Smart Collaboration

Leverage a rich knowledge base to gain competitive advantage in the additive manufacturing industry

America Makes and 3D Ti – Additive Manufacturing

Rob Gorham
America Makes
Director of Operations
Why NNMI, Why America Makes?

The foundation is laid – in March 2012, the formation of a National Network for Manufacturing Innovation (NNMI) was proposed and America Makes (National Additive Manufacturing Innovation Institute) was launched in August as the initial Institute of Manufacturing Innovation (IMI).

The vision is simple – leverage our nation’s brilliant technical minds in all corners of government, industry and academia to accelerate the adoption of additive manufacturing technologies in the U.S. manufacturing sector and increase domestic manufacturing competitiveness.

The goal is bold – create truly collaborative environments to bring technology advancements from the lab to the factory floor, create jobs, produce more competitive products, and ultimately reaffirm our place in the global market.
Building the Network

INSTITUTES IN FY15 COMPETITION/DEVELOPMENT

- **Flexible Hybrid Electronics**
  - Proj. Award: Sep 2015

- **Revolutionary Fibers & Textiles**
  - Proj. Award: December 2015

- **Smart Mfg. for Energy Efficiency**
  - Proj. Award TBD

- **Topic TBA**

ESTABLISHED INSTITUTES

- **AIM Photonics**
  - Albany & Rochester, NY

- **LIFT Light/Modern Metals**
  - Detroit, MI

- **DMDII Digital Mfg.**
  - Chicago, IL

- **IACMI Adv. Composites**
  - Knoxville, TN

- **America Makes Additive Mfg.**
  - Youngstown, OH

- **Power America Electronics**
  - Raleigh, NC

Full Network Goal: 45 Regional Hubs

Other Institutes in FY16 Planning:

- Open topic competition – addressing “white space” between mission agency topics
- Selected topic competitions supporting Agency mission – using agency authorities and budgets
Who We Are

Public / Private Partnership
America Makes has substantial federal, private industry, and academic investment.

Multi-Agency Collaboration
Partnership between industry, government and universities, led by the Defense-wide Manufacturing S&T team.

Membership
Innovation facility in Youngstown, Ohio with 146 members. We continue to grow.

Operations
We are operated by the National Center for Defense Manufacturing & Machining (NCDMM)
Collaborate, Cooperate, Innovate

Technology Development

Technology Transition

Workforce and Educational Outreach
Our Purpose

Our main goal is to “Bridge the Gap” and address Technology & Manufacturing Readiness Levels (TRL & MRL) 4-7 enabling technology transition and commercialization through funding innovation projects.
Technology Roadmap

Innovation projects are a member-driven, collaborative process

1. Innovation Sessions to ensure relevancy and market demand for technology roadmap
2. Project Calls Drafted using member-insight
3. RFP’s Published to membership
4. Proposals Submitted by members
5. Proposals Vetted by member-led review team and funding recommended
6. Winners Announced Funding Awarded
7. Research Performed with regular updates to membership.
8. Final Outcome: Project Output pre-competitive IP accessible to membership (but owned by inventing organizations)
<table>
<thead>
<tr>
<th>Swim Lane</th>
<th>CRITICAL TECHNOLOGY ELEMENT</th>
<th>Impact Focus</th>
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<tbody>
<tr>
<td>Design</td>
<td>Bio-Inspired Design &amp; Manufacturing</td>
<td>Complexity Exploitation, 3D Graded Materials, Multi-Material Integration, Model-Based Development, Product Customization</td>
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<td>Cost &amp; Energy Driver Analysis/Modeling</td>
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<td>Product &amp; Process Design Aides/Apps</td>
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<td>Material Property Characterization</td>
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<td>Next-Gen Materials</td>
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<tr>
<td>Process</td>
<td>Multi-Material Delivery &amp; Deposition</td>
<td>Faster Build Speeds, Improved Surface Quality, Larger Part Envelopes, Improved Detail Capability</td>
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<td>Next-Gen Machines</td>
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<td>Process Temperature Gradient Control</td>
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<tr>
<td>Value Chain</td>
<td>Advanced Sensing &amp; Detection Methods</td>
<td>Material Costs, Processing Costs, Quality Control Costs, Productivity Costs, Energy Efficiency Costs</td>
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<td>Intelligent Machine Control Methods</td>
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<td>Digital Thread Integration</td>
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<td>Rapid Inspection Technologies</td>
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<td>Repair Technologies</td>
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<td>Standards/Schemas/Protocols</td>
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<tr>
<td>AM Genome</td>
<td>Benchmark Validation Use Cases</td>
<td>Concurrent Methods, Computational Tools, Experimental Tools, Modular Open Simulations, Open Multi-Scale Data</td>
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<tr>
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<td>Model-Assisted Property Prediction</td>
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<td>Physics-Based Modeling &amp; Simulation</td>
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</table>
# America Makes Technology Roadmap – Level 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Design</th>
<th>Material</th>
<th>Process</th>
<th>Value Chain</th>
<th>AM Genome</th>
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<tbody>
<tr>
<td>2014</td>
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<td>2018</td>
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</table>

- **Design**: Bio-Inspired Design & Manufacturing, Product & Process Design Aides/Apps, Cost & Energy Driver Analysis/Modeling
- **Material**: “Non Ad-Hoc” Additive Manufacturing Tech Data Packages, Material Property Characterization, Next-Gen Materials
- **Process**: Multi-Material Delivery & Deposition Systems, Next-Gen Machines, Process Temp Gradient Control
- **Value Chain**: Standards/Schemas/Protocols, Advanced Sensing and Detection Methods, Rapid Inspection Technologies
- **AM Genome**: Benchmark Validation Use Cases, Physics-Based Modeling & Simulation, Model Assisted Property Prediction

*Approved for Public Release*
Projects for Highlight

**University of Pittsburgh**
Developing Topology Optimization Tools that Enable Efficient Design of Additive MFD Cellular Structures

**Case Western Reserve University**
Rapid Qualification Manufacturing Methods for Powder Bed Direct Metal Additive Processes

**Northrop Grumman**
Electron Beam Melted Ti64 Additive Manufacturing Demonstration and Allowables Development

**Carnegie Mellon University**
Database Relating Powder Properties to Process Outcomes for Direct Metal Additive Manufacturing

**GE Global Research**
Development of Distortion Prediction and Computational Methods for Powder Bed Additive Manufacturing

**GE Aviation**
In-Process Quality Assurance (IPQA) for Laser Powder Bed Production of Aerospace Components
# America Makes Technology Roadmap

## Level 2

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</table>

### DESIGN Level 2 Maturation Needs

#### Bio-Inspired Design & Manufacturing
- Cellular FEA Topology Models for DMLS Ti-64
- Efficient Structural Analysis Algorithms for Cellular Structures

#### Cost & Energy Driver Analysis/Modeling
- Ti-64 DMLS Production Cost Modeling
- Ti-64 EBM Production Cost Modeling
- Cradle-to-Cradle Life Cycle Energy Use Modeling
- Product/Process Family Energy Use Modeling

#### Product & Process Design Aides/Apps
- FDM ULTEM 9085 Tooling Design Guidelines
- SLS CFR ESD PEKK Topology Optimization Guidelines
- Integrated AM and Secondary Machining Support Guidelines
- FDM ULTEM 9085 Part Design and Build Path Guidelines

### Project Call 3 – Summer 2015 Focus Area
- CAD Linkable Expert Design Advisors
- Rule-Based DFM Methods & Algorithms
- Design Specification Query Algorithms
- Automatic Generation of Process/Material/Machine Compliance
- Design Advisors that Recommend Rapid Qual/Cert Approaches

Approved for Public Release
Developing Topology Optimization Tools that Enable Efficient Design of Additive MFD Cellular Structures

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>APPROACH</th>
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</thead>
<tbody>
<tr>
<td>• Current structural optimization method is inefficient for the design of additive manufactured cellular structures with variable density.</td>
<td>• Calibrate cellular structure micromechanics models from simulation and experiment</td>
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<td></td>
<td>• Topology optimization for mechanical parts based on micromechanics models</td>
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<td></td>
<td>• Reconstruct detailed cellular structure</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>BENEFITS</th>
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<tbody>
<tr>
<td>• Develop experimentally-validated micromechanics, models, topology, optimization, and reconstruction algorithms for different cellular structures.</td>
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<tr>
<td>• Demonstrate and validate capability of design and optimization tools on design of a realistic structural component</td>
<td>• Enable efficient design of cellular structures in load-bearing parts for Defense Wide applications</td>
</tr>
</tbody>
</table>

- **Lead Organization**: University of Pittsburgh
- **Supporting Organization(s)**: ANSYS Inc., United Technologies Research Center (UTRC), ExOne Corporation, General Electric, ALCOA Inc, Materials Science Corporation, AMRDEC, ACUTEC Precision Machining Inc,
- **Start Date**: 03/01/2014
- **End Date**: 11/30/2015

**IMPLEMENTATION**

- Commercial FEA package ANSYS
### America Makes Technology Roadmap

#### Level 2

|------|------|------|------|------|------|------|------|

**“Non Ad Hoc” Additive Manufacturing Tech Data Packages**

- EBM Ti-64 & Co-Cr PV Process Maps
- DMLS Ti-64 & Co-Cr PV Process Maps
- LENS Ti-64 & IN718 Process Window Characterization
- EB-DED Ti-64 Microstructure for Ultrasonic NDI

**Material Property Characterization**

- FDM ULTEM 9085 B-Basis Allowable Data
- SLS CFR ESD PEKK B-Basis Design Allowable Data
- SLS PEKK Characterization
- SLS Cu Characterization
- EBM Ti-64 & Co-Cr Feedstock to Property Relationships
- DMLS Ti-64 & Co-Cr Feedstock to Property Relationships
- EBM Ti-64 & Co-Cr Wire Feedstock Effects on Microstructure
- DMLS Ti-64 & Co-Cr Powder Feedstock Effects on Microstructure
- EBM Ti-64 B-Basis Allowable Development

**Next-Gen Materials**

- SLS CFR ESD PEKK Recyclability Guidelines
- Low Cost Recycled Al Material Specifications
- Forging Tool Wear Resistant Coating Guidelines
- Biocompatible/Bioabsorbable Binder-Jet Fe-Mn

**Project Call 3 – Summer 2015 Focus Area**

**Material Recyclability Indices**

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Rapid Qualification Manufacturing Methods for Powder Bed Direct Metal Additive Processes

**PROBLEM**

- Qualification of a process takes and exorbitant amount of time, holding back adoption of promising AM processes.
- Industry struggles to control microstructure and mechanical properties across direct metal laser (DMLS) and electron beam melting (EBM).

**OBJECTIVE**

- Industry struggles to control microstructure and mechanical properties across direct metal laser sintering (DMLS) and electron beam melting (EBM).

**APPROACH**

- Thermal property modeling, Power / Velocity (P/V) process mapping to melt pool geometry
- Determine effect of powder size distribution on P/V process map and resulting microstructure
- Construct process maps for DMLS and EBM
- Develop process-based cost models
- Demonstrate on “Industry Application”

**BENEFITS**

- Verified methods for tight control of microstructure and mechanical properties
- Reduction in amount of testing / time to qualify
- Ability to switch between high P/V (high rate, low res) and low P/V (low rate, high res) will provide overall faster build times and ability serve new markets
- Industry uses cost models to make decisions on adopting AM into their factory or supply chain.

**IMPLEMENTATION**

- Transition site in discussion

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**Lead Organization**: Case Western Reserve University

**Supporting Organization(s)**: Carnegie Mellon University, University of Louisville, North Carolina State University, Wright State University, Pratt & Whitney, General Electric, Lockheed Martin, Kennametal, Bayer

**Start Date**: 05/01/2013

**End Date**: 04/01/2016
**Electron Beam Melted Ti64 Additive Manufacturing Demonstration and Allowables Development**

**PROBLEM**
- Widespread consideration of EBM additive manufacturing mandates a statistically significant set of materials design allowables

**OBJECTIVE**
- Develop B-Basis allowables for electron beam melted Ti-6Al-4V additive manufactured material.

**LEAD ORGANIZATION**: Northrop Grumman Corporation  
**Supporting Organization(s)**: CalRAM, Arcom, Robert C. Byrd Institute (RCBI), GE Aviation, CTC, Lockheed Martin  
**Start Date**: 03/14/2014  
**End Date**: 09/30/2015

**APPROACH**
- Leverage methodologies, building block approach and transition to production processes previously used in development and implementation of AM technologies at NGAS

**BENEFITS**
- Utilization of structures produced from Ti64 made by additive manufacturing

**IMPLEMENTATION**
- Northrop Grumman aerospace and spacecraft platforms
Database Relating Powder Properties to Process Outcomes for Direct Metal Additive Manufacturing

**PROBLEM**

- The most severe supply chain restriction is requirements to procure quality powders from machine manufacturers. Therefore, a large variety of powder systems must be usable in direct metal machine for broad adoption.

**OBJECTIVE**

- Develop a first-of-its-kind database relating powder properties to process outcomes and identify process variable changes need to make a current incompatible powder, comparable to standard powders.

**APPROACH**

- Include experimental results from studies of powder spreadability, the ability of the powder to be sintered, powder melting outcomes (including meld pool geometry and microstructure).

**BENEFITS**

- Regional cluster of AM powder production, catalyzed by America Makes and bringing powder suppliers and AM machine user together.

**IMPLEMENTATION**

- 10 industry partners across powder production, medical device, aerospace, and electronic connector industries
- As part of the TTP, plan to develop (through separate funding) software to methodically take users through testing methods needed to create and expand powder property vs part quality databases.

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**Lead Organization**: Carnegie Mellon University

**Supporting Organization(s)**: North Carolina State University, ATI Powder Metals, Carpenter Powder Metals, Ametek Specialty Metals, TIMET Medical Modeling, TE Connectivity, Fineline Prototyping, CalRAM, United Technologies Research Center (UTRC) Pratt & Whitney, Alcoa, Robert C. Byrd Institute (RCBI), Walter Reed Army Medical Center, Incodema3D, NIST, ORNL, Oxford Performance Metals

**Start Date**: 07/01/2014

**End Date**: 01/31/2016
## America Makes Technology Roadmap

**Level 2**

<table>
<thead>
<tr>
<th>Year</th>
<th>Multi-Material Delivery &amp; Deposition</th>
<th>Next-Gen Machines</th>
<th>Process Temperature Gradient Control Systems</th>
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<tbody>
<tr>
<td>2013</td>
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<td>2020</td>
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</table>

### Multi-Material Delivery & Deposition

- Project Call 3 – Summer 2015 Focus Area
- 3D-Gradient Material Deposition Control

### Next-Gen Machines

- Modular LENS Machine Tool Retrofit Systems
- Low Cost Recycled Aluminum Desktop Printer
- Micro-Induction Sintering Test Bed
- High-Throughput LHW Ni & Ti Processing
- Hybrid AM and Subtractive Systems

- Project Call 3 – Summer 2015 Focus Area
- Open Source PLC Architectures
- Process Temperature Gradient Control Systems

- Project Call 3 – Summer 2015 Focus Area
- Real-Time Processing Temperature Analysis Methodologies
## America Makes Technology Roadmap

### Level 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Advanced Sensing &amp; Detection Methods</th>
<th>Digital Thread Integration</th>
<th>Intelligent Machine Control Methods</th>
<th>Rapid Inspection Technologies</th>
<th>Repair Technologies</th>
<th>Standards/Schemas/Protocols</th>
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<tbody>
<tr>
<td>2015</td>
<td>In-Situ Laser PBF Defect Monitoring Sensor Test Bed</td>
<td></td>
<td>Integrated AM &amp; Secondary Machining Control</td>
<td>NDE Post-Build Inspection of Laser PBF</td>
<td></td>
<td>EB-DED Ti-64 Ultrasonic NDI Protocols</td>
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<tr>
<td>2016</td>
<td>IR Imaging for Laser PBF Thermoplastics</td>
<td></td>
<td>Thermal Imaging Control of Laser PBF Thermoplastics</td>
<td>Ti &amp; Ni Alloy X-Ray CT NDI Procedures</td>
<td></td>
<td>Data Repository Card Catalog &amp; Pedigrees</td>
</tr>
<tr>
<td>2017</td>
<td>Project Call 3 – Summer 2015 Focus Area</td>
<td></td>
<td>Model-Based Closed Loop Feedback Control Algorithms</td>
<td>Project Call 3 – Summer 2015 Focus Area</td>
<td></td>
<td>Industry Specific Qual/Cert Protocols</td>
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<td>2018</td>
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<td>Third Party Data Capture Templates</td>
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<td>2019</td>
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<td>Shared Data Repository Schemas</td>
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**VALUE CHAIN Level 2**

**Maturation Needs**
Development of Distortion Prediction and Computational Methods for Powder Bed Additive Manufacturing

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>APPROACH</th>
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<tbody>
<tr>
<td>An absence exists with suitable distortion prediction tools resulting in ad-hoc rules of thumb to compensate and mitigate the problem.</td>
<td>Define canonical features</td>
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<td>Validation of distortion prediction</td>
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<td>Distortion compensation</td>
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<td>Curriculum development</td>
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<thead>
<tr>
<th>OBJECTIVE</th>
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<tr>
<td>Benchmark and validate physics-based thermal distortion prediction and mitigation tools for commercialization. Results will lead to a 3X to 4X reduction in development time. TRL - Currently 4 targeting 6</td>
<td>Create the ability to virtually evaluate and optimize processes &amp; product alternative for reduced cost (iterations reduced from 5+ to less than 2)</td>
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<td>Rapid deployment of virtual AM process evaluation through wiki and AM transfer functions</td>
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<tr>
<th>IMPLEMENTATION</th>
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<tbody>
<tr>
<td>• Lead Organization: GE Research, Supporting Organization(s): United Technologies Research Center (UTRC), Honeywell, Pan Computing, LLC, University of Louisville, Penn State University, CDI Corporation</td>
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<tr>
<td>• Start Date: 09/01/2014</td>
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<td>• End Date: 02/28/2016</td>
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<tr>
<td>• GE Leap Engine</td>
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<tr>
<td>• Various other aerospace components</td>
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</tbody>
</table>
# In-Process Quality Assurance (IPQA) for Laser Powder Bed Production of Aerospace Components

## Problem
- No commercially available reliable IPQA system. Post process inspection becoming a field unto itself.

## Objective
- Develop an in situ IPQA process that is not material or platform dependent.

## Approach
- Establish CTQs
- Determine what sensors are most sensitive to CTQs
- Test on Multiple platforms and materials
- Compare with post process analysis

## Benefits
- Material and platform independent In-Situ IPQA process
- Reduced post process inspection time required

## Implementation
- Commercialize the IPQA process with the help of Burke E. Porter Machinery Co.

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**Lead Organization:** GE Aviation  
**Supporting Organization(s):** Areojet Rocketdyne, Honeywell, Burke E. Porter Machinery Co., B6 Sigma, Techsolve, Montana Tech

**Start Date:** 10/01/2014  
**End Date:** 03/15/2016
## America Makes Technology Roadmap

### Level 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
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<tbody>
<tr>
<td>2013</td>
<td><strong>EBM Al Process Modeling</strong></td>
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<td>2014</td>
<td><strong>Laser PBF Al Process Modeling</strong></td>
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<td>2015</td>
<td><strong>DMLS Numerical Simulation Methods</strong></td>
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<td>2016</td>
<td><strong>LENS Ti-64 ABAQUS FEA Set-Up Scripts</strong></td>
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<tr>
<td>2017</td>
<td><strong>Laser PBF Ni, Co, and Ti Distortion Modeling</strong></td>
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<td>2018</td>
<td><strong>Project Call 3 – Summer 2015 Focus Area</strong></td>
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<tr>
<td>2019</td>
<td><strong>ICME &amp; Data Repository Statistical Model Links</strong></td>
</tr>
<tr>
<td>2020</td>
<td><strong>AM GENOME Level 2 Maturation Needs</strong></td>
</tr>
</tbody>
</table>

### Benchmark Validation Use Cases

- EB-DED Ti-64 Ultrasonic NDI Test Coupons
- Ti & Ni Alloy X-Ray CT NDI Reference Test Coupons
- Project Call 3 – Summer 2015 Focus Area

### Model-Assisted Property Prediction

- Project Call 3 – Summer 2015 Focus Area

### Physics-Based Modeling & Simulation

- EBM Al Process Modeling
- Laser PBF Al Process Modeling
- DMLS Numerical Simulation Methods
- LENS Ti-64 ABAQUS FEA Set-Up Scripts
- Laser PBF Ni, Co, and Ti Distortion Modeling
- Project Call 3 – Summer 2015 Focus Area
The Innovation Factory

8 WAYS MEMBERS CAN ENGAGE THE YOUNGSTOWN FACILITY

- Demonstrations & one-off prototyping
- Training on equipment & techniques
- Showcase your projects, equipment, concepts
- House employees at the innovation factory
- Education events (camps, training)
- Workshop space for technical & general meetings
- Fabrication and support capabilities & services
- Technology validation

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When America Makes
America Works

AmericaMakes.us  @AmericaMakes