Technology Transitions Case Study
Critical Materials Institute (CMI)

CMI: Accelerating Energy Innovations

The Critical Materials Institute (CMI) is one of DOE's four Energy Innovation Hubs. Created in response to the "rare earth crisis" that emerged in 2010, the mission of the Critical Materials Institute is to assure supply chains of materials critical to clean energy technologies—enabling innovation in US manufacturing and enhancing US energy security. It began operations in June, 2013.

Although rare earth elements are high on every list of critical materials, not all rare earths are critical, and not all critical materials are rare earths. CMI addresses any material that is subject to supply risks and essential for an existing or emerging clean energy technology.

One of the Grand Challenges in dealing with critical materials is the need for technological solutions on relevant timescales: while materials shortages can become crises in a period of just a few months, materials research and development typically takes more than a decade to deliver solutions to industry. CMI is organized to enable solutions to be delivered at a significantly accelerated pace, and it is beginning to demonstrate success in meeting this goal. The Hub adheres to the principle that the appropriate role of federally funded research is to develop technological options, leaving the marketplace to decide which ones are commercialized; but it also takes care to obtain input from the marketplace as it develops technologies, in order to avoid using its resources to pursue solutions that will be of no interest even if they meet the technological criteria. Early and frequent input from its industrial partners plays a key role in focusing CMI's resources to meet its goals, and is the primary benefit from adopting a consortium approach.

Foundations

The CMI partnership was initially forged during the preparation of a proposal in response to DOE's call for a Critical Materials Hub. Recognizing that the objective of the Hub was to provide secure supply chains, CMI gathered a team of corporations that spanned the entire materials lifecycle, from mining, through processing, to product manufacturing and recycling to guide the development of its proposal. In addition to full coverage of the materials lifecycle, it was necessary to engage expertise across a spectrum from fundamental science to applied technology, leading to the inclusion of four different national labs, seven universities and half-a-dozen companies, many of which have applied research capabilities, too. The team is rounded out with an economic analysis group that helps to anticipate changes in the criticality landscape, identify key points of intervention, and quantify the contributions of CMI.

Once CMI was funded, the partnership was formalized under an Intellectual Property Management Plan and through subcontracts for research to several of the partners (Team Members). Corporate membership has been expanded through the creation of a fee-based Affiliates Program, and extensive outreach efforts that lead to the enrollment of new corporate Members and Affiliates.

Prepared in response to formal guidance and a request by Sam Baldwin, Ellen Williams and Charles Russomanno of the U.S. Department of Energy (DOE) for input into the DOE Industrial Consortia Initiative and the 2015 DOE Quadrennial Technology Review.

The primary funding for CMI comes from DOE EERE AMO and cost-sharing is provided by its corporate Team Members. The Affiliates Membership Program is funded through annual membership fees. It is anticipated that there will be both CRADAs and SPPs (formerly known as WFOs) as the program matures.

Impact

In many cases today, design choices for clean energy technologies are being affected by the availability – or more often the lack – of certain key materials. The location of manufacturing is also frequently determined by access to materials.

- When DOE sought to impose regulations to require the use of T5 fluorescent tubes in place of the older, less efficient T8 technology, lamp manufacturers protested that this change would require greater supplies of europium and terbium, which are in short supply. Lacking an immediate solution for this supply-chain challenge, the proposed regulation was tabled.
- Direct-drive wind turbines are more efficient, quieter, and more reliable than hybrid-drive systems which utilize large gearboxes; but direct-drive units require high-strength magnets made of neodymium, iron, boron and dysprosium. Because supplies of neodymium and dysprosium are uncertain in the US and Europe, the vast majority of wind turbines there are hybrid-drive systems, while China has a significant fraction of direct-drive wind turbines in its inventory.

CMI will be successful when supply constraints such as these are removed as a factor in both the design of clean energy technologies, and the location of their manufacture.

There are fundamentally three technical approaches that can be used to solve a shortage of any material or resource:

- Find more, or
- Find something else that meets the need, or
- Live within the existing supplies by using less.

CMI addresses all three of these in research efforts that are designed to have the maximum impact in the minimum time. The Hub therefore has three R&D Focus Areas, aligned respectively with the strategic approaches outlined above. They are:

1. **Source Diversification**
   Supply chains are especially fragile when there is only a small number of providers of a given material. CMI seeks to develop technologies that make traditional mining less costly and/or more efficient so that more mines are able to survive in the marketplace. It also develops technologies for accessing new, non-traditional sources for critical materials, such as co-production of rare earths from fertilizer processing.
2. **Materials Substitution**
   Reliance on a single source becomes significantly less burdensome when alternative materials

are available to meet the same needs as a critical material. CMI is developing alternatives to rare earth elements in lamp phosphors and high-strength magnets.

3. **Reuse, Recycling and Improved Manufacturing Efficiency**
   Despite their value, many critical materials end up in landfills or distributed into the environment during manufacture or at the end of life of a product or device, because the cost of recovery is too high. CMI is developing technologies to reduce waste and recapture waste materials more economically.

In many cases the technologies under development in CMI are in direct competition with each other for market adoption: this is a healthy and invigorating feature of the Hub as it strives, within its first five years of operation, to develop at least one technology adopted by U.S. companies from each of these three Focus Areas.

CMI also has a fourth R&D thrust:

4. **Crosscutting Research**
   While the first three thrust areas serve the needs of industrial "clients" the primary clients of this thrust are researchers in Focus Areas 1, 2 and 3. It provides access to specialized tools and advanced expertise in relevant basic science disciplines, in addition to ecological assessments, and economic analysis.

Principles for Industry Engagement

"Business as usual" in this area of research tends to produce results that are adopted by industry in 10 to 20 years or more, and CMI is seeking to reduce that to less than five. It is essential to keep all efforts well targeted and closely on track, and to focus resources on the most promising lines of research. To this end, CMI's leadership strives to maintain a clear line of sight from every research effort and activity to its potential industrial application. We seek industrial input at every stage, through a number of formal and informal processes, facilitated by the following structures:

CMI Team: Team members help strategize and formulate the R&D priorities and projects listed within the successful CMI proposal. Team members also worked with the CMI Commercialization Manager to develop and execute the Intellectual Property Management Plan (IPMP). Initial Team Members were chosen based on ability to contribute, willingness to engage, diversity with respect to the supply chain, and the absence of conflicts of interest. Each Team Member has either a research subcontract from the CMI and/or provides cost sharing funds.

Each Industry Team Member has representation on the **Industry Council**, which helps CMI management determine the research agenda and the commercialization strategies for discoveries, as well as has the role and responsibility within CMI to provide commercialization perspective and needs to the FA Leads, Commercialization Manager, and Technology Deployment Manager.

CMI Affiliates: Each affiliate organization pays an annual membership fee based on the organization size and type and signs a membership agreement which outlines the benefits and covers the confidentiality expectations. There are two levels of membership: Full and Observing. There are three organization types defined to determine cost—Large Entities (>= 500 employees); Small Entities (<500

employees); and Start-ups (<5 years old and/or have not completed an IPO). The **Industry Council** includes two members elected from among the Full members of the Affiliates Program

Industry Council: CMI's industrial partners contribute to the success of the CMI by not only becoming members of the Industry Council, which will guide the CMI on the quality and direction of the scientific research program, but will participate in the research efforts as well. Major benefits derived from being an Industry Council member will be the opportunity to receive a non-exclusive license for R&D to one or more of DOE funded technologies arising from the research undertaken by CMI. The Industry Council will also have a six month option to negotiate a commercial license to DOE funded, CMI Intellectual Property.

Technology Workshops: CMI holds several workshops each year, focusing either on a technology or an applicable research tool or method. Recent examples include magnets, thermodynamic tools, ionic liquids, and roadmapping. These workshops are usually open to non-member industrial representatives and always begin by listening to the needs and desires of the corporate sector as a precursor to discussion on how best to focus CMI's resources.

Roadmaps: CMI has created detailed roadmaps for each of its individual research efforts, showing where, when and how key decisions are expected to be made and results are handed off for further development. Industry partners, and particularly potential technology adopters, are engaged in the key decisions and also in ensuring that the products to be handed off continue to have value as circumstances change. The roadmap team is now linking individual project roadmaps together through shared hand-off points, and also developing industry-level roadmaps to ensure that CMI products reach maturity in time to make an impact.

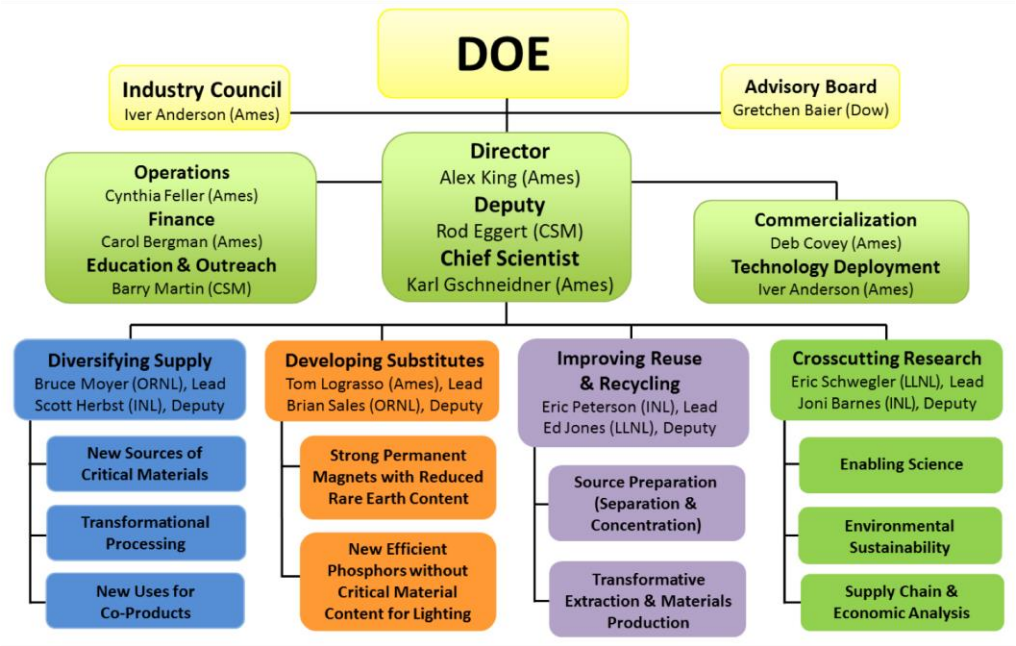
Mini-consortia: All of CMI's projects are undertaken by subsets of the Hub's personnel and resources, collaborating with and drawing upon the resources of the rest of the Hub. These teams may be regarded as mini-consortia, and it has been found that the most effective ones are those that contain more than a single industrial partner, with the ideal group including a materials producer and a potential industrial user, along with several key researchers. This ensures that any material or materials technology invented by the team has both a potential user and a potential producer.

Through all of these structures, and also through many informal interactions with corporations, CMI brings life to its first value statement: "We Listen."

Oversight, Review and Response

CMI has an appropriated budget of $25M per year, and it receives about $1M per year in cost-matching support, primarily from its industrial partners. It supports work carried out by more than 300 individuals spread across the nation in industry, universities and national labs. A certain amount of structure is needed for the purposes of efficient management in an entity of this size and complexity, but it is necessary to strive to maintain flexibility and the ability to redirect resources as needed. The structure of the Hub must respond to the needs of its program, rather than *vice versa*. CMI's current organizational chart is provided below, reflecting the Focus Areas described above. These are robust,

and are applicable to any critical material that might arise. The details within each Focus Area, however, have been adjusted to meet emerging needs and opportunities as they have arisen.



CMI maintains a clear focus on its goals through several layers of formal review.

- Annual reviews are conducted by an expert panel, convened by DOE, on the basis of a written report and a site visit. These high-level reviews assess the extent to which the Hub is operating cohesively and meeting its highest-level goals.
- Annual project reviews are conducted by the Leadership Team, on the basis of accumulated quarterly reports and a short written summary of achievements submitted by the project leader. These reviews assess the extent to which each project is meeting its goals, and addressing market needs as they emerge. This review can result in a project being terminated, merged, restructured or enhanced.
- The Advisory Board reviews overall Hub operations three times per year, providing advice to the Director.
- The Industry Council meets at least once a year and provides broad input on industry needs and directions.
- The Commercialization Council provides input on issues related to intellectual property generated by the Hub.
- Quarterly milestone reviews are conducted by the Hub Director and the program management in AMO. These reviews provide assurance that each project is making headway at an appropriate rate.

Beyond these are several levels of informal review. These include:

- Project highlights are presented at the beginning of each weekly teleconference of the Leadership Team.
- CMI's Director and Chief Scientist attend Focus Area and Thrust Area conference calls.
- Hub leaders and AMO managers make visits to most of CMI's research locations once per year.
- The Annual Meeting provides a forum for all of our projects to see and be seen by every level of participant in the Hub, including industrial members of all kinds.

As we strive to solve problems that are important to our partners, on a schedule that matches their needs, the most important feedback provided to CMI comes from our industrial collaborators. Industrial partners provide input on our research programs at key decision points, particularly helping us to identify lines of research that should *not* be pursued, allowing us to focus our resources on the most fruitful avenues.

All of our research projects have a commercialization plan, and a roadmap that identifies key timelines, decision points and deliverables. Each project also has clients who anticipate making use of the work developed by the project. The clients for our crosscutting research efforts from FA4 are typically R&D projects in Focus Areas 1, 2 and 3. The clients for our R&D projects in FA1, 2 and 3 are product or process development teams in industry. The clients for our economic analysis projects in FA4 may be in industry or in our own R&D projects across the Hub. These relationships are illustrated schematically in Figure1, which represents the knowledge flows necessary for the deployment of new technologies. Each layer represents a generic project roadmap. The lowest layer would be a roadmap for a basic science project in FA4. The middle layer would be in FA1, 2, or 3. The topmost layer represents the work of an industry partner. Information needs are fed downward from layer to layer. Information developed by the research projects is fed upward from layer to layer, and is intended to provide input that is both useful and timely with respect to the higher-level roadmaps. Assessments of progress toward meeting information needs flow downward, with broad input from higher layers, to inform specific decisions in lower layers. Using this structure on a continuous basis, industry feedback guides the development of our projects, keeping them on track to deliver their results when and where it has the most impact, and preventing them from devoting time and resources to unprofitable areas. This type of input is provided primarily in two modes:

- Regular project meetings and teleconferences, attended by industry partners and/or clients.
- Dedicated workshops with groups of industry partners who are potential clients for CMI's work in a particular area.

Impact

After nearly two years of work, carefully heeding the guidance of its industrial collaborators, CMI has announced 28 invention disclosures, across all three strategic thrusts, and four of these have resulted in patent applications because of corporate interest in adopting them. Several new patent applications are also in preparation. Commercial use of CMI-developed technologies is anticipated, well ahead of the end of the Hub's first five-year funding cycle, in all three areas.

In addition to the many technological innovations developed by CMI, it is preparing to release an updated analysis of critical materials for clean energy technologies, looking 15 to 20 years into the future. This will guide future research directions for the Hub and for others.

CMI's roadmapping efforts assess the impact of its R&D programs on materials supply chains for selected technologies. In the arena of wind power, making certain assumptions regarding the industry's technology choices and the scale of wind power development, it is shown that if all of CMI's materials production and recycling R&D programs bear fruit, they have the capacity to provide materials for enough high-strength magnets to allow direct-drive wind turbines to penetrate the market to a level of about 39%. Other anticipated changes in the supply chain provide an additional 22% of the necessary capacity, giving a total potential for more than 60% market penetration. This compares very well with the current penetration of less than 1%, and represents a significant impact on technology choices and engineering options.

CMI has become a recognized force in the area of critical materials and is widely sought out for information, advice and collaboration by other offices in DOE, other federal agencies, US corporations, and international critical materials research teams. The formation of new external collaborations is anticipated, in coming months.

Lessons Learned

- IP management plans, partnership agreements, conflict of interest plans, antitrust waivers and the structures of auxiliary organizations such as Affiliates Programs are subject to many non-obvious federal and/or agency requirements, and they take a great deal of time to get approved. It is essential to start these processes early and push hard to get them completed before the consortium starts work.
- Many industrial partner candidates are unable or unwilling to accept certain IP clauses or other provisions required to engage in the consortium. These barriers can be overcome if the value proposition is sufficient, but sometimes that cannot be achieved.
- An informal connection to an industrial concern is better than no connection, even if it creates management issues and IP control concerns.
- Technologies for promoting long distance collaboration among different institutions (notably videoconferencing and shared fileservers) are often incompatible with local cybersecurity implementations.
- Even the most effective videoconference is not as good as a face-to-face meeting. Budget for plenty of travel.
- All organizational structures promote "silo-ing" at some level: leadership needs to be creative in promoting collaboration, *e.g.* holding events that deliberately cross the organizational lines.
- With industrial collaborators: listen first, talk later.
- An hour of listening to an industrial partner can save a thousand hours of research.
- Industrial partners talk more freely when their competitors are not in the room – irrespective of the existence of an NDA.
- Understand the drivers of your industrial collaborators; they are not always obvious.

- Be rigorous in assessing your progress, and be flexible in adapting to changing market conditions.
- Focus on the smallest number of performance metrics that is possible. The ideal is one. Two is OK. Beyond three, your metrics start to lose value.

Critical Materials Institute: *Basic Facts*

Dates of Operation	**An Energy Innovation Hub initiated by AMO in June 2013. Continued funding anticipated through June 2018. (Renewable for one additional 5-year term).**

Goals	**Mission:**
	• Assure supply chains of materials critical to clean energy technologies—enabling innovation in US manufacturing and enhancing US energy security.
	Strategies:
	• Coordinate basic and applied pre-competitive research to bring technologies to the marketplace to strengthen the supply chains of critical materials in three ways:
	  ○ Diversifying the sources of critical materials
	  ○ Finding alternative materials
	  ○ Enabling more efficient use of existing resources
	Current Goals:
	• One technology adopted by industry in the US, in each of the areas named above.

Current Membership	• **Industry:** Advanced Recovery, Cytec, General Electric, Molycorp, OLI Systems, Simbol Materials,. • **National labs:** The Ames Laboratory, Idaho National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory • **Universities:** Brown, Colorado School of Mines, UC-Davis, Florida Polytechnic University, Iowa State University, Purdue, Rutgers • **Affiliate Members:** ***(Companies)***— Etrema, Infinium, Phinix, Rare Element Resources, Tasman Metals; ***(Universities)***—Montana Tech; ***(Other)***—ASTM International
Significant Achievement	• 28 invention disclosures and 4 patent applications in the first 21 months of operation.
Organizational Structure	• Advisory Board has representatives from all national lab and university team members, plus elected representatives from the industry team members. The Board meets three times a year. • The Industry Council has members from all of the corporate Team Members of CMI who choose to send representatives, and elected members from the Affiliates Program. It meets at least once a year and provides broad input on industry needs and directions. • The Commercialization Council comprises the IP managers from each of the participating institutions. It advises on technology transfer policies and serves to resolve disputes. • Full-time Director provides scientific leadership and administrative oversight. • The Leadership Team works with the Director, and comprises the Deputy Director, Chief Scientist, Operations Manager, Finance Manager, Commercialization Manager, and the four Focus Area Leads. The Leadership Team meets weekly to coordinate CMI research, management and operations. • The Ames Laboratory is the recipient of the DOE funds. • Additional work through WFOs and CRADAs between specific partners is handled by those partners, and IP management is determined in those agreements. • Research planning is independent of, but coordinated with the annual DOE review. • Consideration of new team members determined by existing partners, and new partners require the unanimous approval of the existing membership • Affiliate members pay an annual fee on a sliding scale. Membership requests are approved by the Director
Member Roles and Benefits	**Team Members:** • Actively participate in R&D activities • "First look" at CMI-generated IP. Share in IP as specified by the IP Management Plan **Affiliate Members:** • Participate in CMI meetings. Access to all CMI information streams. • Provide input and perspectives on CMI research

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- "Early look" at CMI-generated IP