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
Accelerating Technology & Manufacturing Innovation

Idea worth scaling

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
Emerging Technologies & Manufacturing Challenges

**Discover**

**Scouting and Surveys**
- Professional Societies
- Trade Associations
- Federal Agencies
- Federal Programs
- Tech Transfer
- Universities
- Industry
- Shows/Events

**"Gamechanger" Events Partners**
- ASME
- MSEC
- TMS
- AUTM
- FABTECH

**Publish Community Highlights**

**Marketing and Outreach**

Seeking innovations and disruptive technologies. MForesight.org

Submit your Gamechanger
Actionable Recommendations

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

Develop

- 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

<table>
<thead>
<tr>
<th>Sector</th>
<th>Discipline</th>
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<tbody>
<tr>
<td>Acoustics</td>
<td>Manufacturing Equipment</td>
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<tr>
<td>Additive Manufacturing</td>
<td>Materials</td>
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<tr>
<td>Aerospace</td>
<td>Medical Devices</td>
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<td>Automation</td>
<td>Metallurgy</td>
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<tr>
<td>Automotive</td>
<td>Nanotechnology</td>
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<tr>
<td>Chemical</td>
<td>Optics/Photonics</td>
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<tr>
<td>Electronics</td>
<td>Packaging</td>
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<tr>
<td>Energy/Power</td>
<td>Pharmaceuticals</td>
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<tr>
<td>Funding/VC</td>
<td>Plastics</td>
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<tr>
<td>Furniture</td>
<td>Semiconductors</td>
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<tr>
<td>IT/Computing</td>
<td>Systems Engineering</td>
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<tr>
<td>Machinery</td>
<td>Tech Transfer</td>
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<tr>
<td>Manufacturing Education</td>
<td>Technology Policy</td>
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</table>
Disseminate

Reports and Briefings
Dissemination Partners

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

MANUFACTURING IDEAS TO WATCH
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, spent over 1000 hours discussing potential solutions

<table>
<thead>
<tr>
<th>Round Tables and Partners</th>
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<tbody>
<tr>
<td>Boston, MA</td>
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<tr>
<td>Washington D.C.</td>
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<tr>
<td>Austin, TX,</td>
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<tr>
<td>San Jose, CA</td>
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<tr>
<td>Raleigh, NC</td>
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<tr>
<td>Indianapolis, IN</td>
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<tr>
<td>Detroit, MI</td>
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MANUFACTURING PROSPERITY
A Bold Strategy for National Wealth and Security

8
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?
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:

<table>
<thead>
<tr>
<th>Next-Generation Conductive Materials</th>
<th>A. Superconducting materials and novel covetic nanomaterials</th>
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<tbody>
<tr>
<td></td>
<td>B. Coatings and dielectric insulators</td>
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<tr>
<td></td>
<td>C. Conductive materials for energy storage and harvesting</td>
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</tbody>
</table>
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:

<table>
<thead>
<tr>
<th>Qualification for New Materials and Processes</th>
<th>A. Framework of best practices for materials qualification</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>B. Model-based qualification approaches for computational materials testing</td>
</tr>
<tr>
<td></td>
<td>C. Sensors and data-driven analytics to enable rapid qualification approaches</td>
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</tbody>
</table>
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  
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<td></td>
<td>B. Data mining, compression, storage, and management</td>
</tr>
<tr>
<td></td>
<td>C. Predictive modeling tools for NDE and sensors</td>
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</table>
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
Chris Spadaccini
Lawrence Livermore National Laboratory
### Metamaterials: Cross-Cutting Impact

<table>
<thead>
<tr>
<th>Antennas, Optical Filters, and Super Lenses</th>
<th>Sonography and Acoustic Damping</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Near Ideal Wavelength-selective Optical Mirror" /></td>
<td><strong>50X Ultrasound Image Resolution</strong></td>
</tr>
<tr>
<td><img src="image" alt="World's Lightest Material" /></td>
<td><strong>Breaks Acoustic Mass Law by 5X</strong></td>
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<th>Light-weighting and Structural Performance</th>
<th>Athermal and Novel Mechanical Properties</th>
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<tr>
<td><img src="image" alt="World's Lightest Material" /></td>
<td><img src="image" alt="Athermal and Novel Mechanical Properties" /></td>
</tr>
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</table>

*(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*
Goal: Identify recommendations to enhance U.S. manufacturing competitiveness in metamaterials manufacturing to enable U.S. opportunities for economic growth and national security.
Scalable Manufacturing is Missing

United States Research Investments

<table>
<thead>
<tr>
<th>Country</th>
<th>Citations</th>
</tr>
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<tbody>
<tr>
<td>United States</td>
<td>42%</td>
</tr>
<tr>
<td>China</td>
<td>15%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>11%</td>
</tr>
<tr>
<td>Germany</td>
<td>8%</td>
</tr>
<tr>
<td>Other EU</td>
<td>5%</td>
</tr>
<tr>
<td>Other Asia-Pacific</td>
<td>9%</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>10%</td>
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</tbody>
</table>

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

Global Metamaterials Market Size by Year

- Market Value ($M)
- CAGR 36.4%
- 2017: 500
- 2018: 600
- 2019: 700
- 2020: 800
- 2021: 900
- 2022: 1000
- 2023: 1100
- 2024: 1200
- 2025: 1300

(bottom right) Image courtesy of NASCENT Center
Input From the Advanced Manufacturing Community

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

~40 Attendees: 50% Industry, 25% Academia, 25% Government
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.
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
Focus Areas for Multi-Material Metamaterials

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

- Communication and Coordination of Industry Needs
- Collaborative Translational Research
- Shared Manufacturing Equipment
- Shared Computational Resources
- Shared Intellectual Property Generation and Use
- Workforce Training Development and Deployment
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
High Entropy Alloys: A Paradigm Shift in Materials
### Cross-Cutting Impact

<table>
<thead>
<tr>
<th>Energy</th>
<th>Defense</th>
<th>Health</th>
<th>Industrial</th>
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<tbody>
<tr>
<td>Efficient natural gas turbines</td>
<td>Higher temperature turbines</td>
<td>Improved MRI imaging</td>
<td>Improved soldering and brazing materials</td>
</tr>
<tr>
<td>Vehicle light-weighting</td>
<td>Harder ballistics</td>
<td>Corrosion resistant stents and grafts</td>
<td>Rare element free magnets</td>
</tr>
<tr>
<td>Solid-state cooling</td>
<td>Impact absorbing</td>
<td></td>
<td>Wear-resistant coatings</td>
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</table>
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

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

~40 Attendees: 50% Industry, 25% Academia, 25% Government
Cross-Cutting Barriers to Manufacturing

- Process Limitations
- Alloy Identification
- Impurities
- Feedstock and Raw Materials
- High-Throughput Experimental Characterization
- Data for Modeling and Simulation
- Intermediate Scale Demonstration
- Alignment with Industry
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

- Alloy Identification
- Melting
- Casting
- Thermo-mechanical Processing and Joining
- Wire-, Powder-, and Coating-Based Manufacturing
- Modeling
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*

*MForesight.org*