Sensitive Information

- Open discussion and free interaction are essential elements of the Hub concept.
- Most attendees are bound by Non-Disclosure Agreements (NDAs).
- All attendees are also subject to the policies of their home institutions.
- Information presented here is not to be relayed to anyone who is not covered by a CMI NDA.
- Our meetings and discussions are open to all CMI Team members, except as posted.
- Affiliate and Associate members are welcome at all plenary sessions and the Industry Council meetings.

CMI Accelerating Energy Innovations

Critical Materials Institute

AN ENERGY INNOVATION HUB

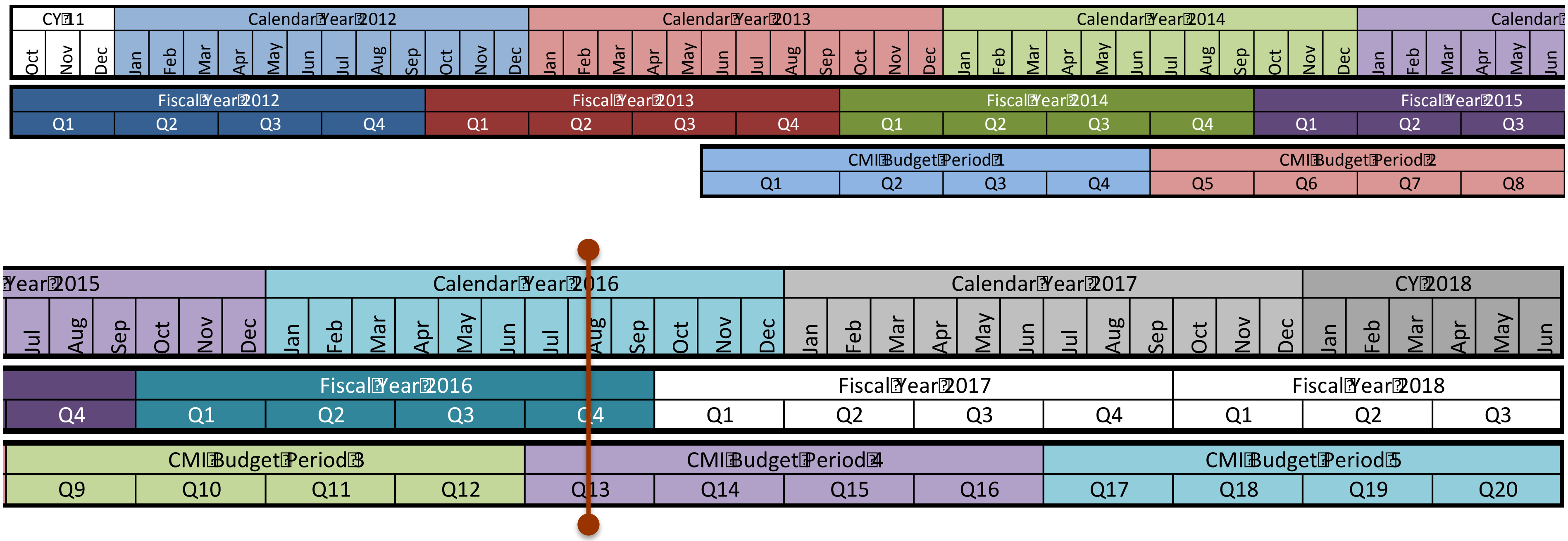
How are we performing?

Alex King
CMI Director

Rockin' an' Rollin'

Jeff Beck at the Starlight Theater, Kansas City
August 5, 2016

Timeline

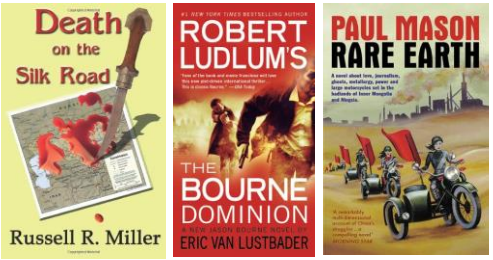


First funding cycle ends: **June 30, 2018**

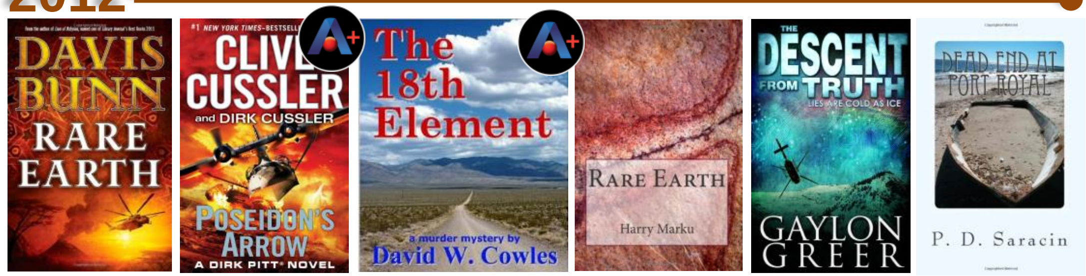
Critical Materials Institute
AN ENERGY INNOVATION HUB

CMI Book Club Selections

2011



2012

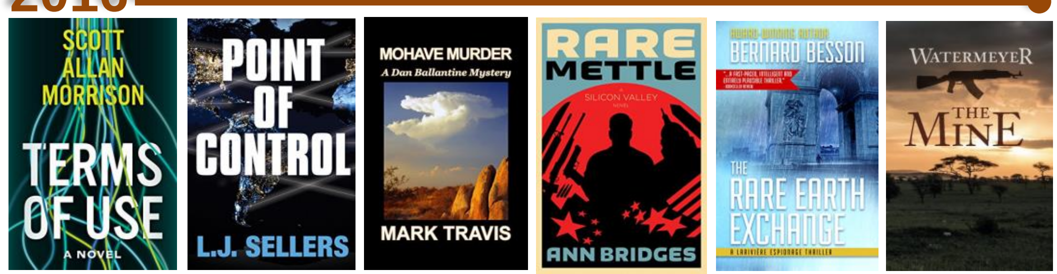


2013

2014

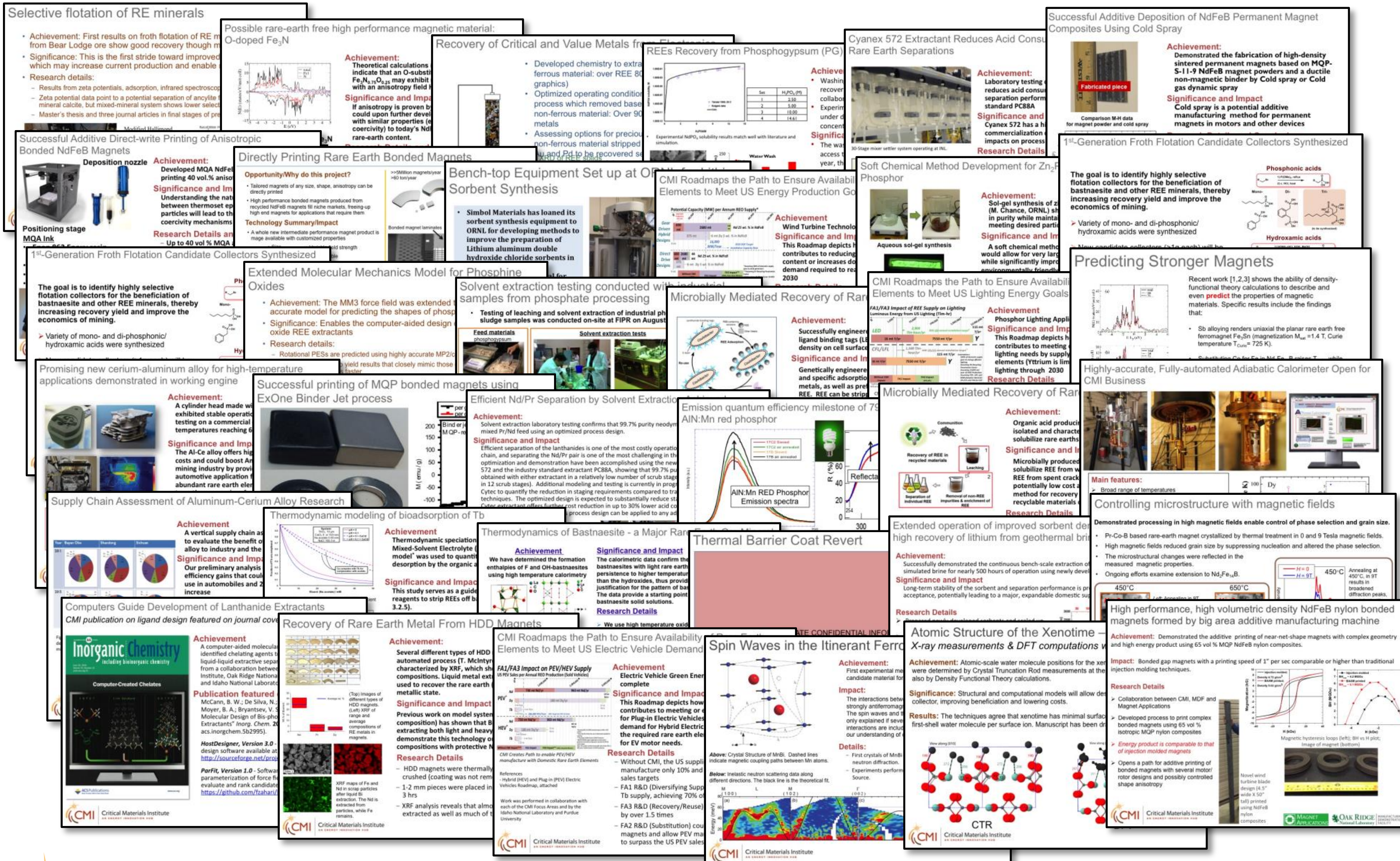
2015

2016



Critical Materials Institute
AN ENERGY INNOVATION HUB

Highlight Slides *- Year 3*



Highlight Slides Submitted to DOE

	FA1	FA2	FA3	FA4	CMI Total
Total, BP1	2	2	0	0	4
Total, BP2	1	1	2	2	5
Total, BP3	13	10	6	9	35
Total, BP4	2	4	0	2	5
Running Total	18	17	8	13	49

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 of bonded permanent magnets using a novel polymer matrix

★ *Patent application submitted* ✩ *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* ✪ *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* ✪ *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 *License awarded*

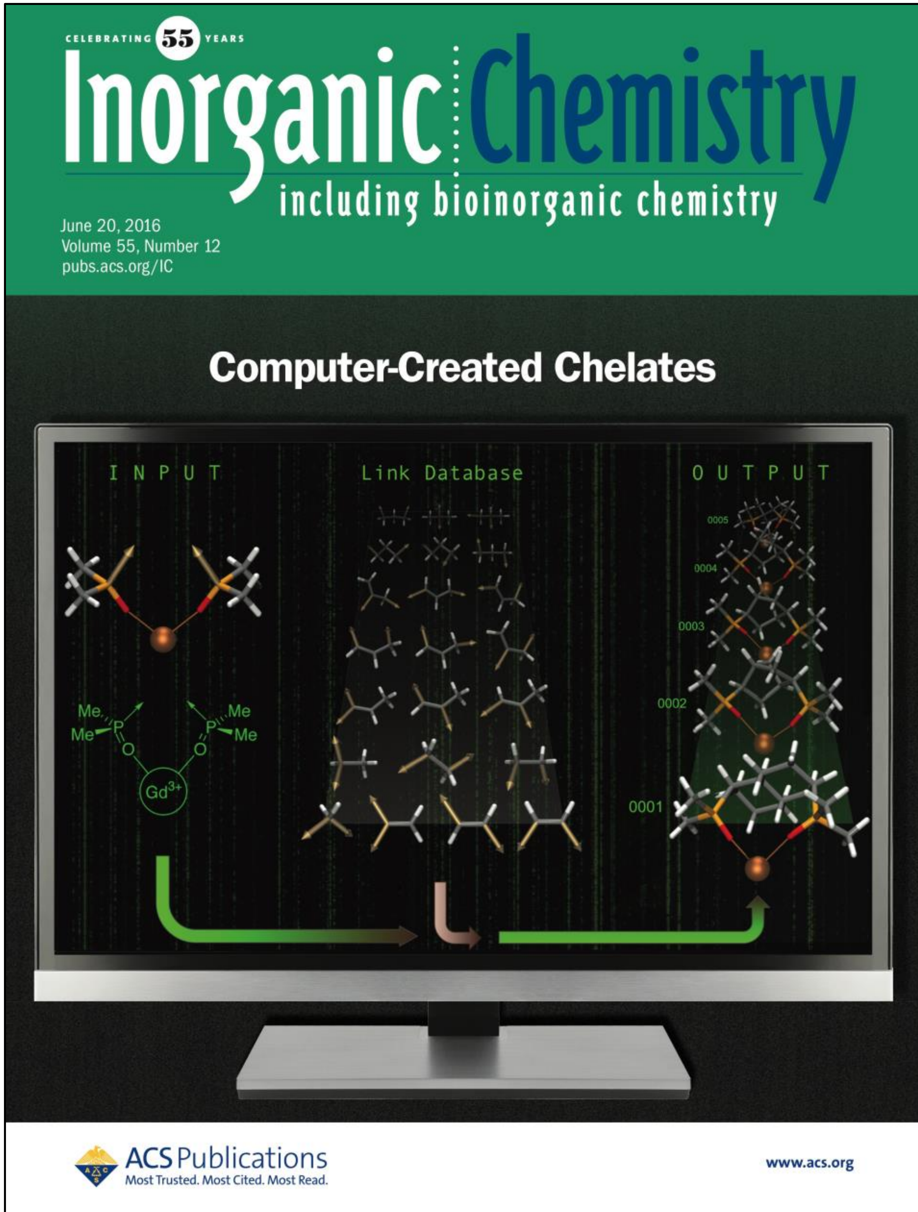
Invention Disclosures

41. Materials designed 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. Multi-functional Liquid Crystalline Networks : 3D Printable liquid crystalline elastomers with tunable shape memory behavior and bio-derived renditions ✪
44. High performance magnets with abundant rare earth elements
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

✪ *Patent application submitted* ✪ *License awarded*

Intellectual Property

	FA1	FA2	FA3	FA4	TOTAL
Invention Disclosures	18	13	16		47
Patent Applications	8	3	4		15
Patents Issued					0
Licenses			1		1



CELEBRATING 55 YEARS
Inorganic Chemistry
including bioinorganic chemistry
June 20, 2016
Volume 55, Number 12
pubs.acs.org/IC
Computer-Created Chelates
INPUT
Link Database
OUTPUT
ACS Publications
Most Trusted. Most Cited. Most Read.
www.acs.org

JOM
JULY 2016
jom.tms.org
An official publication of The Minerals, Metals & Materials Society
Manufacturing
FRANK CROSSLEY: A Man of Mettle
TMS
Springer

Publications

	FA1	FA2	FA3	FA4	CMI Total
2014	6	13	5	5	29
2015	8	22	6	7	43
2016	3	14	1	8	26
Total	17	49	12	20	98

Materials Genome Initiative

www.whitehouse.gov/blog/2016/08/01/materials-genome-initiative-f

BRIEFING ROOM | ISSUES | THE ADMINISTRATION | PARTICIPATE | 1600 PENN

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

Notice:
This draft is restricted to official use only.

This draft report is being provided to ob... not been fully reviewed within GAO and...

Recipients of this draft must not, under... contents for other than official review a... prevent improper disclosure. This draft... must be returned on demand to, the G...

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.

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*

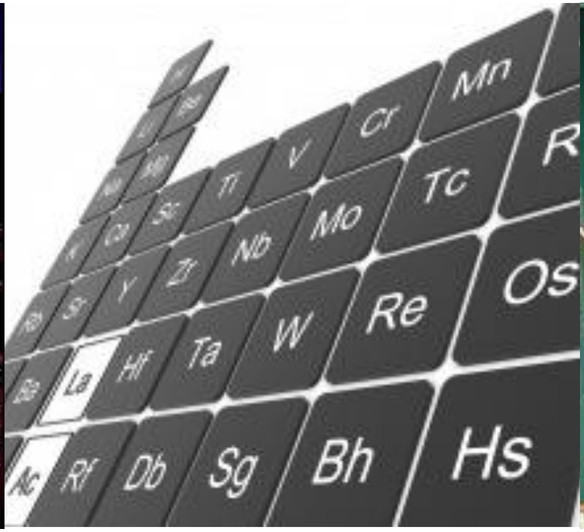
- New materials <u>*can*</u> be developed at an accelerated pace.
  - CMI is close to commercializing a green phosphor and a red phosphor after only three years work.
- New materials are more readily accepted if they are process-compatible with the materials they replace.
  - Close collaboration with 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.

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:

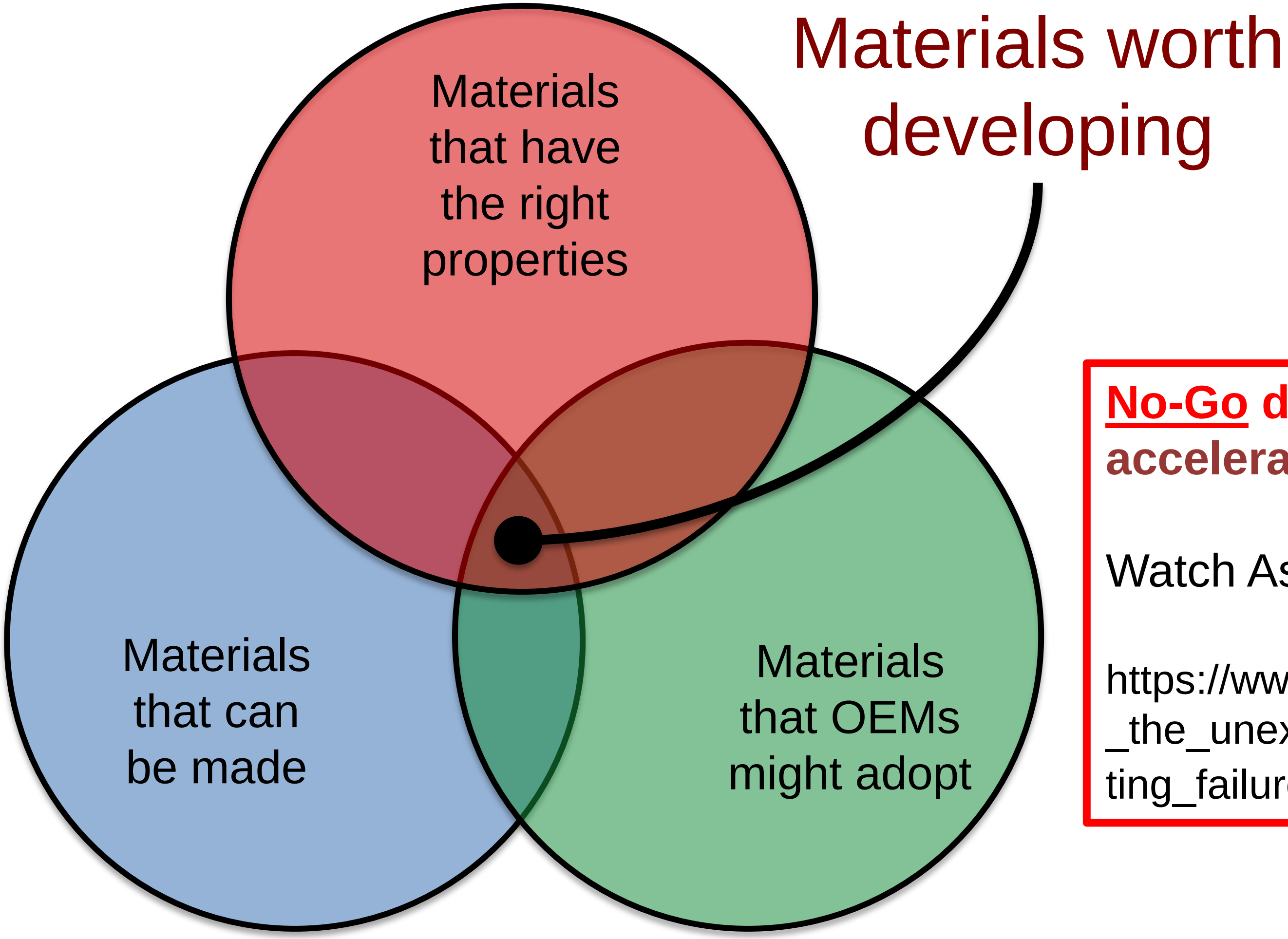


Diversifying & expanding production

Developing substitutes

Reducing wastes

CMI’s materials development paradigm



No-Go decisions are the great accelerators.

Watch Astro Teller’s TED talk:

https://www.ted.com/talks/astro_teller_the_unexpected_benefit_of_celebrating_failure?language=en

New Team Members

INFINIUM™

Rio Tinto

New CRADA Partner *and CMI Associate*

Oddello

INDUSTRIES LLC

New CMI Affiliates

ARKEMA
INNOVATIVE CHEMISTRY

BALDOR
A MEMBER OF THE ABB GROUP

BARR

EEC ELECTRON ENERGY CORPORATION

First Solar.

MARSHALLTON
RESEARCH LABORATORIES INCORPORATED

Mosaic®

NASA

NETL | National Energy Technology Laboratory

PRAIRIE
RESEARCH INSTITUTE

REEcycle

RioTinto

Simplot

SHILOH®

THOR ORE

urbanmining co

The reward for work well done is the opportunity to do more.

- Jonas Salk

What's Next?

- Make like the US womens gymnastics team
  - Expectations have risen. Embrace the new goals.

- Make like Michael Phelps
  - Keep sprinting to the finish line and winning gold.

- Make like Jeff Beck
  - Be the acknowledged master
  - Reinvent yourself
  - Take the show back on the road

CMI Critical Materials Institute
AN ENERGY INNOVATION HUB

Thank You!

Questions?

http://www.cmi.ameslab.gov

CMI Accelerating Energy Innovations

Critical Materials Institute

AN ENERGY INNOVATION HUB

Advanced Recovery, Inc.

CYTEC
Delivering Technology Beyond Our Customers' Imagination™

Eck Industries, Inc.
Specialists in Premium Aluminum Castings

GE

INFINIUM™

OLI systems, Inc.

RioTinto

Sm SIMBOL materials

United Technologies Research Center

BROWN

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

UC DAVIS
UNIVERSITY OF CALIFORNIA

FIPR
Florida Industrial and Phosphate Research Institute

IOWA STATE UNIVERSITY

PURDUE UNIVERSITY

RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

The Ames Laboratory
Creating Materials & Energy Solutions
U.S. DEPARTMENT OF ENERGY

INL
Idaho National Laboratory

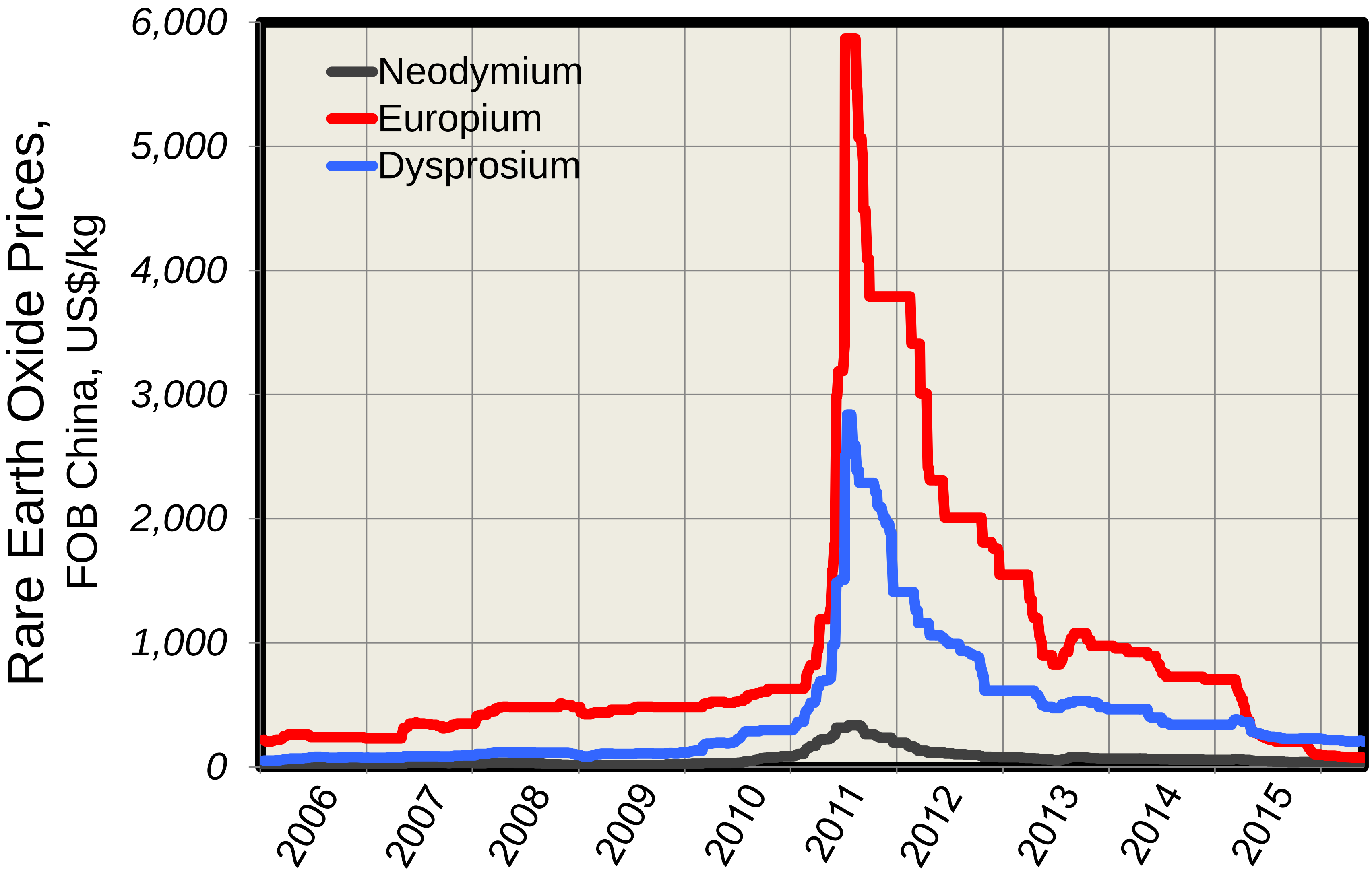
Lawrence Livermore National Laboratory

OAK RIDGE
National Laboratory

cmi.ameslab.gov

U.S. DEPARTMENT OF ENERGY

Rare earth prices



Critical Materials Institute
AN ENERGY INNOVATION HUB