Critical Materials Institute

AN ENERGY INNOVATION HUB

Congressional Testimony

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SUMMARY

The Critical Materials Institute (CMI) exists to mitigate the challenges posed to the manufacturing sector by materials that provide essential functions or capabilities, but are subject to supply risks.

The hub focuses on materials used in clean energy technologies, but many of these have broader uses, notably in the area of defense. Prominent among the hub's research targets are rare earth elements that are used in magnets, lighting and displays; and lithium which is used in rechargeable batteries.

CMI follows the Critical Materials Strategy developed by the U.S. Department of Energy, particularly addressing opportunities to (1) diversify supply, (2) develop substitute materials, and (3) improve efficiency of materials use, and reduce wastes. Within its first five years, the hub will develop, and have adopted by industry, at least one technology in each of these three areas.

The hub adopts an integrated approach, bringing together capabilities across a wide spectrum of basic and applied research, and researchers across a wide range of backgrounds, to accelerate the achievement of specific technological goals. After two years of operation, this approach is already proving its worth.

CMI has developed 34 inventions with significant potential for impact, and has made four patent applications. It is very close to having one replacement material adopted, and is within a year or two of a second. These results have strong potential for providing returns to the U.S. taxpayer.

The hub has earned an enviable international reputation and has been described as the "gold standard" in its field. Several other countries are modeling their own efforts after CMI.

CMI's team includes more than 300 researchers and staff across six corporations, seven universities and four national laboratories.

Background

In 2010, the prices of materials based on the rare earth elements spiked, in some cases rising to 25 times their prior values. While these materials are used in relatively small quantities, they are functionally essential, and presently irreplaceable in a wide range of industries, including the production of clean energy technologies and modern weapons systems.

The 2010 price spike resulted from uncertainty about the ability of supplies to keep up with demand for neodymium and dysprosium in high-performance magnets, and yttrium, europium and terbium in high-efficiency light sources.

As supply uncertainty grew, technology choices were impacted across the U.S.:

- Direct-drive wind turbines are quieter, more efficient, and less failure prone than competing technologies but they represent less than 1% of utility-scale installations in the U.S., because of their demand for neodymium and dysprosium. Almost all utility-scale wind turbines in the U.S. use alternative technologies requiring gearboxes, that are noisier, less efficient and more failure-prone.
- Rules promoting the general use of high-efficiency T5 fluorescent lamps were delayed in the U.S. because of the technology's demand for europium and terbium.

Analyses focusing on a variety of different industries, countries and regions have identified several additional materials that are at risk for similar supply disruptions and downstream impacts on technology. These are called critical materials, and industry's vulnerability to them has become a worldwide topic of concern.

Responses to supply-chain shortfalls generally include three approaches:

- Diversification of supplies. A major factor causing criticality is the concentration of supply in a single company, country or region, resulting in unacceptable supply uncertainty, and, hence, unacceptable supply risk.
- Development of substitute materials. The need for materials properties and functions, such as magnetism or fluorescence, which are conferred only by specific elements is also a major factor in making those materials critical.
- Minimizing the draw-down of existing supplies by improving manufacturing efficiency and enhancing recycling and re-use. When the rate of use approaches the rate of production, a material tends to become critical.

In order to be effective, these solutions must be cost effective, and achievable in a timeframe that compares with the speed with which supply shortfalls emerge.

The Critical Materials Institute exists to promote these solutions. Its work focuses initially on the elements neodymium, dysprosium, europium, terbium, yttrium and lithium, but its methods and approach will be applicable to other critical materials as they emerge.

What are the primary research and development goals of CMI? Since the hub was organized by DOE, what progress has been made towards these goals?

5-Year Goal

- To develop at least one technology and have it adopted by industry in each of the three priority areas identified by the DOE *Critical Materials Strategy*[1]: (1) diversifying supply, (2) developing substitute materials, and (3) improving efficiency of materials use, including reducing wastes.

Research

- CMI's current research focuses on neodymium and dysprosium (used in permanent magnets); europium, terbium, and yttrium (fluorescent and LED lighting); and lithium (batteries)—all identified as "critical" or "near critical" in DOE's Critical Materials Strategy.
- CMI aligns its research and development efforts with the three priorities of the DOE *Critical Materials Strategy*. In addition, CMI carries out research cutting across and supporting progress in these areas, including fundamental research in chemistry and physics, environmental impacts, and economic and business analysis.

Basic Information

- The Critical Materials Institute (CMI) began operations on June 1, 2013, and is one of four Energy Innovation Hubs funded by the U.S. Department of Energy (DOE).
- Its mission is to assure supply chains of materials essential to clean energy technologies—enabling innovation in U.S. manufacturing and enhancing U.S. energy security.
- Led by the Ames Laboratory, CMI brings together facilities and expertise located at six U.S. corporations, seven universities, and four DOE national laboratories. A number of additional corporations are collaborating with CMI in a range of capacities.

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[1] *Critical Materials Strategy*, US Department of Energy, Washington, DC, December 2011.

Achievements to Date

Among CMI's accomplishments so far, we have:

- Formally announced 34 invention disclosures and filed four patent applications.
- Published 30+ archival technical papers.
- Made over 70 presentations at conferences and meetings, with the majority of them being keynote or invited presentations.
- Drafted a new materials criticality matrix, assessing "what is critical" for clean energy technologies looking fifteen years into the future.

Supporting and facilitating these achievements, we have:

- Built an outstanding and highly capable research team of over 300 scientists, engineers and support staff.
- Completed all major equipment acquisitions, providing unique and focused tools for the hub's work.
- Generated detailed technological roadmaps for all of our research projects.
- Established a broad network of industrial collaborations.
- Established an exceptional level of global visibility.

How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

CMI is funded through DOE's Advanced Manufacturing Office (AMO), an applied energy program, but it is headquartered at the Ames Laboratory, which is an Office of Science national laboratory. By design, the hub is integrated across the spectrum of basic and applied research as necessary to achieve its goals, and has the ability to draw on resources developed by the Office of Science, as needed, in pursuit of the goals of the Advanced Manufacturing Office. The hub has the structure and the connectivity to access facilities from the Office of Science and EERE as needed.

For one example, in pursuit of new magnet materials to replace neodymium-iron-boron, we have adopted an approach that includes computer simulations, experimental exploration of candidate alloy compositions using combinatoric methods, and rapid analysis and testing. These methods are each founded in tools previously developed among CMI's partners, largely with Office of Science support, but they have been advanced and made specifically useful for CMI's purposes by the hub itself. Among many other advances of this kind, the hub has:

- Developed the first successful computer model for predicting magneto-crystalline anisotropy in proposed new materials - an essential contribution from fundamental condensed matter physics in support of developing new magnet materials.
- Developed a new tool, based on additive manufacturing technologies, which allows for the rapid production of target magnet compositions at manufacturing scale. This tool along with the two below, was used to validate the computer code described above.
- Added new capabilities for rapid structural and chemical analysis of materials that take advantage of the additive manufacturing tool described above.
- Added high-throughput magnetic testing capabilities.

All of these capabilities work with each other to meet the needs of the hub, but they also enhance the capabilities of other Office of Science and AMO programs. Bringing together capabilities across all of CMI's participating institutions, across a wide spectrum of basic and applied research, we have created a range of candidate materials for new high-performance magnets.

While it is conceivable that these advances could have been made without the existence of a hub, under the usual operating procedures, even this simple case would have required four separate projects to have been funded through regular Office of Science or EERE programs to develop the tools, and then a fifth funded program to work on the desired material. We hesitate to speculate about the likelihood of all of these components coming together without the existence of a hub.

As illustrated in this example, CMI identifies significant expertise, capabilities and tools from across the DOE complex and its other partners, enhances them as needed, and integrates them in the context of research efforts to meet specific needs. This enables us to obtain essential outcomes rapidly, across a wide range of technology readiness levels (TRLs) in support of our applied research and development goals.

In addition to being integrated across technology readiness levels (TRLs), the hub brings together the full range of technical skills needed to address challenges at any point in the supply-chain, from extracted minerals, to materials, to components, to devices, to re-use and recycling, including economic analysis of every aspect. The hub's economic analysis capabilities provide an essential filter, helping us to identify the most promising technological points of intervention and focus our resources where they are most likely to have the desired impact.

CMI's ability to identify key points of intervention, and to integrate capabilities and facilities to address them, enable it to accelerate the development of solutions to supply-chain challenges very significantly.

In the case of finding replacement phosphors for fluorescent lighting, for example, after two years of work we are already very close to getting one new material adopted by industry, and a year or so away from a second. This compares with the typical materials adoption timescale of around 18 years. As noted in the background section, the ability to respond quickly is a key capability in addressing supply-chain challenges, and we are already demonstrating significant advancements in this area.

How does the private sector interact with CMI? In what way does CMI prioritize technology transfer of technologies developed at the hub?

CMI has several means of interacting with corporations in the private sector and seeks to be flexible and responsive to industry needs. It has been our observation that progress toward our goal of technology adoption is accelerated – often very considerably – when industry input is obtained early and often during our research efforts. Our interactions with industry allow for and promote increasingly intense collaborations as a company moves from one mode to another. CMI covers a wide range from basic research to commercialization, and the discussion, below, moves generally from the basic end of the spectrum toward industrial applications.

Our cross-cutting research efforts produce basic knowledge, information or tools that are of specific value to the applied research, development and demonstration (RD&D) projects described below. These projects generally do not produce intellectual property and are characterized by very low technology readiness levels (TRLs). Research outcomes from this type of work are generally published in the open literature and made available through the usual means.

Our research and development efforts on source diversification, materials substitution and minimizing the draw-down of existing resources all proceed to progressively higher TRLs, and every project has a specific commercialization goal and a roadmap that guides the decision-making process for the project. Most of these projects interact with the private sector in one or more of the modes described below:

- Informal interactions, usually facilitated by appropriate bilateral non-disclosure agreements (NDAs), allow us to respond to inquiries from the corporate sector, or to reach out to corporations that might have information useful to CMI researchers, or potential interest in CMI-developed technologies. These interactions may lead to enrollment of the corporate entity in our Affiliates program, or as a Team Member. Interactions of this type are increasingly being conducted in the form of industry-sector workshops.

- CMI's corporate *Affiliates* share information with CMI's researchers. Contributing funds through a sliding scale of fees, they provide input and advice to CMI researchers and have early access to CMI's research results. The Affiliates program is designed to cultivate potential corporate Team Members. Affiliates sign a uniform joint NDA, allowing them access to federal or affiliate-funded CMI information.

- CMI's corporate *Team Members* are actively engaged in our research programs on pre-competitive technologies. They contribute materials, facilities and/or expertise. In many cases they are anticipated to be the primary partners for commercialization of CMI-developed technologies. Team Members are bound by a uniform joint NDA and an intellectual property management plan (IPMP), which provides them with the right of first refusal to license CMI-developed technologies.

- Any corporate entity has the right to negotiate a license to the federally funded IP developed through the CMI that is not exclusively licensed in a field or fields of use to Team Members.

- CMI also has the ability to collaborate with the private sector through Strategic Partnership Programs (SPPs) and Cooperative Research and Development Agreements (CRADAs) that, respectively, involve the corporate entity paying for specific projects to be performed, or collaborating in a specific research project on a "funds-in" basis. In both cases, the sponsoring corporation may own new IP generated by the project, subject to standard federal stipulations. These funding mechanisms are appropriate when a technology advances from the "pre-competitive" stage to "pre-commercial."

All projects carried out under the auspices of CMI are targeted toward commercialization, and to that extent, prioritization takes place initially, when the hub elects to pursue (or drop) a particular line of research. Decisions to add or drop projects are made annually, as the hub approaches the anniversary of its inception, and choices are based upon the following criteria:

- Pre-competitive nature. Work initiated by the hub is not intended to benefit any single corporation, but to have potential for broad utilization among all corporations in the appropriate industry sector.

- Necessity for impact. The work must have a reasonable prospect for success, and if successful, a strong prospect of making significant impact on the supply chain of one or more critical material.

- Cost considerations. The technology will meet or exceed the cost points necessary for adoption by the appropriate industry sector(s). Costs include the cost of the material, and, usually more significantly, the costs to integrate new materials and/or processes into each company's product lines.

- Timeliness. Technologies developed by CMI must enter the industrial sector at an appropriate time in the product development lifecycle in order to have an impact.

- Preference for U.S. companies. There should be at least one U.S.-based company at which the technology would be considered for adoption. Foreign corporations with substantial operations in the U.S. are also considered as commercialization partners.