recovering Rare Earth Metals using Bismuth Extractant ✪
37. Structural Optimization of Complex Materials using High-throughput Hierarchical Decomposition Methods
38. Novel 3D Printing Method to Fabricate Bonded Magnets of Complex Shape ✪
39. Rare Earth Free High Performance Doped Magnet
40. Acid-free Dissolution and Separation of Rare-earth Metal ✪

✪ *Patent application submitted*
✪ *Patent awarded* ✪ *License awarded*

Invention Disclosures

41. Materials for Structural Direct Write Additive Manufacturing of Molten Metals
42. A Process for the Recovery of Mercury and Rare Earth Elements from Used Fluorescent Lamps ✪
43. High performance magnets with abundant rare earth elements
44. Multi-functional Liquid Crystalline Networks : 3D Printable liquid crystalline elastomers with tunable shape memory behavior and bio-derived renditions ✪
45. Aluminum-RE alloys for electrical power transmission applications
46. Method for Manufacturing of Samarium Cobalt and Neodymium Iron Boride Magnets
47. Additive printing of bonded magnets using magnet powders and a polymer composition
48. Eutectic Alloy Compositions to Improve the Coercivity and Density of Binder Jet Printed Bonded Magnets
49. Separation of Rare Earth Elements Recovered from Scrap Permanent Magnets
50. Surface-Hardened Al-Ce Alloys and Methods of Making the Same ✪

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✪ *Patent application submitted*
✪ *Patent awarded* ✪ *License awarded*

Invention Disclosures

51. Big Area Additive Manufacturing of High Performance Bonded Magnets
52. Production of Indium Concentrate from Waste LCD Screens ✪
53. Al-Ce Alloy for Additive Manufacturing ✪
54. Phosphor for LED Applications
55. Stabilization of Magnetic Soft Phase in a Hard Magnetic Matrix
56. $SmCo_5$-based compounds doped with Fe and Ni for high-performance permanent magnets ✪
57. Die-Cast Aluminum-Cerium Alloy
58. Developing Bulk Exchange Spring Magnets ✪
59. Method for Manufacturing of Samarium Cobalt and Neodymium Iron Boride Magnets

✪Patent application submitted

✪Patent awarded *✪License awarded*

Materials and Technologies: *Lessons learned*

- It is often easier to replace a technology than provide a material.
  - Wind is the fastest-growing energy source in the U.S., but land-based wind turbines use DFIG technologies instead of direct-drive generators, to avoid the need for rare earth magnets.
  - Lighting moved rapidly to LEDs, and away from fluorescent lamps in 2013, partly as a result of the cost of rare earth phosphors.
  - Tesla PEVs use induction motors rather than rare earth permanent magnet motors, largely because of concerns about Nd and Dy supplies.
- Demand destruction follows price spikes.

Source Diversification: *Lessons learned*

- Financing (investment) is the rate-limiting step for starting a new mine.
- Reducing capex reduces the investment need.
  - Process improvements can have a big impact. For the rare earths, separations technologies are an important target.
  - Process technology improvement accelerates after a price spike.
  - Every new mine that comes on line operates with obsolete technology.
- Reducing opex accelerates return on investment.
  - This attracts investors and accelerates financing.
- Early revenue streams are essential.
  - Find ways to sell *all* of the mine's products.

Materials Substitution: *Lessons learned*

- New materials *can* be developed at an accelerated pace.
  - CMI is close to commercializing a green phosphor and a red phosphor after only three years work.
- New materials are more readily accepted if they are process-compatible with the materials they replace.
  - Close collaboration with the user is essential.
- A new material may not replace an old one in all of its applications.
- New materials that are not as good as the old ones can still have value.
  - *e.g.* “gap” magnets.

Recycling & Re-Use: *Lessons learned*

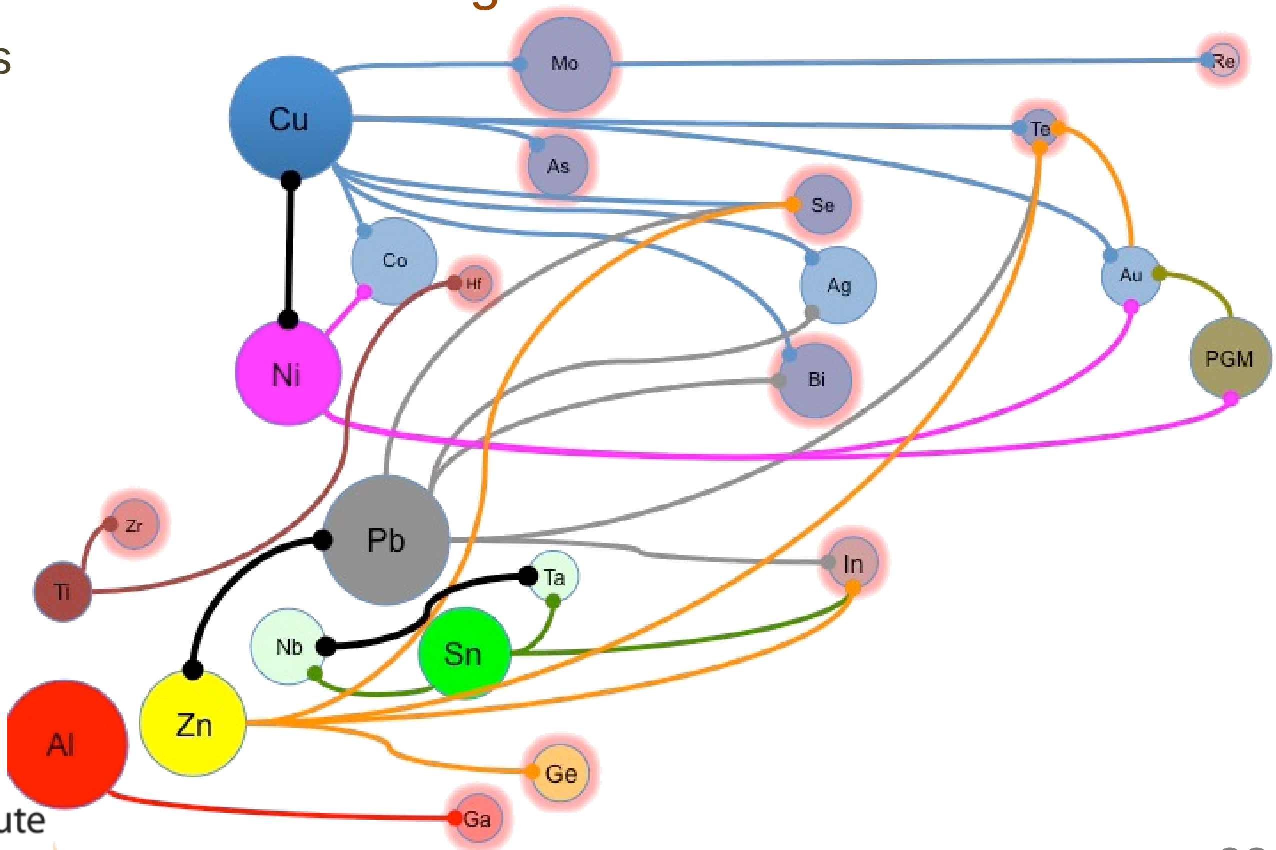
- You don't recycle a material, you recycle a device.
  - This is a pathological case of materials co-production.
- Front end costs can easily exceed the value that can be recovered.
  - Focus efforts on collection and disassembly.
  - Design for disassembly is a hard, hard sell.
- Critical mass is important.
  - Economies of scale are essential to solving front end costs, and making sales.
- End use of the recycled material is paramount.
  - There have to be willing customers for the recycled materials,
  - Production levels have to be sufficient to justify qualifying the recycled materials.

New Goals

- Demonstrate the production of Nd-Fe-B magnets using materials and technologies located entirely within the United States.
- Develop a commercial product based on the Al-Ce-X casting alloy.
- Develop a new permanent magnet material that rivals Nd-Fe-B, using reliably available elements.
- Develop a working, inexpensive bulk exchange coupled spring magnet.
- Develop a new motor design with optimized system performance.
- Discover new red and green LED phosphor candidates suitable for use in LED lamps.
- Demonstrate hard disc drive disassembly rates exceeding 5,000 per day, to enable the recovery of voice-coil motor magnets for recycling or re-use.
- Scale up the supercritical fluid process for dissolution, separation of dissolved components, and refinement of separated critical elements, from milligram to kilogram quantities.

Emerging Issues:
1. *Co-production*

- Materials are increasingly obtained as by-products of other materials.
  - This enables the production of materials that cannot justify dedicated mines.
- Co-production creates risks and challenges
  - Separation technologies
  - Production balance
  - Supply inelasticity.
  - Profit optimization.
  - Process risk mitigation.



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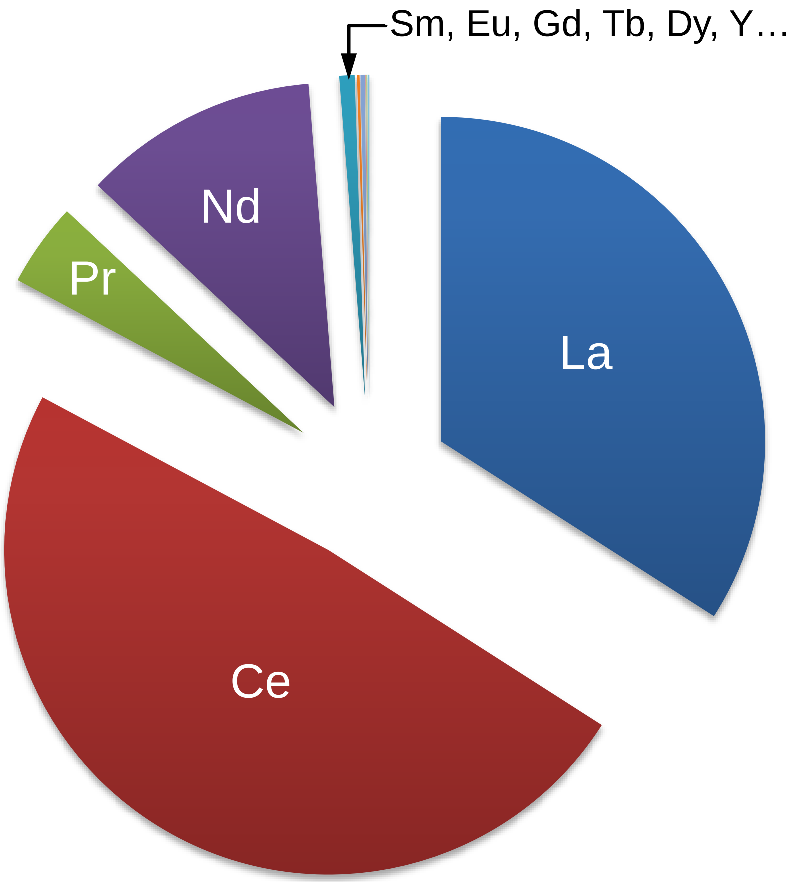
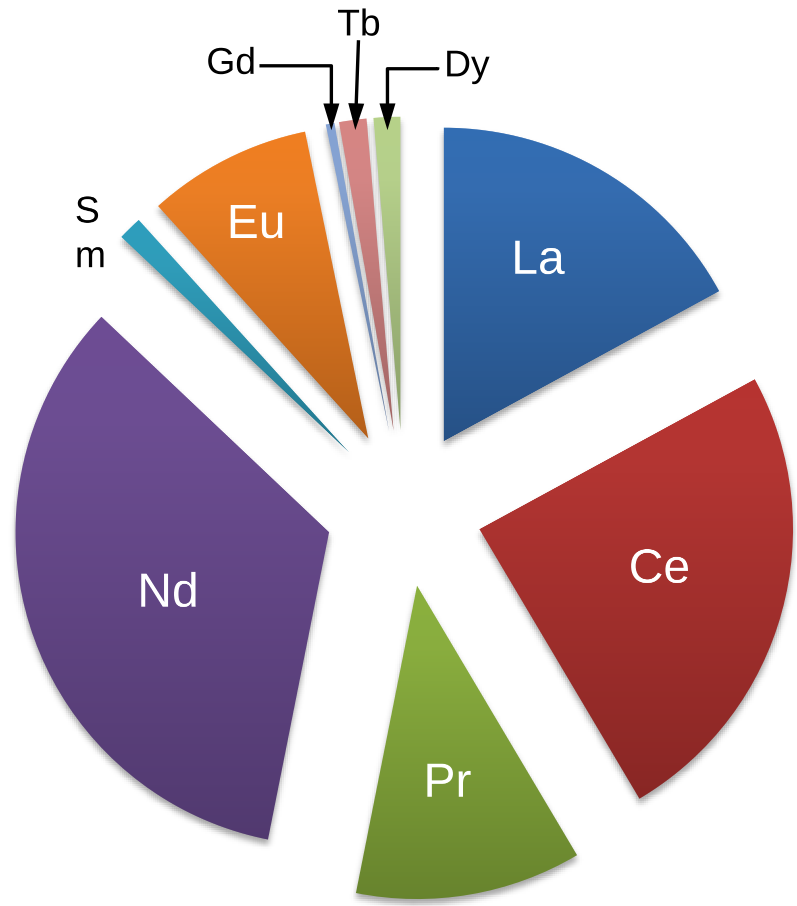
Mixed Source Challenges: *Bastnaesite Mines*



Typical Production by Mass



Production by Value (but not all value is realizable)

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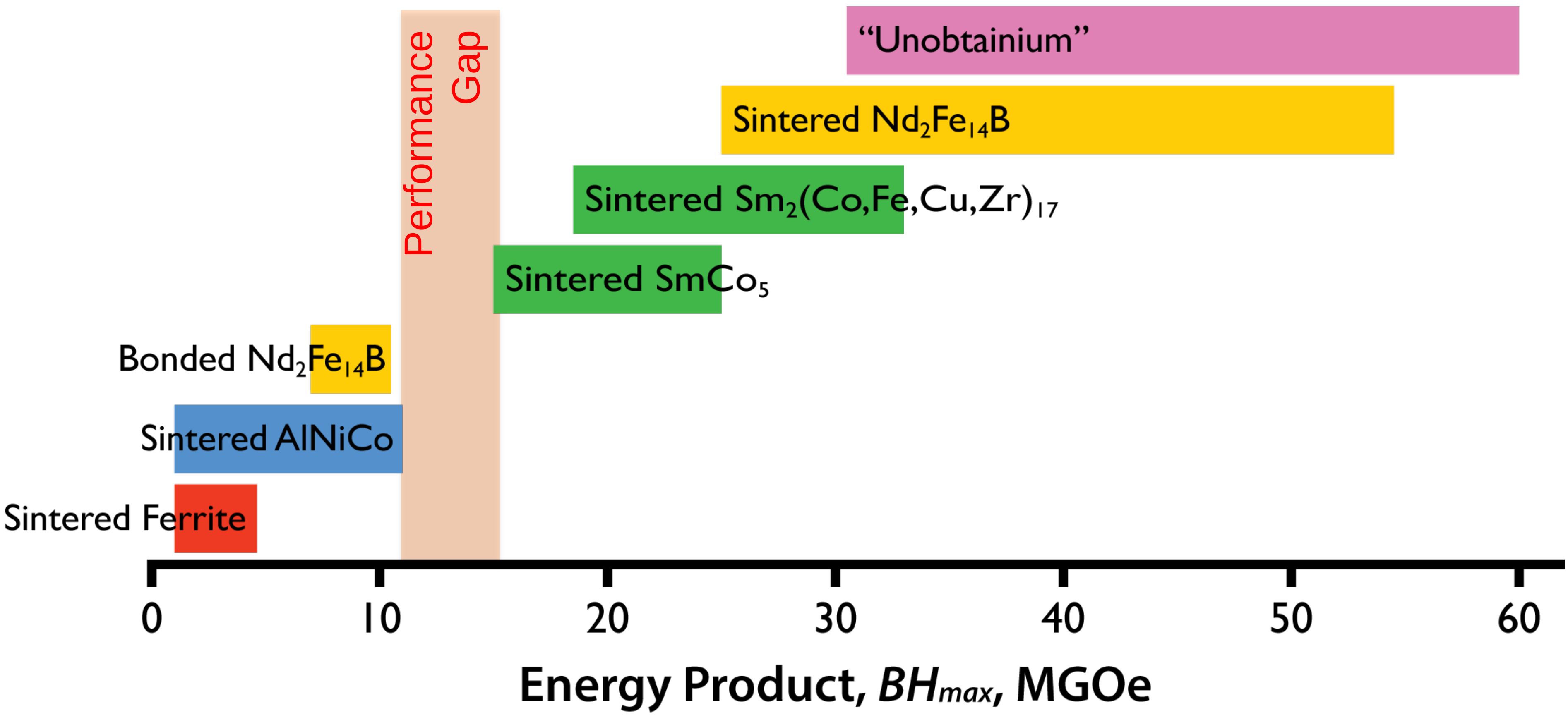
Emerging Issues
2. *Advanced technology needs*

- Smaller and ever more complex devices.
  - More exposure to supply risks, with more different materials in the product.
  - Greater challenges to re-use and recycling.

- New devices, manufacturing processes, new materials.
  - Additive manufacturing.
  - Purity and consistency.
  - Changing design constraints with advanced materials.

Magnet options

Note: *Energy product is not the only consideration!*



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Emerging Issues

3. *Social, regulatory and legislative issues*

- Trade Issues
  - Moving manufacturing back to the U.S. tends to increase dependence on imported materials.
- Conflict Minerals
  - Avoidance of conflict minerals impacts supply chains.
- RoHS, REACH
  - Even if U.S. regulations roll back, products must still be exportable.
- Transportation
  - Restrictions on certain materials or products may affect where they are produced.

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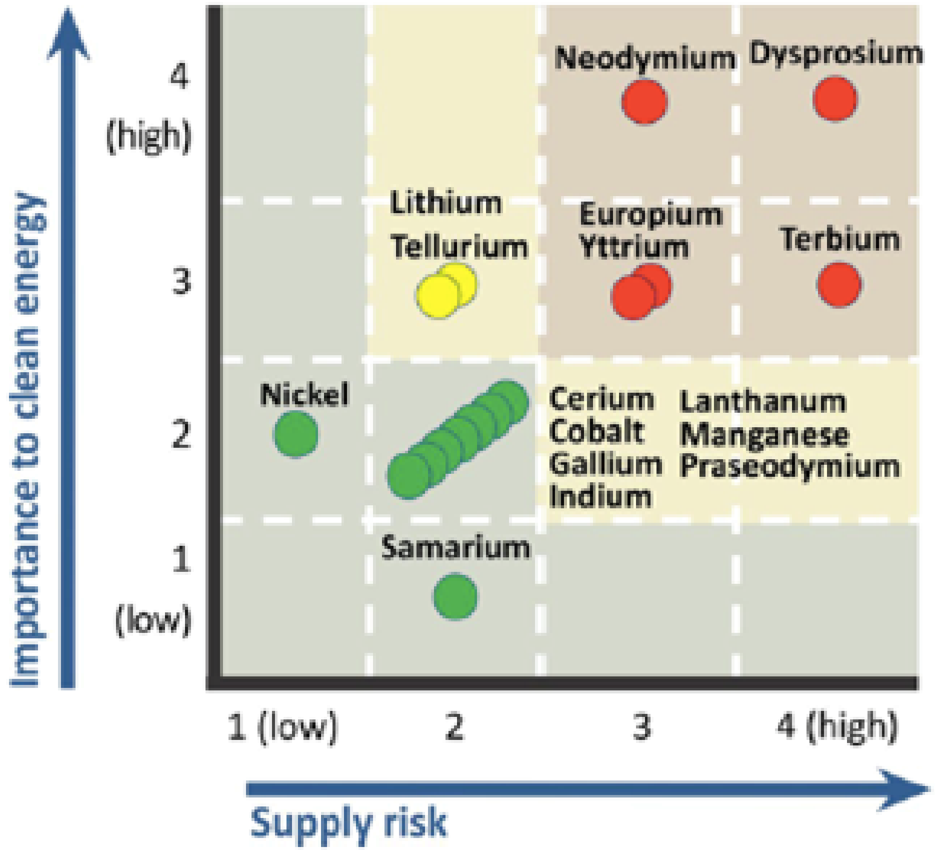
Emerging Issues

4. *Emergent criticality*

- Criticality is not static.
  - It changes with time, location, industry sector...

- Emerging concerns:
  - Tin
  - Indium
  - Gallium
  - Cobalt
  - Cerium
  - Graphite
  - Hafnium
  - Helium
  - Uranium
  - Lithium
  - Tellurium
  - Rhenium
  - PGMs
  - Tungsten
  - Copper
  - Iron???



DOE Medium Term Criticality Outlook: *2015 – 2025*, as of Dec. 2011

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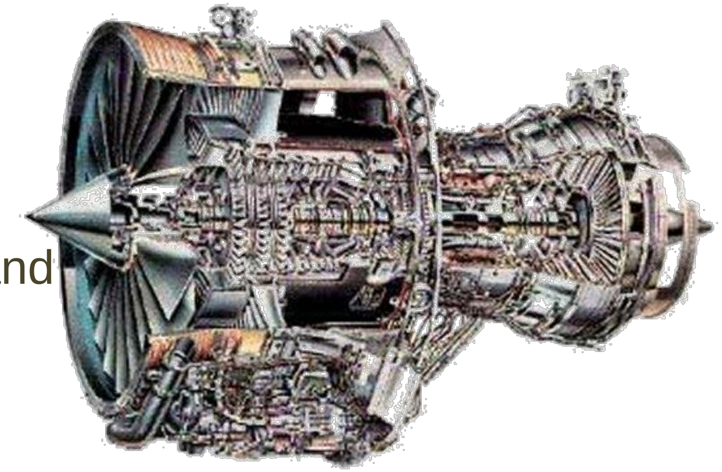
5. *Costs and business decisions.*

- The price of a material does not reflect the cost of integrating it into a product.
  - We need to understand the full costs of new sources or new materials.

- Price instability is a concern in many cases.
  - "I'd love to live without cobalt..."
  - Solutions are created mostly through contracting and supply-chain management rather than technology.



- Source diversity has value, but it comes at a price.
  - Both the value and the price are typically "business confidential" information.

Emerging Issues

6. *Workforce development*

- What skills are needed to assure your supply-chains?
  - Management, economics, math, physics, chemistry, engineering, teamwork, communication, data-mining, modeling….
- What educational level(s) are needed?
  - High-school, community college, bachelors, masters, doctoral, post-doc, in-service training.
- How will expertise be acquired?
  - In-house, contractors, consultants, universities, national labs…

- How far ahead do you plan?

Thank You!

Questions?

http://www.cmi.ameslab.gov