# Engineering Laboratory

## *NIST Measurement Science for Additive Manufacturing*

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NIST
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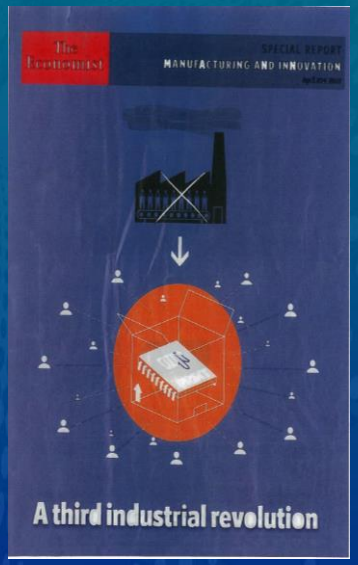
# Interest and Opportunities in Additive Manufacturing Continue to Grow

- Recent events and media visibility have generated much emphasis on AM, including attention at the highest levels of corporate management and the federal government
- Much synergy and momentum – the AM industry seems poised for growth, innovations, and advancements
- Examples:
  - Publicity in mainstream media
  - AM industry roadmaps
  - AM industry consortiums and collaborations
  - ASTM F42 and ISO TC261 standards committees
  - National Additive Manufacturing Innovation Institute (NAMII)
  - Federal emphasis on manufacturing

# Substantial Media Visibility!




The Economist, April 21, 2012


Technology Review, Jan/Feb 2012

"The Wow Factor of 3-D Printing," New York Times, Jan. 12, 2011


Manufacturing Engineering, April 2012

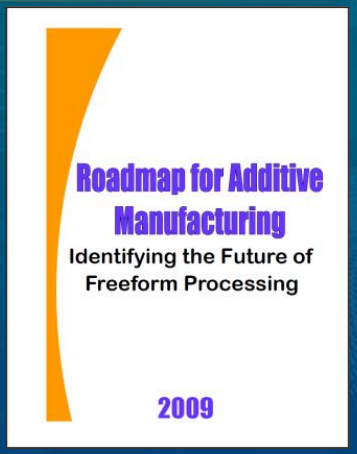

"The Future of America's Manufacturing Sector," Washington Post, March 6, 2012


The Economist, Feb 10, 2011


Atlantic Council, October 2011

NPR, Forbes, Motley Fool, BBC News, etc. – the list goes on!

# 2009 AM Industry Roadmap




- Roadmap Development Workshop sponsored by National Science Foundation (NSF) and Office of Naval Research (ONR)
- Expert participants from AM system vendors, industry users, technology suppliers, academia, government
- Focused on needs, priorities, and a research roadmap for AM over next 10-12 years
- Roadmap recommends several high-priority developments that are needed to advance the AM industry; grouped in the following categories:
  - Research
  - Education and Outreach
  - Development and Community
  - National Testbed Centers

# A Sampling of Recommended Developments Identified in the AM Industry Roadmap

- Process-structure-property relationships for each material and process
- Closed-loop and adaptive AM systems with feed-forward and feedback capabilities
- A much better understanding for the basic physics and chemistry of AM processes
- Conceptual design methods to aid designers in defining and exploring design spaces enabled by AM
- A new foundation for CAD systems that overcomes limitations in representing very complex geometries and multiple materials
- Sustainable (green) materials to reduce environmental impact, including recyclable, reusable, and biodegradable materials
- University courses and materials, and training programs for industry practitioners
- Development and adoption of robust standards for AM
- Establishment of a national testbed center to leverage equipment and serve as a highly visible showcase facility (or network of facilities)

# Barriers to Broad Adoption of AM

- Material Types and Properties
- Process Understanding and Performance
- Part Accuracy
- Surface Finish of Contoured Surfaces
- Fabrication Speed
- Build Volumes / Part Size
- Need for Qualification and Certification
- Lack of AM Standards
- Data Formats

# Additive Manufacturing Consortium (AMC)

Consortium Priority Needs*

- Property Database
- Quality Control
- Distortion Control
- Equipment Development
- Feedstock / Input Materials
- Design Rules
- Standards
- Process Modeling / Optimization
- AM Knowledge Base

* Focus: precompetitive technology development

# NIST Focus on Additive Manufacturing

- Major thrust within NIST Smart Manufacturing Processes and Equipment (SMPE) program
- Substantial EL expertise in manufacturing domains is being applied to AM
  - equipment and process metrology, process optimization and control, remote sensing, materials characterization, data formats, standards development, etc.
- Primary focus is metal-based AM processes
- Improved measurements and standards can help overcome existing AM limitations and barriers

# Unique Role of NIST Laboratory Research Programs - Measurements and Standards

- Emphasis on infrastructural metrology and non-proprietary, standardized metrology methods that address a broad class of measurement challenges
- Emphasis on rigorous and generic procedures to characterize measurement uncertainty that comply with international standards
- Long-term commitment, expertise, and neutrality essential for harmonized and unbiased national and international standards
- Leverage NIST core competences in measurement science, rigorous traceability, and development and use of standards -- as well as specific expertise in measurements and standards for manufacturing systems, processes, and equipment

# Primary Outputs of NIST Research Laboratories

- Measurement methods
- Performance test methods and metrics
- Documentary standards
- Standard reference data
- Standard reference materials
- Calibration services
- Technology transfer: technical publications, industry workshops, collaborations

# NIST Projects in Additive Manufacturing

Powder + Process = Part

# NIST Projects in Additive Manufacturing

Powder

Uncertainties in the Input Materials

+

Process

Uncertainties in Equipment and Process Performance

=

Part

Uncertainties in the Final Parts

# NIST Projects in Additive Manufacturing

Powder

Uncertainties in the Input Materials

+

Process

Uncertainties in Equipment and Process Performance

=

Part

Uncertainties in the Final Parts

1. Fundamental  Measurement Science for Additive Processes
2. Materials Standards for Additive Manufacturing

# Technical Focus for NIST Projects

## Fundamental Measurement Science for Additive Processes

- *Technical Focus:*
  - Standard test methods to evaluate and improve AM equipment performance
  - Standard test methods to evaluate fundamental process characteristics
  - Standard test artifacts to determine the accuracy and capabilities of AM processes
  - Physics-based modeling of AM processes and material transformation
  - *In-situ* measurements of AM parts

## Materials Standards for Additive Manufacturing

- *Technical Focus:*
  - Standard test methods for metal powder characterization
  - Standard test methods to obtain material properties of AM parts
  - Test protocols, procedures, and analysis methods for industry round robin testing of AM materials for consensus material property data

# In-house Metal-Based AM Research Platform

**EOS M270 System**

- Direct Metal Laser Sintering (DMLS)
- Standard STL data input from 3D CAD model
- Build volume: 250 mm x 250 mm x 215 mm
- Metal powders: stainless steel, titanium, aluminum, Inconel, cobalt-chrome
- Powder size: 5 micron to 60 micron, with 30 micron median (for stainless steel)
- Layer thickness: 20 micron (for stainless steel)
- Laser : Yb-fiber, 200 W, 1060 – 1100 nm wavelength
- Safety interlocks: Class 1 laser while in operation
- Built-in oxygen sensors and warning system
- Dual-mode: nitrogen or argon environments


Plus:
- ZCorp 3D printer
- MakerBot
- ExOne M-Lab (future)

# ASTM Standards Committee F42

- Established in January 2009 to address high-priority needs for standards in Additive Manufacturing Technologies
- Initiated with Society of Manufacturing Engineers (SME), Rapid Technologies & Additive Manufacturing community
- F42 subcommittees formed for :
  - *Terminology*
  - *Test Methods*
  - *Processes and Materials*
  - *Design (including data formats)*


- Many candidate standards identified; multiple standards developed in parallel; rapid pace; much AM system user and vendor support
- Formal agreement with ISO TC261 committee on Additive Manufacturing

# NIST Role in ASTM F42 Standards Development

- Substantial NIST technical presence and contributions to ASTM F42
  - Test Methods, U.S. TAG, Terminology, ballot comments
- Leadership of task groups
- Developed and presented “Future Vision of AM Standards” at January 2012 meeting
  - Strategic approach and vision; focused on maximizing impact of F42 standards
- NIST now member of F42 Executive Committee, and tasked to lead the strategic planning for F42

# Strategic Approach for Development of AM Standards

- Needed to establish the overall structure and give guidance to the task teams, helping with planning and prioritization
  - Where do we want to be in 5 years? What standards are needed to get there? What steps can be taken now to maximize future impact?
- Will maximize the impact of the standards by:
  - Preventing overlap and contradiction among F42 standards
  - Ensuring that future F42 standards work together as an integrated and cohesive set
  - Improving usability and acceptance for future users of all types

# Proposed General Structure

## Fundamental AM Standards

- Terminology
- Certification
- Test Artifacts
- Test Methods for Raw Materials
- Test Methods for System Performance
- Data Formats
- Qualification
- Procurement Requirements for AM Parts
- etc.

**Candidate Top-Level Standards**

- General concepts
- Common requirements

### Raw Materials

- Metal Powders—Part 1: Size, Part 2: Morphology, Part 3: viscosity, etc.
  - Spherical Powders
  - Disk-Shaped Powders
  - etc.
- Polymer Powders—Part 1, Part2, etc.
- Photopolymer Resin—Part 1, Part 2, etc.
- etc.

### Process / Equipment

- Process-Specific Performance Test Methods
  - Process Category
- Process-Specific Test Artifacts
  - Process Category
- System Component Test Methods
  - System Components by Process Category
- etc.

### Finished Parts

- Material Test Methods—Part 1: Tension Testing, Part 2: Porosity Testing, Part 3: Fracture Toughness, etc.
  - Metals
  - Polymers
  - Others
- Material Specifications—Part 1: Powder Bed Fusion, Part 2: Photopolymer Vat, Part 3: Binder Jetting, etc.
  - Specific Materials by Process Category
- etc.

**Specialized AM Standards**

- Specific to process or technology

# NIST Roadmapping Workshop: Measurement Science for Metal-Based Additive Manufacturing

- Held at NIST on December 4-5, 2012, with 88 AM experts
- Workshop objectives:
  1. Build on prior AM roadmaps
     - In-depth coverage of measurement science barriers, challenges, and gaps that prevent the broad use of metal-based AM
     - Create actionable plans: what's needed and how to get there
  2. Provide direction and input to ASTM F42 strategic planning
  3. Influence and coordinate with NAMII development of national AM roadmap
- Plenary Talks, Industry Panel, Moderated Break-Out Groups

  AM Materials, AM Processes and Equipment, AM Modeling and Simulation, Qualification and Certification of AM Materials, Processes, and Products

http://events.energetics.com/NIST-AdditiveMfgWorkshop/index.html

# Workshop Results

- Workshop Final Report and AM Measurement Science Roadmap
  - Summary of results, including recommendations, presentation slides, white papers, break-out group results, etc.
  - Actionable plan: beyond a list of research needs
  - Addresses one slice of overall AM roadmap
  - To be integrated with NAMII national AM roadmap
- Foundation for ASTM F42 Strategic Plan
- Establish consensus needs and priorities, and influence the national research agenda for metal-based additive manufacturing

# Substantial NIST Interactions with Stakeholders

- Additive Manufacturing Consortium (AMC)
- National Additive Manufacturing Innovation Institute (NAMII)
- Interagency Working Group on AM (OSTP, NASA, Army, Navy, Air Force, DOE, NIST)
- Federal agencies: DARPA, AFRL, ARL, NRL, NSF, NASA, DOE, LLNL, ORNL, FBI, CRS
- Industry: Morris Technologies (OH), GE Aviation and GE Global Research, Pratt & Whitney, Carpenter Powder, ExOne, others
- Universities: Univ. of Louisville, CMU, Virginia Tech, NCSU
- Events: ASTM F42, SME RAPID, SFF Symposium, JDMTP Metals AM Roadmap Workshop

# National Additive Manufacturing Innovation Institute (NAMII)

- Public-private partnership launched in August 2012 to accelerate AM innovation – bridges the critical gap between basic research and widespread industry use
- Managed and operated by NCDMM, the National Center for Defense Manufacturing and Machining
- 30-month federal award: DOD, DOE, NASA, NSF, NIST
- Substantial cost-share by 70+ members: industry users, AM vendors, universities
- Technology Development, Technology Transition, Advanced Manufacturing Enterprise, Workforce / Educational Outreach
- NAMII Innovation Hub located in Youngstown, OH
- First project call in December; project kick-off is imminent

# Partnering with NIST

- NIST partners with industrial consortia, individual companies, other government agencies, and universities
- The NIST stake in partnerships tends to focus on issues that can benefit industry sectors in a broad sense
  - typically relating to measurements and standards
- Several mechanisms available:
  - e.g., cooperative agreements, contracts, MOUs, guest researchers, letters of agreement, grants, sabbaticals

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