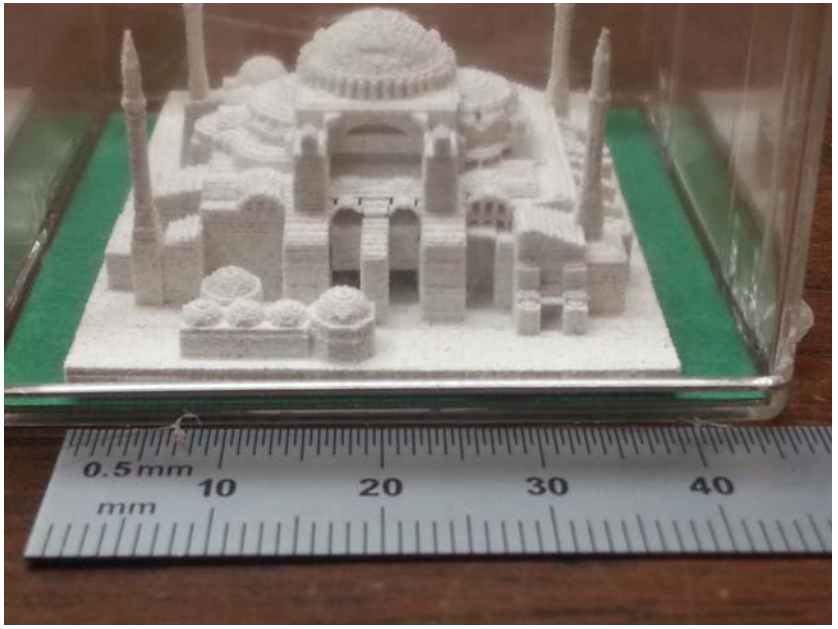
America Makes

Driven by… NCDMM NATIONAL CENTER FOR DEFENSE MANUFACTURING AND MACHINING

Accelerating the Adoption and Insertion of Additive Manufacturing through Collaboration

NSF Workshop: Additive Manufacturing for Health
Arlington, Virginia
March 17-18, 2016

Ralph Resnick
NCDMM Pres & Exec Director
America Makes Founding Director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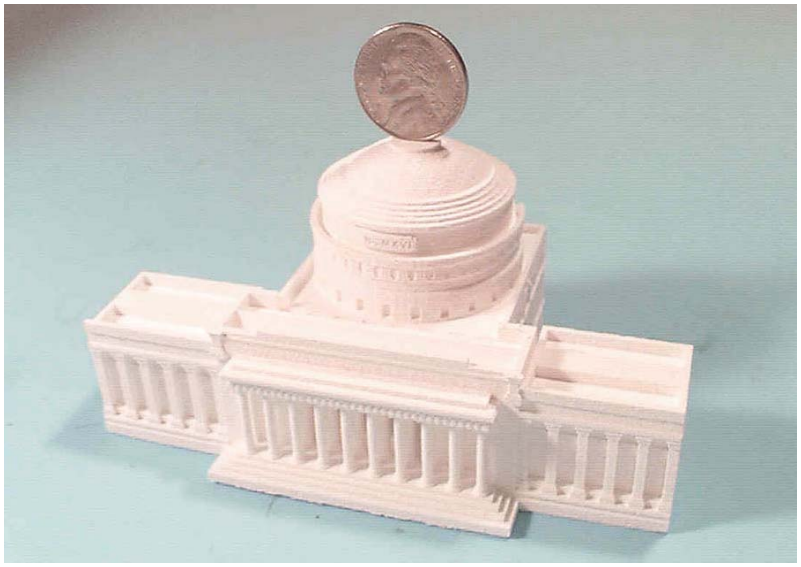
Three Dimensional Printing©

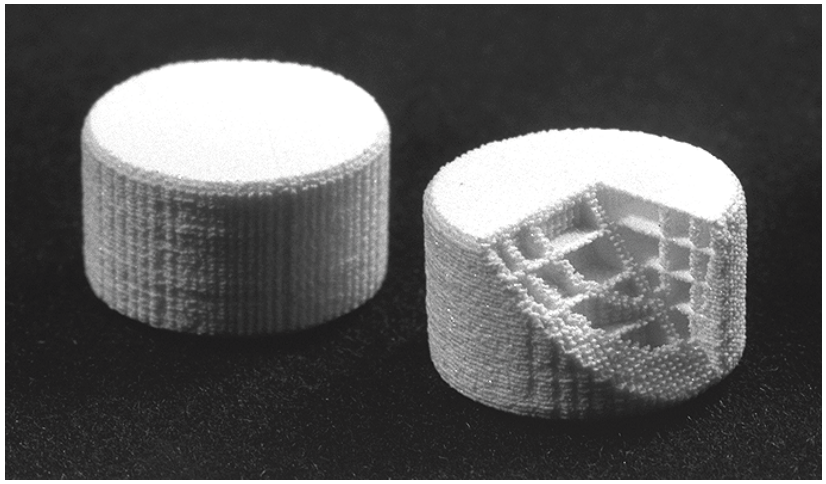
Emanuel Sachs
Professor of Mechanical Engineering
sachs@mit.edu



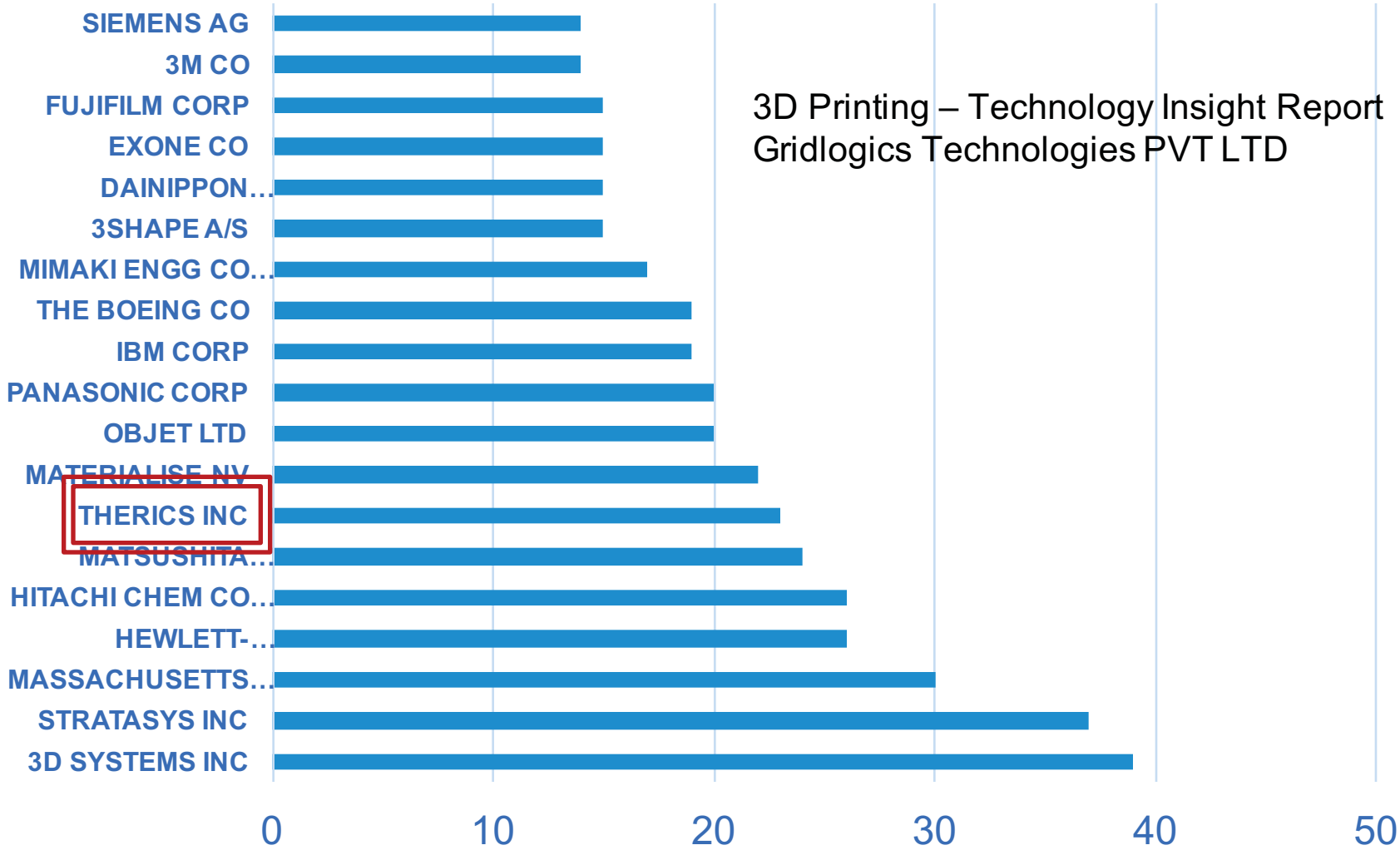
Medical Applications;

Therics, Inc. Princeton, NJ

- Chronopharmacological drug delivery systems.
- Scaffolds for tissue engineering.
- Direct printing of tissue and organs.
- Direct printing of metallic prostheses.



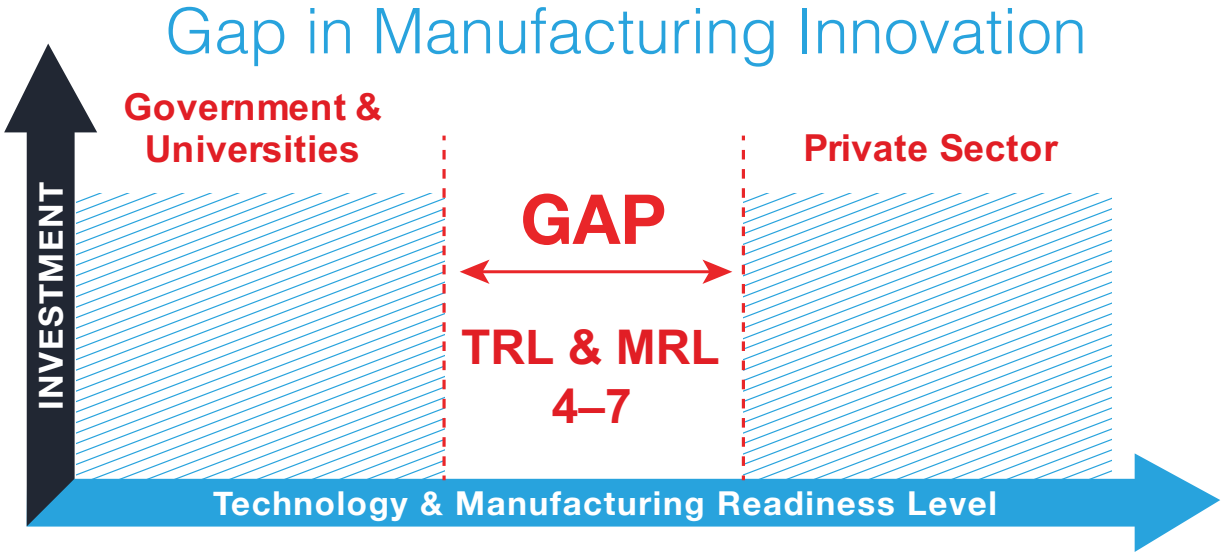
3D Printing Patent Activity 1990 - 2013



3D Printing – Technology Insight Report
Gridlogics Technologies PVT LTD

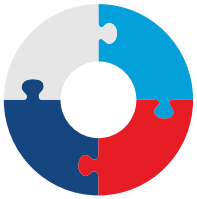
NNMI Purpose

Our main goal is to "Bridge the Gap"
and address Technology & Manufacturing Readiness Levels (TRL & MRL) 4-7 enabling technology transition and commercialization through funding innovation projects.



Why NNMI, Why America Makes?

The foundation is laid – in March 2012, the formation of a National Network for Manufacturing Innovation (NNMI) was proposed and America Makes (National Additive Manufacturing Innovation Institute) was launched in August as the initial Institute of Manufacturing Innovation (IMI).



The vision is simple – leverage our nation's brilliant technical minds **in all corners** of government, industry and academia to **accelerate the adoption** of additive manufacturing technologies in the U.S. manufacturing sector and increase domestic manufacturing competitiveness.

The goal is bold – create truly **collaborative** environments to bring technology advancements from the lab to the factory floor, create jobs, produce more competitive products, and ultimately **reaffirm** our place in the global market.

America Makes – Who We Are

Public / Private Partnership

America Makes has substantial federal, private industry, and academic investment.

Multi-Agency Collaboration

Partnership between industry, government and universities, led by the Defense-wide Manufacturing S&T team.

Membership

Innovation facility in Youngstown, Ohio with over 160 members. We continue to grow.

NCDMM
NATIONAL CENTER FOR DEFENSE MANUFACTURING AND MACHINING

Operations

We are operated by the National Center for Defense Manufacturing & Machining (NCDMM)

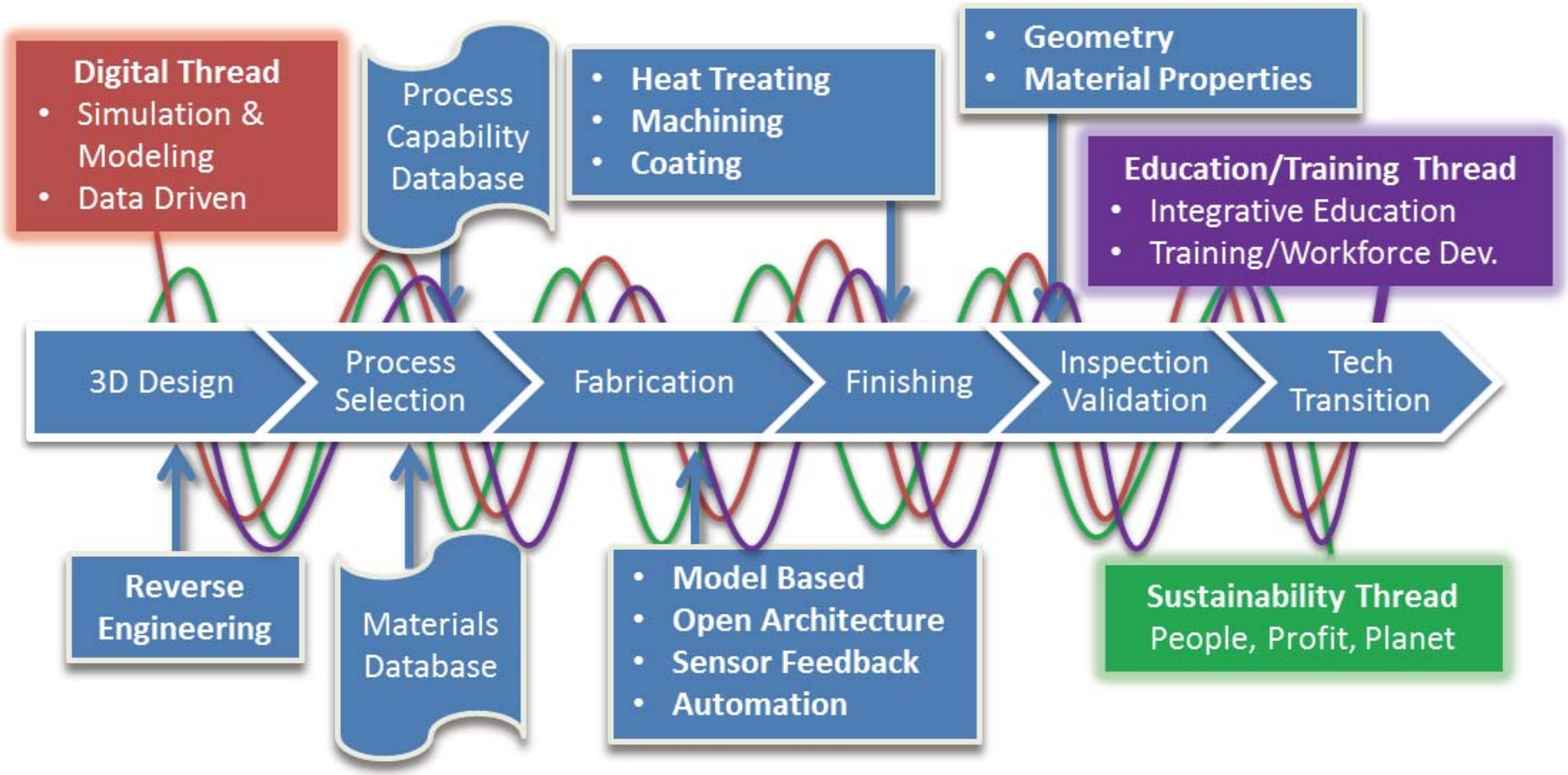
How We Approach Innovation

Project Funding – We competitively award projects to members using public and private funds, addressing prioritized topics on our member-driven technology roadmap.

Our Vast Network – We act as a connector and facilitator between all of our members. Everyone has a seat at the table to contribute and collaborate with us and one another.

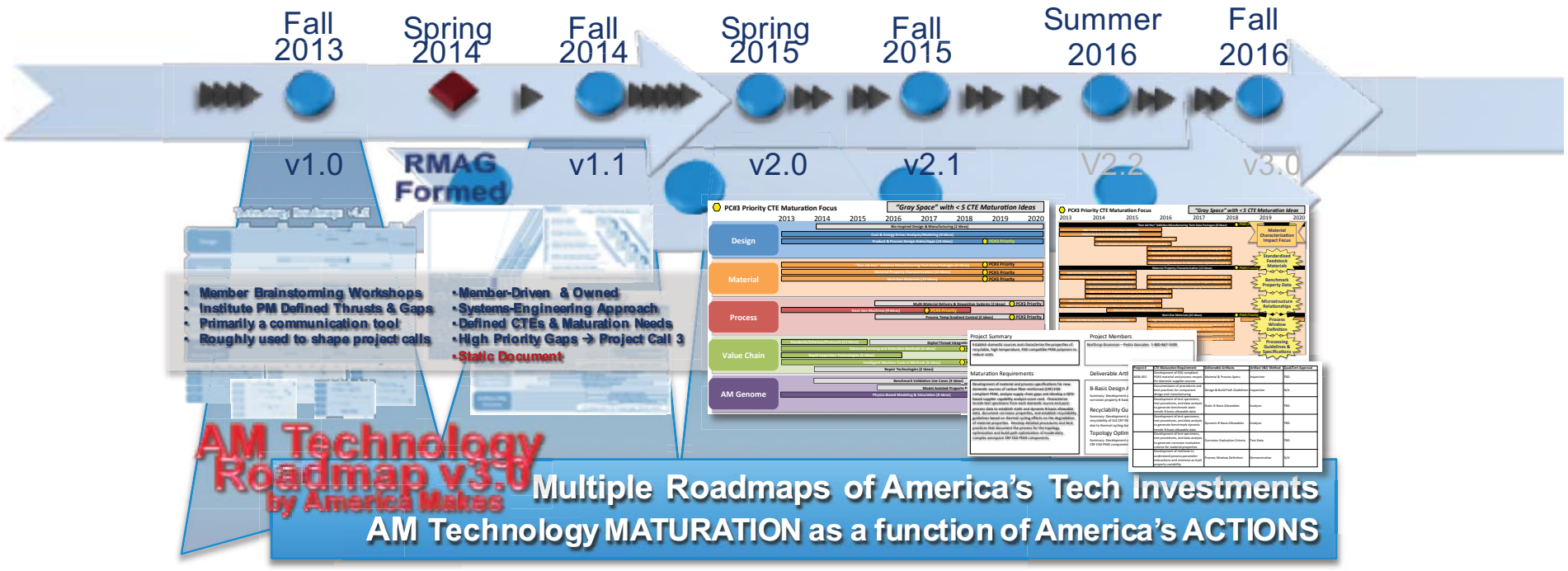
Workforce Readiness – Training and educational outreach is a priority for the institute. Every Public/private funded project requires an educational outreach component.

Technology Transition – We make it real. Every public/private funded project requires a pilot transition component.



- Process development: metals, polymers, ceramics, electronics, tissue
- Digital thread / AME
- Specialized, portable AM systems
- Open Architecture
- Process planning
- Process Control
- Material Development
- Component Design

Dynamic, Functional, Living Roadmap

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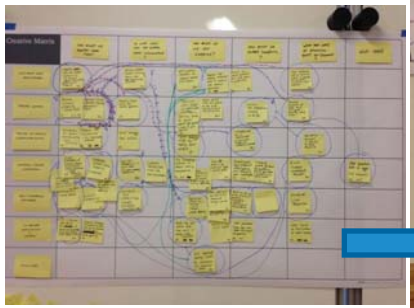
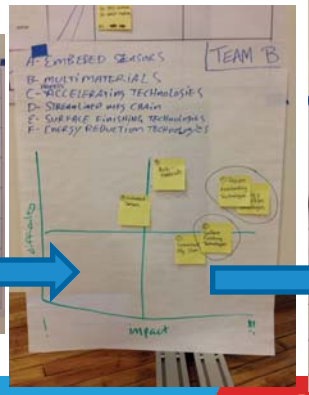
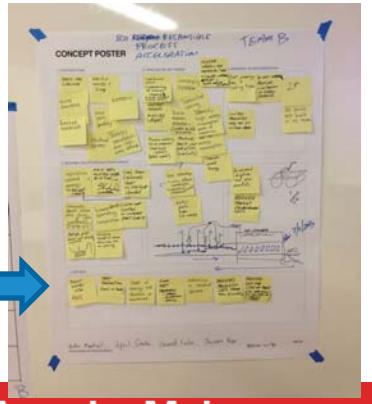
Technology Roadmap Workshop: Next-Gen 3DP Metal Alloys
From November 18, 2014 12:00 pm until November 18, 2014 5:00 pm
America Makes
This workshop will focus on defining roadmap CTE maturation requirements for next-gen 3D-printed metal alloys and the prioritization of material development needs by industry segment. This focus area may include, but is not limited to, alloy families such as Cobalt-based, Ti6V4, H13 Tool Steel, Inconel 625, 7075-F Al, 17-4PH Stainless, etc. as well as next-gen materials such as printed shape memory alloys, bio-degradable and bio-compatible implant materials, intermetallics, and 3DP tailored materials.
The objective of this workshop will be to identify targeted high priority next-gen materials for future project calls and critical enabling multi-material delivery and deposition system technologies for each material family focus area. Additional

Technology Roadmap: Workshop Participation

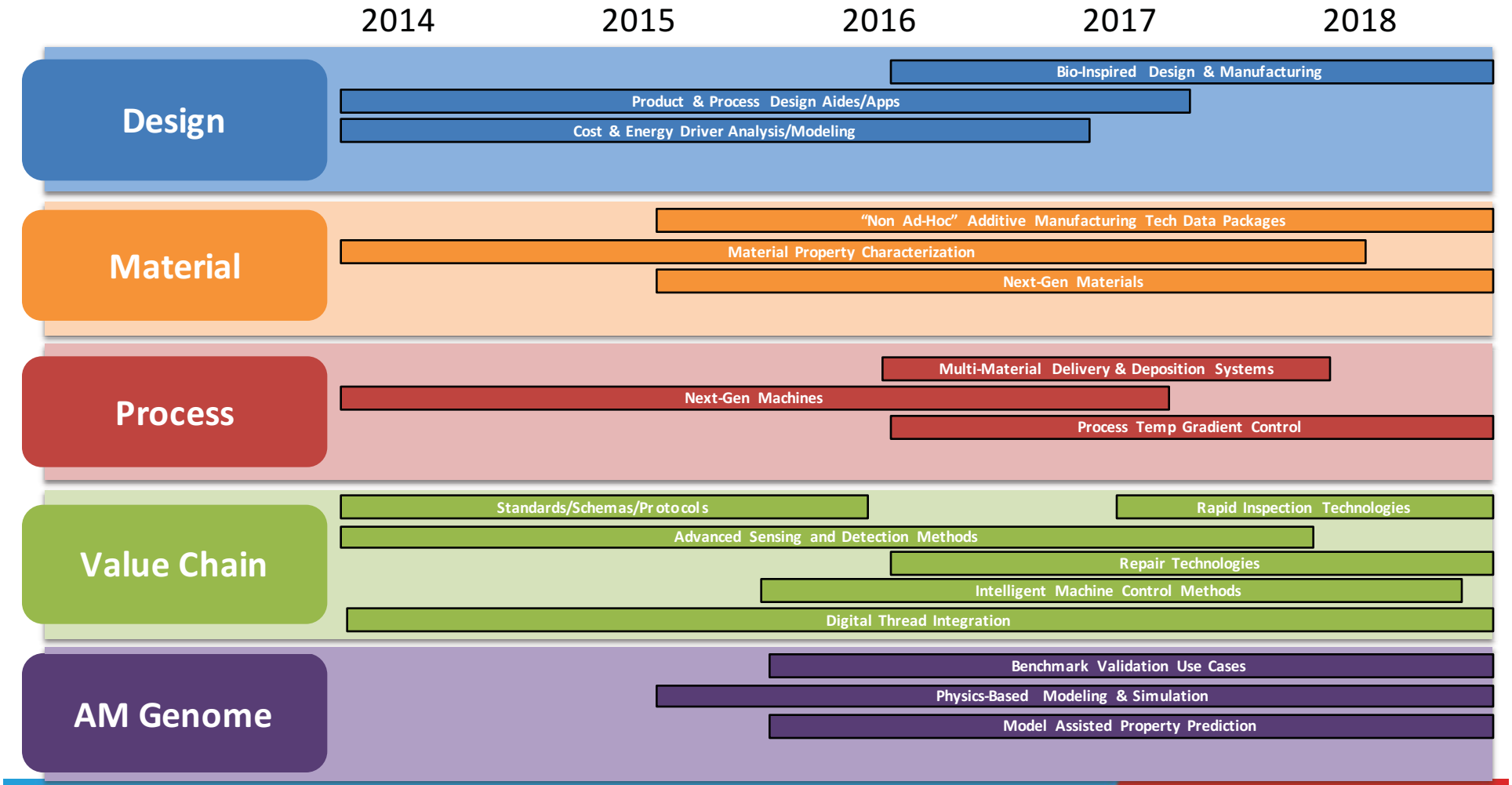






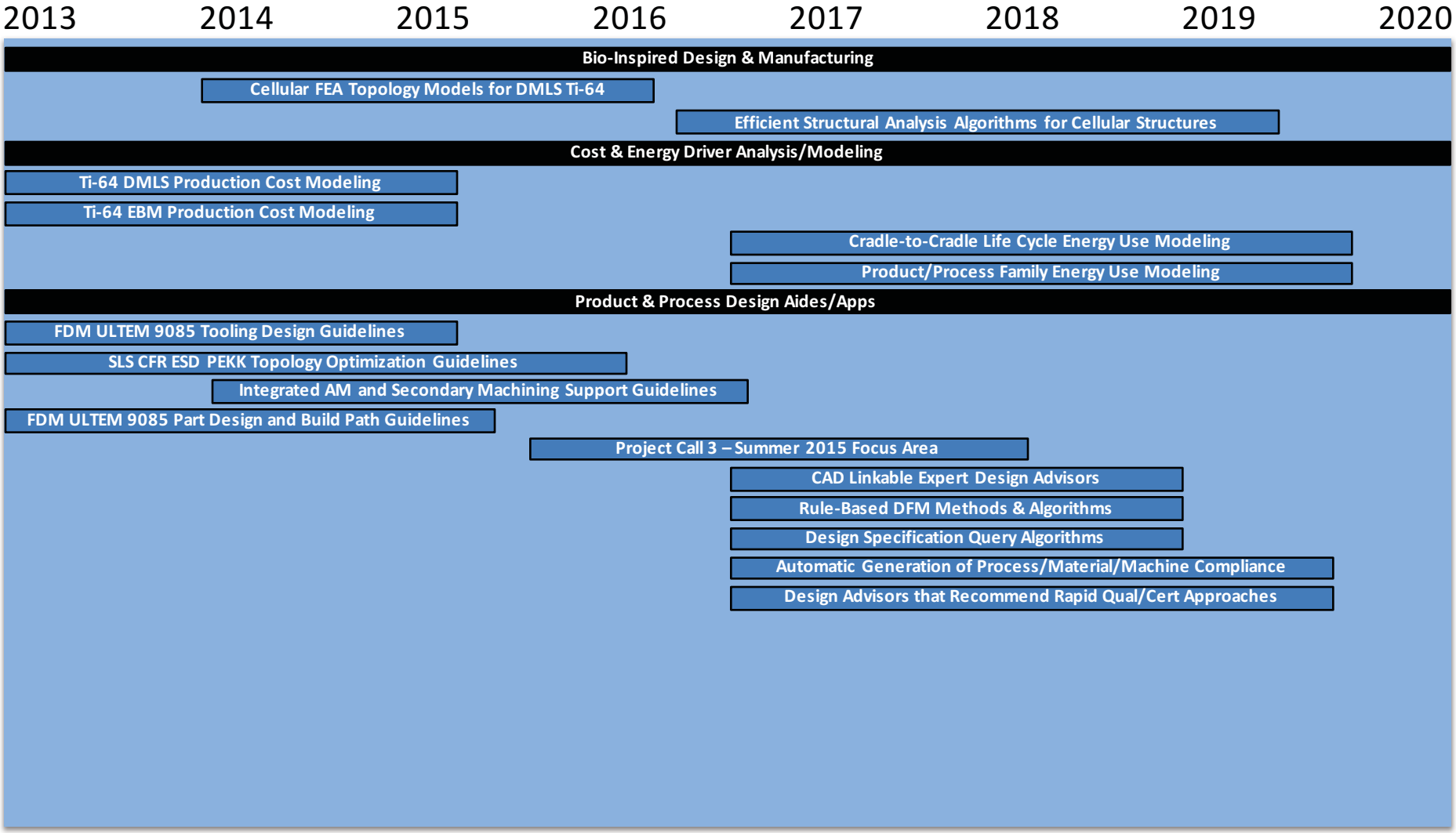
Swim Lane	CRITICAL TECHNOLOGY ELEMENT	Impact Focus
Design	Bio-Inspired Design & Manufacturing	Complexity Exploitation, 3D Graded Materials, Multi-Material Integration, Model-Based Development, Product Customization
	Cost & Energy Driver Analysis/Modeling	
	Product & Process Design Aides/Apps	
Material	Additive Mfg Tech Data Packages	Standard Feedstock Materials, Benchmark Property Data, Microstructure Relationships, Process Window Definition, Processing Guidelines & Specifications
	Material Property Characterization	
	Next-Gen Materials	
Process	Multi-Material Delivery & Deposition	Faster Build Speeds, Improved Surface Quality, Larger Part Envelopes, Improved Detail Capability
	Next-Gen Machines	
	Process Temperature Gradient Control	
Value Chain	Advanced Sensing & Detection Methods	Material Costs, Processing Costs, Quality Control Costs, Productivity Costs, Energy Efficiency Costs
	Intelligent Machine Control Methods	
	Digital Thread Integration	
	Rapid Inspection Technologies	
	Repair Technologies	
	Standards/Schemas/Protocols	
AM Genome	Benchmark Validation Use Cases	Concurrent Methods, Computational Tools, Experimental Tools, Modular Open Simulations, Open Multi-Scale Data
	Model-Assisted Property Prediction	
	Physics-Based Modeling & Simulation	

America Makes Technology Roadmap – Level 1



America Makes Technology Roadmap Level 2

DESIGN Level 2 Maturation Needs



America Makes Projects

- **71 Projects, ~$73M P/P funds engaging more than 120 partners**
  - Each project must have at least 50/50 cost share (partners buying in)
  - Each project contributes to a capability gap or opportunity shown in the roadmap
  - Workforce development or educational outreach deliverables
  - Address sustainability from an energy perspective
  - Must have industry members on their team, government technical advisors
  - All project results are shared amongst members
  - Many are producing design rules and guides, workforce training materials, such as curricula and certifications and disseminating detailed M&P data
  - Many with partners at major organizations such as ASTM
  - Many have military/aerospace applicability

Example of Funded Project

Topology Optimization Tools to Enable Efficient Design of Additively Manufactured Cellular Structures

Designing and building lightweight strength where it is needed the most

Total project value: ~ $500K Public; $526 Private
Project team: University of Pittsburgh, ANSYS, ALCOA, GE, ExOne, UTRC, Material Sciences
Timeline: April 2014 – November 2015

CTE – Bio Inspired Design

1. **Develop experimentally-validated micromechanical models for different cellular structures**
2. **Develop topology optimization and reconstruction algorithms**
3. **Demonstrate and validate capabilities of models and algorithms on realistic structural polymer and metal components**

Tech Transfer – Implement into ANSYS commercial FEA package

U.S. Additive Manufacturing Cultural Issues/Roadblocks & America Makes Role

- Multiple, Uncoordinated Roadmaps
  - DoD (Navy, Army, Air Force, DLA, MDA, DARPA, SOCOM, PEOs/Programs)
  - DoE (HQ & Labs)
  - NASA (HQ & Centers)
  - Individual U.S. Companies
- Duplicative/Redundant R&D, especially for Materials Properties
- Funding for Required Technology & Process Development as a Pre-cursor to Funding Transition to Products (Industry, Government, or Shared Responsibility?)

America Makes Role

- America Makes member-driven roadmap in-place and being expanded & updated
- Pursuing development of an integrated DoD Additive Manufacturing Roadmap with the Joint Defense Manufacturing Technology Panel (JDMTP)
- Discussions initiated to develop integrated AM Roadmaps for DoE & NASA

GOAL: *An integrated "American Additive Manufacturing Roadmap" and Coordinated, Collaborative National R&D Investments*

Workforce & Education Outreach Roadmap

EDUCATION RECOMMENDATIONS

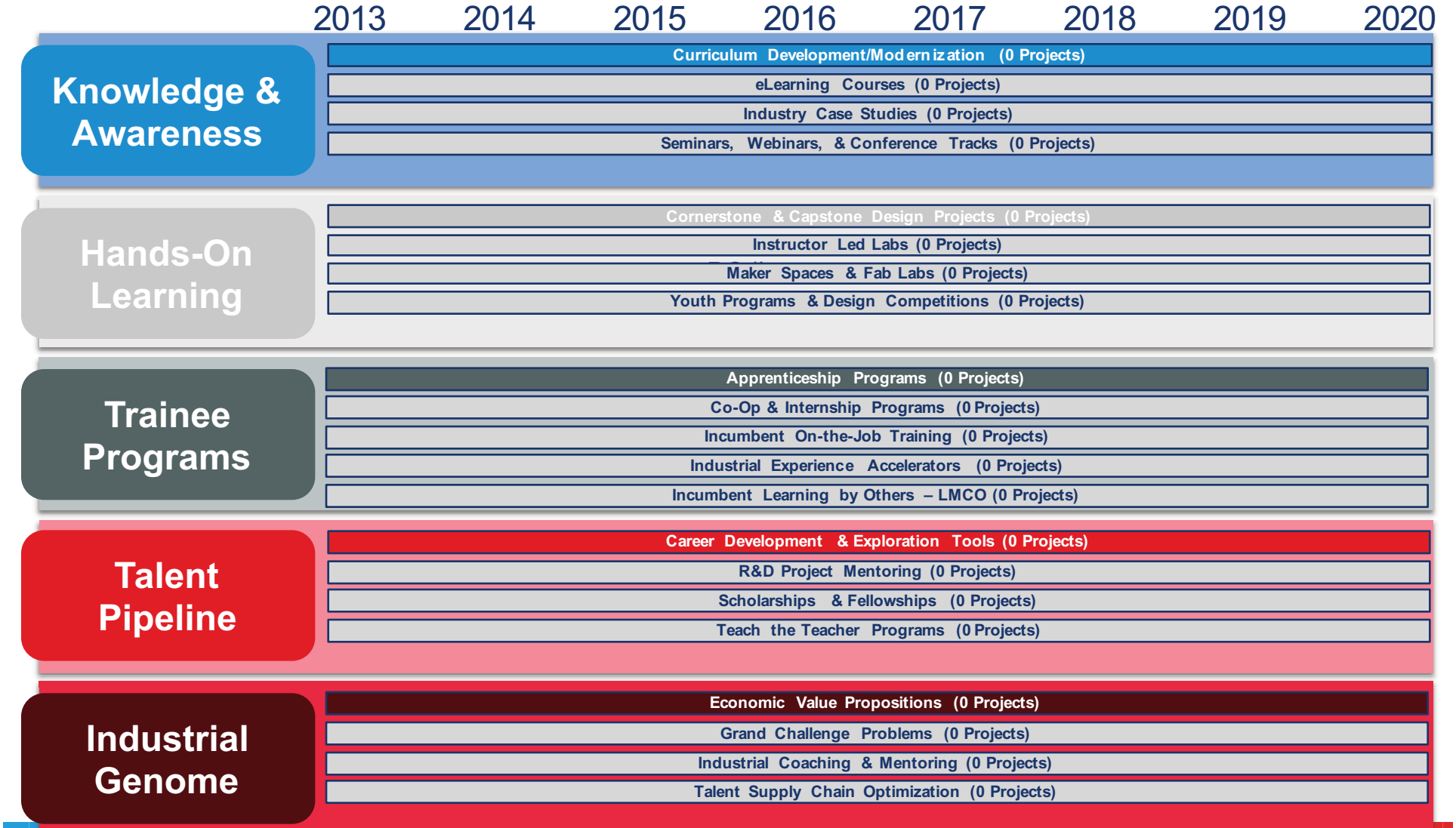
- Promote K-12 Education STEAM programs across formal and informal environments
- Ensure AM Curriculum provides students with understanding of processes, material properties and Design for AM
- Develop a national network for AM Education
- Provide support for collaborative and community-oriented maker spaces
- Develop Opportunities for Trans-Disciplinary Learning

WORKFORCE CHALLENGES

- Insufficient skills for using current design/analytical tools
- Lack of training for equipment use/maintenance
- Lack of “design for additive manufacturing” awareness
- Lack of general understanding of use-cases for additive manufacturing
- Lack of understanding of commercial and economic considerations
- Lack of credible industry-wide source for hands-on training, resulting in reliance on webinars

WEO Roadmap v1.0 Level One View

"Gray Space" with < 5 CTE Project Ideas



America Makes
Biomedical Devices Working Group

12-06-2014 Workshop Results

Workforce skilled in design
Portfolio of materials – databases with pedigree
Fatigue and corrosion data
Multi-materials, embedded systems
AM of ceramics
Miniaturization and mobilization for field use
Composite functional materials
- gradient polymers
- composite tissue (bone/cartilage)
- 3D tissues
- vascularized, multi-cellular tissue

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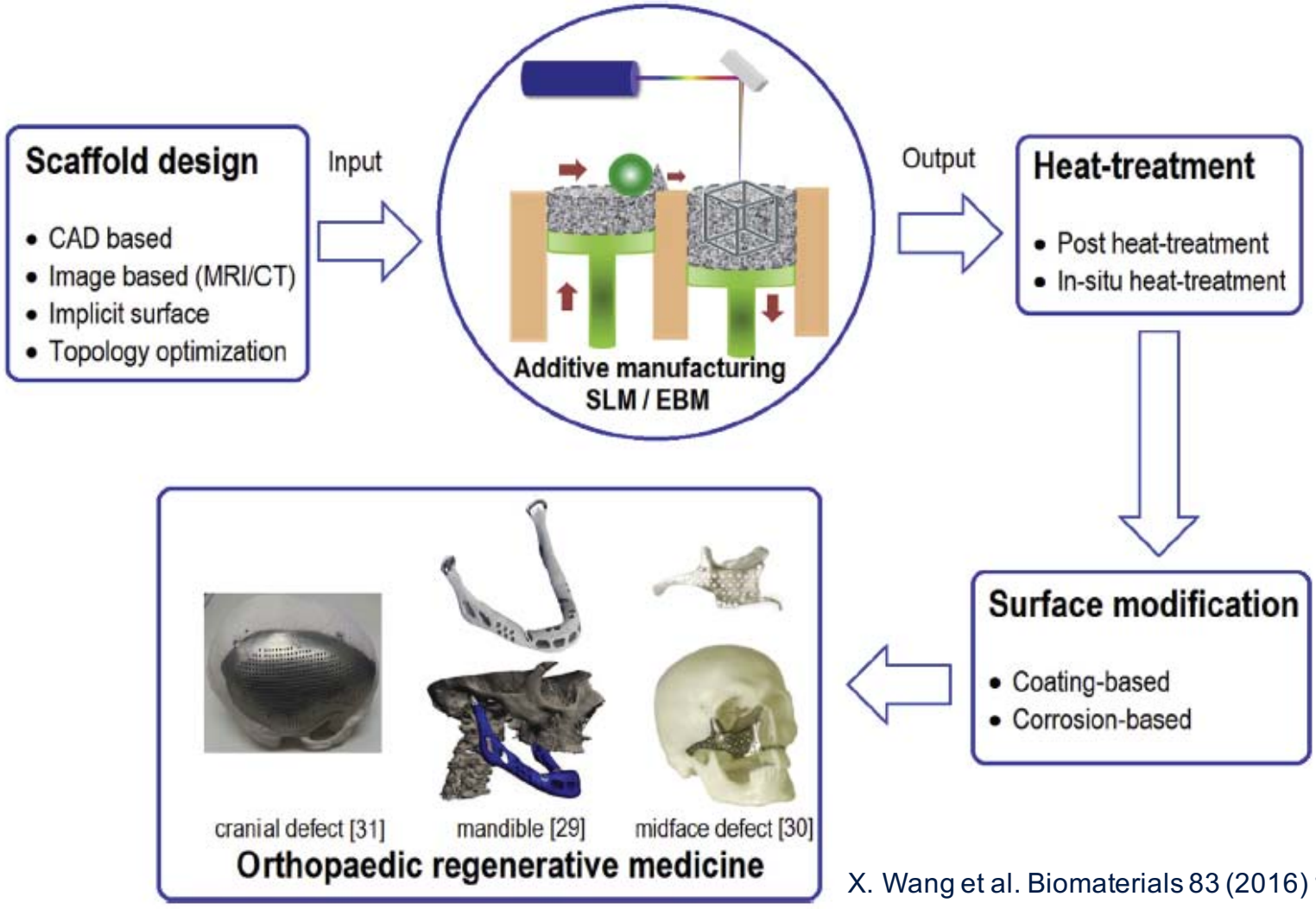
Similar to Aerospace Applications

Unique to Biomedical Devices

Current Additive Manufacturing Approach



X. Wang et al. Biomaterials 83 (2016) 127-141

Limitations and Challenges of Current Additive Manufacturing Approach

Materials limitations/challenges

- **Predominantly used for non-degradable materials**
- **Not compatible for printing biologics and cells**
- **Develop materials to enhance the mechanical and biological performance, together with new post-treatment technologies for improving the bioactivity and biocompatibility**

Design limitations/challenges

- **Need topology optimization algorithms to print multi-functional designs on multiple length scales**
- **Need design of lattice structures that exhibit anisotropic mechanical properties similar to human bones**

X. Wang et al. Biomaterials 83 (2016) 127-141

America Makes Biomedical Devices Projects

Additive Manufacturing of Biomedical Devices from Bioresorbable Metallic Alloys

- University of Pittsburgh

Economic Production of Next Generation Orthopedic Materials through Powder Reuse in Additive Manufacturing

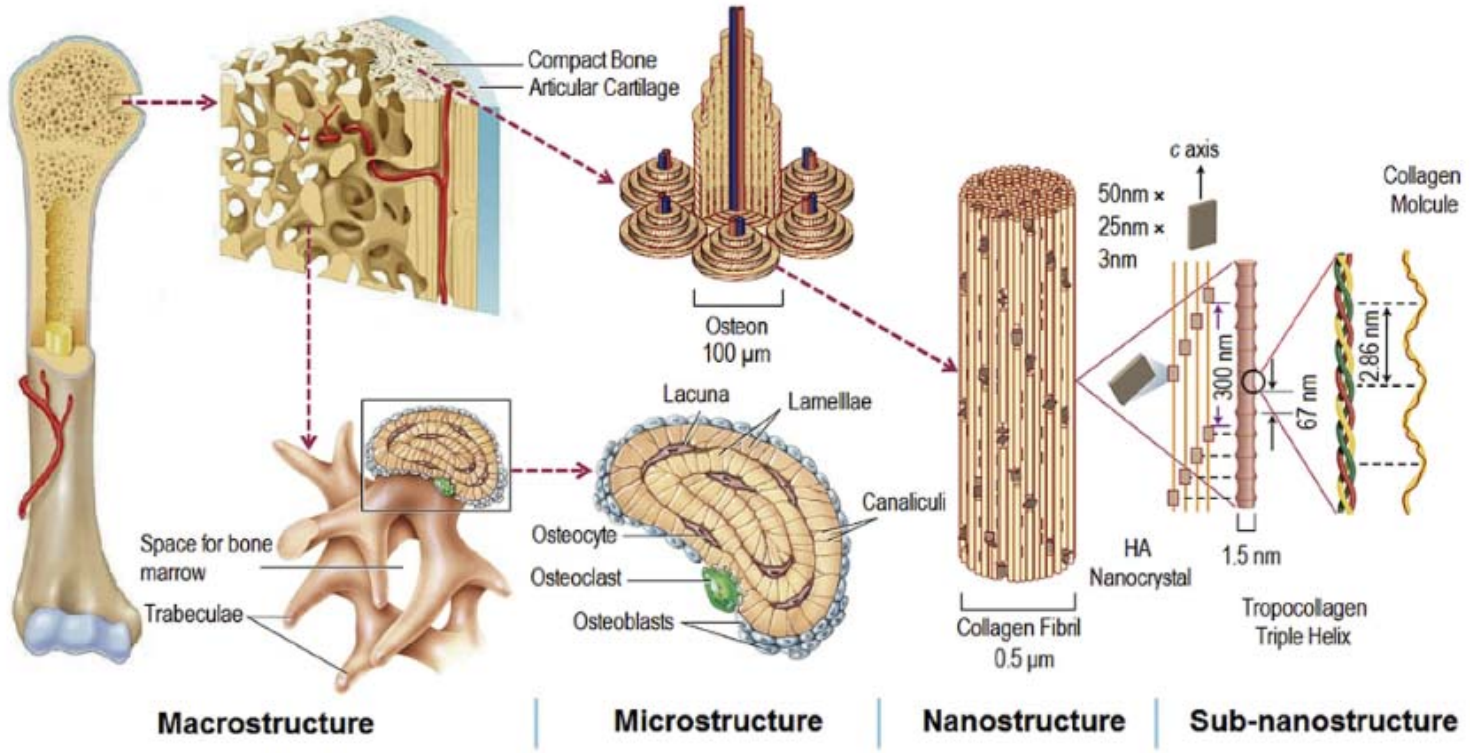
- Notre Dame University

Cyber-Physical Design and Additive Manufacturing of Custom Orthotics

- University of Michigan

Bio-printing for Regenerative Medicine

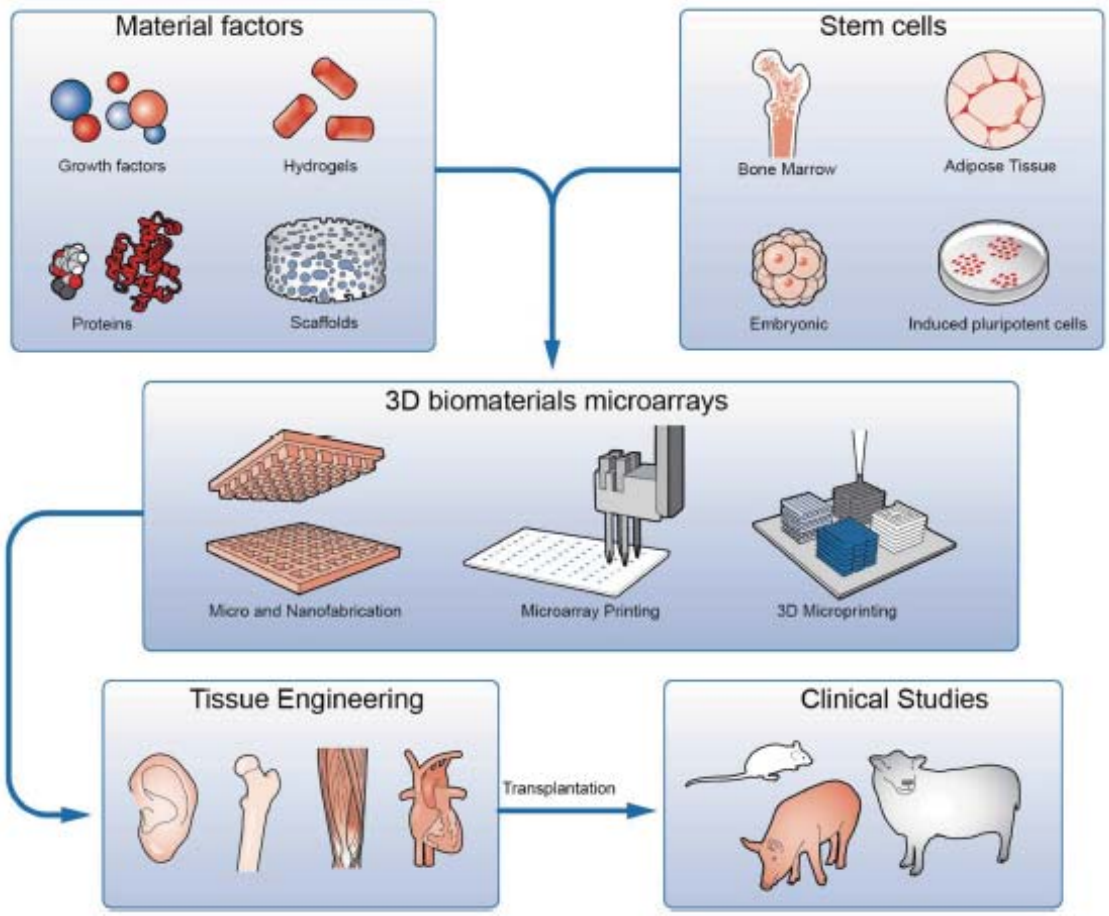
Structural complexity



- **Bone has a hierarchical structure**
- **The hierarchical levels of bone include macroscale, microscale, sub-microscale, nanoscale, and sub-nanoscale**
- **Each level performs diverse mechanical, biological and chemical functions**

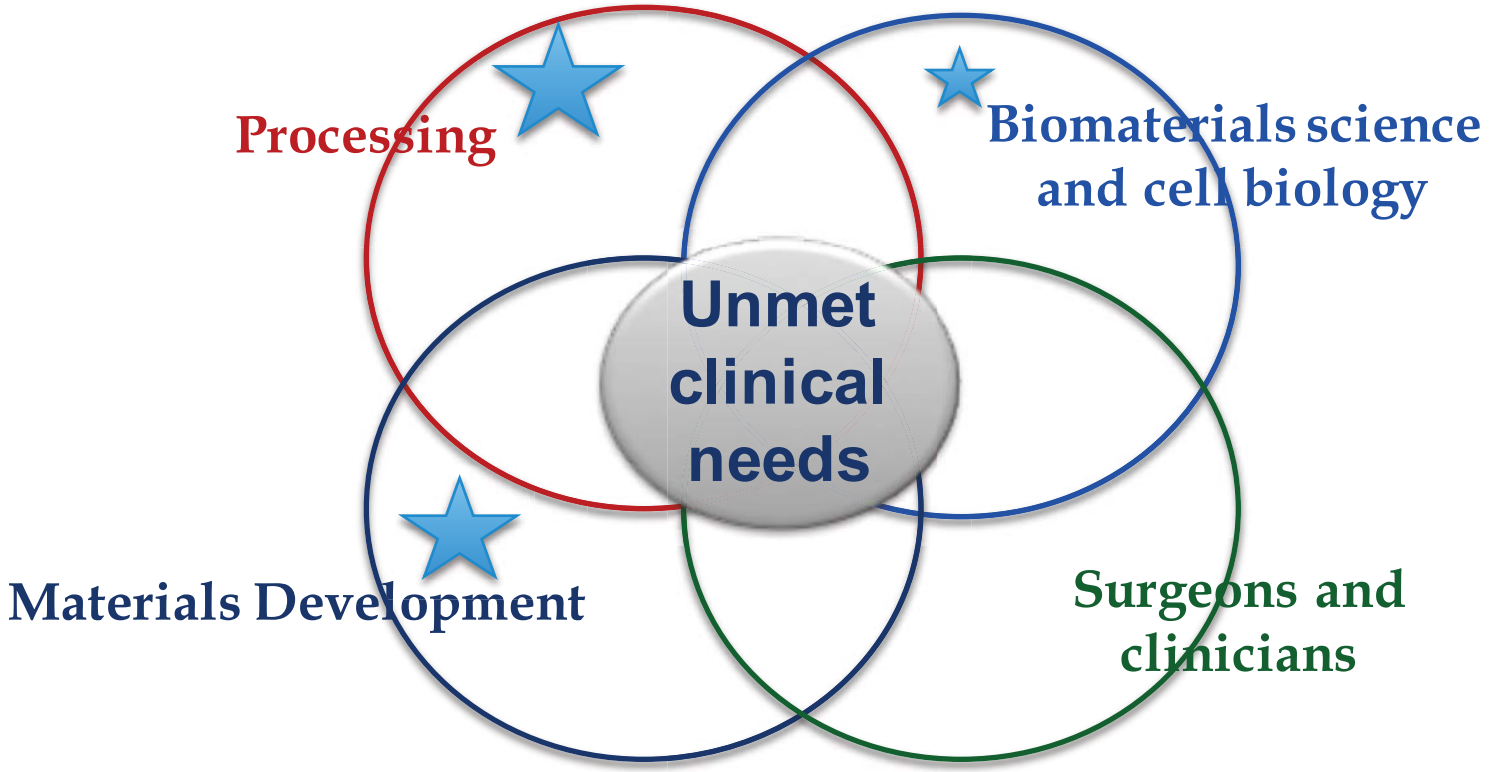
X. Wang et al. Biomaterials 83 (2016) 127-141

Bio-printing: 2nd Generation Additive Manufacturing?



Akhilesh K. Gaharwar et al. Adv. Mater. 2015

Role of America Makes (AM) in Bio-printing



Regulatory issues must be considered at all phases

★ AM supported efforts

Huge Opportunity with High Stakes

- *"None of us can do it alone. For this to succeed, it needs to scale, and for it to scale, we need a passionate and motivated community"*

  Avi Reichental, Former President and CEO, 3D Systems

- *"Rather than companies having to bear all of the cost and burden of qualifying these processes and materials, much can be done through collaborative efforts"*

  Terry Wohlers, Principle Consultant and President, Wohlers Associates

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