Manufacturing Demonstration Facility Overview

Bruce Pint
Deputy Manager, Fossil Energy Program
Materials Science & Technology Division
Oak Ridge National Laboratory

November 3, 2015

Atlanta, GA

Oak Ridge National Laboratory | Manufacturing Demonstration Facility

ORNL is managed by UT-Battelle
for the US Department of Energy

MDF supports Adv. Manufacturing Office's mission

DOE-EERE/AMO Mission

- **Develop and demonstrate new, energy-efficient processing and materials**
  - broadly applicable
  - improved products and reduced lifecycle energy consumption
- **Technical assistance to**
  - promote use of advanced technologies
  - capture U.S. competitive advantage in clean energy manufacturing

Manufacturing Matters

- 12.5% of U.S. GDP
- 12 million U.S. jobs
- 70% of U.S. engineering and science jobs
- 75% of U.S. Exports
- 17% of the world's manufacturing output
- 25% of US energy use

Manufacturing Demonstration Facility

A public-private partnership to engage industry with national labs

Leveraging ORNL's Science and Manufacturing Capabilities

Neutron scattering: SNS and HFIR

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

Leadership-class computing: Titan

- Nation's most powerful
  open science supercomputer

Advanced materials

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

Advanced manufacturing

- Novel materials
- Advanced processing

OAK RIDGE National Laboratory

Supporting Industry and R&D with a Wide Range of AM Capabilities

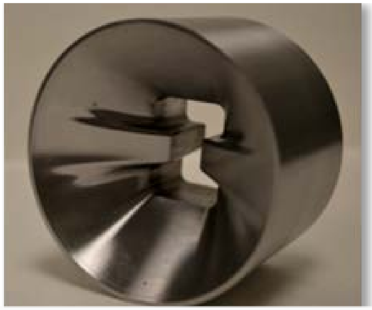
Electron Beam Melting

CAD TO METAL
Arcam AB

Laser Sintering

RENISHAW

Laser Blown Powder Deposition



POM
DM3D

Binder Jetting

ExOne
DIGITAL PART MATERIALIZATION

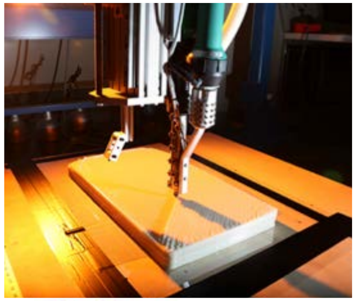
Fused Deposition Modeling

Stratasys
FOR A 3D WORLD
AFINIA
MakerBot
Solidoodle
Cubify

Multi-head Photopolymer

OBJET
Stratasys
FOR A 3D WORLD

Large-Scale Polymer Deposition



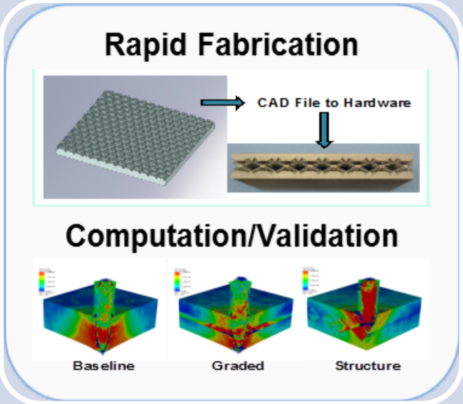
Oak Ridge National Laboratory
CINCINNATI
CINCINNATI INCORPORATED

Future Systems

CONCEPTLASER
hofmann innovation group
Oak Ridge National Laboratory

Understanding Additive Manufacturing

Mainstream applications and beyond



Direct Fabrication

- Complex shapes or designs only possible from additive manufacturing
- High yields for specialty materials
- Improved production time

Prototyping and ICME

- Using additive and computation to simulate and experimentally validate design
- Can provide structural or functional data rapidly
- Final part may be conventionally fabricated

Tooling & Indirect Fabrication

- 37% of tool and die business closed within the last decade
- Long lead times for tooling and dies
- Binder jet sand molds

ICME: Integrated Computational Materials Engineering

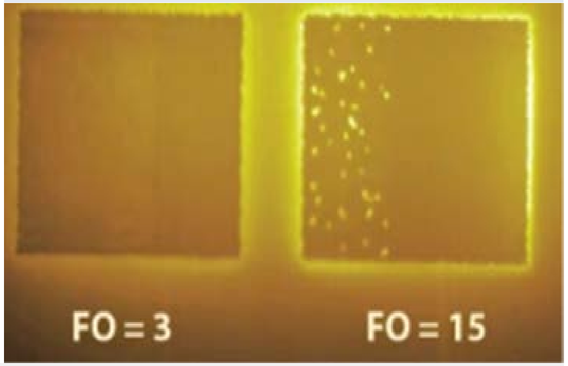
Oak Ridge National Laboratory

AM is an exciting, high-potential technology that is in the embryonic stage of development

Warping in Conventional Materials

Columnar Grain Growth

Porosity Due to Focus Offset Values



Challenges with additive manufacturing technologies and deployment include:

Materials

- Costly Material Feedstocks
- Limited Materials
- No AM Developed Materials
- Required Materials Specifications & Practices

Process Limits

- Limited Sensor Employment
- No Closed Loop Control
- Slow Processing
- Limitations in Build Volumes
- Post-Processing Required

Reliability

- High Variability
- Lack of Understanding On How Local Microstructure Impacts Properties
- Warping
- Anisotropic Properties

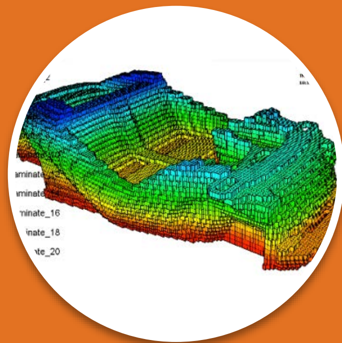
Most companies do not have the background and resources required to mature the technologies or commercialize additive manufactured components.

R&D to enable broader AM application

ORNL is working to understand challenges and accelerate technology implementation

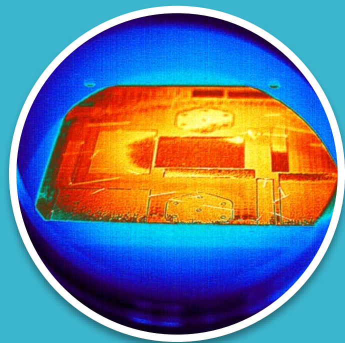
Improved and AM-Specific Materials Development

- High Temperature Applications
- Light Weighting
- Bio Derived Materials
- Functional Materials



AM Process Science

- Material Property Dependency on Process Inputs
- Computational Framework for Data Visualization and Analytics
- Improved Machine Control



Process Characterization for Qualification

- In-Situ Non-Destructive Evaluation
- Neutron Diffraction and Imaging
- Coupling to National Laboratory Network

Exploring Next-Generation Systems

- Bigger, Faster, Cheaper, & Better
- Integrating the Supply Chain
- Working with Current and Future Equipment Developers

Integrated Process and Material Understanding

OAK RIDGE National Laboratory

Improved and AM Specific Materials Development

Improved and AM-Specific Materials Development

Past & Present

Conventional Materials for AM have been based off wrought or casting alloys. Powders and wire have been expensive with limited supply.

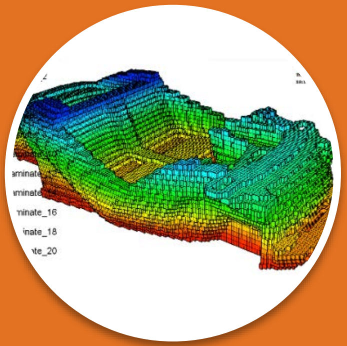
- **High Temperature Applications**
  - Cobalt chrome
  - Inconel 625 and 718
- **Light Weighting**
  - Ti-6Al-4V and CP Ti
  - Al-Mg-Si
  - ABS with chopped fiber
- **Bio Derived Materials**
  - PLA (desktop printers)
- **Functional Materials**
  - Copper printing
  - Direct write

Going Forward…

Developing Materials & Chemistries that Take Advantage of the Additive Process to Improve Performance

- **High Temperature Applications**
  - Ni/Fe-Based alloys that precipitate advantageous phases
  - Fracture resistant ceramics
  - Polymers for higher temperatures
- **Light Weighting**
  - Aluminum alloys designed for AM
  - High specific strength reinforced polymers
  - Low cost AM titanium alloys/feedstocks
- **Bio Derived Materials**
  - Degradable polymers
  - Bio derived fiber reinforcement
  - New binders for binder jet
- **Functional Materials**
  - Hybrid structures or multi-purpose materials
  - Chemical bonding and/or joining of dissimilar materials
  - Thermal and electrical systems printed in structure

AM Process Science



AM Process Science

Past & Present

Limited tools and controls are provided on current AM systems. Industry is only at the beginning of understanding AM properties and process.

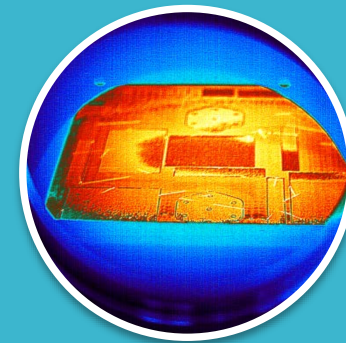
- **Initial Applications in Biomedical and Aerospace**
  - Conventional methodologies for qualification of components based on statistical models
- **Proprietary Machine Controls**
  - Part-specific processing recipes provided to end user
  - STL files for machining and AM part fabrication limit surface smoothness
- **Value of Data Analysis Discovered**

Going Forward…

New framework that provides real time information on the integrity of AM components with CAD packages that design the part for AM microstructures.

- **Property Dependency on Process Inputs**
  - Structural, chemical, and other pertinent data for energy relevant materials
  - Determination of process parameters and algorithms effect of final build properties
  - Development of process methodologies and materials that enable improved isotropic properties
- **Computational Framework for Data Visualization and Analytics**
  - Large data analysis for AM qualification
  - Use of 3D Imaging Software to capture data analytics visualization
- **Improved Machine Control**
  - Open-source development incorporating more sophisticated curve fitting will yield surfaces closer to desired contour

Process Characterization for Qualification



Process Characterization for Qualification

Past & Present

AM process & microstructure characterization are in its infancy. Qualification of AM continues to be case by case basis.

- **Potential for Continuous Information Acquisition During Component Fabrication**
  - High Speed thermography used to characterize porosity formation
- **Neutron Diffraction and Imaging**
  - Tomographic scans to characterize internal surfaces
  - Microstructure through the bulk revealed by neutron diffraction

Going Forward…

Utilization of Advanced or Unique Characterization Capabilities at the Laboratories to Better Understand Additive Manufactured Materials

- **In-Situ Non-Destructive Evaluation**
  - Integrated systems with real-time data analysis
  - On-the-fly repair of defects
  - Qualified components directly off the machine
- **Correlation of sophisticated post process characterization with as-built product**
  - New Advanced Neutron Imaging Capability - Venus
- **Networking among National Laboratories to apply complete suite of tools to AM**

OAK RIDGE National Laboratory

Exploring Next Generation Systems

Exploring Next-Generation Systems

Past & Present

Current systems are slow, limited in size, use feedstocks that are typically expensive, and print materials with highly anisotropic properties.

- **Powder Bed Systems**
  - Typically one energy source
  - Limited build volume
  - Expensive spherical powders
- **Free Form Metal Deposition**
  - Enclosed Furnace
  - Typically Titanium Alloy or other expensive feedstock
  - Maximum 5-15 kg/hr or 160 to 1600 cm^3/hr
- **Fused Deposition Modeling**
  - Thermoplastics
  - 16 to 64 cm^3/h (1-4 in^3/h)
  - Limited build volumes
  - Expensive powder or wire

Going Forward…

New large systems that can print a wide range of affordable materials at deposition rates 2 to 3 orders of magnitude faster than today's rates.

- **Fast, Large Powder Bed Systems**
  - New deposition technologies or multiple head systems
- **Metal BAAM**
  - Large, low cost metallic structures
  - Deposition rates of 16,000 cm^3/h (1,000 in^3/h)
- **Large BAAM**
  - Building Structures that exceed 6m (20')
  - Applications in wind turbine, oil and gas, marine, etc.
  - Deposition rates exceeding 500 kg/h (~1000 lb/h)
- **Thermoset Additive Manufacturing Systems**
  - Rapid manufacture of parts up to 2m on major dimension with targeted epoxy, reactive and thermally activated materials
  - Continuous Carbon Fiber BAAM
  - Multi-axis (5 dof), no support, large light weight structures

Ever Growing Partnerships: Integrating the AM Supply Chain

Materials Suppliers

- TECHMER PM – Polymer Modifiers
- ATI
- nanocomp Technologies, Inc.
- American Process
- IMERYS
- FMC Technologies
- Metal Powder Products (MPP)
- ERASTEEL
- Stratasys – For a 3D World
- PolyOne
- SANDVIK
- TLS Technik Spezialpulver
- CARPENTER
- sabic
- TIMET
- CRISTAL
- HMI Metal Powders
- Raymor Industries Inc.
- Fukuda Metal Foil & Powder Co., Ltd.

Equipment Suppliers

- Arcam AB – CAD to Metal
- FABRISONIC
- ExOne
- Stratasys – For a 3D World
- CINCINNATI – Cincinnati Incorporated
- Impossible Objects
- Ajax Tocco
- DM3D
- POM
- ECM Technologies
- MakerBot
- GRID LOGIC
- RENISHAW
- HotEnd Works
- Solidoodle
- AFINIA
- MVP – Magnum Venus Products
- OBJET
- Cubify
- AO Applied Optimization

End Users

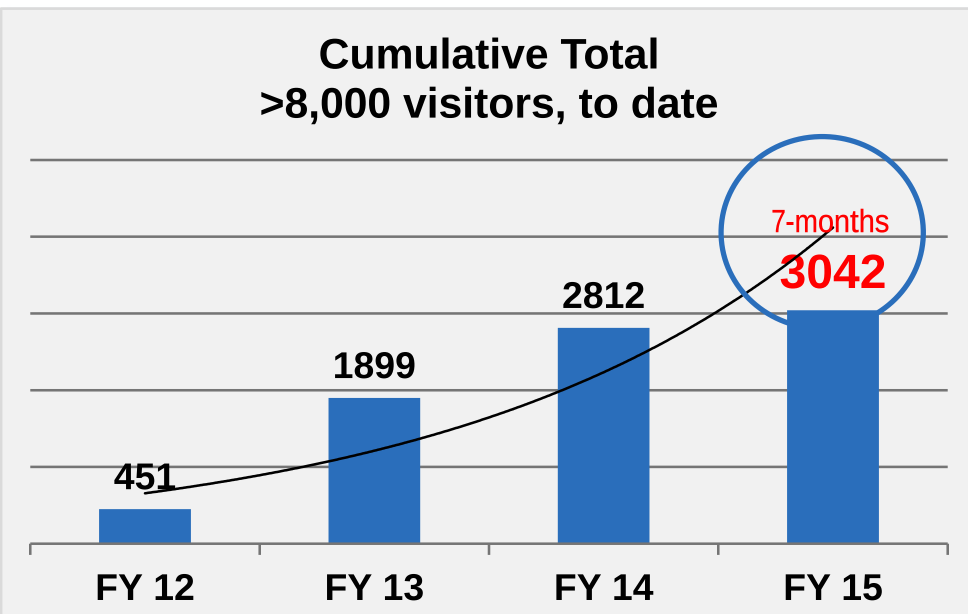
- Local Motors
- Cummins
- OS-RAM Dynamics
- PPG
- Lockheed Martin
- EPRI – Electric Power Research Institute
- Solar Turbines – A Caterpillar Company
- faurecia
- GE
- Hendrickson – The World Rides On Us
- Brayton Energy LLC
- Eaton
- Whirlpool Corporation
- United Technologies Research Center
- Arnold Magnetic Technologies
- PRAXAIR
- Piedmont Propulsion Systems, LLC
- Honeywell
- aerovalve
- Radio Systems Corporation
- Tri D Design
- Planetary Systems Corporation
- Northrop Grumman
- Boeing

Working with Industry and AM Community to Develop Research Priorities in AM

FY15 Activities

MDF Roadmaps & Workshops

- Army Additive Manufacturing
- NASA AM Meeting
- EWI AM Consortium 2015
- Advanced Simulation for AM
- Neutron Characterization for AM
- Fuel Cell and Building Technologies for AM
- AM for Small Modular Hydropower, planned for August



OAK RIDGE National Laboratory

Working with ORNL’s MDF

Manufacturing Demonstration Facility

- **Identify opportunities aligned with ORNL’s MDF technology thrust areas**
- **Discuss ideas with MDF director**
- **Jointly pursue funding to support collaborative activity**

	Assess	Assist	Collaborate
Type of Agreement	User Agreement (Non Proprietary)	Work for Others Agreement (Proprietary)	Cooperative Research & Development Agreement
Length of Engagement	Up to 12 months	As defined by agreement	Longer-term basis of a year or more
Cost to Company	NO COST	Full cost recovery	Cost-share required
Intellectual Property Rights	Each party owns its own inventions. Jointly developed inventions will be jointly owned.	Companies own intellectual property made or created using corporate funds as a result of these engagements.	Companies own inventions they make during the collaboration and have an option to negotiate an exclusive license in a specific field of use to inventions made by ORNL.
Protection of Generated Information	Information generated is publicly available.	Companies paying for services with corporate funds can treat all generated data as their proprietary information.	Commercially valuable information generated under a CRADA may be protected for up to 5 years, depending on funding source.

Questions

Bill Peter, MDF
Deputy Director
865.241.8113
peterwh@ornl.gov

Today, ORNL is DOE's largest science and energy laboratory

- $1.5B budget
- Forefront scientific computing facilities
- $750M modernization investment
- Nation's largest materials research portfolio
- 3,200 research guests annually
- World's most intense neutron source
- 4,300 employees
- Nation's most diverse energy portfolio
- World-class research reactor
- Managing billion-dollar US ITER project