Critical Materials Institute

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11 Corporations, 7 Universities, 4 National Labs
Led by the Ames Laboratory
6/1/2013 – 6/30/2018

Alex King, The Ames Laboratory
CMI Director

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Arlington, VA
June 13-14, 2017

CMI Accelerating Energy Innovations

Critical Materials Institute

AN ENERGY INNOVATION HUB

Advanced Recovery, Inc.

AAE Where Power, is Saved

ARNOLD MAGNETIC TECHNOLOGIES

CYTEC SOLVAY GROUP

Eck Industries, Inc. Specialists in Premium Aluminum Castings

EEC ELECTRON ENERGY CORPORATION

INFINIUM

GE

OLI systems, Inc.

RioTinto

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

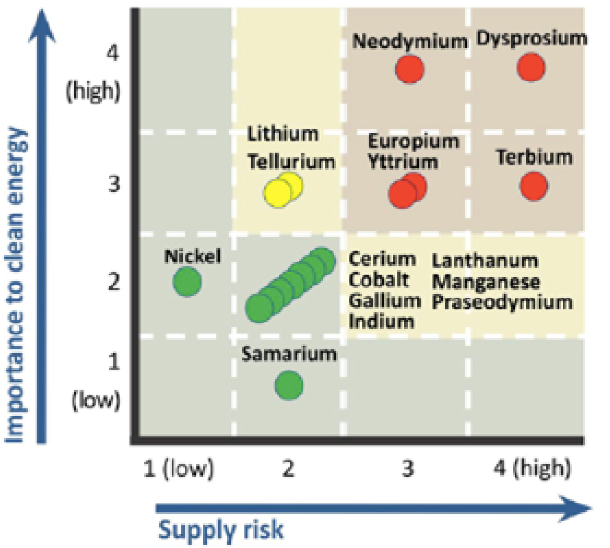
Project Objective

Wind turbine gearbox failure.
Gearboxes are unnecessary if you have magnets strong enough to enable direct drive generators. Today, that means $Nd_2Fe_{14}B$.

- CMI's primary goal is to assure the supplies of materials necessary for advanced manufacturing.
- Certain materials, such as rare earth elements, provide essential functional properties. They often have no easy substitutes, and if their supply chains are vulnerable they can constrain technology adoption, design choices, or manufacturing locations.
- While needs for materials emerge on very short timescales, solutions typically take decades. We strive to make solutions available when they are needed.

Technical Approach

- Address materials that have been identified to be critical for U.S. manufacturing, in the 5-15 year timeframe.

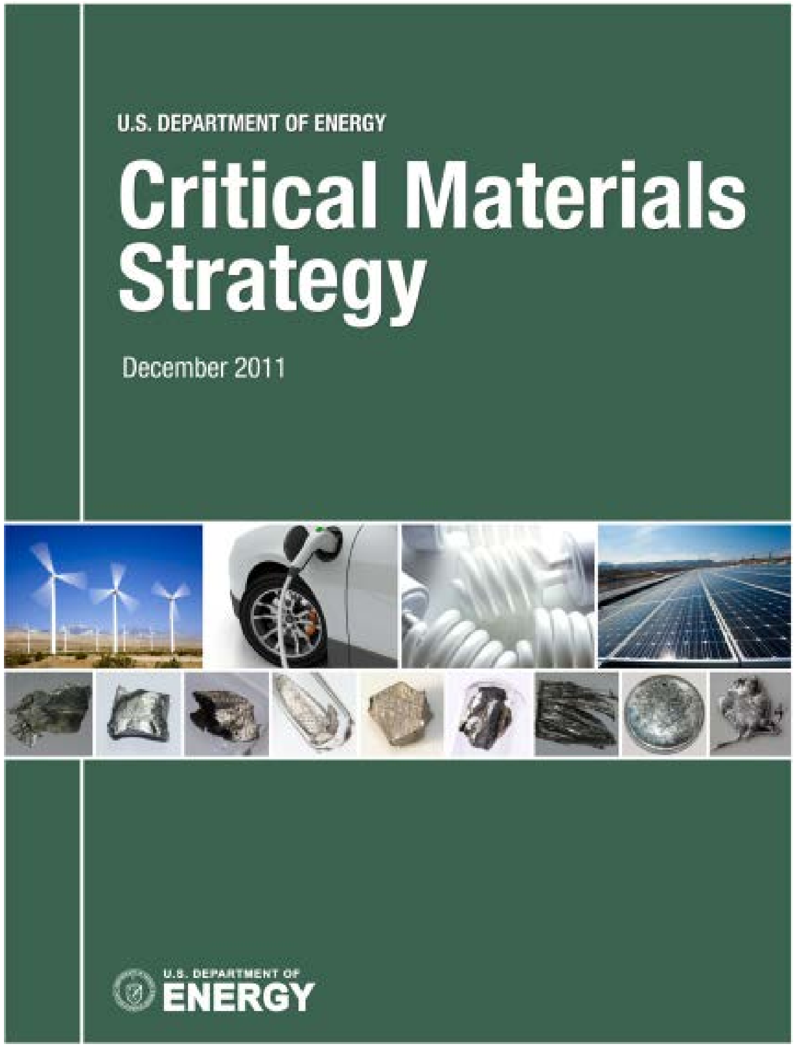


  - We identify specific barriers to technology deployment and remove them through early-stage applied research.
  - Research teams include materials producers and users (OEMs), along with university and national lab researchers.
  - Speed and agility are key. We compete with alternative solutions, including technology substitution.

Technical Approach

- Find ways to:
  - diversify 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.*



Technical Approach

- CMI is the established resource for delivering critical and strategic materials solutions.
    - It has unique skills, equipment and information relative to critical materials.
    - It provides an innovative ecosystem in which industry, academia and government share information and contribute to solving critical materials challenges.
    - It sustains cutting edge knowledge in relevant fields, and applies it to industry and societal needs.
    - It provides foresight into emerging factors that may affect materials criticality.
    - It stands ready to respond to emerging problems.

Lessons learned: *Materials and Technologies*

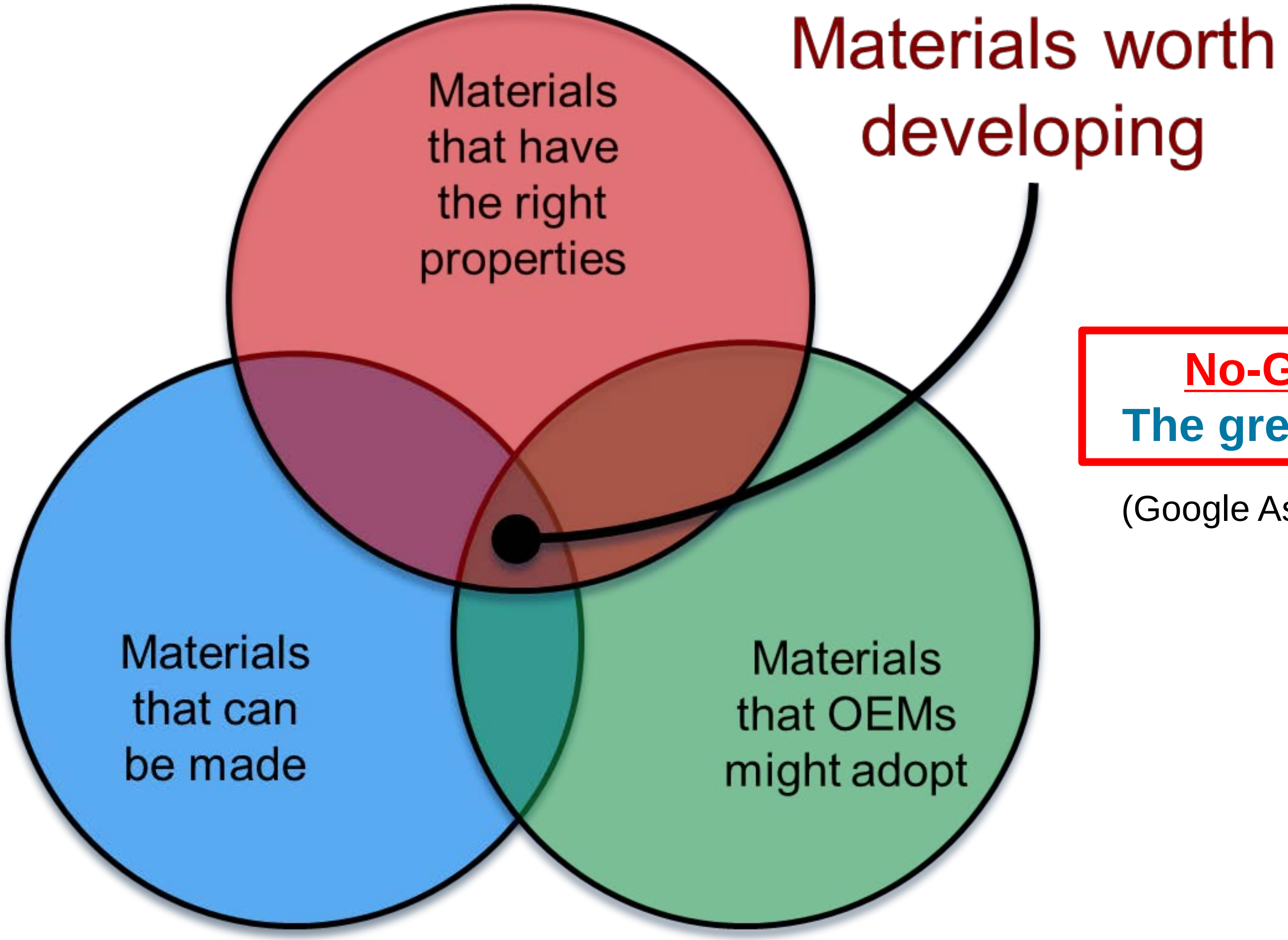
- It is often easier to replace a technology than provide a material for an existing one.
  - Wind is the fastest-growing energy source in the U.S., but land-based wind turbines use gearboxes instead of direct-drive generators, to avoid the need for rare earth magnets.
  - Lighting moved rapidly to LEDs, 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, at least partly because of concerns about Nd and Dy supplies.

- Demand destruction follows price spikes.

Technical Innovation

- Current approaches are too slow to have an impact
  - *Source Diversification*: Mine development takes about 15 years, and has costs in the billions of dollars.
  - *Material Substitution*: Development and deployment of new materials takes an average of 18 years.
  - *Recycle and Reuse*: There are no empirical data to suggest how long it takes for recycling programs to have an impact.

CMI's Approach



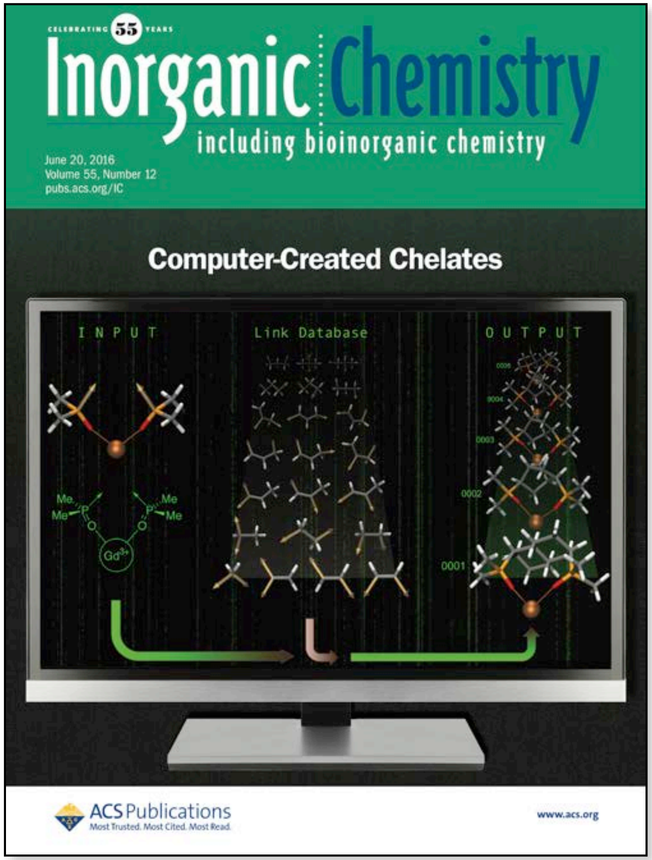
No-Go decisions:
The great accelerators.

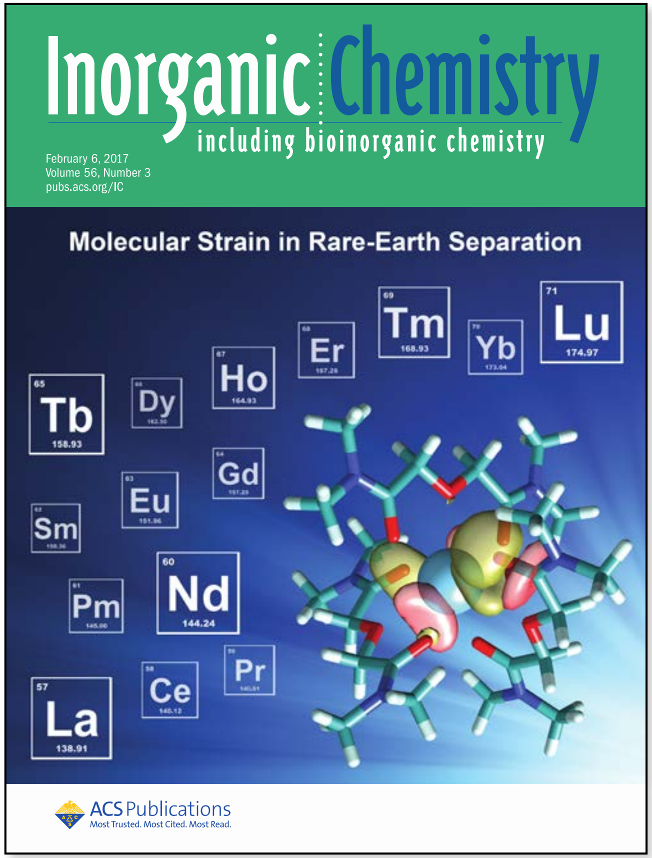
(Google Astro Teller's TED talk)

Lessons learned: *Source Diversification*

- Financing (investment) is the rate-limiting step for starting a new mine.
- Co-production (Multiple Elements from Single Sources) is a huge challenge.
- 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.

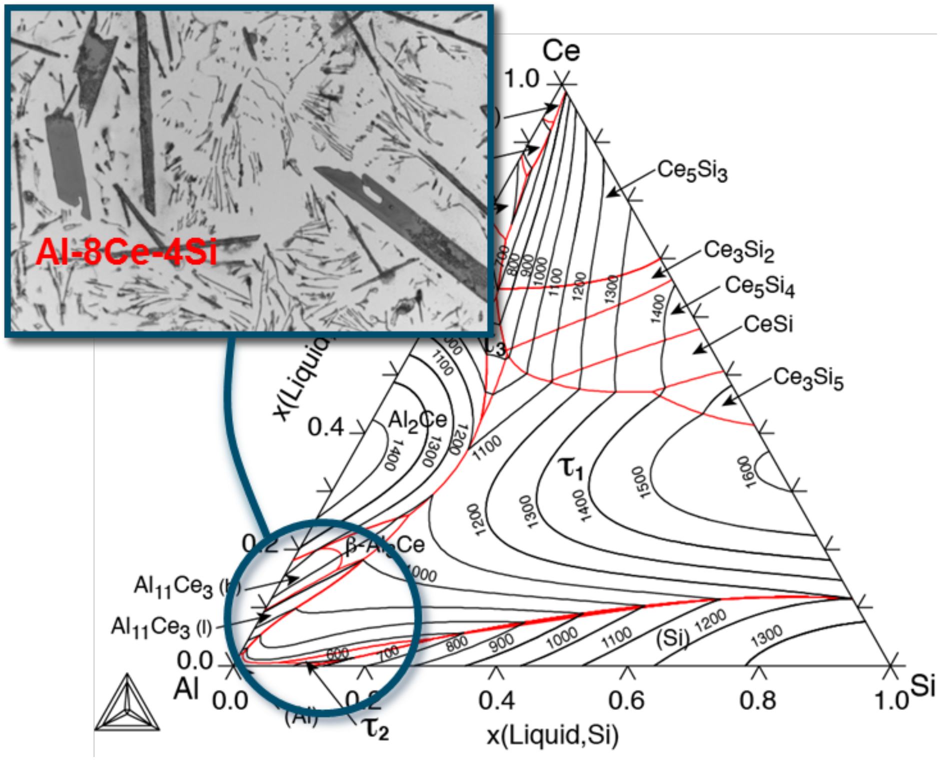
Computerizing ligand design





- Customized ligands to improve selectivity in chemical separations.
- Computer-designed ligands have been synthesized and are undergoing lab-scale testing.

Using up the by-products

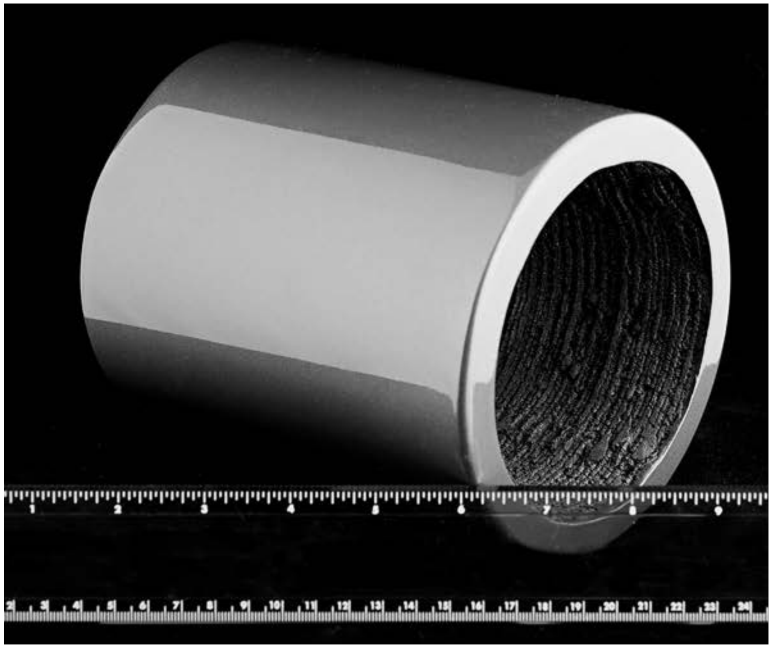


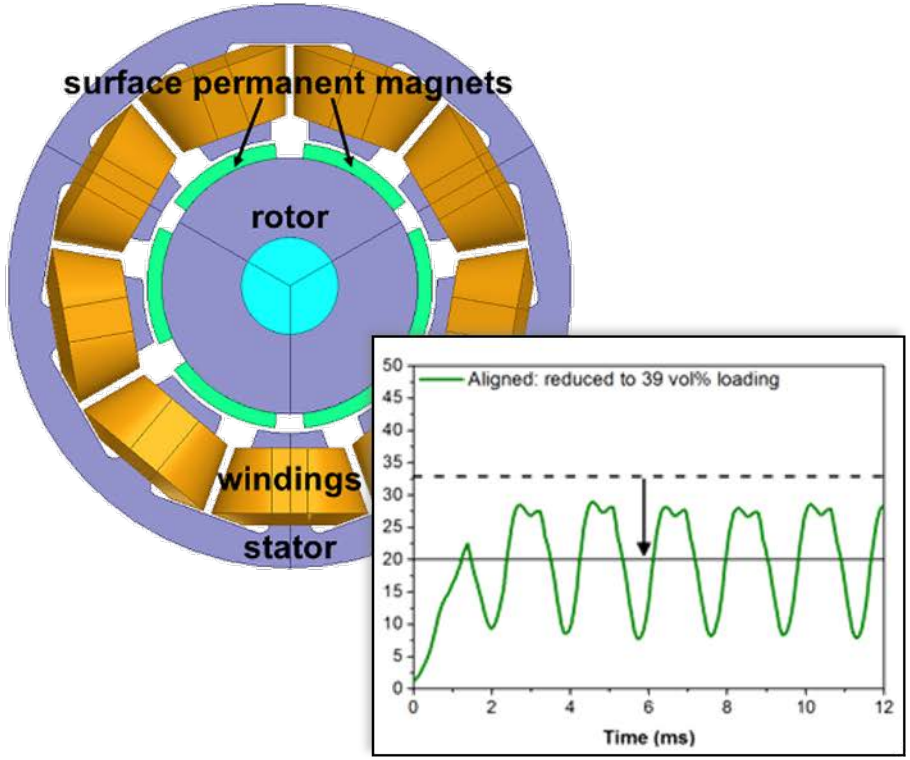
- New class of aluminum-cerium alloys outperforms existing options.
- Generates uses for over-produced cerium, enhancing rare earth mine economics.

Lessons learned: *Materials Substitution*

- New materials *can* be developed at an accelerated pace.
  - CMI has a green phosphor *and* a red phosphor in production testing in our fourth year of work.
- New materials are most 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.

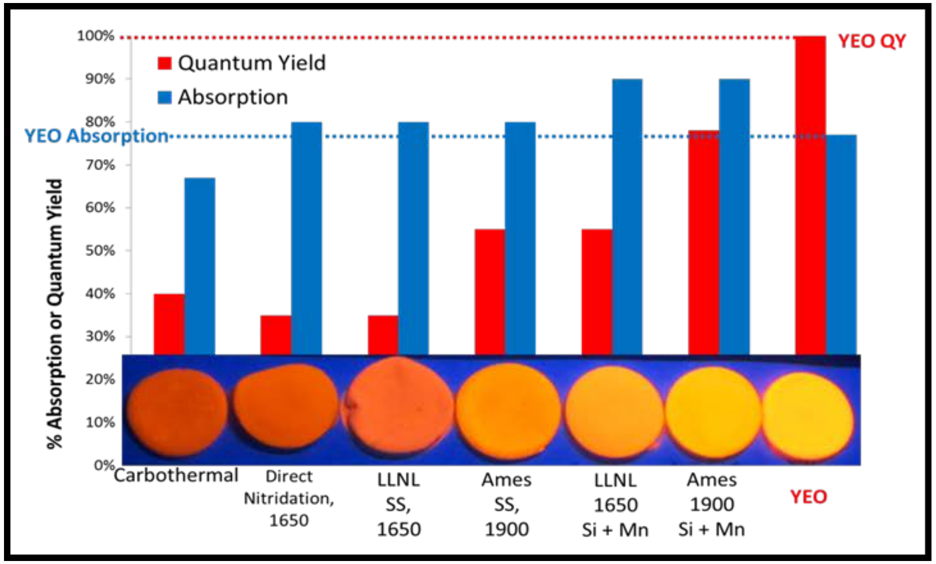
Printable magnets



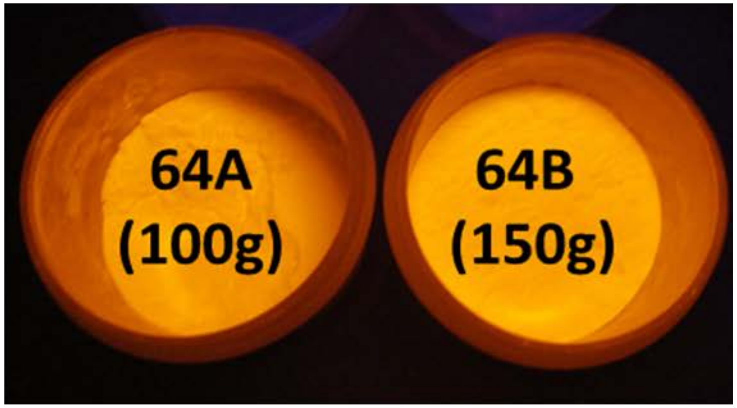


- Additive manufacturing reduces material wastage and allows the creation of novel shapes.
- Shapability allows electric motors to be manufactured using less critical materials.

New light-emitting materials



Improvements in AlN:Mn performance



Performance holds *or improves* with scale-up.

- Theory and computation indicated that AlN:Mn could replace europium-based red phosphors.
- Synthesis and subsequent process refinement have yielded a phosphor that is now in production testing.

Lessons learned: *Recycling and Reuse*

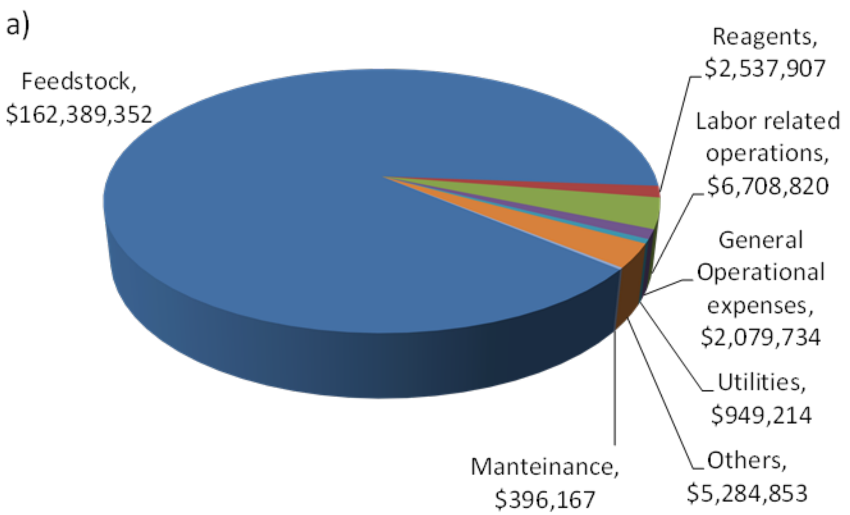
- You don't recycle a material, you recycle a device.
  - This is a pathological MESS.

- 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.

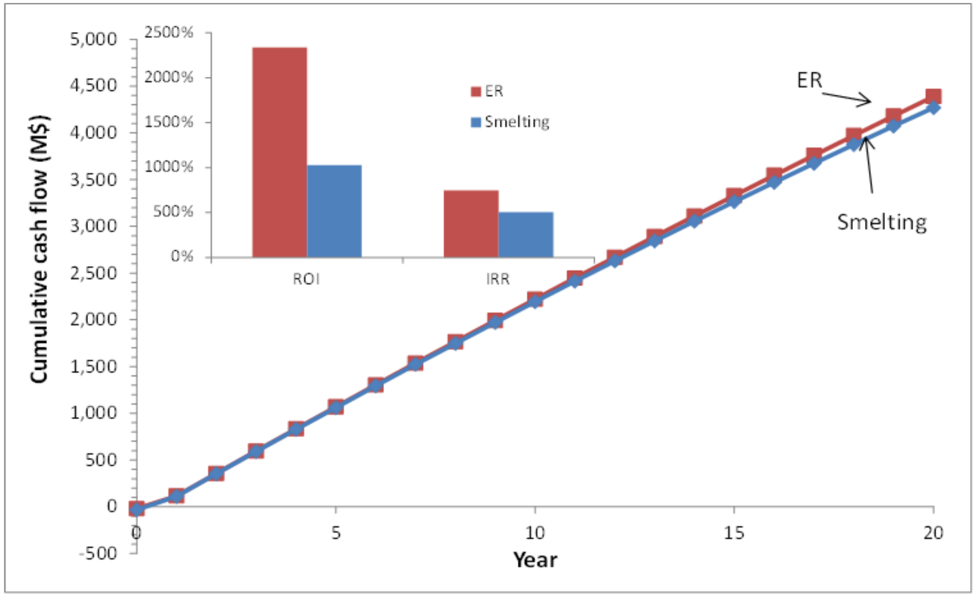
- Critical mass is important.
  - Economies of scale are essential to solving front end costs, and making sales.

- 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.

Economic Analysis of Electronics Recycling



Cost distribution for electro-recycling



Comparison of electro-recycling to smelting

- Economic analysis guides research agendas, helping us to apply resources where they have greatest impact.
- Separations processes represent a small fraction of the total cost of recycling. Bigger impacts can be obtained by addressing feedstock costs.

Automating magnet harvesting from HDDs

Historical best rates

2006	Manual disassembly	8/hr
2012	Tumbler screw extractor	100/hr
2014	Punching (CMI)	~1,000/hr
2016	Robotic disassembly (CMI)	>1,000/hr

- Cost-effective extraction of magnets from hard disk drives enables economic recycling.
  - Prototype system development with Oddello Industries.
  - License issued to Momentum Technologies, Inc.

Aligner

Punch

Separated section containing magnets

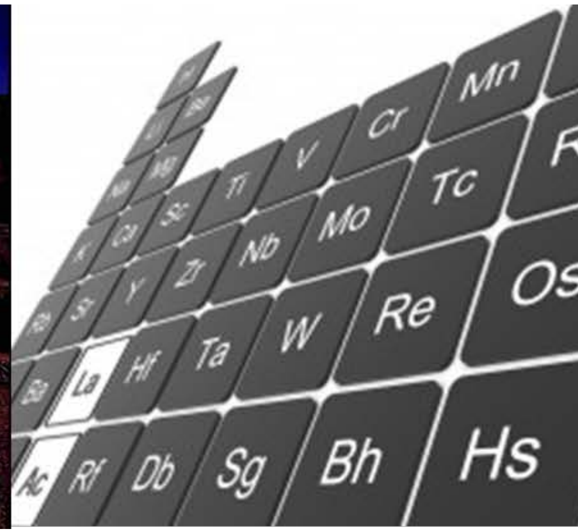
Technology Adoption

- 60+ invention disclosures
- 35+ patent applications
- 2 patents awarded
- 5 technology licenses issued

Original Five-Year Goal

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

Results and Accomplishments

At the end of Year 4, the original goals have been met and new targets have been established:

- 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.

Project Management & Budget

- Project duration: five years (ends on June 30, 2018)
- 34 individual projects, each with quarterly progress measures, annual milestones & go/no-go decisions

Total Project Budget	
DOE Investment	$120 million
Cost Share	$6 million
Project Total	$126 million