MFORESIGHT:

Alliance for Manufacturing Foresight

The Nation's Advanced Manufacturing Advisory Consortium

A federally-sponsored consortium of national thought leaders from industry and academia focused on the future of American manufacturing.

www.mforesight.org

Sridhar Kota – Executive Director

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

NSF

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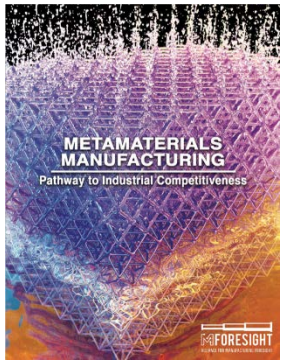
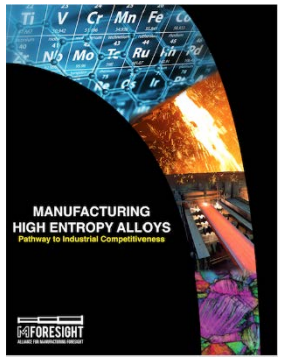
Accelerating Technology & Manufacturing Innovation

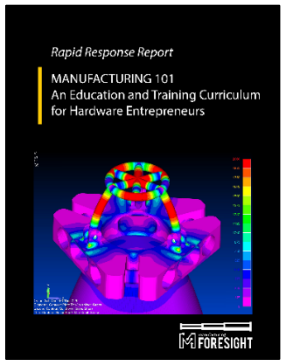


Metamaterials Manufacturing

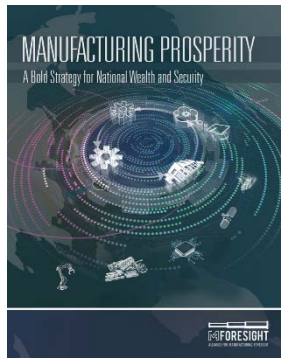
Regenerative Medicine



Manufacturing High Entropy Alloys



Manufacturing 101



Manufacturing Prosperity

Education and Skills Building

Next Generation Supply Chains

Cybersecurity for Manufacturers

Ideas worth scaling

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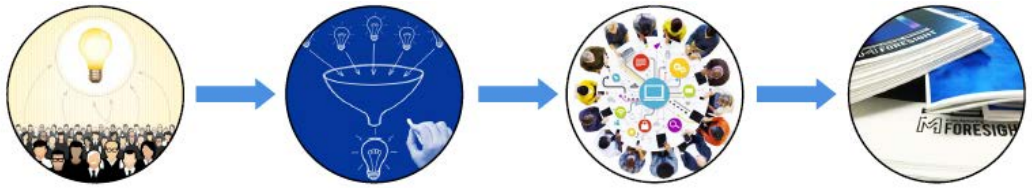
Challenges worth addressing

Basic Research	Translational R&D	Applied R&D	Full Volume Manufacturing

Stakeholder Engagement and Community Building

4 Phases

- ***Discover***
- ***Prioritize***
- ***Develop***
- ***Disseminate***



MForesight Leadership Council

Industry

Nonprofits

Academia

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Discover Emerging Technologies & Manufacturing Challenges

Scouting and Surveys

Professional Societies
Trade Associations
Federal Agencies
Federal Programs

Tech Transfer
Universities
Industry
Shows/Events

"Gamechanger" Events Partners

ASME SETTING THE STANDARD

MSEC Manufacturing Science and Engineering Conference

TMS The Minerals, Metals & Materials Society

AUTM

FABTECH

Publish Community Highlights

Marketing and Outreach

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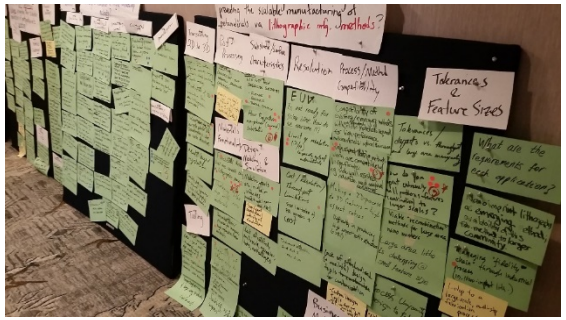
Develop

Actionable Recommendations



1. **R&D Priorities**
2. **Implementation challenges**
3. **Related policies**

- Deep Dive Workshops:
  - 50% Industry, 25% Academia, 25% Government
  - Community-led Steering Committee
- Industry interviews
- Roundtables
- Internal Research

Geographic Distribution of MForesight Contributors and Events

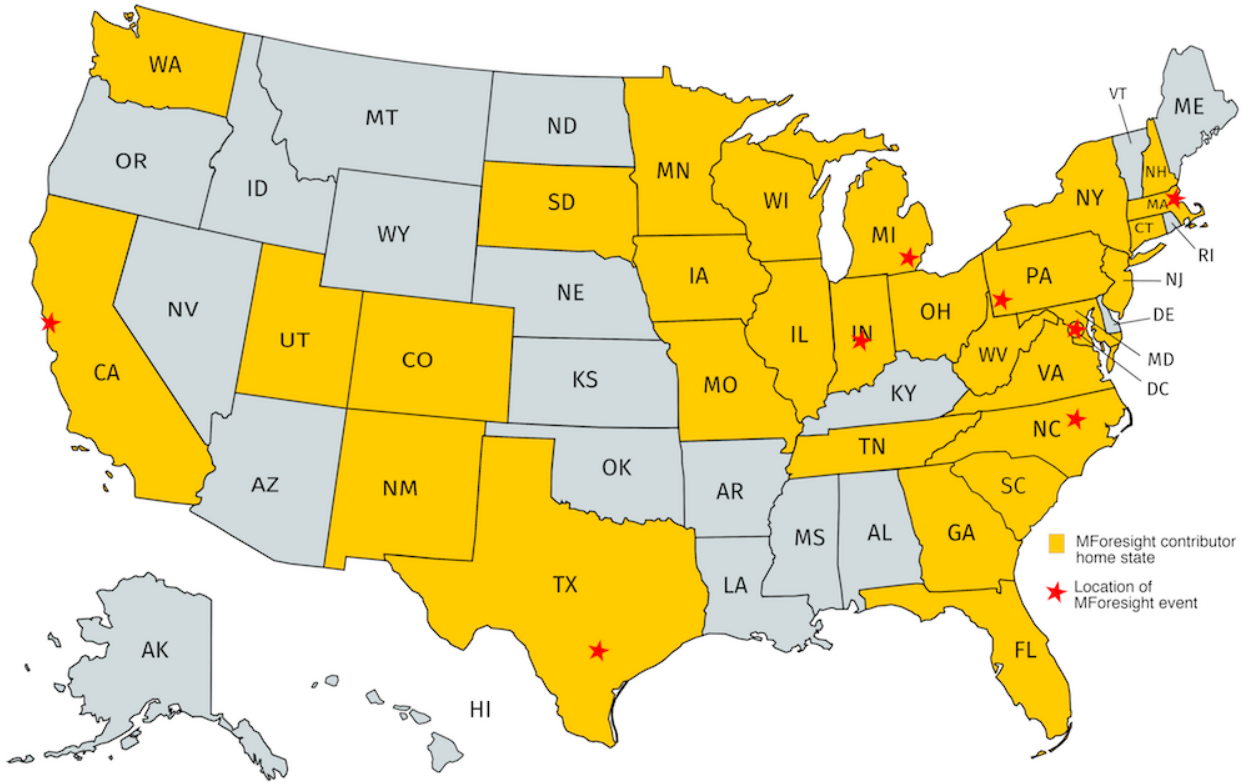


Table 1: Contributor Sectors & Disciplines	
Acoustics	Manufacturing Equipment
Additive Manufacturing	Materials
Aerospace	Medical Devices
Automation	Metallurgy
Automotive	Nanotechnology
Chemical	Optics/Photonics
Electronics	Packaging
Energy/Power	Pharmaceuticals
Funding/VC	Plastics
Furniture	Semiconductors
IT/Computing	Systems Engineering
Machinery	Tech Transfer
Manufacturing Education	Technology Policy

Federal Agencies & Capitol Hill Briefings

Disseminate

Reports and Briefings

Dissemination Partners

National Association of Manufacturers · SME · MRS · House Manufacturing Caucus, Co-Chairs Tom Reed and Tim Ryan · Association of Public & Land-Grant Universities · Alliance for American Manufacturing · NDIA · TMS · SSTI

Op-eds

“America is outsourcing innovation and we need to bring it back” – The Hill

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Grand Challenges in U.S. Manufacturing

Grand Challenge: "Innovate here, Manufacture there" is reaching its logical conclusion:

"Innovate there, Manufacture there"

Convened 7 roundtables across the nation with **over 100 thought leaders, s**pent **over 1000 hours** discussing potential solutions

Round Tables and Partners

Boston, MA

Washington D.C.

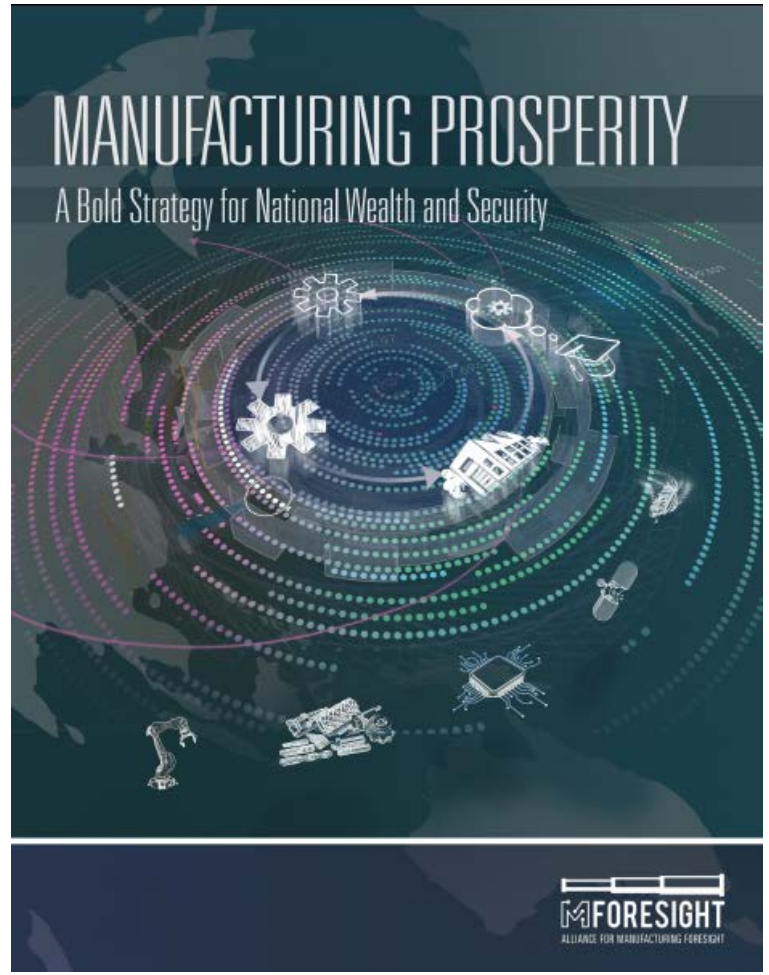
Austin, TX,

San Jose, CA

Raleigh, NC

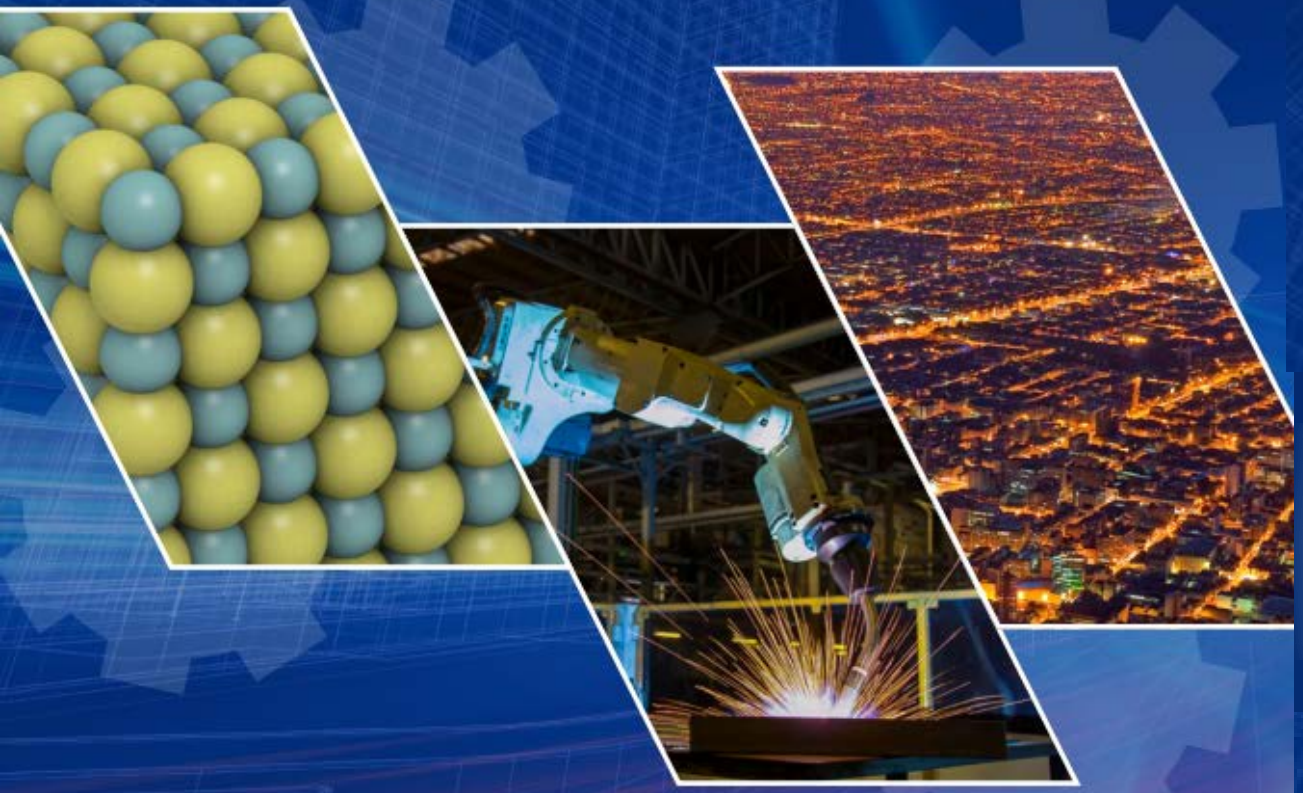
Indianapolis, IN

Detroit, MI



A WORKSHOP STUDY ORGANIZED BY

The Minerals, Metals & Materials Society (TMS) on behalf of
MForesight: Alliance for Manufacturing Foresight



TMS

manufacturing FORESIGHT

Harnessing Materials Innovations to Support

NEXT GENERATION MANUFACTURING Technologies

Ed Herderick

The Ohio State University

Center for Design and Manufacturing Excellence

In partnership with

TMS

The Minerals, Metals & Materials Society

Materials in Manufacturing

- Materials are involved at every step in the manufacturing process chain
- Innovations in Materials Science & Engineering (MS&E) are essential for technological advances needed for next-generation U.S. manufacturing
- Imperative that U.S. manufacturing retain its global leadership in cutting-edge technology

Goal: What are the most significant opportunities for materials innovations to unlock the next wave of U.S. manufacturing?

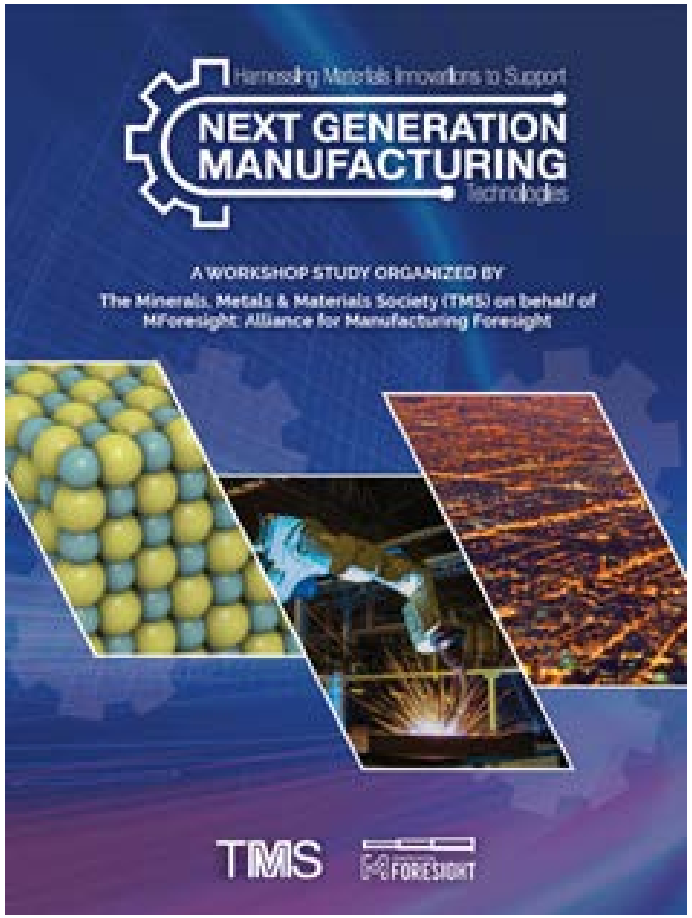
Input From the Advanced Manufacturing Community

~40 Thought Leaders:
50% Industry,
25% Academia,
25% Government

Evaluation criteria:

1. Leads to manufacturing process improvement in next 5-10 years- enhances U.S. manufacturing competitiveness
2. Provides opportunity for economic growth and national security
3. In need of govt. support for pre-competitive investment
4. Favors U.S. advantage using existing/available resources

High Priority Areas of Research

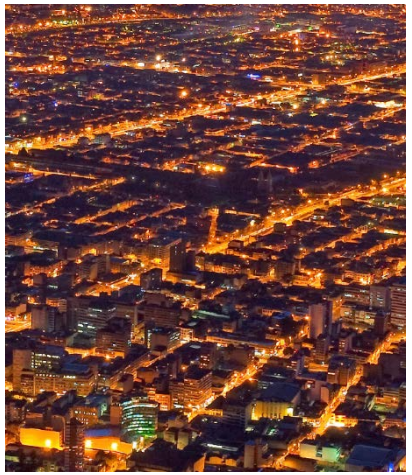


1. Nondestructive evaluation and sensors
2. Joining of dissimilar materials
3. Machine learning for accelerated materials discovery and design
4. Qualification for new materials and processes
5. Next-generation conductive materials
6. Materials for smart manufacturing & digital thread technologies
7. Smart materials

Technology breakthrough areas that could enable each opportunity

Opportunity: Next-Generation Conductive Materials

- Lightweighting, fuel efficiency, and reduced emissions in the transportation industry and in military applications
- Efficient inexpensive alternatives for copper and electric grid infrastructure
- Enabling technology for renewable energy platforms (e.g., solar, wind)

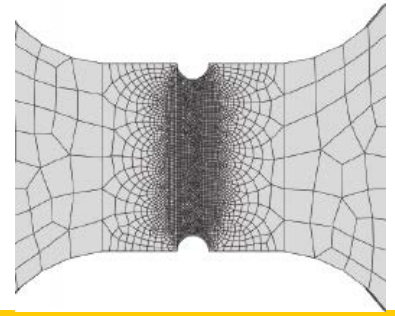


Potential Breakthrough Areas:

Next-Generation Conductive Materials	A. Superconducting materials and novel covetic nanomaterials B. Coatings and dielectric insulators C. Conductive materials for energy storage and harvesting

Opportunity: Qualification for New Materials and Processes

- Qualification is resource intensive, especially for new materials.
- Digital methodologies relying on models, simulations, and in situ monitoring during production – would streamline qualification processes
- Maintain requisite standards, safety, and national security considerations

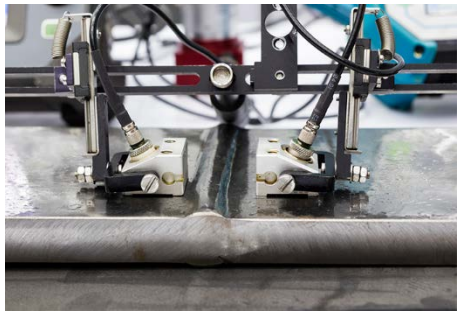


Potential Breakthrough Areas:

Qualification for New Materials and Processes	A. Framework of best practices for materials qualification B. Model-based qualification approaches for computational materials testing C. Sensors and data-driven analytics to enable rapid qualification approaches

Opportunity: Analytics for Non-Destructive Evaluation & Sensors

- Elucidate quality, reliability, and behavior of materials during manufacturing processes
- Inform vital underlying analytics used to assess and improve manufacturing procedures, and potentially provide new breakthroughs
- Reduce costs, accelerate time-to-market, lower risk of human error in data analysis, and enhance safety

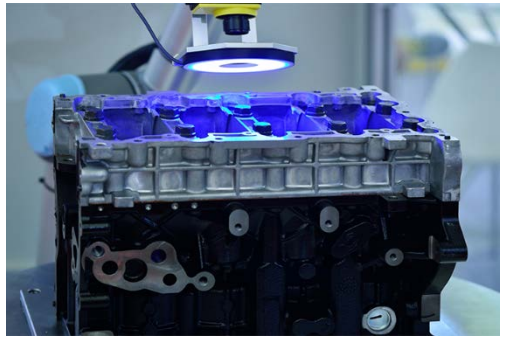


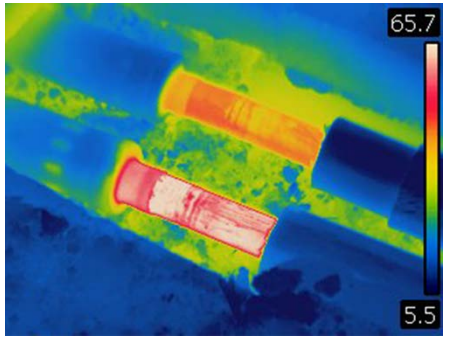
Potential Breakthrough Areas:

Analytics for Nondestructive Evaluation (NDE) and Sensors	A. Novel sensing technologies and real-time sensing B. Data mining, compression, storage, and management C. Predictive modeling tools for NDE and sensors

Next Area of Study: Next-Gen Non-Destructive Evaluation

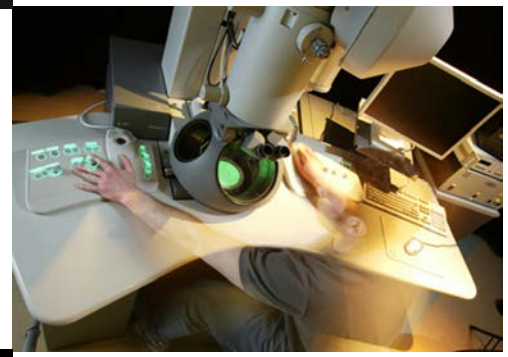
- Emerging technologies and operational requirements are driving the need for the next generation of NDE.
- Goal is to identify current and emerging challenges and opportunities in sensors, data analysis, automation, and implementation of non-destructive evaluation and metrology for manufacturing
- Examples include:
  - Leveraging new technologies for evaluating composites
  - How to inspect and evaluate complex geometries created by metal additive manufacturing
  - Identifying defects in engineering ceramics at relevant length scales for structural and functional applications

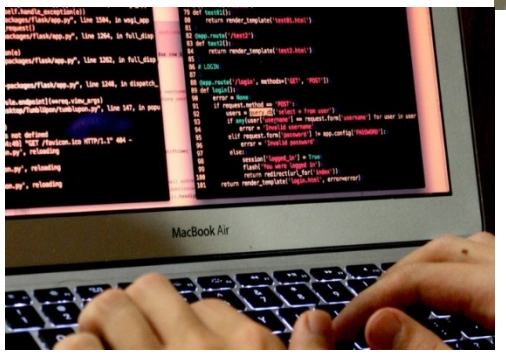




Who Should Read these Reports?

- Public officials, program officers at federal agencies, and leaders from private enterprises to support investments in promising technology areas
- University leaders for decisions on research directions, faculty hires, and/or budgets
- Scientists and Engineers to begin addressing opportunities, including those from other disciplines needed for critical collaborations

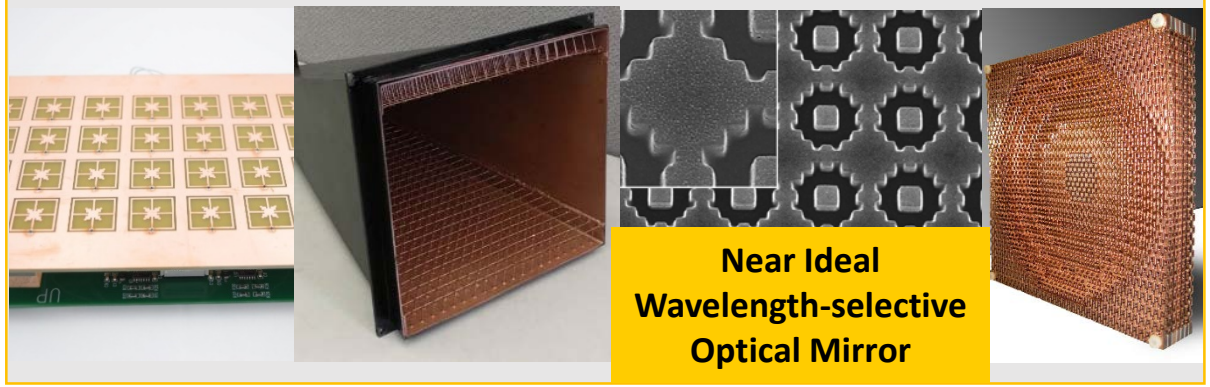





METAMATERIALS
MANUFACTURING
Pathway to Industrial Competitiveness
Chris Spadaccini
Lawrence Livermore National Laboratory
MFORESIGHT
ALLIANCE FOR MANUFACTURING FORESIGHT

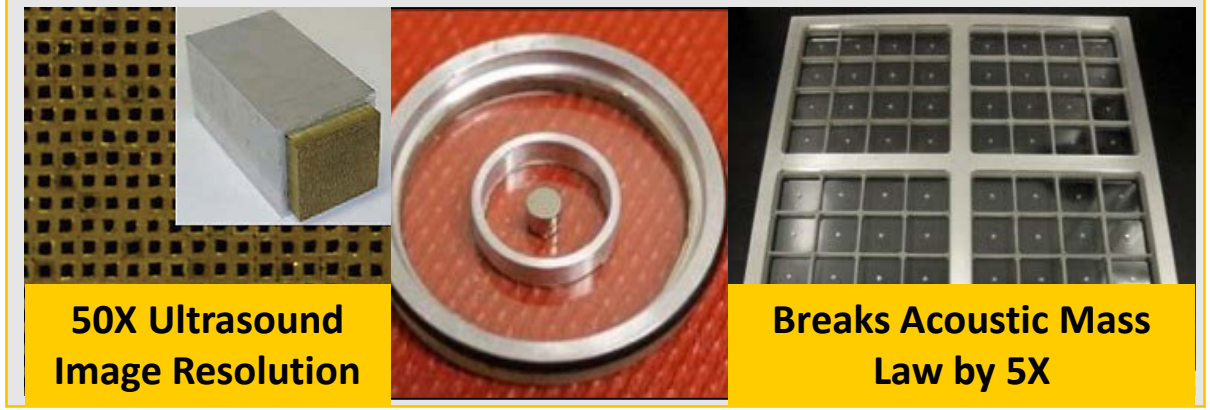
Metamaterials: Cross- Cutting Impact

Antennas, Optical Filters, and Super Lenses



Near Ideal Wavelength-selective Optical Mirror

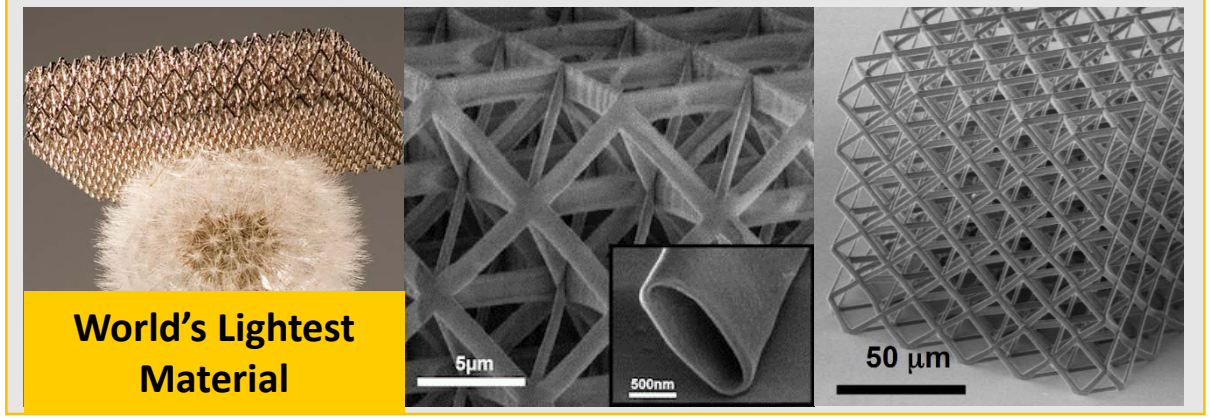
Sonography and Acoustic Damping



50X Ultrasound Image Resolution

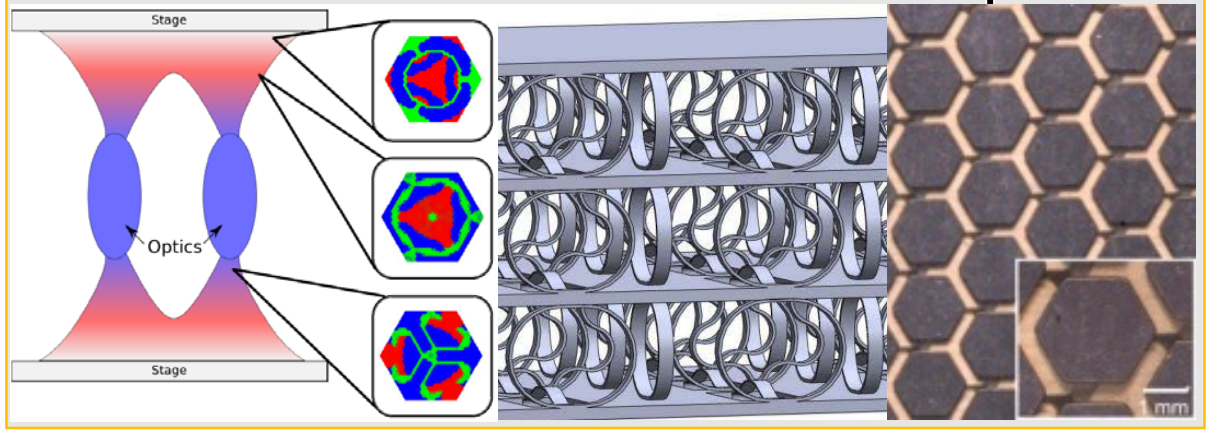
Breaks Acoustic Mass Law by 5X

Light-weighting and Structural Performance



World's Lightest Material

Athermal and Novel Mechanical Properties

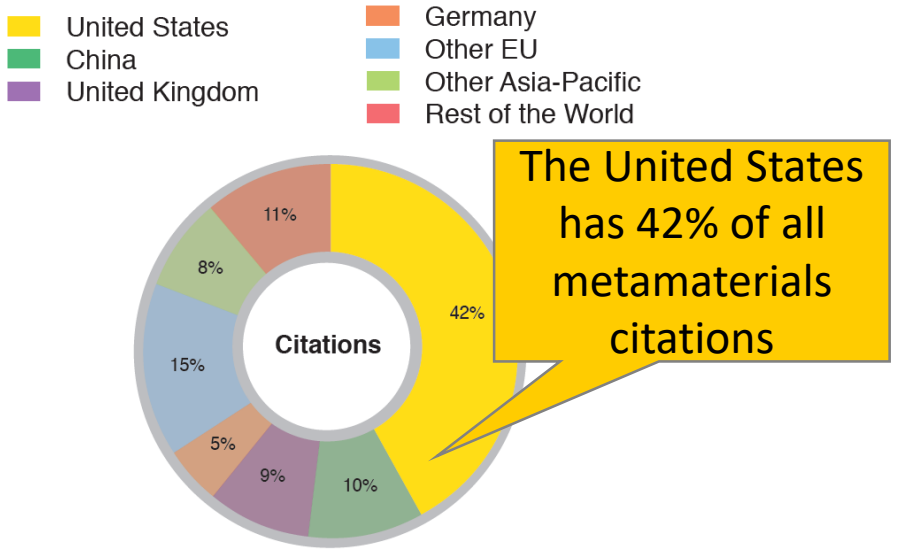


(top left) Metawave, Lockheed Martin, Lockheed Martin, Dylan Erb [MIT]; (top right) Xiang Zhang [UC Berkeley], HRL, HRL; (bottom left) HRL, Julia Greer [Caltech], Julia Greer [Caltech]; (bottom right) Chris Spadacinni [LLNL], Lorenzo Valdevit [UC Irvine], HRL

United States Manufacturing Competitiveness

Scalable Manufacturing is Missing

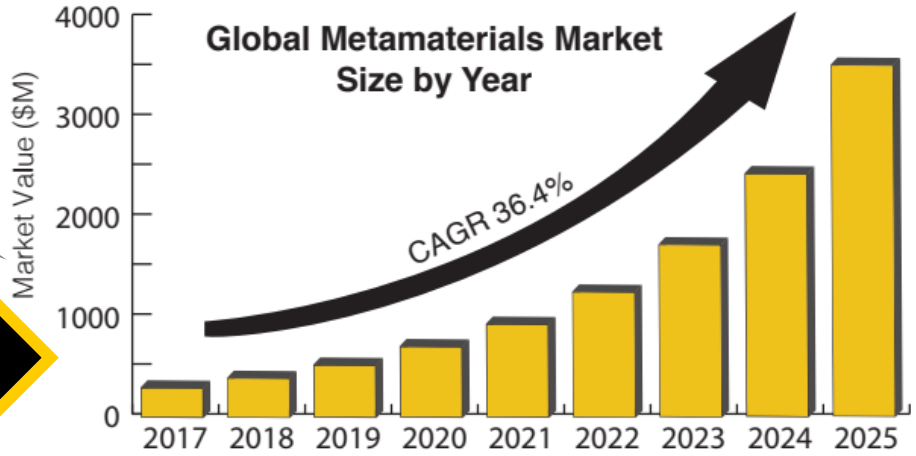
United States Research Investments



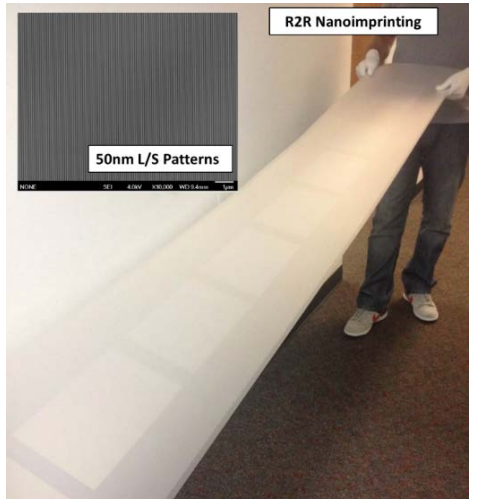
The United States has 42% of all metamaterials citations

Metamaterials predicted to be a $3.5 Billion Market by 2025

Research to Market Impact



Prototypes to Scaled Production



(bottom right) Image courtesy of NASCENT Center

Input From the Advanced Manufacturing Community

~40 Attendees: 50% Industry, 25% Academia, 25% Government

LOCKHEED MARTIN

GM

3M

Raytheon

APPLIED MATERIALS®

HRL LABORATORIES

Kodak

magic leap

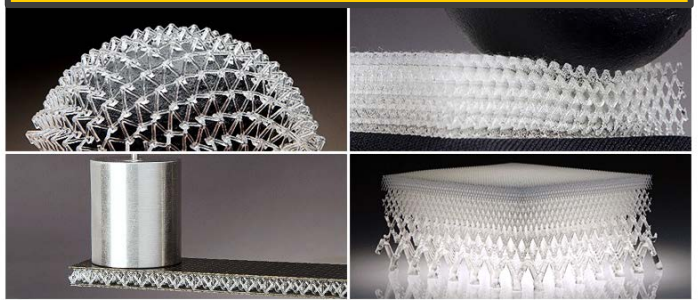
MOXTEK

zyvex™ LABS

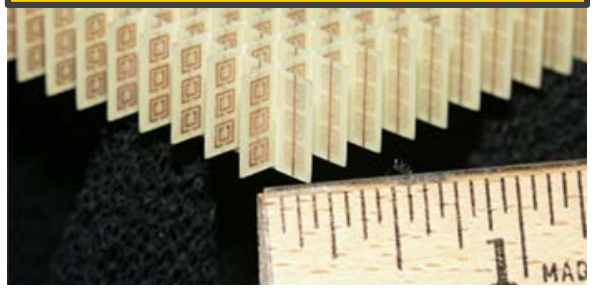
Steering Committee:
Dr. Chris Spadaccini
Dr. Bill Carter
Dr. Bernard Casse
Dr. Clara Rivero-Baleine
Dr. S.V. Sreenivasan
Dr. Jim Watkins

Cross-Cutting Barriers to Manufacturing

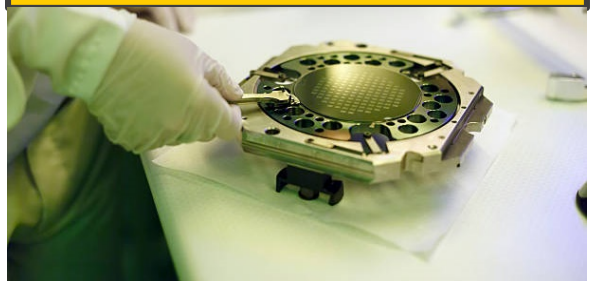
Novel scalable process technologies are needed.



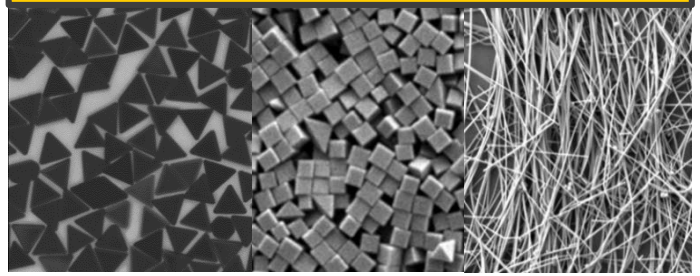
Practical applications require innovation in metrology and modeling.



Metamaterials requires a coordinated, collaborative, and focused approach.



Value is only delivered if the supply of high-quality feedstocks is consistent and affordable.



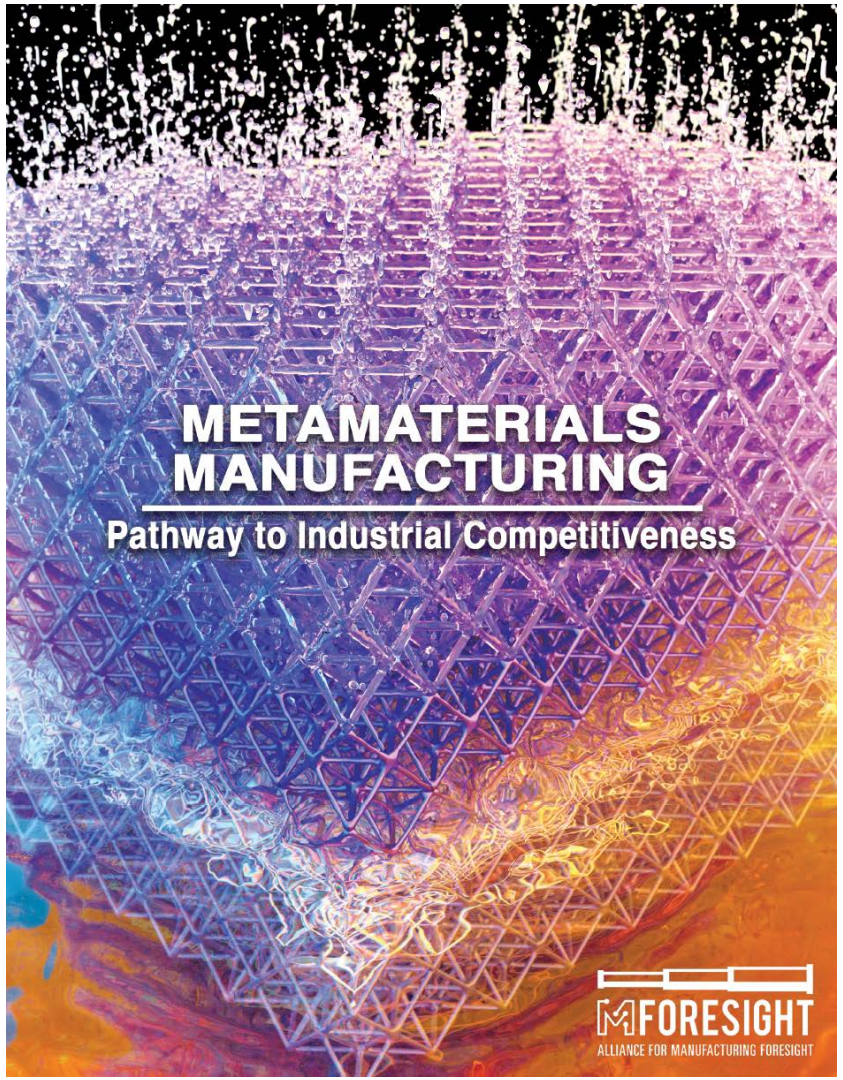
Access to equipment, tools, and experts accelerates process innovation.

Lawrence Livermore National Laboratory

SLAC NATIONAL ACCELERATOR LABORATORY

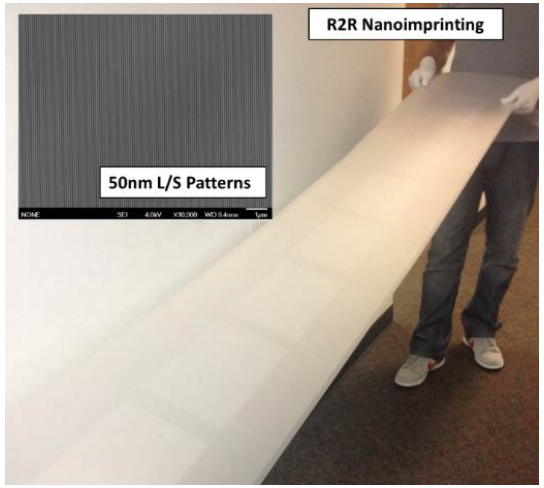
MDF Manufacturing Demonstration Facility

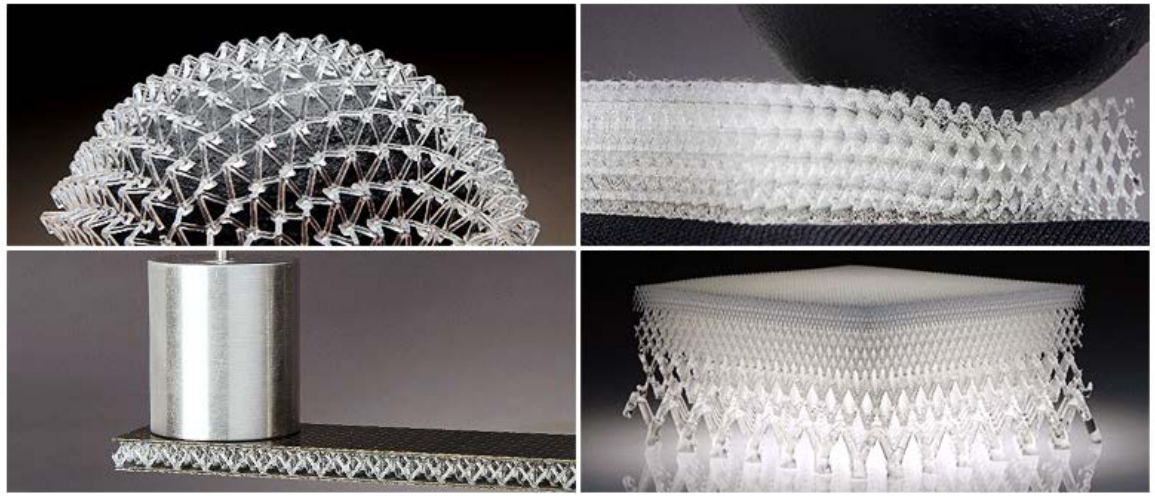
Actionable Recommendations



1. Research Initiative on Process Barriers
   - Scaled Manufacturing Technologies
   - Multi-material
   - Metrology
   - Simulation and Design
2. Feedstock Quality and Availability
   - Substrates, nanomaterials, and facilities
3. Center of Excellence
4. Access to Federal Facilities and Experts
5. Roadmapping and Expert Guidance

Focus Areas for Scaled Manufacturing Technologies

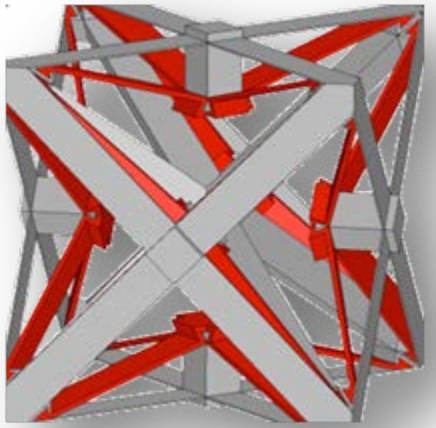


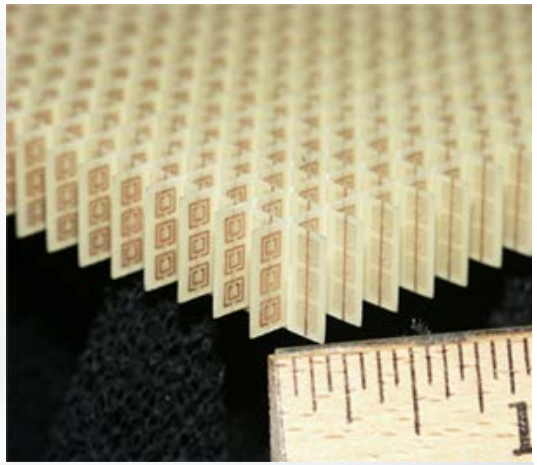


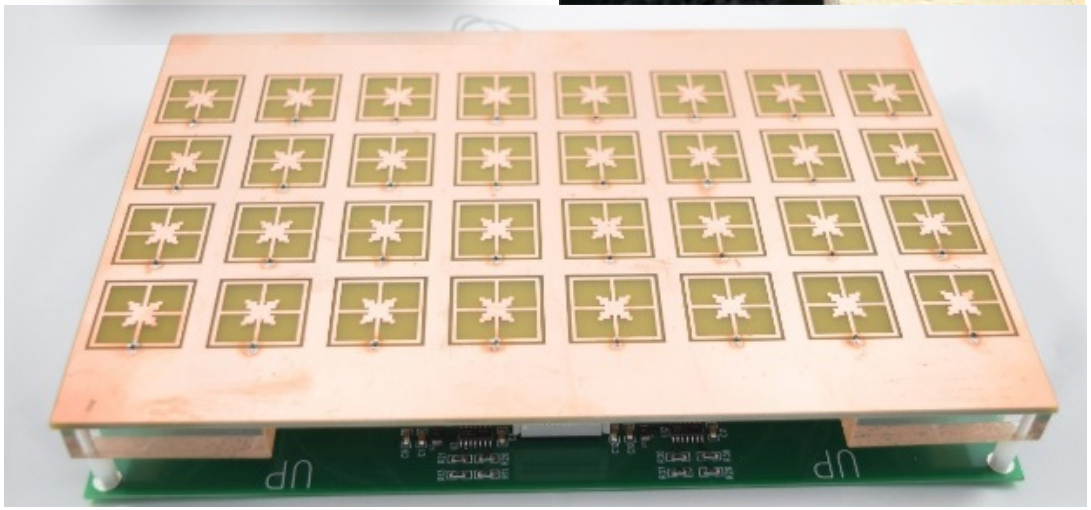
- Stepping Technologies
- Nanoimprint Lithography
- Pattern Transfer
- 3D Printing
- With Roll to Roll
- Self-Assembly

Image courtesy of NASCENT Center: Roll to roll nanoimprint lithography

Focus Areas for Multi-Material Metamaterials



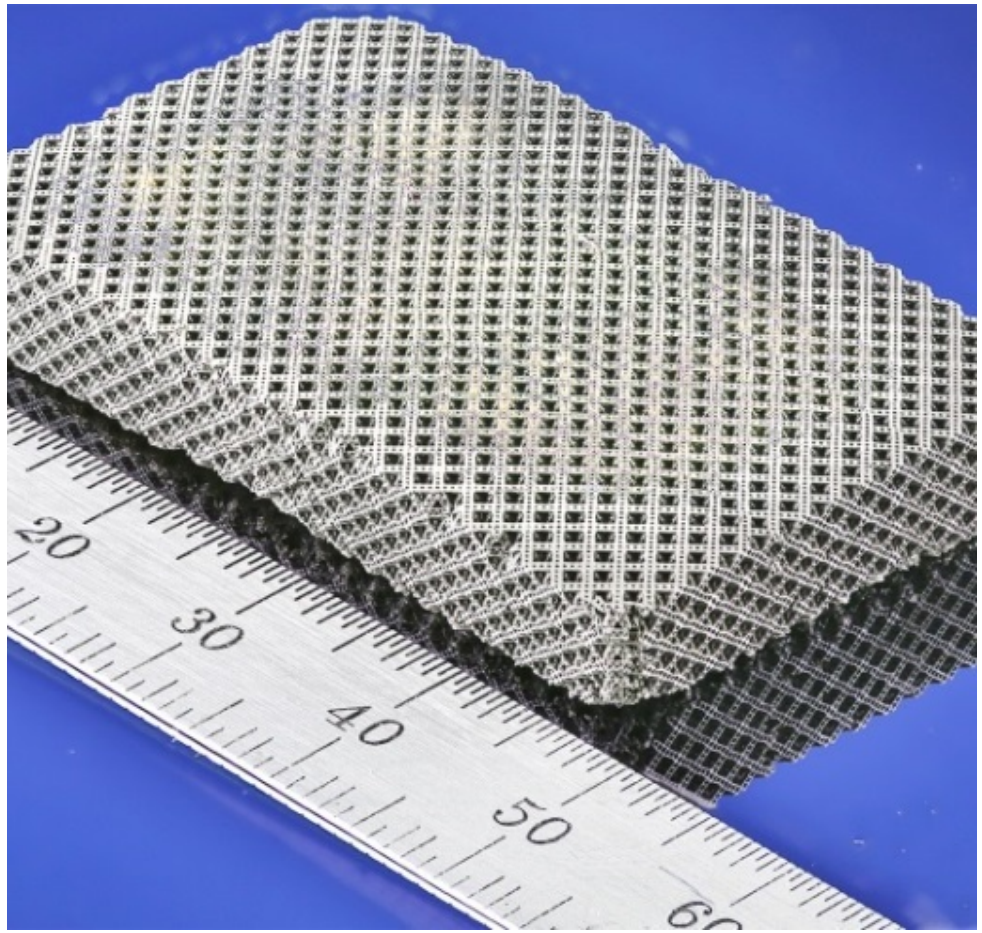




- Joining of disparate materials
- Materials conducive to joining
- Efficient multi-material manufacturing processes
- Novel material agnostic processes

(top left) Image courtesy of Jonathan Hopkins: negative thermal coefficient materials. (top right) Image courtesy of NASA [public domain image]: Split ring resonators. (bottom) Image courtesy of Metawave: metamaterial antenna.

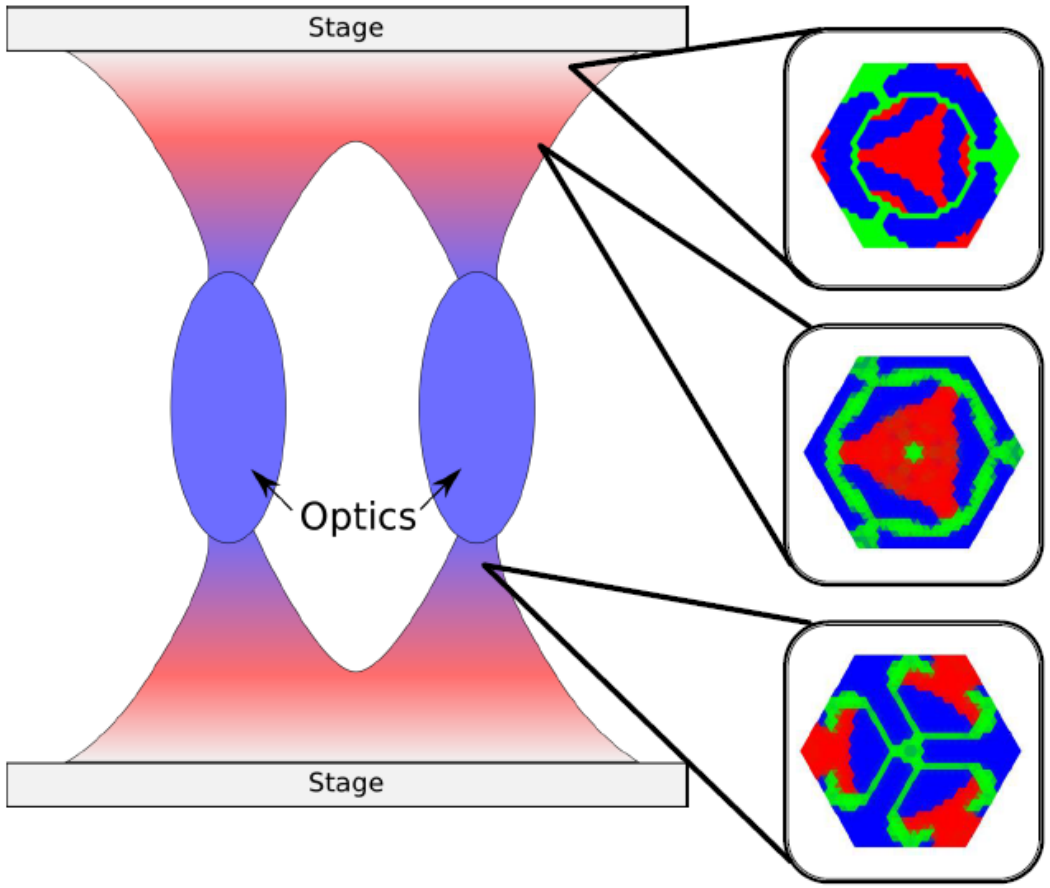
Focus Areas for Metrology for Metamaterials



- High-resolution, large-area 3D metrology
- Evaluation for multi-material
- Metrology for multi-scale (nano to macro)

Image courtesy of Chris Spadaccini (LLNL): Multi-scale lightweight structural metamaterial

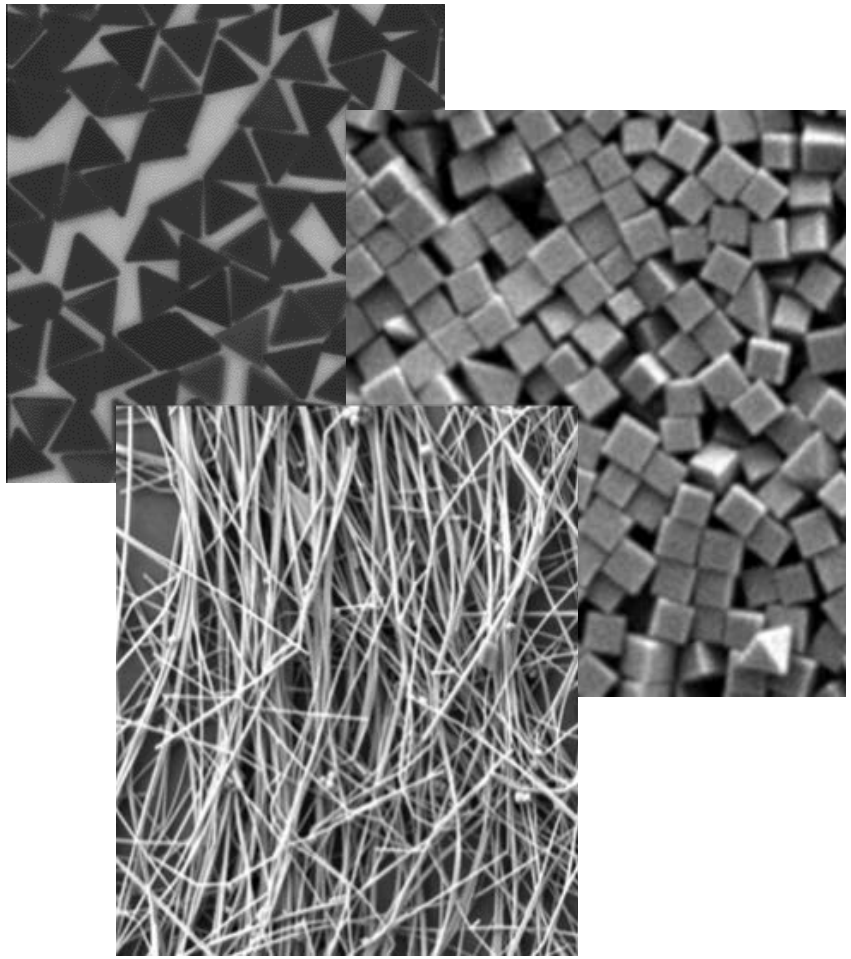
Focus Areas for Simulations and Design for Manufacturing



- Design tools for manufacturability
- Design and simulation for periodic structures
- 3D, multi-scale, multi-material
- Manufacturing sensitivity analysis
- Process technology models
- High performance computing codes

Image courtesy of Chris Spadaccini (LLNL): Multi-scale lightweight structural metamaterial

Focus Areas for Feedstock Quality and Availability



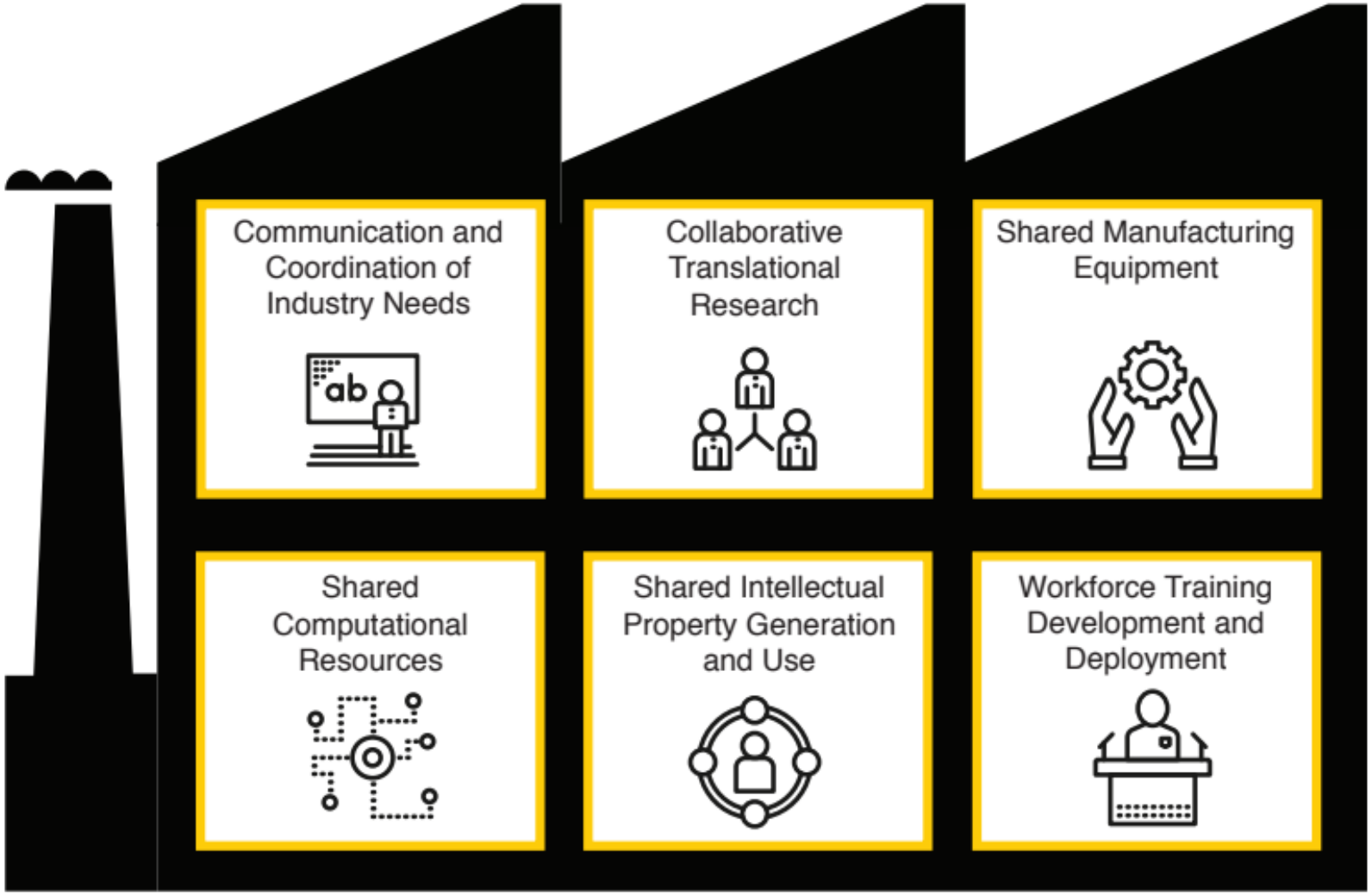
- Materials Research Areas:
  - Environmentally robust materials
  - Novel plasmonic materials
  - Scalable manufacturing processes
- Substrate Research Areas:
  - Manufacturing large-format substrates
  - Curved substrates
  - Non-traditional materials, doping, and coatings
- Federal Facility and Policy:
  - Temporary federal co-funding of nanomaterial production
  - Enhanced standards and certifications
  - Alignment of nanomanufacturing efforts

Images courtesy of Lawrence Livermore National Laboratory: nanoparticles and nanowires

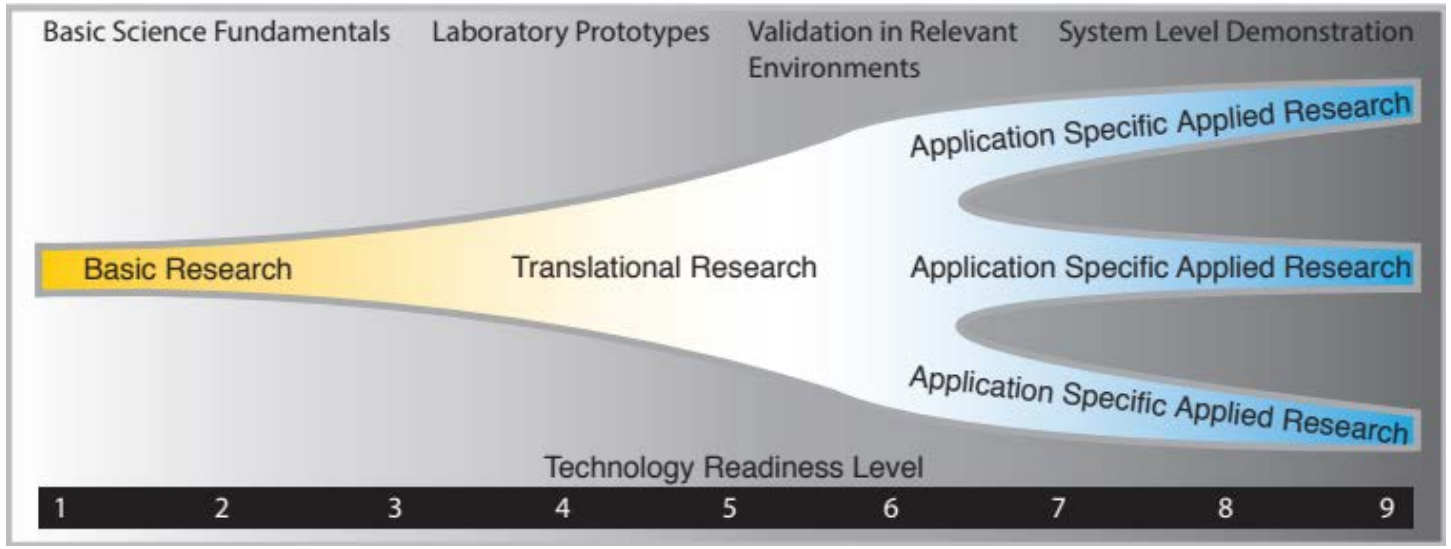
Access to Federal Facilities and Experts

- Enhance **access to federal resources** for small and medium U.S. manufacturers
- Examples include HPC4Manufacturing, HPC4Materials, DOE Small Business Vouchers pilot program

Metamaterials Manufacturing Center of Excellence

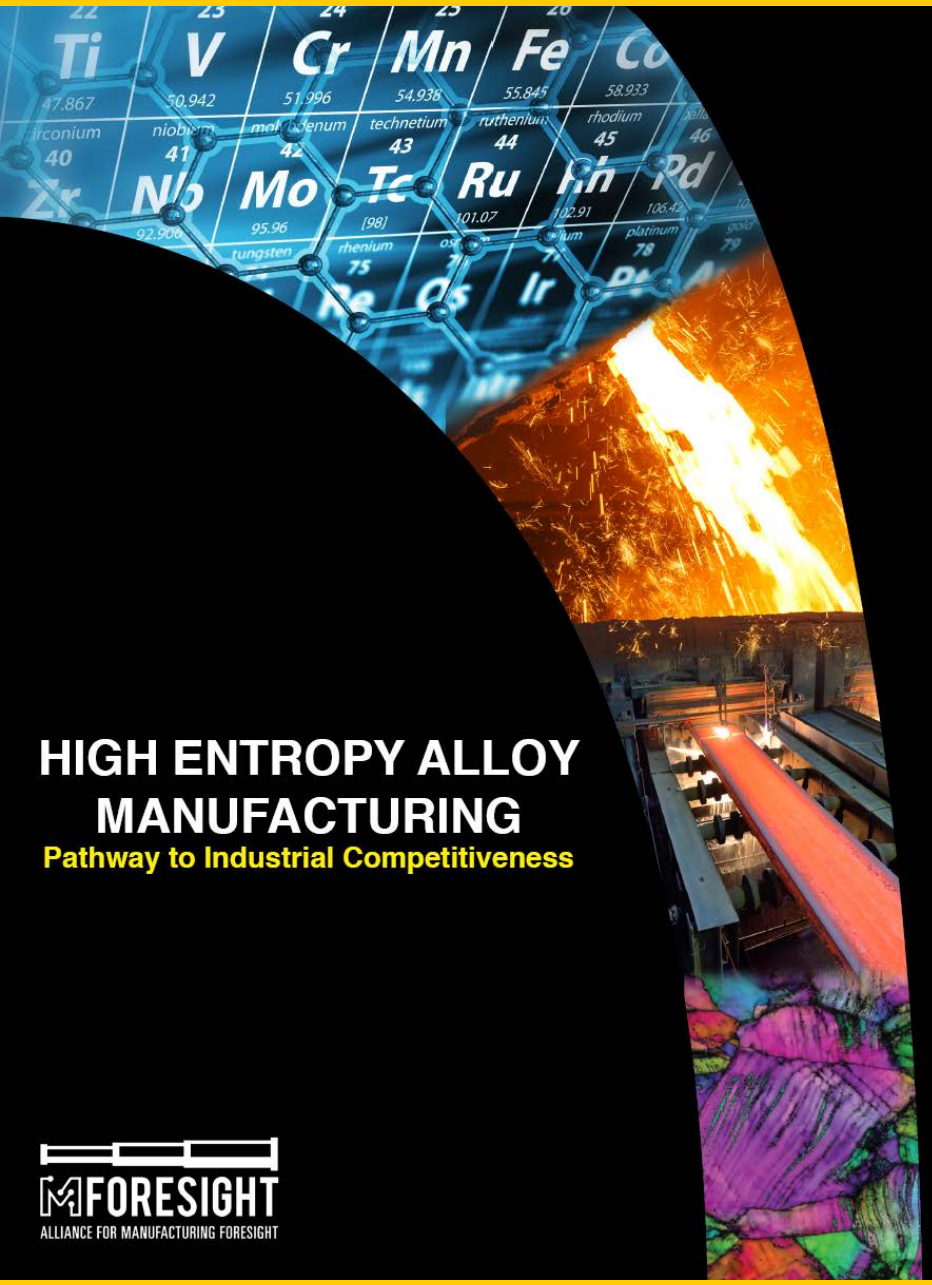


Roadmapping and Expert Guidance



- Roadmapping Working Group
  - Focus on areas of national priority and interest
  - Multidisciplinary
  - Industry, academia, federal labs, and government
  - Real-time input

- Intellectual Property and Policy Working Group:
  - USPTO education
  - Policy guidance



HIGH ENTROPY ALLOY MANUFACTURING

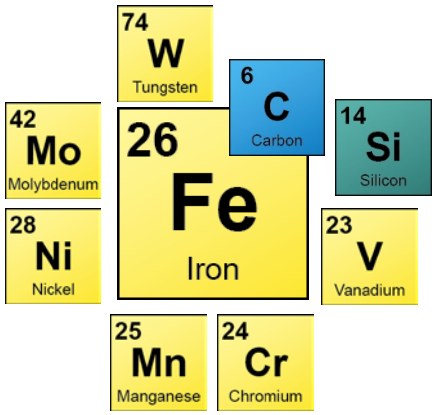
Pathway to Industrial Competitiveness

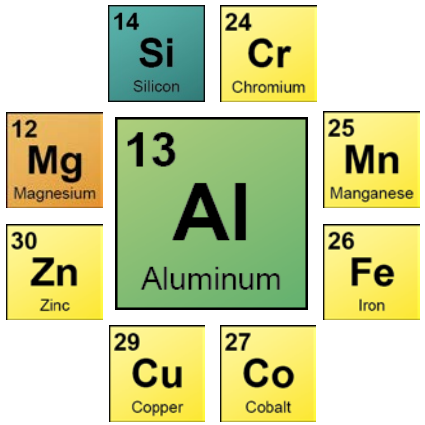
Dan Miracle

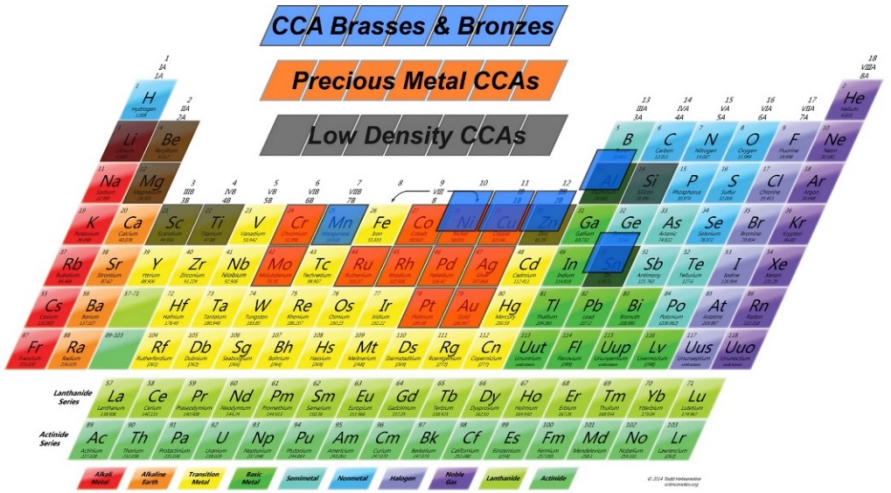
Air Force Office of Scientific Research

FORESIGHT
ALLIANCE FOR MANUFACTURING FORESIGHT

High Entropy Alloys: A Paradigm Shift in Materials





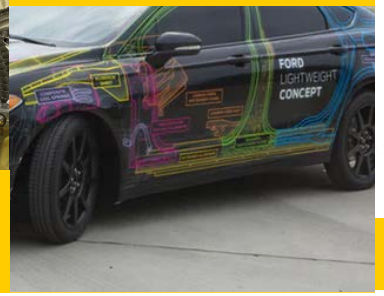


Cross-Cutting Impact

Energy

Efficient natural gas turbines

Vehicle light-weighting



Solid-state cooling

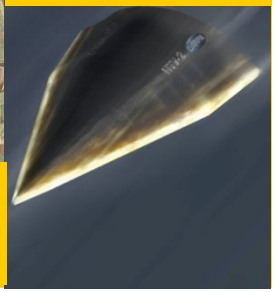
Defense

Harder ballistics

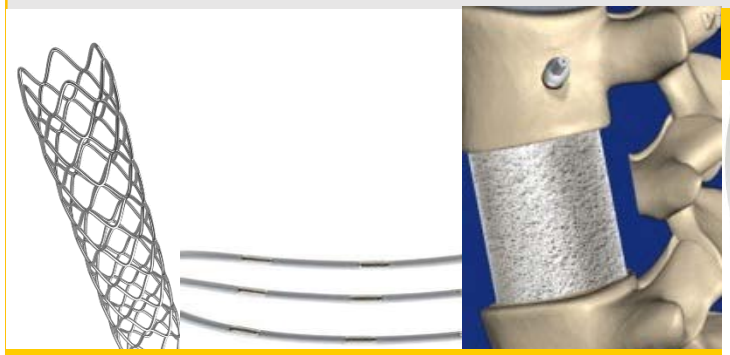
Higher temperature turbines

Impact absorbing

Hypersonic materials



Health



Corrosion resistant stents and grafts

Improved MRI imaging

Industrial

Rare element free magnets

Improved soldering and brazing materials

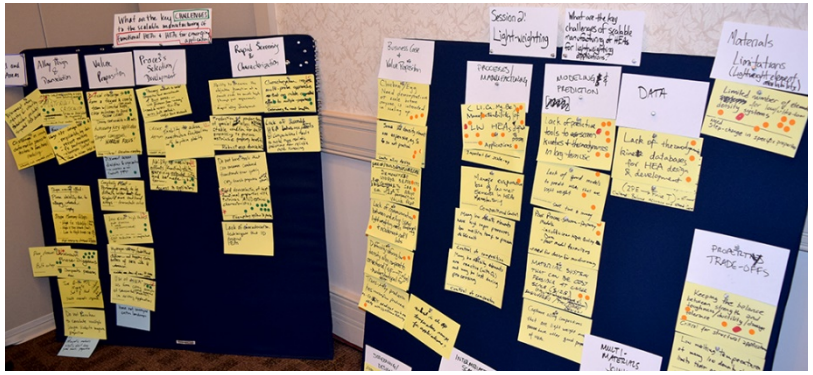
Wear-resistant coatings

United States Manufacturing Competitiveness

Goal: Identify recommendations to enhance U.S. manufacturing competitiveness in high entropy alloy manufacturing to enable U.S. opportunities for economic growth and national security.

Input From the Advanced Manufacturing Community

~40 Attendees: 50% Industry, 25% Academia, 25% Government



LOCKHEED MARTIN

ExxonMobil

ARCONIC

SPECIAL METALS

GE

Metalsa
Quality as a way of life

Exelon

INTERMOLECULAR

ROLLS ROYCE

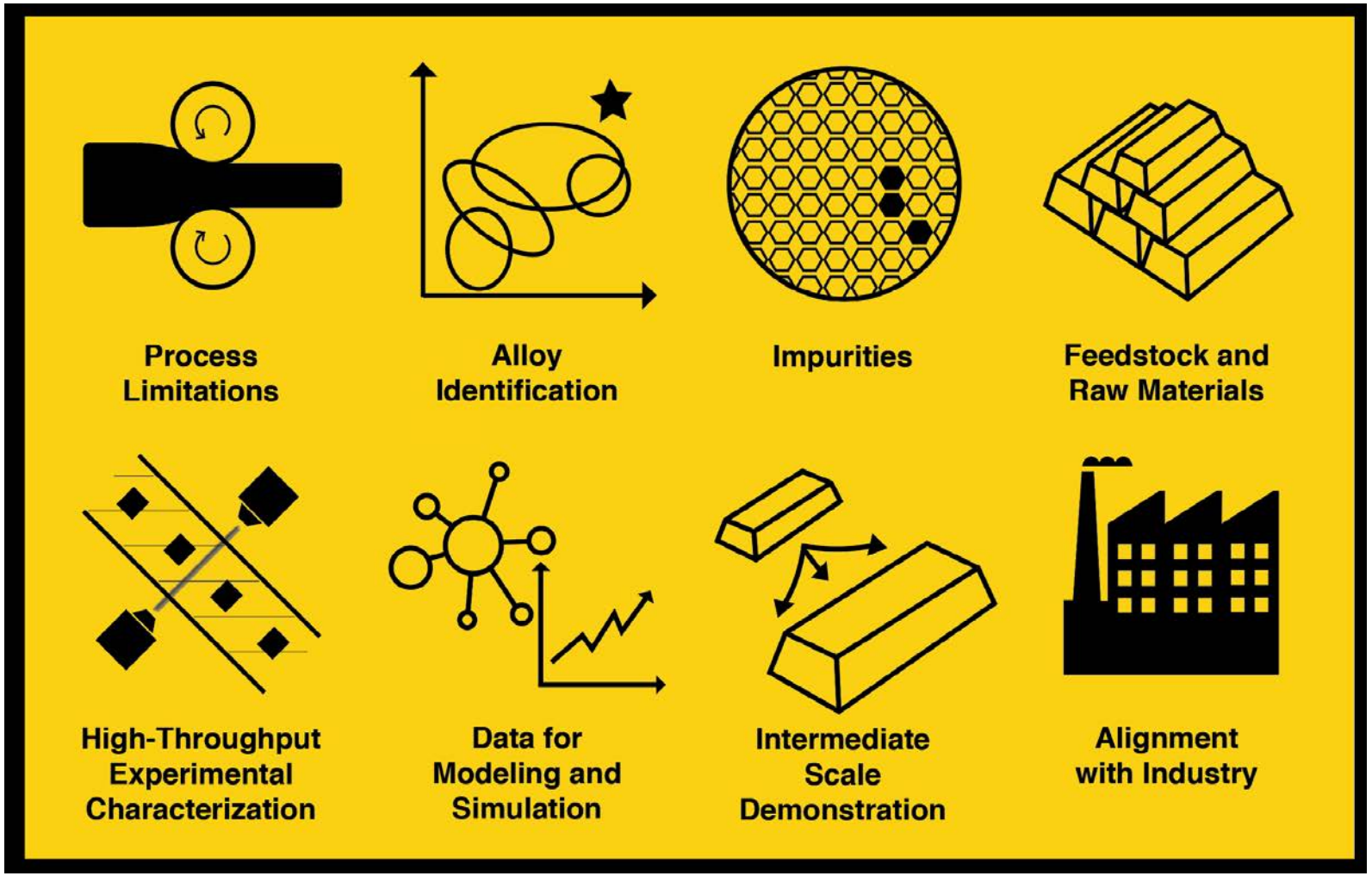
FORT WAYNE METALS

ATI

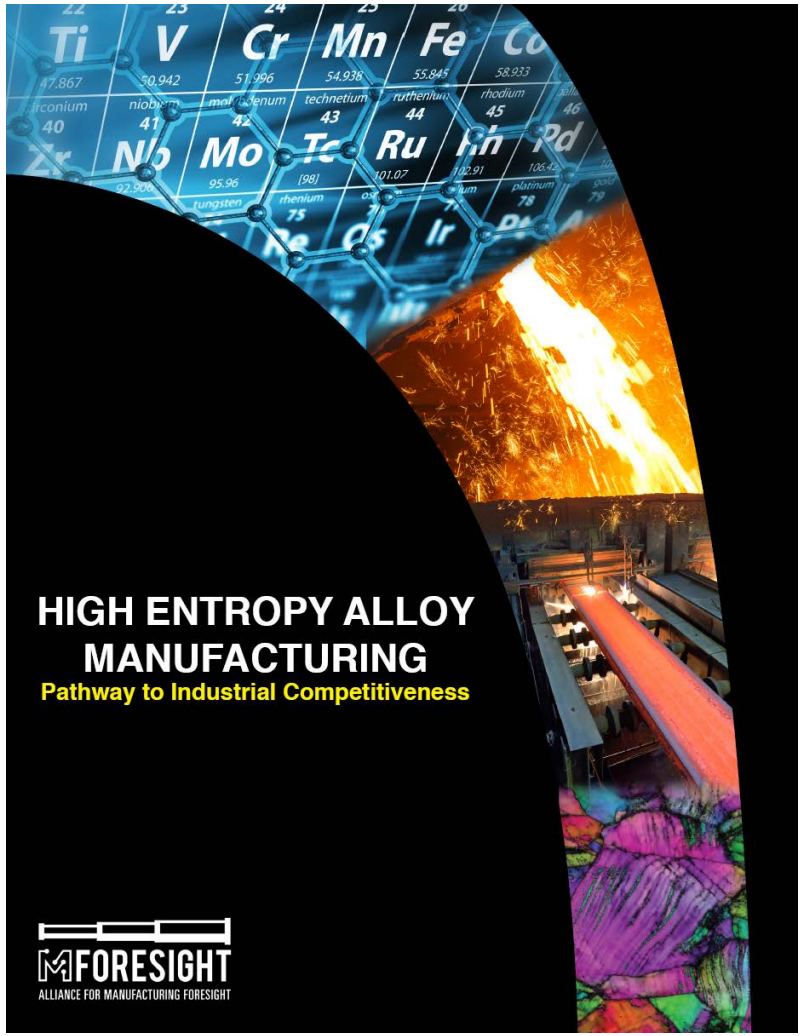
H.C.Starck

Steering Committee:
Dr. Dan Miracle
Dr. Easo George
Dr. Carl Koch
Dr. Peter Liaw
Dr. Vivek Sample
Dr. C. Cem Tasan

Cross-Cutting Barriers to Manufacturing

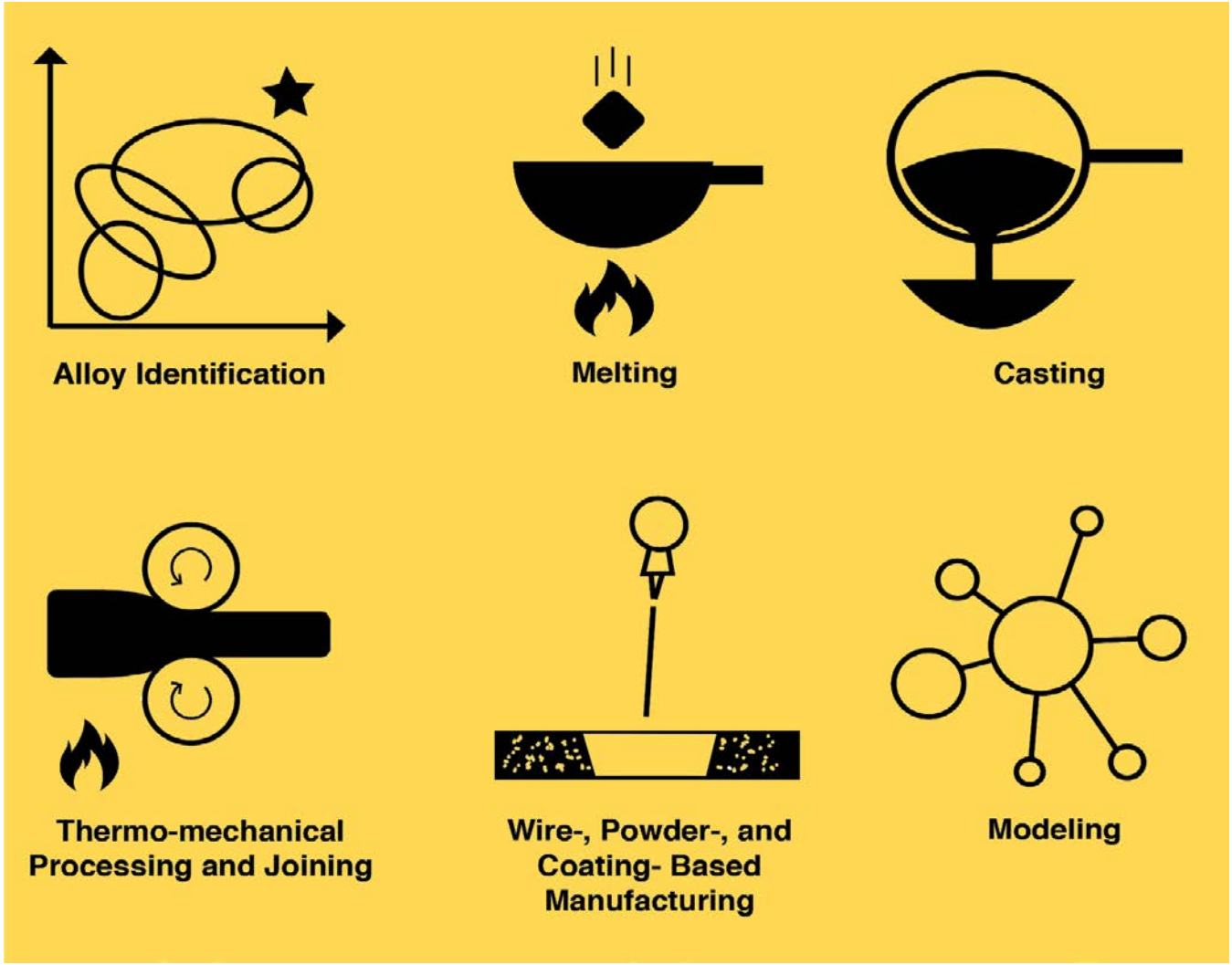


Actionable Recommendations

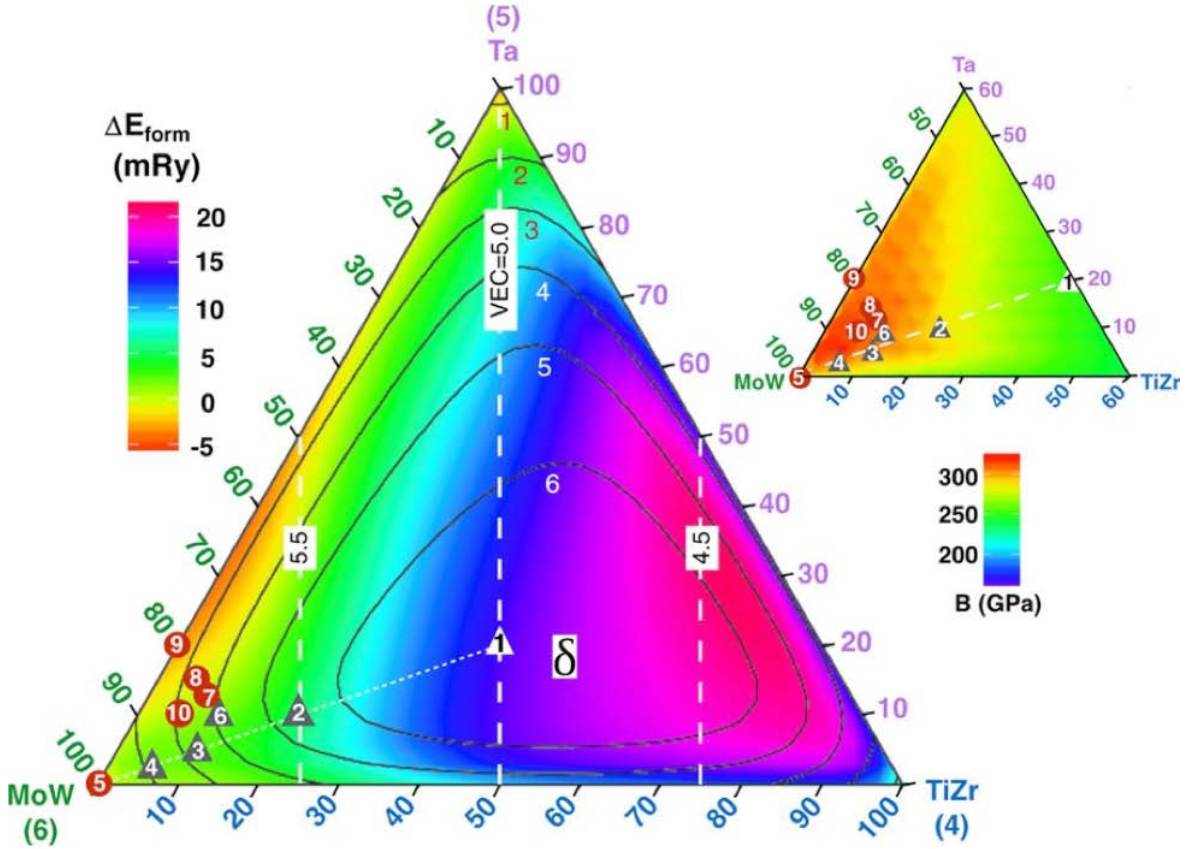


1. Create a Research Initiative on Manufacturing Technologies
2. Establish a National Testing Center
3. Develop a Central Database for High Entropy Alloy Data
4. Enhance Collaborative Efforts

Research Initiative on Manufacturing Technologies

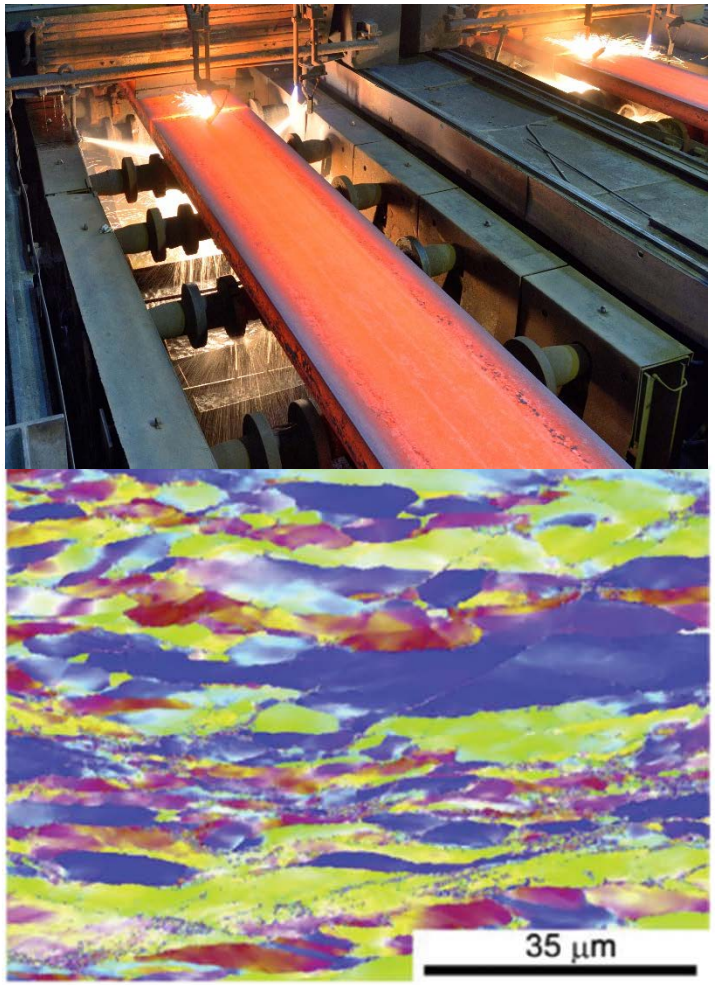


Focus Areas for Alloy Identification and Modeling



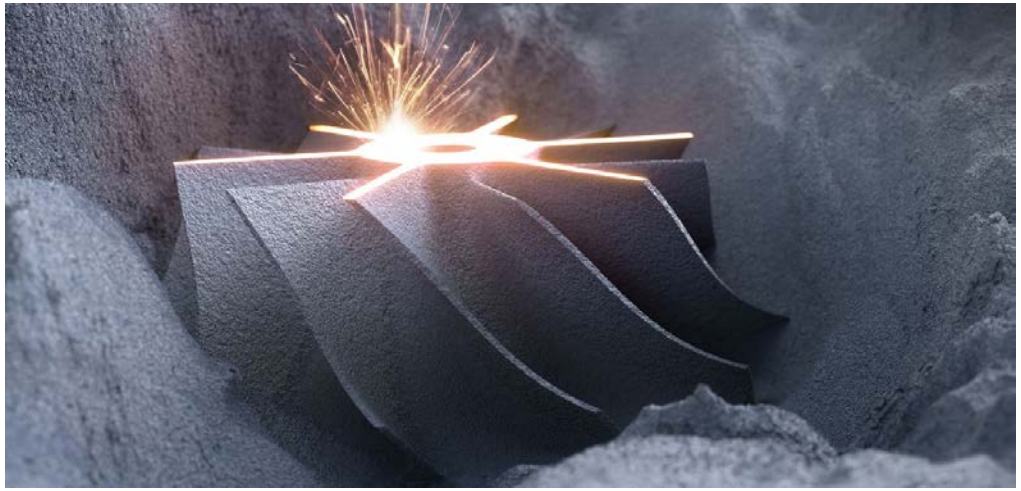
- **Streamlining and linking** modeling and experimentation
- Modeling high entropy alloy **manufacturing processes and properties**
- **Benchmarking** models

Melting, Casting, and Thermo-mechanical Processing



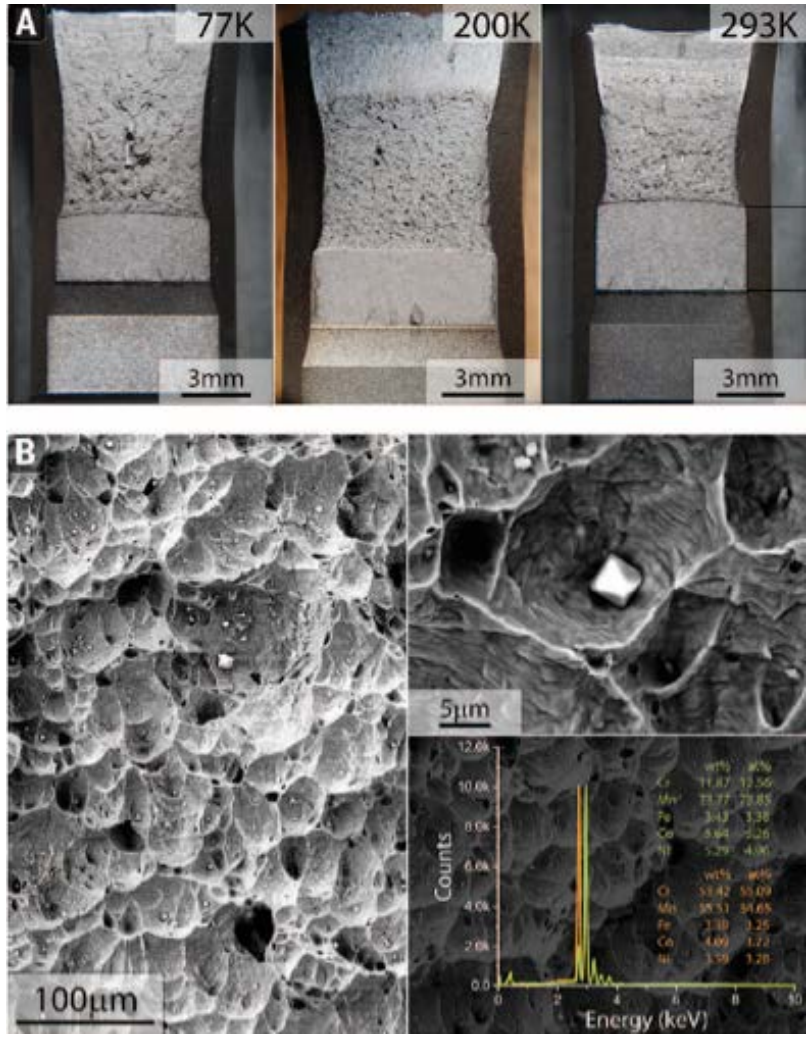
- Novel **electromagnetic and directed energy induction**
- **Rheocasting** and other high performance casting methods
- Intermediate scale **“mini mills”** for high entropy alloys
- High-temperature melting, casting, and **processing equipment**

Wire- Powder- and Coating-Based Manufacturing



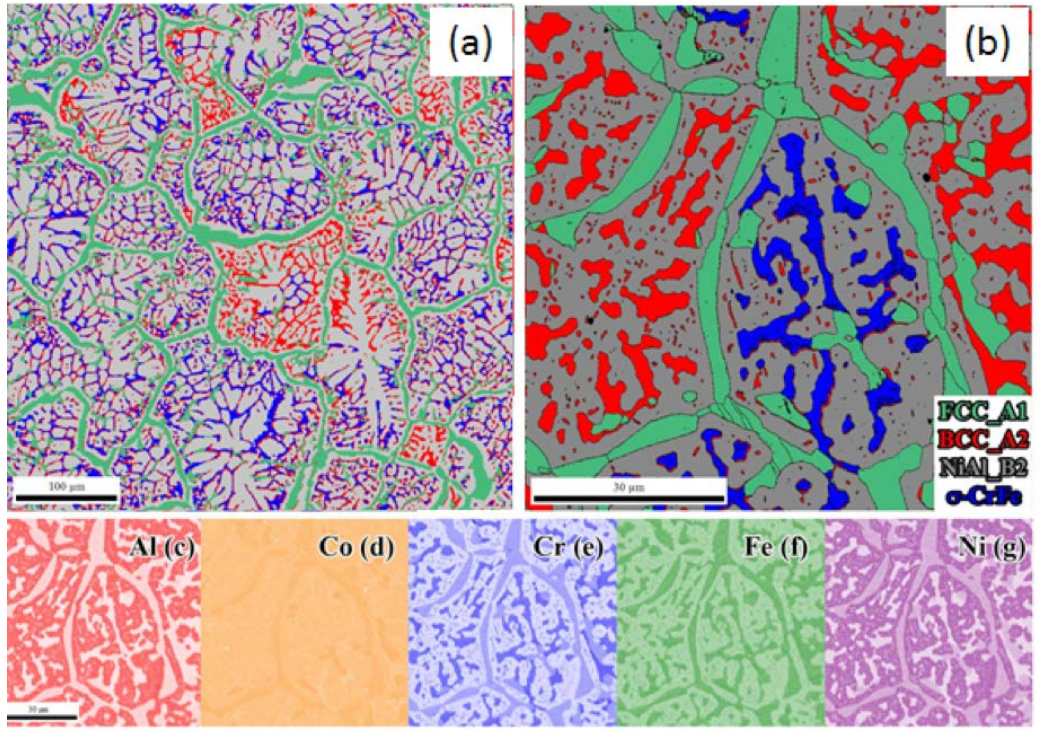
- Novel **multi-element additive manufacturing**
- Advanced **multi-element sputter coating**
- Modeling and development of **powder quality**

Establish a National Testing Center



- Create novel mechanical, materials, environmental, and functional **testing methods** for high entropy alloys
- Provide a suite of advanced **materials testing capabilities** for United States researchers and manufacturers
- Advance a **Materials Testing Collaboratory** that connects federal testing resources
- Enhance **standards, certifications, and benchmarks** critical to high entropy alloys

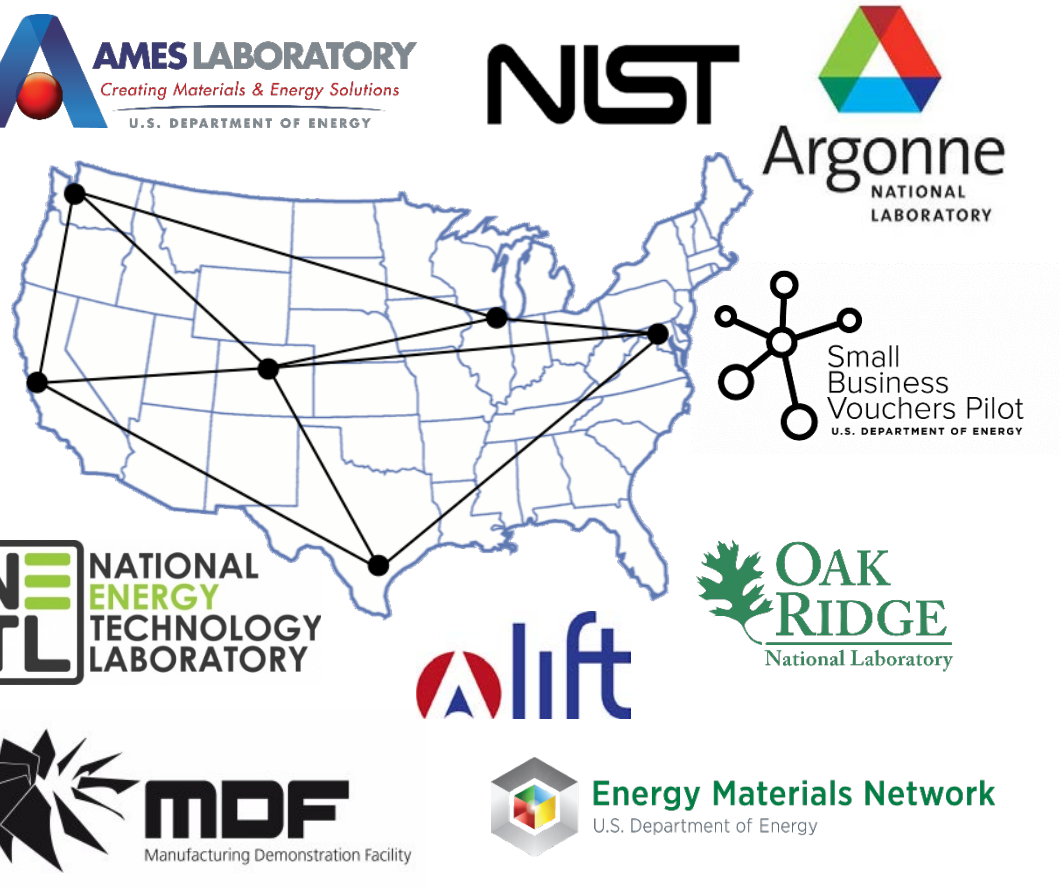
Develop a Central Database for High Entropy Alloy Data



- Avoid duplicate efforts
- Expand analysis methods
- Expand complex models
- Consider unfavorable results
- Accelerate progress

- **Collect** alloy, manufacturing process, and simulation data from universities, federal labs, and industry
- **Qualify** the data using machine learning and expert involvement
- **Organize and provide** access to the data to United State researchers and manufacturers

Enhance Collaborative Efforts



- Advisory Group
  - Provide **real-time input** on areas of national priority and interest
  - **Roadmapping** of manufacturing technologies, applications, and long-term strategies
  - Prioritization of **industry needs**
- Enhance **access to federal resources** for small and medium U.S. manufacturers

Thank you

- **Sridhar Kota,** Executive Director, *MForesight*
- **Ed Herderick**, Director of Additive, Center for Design and Manufacturing Excellence, *The Ohio State University*
- **Chris Spadaccini,** Director of the Center for Engineered Materials and Manufacturing, *Lawrence Livermore National Laboratory*
- **Dan Miracle,** Chief Scientist (Acting), Air Force Office of Scientific Research, *Air Force Research Laboratory*

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