# The Manufacturing Demonstration Facility

*Oak Ridge National Laboratory*

### Core Research and Development

Leveraging ORNL's Science Capabilities to Solve Challenges in Additive Manufacturing.

### Industry Collaborations

Cooperative research to develop and demonstrate advanced manufacturing to industry in energy related fields

### Education and Training

Internships, academic collaborations, workshops, training programs, and course curriculum for universities and community colleges.

*Funded by the DOE-EERE Advanced Manufacturing Office*

**Neutron scattering: SNS and HFIR**

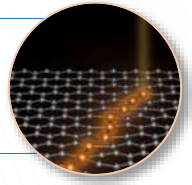
- World's most intense pulsed neutron beams
- World's highest flux reactor-based neutron source

**Advanced Materials**

- DOE lead lab for basic to applied materials R&D
- Technology transfer: Billion dollar impacts

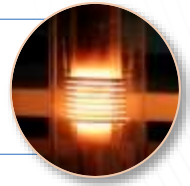
**Leadership-class computing: Titan**

- Nation's most powerful open science supercomputer



**Advanced Manufacturing**

- Novel materials
- Advanced processing



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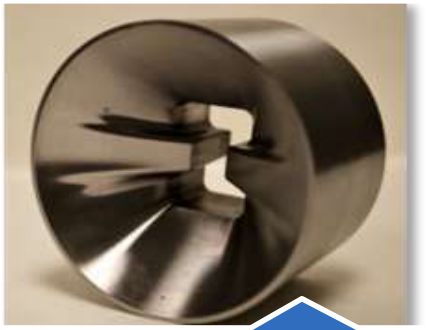
# Additive Manufacturing Systems

*Research in a Wide Range of AM Technologies*

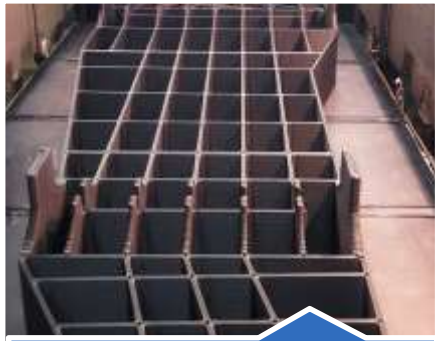
### Powder Bed Fusion

- Electron Beam Melting
- Laser Sintering



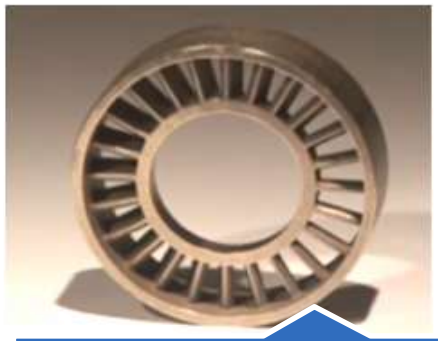
### Directed Energy Deposition

- Laser Blown Powder Deposition
- Large-scale Laser Metal Wire Deposition
- Large-scale MIG Metal Wire Deposition



### Fused Deposition Modeling

- Large and small-scale polymer deposition



### Metal Binder Jetting

- Metal matrix composites and sintered materials including stainless steel + bronze, tungsten + titanium and ceramics + sand

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# Objectives & Approach

*4 Goals for Enabling Additive Manufacturing*

## Enhancing Additive Manufactured Components Performance Through Materials Development

- 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

## Developing New Methodologies for Certifying Additive Components for Use

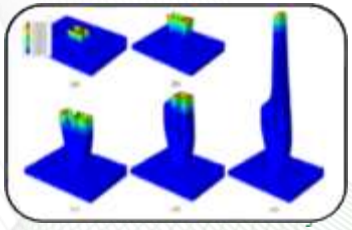
- In-Situ Process Monitoring
- Filters and Correlative Data Analysis
- Machine Learning and Uncertainty Quantification
- Integration and Deployment of Rapid Qualification tools

## Develop new machines with increased deposition rates, build volumes, and mechanical properties

- Increased Reliability through Better Controls, Hardware, Feedstock and Software
- Next Generation Machines with Capability to Deposit Out of Plane

## Develop characterization and Integrated Computational Materials Engineering (ICME) capabilities to advance the understanding of AM.

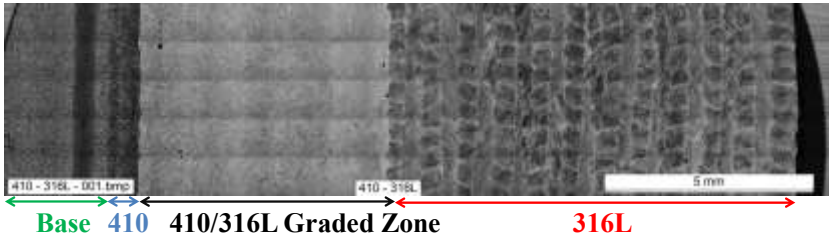
- Physics Based Simulations
- In-Situ Non Destructive Evaluation and Post Processing Metrology Techniques
- Crystallographic & 3-D Tomographic Information



# Additive Manufacturing Developing New Opportunities for US Businesses

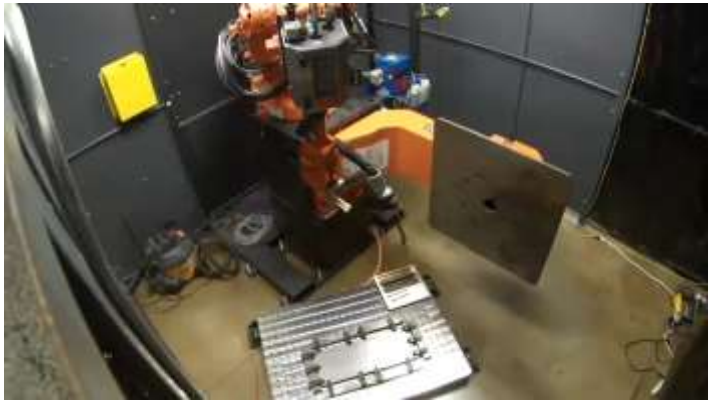

## Enabling Innovative Ideas to be Realized while Reducing Time to Market

- Both rapid development of working prototypes fabrication of tools.
- Lead times an order of magnitude less than conventional processes
- Reduce time from good idea to market




## New Alloy Development and Dissimilar Material Joining

- Novel methodologies to rapidly synthesize and characterize materials.
- Continued development in cladding.
- Joining of multiple materials by grading and other strategies.



## Next Generation of Additive Machines

*Big, Fast, and Low Cost Feedstocks*

- Ever increasing range of feedstocks.
- Build envelopes that are measured in meters not cm.
- Fast deposition rates 3 orders of magnitude above conventional print rates.
- Low Energy Consumption (e.g. BAAM CI 1.17 kWh/kg)

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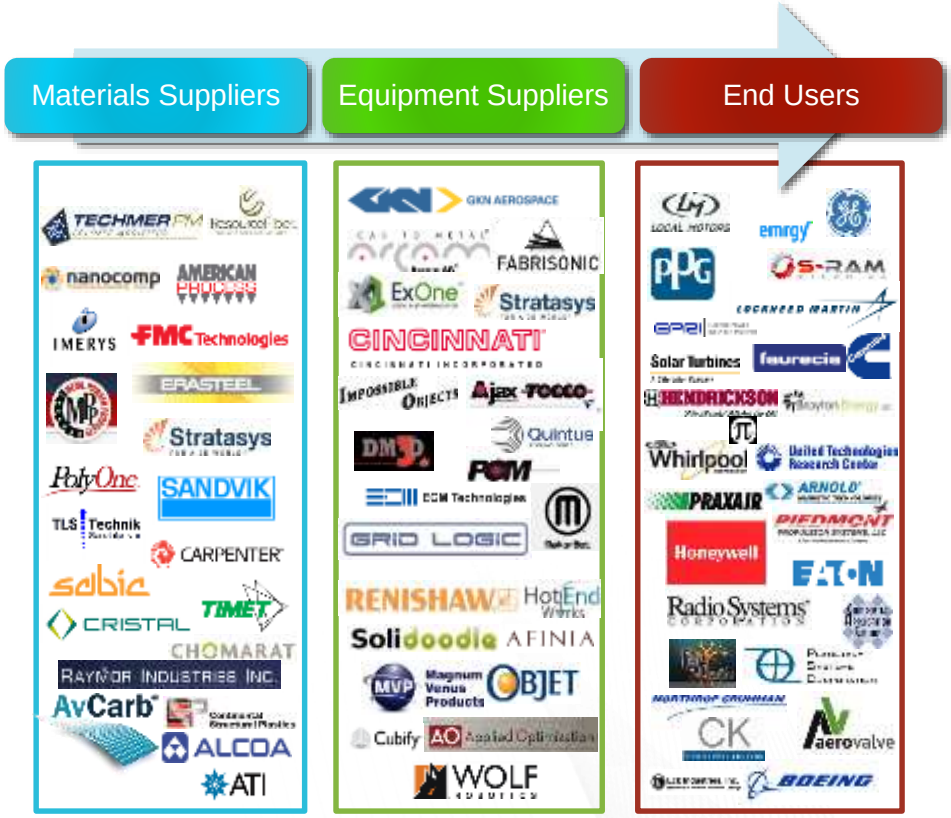
# Partnering with Industry

*Transitioning Additive Manufacturing Developments to Industry*


**Ever Growing Partnerships: Integrating the AM Supply Chain**

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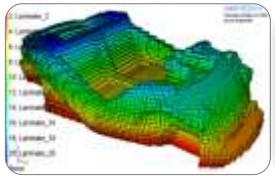
# Developing Reliable, Large-scale Processes

*Bigger, faster, and cheaper*

- ✓ Cincinnati System 8’x20’x6’ build volume
- ✓ Ingersoll system up to 100’ x 80’ x 60’
- ✓ Up to 100 lbs/hr (or 1,000 ci/hr)
- ✓ Pelletized feed replaces filament reducing cost up to 50%

Model



Make

Measure

## FY17 System Research Activities

- Baseline Performance Metrics: standard test articles to quantify overhangs, gaps, surface finish, accuracy,
- High speed, high resolution, high performance deposition: hardware and software that enables fine surface finish with course infill
- Five axis deposition: hardware and software to enable out of plane AM.


2015 R&D 100 WINNER

Oney Magazine's MANNY AWARD 2016 Winner

JEC WINNER OF 2016 INNOVATION AWARD

sme

ASM INTERNATIONAL

CAMX Combined Strength Award Winner – 2015

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# Large-Scale Metals

*AM System for Steel*

ORNL is developing large-scale systems for metal deposition with the following capability:

***Modeling of the process and Component Performance***

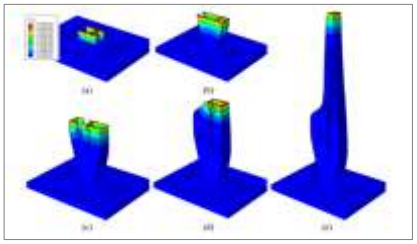
- System design: energy source, manipulator kinematics
- Process refinement: Sensor selection, controls
- Part design: Geometry, predicted stress and distortion

***Development of Systems***

- Prototype systems: Different materials, applications…
- Material: Synthesize material for AM
- Parts: Geometry, predicted stress and distortion

***Methodologies for Measuring***

- Part distortion during manufacturing: Adaptive control
- Residual stress to validate models: HIFR, SNS



## FY17 Research Activities

- Integration of System and Slicing Software
- Thermal Models to Predict Part Distortion
- Process Controls to Maintain Geometry

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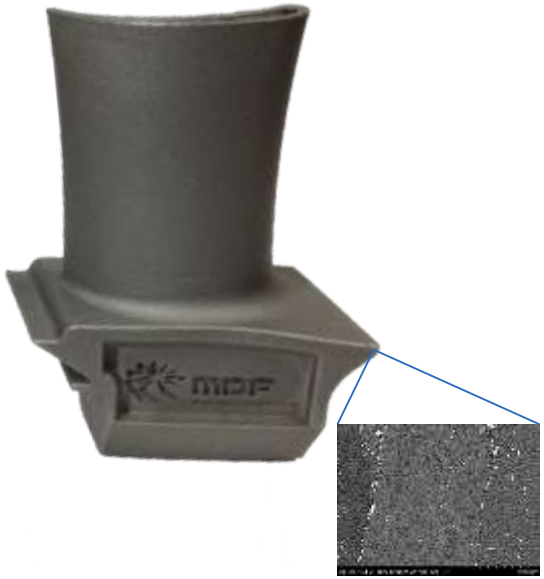
# High Temperature Materials

*For Energy Applications*

Most high temperature alloys used today were not designed for additive manufacturing, resulting in detrimental precipitates and non-optimal properties.



**Multiscale modeling of Powder Bed processes**

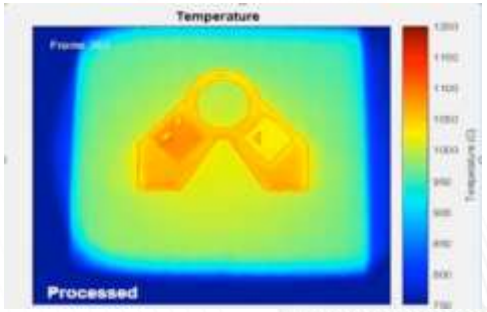
- High fidelity models for solidification, understanding residual stress and precipitation kinetics
- HPC and reduced order models to capture relevant physical phenomena over entire build

**Materials deposition and testing**

- Understand links between process parameters, microstructure and mechanical behavior
- Design AM specific alloy chemistries for improved properties
- Understanding links between transient thermal behavior and defect formation (porosity and cracking)

**Fabrication and Certification of Components**

- Manufacture defect free, complex geometry components
- Demonstrate a 3-5% efficiency improvement in land based gas turbines




## FY17 Research Activities

- Successful deposition of high γ' containing Ni-base Superalloys (MARM 247 and IN718)
- Increase high temperature yield strength by 50% compared to IN718

*Electron Beam Melting of MARM 247*

# Improved Performance & Reliability

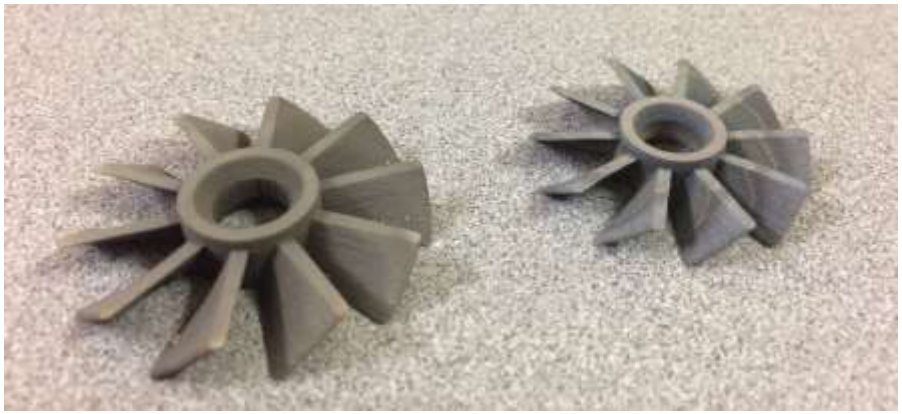
*For widespread adoption of binder-jet AM*

**Enhanced Process Modeling**

- Understanding effects of powder morphology and size distribution on processing
- Prediction of distortion and shrinkage during densification

**Materials Development**

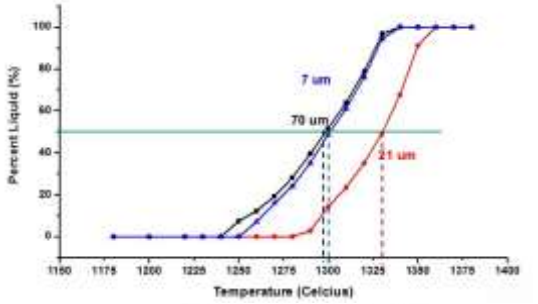
- Fully dense monolithic alloys designed for the AM process
- Hybrid structures not possible though conventional processing
- New binder development for ease of use, reliability, and compatibility with specific alloys

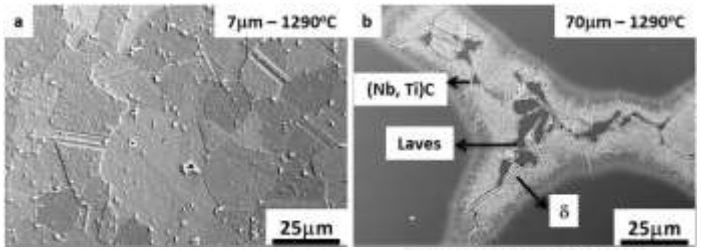


*Fully dense printed turbines*

## FY17 Research Activities

- Creation of fully-dense H13 tool steel equivalent materials
- Investigation of powder chemistry on liquid phase sintering approaches for full density
- Model development on distortion prediction during consolidation

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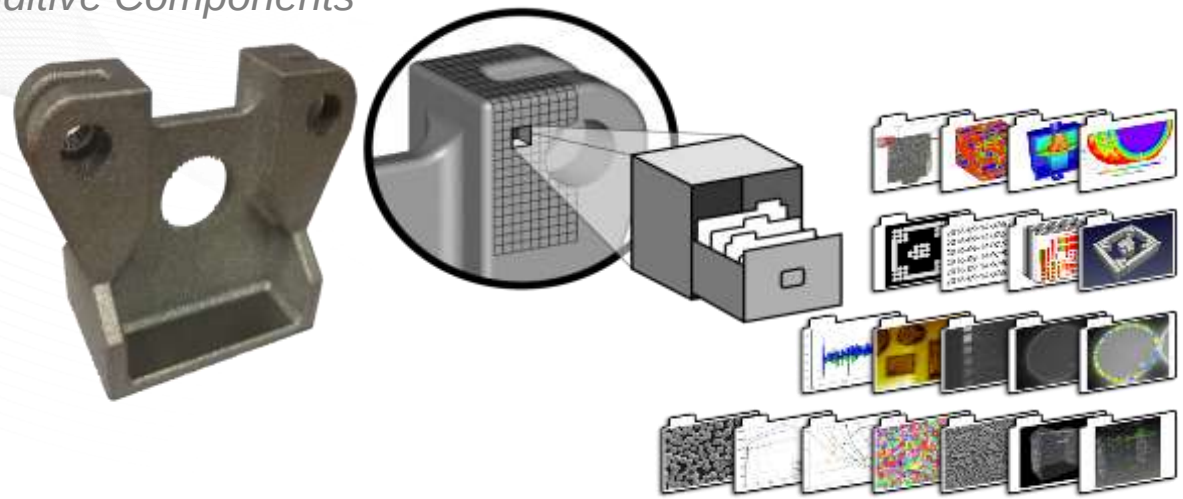
# Qualification and Certification

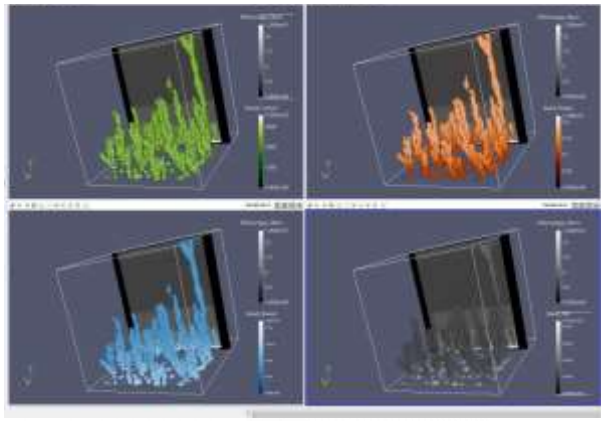
*For Additive Components*



**Machine Learning**

**Statistical Correlation**

**Analysis and Data Driven Model Verification & Validation**



**Creation of a 3D data framework for Additive Manufacturing**

- Utilizing DREAM3D in collaboration with AFRL
- Independent of size scale, material or deposition technology

**Software tool development**

- Broad dissemination of tools to help users understand process variables which govern material quality
- Visualization and statistical correlation methodologies

**Certification with Industry**

- Novel data driven construct for certification of AM processes as opposed to individual parts: Built-certified components