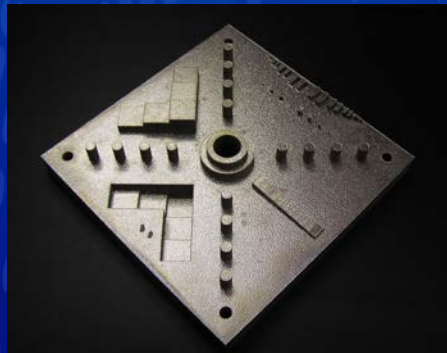
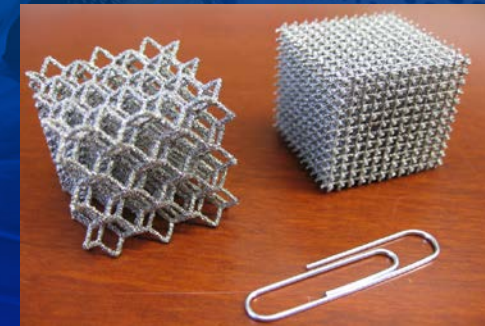
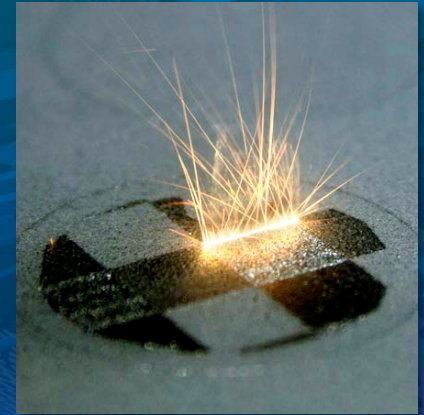
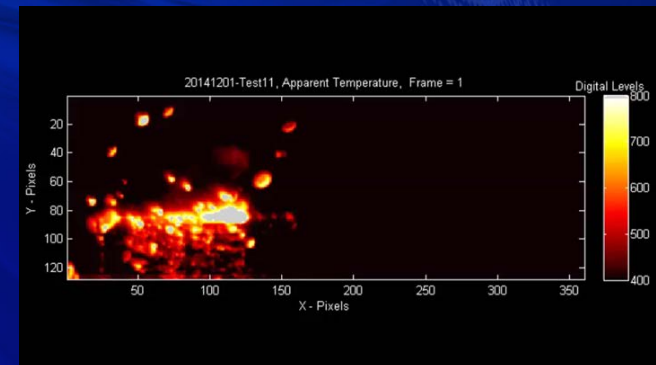




# NIST Perspective on Additive Manufacturing Standards



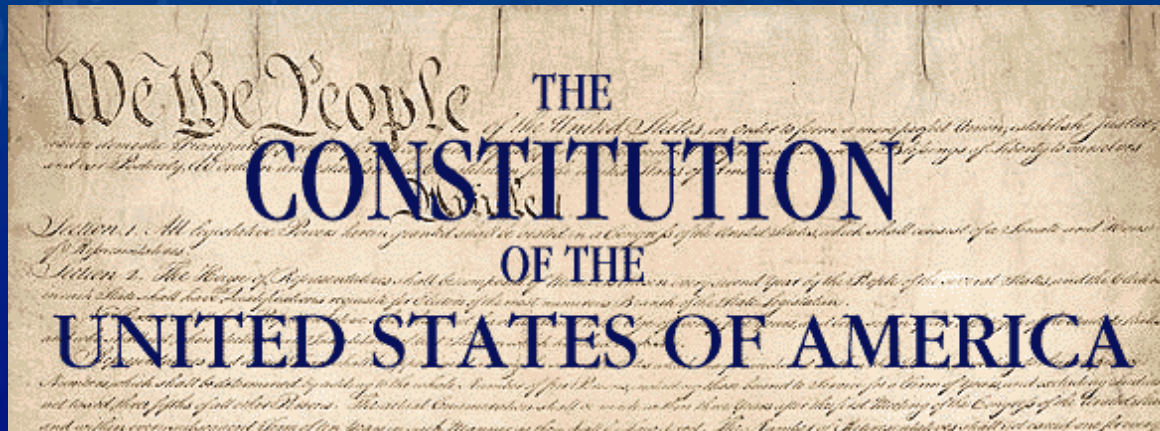
Shawn Moylan  
Intelligent Systems Division  
Engineering Laboratory  
National Institute of Standards  
and Technology  
U.S. Department of Commerce



# The History of Standards in the U.S.

“Uniformity in the currency, weights, and measures of the United States is an object of great importance, and will, I am persuaded, be duly attended to.”

*George Washington, State of the Union Address, 1790*



**Article I, Section 8:** “The Congress shall have the power to...*fix the standard of weights and measures*”

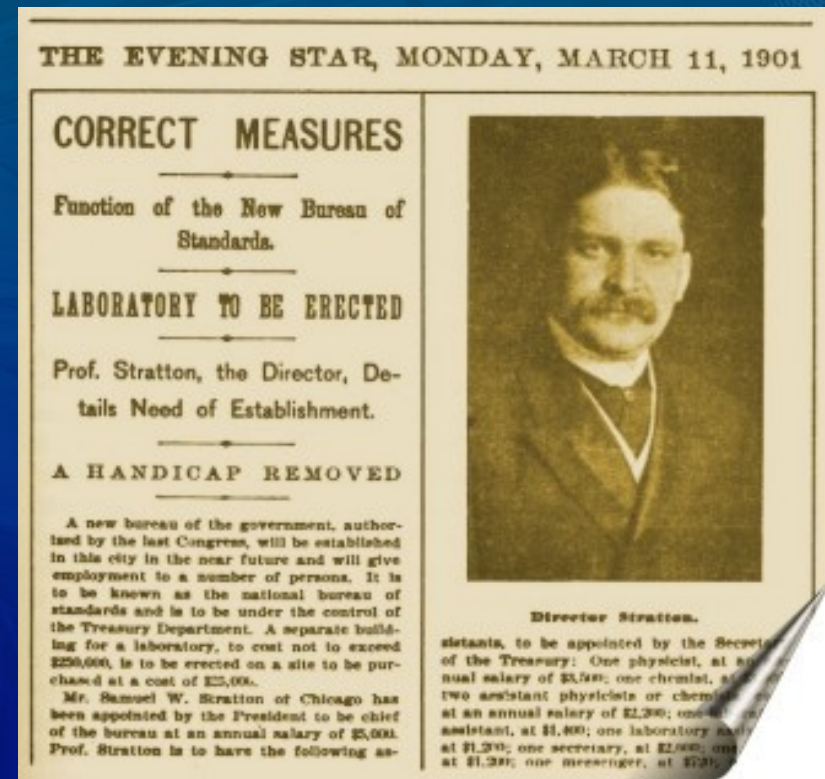


# Founding Charge of the National Bureau of Standards (1900)

“It is therefore the unanimous opinion of your committee that no more essential aid could be given to

- manufacturing
- commerce
- the makers of scientific apparatus
- the scientific work of Government
- schools, colleges, and universities

than by the establishment of the institution proposed in this bill.”



*House Committee on Coinage, Weights and Measures, May 3, 1900, on the establishment of the **National Bureau of Standards (now NIST)***



# Unique Role of NIST Research Laboratories

- 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

## ➤ **Measurements and Standards**

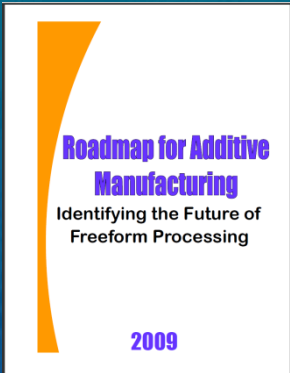


# Primary Outputs of NIST Research Laboratories

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



# Additive Manufacturing Needs and Priorities



**2009 AM Industry Roadmap**

**America Makes / National Additive Manufacturing Innovation Institute**

Public-Private Partnership  
National AM Roadmap

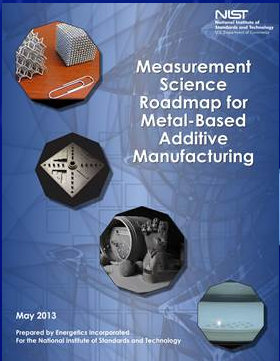
**Additive Manufacturing Consortium (AMC)**

**AM Needs and Priorities**

**AM Standards Committees: ASTM F42, ISO TC261, ASME Y14.46, SAE AMSAM**

Standards Development

Precompetitive Technology Development



**NIST Workshop: Measurement Science for Metal-Based AM**

**Substantial Collaborations and Stakeholder Interactions**

Joint research, site visits, events, etc.

Needs, Priorities, and Action Plans (Dec. 2012)



# Barriers that Prevent Broad Adoption of Metals-Based Additive Manufacturing

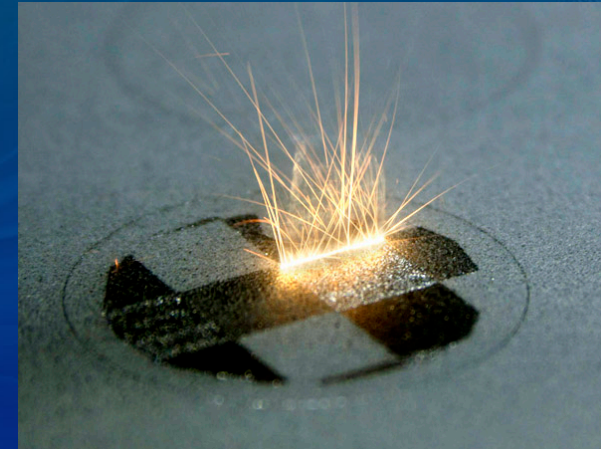
- Limited **material types** and unknown / non-uniform properties
- Lack of **process repeatability** and inconsistent system performance
- Consensus protocols and test data for **qualification and certification** do not exist
- Insufficient **part accuracy** without significant post-processing
- Insufficient **surface finish** (e.g., for contoured surfaces)
- Current **AM data formats** define approximated geometry
- Lack of **AM standards** (materials, process, machine, quality)
- Need for improved **non-destructive evaluation** methods for complex defects and part geometry
- Requirements for **post-processing** (e.g., heat treatment, surface treatment, support removal, finish machining)
- Lack of AM-specific **design tools / design guidelines**
- **Fabrication speed** too slow / **costs** too expensive
- Build volumes / **part size** too small



# NIST-EL Measurement Science for Additive Manufacturing (AM)

Four research thrusts:

- Characterization of Additive Manufacturing Materials
- Real-Time Control of Additive Manufacturing Processes
- Qualification of Additive Manufacturing Materials, Processes, & Parts
- Additive Manufacturing Systems Integration



**Program focuses on metals-based AM**

One of Four Programs in the NIST Engineering Laboratory Advancing Essential Measurement Science and Standards for Smart Manufacturing





# NIST-Wide Contributions to AM

- **Engineering Laboratory:** Measurement Science for Additive Manufacturing program
- **Material Measurement Laboratory:** AM material property measurement, material testing and modeling, defect detection
- **NIST Center for Neutron Research:** neutron imaging, AM residual stress measurement
- **Information Technology Laboratory:** statistical analysis of AM round robin test results; AM cybersecurity and IP protection
- **Physical Measurement Laboratory:** thermal emissivity of powders and melts; laser power measurement; X-ray CT
- **Manufacturing Extension Partnership:** industry outreach and assistance provided by innovation centers in every state
- **Advanced Manufacturing National Program Office:** Measurement Science for Advanced Manufacturing Awards



# Role of Additive Manufacturing Standards

- Standards can be used for (among others):
  - specifying requirements
  - communicating guidance
  - documenting best practices
  - defining test methods and protocols
  - documenting technical data
  - accelerating the adoption of new technologies
- Certifying bodies typically reference publicly available standards in their procedures
- Standards development in the U.S. is conducted through voluntary participation and consensus
- Companies and agencies must participate to impact the priorities and content of standards



# NIST Measurement Science Contributes to New AM Standards

- Identify needs and priorities through workshops and industry meetings
- Coordination, facilitation, and communication roles
- Develop technical basis for standards through measurement science research
  - Draft content and starting point for standards development
  - Provide unbiased technical expertise
  - Assist in validation testing of proposed standard test methods
- Providing significant technical contributions and leadership in several AM standards committees in various SDOs
  - ASTM F42, ISO TC261, ASME Y14.46



# Current Challenges in AM Standards Landscape

- Rapidly growing list of organizations working/planning to develop AM standards
  - Scopes of SDOs have evolved
- High risk of **duplication of efforts** and overlapping content
- Potential for **inconsistencies** (or even contradictions)
- **Conflicting standards** create ambiguity and confusion



# Many Examples of Difficult, Time Consuming Standards Harmonization

- ASTM/ISO harmonization of terminology standard
- Roller coaster industry
- Wireless sensor networks, etc.
- International and U.S. machine tool standards
  - Existed in parallel for many years
  - Increased costs for U.S. industry
    - Sellers had limited market penetration due to conformance to multiple standards
    - Higher costs to buyers due to unique requirements (added tests) of multiple standards
  - Complete harmonization took about 20 years

**The AM Industry has the opportunity to avoid this challenge**



# Vision for AM Standards

- **Integrated and cohesive set of AM Standards** – to be used all over the world
  - Consistent, non-contradictory, non-overlapping
- Common roadmap and organizational structure for AM standards
- Use and build upon existing standards, modified for AM when necessary
- Standards committees work together and follow a common standards development plan
- Resulting standards are usable and acceptable for future users of all types (novice and expert)



# Structure of AM Standards

## General AM Standards

### Terminology

- ASTM F2792-12a
- ISO 17296-1
- ISO/ASTM 52921-13

### Processes / Materials

- ISO 17296-2
- Qualification and Certification Methods
- Requirements for Purchased AM Parts
- Non-Destructive Evaluation Methods

### Test Methods

- ISO 17296-3
- Test Artifacts
- General Test Methods
- Performance Test Methods

### Design / Data Formats

- ISO 17296-4
- ISO/ASTM 52915-13
- Data Structures and Metrics for AM Models

## General Top-Level AM Standards

- General concepts
- Common requirements
- Generally applicable

## Feedstock Materials

## Process / Equipment

## Finished Parts

### Material Category-Specific

- Metal Powders
- Polymer Powders
- Photopolymer Resins
- Ceramics
- etc.

### Process Category-Specific

- Powder Bed Fusion
- Material Extrusion
- Binder Jetting
- Directed Energy Deposition
- etc.

### Standard Protocols for Round Robin Testing

Mechanical Test Methods – e.g., Part 1: Tensile Tests, Part 2: Porosity Tests, Part 3: Fracture Toughness, etc.

- Metals
- Polymers
- Others

### Part Specifications

etc.

## Category AM Standards

- Specific to material or process category

### Material-Specific Standards

- Material-Specific Size Specification
- Material-Specific Chemical Composition
- Material-Specific Viscosity Specification
- etc.

### Process-Specific Standards

- Process-Specific Performance Test Methods
- Process-Specific Test Artifacts
- System Component Test Methods
- etc.

### Application-Specific Standards

- Aerospace
- Medical
- Automotive
- etc.

## Specialized AM Standards

- Specific to material, process, or application

# Draft Revision: AM Standards Structure

## General Top-Level AM Standards

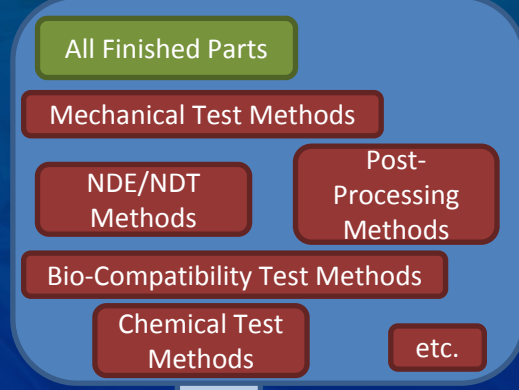
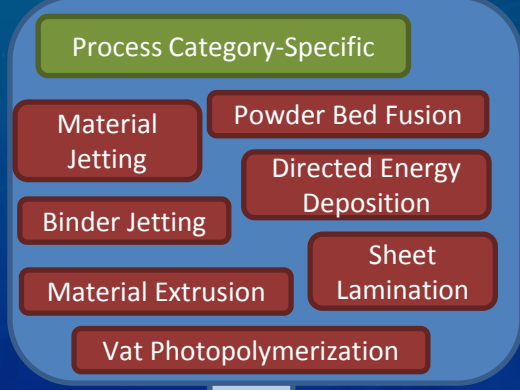
- General concepts
- Common requirements
- Generally applicable



## Feedstock Materials

## Process / Equipment

## Finished Parts



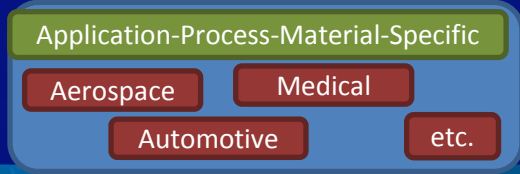
## Category AM Standards

- Specific to material category or process category



## Specialized AM Standards

- Specific to material, process, or application





# Recommendations for “Way Forward”

- Each committee needs a **clearly defined scope** statement
- Use of **common terminology** is essential
- Standards developed by each group should use the **structure diagram** and indicate where each document is intended to fit in
- **Formal agreements** between organizations might be necessary



# Recommendations for “Way Forward”

- **Liaisons** between committees are the key approach for communication, coordination, and collaboration
  - Organizational liaisons: At least at highest levels (committee chairs and administrators) to allow **knowledge of procedures, activities, and strategies**
  - Technical liaisons: Should have voting rights and ability to make technical and editorial comments on all proposed standards
  - Significant cross pollination of all committees at all levels is preferred
  - It is not enough to merely know what standards have been passed by an organization; must know active and planned work items as well
- **Joint planning/working sessions** need to be held at regular intervals



# Summary

- NIST has been involved in developing AM standards from the start
- NIST will continue to support AM standards development through its measurement science research
- Priorities:
  - High quality, technically accurate standards
  - Usable and high impact standards
  - Integrated and cohesive set of standards: consistent, non-contradictory, non-overlapping
  - No duplication of effort
- Several recommendations provided to enhance communication, coordination, and collaboration among AM users, standards bodies, and regulatory agencies



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