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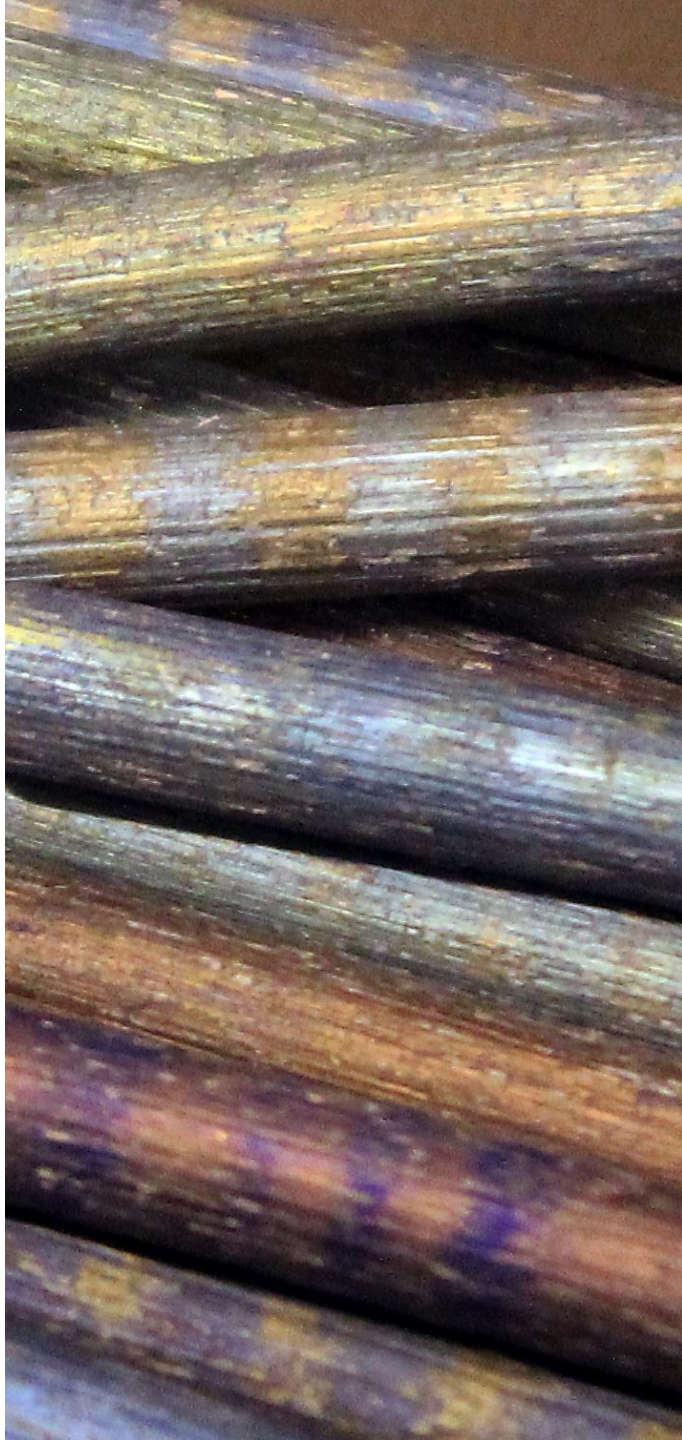
Critical Materials Institute

AN ENERGY INNOVATION HUB

What is a “Critical Material?”

- Any substance used in technology that is subject to supply risks, and for which there are no easy substitutes.
- Or, in plain English – stuff you really need but can’t always get.
- The list of materials that are considered critical depends on *who*, *where* and *when* you ask.
- CMI focuses on clean energy technologies, in the US, over the next 10 to 15 years.



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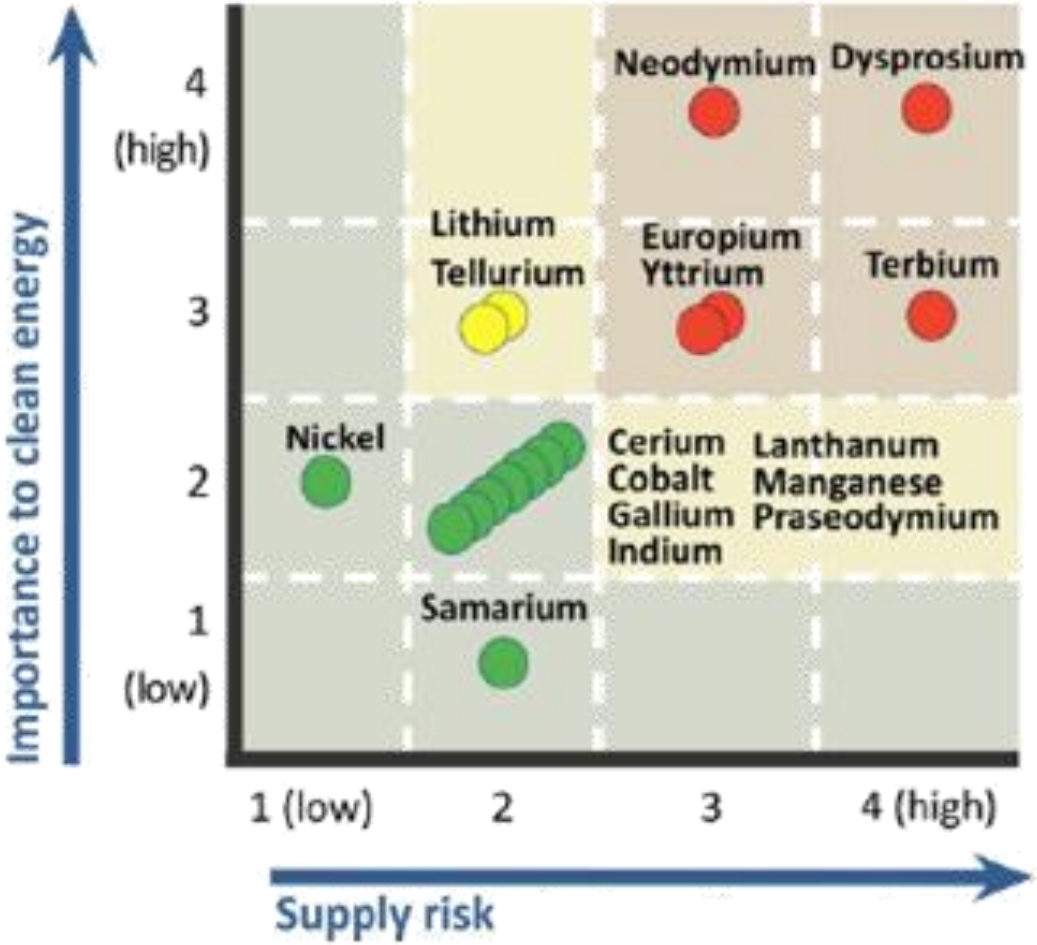
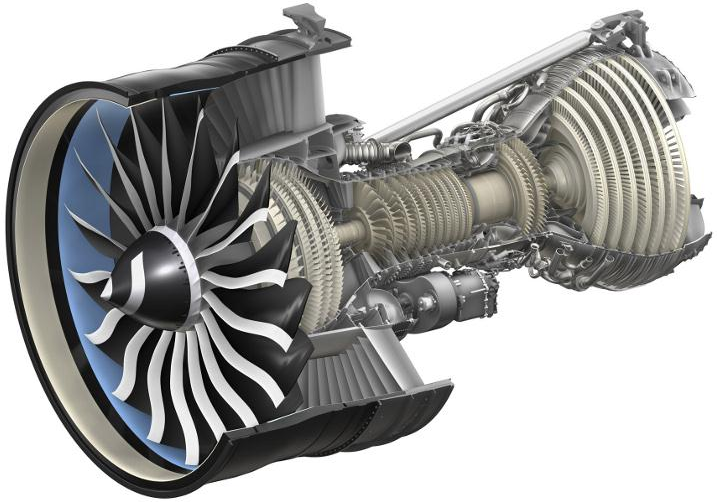
How is criticality assessed?



DOE Medium Term Outlooks: *2015 – 2025*

Materials criticality is affecting us *today*

- Jet engine manufacturers, including CMI partner GE, have had to deal with shortages of rhenium.
  - http://www.gereports.com/engineering-ways-to-reduce-the-rare-metal-rhenium-in-jets/



- A major disk-drive manufacturer came within one week of shutting down production for lack of Nd-Fe-B magnets.

Materials criticality is affecting us *today*

- Loudspeaker manufacturers have been severely impacted by magnet price increases.

- Tesla Motors may be forced to reduce production because of short supplies of Li-ion batteries.
  - http://wheels.blogs.nytimes.com/2013/09/06/as-it-increases-production-tesla-worries-about-battery-supply/?_r=0

Materials criticality is affecting us *today*

- Even military hardware is occasionally being sourced from China, because of the lack of a domestic supply-chain for certain key materials.

http://www.reuters.com/article/2014/01/03/us-lockheed-f-idUSBREA020VA20140103

REUTERS EDITION: U.S.

HOME BUSINESS MARKETS WORLD POLITICS TECH OPINION BREAKINGVIEWS

Exclusive: U.S. waived laws to keep F-35 on track with China-made parts

BY JOHN SHIFFMAN AND ANDREA SHALAL-ESA

WASHINGTON | Fri Jan 3, 2014 3:45pm EST

69 COMMENTS | Tweet 371 | Share 51 | Share this | 73 | Email | Print

The flight deck crew secures an F-35B Lighting II aircraft aboard the amphibious assault ship USS Wasp following testing in this handout photo taken off the coast of North Carolina August 24, 2013.

CREDIT: REUTERS/U.S. NAVY/HANDOUT

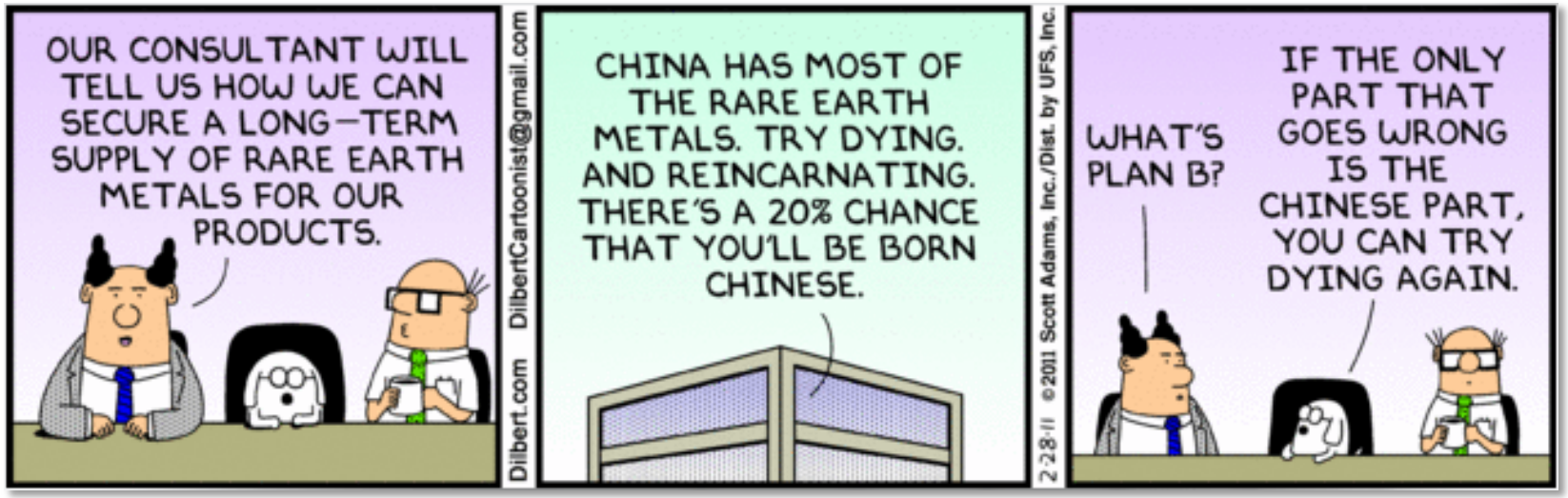
(Reuters) - The Pentagon repeatedly waived laws banning Chinese-built components on U.S. weapons in order to keep the $392 billion Lockheed Martin Corp F-35 fighter program on track in 2012 and 2013, even as U.S. officials were voicing concern about China's espionage and military buildup.

Materials criticality is affecting us *today*

- The target date for transition to high-output T5 fluorescent lamps has been delayed by two years because manufacturers claim that there is a shortage of Eu and Tb for the phosphors.

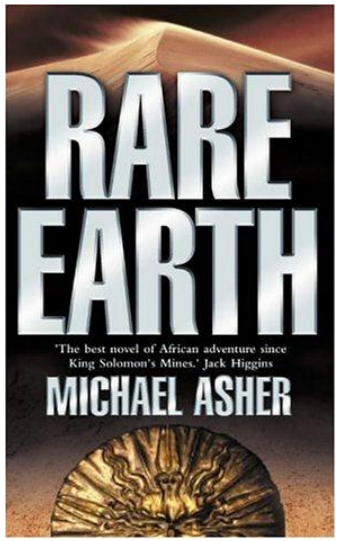
- Utility-scale wind turbine installations are overwhelmingly gearbox-driven units, despite the high failure-rate of the gearboxes, because of the cost and unavailability of Nd and Dy required for direct-drive units.

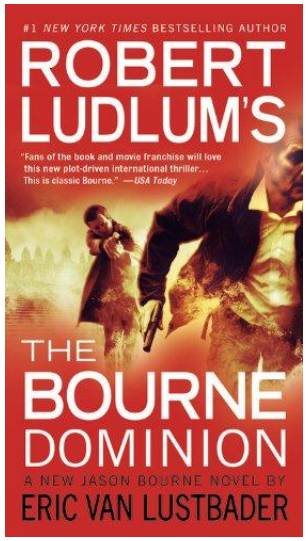
Cul de Sac, August 7, 2010

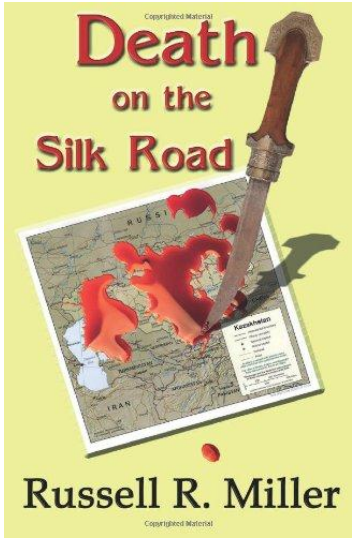


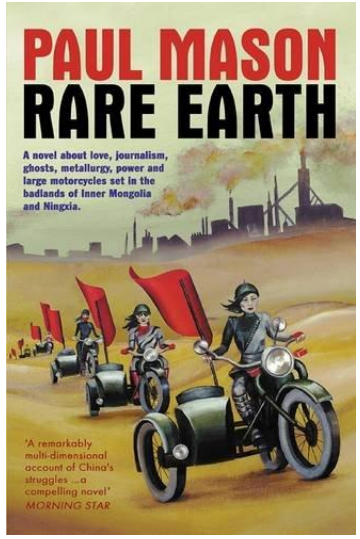
Dilbert, February 28, 2011

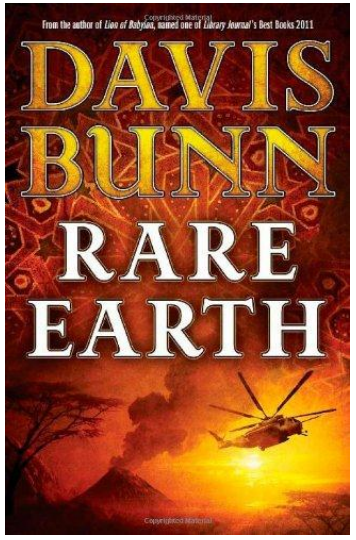
The hottest new literary sub-genre?

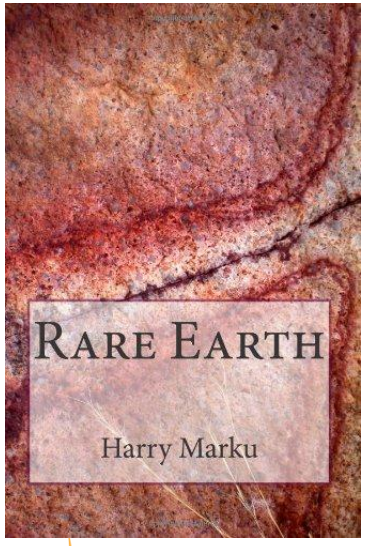


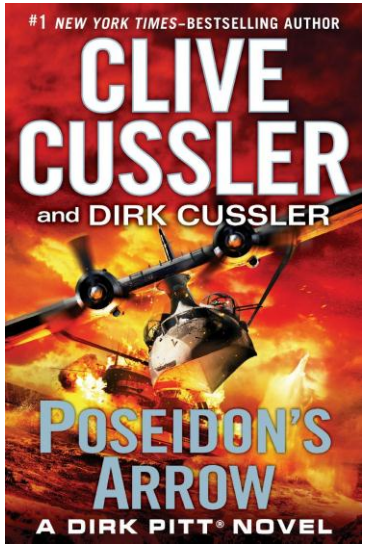


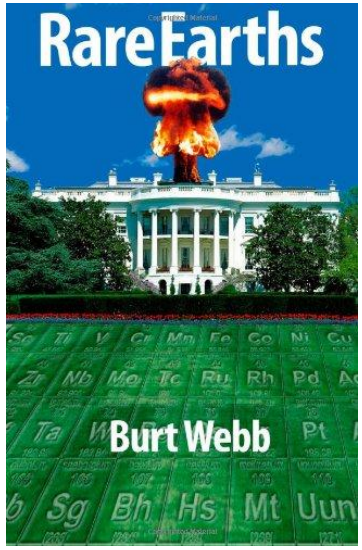


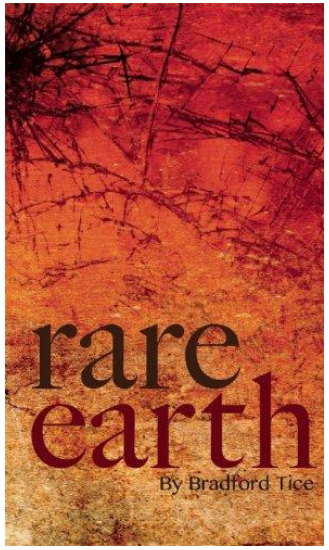


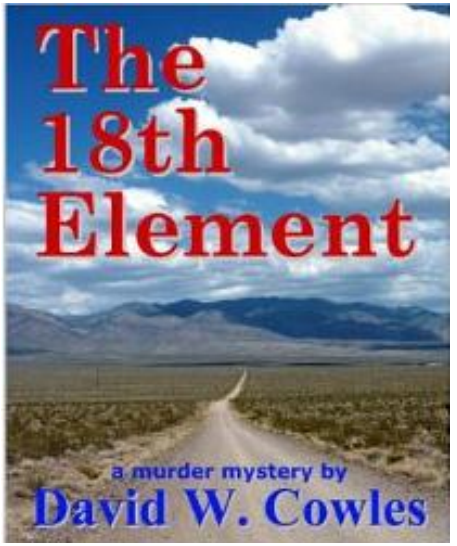












Corruption and Intrigue in Washington…

In one of many subplots, Chinese billionaire Xander Feng, is in a joint-venture, rare-earths mining operation with U.S. power plant billionaire Raymond Tusk.

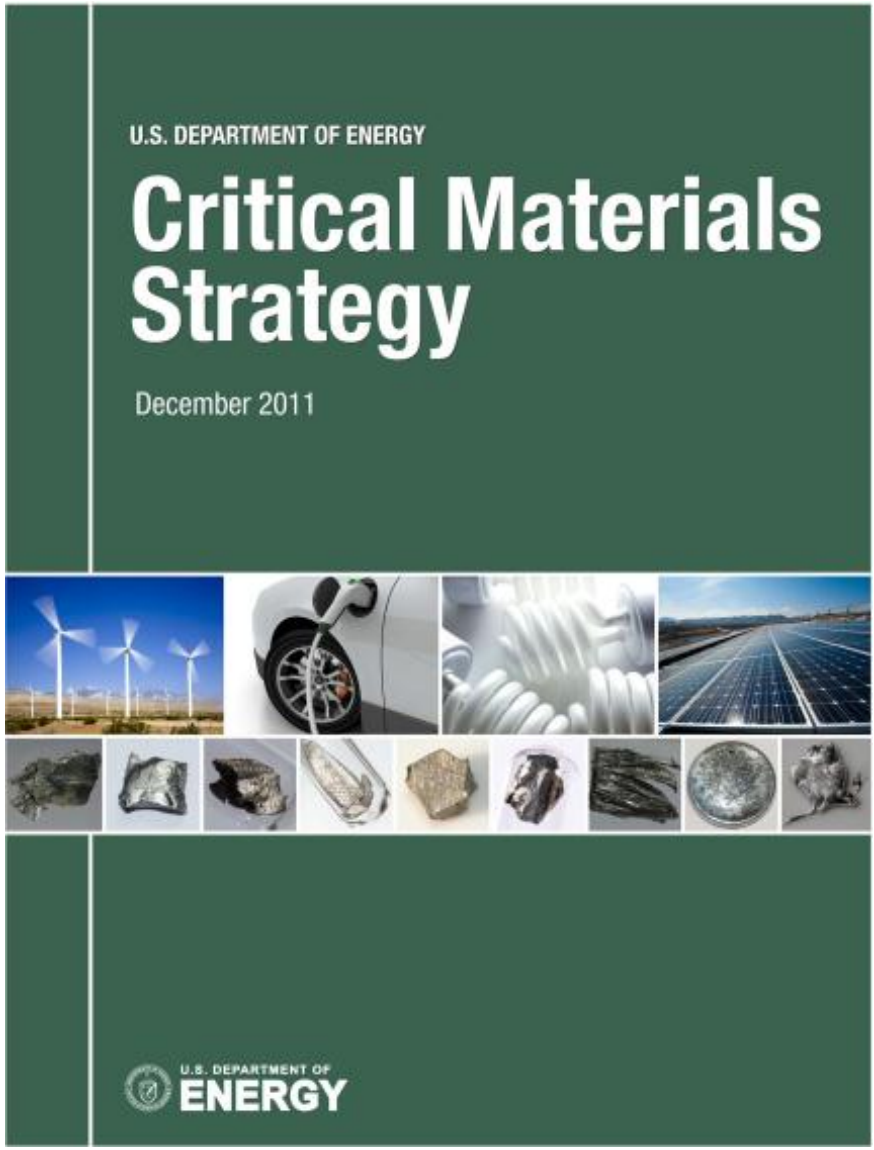
"*Samarium is the new opium*."

Three-D Approach

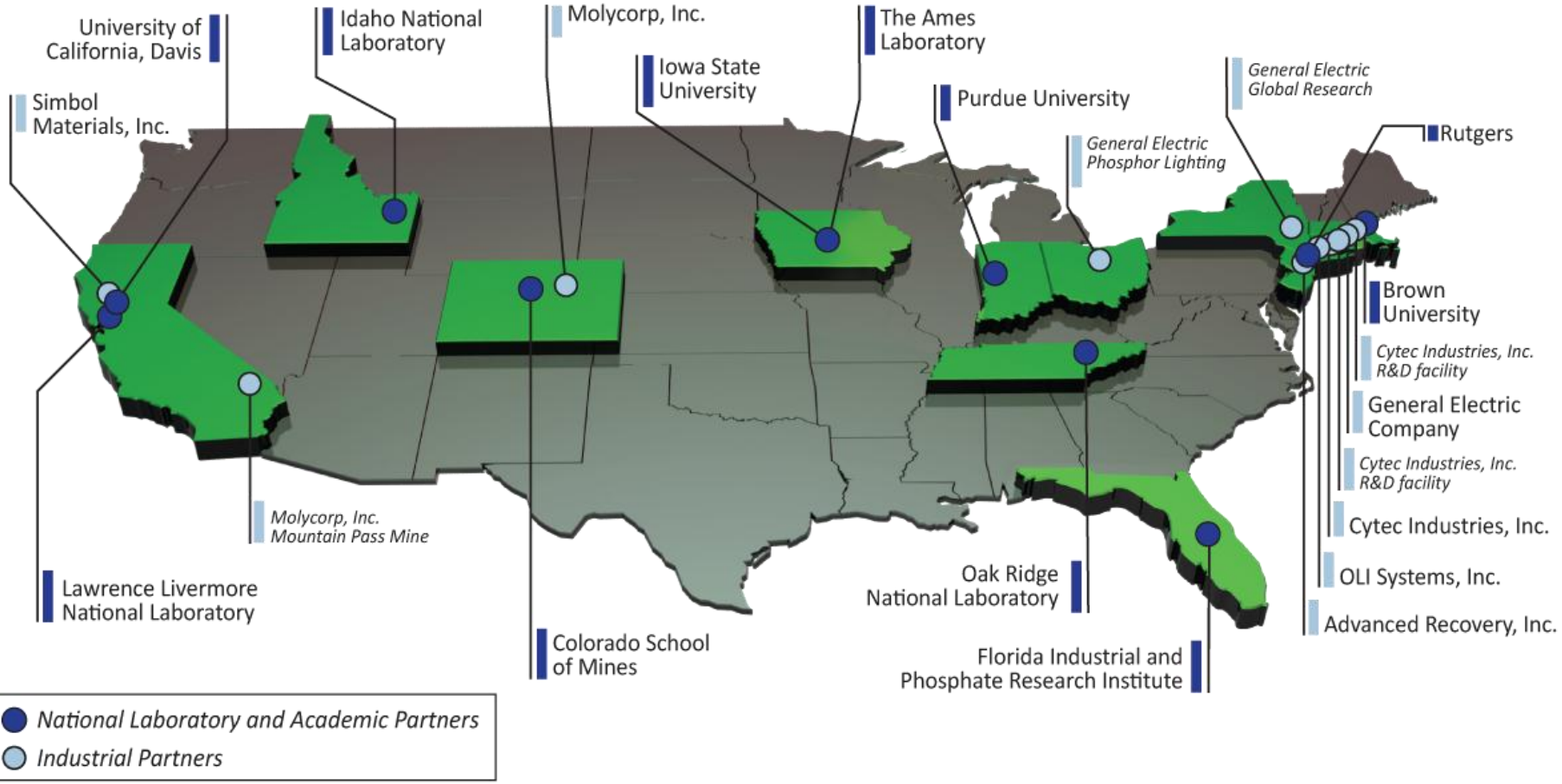
- Diversify supply
- Develop substitutes
- Drive reuse, recycling, and efficient use of materials in manufacturing

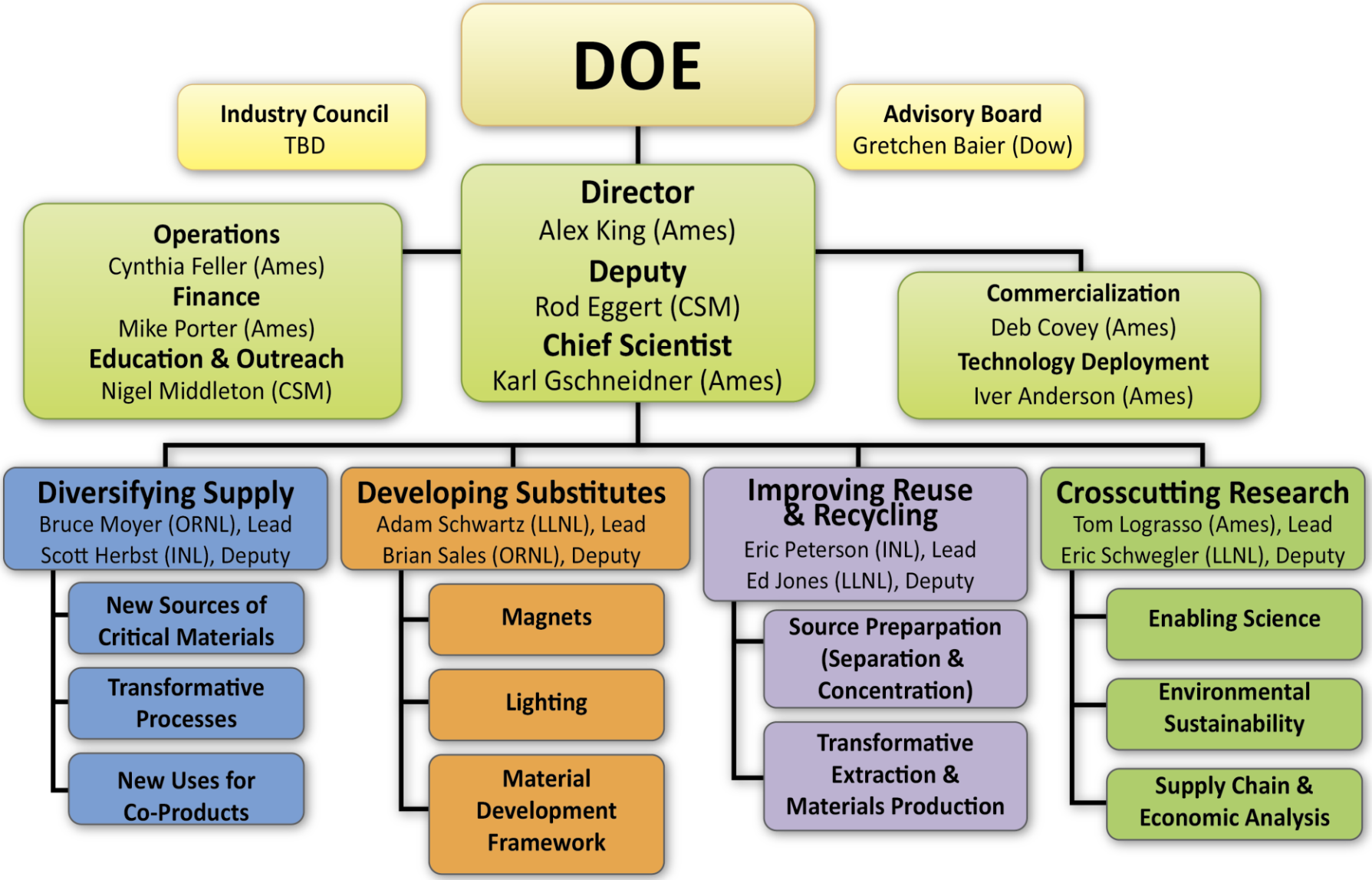
Essentially following DOE's Critical Materials Strategy, but applying it very selectively

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



One Integrated Team



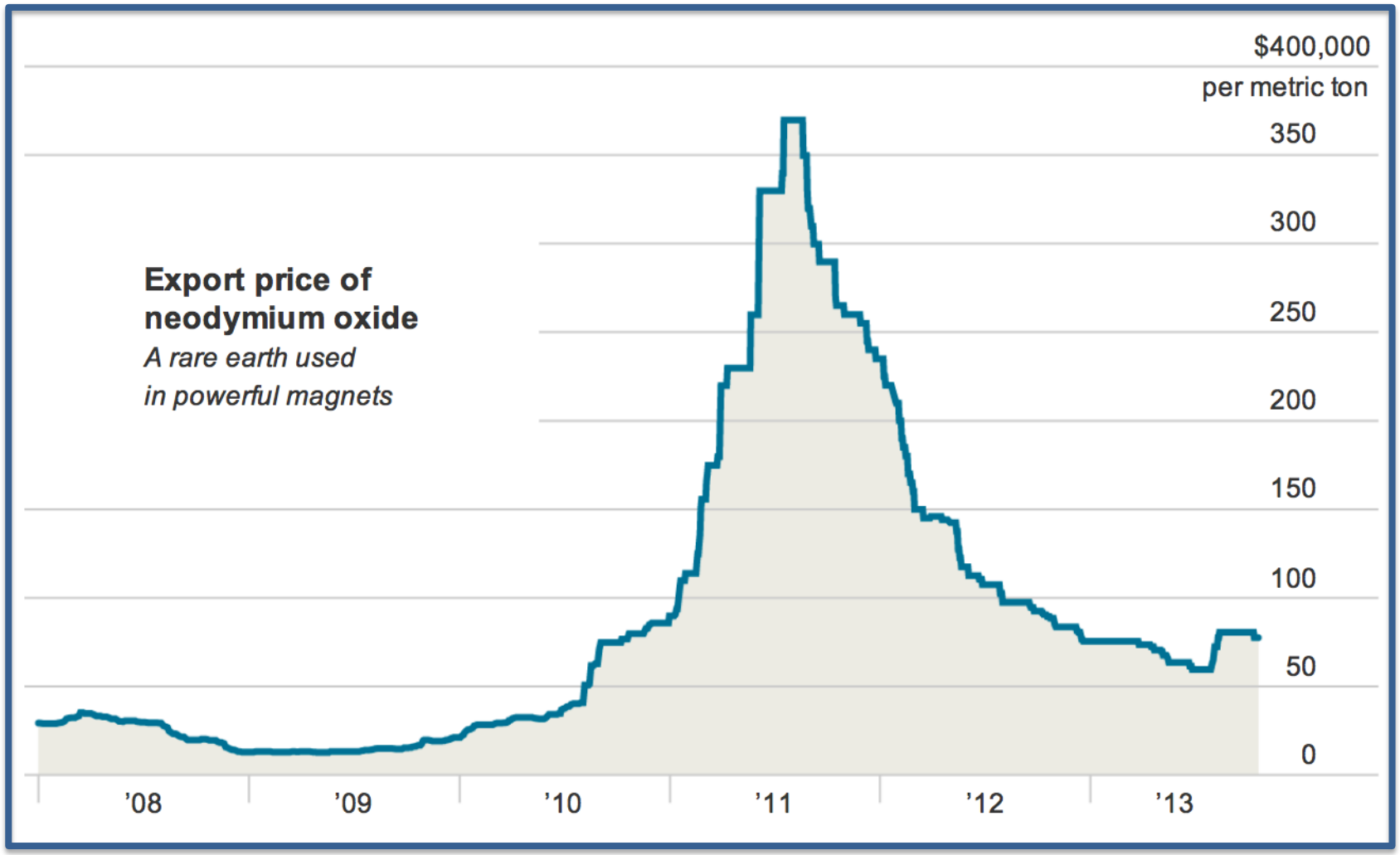

DOE
Industry Council
TBD
Advisory Board
Gretchen Baier (Dow)
Director
Alex King (Ames)
Deputy
Rod Eggert (CSM)
Chief Scientist
Karl Gschneidner (Ames)
Operations
Cynthia Feller (Ames)
Finance
Mike Porter (Ames)
Education & Outreach
Nigel Middleton (CSM)
Commercialization
Deb Covey (Ames)
Technology Deployment
Iver Anderson (Ames)
Diversifying Supply
Bruce Moyer (ORNL), Lead
Scott Herbst (INL), Deputy
New Sources of Critical Materials
Transformative Processes
New Uses for Co-Products
Developing Substitutes
Adam Schwartz (LLNL), Lead
Brian Sales (ORNL), Deputy
Magnets
Lighting
Material Development Framework
Improving Reuse & Recycling
Eric Peterson (INL), Lead
Ed Jones (LLNL), Deputy
Source Preparpation (Separation & Concentration)
Transformative Extraction & Materials Production
Crosscutting Research
Tom Lograsso (Ames), Lead
Eric Schwegler (LLNL), Deputy
Enabling Science
Environmental Sustainability
Supply Chain & Economic Analysis

Most solutions take effect *tomorrow*

- Mine development, *where there is a known resource*, takes about 15 years, and has costs in the billions of dollars.
- Development and deployment of new materials takes an average of 18 years.
- There are no empirical data to suggest how long it takes for recycling programs to have an impact.

We have 5 years in which to make an impact.

CMI was created in response to a perceived crisis.



Price Graphic: *New York Times,* 10-22-2013

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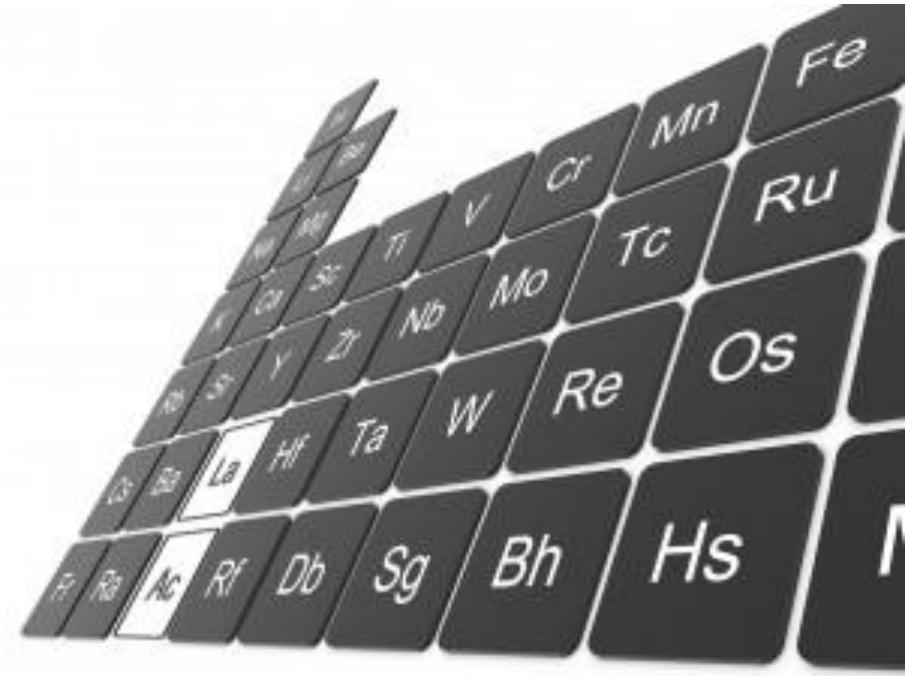
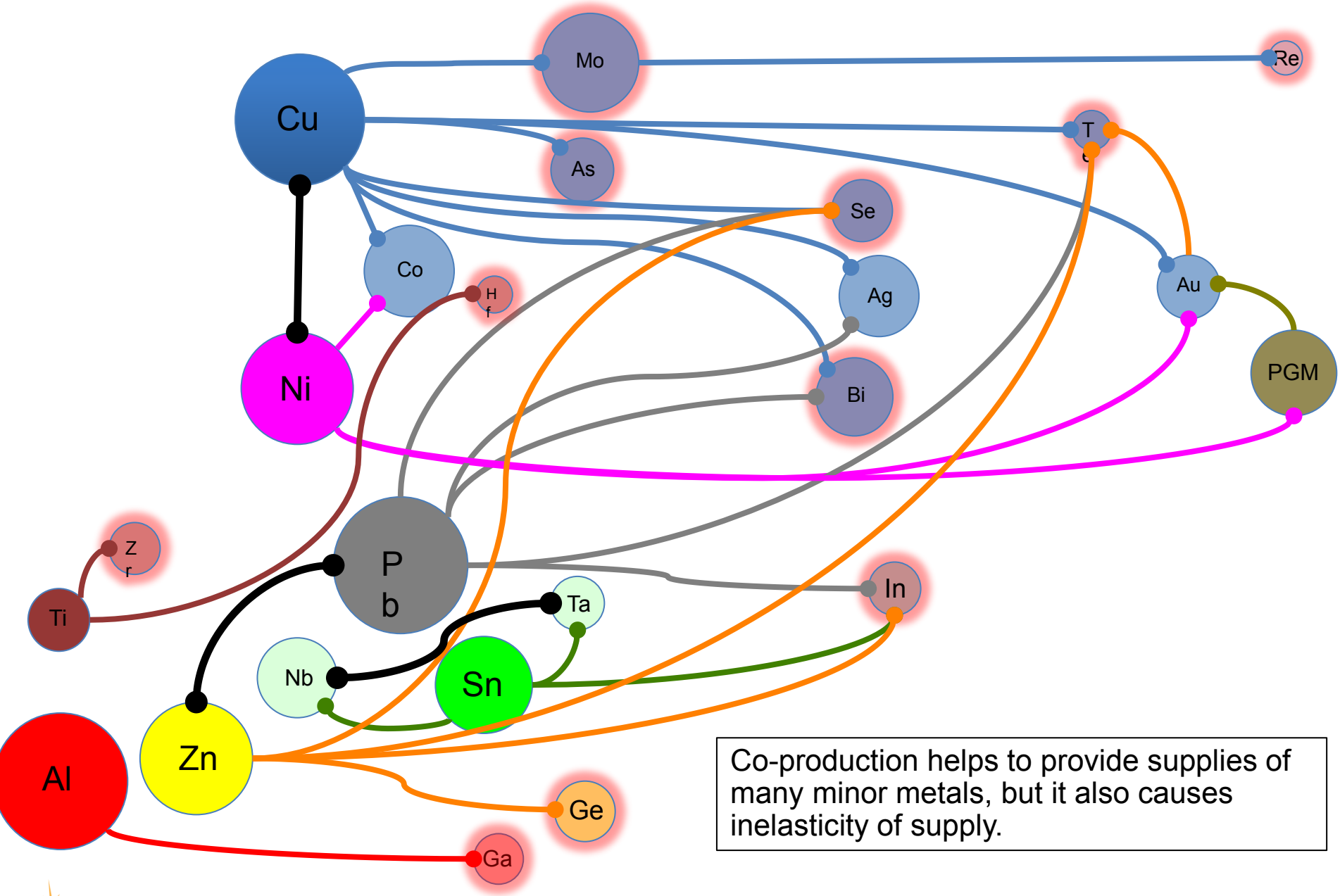
Two universal grand challenges

- Starting sooner
  - We need to anticipate criticality, not just respond to it.
- Working faster, faster
  - 200 years at ~1000 BC
  - 20 years at ~ 2000 AD
  - 2 years by ~ 5000 AD?

Emergence of new critical materials

- Supply shortfalls
- Demand spikes
- Can we predict?
- Are we prepared to respond?





Co-production helps to provide supplies of many minor metals, but it also causes inelasticity of supply.

Technology emergence
Case study: electric vehicles

Assumption: The market penetration of EVs will rise when a battery technology emerges that provides all-electric range close to that of a single tank of gasoline, if the price premium is similar to that of a hybrid.

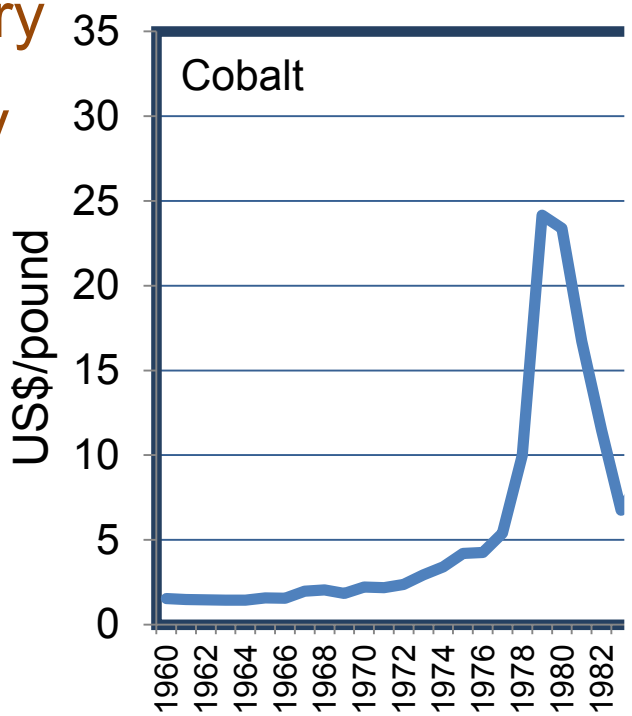
- ~15,000,000 new cars are sold in the US every year.
- ~7% of new car sales in California are hybrids.
- Guess that the market for an all-electric vehicle could rise to 1,000,000 per year.
- If the battery requires 20kg of “unobtainium” the demand is around 20,000 tonnes, for US consumption alone. This is a small percentage of current world production for some elements, but a very large percentage for others.

We are working on the problems of today to prepare for the problems of tomorrow

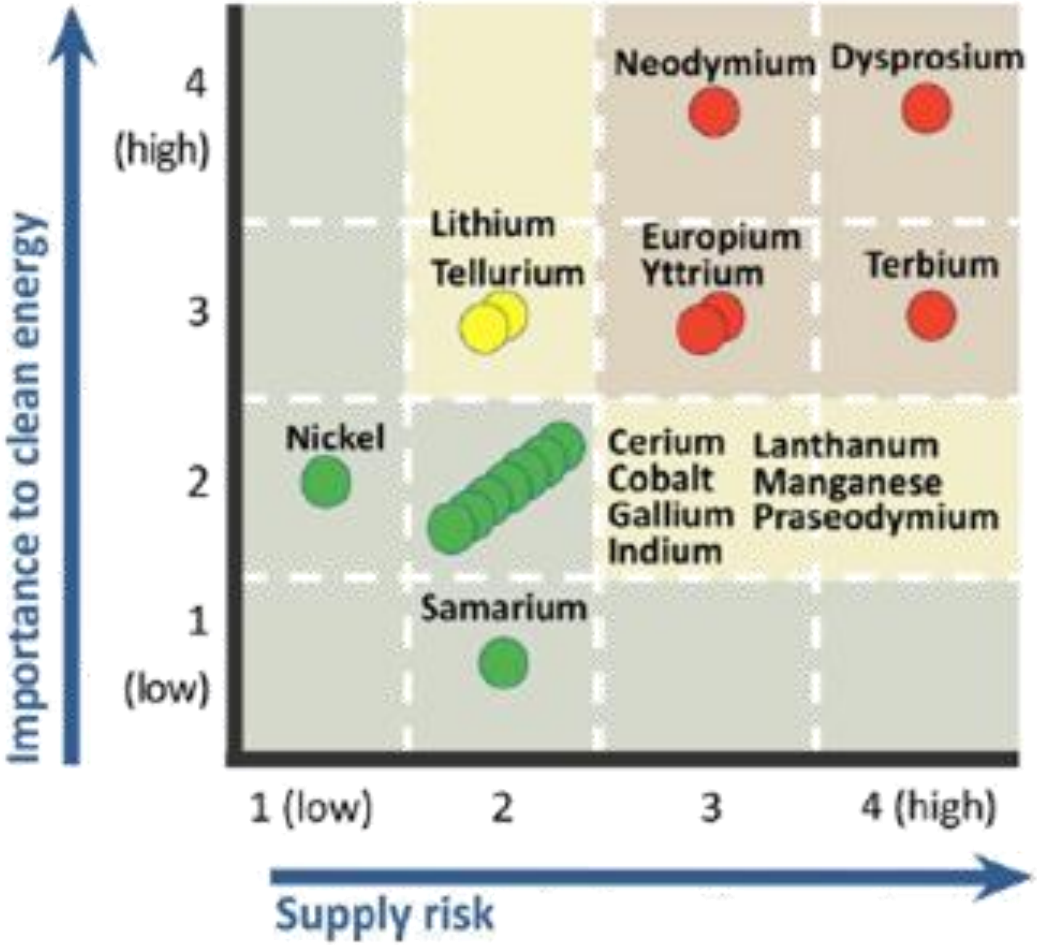
- Better foresight through improved economic analysis
- Faster response through improved technical capabilities
- Learning from industry
- Learning from history

Criticality is a recurring phenomenon, and there is reason to believe that it will increase in frequency in the coming decades.

History shows that criticalities do not tend to have smooth recoveries.



What materials are critical for clean energy applications, now and in the near future?



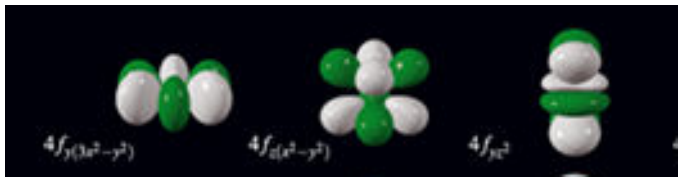
DOE Medium Term Outlooks: *2015 – 2025*

Three rare earth grand challenges

- **Separations**
  - Nature does this badly. Industrial processes are inefficient, energy-hungry, and use large quantities of solvents. It is largely done only in China.

- **Smelting**
  - Energy-hungry and polluting. Largely only done in China.

- **Understanding the f-electron**
  - Current theories are not very helpful.

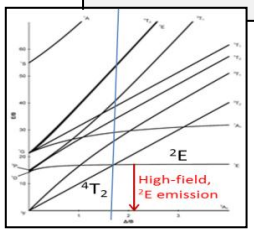


CMI Project Selection and Design

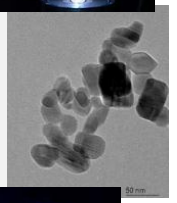
- CMI addresses 7 critical or near-critical chemical elements.
- 35 initial projects, selected for several criteria
  - Potential for impact at a key point in the materials lifecycle, in a realistic timeframe.
  - Integration of strengths and capabilities across the Hub. (No project is carried out by a single partner institution.)
  - Clear path to deployment. Commercialization plan in place on day one.
  - Annual evaluation addresses continued adherence to the timeline and each of the above criteria.
- As the world changes, we expect to terminate projects and start new ones.

Phosphor substitution efforts have four key pieces

Candidate Selection
- Literature & databases
- Classic models: Judd-Ofelt; Tanabe-Sugano; Crystal field
- Advanced quantum models

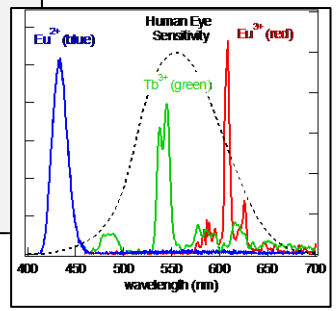


Synthesis
- Combustion
- Precipitation (e.g. urea)
- Solid state reaction
- Flame synthesis
- Vapor doping
- Post-treatments

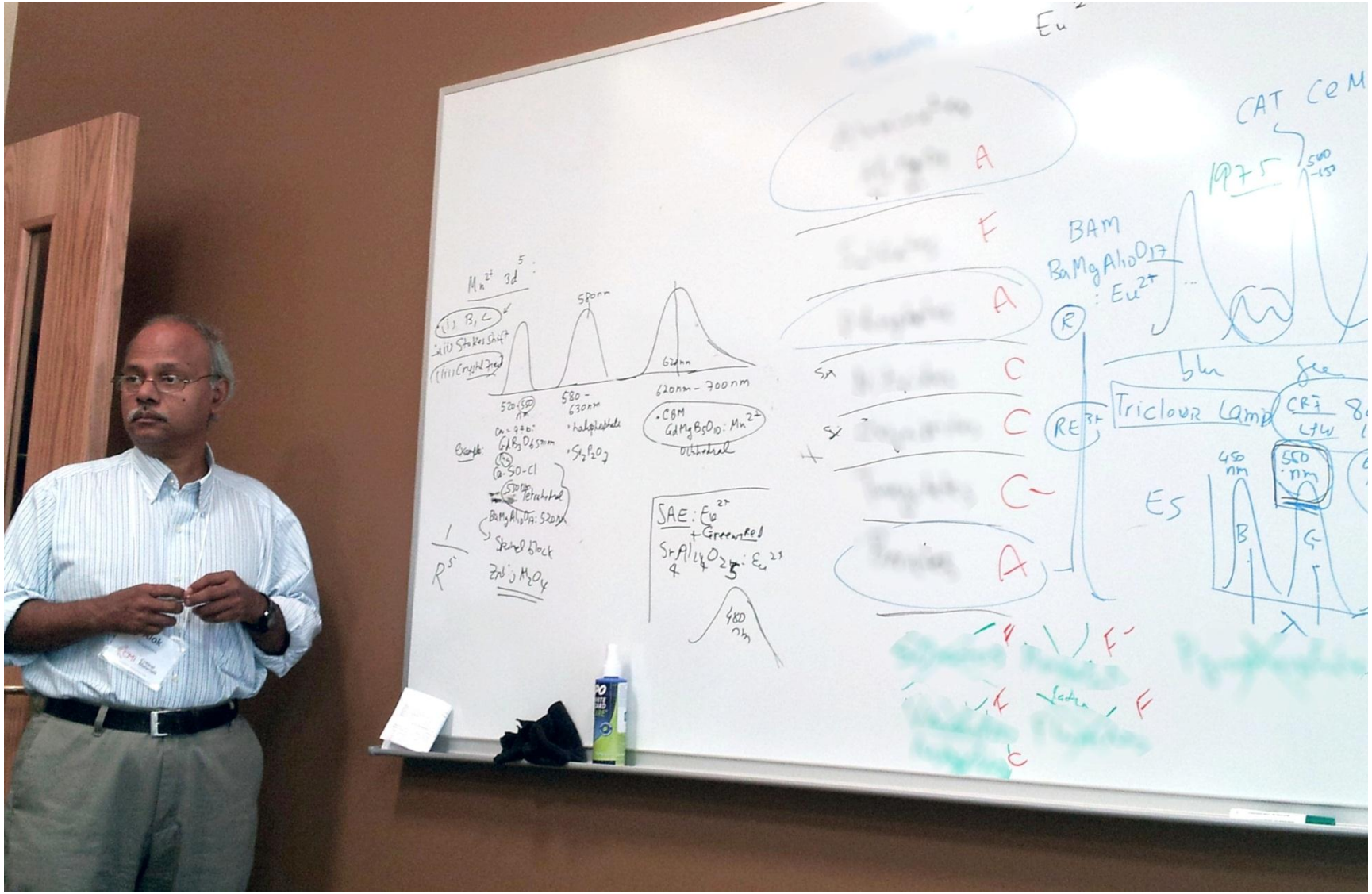


New phosphor meeting all specifications

Characterization
- Emission (CIE)
- Absorption
- Decay time
- Photo-stability
- Structure
- Composition



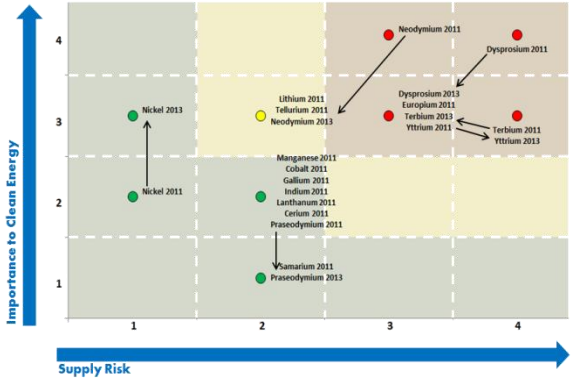
Lamp Performance
- Mercury resistance
- Water insensitivity
- Firing stability
- Radiation resistance
- Protective coating (?)
- *Long-term stability*

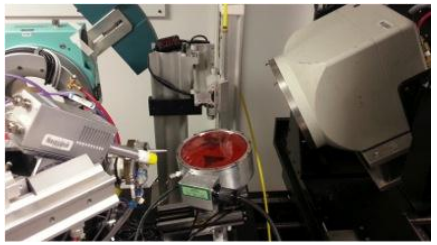


"The magic that happens when industrial researchers get in the room with lab and academic research staff" (*David Danielson*).

Salient facts

- Started operations on June 1, 2013
- Several new facilities established
  - Improved criticality assessment capacity
  - Bulk combinatoric library production facility
  - Thin-film combinatoric library production facility
  - High-throughput analysis (at SSRL, with JCAP and JCESR)
  - Solvent exchange (SX) pilot scale test facility
  - Electrophoretic deposition capability
  - Filtration test facility
  - Toxicology test capability
- Ten invention disclosures in our first ten months
- Ten technical publications
- Industrial Affiliates program about to launch





Leadership & visibility

- Strong national & international presence
  - CMI will host the next meeting of the EU-US-Japan trilateral group
  - Outreach from Australia, Brazil, Canada, EU, Japan, Korea…
  - Testimony at hearings on Capitol Hill
  - Testimony at hearings in the Canadian parliament
  - Meetings with Korean elected officials
  - Meetings with Japanese ministry staff
- Presence at major symposia
  - COM/MS&T; AIChE; ACS; SME; SST; RERC.
- Requests to assist in developing industry standards
  - ASTM; EPEAT.
- Overtures from publishers
  - Three requests to develop reference books.
- Educational outreach

Achievements

- Ten invention disclosures, to date
  - Extraction of rare earth elements from phosphoric acid streams
  - Recovery of neodymium from neodymium iron boride magnets
  - Membrane solvent extraction for rare earth separations
  - Selective composite membranes for lithium extraction from geothermal brines
  - Methods of separating lithium-chloride from geothermal brine solutions
  - Extraction of rare earths from fly ash
  - Recovery of Dy-enriched Fe alloy from magnet scrap alloy via selective separation of rare earth elements
  - Aluminum nitride phosphors for fluorescent lighting
  - Novel surface coatings to improve the functional properties of permanent magnets
  - Additive manufacturing of bonded permanent magnets using a novel polymer matrix

CMI Partner Benefits / Responsibilities	Affiliate		Associate	Industry Council
	Full	Observing		
Participate in the IP Management Plan, including licensing options.				■
Provides cost share or is a subcontractor in support of CMI projects.				■
Representation on Commercialization Council.				■
Participation in writing and reviewing CMI related documents.				■
Full access to Award-supported activities.				■
Active participation in at least one CMI Award project.				■
Vote on use of the pooled Affiliates' Fund.	■			
Mentoring research projects related to the Affiliates' needs.	■			
Option for non-exclusive R&D use license to Affiliate Fund research.	■			
Six month option for commercial license to Affiliate Fund research.	■			
Annual CMI Meeting, for networking, input and early access to research results.	■	■		■
Access to CMI researchers for brainstorming and recruitment.	■	■	Limited to the project	■
CMI newsletters.	■	■	■	■
Priority notification of inventions available for licensing.	■	■	■	■
Access to CMI expertise & unique capabilities.	■	■	■	■
WFO, CRADA or other agreement to sponsor project work.	Optional	Optional	■	Optional

Thank You!

Questions?