The Critical Materials Institute

An Energy Innovation Hub

DE-AC02-07CH11358

15 Corporations, 7 Universities, 4 National Labs

Led by the Ames Laboratory

2013 - 2019

Dr. Chris Haase (Director), Prof. Rod Eggert (Deputy Director)

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 11, 2019

CMI Mission & Strategy

Mission: Accelerate the development of technological options that assure supply chains of materials essential to clean energy technologies – enabling innovation in US manufacturing and enhancing energy security.

Strategy:

- Diversify our sources;
- Provide substitutes to the existing materials;
- Make better use of the existing supplies through efficient manufacturing, recycling and re-use.

Overview: Critical Materials Institute

Timeline

- June 1, 2013: Startup of Phase 1, 5 years
- July 1, 2018: Program Renewal, nominal 5 additional years
- Funds appropriated for CMI Years 7 & 8
- Program 60% complete
- An Energy Innovation Hub
  - Supported by the US DOE, Advanced Manufacturing Office
  - One of four such Hubs supported by DOE

Budget

	FY18 Costs	FY 19 Costs	Total Planned Funding (FY19-FY23, end date)
DoE Funding	$25M	$25M	$125M
Project Cost Share	$0.8M	$1M	>$4M

Barriers

- **Supply diversity**: reliance on sole (or nearly sole) suppliers and politically unstable regions for key energy materials
- **Lack of material substitutes**: need for viable material- or system-level substitutions to reduce the dependence of energy technologies on particular critical materials.
- **Cost and regulatory barriers for new mines**: inability to quickly commission new mines
- **Separation and other processing challenges**: technical difficulty and inefficiency of certain separations and other processes
- **Recycling and reuse**: uncertain market and collection logistics for recovering critical materials

Partners

- National Labs: Ames Lab (lead), Oak Ridge NL, Idaho NL, Lawrence Livermore NL
- Universities: Iowa State Univ, Colorado School of Mines, Purdue Univ, Rutgers Univ, Univ of California at Davis, Brown Univ, Florida Industrial and Phosphate Research Institute
- Corporations: Arnold Magnetic Technologies, Corporation, Advanced Recovery Inc., All American Lithium, American Manganese, Borg Warner, Solvay, Eck Industries Inc., Electron Energy Corporation, General Electric Corporation, Infinum, OLI Systems Inc., Rio Tinto

CMI Alignment with AMO Mission

- **AMO Mission**: Catalyze research, development and adoption of energy-related advanced manufacturing technologies and practices to drive U.S. economic competitiveness and energy productivity.

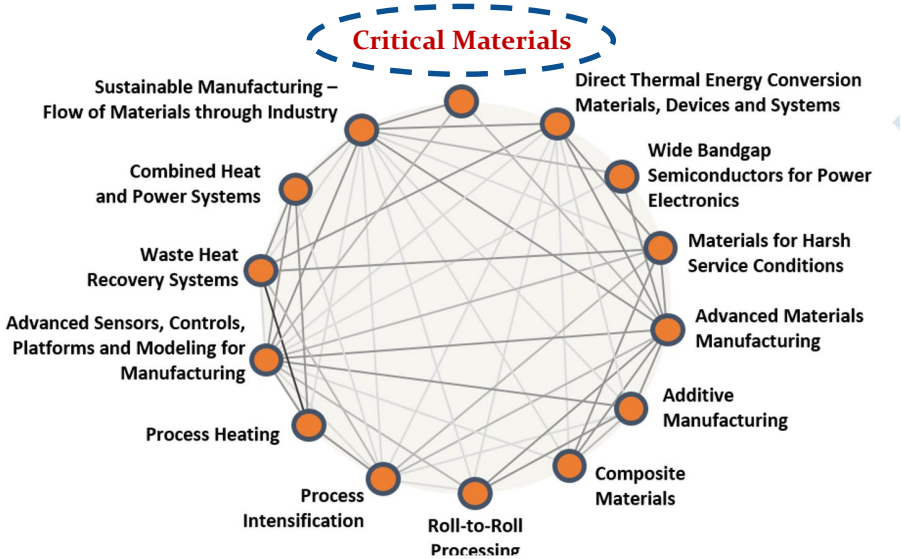
- **Manufacturing**: 25% of nation's energy

- **Competitiveness:** Requires energy security, resource availability, cost competitiveness, and full lifecycle energy and material management
  - **Critical materials** provide unique and essential properties for manufacturing and systems

- **CMI Mission**: Accelerate the development of technological options that assure supply chains of materials essential to clean energy technologies – enabling innovation in US manufacturing and enhancing energy security.

- **CMI Hub Strategy:**
  - *Diversifying our supplies*
  - *Develop cost-effective substitutes*
  - *Improve recycle and reuse of critical material*

14 RD&D Technology Areas ("TA")



AMO Critical Materials TA: "advance solutions that enable availability of materials essential to clean energy technologies by:

- *Diversifying supply*
- *Developing substitutes*
- *Improving recycle and reuse*

Focusing the Current CMI Material "Palette"

CMI Material Palette for Year 7, commencing July 1, 2019

	REEs *	Li	Co	C**	Ga	In	Mn	V	PGM
Vehicles/ Motors	X	X	X	X			X	X	X
Storage		X	X	X			X	X	
Solar/ Semi-conductors					X	X			
Catalysts	X								X
Lighting	X				X	X			
Nuclear	X		X			X			
Wind	X								

* = Selected rare earths: Nd, Pr, Dy

** = Battery-grade graphite

TECHNOLOGY INNOVATION

Recycling & Reuse: Lessons Learned from first 5 years

- Don't recycle a material, recycle a device
  - This is another embodiment of materials co-production
- Front end costs can easily exceed the recovery value
  - Focus efforts on collection and disassembly
  - Design for disassembly is an industry challenge
- Critical mass is important
  - Economies of scale are essential to solving front end costs, and making sales.
- Mind the end use of the recycled material
  - Processes must meet end-customer spec

Recycling & Reuse: Innovation Step-Change Examples

Challenge

- Preparing & concentrating sources for recycling is uneconomical

- Shredding dilutes high-value critical materials with low-value waste, destroying subassemblies for reuse

- Extraction and recovery are energy consuming & slow with high environmental impact

Automated disassembly

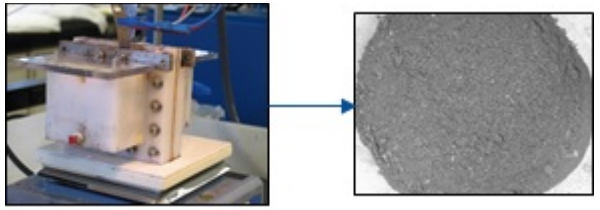
Novel process flow

Efficient, environmentally-friendly systems

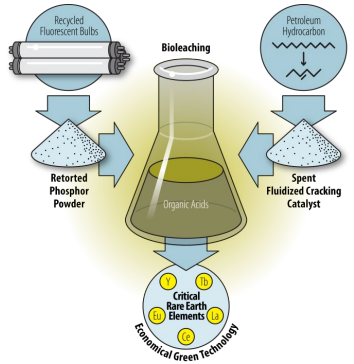
How Overcome

- Automated product-specific systems

- Co, Li, Mn, Ni solvent extraction



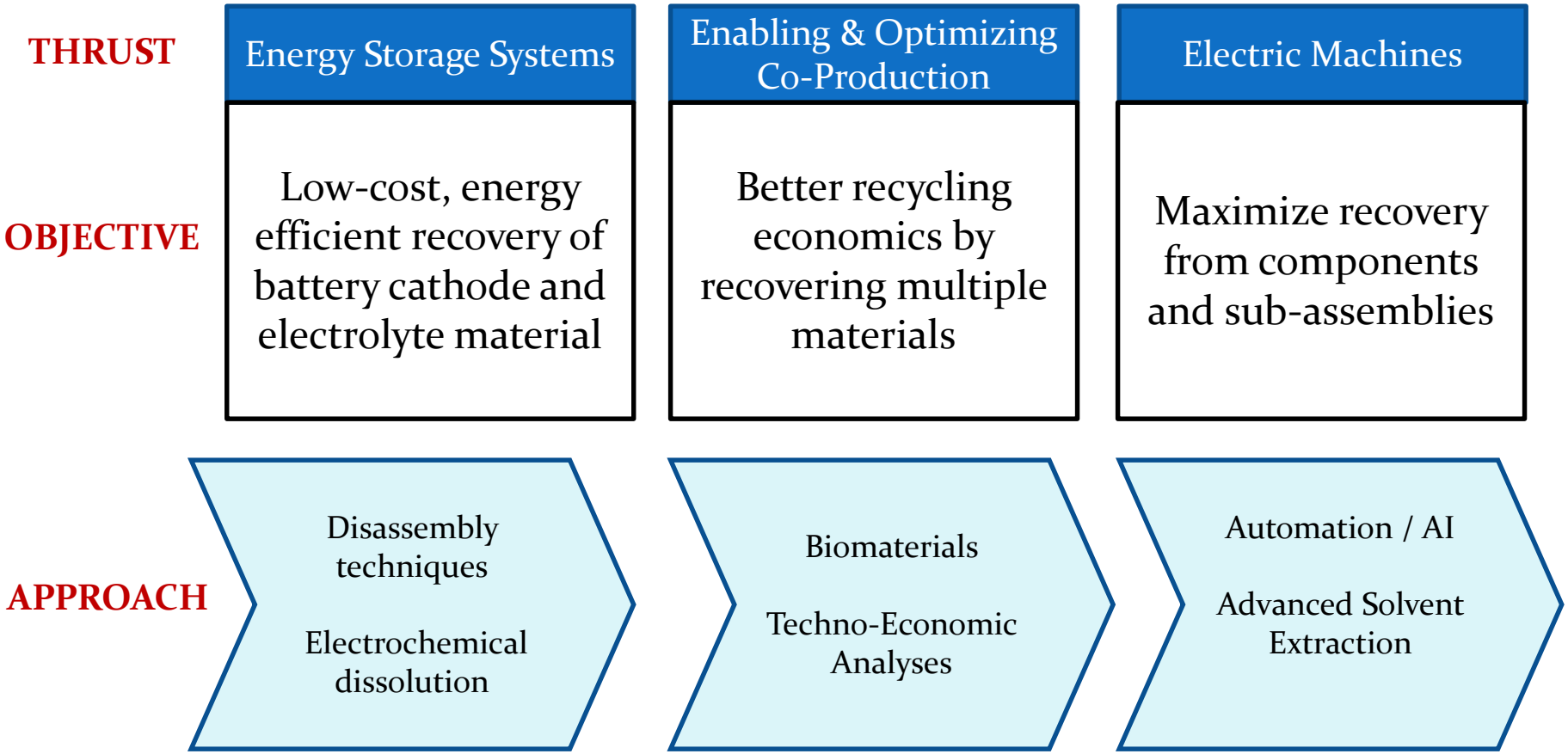
- Organic biosystems for RE leaching and separation



TECHNICAL APPROACH

Technical Approach: Example from Recycle & Reuse

- Complementary Thrusts, Objectives, and Technical Approaches



PROJECT MANAGEMENT AND BUDGET

Project Management

- **Roadmaps**
  - Where do we start, where are we going, how do we relate to other CMI efforts? Where are the key decision points?

- **Quarterly Reports**
  - Progress Measures: technical, financial, partner, commercial (where applicable)
  - SMART Milestones – *Specific, Measurable, Aggressive, Relevant, Timely*
  - Go/No-Go Decisions
  - Cost status, Accomplishments, Risks, Challenges, Staffing…

- **Techno-Economic Analyses**
  - Required of all Tasks and Projects after they reach TRL 4

- **Annual Project Evaluations**
  - Two-thirds of our projects have been changed in some way, over the five-year program in this process

CMI Year 6 Budget (baseline Year 7)

	Diversifying Supply	Developing Substitutes	Recycling & Reuse	Cross-Cutting Research	Management & Ops
Federal Funds	$4850	$5100	$4830	$4980	$4900
Cost Share	$500	$200	$100	$60	-
Total	$4910	$5300	$4930	$5040	$4900

Dollars in Thousands

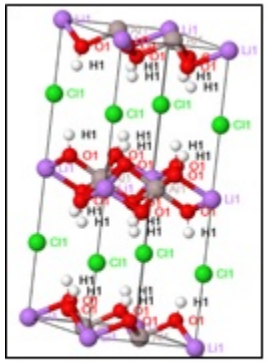
CMI Year 6: July 1, 2018 – June 30, 2019

CMI Year 7: July 1, 2019 – June 30, 2020

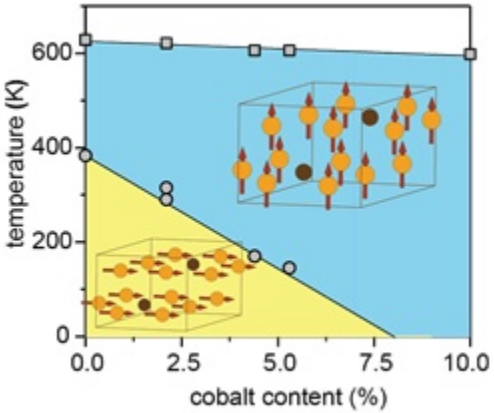
ACHIEVEMENTS

Highlight Achievements

Capacity & stability of Li sorbents



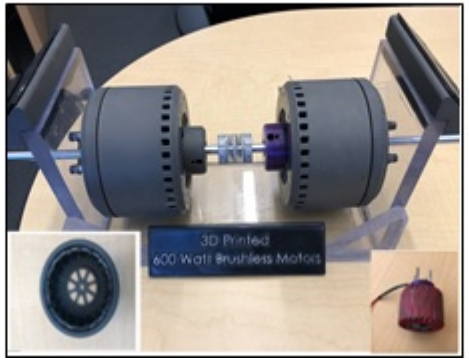
New rare-earth-free magnet material



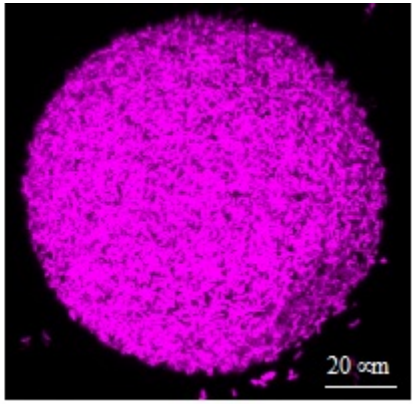
Optimizing Acid-free Dissolution Process

Rh Recovery from Cu Smelting

Additively-Printed NdFeB Magnets for All-3D Printed Motor



REE Recovery by Biosorption



Metrics Since Inception

Refereed publications:	273
Invention disclosures:	110
Patent applications:	55
Patents awarded:	10
Technologies licensed:	7

Data as of 15 May 2019

Awards

- CMI technologies received four R&D Magazine's prized R&D 100 award
  - Presented annually to the top 100 scientific innovations as judged by a panel of 50 R&D leaders from a variety of fields

Education & Workforce Development

- CMI Leadership Academy
  - Year-long experience designed to develop leadership management skills for a group of emerging leaders within the CMI community

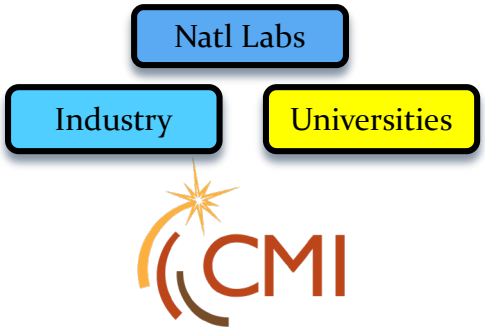
- Educational Outreach
  - Webinars, professional societies (e.g., SWE), undergraduates, high-school students
  - CMI Museum at CSM

- Education Toolkits
  - Resources for K-12, university teachers and students

TRANSITION BEYOND DOE ASSISTANCE

Transition Beyond DOE Assistance

- CMI Enduring Capability
  - Multi-disciplinary team
    - 350 research community
    - Spanning 30+ institutions
  - CMI Portfolio
    - Four focus areas
    - 36 projects
  - Team & Affiliate program
    - 13 team members (2 in process)
    - 17 affiliate members
    - Options for supply-chain focused consortia
  - Economic & supply chain analysis
    - Annual criticality review
    - Techno-economic analyses
    - Project roadmapping
  - Specialist technical consultancy
    - Two strategic partnership programs



Development & Revenue Options

- R&D Portfolio Mgt
- Annual Criticality Review
- Critical Material Supply Chain Expertise
- Licensing & Consortia
- Specialty Manufacturing

Key Messages

- 1st Five Years
  - Recognized exemplar of inter-institutional and disciplinary collaboration
  - Delivered a high-performing research institution with facilities and capabilities dedicated to critical materials R&D
  - Accelerated delivery of translational R&D into industry to mitigate risks to US supply chains

- 2nd Five Years
  - Recommitment to CMI mission with new project portfolio
  - Partnering to accelerate technology validation and industrial uptake
  - Leveraging R&D network and enduring capabilities with a more focused material palette
  - Defining a long-term path to funding sustainability

Questions?

Backup Material

Robust Base of Private Sector CMI Team Members

- All American Lithium, LLC
- American Manganese, Inc
- Arnold Magnetic Technologies Corporation
- BorgWarner
- Eck Industries, Inc
- Electron Energy Corporation
- General Electric Company
- Infinium
- Marshallton Research Laboratories
- OLI Systems, Inc
- Rio Tinto
- Solvay Group
- United Technologies Research Center

Year 6 (2018-2019) Project List

Diversifying Supply	Developing Substitutes	Recycle & Reuse	Crosscutting Research
Lithium Extraction and Conversion from Brines	Additive Manufacturing of Polymer Based Bonded Magnets	Li, Co & PGM Recovery from Li-ion Batteries & E-waste	Advanced Search for High-Performance Materials (AS4HPM)
Critical Material Recovery from Ores and Lean Sources	High-performance, Critical-element-free Permanent Magnets	Li-ion Battery Disassembly, Remanufacturing, and Li & Co Recovery	Machine Learning Materials Design
Recovery of Critical Materials as By-Products	Finite Element Modeling of Magnetic Systems	Ce Gettering of Cu and Fe in Aluminum Alloy Recycling	Accelerated Alloy Development and Rapid Assessment
New In-Silico Molecular Design Methods for Improved Separations	Reduced Rare Earth Content High Performance Magnets	Co-Product Optimization for Indium Recycling from LCDs	Predicting Magnetic Anisotropy
Low-Temp Electrochemical Synthesis of Graphite	Heterogeneous Sm-Co and Nd-Fe-B Magnets	Biomaterials for Critical Material Dissolution, Recovery and Separation	Modeling of Intrinsic and Extrinsic Properties of Magnets
Molten Fluorides for Rare Earth Electroreduction	Practical Reliable Exchange Spring Magnets (PRES-M)	Rare Earth Permanent Magnet Motors from Salvaged Automobile	Cross-Cutting Thermodynamic Properties of Critical Materials
Enhanced Separation of Critical Materials	High Magnetic Field Processing of Permanent Magnet Materials	Low Temperature Electrochemical Processing of Rare Earth Elements	Biogeochemical Impacts of Wastes from Critical Materials Recovery
Structure and Properties of Ce-Strengthened Al Alloys	Ceramic Phosphors for LED Lighting	Recovery of Critical Materials from Dilute Electronic Waste Streams	Roadmaps for Technology Development
		Separation and Recovery of Dysprosium and Cobalt from E-Waste	Impact of Research on Global Material Supply Chain
			Optimizing the Economic Performance of CMI Technologies
			Criticality, Life Cycles, Material Flows and Scenarios

CMI Focus Area Moonshots

Diversifying Supply

- Enable Domestic Production for Source Diversification
- Enable Better Co-Production
- Modular, Scalable Systems That Are Environmentally Friendly
- Supply Chain Integration

Developing Substitutes

- Critical-Material Free, High-Performance Magnets From Domestically Sourced Materials
- Prediction of Magnetic Properties
- No-Loss Additive Manufacturing
- Fracture Resistant SmCo Magnets For Broad Applications

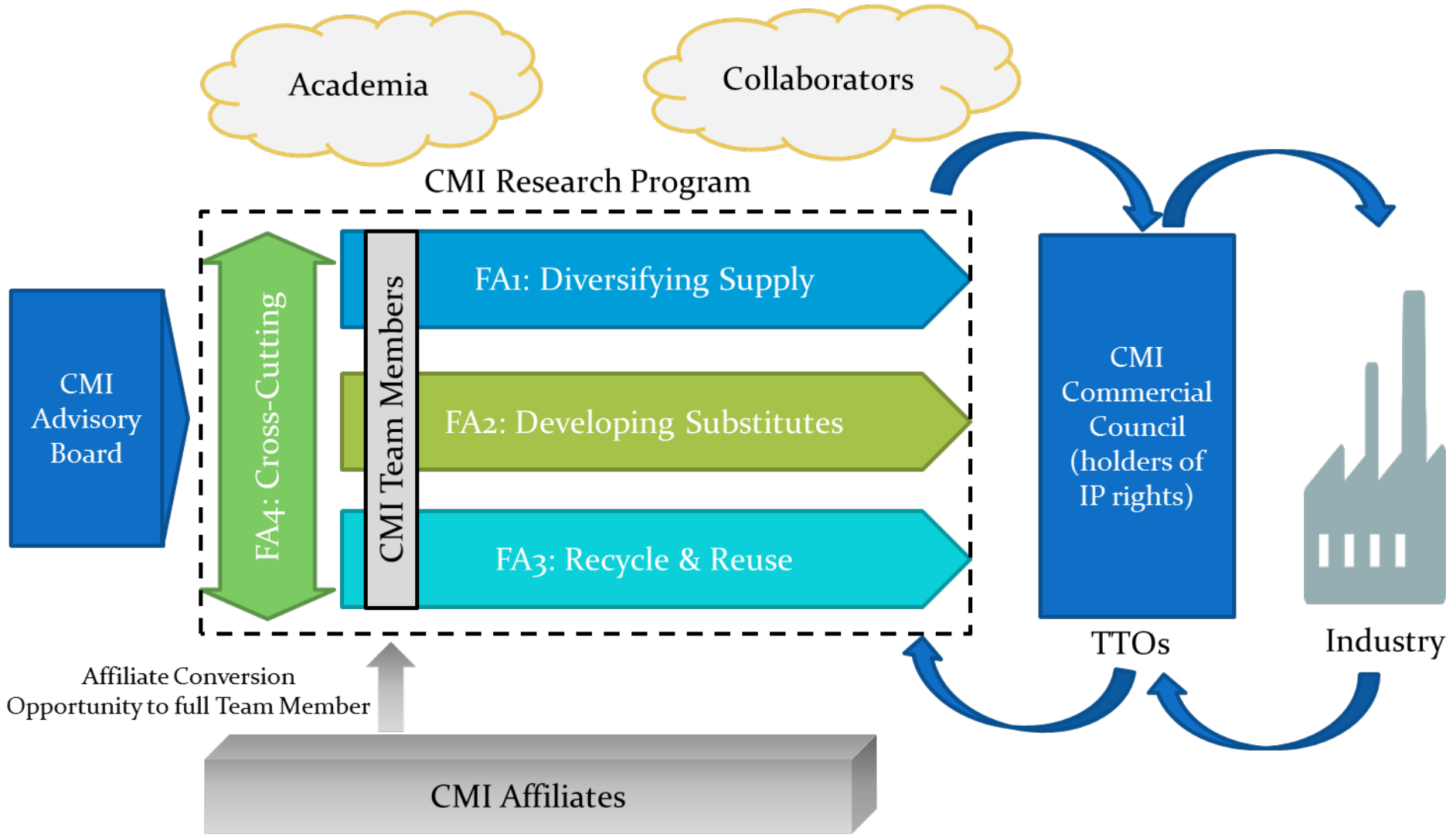
Recycling & Reuse

- Cost-Effective, Safe, Efficient Recovery
- Enable Sustainable Circular Economy Businesses
- Meet Half the Needs of One US Business within 10 years
- Satisfy significant domestic demand by 2040

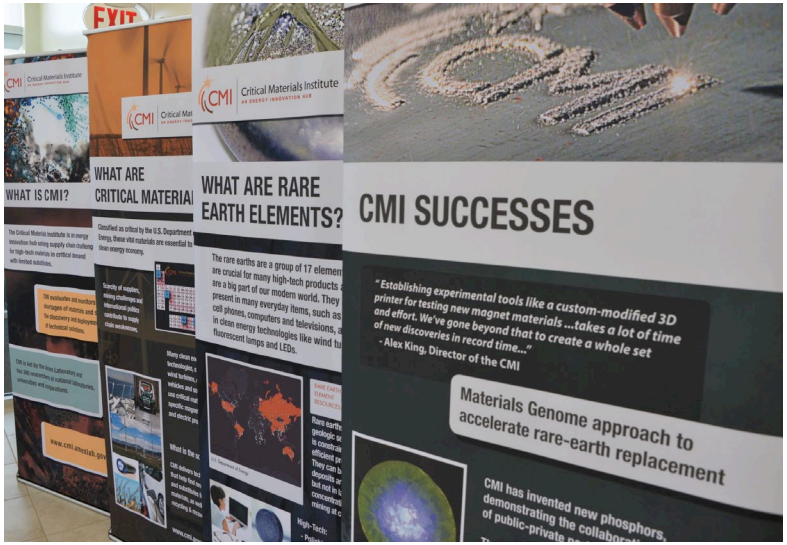
Cross-Cutting Research

- Specific Material Application Maps
- Tools for Accelerated Materials Development
- Extrinsic Magnetic Property Prediction
- Rapidly Quantify Economic Competitiveness for Adoption

CMI Commercial Council



Private Sector & Government Contributions



- Team Members
  - Participate in CMI research projects
  - Share in the research costs
  - Participate in the IP management plan
- Affiliates
  - Participate in CMI meetings and information streams
  - Pay an annual membership fee
  - Get an "early look" at CMI intellectual property
- Sponsored Research Partner
  - Sponsor research using CMI's assets
  - Example structures: Strategic Partnership Project (SPP), CRADA
  - May wholly own the resulting IP, subject to DOE rules & regulations

CMI Material Selection Criteria