U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ADVANCED MATERIALS & MANUFACTURING TECHNOLOGIES OFFICE

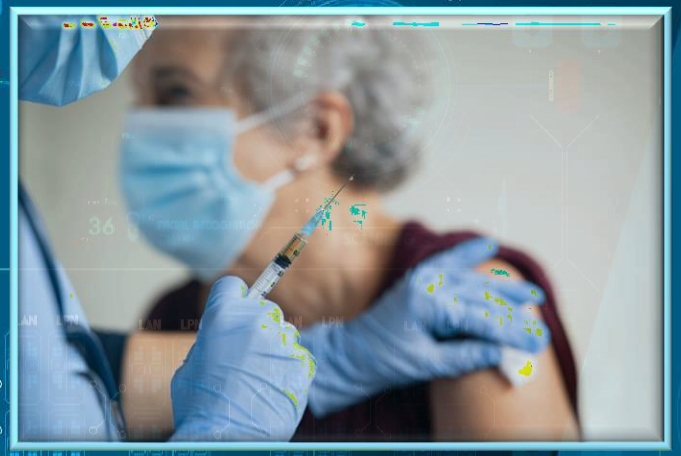
Smart Manufacturing Technologies for Composites - Material and Process Innovation

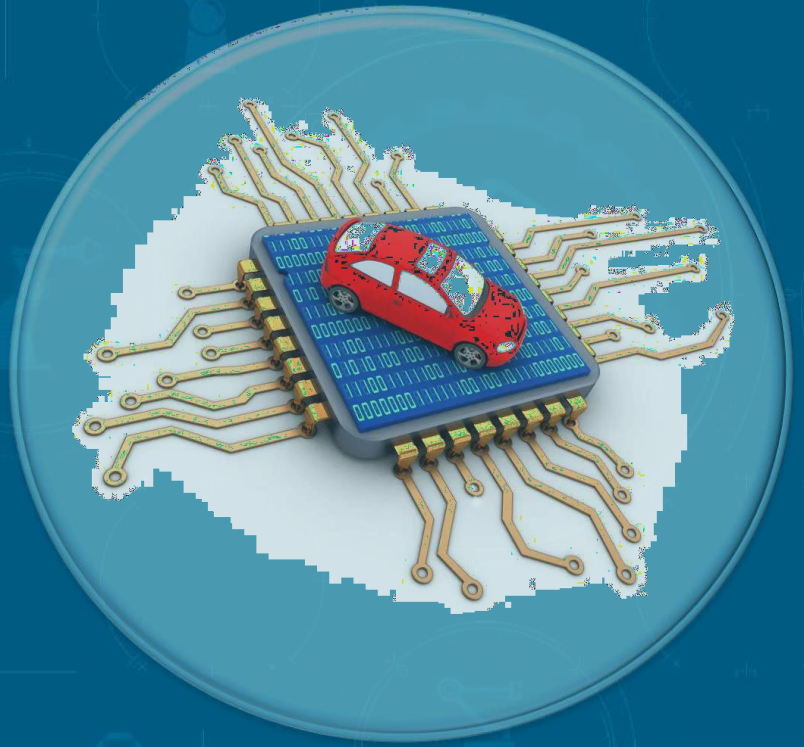
John Winkel

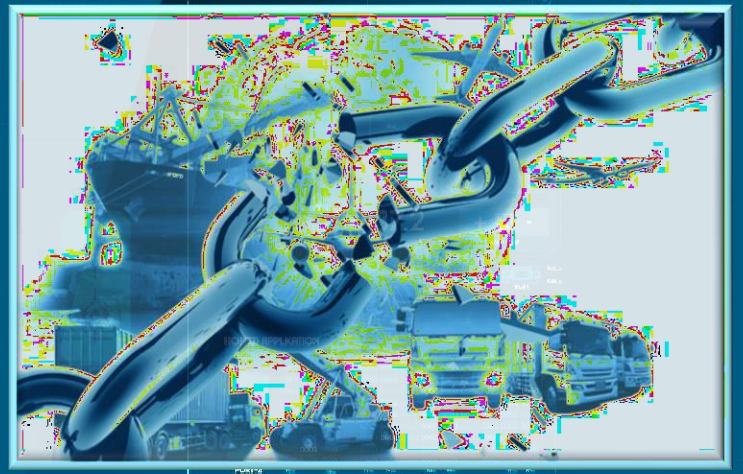
Advanced Materials and Manufacturing Technologies Office (AMMTO)

August 15, 2024

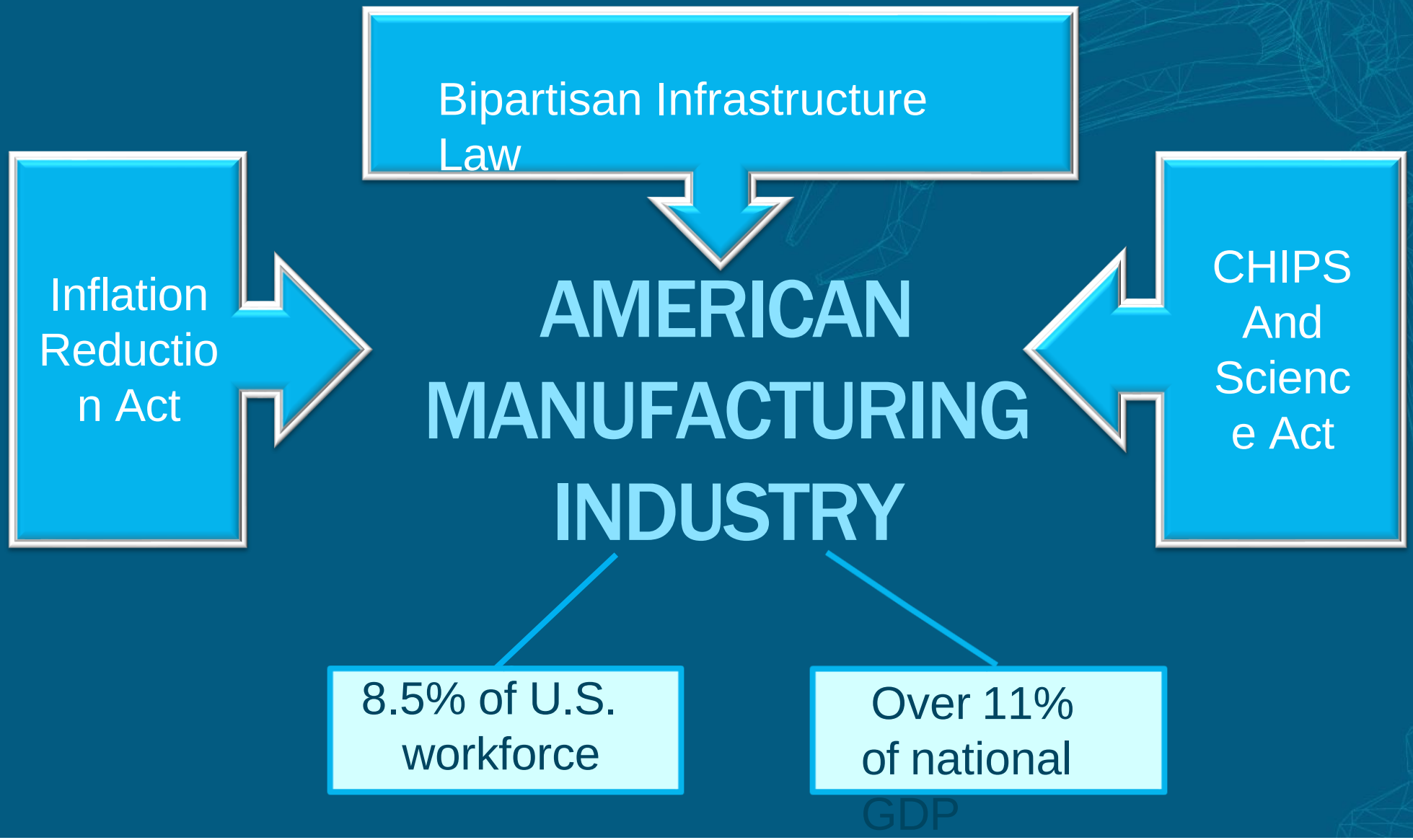
The World is Changing...







Unprecedented Federal Investment in Manufacturing



America’s Clean Energy Goals

2030

U.S. greenhouse gas emissions 50-52% below 2005 levels

2035

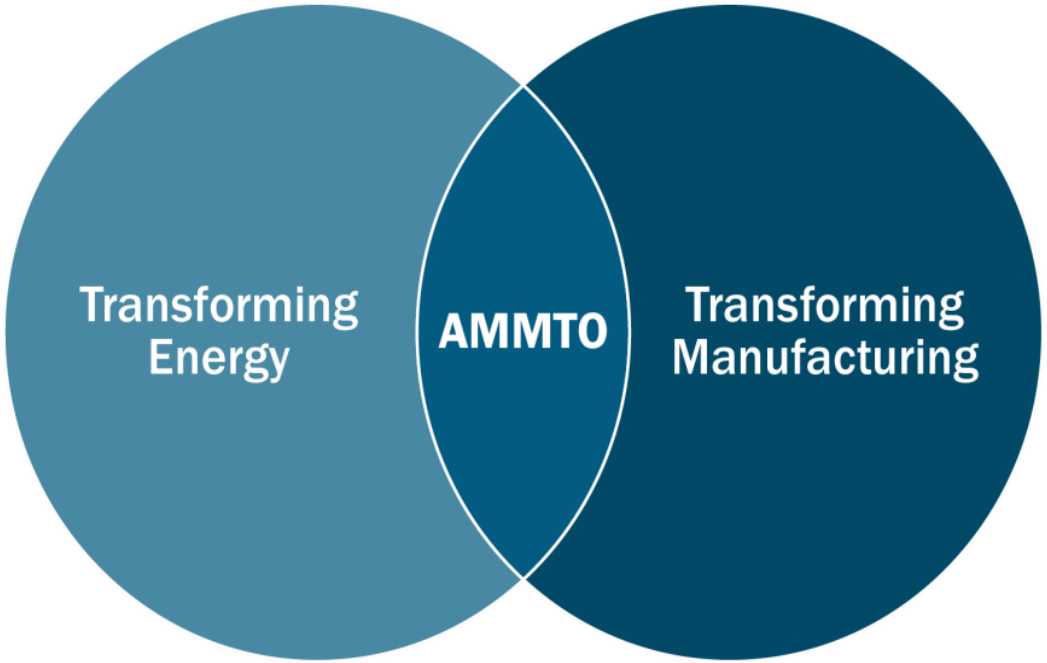
100% carbon pollution-free electricity by 2035

2050

Net-zero emissions economy by 2050

Advanced Materials and Manufacturing Technologies Office

- Vision: A globally competitive U.S. manufacturing sector that accelerates the adoption of innovative materials and manufacturing technologies in support of a clean, decarbonized economy.
- Mission: We inspire people and drive innovation to transform materials and manufacturing for America's energy future.



Advanced Materials and Manufacturing Technologies Office

Supporting Clean Energy Manufacturing








- Wind turbines and blades
- Hydropower components
- Industrial motors
- Batteries and long-duration storage
- Power electronics
- High-efficiency conductors
- Microelectronics
- Hydrogen storage

Advanced Materials and Manufacturing Technologies Office

Platform Manufacturing Technologies, Advanced Materials, Workforce

Manufacturing Technologies

- Smart manufacturing
- AI/Machine Learning
- Cybersecurity
- High performance computing
- Roll-to-roll manufacturing
- Additive manufacturing
- Circularity

Advanced Materials

- Advanced composites/metals/ceramics
- Critical materials
- High-conductivity metals
- Materials for harsh environments

Workforce

- Training programs
- Curricula development
- Entrepreneurship

AMMTO's Subprogram Structure

NEXT-GENERATION MATERIALS & PROCESSES

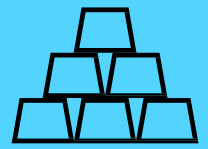
Advanced Manufacturing Processes and Systems

High Performance Materials

Digital Manufacturing

SECURE & SUSTANDABLE MATERIALS

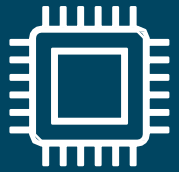
Circular Economy Technologies and Systems



Critical Materials

ENERGY TECHNOLOGY MANUFACTURING & WORKFORCE

Energy Conversion and Storage Manufacturing

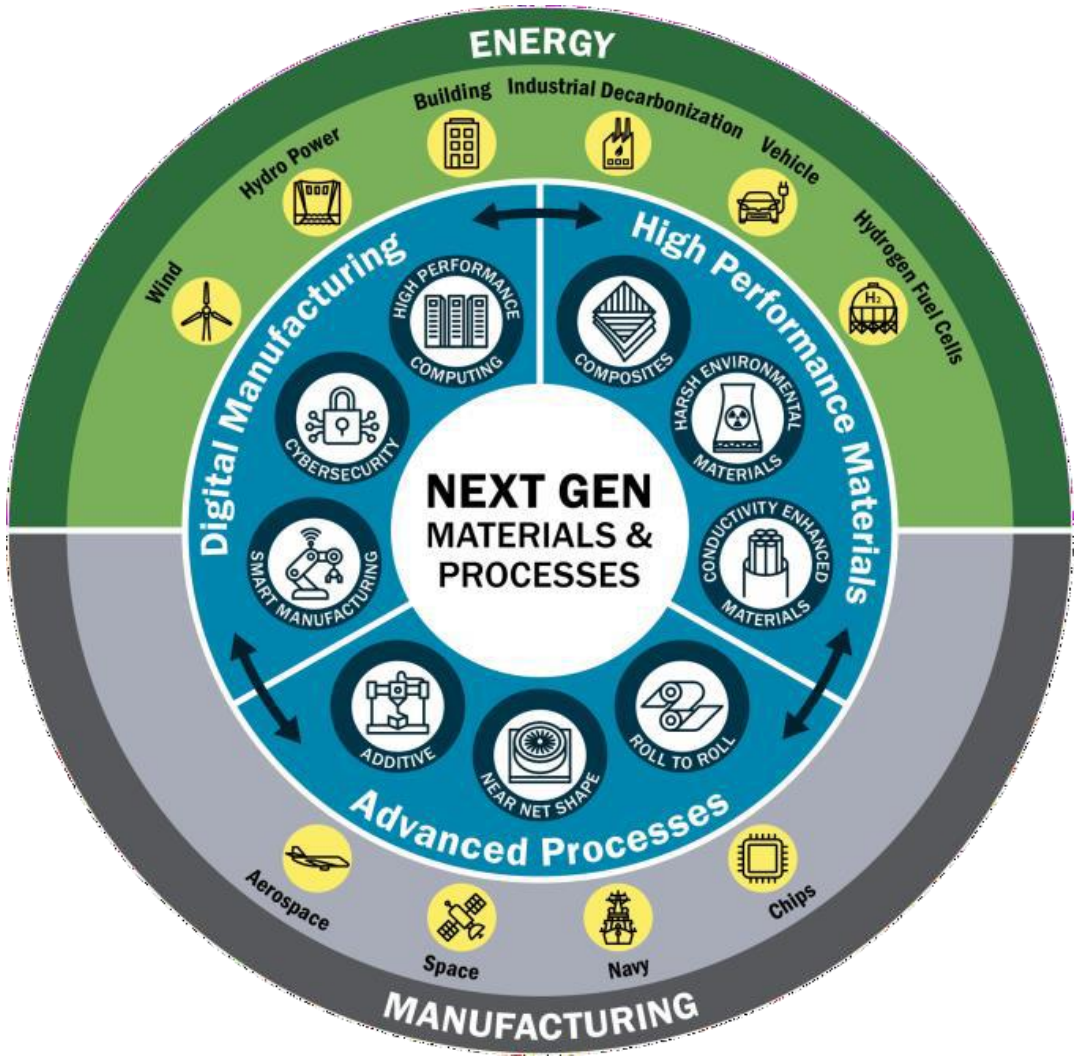


Semiconductors, Electronics, and Other Technologies Manufacturing

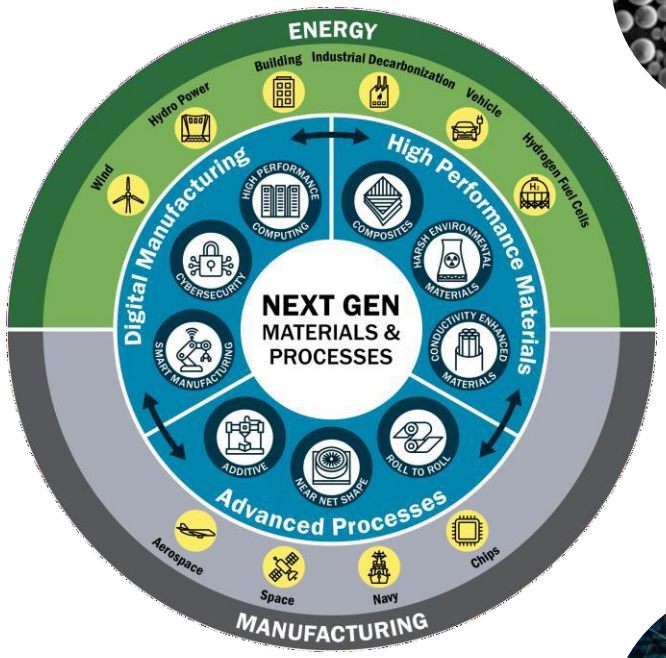
Entrepreneurial Ecosystems and Advanced Mfg. Workforce

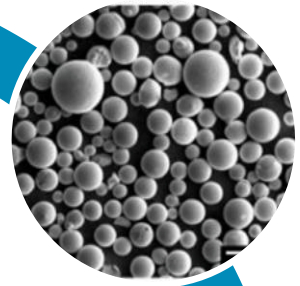
Next Generation Materials and Processes (NGMP) Program

Objective: Support AMMTO's mission through the development of novel materials and manufacturing processes.



Next Generation Materials and Processes (NGMP) Program





High Performance Materials

Novel materials have improved properties that improve functionality, extend product lifetime, increase lifecycle energy, and increase materials efficiency.

- RD&D Consortia: IACMI, CFTF
- AMMTO MT FOA ($27.6M), IEDO MT FOA ($4M)

Advanced Processes

- Additive Manufacturing
- Near Net Shape Manufacturing (NNS)
- Roll-to-Roll Manufacturing
- RD&D Consortia: MDF
- Wind FOA ($30M), NNS FOA ($30M)

Digital Manufacturing

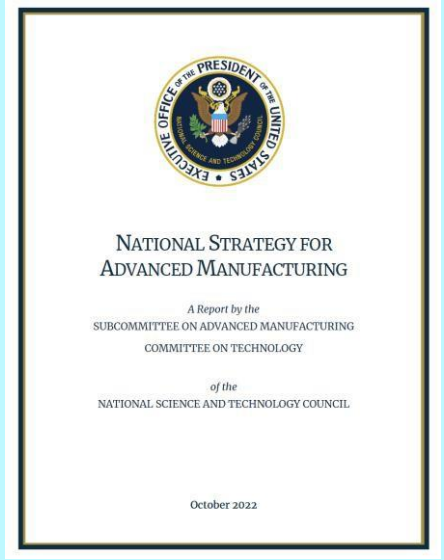
- Smart Manufacturing (AI/ML, Digital Twin)
- High Performance Computing
- Cyber Security
- RD&D Consortia: CESMII, CYMANII
- HPC4MFG (~$5M), National Strategy for Smart Manufacturing

Enhance Material Properties and Energy Efficiency of Manufacturing, Improve the Resiliency of Domestic Supply Chains

National Strategy For Advanced Manufacturing

Vision: United States Leadership in Advanced Manufacturing

Grow the economy, create jobs, enhance environmental sustainability, address climate change, strengthen supply chains, ensure national security, and improve healthcare.



National Goals:

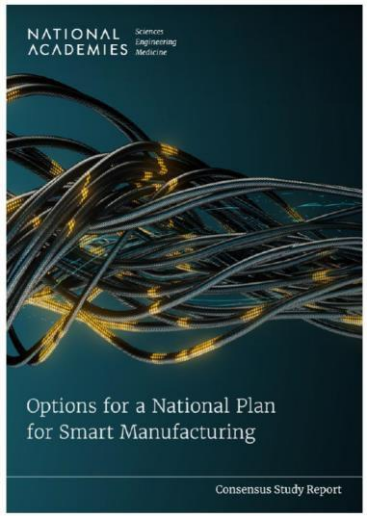
1. Develop and implement **advanced manufacturing technologies**
2. Grow the advanced manufacturing **workforce**
3. Build resilience into manufacturing **supply chains** and ecosystems

Recommendation 1.1.2.
Clean Energy Manufacturing Technologies:

Manufacturing advances that produce cost-competitive technologies for clean energy production, storage, and utilization domestically position the United States to lead the global energy transition. Innovations such as advanced materials for wind turbine blades and efficient power electronics for charging and grid integration are needed to meet growing demands driven by the electrification of multiple sectors.

Recommendation 1.4.1.
High-Performance Materials Design and Processing: Accelerate testing, qualification and process validation of high- performance materials to streamline entry into market. Develop predictive capabilities for materials behavior and performance under harsh service conditions….Systems that…have profound national security or economic impact,…typically involve operation under harsh service conditions….The development and adoption of lightweight, high strength, high conductivity, corrosion-resistant metals, composites, and other classes of advanced materials are important enablers for emerging manufacturing capabilities.

Smart Manufacturing National Plan

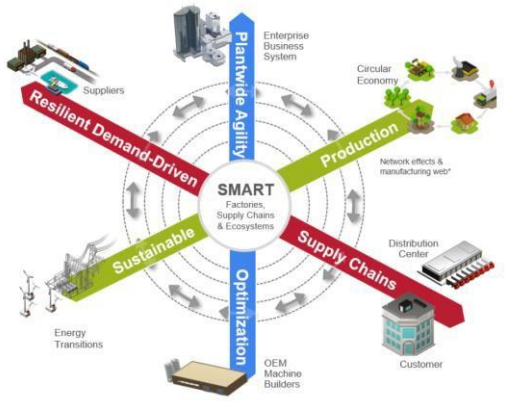


DOE turned to the National Academies to convene a consensus study committee to explore and recommend options for a national plan for smart manufacturing.

A committee of leading experts in advanced and smart manufacturing was assembled from across academia, industry, and trade and technology associations to:

- **examine** the state of the smart manufacturing industry;
- **explore** technology, workforce and education, social and environmental, and economic challenges and opportunities;
- and **recommend** critical elements and considerations for DOE's national plan for smart manufacturing.

Smart manufacturing has the potential to transform the U.S. manufacturing sector



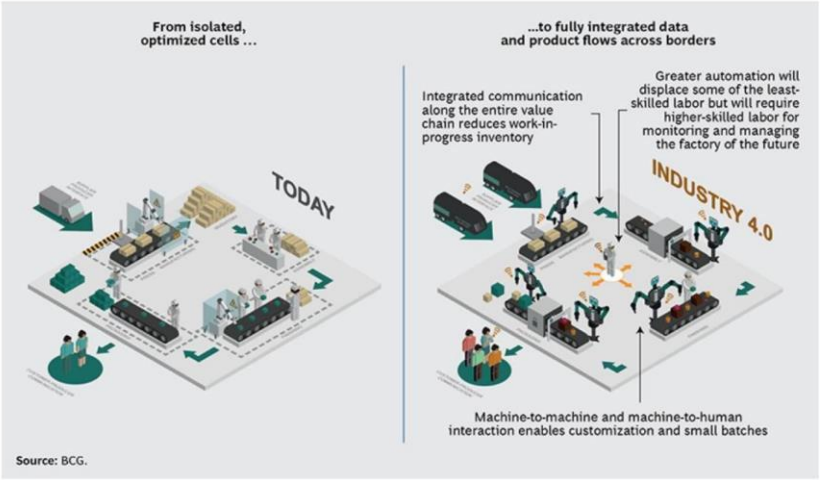
Smart manufacturing uses next-generation technologies such as artificial intelligence (AI) and machine learning, high-speed connectivity, advanced data analytics, and hard and soft automation to augment human beings in the workforce.

Implementing these technologies could:

- **Improve productivity, efficiency, and sustainability** for the manufacturing workforce, factories, and supply chains.
- Provide opportunities to **expand and develop the smart manufacturing workforce**
- Increase **U.S. economic competitiveness and resilience**.

NATIONAL ACADEMIES Sciences Engineering Medicine

A Vision for the Future of Manufacturing in the United States



The Digital Revolution in Composites Manufacturing

Smart Manufacturing IACMI 1.0 Successes

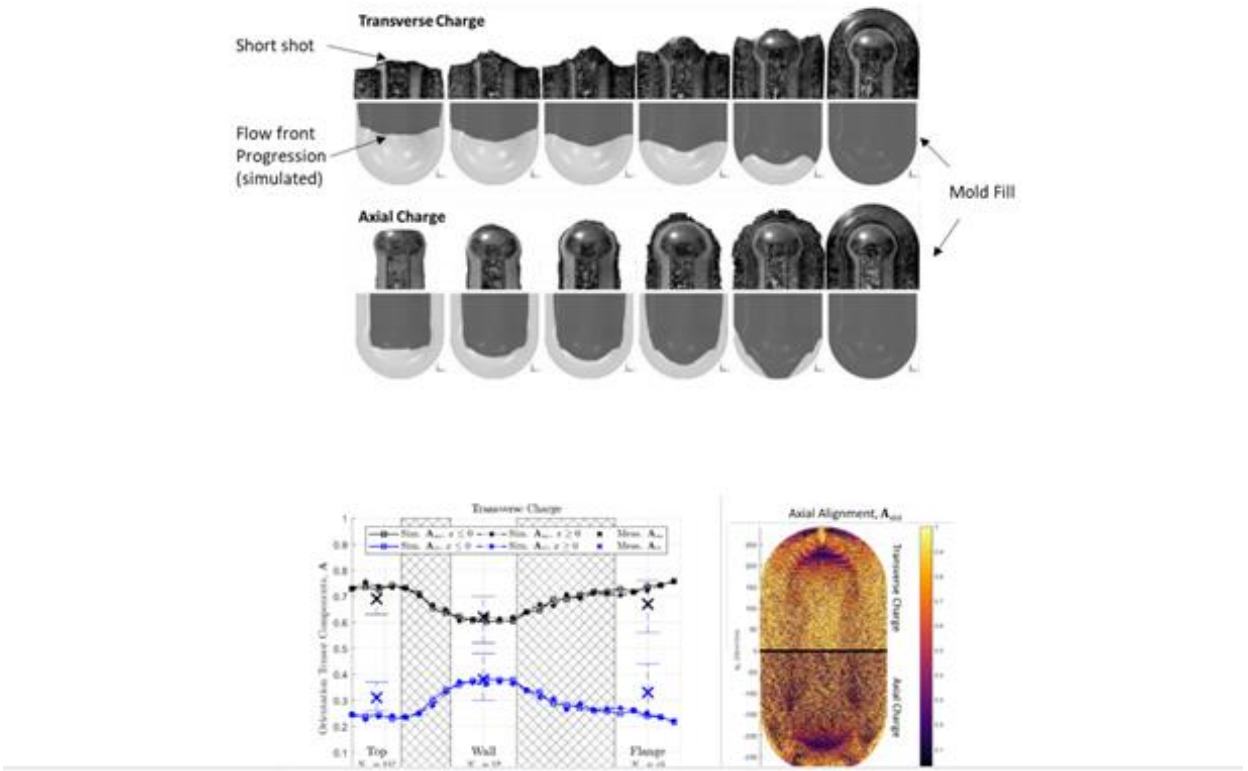


Figure 8. Short shot experiments as compared to flow simulation predictions show that the flow simulation captures the essential features of the flow pattern, including knit lines in the case of the transverse charge.

IACMI – The Composites Institute

Project Overview

IACMI-The Composites Institute

The Institute for Advanced Composites Manufacturing Innovation
Knoxville, Tennessee

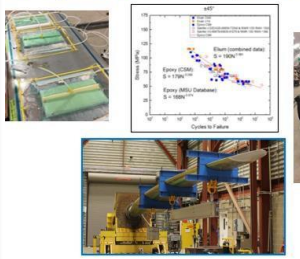
- Established in 2015 DOE Advanced Manufacturing Office
- One of 16 Manufacturing USA Institutes
- **IACMI Mission:** Convene, connect and catalyze the composites community to accelerate advanced composites design, manufacturing, technical and workforce solutions to enable a cleaner and more sustainable, more secure and more competitive U.S. economy
- Founding partners: **University of Tennessee, Oak Ridge National Laboratory**
- Additional core partners: **Purdue (IN), National Renewable Energy Laboratory (CO), Michigan State University (MI), University of Dayton Research Institute (OH)**
- Extensive ecosystem of core partners, state economic development agencies, trade associations, professional societies, workforce partners and multiple industry participants

Budget:

DOE Funded	$70M
Project Cost Share	$130M
Total	$200M

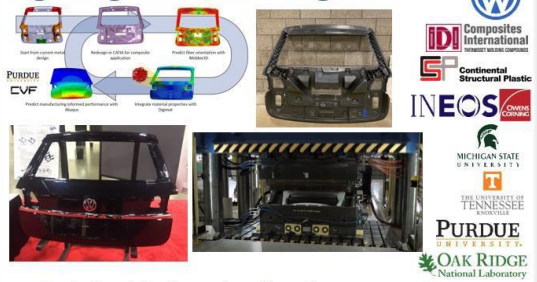
Results and Achievements - Examples

Recyclable Thermoplastic Wind Blade



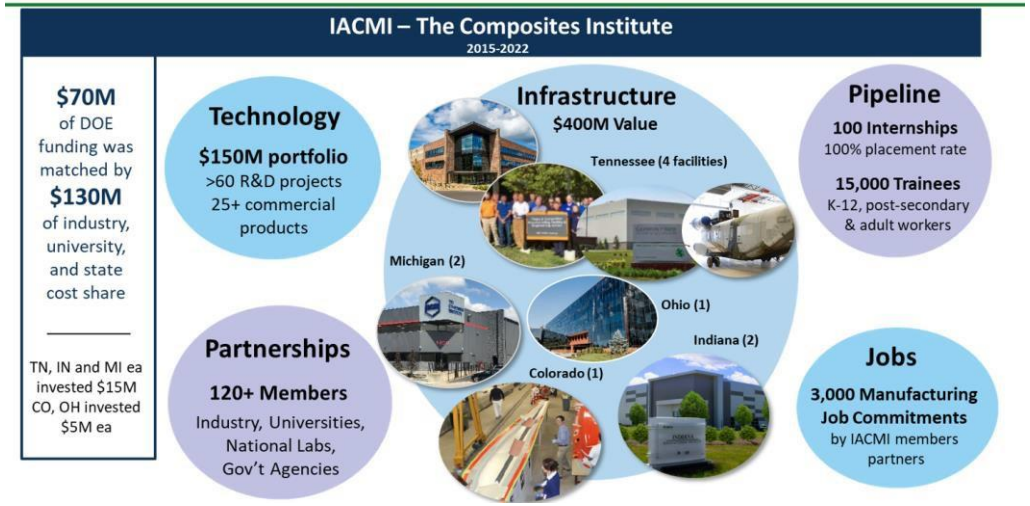
- Novel polymerizing thermoplastic technology
- Small infusion studies, then scaling to 13m blade
- Static and fatigue testing coupon and at full scale
- Lower tooling and recurring costs demonstrated
- R&D 100 winner

Lightweight Composite Liftgate



- Optimized design using fiberglass composite
- Sub 3-minute cycle time
- 36% lighter than steel, 77% reduction in investment
- Recurring costs 9% lower vs. steel, 37% lower vs. Al
- Qualified for future production on US electric platforms

Results and Achievements



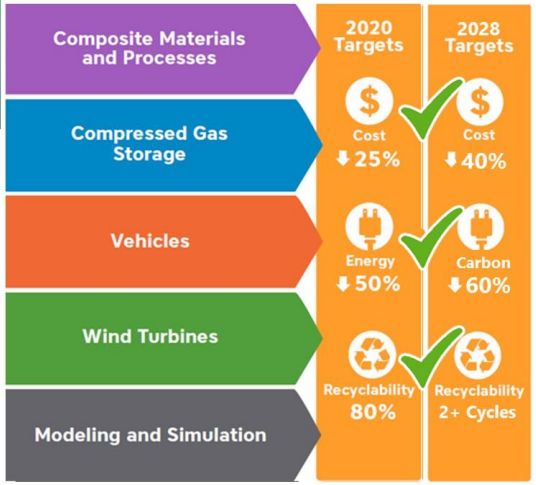
Future Work, Technology Transfer, & Impact

Advanced Materials & Manufacturing Technologies Office

DOE Furthers Commitment to Advancing Composites Manufacturing Through Innovation Institute Renewal

APRIL 11, 2023

IACMI Priorities 2023-2028	
Clean Energy Markets	Wind Energy, EVs, Hydrogen Storage
Cross-cutting Technologies	Circular Economy, Digitalization, Materials & Processes
Workforce of the Future	Education and Workforce Development, DEIA
Industry health	Small & Medium Enterprises; Robust, Resilient Supply Chains; Regional Partnerships/Clusters



Clean Energy Smart Manufacturing Innovation Institute

CESMII THE SMART MANUFACTURING INSTITUTE

mission. strategy. role.

Driving the **next wave** of manufacturing productivity, energy productivity and competitiveness through smart manufacturing innovation.

U.S. DEPARTMENT OF ENERGY

2017
Founded by the D.O.E

$140M+
Private/public partnership

Improve energy productivity through sensing, control, modeling, analytics & platform technologies

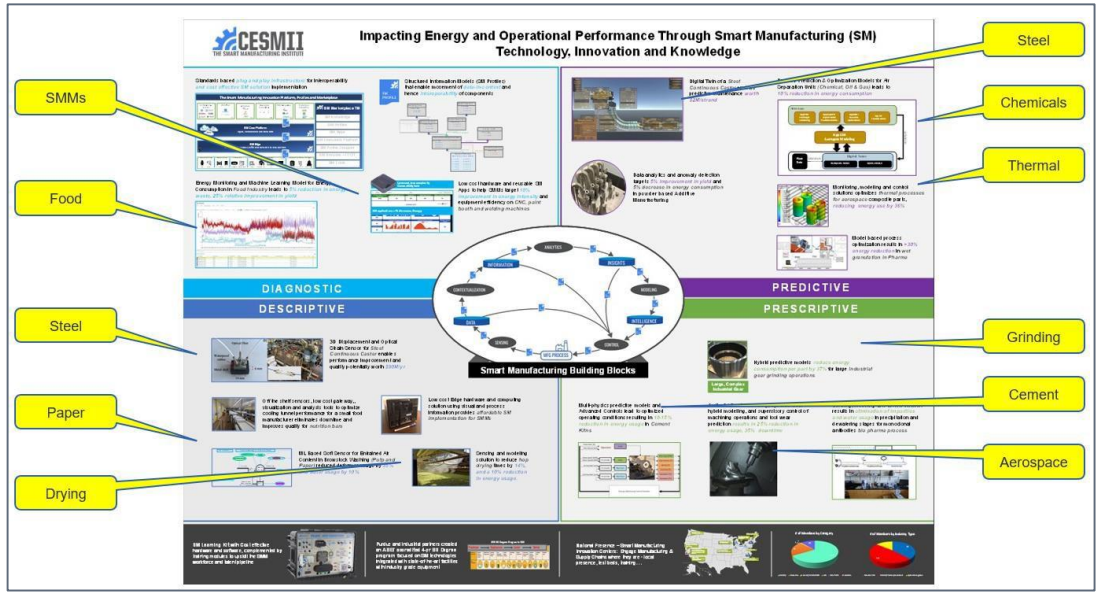
How. Fund the Innovation and R&D necessary to **dramatically** reduce the **cost** & **complexity** of using **real time operations data** to drive **revenue** & **cost improvements** and **generate cash.**

*CESMII represents the **voice of manufacturing;** engaging the smart manufacturing ecosystem through a membership model*

- **Manufacturers** Small, Medium & Large
- **System Integrators & Consultants**
- **Machine Builders**
- **Technology Providers**
- **Academia & Labs**

INDUSTRIES IMPACTED

- Steel
- Agriculture
- Cement
- Chemical
- Aerospace
- Pulp & Paper
- Additive Manufacturing
- Pharmaceutical
- Thermal Treatment
- Injection Molding
- Automotive
- Supply Chain & Warehousing
- Metal
- Food
- Machine tools



The Cybersecurity Manufacturing Innovation Institute

CYMANII
cybersecurity manufacturing innovation institute

CyManII's Vision

is to secure U.S. manufacturers as they digitize by fortifying their physical systems with embedded cybersecurity and energy-efficient solutions.

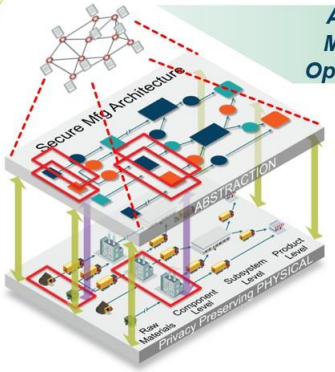
Core Pillars

ε-PURE

1	2	3
Secure the digital thread	Secure.*TOGETHER*	Create a cyber-informed workforce
• Build defensible architectures • Create identify-centric cyber-physical passports • Secure a decarbonized ecosystem	• Partner across industry's supply chain • Cooperate across Govt stakeholders • Focus on: Manufacturing Sectors Critical Energy Infrastructure Data and beyond…	• Focus on OT / ICS security • Leadership on CIE • Empower current workers • Expand emerging workforce (students)

CYMANII the cybersecurity manufacturing innovation institute

Secure Defensible Architecture (SDA)



Analysis
Modeling
Optimization

- Maximize E&E Efficiency
- Maximize Production
- Minimize Risk

Integrated Model of Automation & Supply Chain

- Perimeter defenses insufficient in modern **digital design lifecycle**
- We treat **Automation as nodes in Supply Chain** network

Framework for Security & Efficiency Across "Sectors"

- Digital **identity** = physical + cyber + energy (Cyber-Physical Passport)
- Automation **activities** validated across supply chain

Agile, Adequate, & Consequential Formalism to Validation

- **Targeted formal methods** and evidential basis for design & implementation
- Continuous Integration/Deployment (**CI/CD**) in manufacturing context

Unify security across the digital thread of design, build, deliver for industries of all sizes

SDA Project Update: Cyber-Physical Passport on CNC parts

Results to Date: A key concept in SDA is automatically deploying a **Cyber-Physical Passport (CPP)** to support system hardening, provenance tracking, process verification, and attack monitoring:

- Needed both locally at the manufacturing site and across companies along the product's supply chain.
- CyManII demonstrated the CPP on a CNC's aluminum parts productions and verification of the parts' **digital authenticity** against intended **design** (@ONRL MDF).

Future Work: Expand SDA framework and tools to support multiple innovations through **Industrial Use Case** pilots.

- Additive Manufacturing
- Smart Manufacturing enterprise (CESMII)
- Energy components supply chain

Manufacturing Demonstration Facility (MDF)

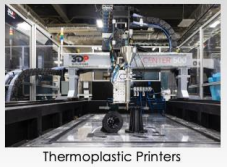
MDF By the Numbers

- **$1B+ impact** on U.S. manufacturing
  >20:1 ROI of DOE funding
- **200+** partnerships with **$100M+** in CRADAs (50% industry)
- **80-100** student interns per year
  >50 university collaborations
- **50–100** publications/year
  145 awards since 2012
- **100+** Industry Fellows at MDF from industry and academia
- **Within a day's drive** from 2/3rds of U.S. population
- **>140** staff members; **251** total (including interns, students & co-located industry partners)
- **49** licensed technologies
  105 patents/applications
- **>100** AM systems; **$30M** in equipment, **50%** placed through no-cost leasing
- **110,000+** sq. ft. facility space
- **34,000+** visitors & **5,900** company visitors representing entire supply chain

MDF Creating a Polymer and Composites Additive Supply Chain

OAK RIDGE National Laboratory

New AM Systems



Thermoplastic Printers

Thermoset Printer

Materials

Composites for Large Printing

High Temp Composites

Foams

Biocomposites

Interpenetrated Network Composites

End Applications

3D Printed Underwater Vehicles
https://roboticsandautomationnews.com/2021/09/01/ocean-engineers-optimize-design-and-performance-of-autonomous-underwater-vehicle/46058/

Concrete Molds, Domino Sugar Building
https://www.6sqft.com/amazing-photos-show-cookfoxs-domino-sugar-tower-getting-its-crystalline-facade/

Future Digital Systems

Configurable Holonomic Additive Manufacturing Platform (CHAMP)

Additive Manufacturing – Compression Molding (AM-CM)

Equipment OEM's

Feedstock Suppliers

End Users

AMMTO & MDF Support DOE Program's to Enable Clean Energy

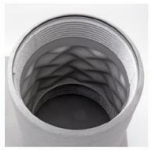
MDF research is accelerating advanced manufacturing to impact clean energy

1) Securing a U.S. supply chain.
2) Addressing affordability of clean energy technologies.
3) Improving energy efficiency in fabrication and application.

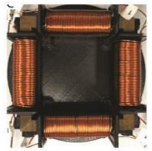
DOE & EERE

AMMTO

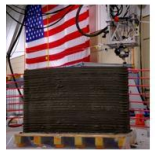
- Stakeholder Engagement
- Core Projects
- Technical Collaborations



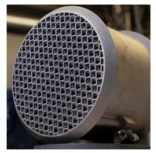
Complex geometries for Geothermal Prize: Geothermal



Printing of Transformers for Grid: Office of Electricity



Thermal Energy Storage for Buildings: EMPOWER Wall FEMP / Buildings



Enhanced CO2 Emission Capture: Fossil Energy and Carbon Management

Deposition of Tungsten for Plasma Facing Surfaces: Fusion Energy

New Materials for Efficient Transportation: Vehicles

Digital Certification of AM for Nuclear Components: Nuclear Energy

Wind Turbine Blade Manufacturing: AMMTO and Wind

Affordability for Low Head Hydro Power: Water Power and AMMTO

ORNL & U-Maine MDF Hub& Spoke

Sustainable Forest Products in Additive and Composite Manufacturing Processes

- Connects a $2+ Billion national laboratory to local ecosystems.
- U-Maine's Advanced Structure & Composites Center (ASCC) is the largest university-based research Center in Maine; 260 personnel.
- Combines MDF-ORNL expertise in advanced manufacturing with UMaine innovation in forest-derived biocomposites.
- Facilitates access to ORNL and UMaine assets and expertise to bring new, sustainable, and functional materials and processes to the market.

- **Optimize the production, implementation, and manufacturing of bio-based materials to reduce dependence on fossil fuel-derived polymers and composites.**
- **Integrate these materials and processes into mainstream manufacturing industries to achieve carbon neutrality and clean energy in US industries.**

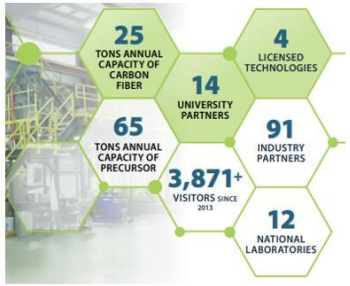
Carbon Fiber Technology Facility (CFTF)

OAK RIDGE National Laboratory | CARBON FIBER TECHNOLOGY FACILITY

Project Outline

Innovation: Scale-up Science Technologies for Advanced Fiber Manufacturing
Project Lead: Merlin Theodore
Project Partners: Over 90 industrial partners, 14 universities, 12 national laboratories
Timeline: Oct 1, 2013 – present
Budget: $5M annually

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$5M	$5M	$5M	$5M
Project Cost Share	$123K	$231K	$0K	$354K
IACMI (Consortia)	$74K	$69K	$0	$143K
IACMI costs	$42K	$69K	$0	$111K

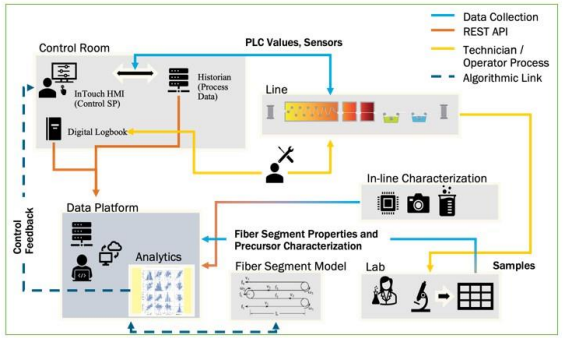


End Project Goal: Develop and advance scale-up science and technologies for advanced fiber manufacturing from the research and development stage to validation and deployment, enabling domestic commercial sources of these technologies thus enhancing U.S competitiveness in advance fiber manufacturing.

FY 23 Results and Achievements - CF Digital Data Platform Highlights

- **Challenge**: Current "off the shelf" solutions do not efficiently serve CF research and production environments, leading to data being siloed and difficult to fully utilize for optimization tasks (energy reduction or quality improvements).
- **Approach:** Create a custom digital data platform to enable efficient data input and retrieval at the CFTF.
- **Solution:** Designed and built a software API with supporting server code and database backends that allow for:
  1. digital twin modeling,
  2. characterization and process monitoring,
  3. data analytics.
- **Result**: Our current understanding of carbon fiber specific needs and best principles of design for a data platform are being described in a software requirements specification document.

Recording a fiber segment's history allows us to attribute characterizations to process parameters and materials and understand where energy can be saved.

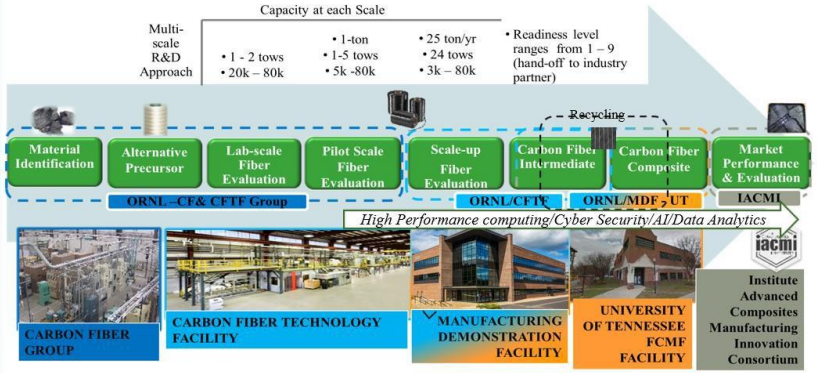


Artifacts:
- Platform software requirements specifications
- Custom designed database schemas
- Data server software creating connections between facility data collection points
- OpenAPI specifications

Strategic Approach - Multi-scale Integrated Precursor-to-Part Approach

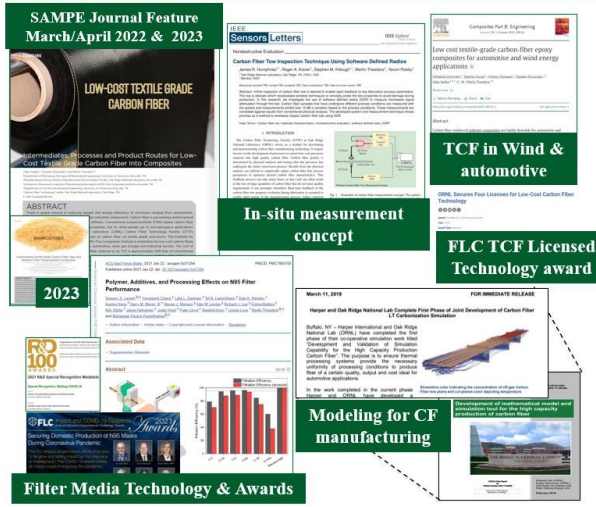
- Identify high potential, low-cost alternative precursors
- Multi-scale approach to reduce the uncertainties associated with scaling & develop optimal mechanical properties of resultant carbon fiber from
- Utilize the data analytic framework developed for CF manufacturing
- Provide quantities to industrial partners for testing based on DOE approval
- Address feedback from industrial partners
- Improve carbon fiber manufacturing cost metrics

Scaling of Science



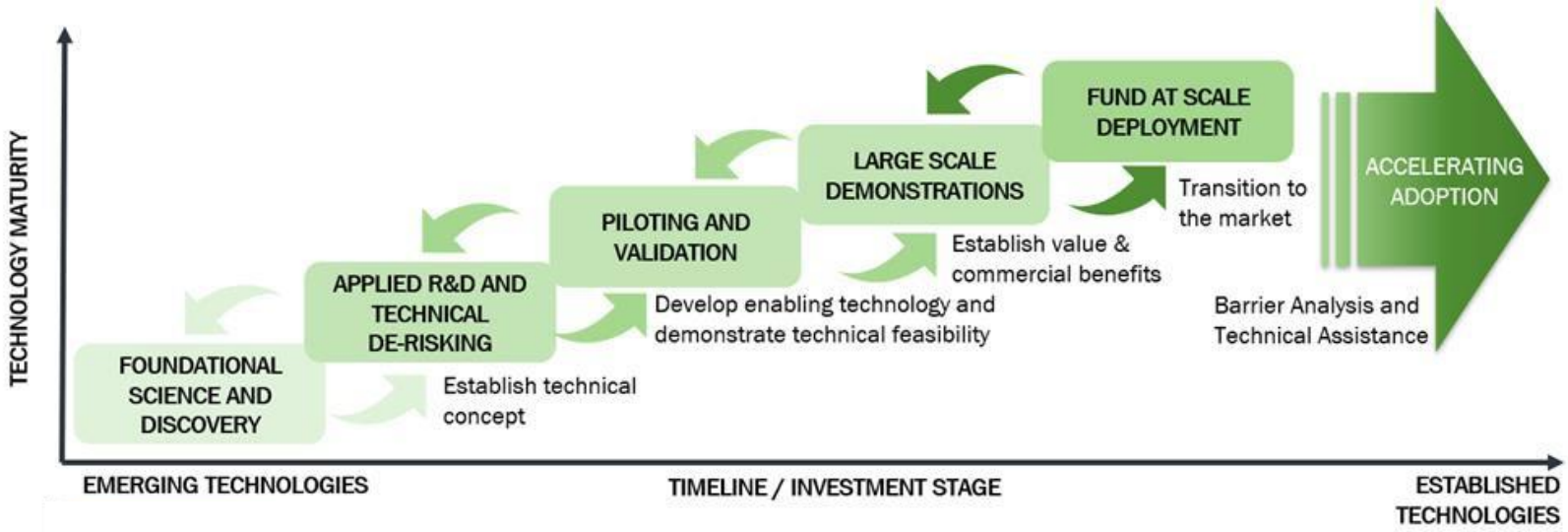
• *Integrator of research initiatives/strategies across the supply chain with unique supporting research facilities and capabilities, projects, technical skills, and established industry partner relationships*

Results and Achievements - Publications & Intellectual Property



Achievements
- Market Study completed
- API Best Practices
- > 20 publications
- Carbon Fiber Market Study/Industry Panel Identified
- 2 Copyrights1 Mathematical model and 1 Simulation tool:
  - Bayesian Model Software copyright: https://code-int.ornl.gov/cftf-data/analytics/boots
  - Transport Model Software copyright
  - Mathematical Model & Simulation Tool
- >10 Invention Disclosures/Patents:
- Workforce Development - 77% Students/Interns landed jobs
  - Students – 33% Current, 40% Academia, 20 % Industry, 7% Government
  - Tech Interns - 16% Industry, 66% Government

Funding Mechanisms



Lab Calls, Hubs, Lab-Led Consortia

- Foster early-stage innovation.
- Develop national resources that provide intellectual leadership.
- Supports the seeding of applied innovations that can be pulled forward into Institutes or FOAs.

FOAs, Institutes, Prizes

- Develop early-stage research to the pilot scale.
- Accelerate technology progression through coordination between industry, academia, and the NLs.
- Provide shared infrastructure and workforce development.

SBIR/STTR, LEEP, S3, Non-Fed

- Progress promising technologies that are closer to deployment.
- Encourage entrepreneurship as a pathway to commercialization.
- Institute projects can compete for follow-on funds.

Active Funding Opportunity

Smart Manufacturing Technologies for Material & Process Innovation

FOA overview: This $33M FOA will accelerate adoption of smart manufacturing technologies by domestic clean energy manufacturers, helping them to deliver product innovations and enhance competitiveness. It leverages AMMTO's draft Smart Manufacturing Strategy.

FOA goals:

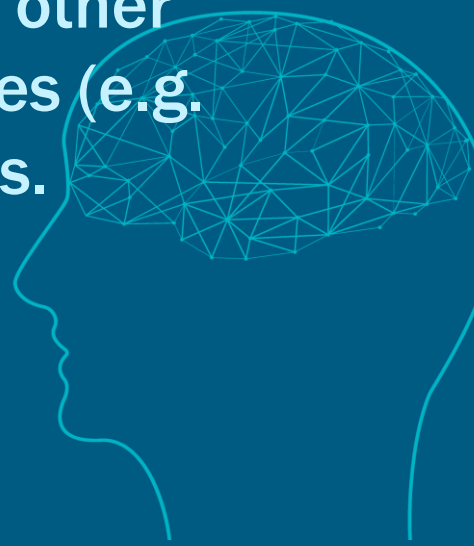
- De-risk technologies through collaboration with industry to advance smart manufacturing technologies and processes.
- Foster partnerships across supply chains to accelerate the adoption of smart manufacturing technologies and processes for more efficient, resilient, and responsive US manufacturing.
- Demonstrate innovations that can be deployed across the clean energy manufacturing sector to improve US competitiveness.

Synergy with AMMTO-related consortia:

- ORNL Manufacturing Demonstration Facility (MDF) Digital Factory Initiative
- Clean Energy Smart Manufacturing Innovation Institute (CESMII)
- Cybersecurity Manufacturing Innovation Institute (CYMANII)
- Sustainable Materials and Manufacturing Alliance for Renewable Technologies (SM2ART)

Developing Platform Technologies and Expanding Collaboration

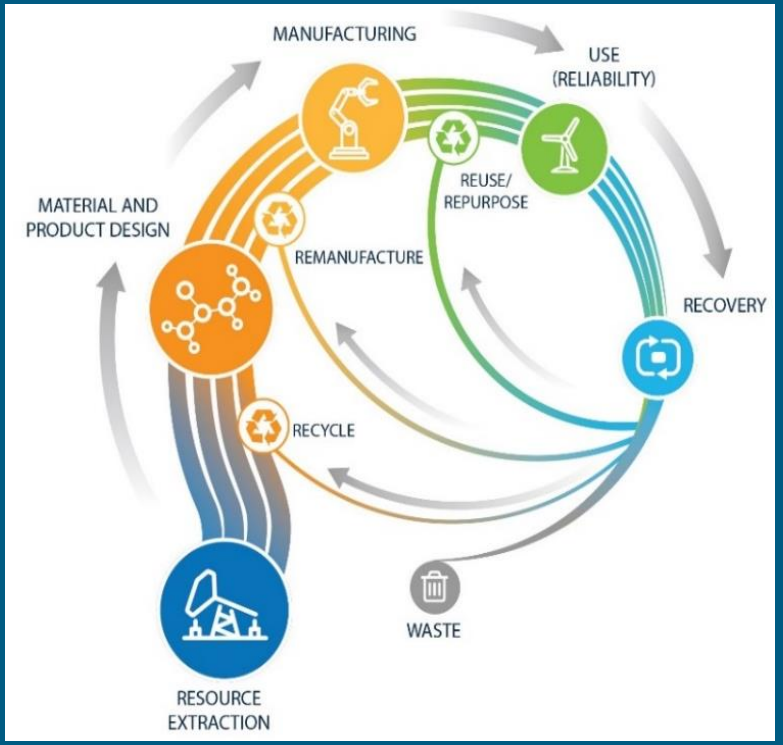
- This FOA will develop and demonstrate platform smart manufacturing technologies that can be leveraged across the clean energy technology ecosystem.
- Smart manufacturing technologies such as AI and ML are of increasing interest, and this FOA will contribute to expanding their use across the clean energy landscape.
- It will also contribute to expanding AMMTO's collaboration with other offices within DOE (e.g. VTO, BTO, FECM) and with other agencies (e.g. NIST, DOD, NSF) through engagement during the review process.



Topic 1: Smart Manufacturing for a Circular Economy

Topic Focus: Increase the viability of circular supply chains (Re-X pathways), such as recycling, repair, remanufacture, and reuse, by improving their efficiency and economics.

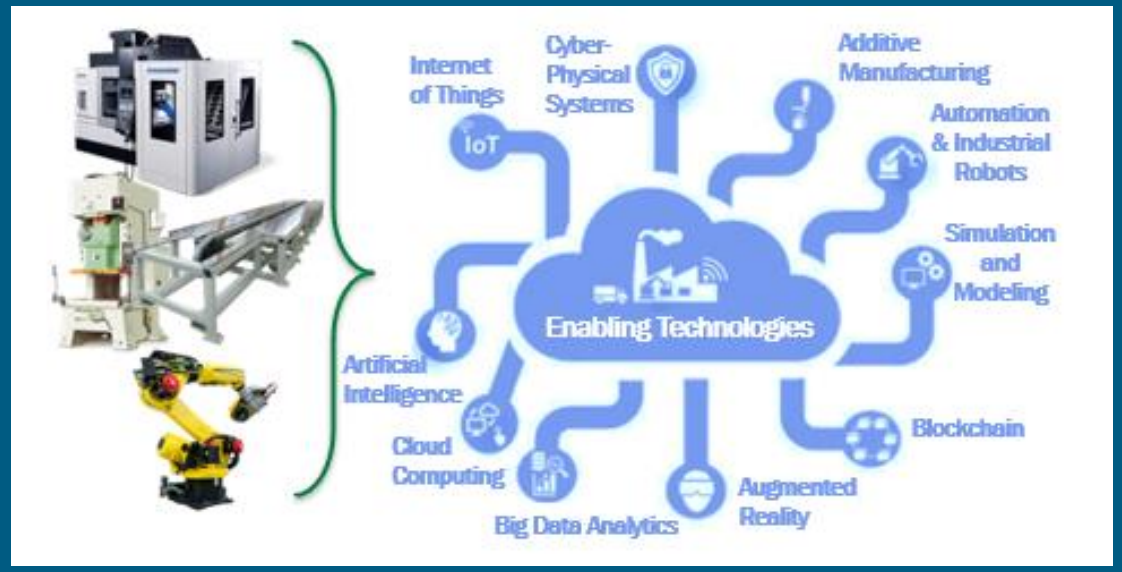
- **AOI 1: Smart Manufacturing Technologies for Improved Sorting and Characterization**
  - Broadly applicable to material classes and Re-X pathways of interest
  - Leverages sensors, data collection/integration, ML, etc.
- **AOI 2: Interoperable and Open Supply Chains for Expanded Re-X**
  - Re-designing products for Re-X, developing software and/or hardware to enable disassembly and characterization for Re-X, etc.
- **AOI 3: Improved Data Transparency for Accurate LCAs**
  - Improving data availability, transparency, and sharing across supply chains for more accurate LCAs to guide decision making.



NREL, Circular Economy Model (2022)

Topic 2: Smart Mfg. of Tooling/Equipment for Sustainable Transportation

- **Topic Focus: D**evelop and demonstrate broadly applicable smart manufacturing technologies that can advance manufacturing processes and strengthen supply chains for sustainable transportation technologies.
- Areas of interest: Applications can focus on machinery, tooling/equipment that supports sustainable transportation, or broadly applicable technologies (which can be leveraged by sustainable transportation in addition to other sectors)



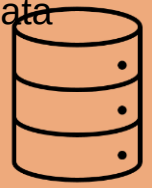
Proposed technologies must be related to automation (integrating hardware and software to improve productivity) and/or manufacturing asset management (improving the cost, quality, and throughput of the tooling and equipment, industrial controls, and automation network).

Topic 3: Smart Manufacturing for High Performance Materials

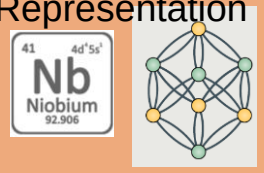
- **Topic Focus**: Develop smart manufacturing techniques to accelerate introduction of high-performance materials (HPMs) including advanced conductors for grid applications and harsh condition materials for renewable/nuclear energy.
- **Areas of interest**: 1) Smart techniques for optimization of HPM composition and for HPM process discovery, and 2) Scale up HPM processing with smart manufacturing

Area of Interest 1: AI/ML-enabled Materials

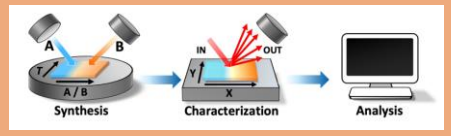
1. Material data



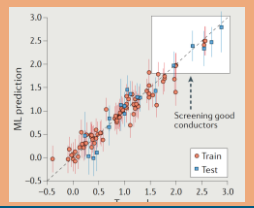
2. Materials Representation



3. Synthesis and characterization



4. Properties Prediction



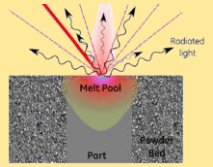
Researchers | Material Vendors | Service Companies

Co-design is Essentia

Area of Interest 2: Processing/Manufacturing

5. Design

6. Process Models



7. Performance Testing

8. Process Control

Manufacturers | System Integrators | Cloud Computing Vendors

Topic 4: Smart Technologies for Sustainable & Competitive U.S. Mining

Topic Focus: Increase the sustainability and competitiveness of U.S. mining for critical materials using smart technologies.

AOI 1: Sustainable and Competitive U.S. Mining

- Targets smart manufacturing technologies to minimizes mining byproducts through remediation, conversion, and/or valorization
- Seeks to increase sustainability and economic competitiveness of mining operations

AOI 2: Sensing, Analytics, and Data-Driven Decision Making in Mining

- Targets sensors / instrumentation to inform mining operation
- Seeks to increase accessibility and affordability of sensors and analytical instruments, reducing need for off-site analysis, and enabling real-time decision making

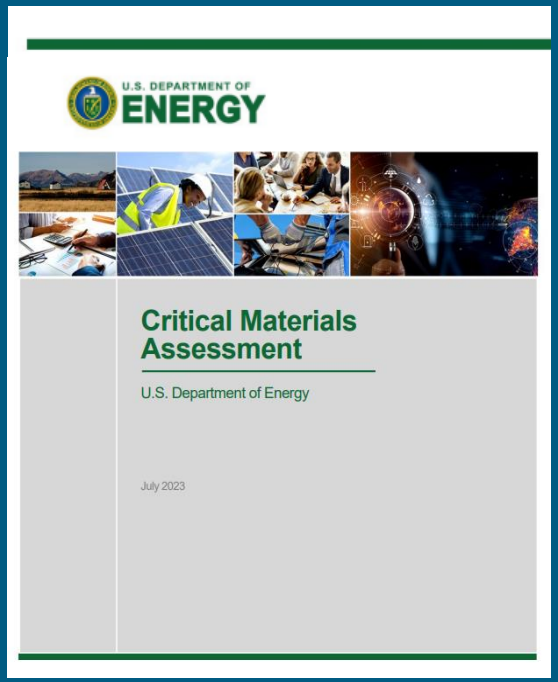
DOE Wide Considerations

Consulted with FECM and ARPA-E for equities:
- FECM --> Mine of the Future
- FECM/ARPA-E- -> Upcoming RFI and workshops
- MESC likely to enter space but at later TRL/ARL

AMMTO Tailoring & Equities

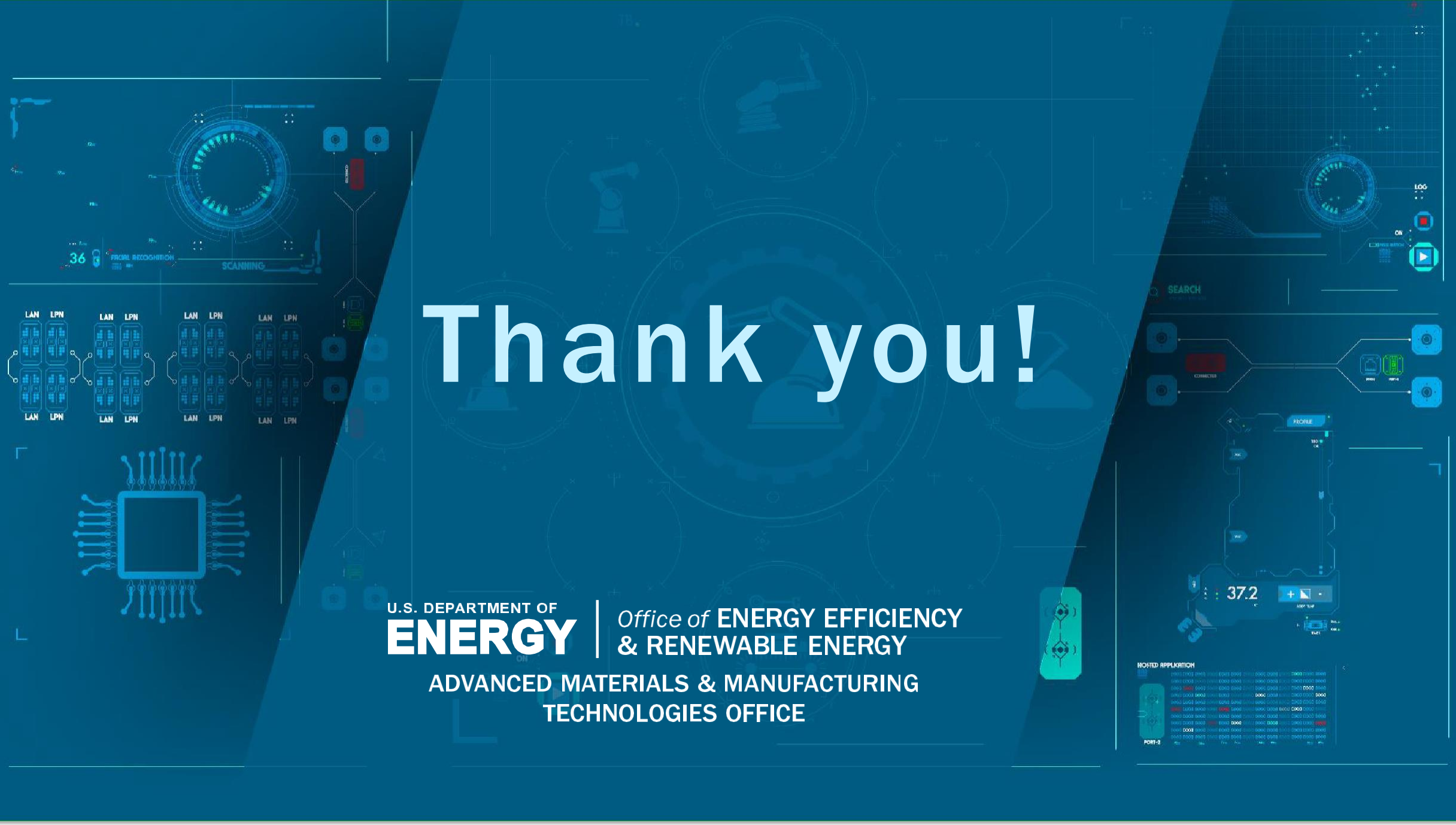
- Narrowed topic focus
- Limitations on eligible mineral sources: rock/clay
- Required TEA, LCA, and CMC participation
- Tackles performer and portfolio needs

CRITICAL MATERIALS COLLABORATIVE
U.S. DEPARTMENT OF ENERGY



Timeline

- NOI released: April 15
- FOA released: July 18
- Concept Papers Due: August 22
- Concept Papers Reviewed, invite Proposals: Late September
- Full Applications Due: November 18
- Application review period: Late November – Late December
- Federal Consensus Board Meeting: February 2025
- Awards Selected: Mid April 2025
- Awards Negotiated: Late April - Late June 2025
- Planned Award Date: Late September 2025



Thank you!

U.S. DEPARTMENT OF ENERGY | *Office of* ENERGY EFFICIENCY & RENEWABLE ENERGY

ADVANCED MATERIALS & MANUFACTURING TECHNOLOGIES OFFICE