Oak Ridge National Laboratory

Manufacturing Demonstration Facility

CPS Agreement: 24759
Partnerships: Over 180 companies and 50 university partners in 2018-2019

Bill Peter
Director, Manufacturing Demonstration Facility

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 10-12, 2019

U.S. DEPARTMENT OF ENERGY

MDF Overview

Timeline and Budget

- Start Date: October 2011
- Entering Year 4 of Current 5 Year Strategic Plan (Revising 5 Year Plan FY19)
- FY18: **$15.4M** (DOE) + **$9M** (Cost Share)
- FY19: **$21M** (DOE) + **$4.4M** (Cost Share as of 3/19)
- $30M in No Cost Loaned Equipment (Supplied by Partner)
- Executed/In-review >**$100M** in CRADAs with **>50%** from industry
- Additional investments by industry (SPP), other government agencies (SPP), and other DOE offices (e.g., Fossil, Geothermal, Vehicle, Wind, Nuclear, etc.)

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

- ✓ Over **180** industry partners
- ✓ **64** industry fellows
- ✓ More than **26,200** visitors
- ✓ Over **4,100** visiting companies
- ✓ Over **50** university partners

Ever growing industry partnerships

Material Suppliers | Equipment Suppliers | End Users

Partnerships/projects with 10 other DOE laboratories

Sponsorship/collaboration with 6 other federal agencies

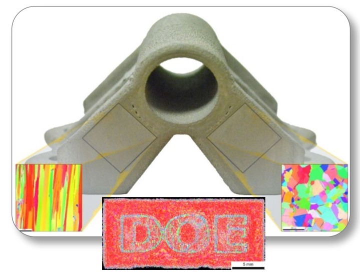
Membership/participation in >3 of the Manufacturing USA institutes

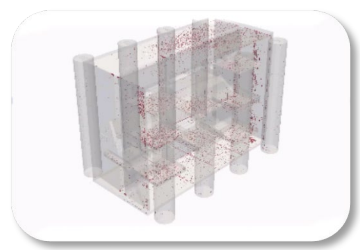
Project Objectives

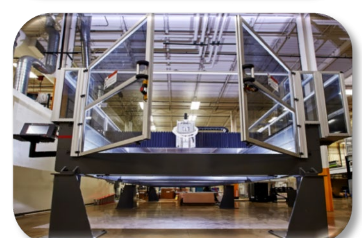
"…while still evolving, (Additive manufacturing techniques) are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, reduce lifecycle energy use, and shorten time to market."

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.







Energy Relevant Benefits

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

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.

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

Technical Innovation

Advanced Manufacturing: high potential, early-stage R&D

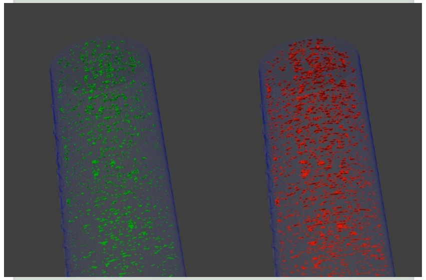
Materials

- *Developing materials designed for additive manufacturing, creating composite and hybrid materials and understanding the role of feedstocks.*

- Localized microstructure control
- Materials designed for harsh conditions such as superalloys, ceramics, refractories, and composites
- Developing polymer materials with anisotropic properties
- Spatially graded & hybrid materials

Software

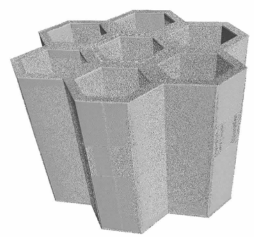
- *Development of material theory, simulation tools, data visualization and machine learning for deploying rapid qualification tools.*



- In-situ process monitoring
- Physics-based simulations
- Filters and correlative data analysis
- Machine learning and uncertainty quantification
- Integration and deployment of rapid qualification tools

Metrology

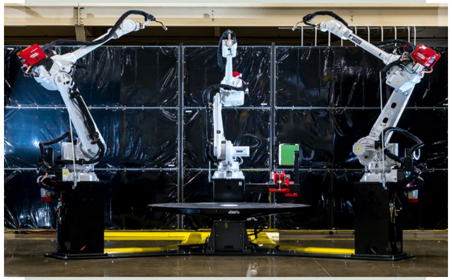
- *Integrating in situ nondestructive evaluation, 3D tomography, post-processing and metrology techniques for a better understanding of additive processes.*



- Feedstock characterization
- Development, implementation and validation of AM-specific workflow
- In-situ non-destructive evaluation
- Crystallographic & 3D tomographic information
- Multi-scale post processing metrology techniques

Systems

- *Developing next generation additive and hybrid systems that enable new materials, applications and solutions for energy relevant fields.*



- Increased process reliability & productivity of processes to reduce costs
- Additional process understanding and control via the digital thread, cloud and big data
- Exploration of coordinated control of multiple energy sources and new materials
- *Integrating technologies*

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Technical Innovation (continued)

Rapid advanced manufacturing of solutions for energy generation and efficiency

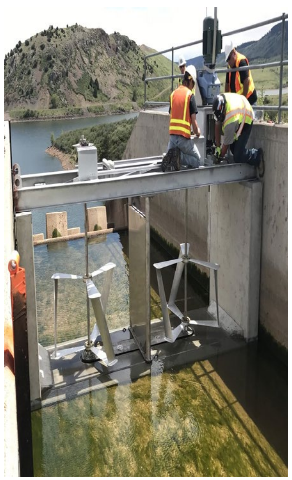
Rapid prototyping

Direct fabrication

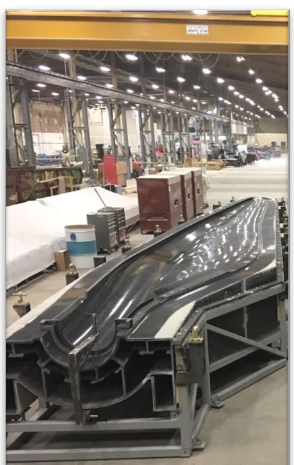
Tools, dies, molds

Using advanced manufacturing for energy generation, national and economic security, and revitalizing America's manufacturing competitiveness.

Hydro



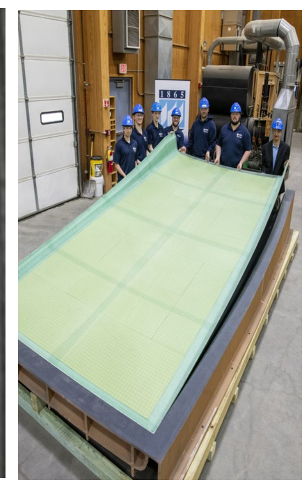
Wind



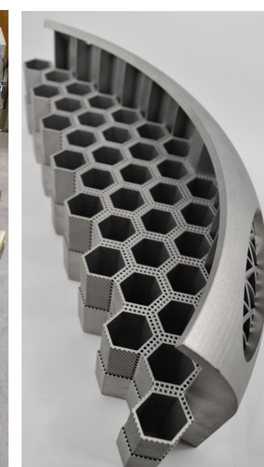
Buildings

Fossil

Transportation



Nuclear



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Technical Approach: Core Research & Development

The Manufacturing Demonstration Facility

	2018		2019	
Number of systems		35		80
Sq. ft. of high bay		17,000		40,000

MDF by the Numbers	# of People
Staff	82
Interns	33
Students	51
Summer Interns	37
Total	**166 to 203**

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
- ✓ **~5,000** annual visitors representing **~700** companies per year providing insight
- ✓ **5** year strategic plan, **4** technical areas
- ✓ **2-3 day** Annual MDF Peer Review
- ✓ **DOE approval** of MDF annual project plan

*Includes **>$30M** of no-cost leased equipment*

Technical Approach: Industry Collaborations

Explore

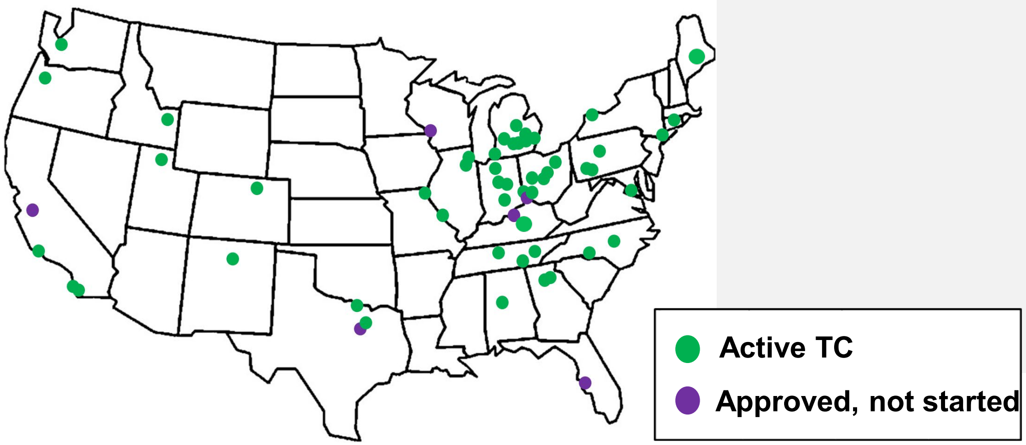
- Opportunity for industry to discover and apply new manufacturing technologies

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	4	1	5
Active	36	15	51
Complete	93	10	103
Total	**133**	**26**	**159**

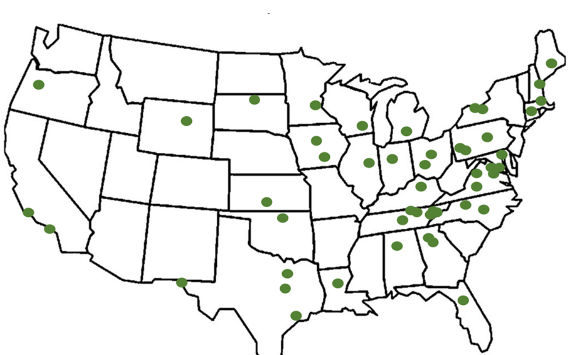
Currently **51 active** Collaborative Research and Development Agreement partners, and **159 total**.

Technical Approach: Universities and Work Force Development

Developing future leaders in U.S. manufacturing

University Partnerships

Greater than **50** partnerships



Local Education Ecosystem

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

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

32 Current & Future Leaders in Manufacturing Companies & New Businesses

Summer Internships

>100 internships each summer

- Internships **doubled** in last 4 years
- Projects include:
  - AM software development
  - Robotic design & AM simulation
  - Hydraulics
  - Materials characterization
  - Design, and more

Accomplishments: *Significant Technical Achievements in FY19*

ExOne

3D printing H13 tool with conformal cooling channels successfully produces injection molded cups

AM precast concrete molds used to refurbish Domino Sugar Bldg. in NY 50% faster than conventional molds

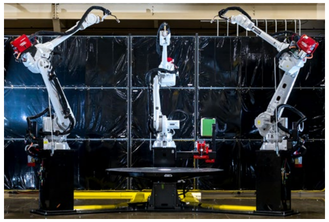
GATE
AES

MVP
Polynt Composites

Fabrication of 1st large-scale thermoset tool via 3D printing

Successfully printed marine propeller using innovative slicing software

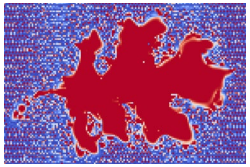
LINCOLN ELECTRIC
WOLF ROBOTICS



Installation of large-scale, high rate metal multi-material system to rapidly develop/demonstrate new mfg. processes

LINCOLN ELECTRIC
WOLF ROBOTICS

Development of geometry agnostic scan strategy optimization algorithm to achieve microstructure control in AM IN738 components



Development of cementitious materials and fieldable concrete deposition system for infrastructure-scale AM

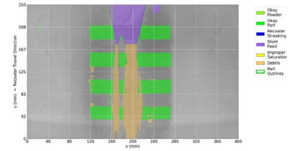
OSHKOSH
GE

Successful printing of SiC and B_4C high temperature heat exchanger geometries for power generation applications

ExOne

ExOne

Using machine learning algorithms to identify and self-correct binder jet prints



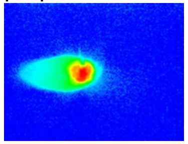
CINCINNATI

1st successful test of a 3D printed motor

3D printed Al-Ce-Mn has ~300% improvement in yield strength compared to conventionally manufactured Al alloys

volunteer aerospace

Controlling melt pool size of LMD-w components to achieve thermal control of 3D printed components, achieving complex geometries with enhanced mechanical properties



GKN

Improving lifetime and decreasing cost of large-scale metal components by 3D printing multi-materials

LINCOLN ELECTRIC
WOLF ROBOTICS

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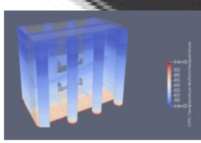
Accomplishments: *Playing a Leading Role in the Future of AM*

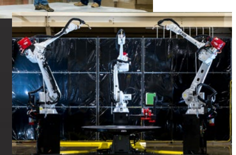
Developing intelligent machine tool capabilities

Using innovative R&D for nuclear energy applications

Creating a digital factory to bridge the gap between systems/software



Fabricating next generation systems to increase US manufacturing competitiveness



Integrating pick and place capabilities into large-scale thermoplastic and thermoset systems for fabricating smart tooling

Developing processes for thin film electronics that will allow multifunctional devices to be integrated into AM components

Enabling a broader use for adv. composites such as CF to reduce costs and increase commercial viability

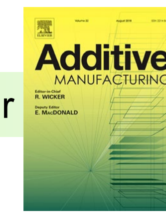
100s of materials explored for AM

>9 co-developed systems

FLC Federal Laboratory Consortium for Technology Transfer

>131 awards, including **12** for FY18-19

>70-80 peer reviewed publications/year



>26,200 visitors representing **>4,100** companies

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

Transition Plan: Making a Difference in Energy Systems

Metal Powder Bed Deposition

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 2013 – **Arcam and DiSanto Technology sign Strategic Alliance**
accelerate market adoption and penetration of commercially manufactured, finished EBM-based implants and components.

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.

August 2014 – **Data Analytics Framework for Certification and Qualification**
In collaboration with AFRL, ORNL launches Dream.3D as the future platform for data analytics for certification and qualification of AM components

January 2015 – In collaboration with Oak Ridge National Laboratory, **Honeywell became the first company** to use electron beam melting (EBM) to produce an **aerospace component from Inconel 718**

June 2015 – **ORNL Publishes Microstructure Control**
Site Specific Material Property Control

July 2016 – **Development of Crack Free LSHR**
Successful processing of non-weldable NASA alloy

March 2016 – **ORNL and Quintus CRADA**
on post processing of additive manufactured components

June 2016 – **Inauguration of Woburn, MA Office**
CEO Relocates to US, 50% Arcam employees in North America, Acquisition of DiSanto and AP&C, and Dramatic expansion of installed EBM systems

November 2016 – **"GE to buy SLM, Arcam for $1.4billion in 3D printing push" -CNBC**

- *GE offered 5.86 billion crowns or $685M for the purchase of ARCAM*
- *GE holds >73% of Arcam shares in November*

February 2017 – **ORNL and Siemens Energy deploy HX and Haynes-282**
Multiple fossil energy applications

August 2017 – **In-Situ Monitoring of AM Parts**
Published in Nature Scientific Reports

November 2017 – **ORNL and Solar Turbines**
Complete 3D printed crack-free turbine blades for land based industrial gas turbines

March 2019 – **ORNL And Voxel complete Surface Finishing Trials**
EBM Surface exceeds cast material

March 2019 – **Multi-Length Scale Characterization for AM**
Full metrology and material characterization

Oak Ridge National Laboratory · Arcam A GE Additive Company · Honeywell · GE · SIEMENS · Solar Turbines A Caterpillar Company · voxel · Quintus Technologies · NASA · AFRL · ZEISS

Transition Plan: Industry Co-Location

91 Industry Fellows Working at the MDF Since Its Inception

Current industry fellows

- BWXT – BWX Technologies, Inc.
- Wolf Robotics – A Lincoln Electric Company
- Cincinnati
- GKN Aerospace
- Polynt Composites
- Strangpresse
- MVP – Magnum Venus Products
- Boeing
- Techmer PM – Polymer Modifiers
- LeMond Composites
- HTS IC
- Cummins
- Innovation Crossroads
- Pioneer Natural Resources
- Volkswagen
- TruDesign
- Volunteer Aerospace
- GE
- Zeiss

Past industry fellows

- EPRI – Electric Power Research Institute
- Arcam EBM – a GE Additive company
- Fraunhofer
- Lockheed Martin
- Alcoa
- Cosine Additive
- Local Motors

Other labs & agencies

- AFRL – The Air Force Research Laboratory – Lead | Discover | Develop | Deliver
- Y12 National Security Complex
- NASA
- United Technologies
- Sandia National Laboratories
- IACMI – The Institute for Advanced Composites Manufacturing Innovation – The Composites Institute

Transition Plan: Events, Summits and Workshops

Recent Example

INNOVATION X LAB ADVANCED MANUFACTURING SUMMIT

Almost 300 attendees registered-

- **140** industry/other
- **95** national labs (aside from ORNL)
- **52** government

Attendees included-

- Multiple high-level DOE officials
- C-Suite Executives
- Political Representatives
- Five other National Lab Directors

MDF- related announcements-

- CRADA with Lincoln Electric
- Opening of TechmerPM's new dedicated production line

-Several companies and all **17** national labs hosted exhibits

-Approximately **60** attendees visited the MDF prior to event

Measure of Success: Birth of a New Industry

Example: *Large Scale Polymer Additive Manufacturing*

Feb '14: CRADA with CI Inc. signed

CINCINNATI

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

THERMWOOD

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

August '16: Develops robotics polymer BAAM

WOLF ROBOTICS

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

INGERSOLL Machine Tools

May '17: Develops extruders for CNC machines

HYBRID MANUFACTURING TECHNOLOGIES

Strangpresse

Oct '17: Licenses ORNL extruder technology

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

MVP MAGNUM VENUS PRODUCTS

October '18: ORNL wins ACE award at CAMX for 3rd year in a row for collaboration with MVP on large-scale thermoset printing.

May '19: TechmerPM announces initiation of dedicated polymer pellet lines.

TECHMER PM POLYMER MODIFIERS

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
Save Labor. High Performance. Continuous Insulation.
ResourceFiber.
EASTMAN
Eastman Chemical Company
PLASTECH CORPORATION
Dixie Chemical
The Element of Open Innovation

- Key Measures
  - 3 Orders of Magnitude Increase in Deposition Rates
  - 1 Order of Magnitude Increase in Volume
  - 7 Equipment Manufacturers
  - >100 Different Material Combinations
  - >50 End Users

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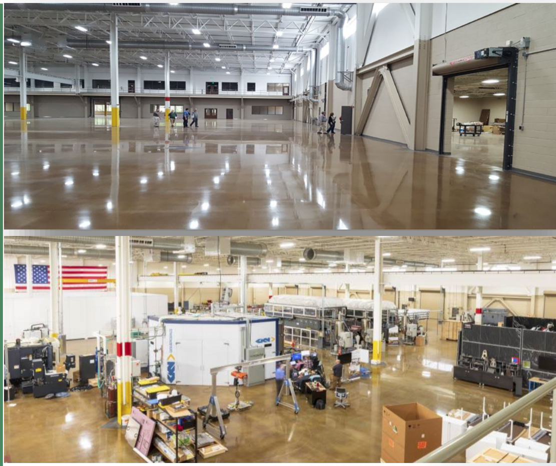
Questions?



Last year vs. today

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