Manufacturing Demonstration Facility

CPS Agreement: 24759
Partnerships: Over 170 Companies and 50 University Partners
2017-2018

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Director, Manufacturing Demonstration Facility

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
July 17-19, 2018

This presentation does not contain any proprietary, confidential, or otherwise restricted information

MDF Overview

Timeline and Budget

- Start Date: October 2011
- Entering Year 3 of Current 5 Year Strategic Plan
- FY17: DOE Annual Budget: **$16M**
- FY18: DOE Annual Budget: **$7.5M/$14M/$16M**
- Additional Investments by Industry (SPP), Other Government Agencies (SPP), and Other DOE Offices (e.g., Fossil, Geothermal, Vehicle, Wind, Nuclear, etc.)

Ever growing industry partnerships

Material Suppliers | Equipment Suppliers | End Users

Barriers*

- Barriers to commercialization of additive manufacturing include process control, tolerances, surface finishes, processing speed, scalability, materials compatibility, modeling, validation, and demonstration

**Source: The Advanced Manufacturing Office Multi-Year Program Plan*

Partners

- **>170** Industry Partners to date
- **>50** University Partners
- **>21,300** Visitors**, >3,200** Companies
- **56** industry fellows
- Partnerships with **10** Other DOE Laboratories
- Sponsorship or Collaboration by **6** Other Federal Agencies
- Membership and Participation in >**3** of the Manufacturing USA Institutes

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Project Objectives

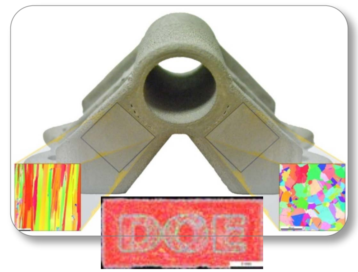
"…while still evolving, (Additive manufacturing techniques) are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, reduce lifecycle energy use, and shorten time to market."

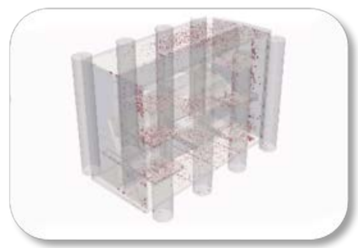
Source: The Advanced Manufacturing Office Multi-Year Program Plan, 3.1.6 Additive Manufacturing, pp. 65-68

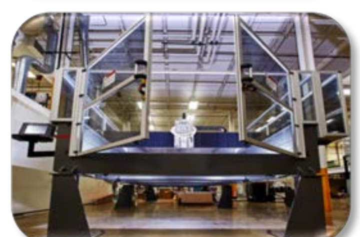
– **Target 6.1:** Demonstrate AM components whose physical properties and cost/value outperform selected conventionally produced parts by 20%.

– **Target 6.2:** Develop rapid qualification methodologies that reduce certification cost to 25% of the total component cost.

– **Target 6.3:** Develop next-generation AM systems that deliver consistently reliable parts with predictable properties to six standard deviations ("six-sigma") for specific applications.







Challenges and Barriers:

- **Process control:** feedback control systems and metrics to improve precision, reliability, and quality.
- **Tolerances:** micron-scale accuracy.
- **Surface finishes:** finishes to achieve desired tribological and aesthetic properties.
- **Processing speed:** high-throughput additive processing methods to compete with conventional techniques.
- **Scalability:** capabilities for large-volume production, both in size and number of parts produced.
- **Materials compatibility:** new metal and polymer materials formulated for additive manufacturing, providing application-specific properties such as flexibility, conductivity and transparency.
- **Modeling:** physics-based models to understand the fundamentals of additive processes, especially for multi-material and multi-phase systems and interfaces.
- **Validation and demonstration:** established material properties for additive manufacturing materials and qualification of manufactured components.

Energy Relevant Benefits

✓ Innovation
✓ Part Consolidation
✓ Low Energy Consumption
✓ Less Waste
✓ Reduced Time to Market
✓ Light-weighting
✓ Agility of Mfg. Operations

Source: *Department of Energy, Quadrennial Technology Review 2015, Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing, Additive Manufacturing, pgs. 4-6*

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Technical Innovation

Advanced Manufacturing: High Potential, Early-Stage R&D

	Materials	Qualification and Certification	Modeling and Characterization	AM Systems
Challenges	• Costly material feedstocks • Limited materials • No AM-developed materials • Post-processing required	• Limitations in conventional metrology • Required materials specifications & practices • Costs in certification • Variability of process	• Complex temporal-spatial process • Lack of understanding on impact of local microstructure • Warping • Anisotropic properties	• Limitations in build volumes • Slow processing • Reliability • Limited sensor employment • No closed loop control
R&D Solutions	• Microstructure engineering through precise process control and monitoring • New metallic alloys and polymers designed for AM • Spatially graded & hybrid materials • Understanding the role of feedstock	• In-situ process monitoring • Filters and correlative data analysis • Machine learning and uncertainty quantification • Integration and deployment of rapid qualification tools	• Development, implementation and validation of AM-specific workflow • Crystallographic & 3D tomographic information • Physics-based simulations • In-situ non-destructive evaluation and post processing metrology techniques	• Improved reliability • Pick and place/hybrid • Expansion of materials • Large-scale/fast rates

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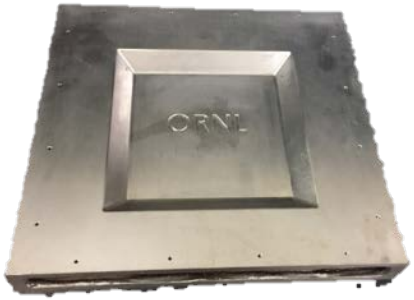
Technical Innovation (continued)

Rapid Advanced Manufacturing of Solutions for Energy Generation and Efficiency

- **Rapid Prototyping and Direct Fabrication of Final Components**
- **Additive Manufacturing of Tooling, Die, Molds, Jigs, Fixtures, etc.**



- Over one-third of U.S. tool, die, and mold establishments have gone out of business. *Source: 2012 U.S. Congressional Report*
- AM provides opportunity to fabricate tools at reduced times and costs

Hydro

Wind

Buildings

Fossil

Transportation

Technical Approach: Core Research & Development

2018: The Manufacturing Demonstration Facility

>35 Additive Systems

***>$12M** of No-Cost Leased Equipment*

The MDF is an ORNL user facility focused on cost-shared early-stage applied R&D in the areas of additive manufacturing and carbon fiber materials research related to energy.

- Based on ORNL strengths in materials, computation, engineered systems and characterization
- **4,500 – 6,500** visitors annually representing **>700** companies providing insight
- **5** year strategic plan, **4** goals
- **2-day** MDF Peer Review each spring
- **DOE approval** of MDF annual project plan

Core Research & Development Goals:

Improved Performance Characteristics of AM Components Through Materials-Process Development

Qualification & certification framework for AM components

Comprehensive Understanding of AM Process Capabilities and Limits Through Physics-Based Simulation and Advanced Characterization

AM Systems Optimized to Achieve Mainstream Manufacturing

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Technical Approach: Industry Collaborations

Explore

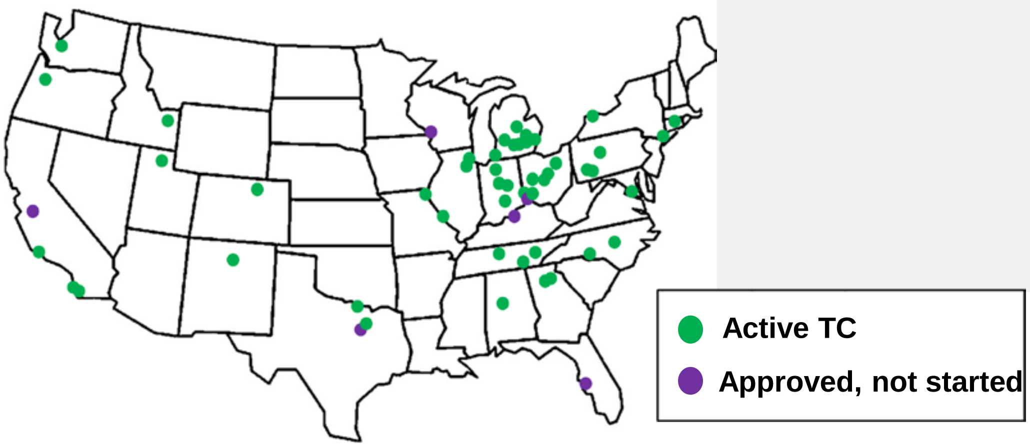
- Opportunity for industry to discover and apply new manufacturing technologies

Engage

- Work with MDF staff to develop scope of work

Execute

- Phase 1 $40K, Phase 2 $200K
- 1:1 Cost Match
- Non-Negotiable CRADA
- ~90-day cycle time from review to a signed agreement



Status	Phase 1	Phase 2	TOTAL
Pending Agreement	13	1	14
Active	31	6	37
Complete	79	10	89
Total	**123**	**16**	**140**

Currently **37 active** Collaborative Research and Development Agreement partners, and **140 total**

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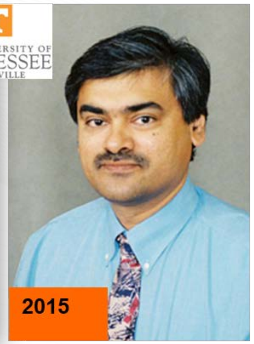
Technical Approach: Education and Training

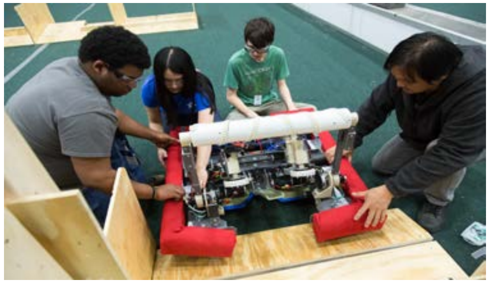


Dr. Suresh Babu
Mechanical, Aerospace & Biomedical Eng.(Ohio State) light weight metals *additive manufacturing*

Dr. Uday Vaidya
Mechanical, Aerospace & Biomedical Eng.(UAB) *composites manufacturing*

Governor's Chairs in Strategic Areas

- 50% ORNL & 50% UTK with shared lab space
- ~54 undergrad & graduate students performing R&D in advanced manufacturing
- MAJIC IUCRC (The Ohio State University, Colorado School of Mines, the University of Tennessee, etc.)



Workforce Development

- Advanced Manufacturing Veterans Internship Program (Pilot 2014)
- Boeing Design for AM Program (>100 designers)
- Navy Additive Manufacturing Workshops

Training Our Next Generation

- >5 years of volunteer mentorship for FIRST ROBOTICS
- >750 students engaged
- DOE-AMO enabled 400 desktop printers 2014 FIRST Robotics partnering with America Makes.

Growing Internship Program

- >100 internships
- Internships doubled in last 4 years
- Projects include AM software development, robotic design, hydraulics, materials characterization, AM simulation, design, etc.

50 universities have partnered with the MDF

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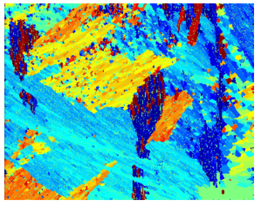
Accomplishments: Significant Technical Achievements in the Last Year, FY17-FY18

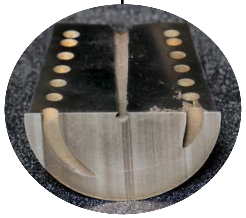
Developing various algorithms to **optimize scan strategies** for Arcam builds

Strength retention of additively manufactured Al-Ce at high temperatures

- 300% improvement in tensile strength
- Yield strengths of 300MPa with minimal decrease up to **300°C**



Illustrated ability to **predict Ti alloy performance** based on correlation to database on mech. properties



Achieved **97%** density of H13 injection molded tool with part consolidation within **3%** of target geometry

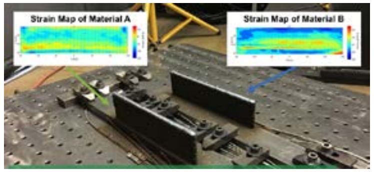
ExOne

KENNAMETAL

TECHMER PM

ORNL and TechmerPM are printing **high thermal conductivity polymers** and have achieved heat conduction up to 4W/(m·K)

Low transition temperature steels identified to help manage stress fields in large scale additive manufacturing



ChoiceSpine granted FDA clearance on Jan 26 for 3D Printed Vertebral Body Replacement Device based on ReVV program

REVV!

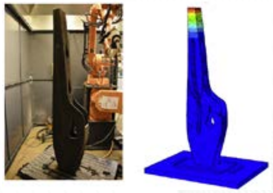
ChoiceSpine

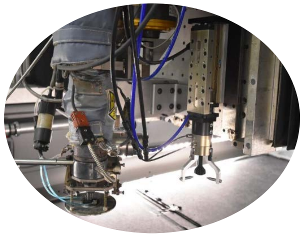
Additively manufacturing soft and rigid foams using BAAM with densities of **0.25g/cc**

WOLF ROBOTICS

LINCOLN ELECTRIC

Development of thermal mechanical models to **predict distortion and thermal history** of large-scale steel structures.





System that works in tandem with existing large-scale AM equipment to **'pick and place'** components into a part as it is printed

ORNL 3D prints **crack-free turbine blades** using IN738

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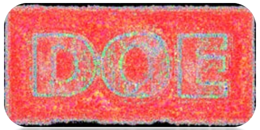
Accomplishments: Playing a Leading Role in the Future of AM

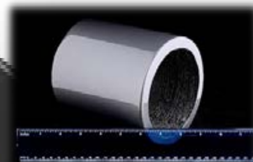


Altering process parameters of EBM systems to achieve microstructure control

R&D 100

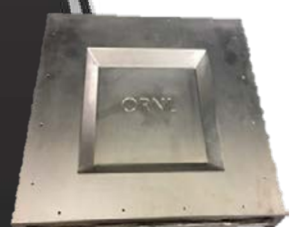
Optimization of hardware & software development on BAAM system; will be 3 orders of magnitude over state-of-the-art when complete

Printed with 87 various polymer composites, including bio-derived materials like poplar-PLA



Using BAAM to 3D print rare earth magnets CMI Critical Materials Institute

Process parameter development of high temp alloys

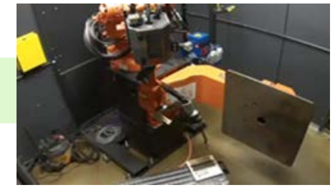


Development of fast-deposition MIG welding capabilities for steels on large-scale metal printer

Development of thermoset materials for AM

>100 materials explored for AM

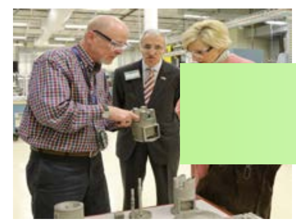
4 co-developed systems



FLC Federal Laboratory Consortium for Technology Transfer

>60 awards, including 16 for FY17-18

>50-70 peer reviewed publications/year



>22,000 visitors representing >**3,200** companies

>35 patent applications with **20** agreements for licensed technologies

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Transition Plan

Examples of using core R&D to Lead Industry Growth

On-Shoring of a Powder Bed Technology

- *Acquisition of Arcam by GE*
- *13 Technical Collaborations*

July 2012

ORNL, Arcam sign CRADA *to improve process reliability, develop in-situ process monitoring and closed loop control, expand materials systems, increase deposition rate, and increase build volume of the Electron Beam Melting (EBM) technology*

Feb 2014

ORNL, CI Inc. sign CRADA *to develop commercial large-scale additive manufacturing (BAAM) system*

June 2014

Arcam launches Nickel Base Superalloy process for 3D printing: The *Inconel process is "initially" available for its A2X platform. Arcam's A2X is highly suited for processing high temperature materials and is used for aerospace applications.*

Sept. 2014

Strati car printed live at IMTS Show on BAAM system; CI Inc. sells first BAAM beta system

January 2015

Honeywell became the first company to use electron beam melting (EBM) to produce an **aerospace component from Inconel 718**

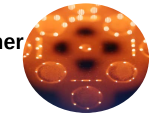
Jan. 2015

CI delivers next-generation BAAM system to MDF

Shelby goes global

February 2015

ORNL launches efforts for printing **higher temp., conventionally non-weldable** alloys



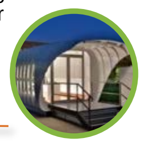
March 2015

ORNL and Solar Turbines develop HastelloyX for high temp gas turbine applications

Solar Turbines
A Caterpillar Company

Sept. 2015

Additive Manufactured Integrated Energy (AMIE) 3D printed house and utility vehicle for off the grid: Integration of natural gas and solar



January 2016

ORNL and Haynes successfully demonstrate the ability to 3D print **Haynes 282** which is under development by **Siemens.**

HAYNES International
SIEMENS

April 2016

ORNL initiates a data analytics framework **for certification and qualification** of AM

DREAM.3D Open Source Edition

Sept. 2016

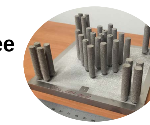
ORNL receives GUINNESS World Record award for Boeing 777x trim tool, the largest single 3D printed component, now being used on Boeing production floor

Jan. 2017

TPI uses 3D printed mold to fabricate wind turbine blade for the 1st time

May 2017

ORNL 3D prints **crack free MARM 247** simple geometries

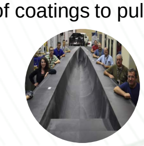


Dec 2017

GE acquires Arcam for **>$750M**

April 2018

Alliance MG uses 35' long 3D printed boat mold without the use of coatings to pull boat hulls



May 2018

ORNL 3D prints crack free turbine blades using IN738

Creation of an Industry

- 14 Units Sold
- *Over 7 AM Equipment Manufacturers Using/Evaluating Technology*
- *Over 136 total CRADAs*
- *10s to 100s of End Users Evaluating the Technology*
- *New Materials Suppliers*

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Transition Plan- Birth of a New Industry

Revolutionizing the Speed & Size of Mfg. Tools, Dies & Components

Feb '14: CRADA with CI Inc. signed

Sept '14: Strati printed live at IMTS

June '15: Startup initiates after seeing BAAM at IMTS

Cosine

July '16: Additive Engineering Solutions becomes service bureau & purchases BAAM after interacting w/ORNL

August '16: Develops robotics polymer BAAM

WOLF ROBOTICS

THERMWOOD

August '16: Manufactures Large Scale Additive Manufacturing (LSAM) system

Sept '16: Announces partnership with ORNL to develop very large polymer extrusion system (WHAM)

May '17: Develops extruders for CNC machines

HYBRID MANUFACTURING TECHNOLOGIES

Oct '17: Licenses ORNL extruder technology

Nov '17: Has sold 14 BAAM machines (licensed technology) to various industries such as aerospace, automotive, material providers, tooling, etc.

CINCINNATI

March '18: MVP and ORNL co-develop large-scale thermoset printer.

BAAM's Impact on Manufacturing in the US

ARKEMA INNOVATIVE CHEMISTRY · TECHMER ES ENGINEERED SOLUTIONS · American Chemistry Council · sabic · SAINT-GOBAIN · Polynt · TECHMER PM POLYMER MODIFIERS · AvCarb · BASF · CHOMARAT · NRG: The CMU Designed for Today · ResourceFiber · EASTMAN Eastman Chemical Company · PLASTECH CORPORATION

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Questions?

New facility 110,000 sq. feet total with 40,000 sq. feet of high bay

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