America Makes Efforts Relevant to AM for Nuclear Applications

9 December 2020

Brandon D. Ribic, PhD.
Technology Director, America Makes
Brandon.Ribic@ncdmm.org

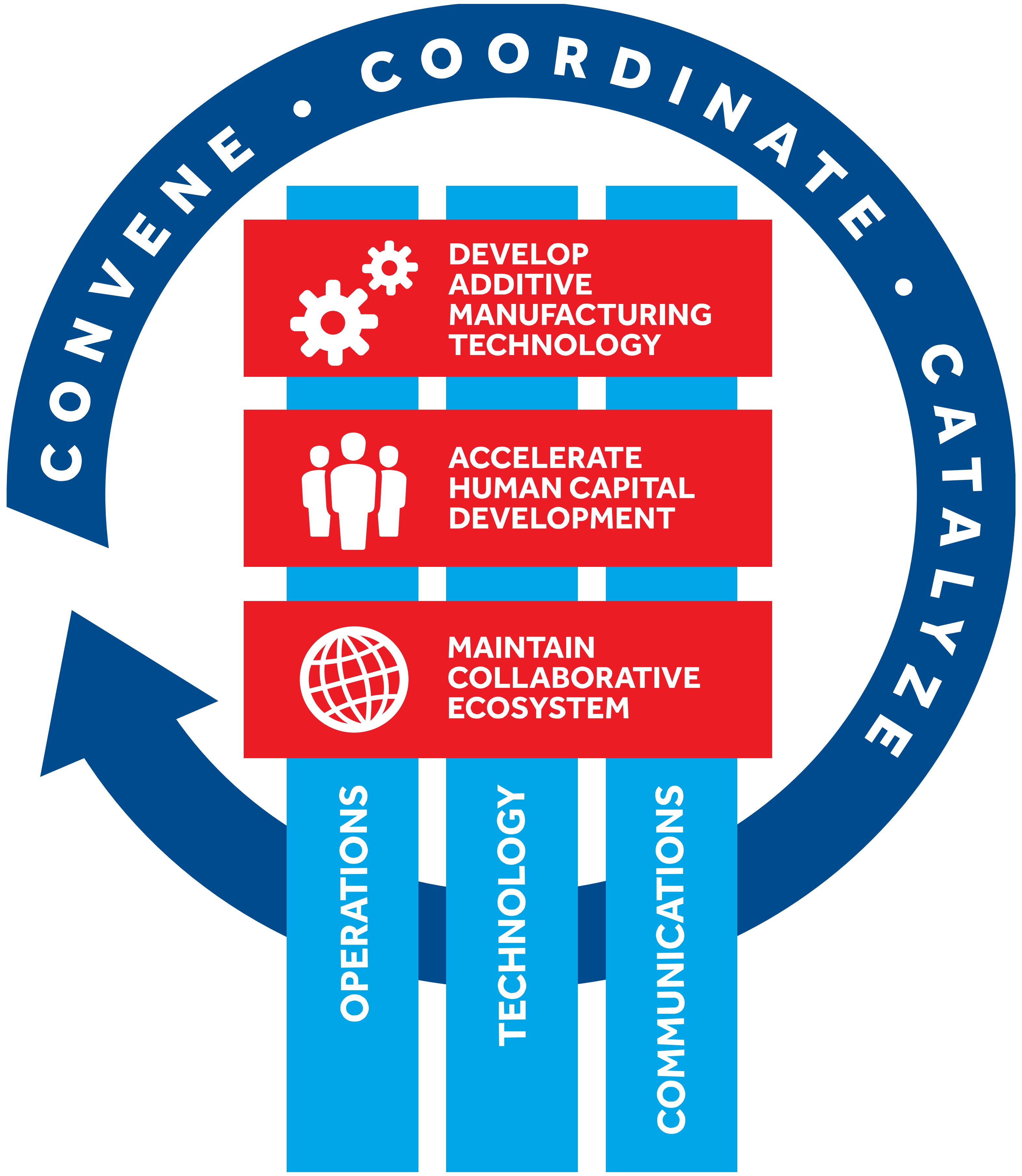
Overview

The three core activities of the Institute are:

- **Develop Additive Manufacturing Technology:** Projects, Innovation, Technology Transfer, Implementation
- **Accelerate Human Capital Development:** Workforce, Education, Training, Outreach
- **Maintain Collaborative Ecosystem:** Government, Membership, Community

These focus areas are enabled by:

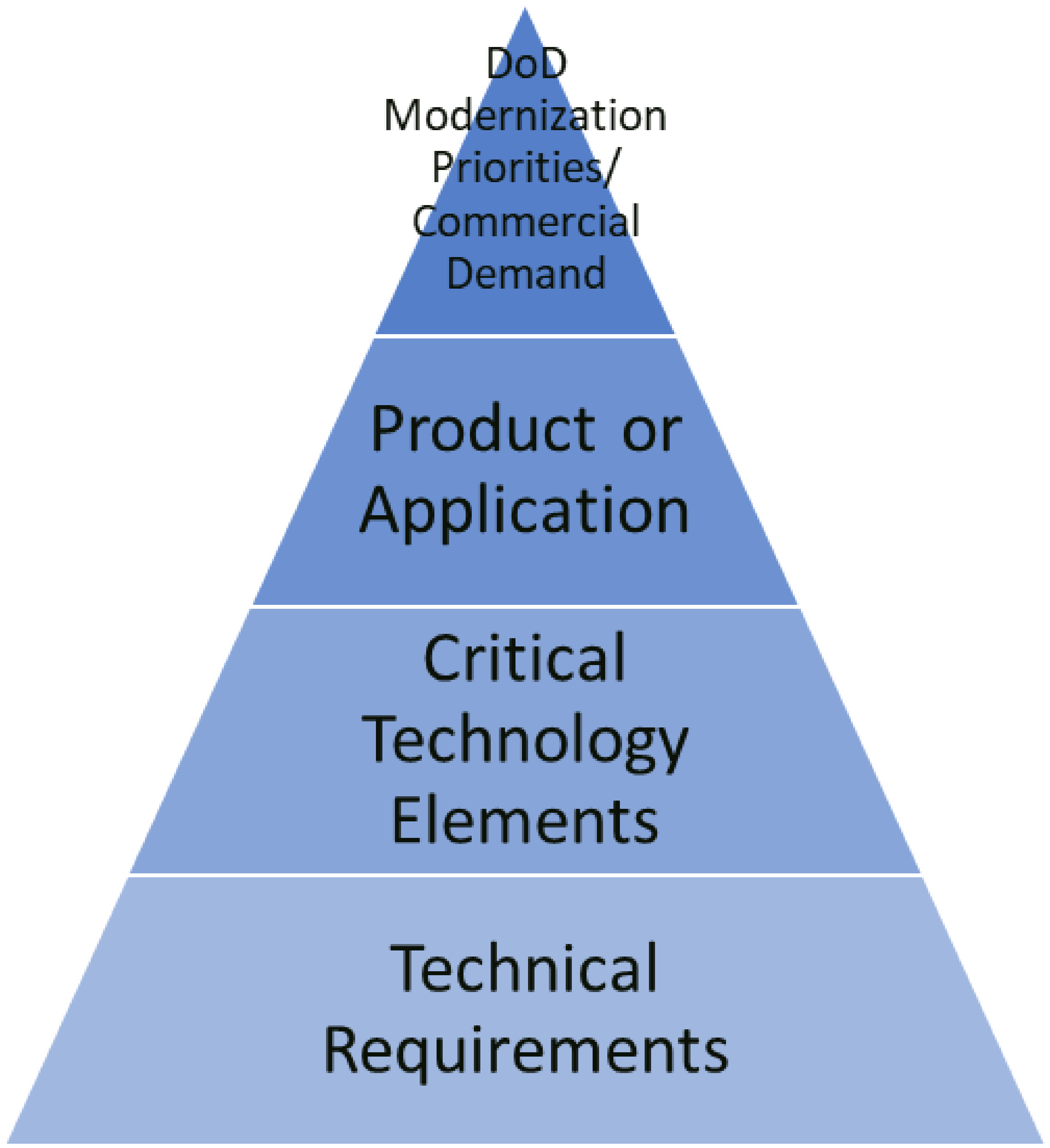
- **Operations:** Run by a not-for-profit organization with a lean and collaborative structure
- **Technology:** A dynamic advanced manufacturing technology including the core AM technologies as well as supporting technologies like the digital thread, standards, etc.
- **Communications:** Spreading the word to government, members, stakeholders, community



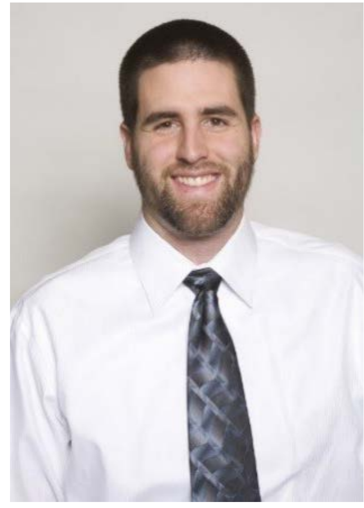
Collaboration Drives Our Strategic Focus

- Focus and strategy is documented within the Technology Roadmap
  - Application/process agnostic
  - Informed by not only end users
- Multitude of interconnected technical considerations
  - TRL 4-7
  - Address risk and maturation
  - Assess performance/function
- Roadmap is a data model
  - Integral to institute operation
  - Connects research efforts to roadmap taxonomy
  - Identifying needs/opportunities
  - Charting progress
  - Organizes lessons learned

Swimlane	CTE
Design	Bio-Inspired Design & Manufacturing
Design	Product & Process Design Aides/Apps
Material	Material Property Characterization
Material	Next-Gen Materials
Material	Additive Manufacturing Tech Data Packages
Process	Multi-Material Delivery & Deposition Systems
Process	Next-Gen Machines
Process	Process Temperature Gradient Control
Value Chain	Advanced Sensing & Detection Methods
Value Chain	Cost & Energy Driver Analysis/Modeling
Value Chain	Digital Thread Integration
Value Chain	Intelligent Machine Control Methods
Value Chain	Rapid Inspection (Post-Build)
Value Chain	Repair Technologies
Value Chain	Standards/Schemas/Protocols
AM Genome	Benchmark Validation Use Cases
AM Genome	Model-Assisted Property Prediction
AM Genome	Physics-Based Modeling & Simulation

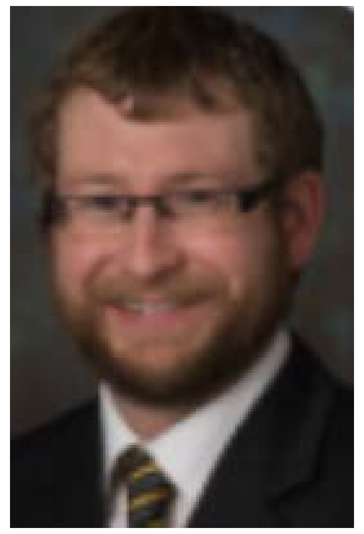


Roadmap Advisory Group



Brian Thompson
GE Additive
Brian.Thompson1@ge.com

Teresa Clement
Raytheon Technologies
Teresa.Clement@Raytheon.com



Steven Floyd
Northrop Grumman
Floyd, Steven J
Steven.Floyd@ngc.com

Thierry Marchione
Caterpillar
Marchione_Thierry_A@cat.com

Anil Chaudhary
Applied Optimization
anil1@ao.com

Federico Sciammarella
MxD
federico.sciammarella@mxdusa.org

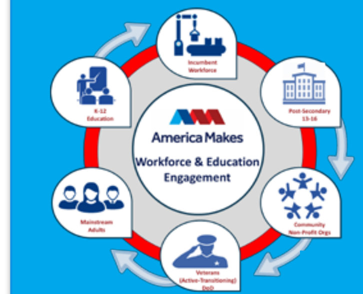
Prabir Chaudhary
Education and Consulting LLC.
prabir.chaudhury@gmail.com

Frank Medina
UTEP
fmedina@utep.edu

Craig Brice
Colorado School of Mines
craigabrice@mines.edu

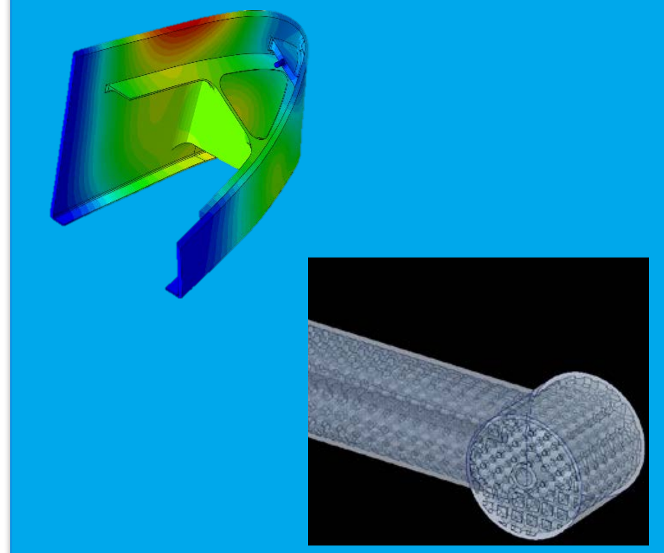
Ray Xu
Rolls-Royce Corp.
Ray.Xu@Rolls-Royce.com

Addressing Technology Gaps to Strengthen Domestic Supply Chain

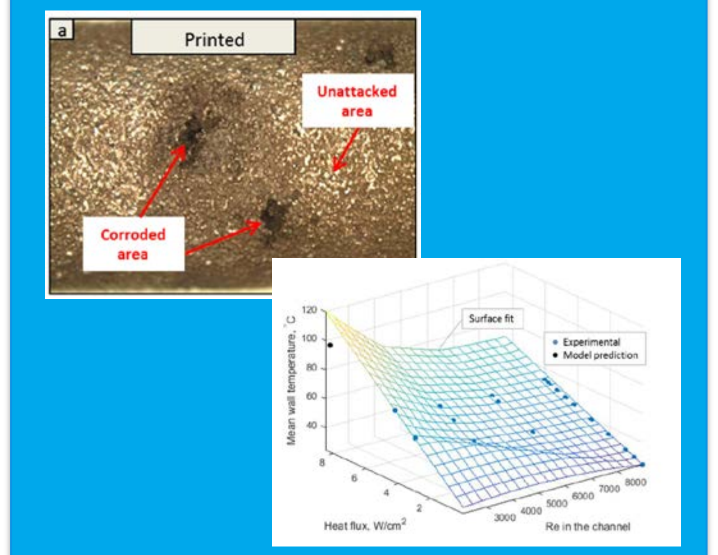


AMNOW

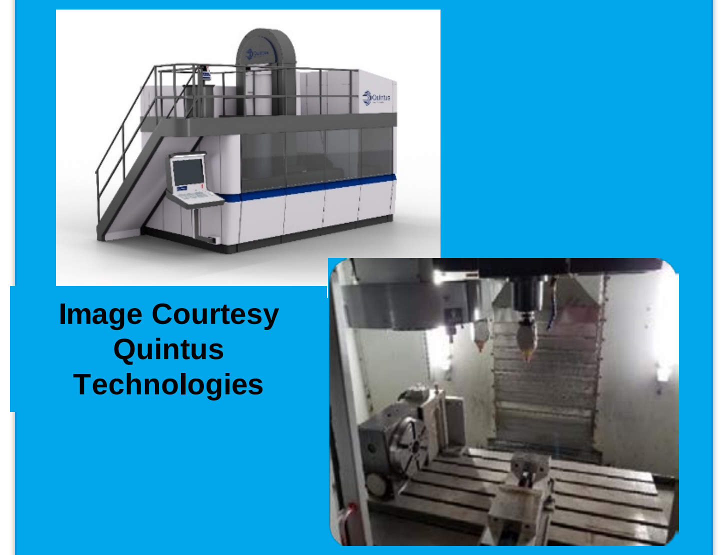
Supply Chain & Sourcing



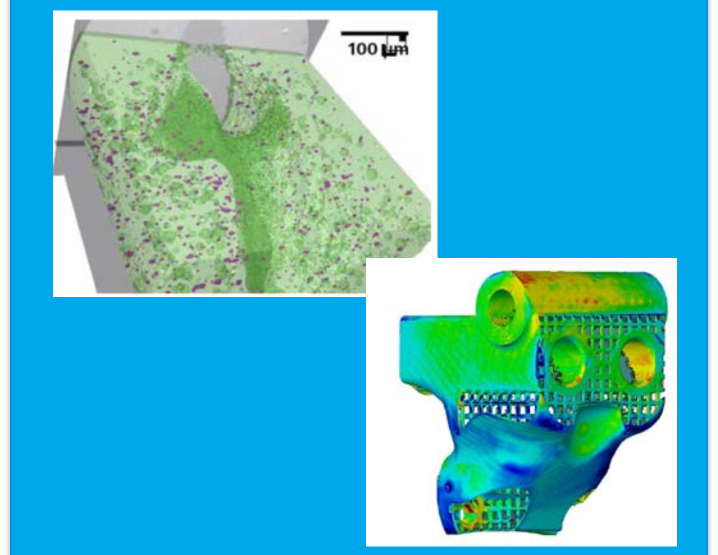
Design



Performance & Durability



Post-Processing & Finishing



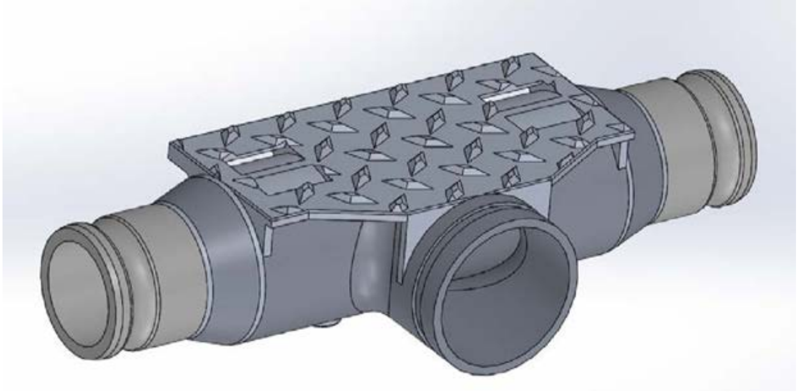
Inspection/ NDE

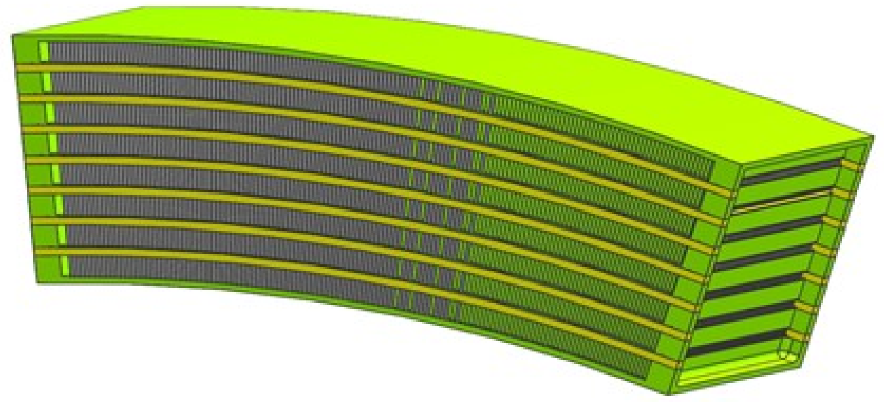
Cost & Rate

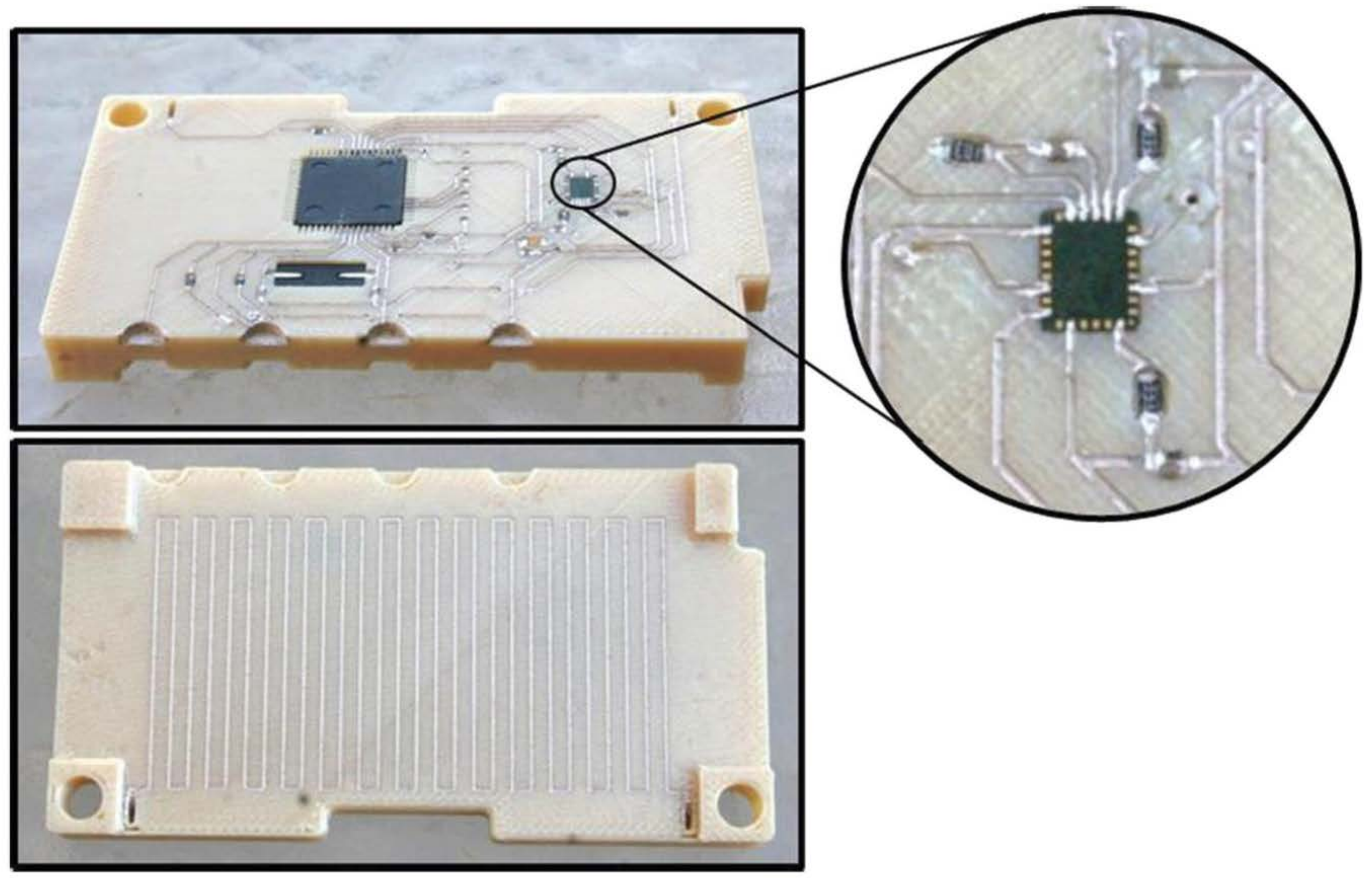
Key Additive Manufacturing Technology Focus Areas

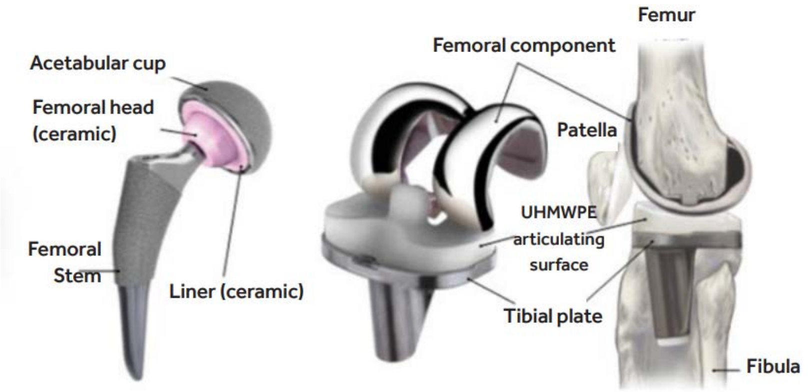
Strengthen Warfighter Capability Needs

Previous and Current Applications









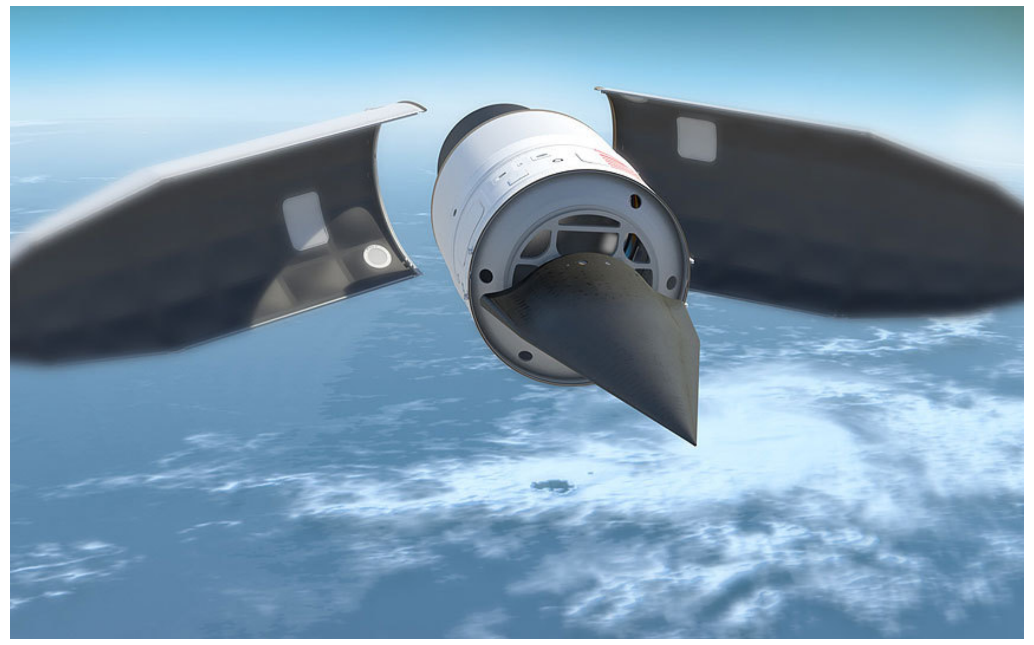
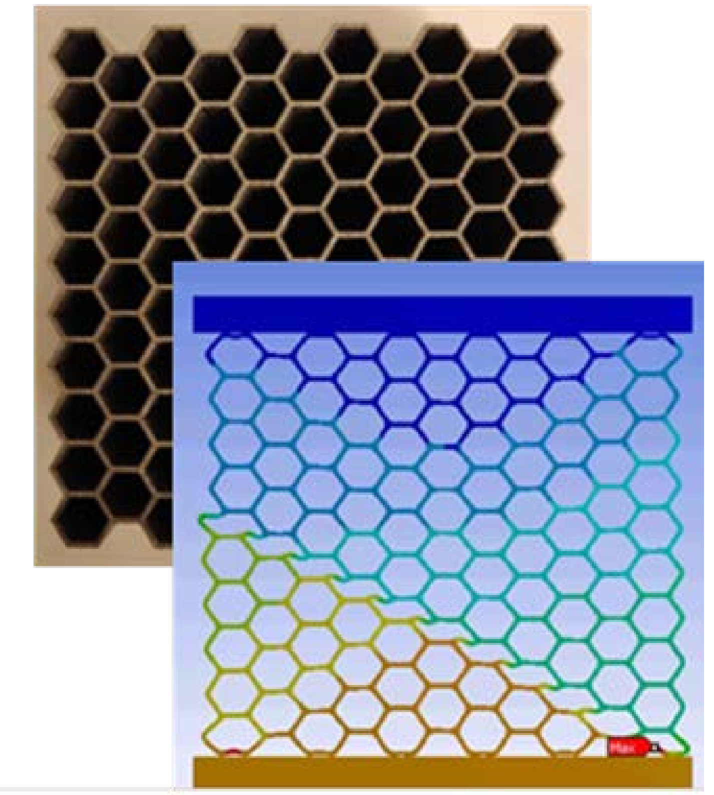


Image courtesy DARPA

http://www.optisurf.com/index.php/mirror-mounts-for-high-precision-optics/

Image credits: Dr. Beth Ripley and Timothy Prestero

Demo part 1: aircraft vent



Merits of Additive Manufacturing for Nuclear Applications

- Design
  - Filtering
  - Thermal management
  - Vibration/shock
  - Part consolidation
  - Tooling, jigs, and brackets

- Materials & Process
  - Tailored material chemistries and microstructures for performance
    - Shielding/passivation
    - Mechanical performance
    - Thermophysical properties
  - Multi-material
    - Metal, polymer, ceramic, composite
    - Part count reduction
    - Embedded sensors
  - Repair, cladding, hard facing
  - Reverse engineering

- Adaptive distributed manufacturing base
  - Adaptable and readily adjusts to iterative/evolving product definition
  - Single article production lots are tolerable
  - Lead time reduction

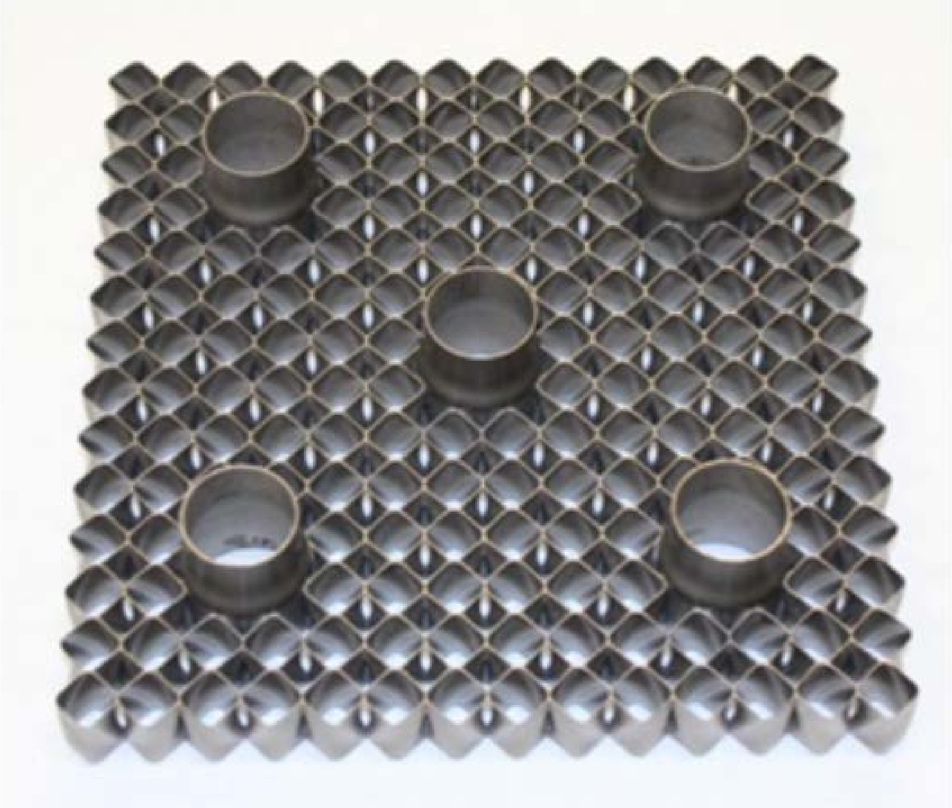
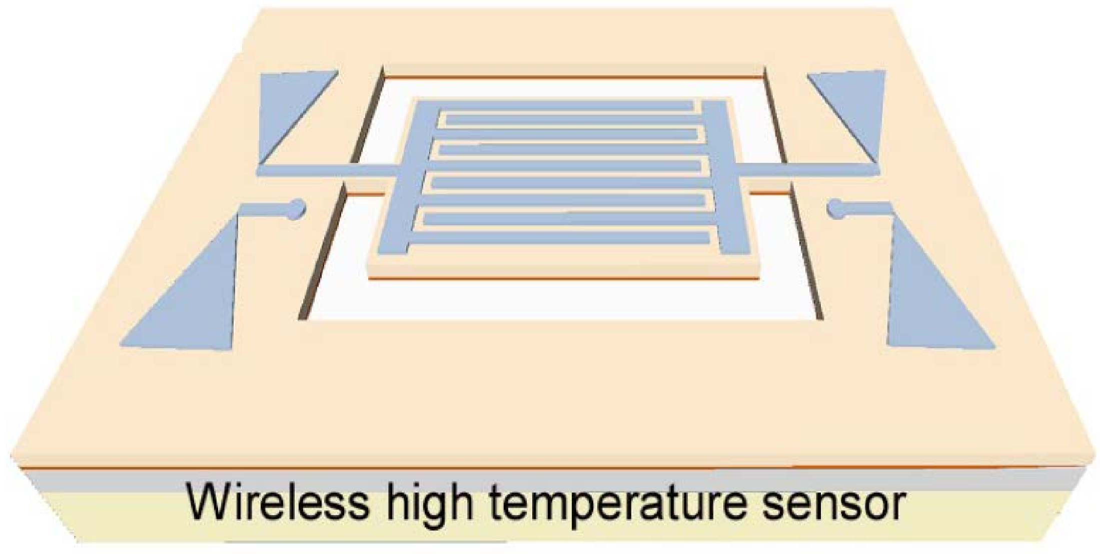


Image Courtesy of Westinghouse



Lu et al. *AOI2 Wireless High-Temperature Sensor Network for Smart Boiler Systems.* 2020

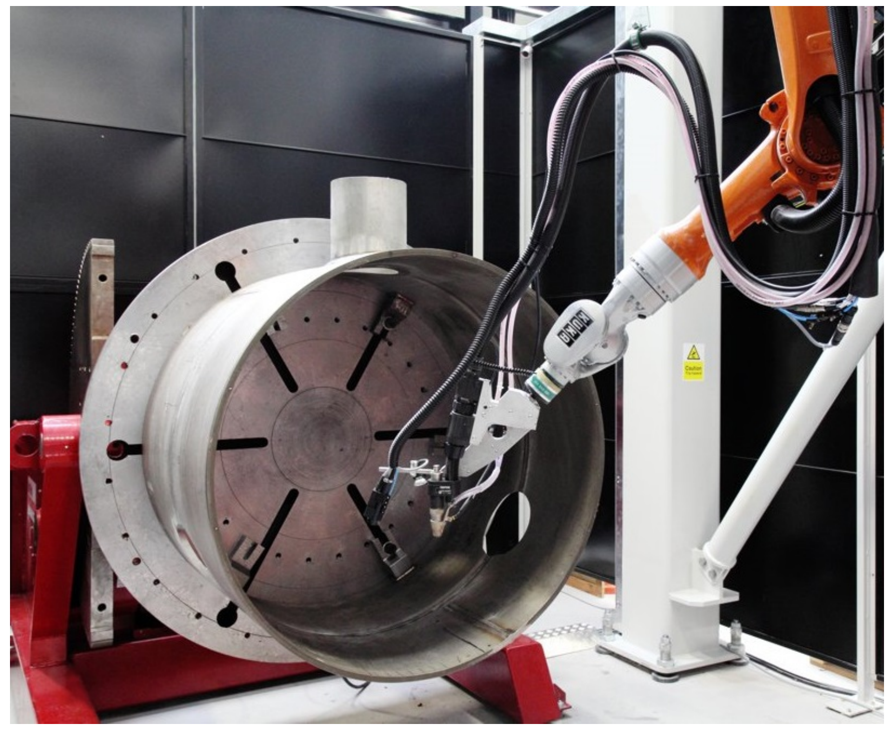
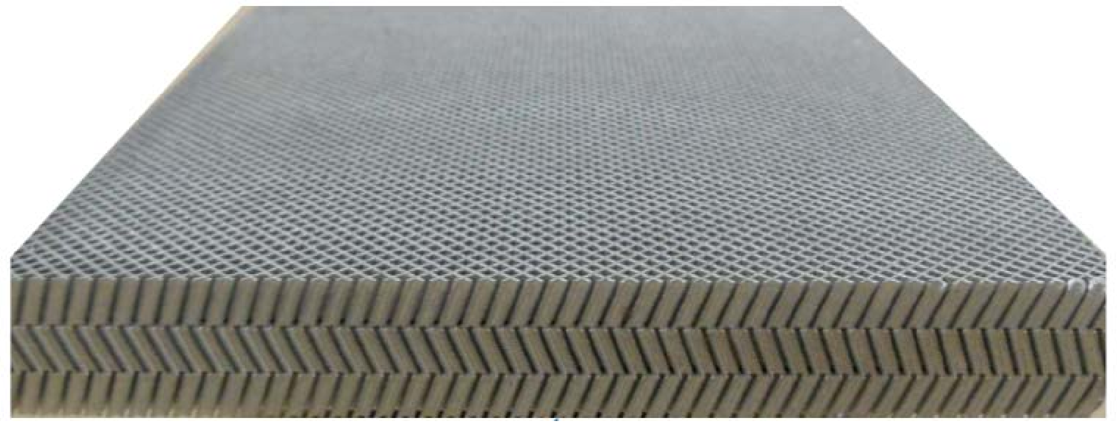


Image Courtesy of Nuclear AMRC



GE Hitachi 2017

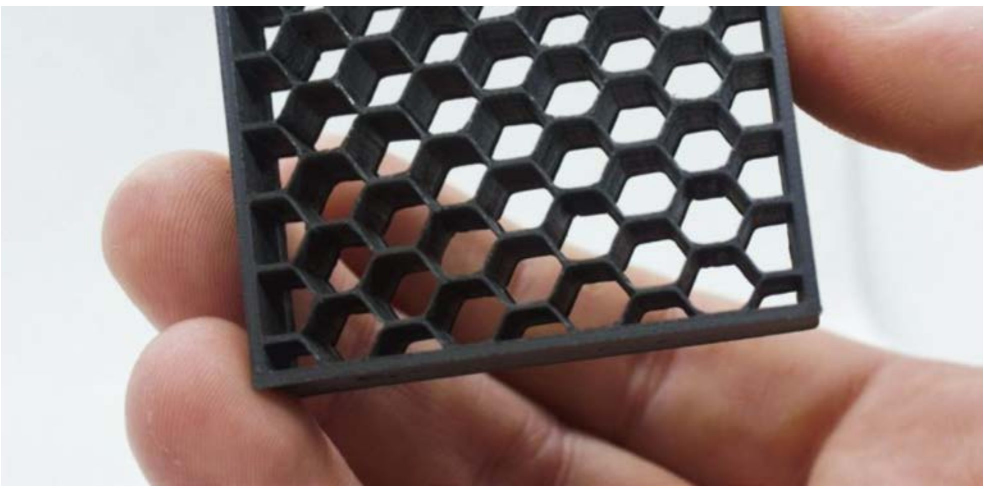
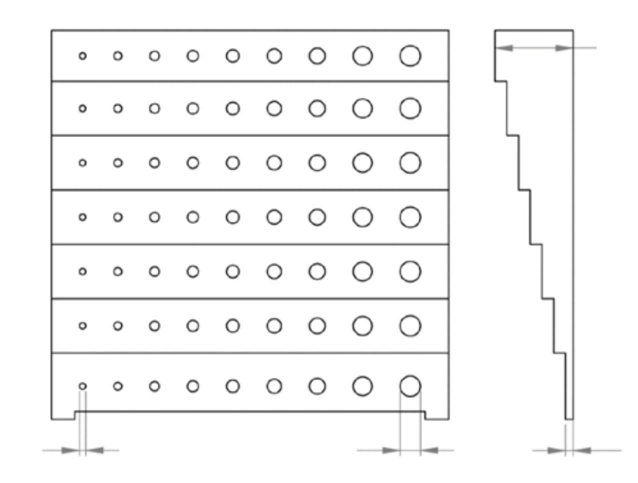
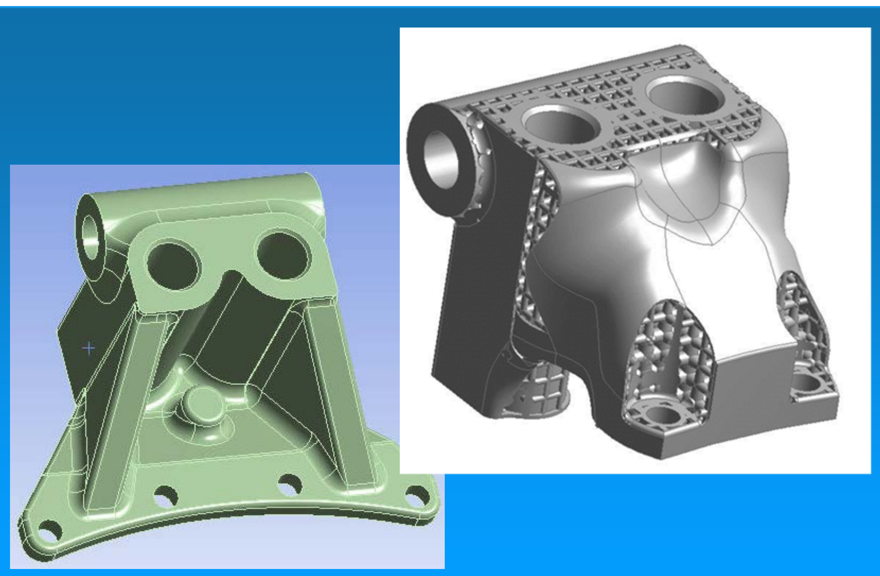
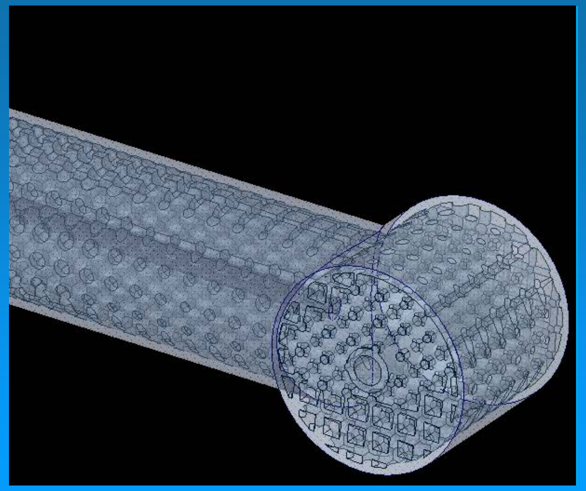


Image Courtesy of Additive Composite

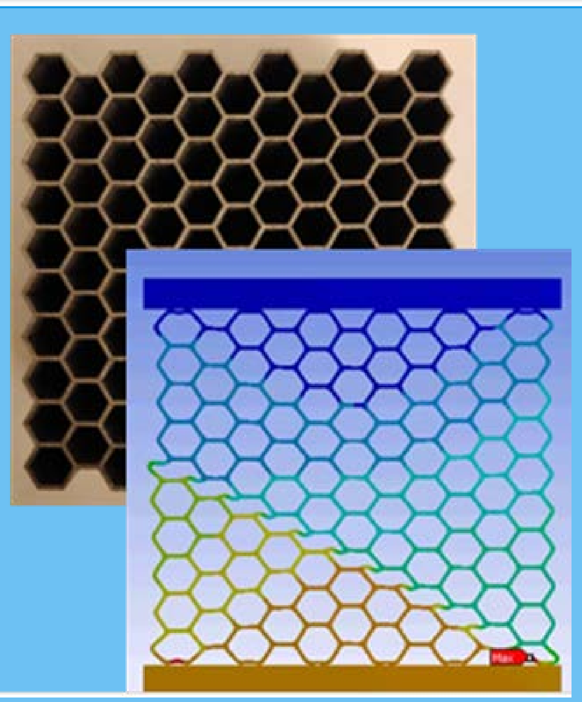
Design

- GD&T of metals, polymers, composites
- DfAM
  - Guides, process selection aides, and apps
  - Product development and qualification
- Structural Optimization
  - Including lattice structures
- Materials and data play a vital role
- Design for:
  - Life limited applications
  - Complex parts/assemblies
  - Anisotropic materials
  - Multi-material
  - Multi-process
  - Multi-physics
- Validation and vetting manufacturability and product equivalence to known designs

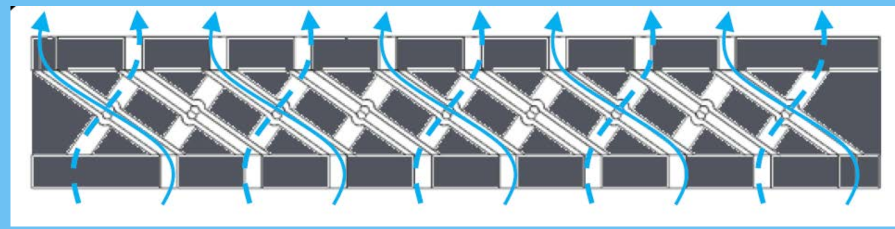
Structure

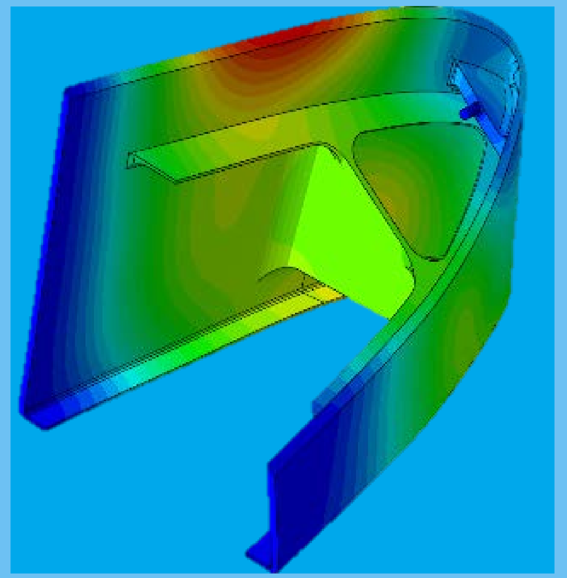
Performance




Bogard et al., *Integrated Turbine Component Cooling Designs Facilitated by Additive Manufacturing and Optimization*. 2019.

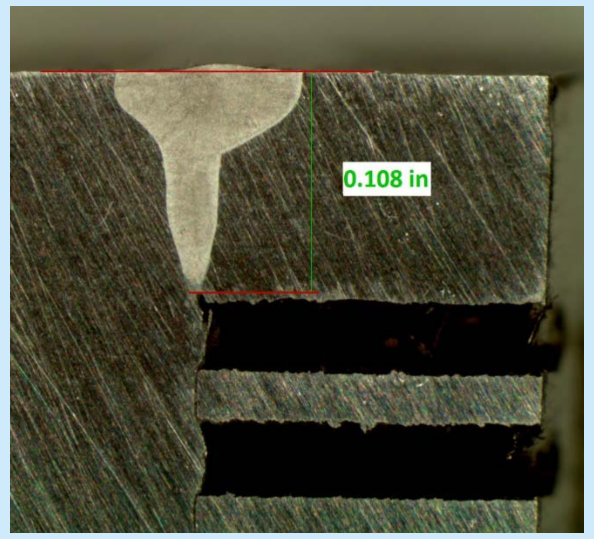


Chyu, To, and Kang., *Integrated Transpiration and Lattice Cooling Systems Developed by Additive Manufacturing with Oxide-Dispersion Strengthened Alloys*. 2017.



Manufacturability

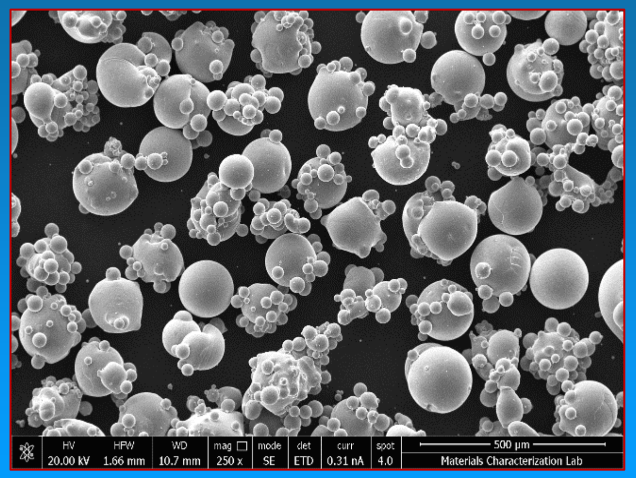
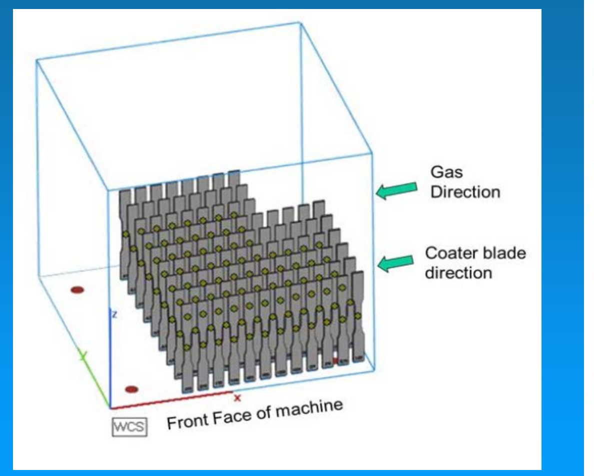


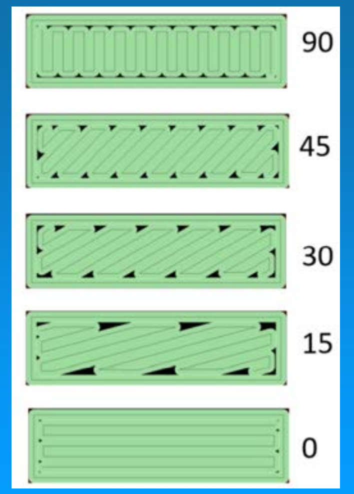


Material

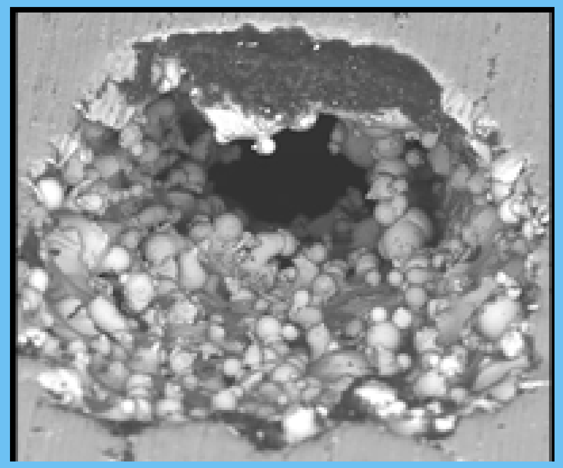
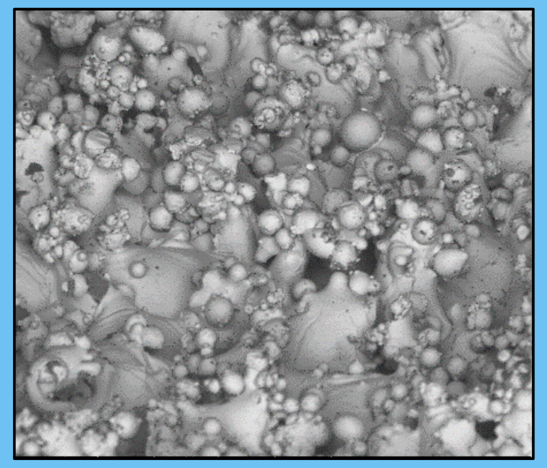
- Material Types
  - Ti, Ni, Al
  - Polymers
  - Composites
- Evaluation of austenitic, ferritic, or PH stainless steels
  - Beyond 718 and 625 nickel alloys
- Pedigreed materials allowable data sets
- Service life modeling – probabilistic approaches
  - Dissimilar materials
  - Elevated temperature
  - Various degradation mechanisms
- Materials which improve system performance
  - Certified as-built
  - Recycling
  - Methods for AM materials development
- Functional testing for equivalence
- Feedstock production capability

Process

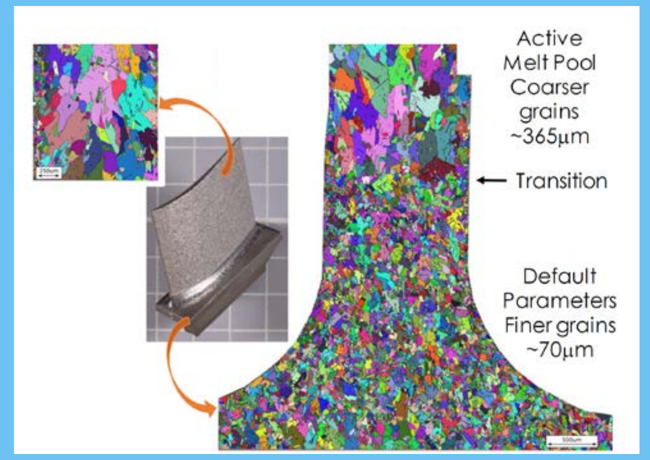





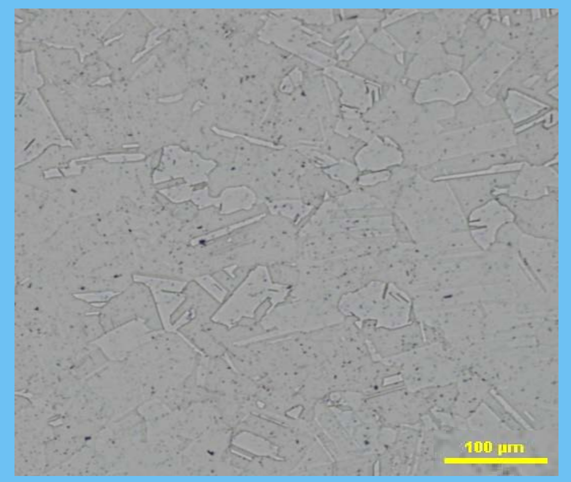
Structure

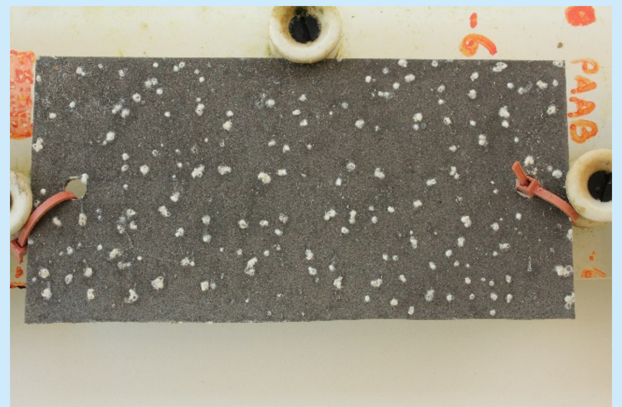
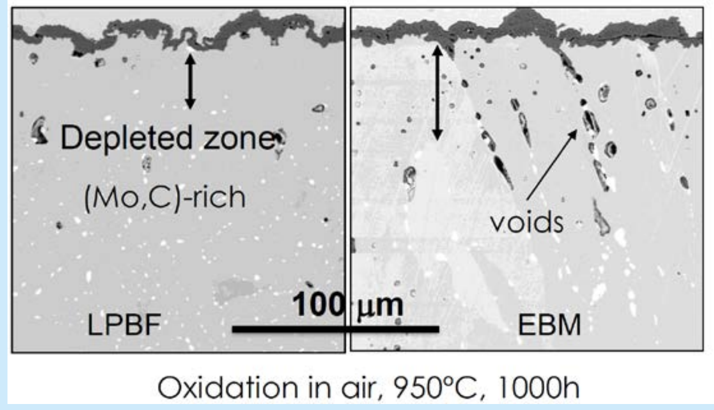
Chyu, To, and Kang., *Integrated Transpiration and Lattice Cooling Systems Developed by Additive Manufacturing with Oxide-Dispersion Strengthened Alloys*. 2017.



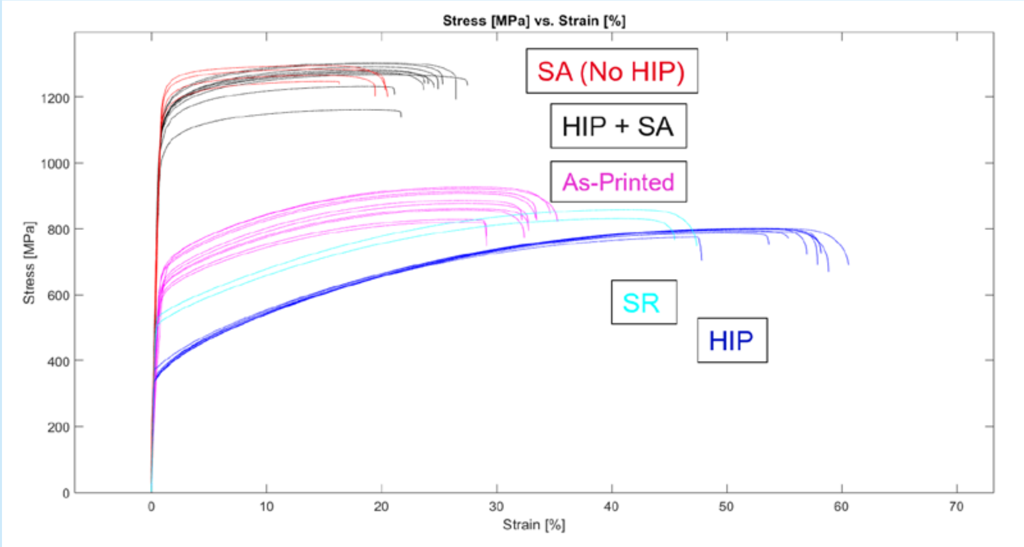
Acharya et al., *Computational Tools for Additive Manufacturing of Tailored Microstructure and Properties*. 2020.



Properties

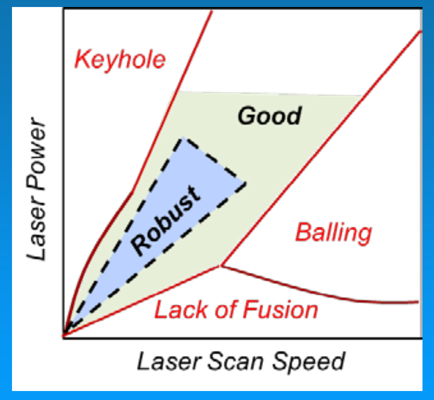
Dryepondt et al., *AM of Nickel Components and Joining of Dissimilar Metal Welds*. 2020.

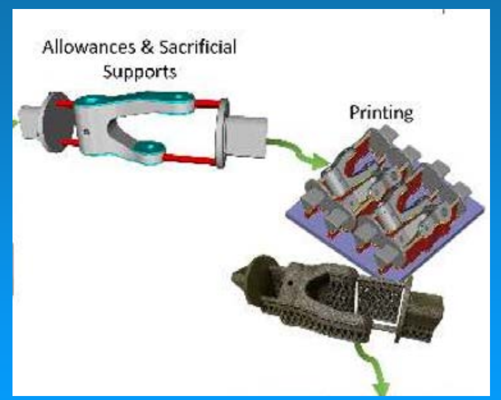


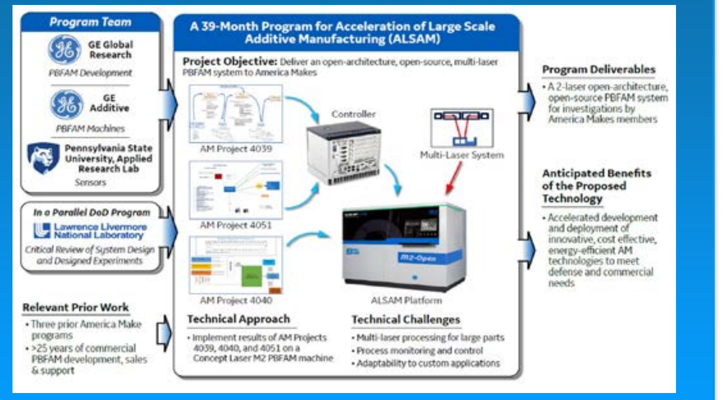
Process

- Advancements in controls, software, and hardware
  - Geometric, microstructural, and performance (quality) enhancements
- Multi-laser/multi-deposition
  - Larger build volumes
  - Increased productivity
  - Expanded capacity/capability
- New capabilities can come with new challenges
- Increased degrees of freedom for operators
  - Scan path optimization tools/methods
  - Process control methods and validation
  - Repeatability
- Transferability between different machine platforms
- Process calibration methods and tools
  - Equipment maintenance

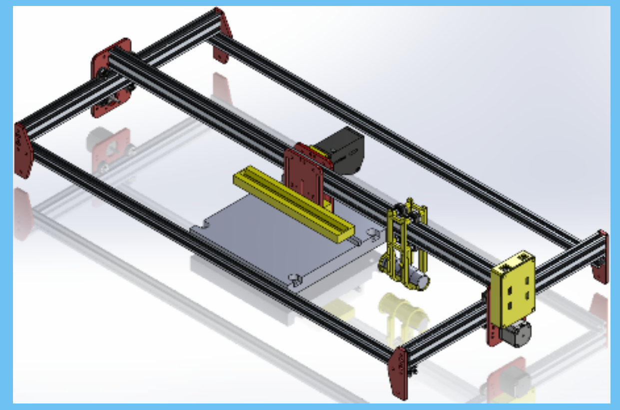
Control

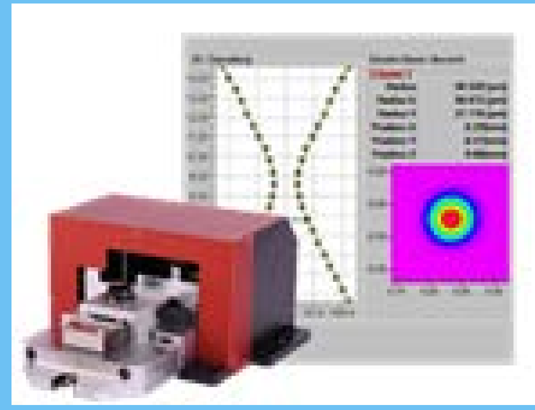
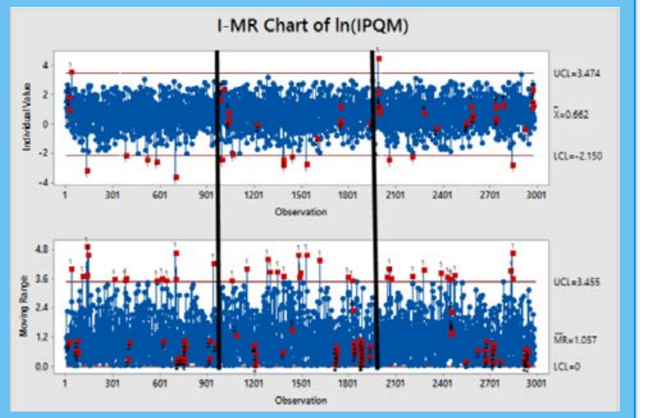







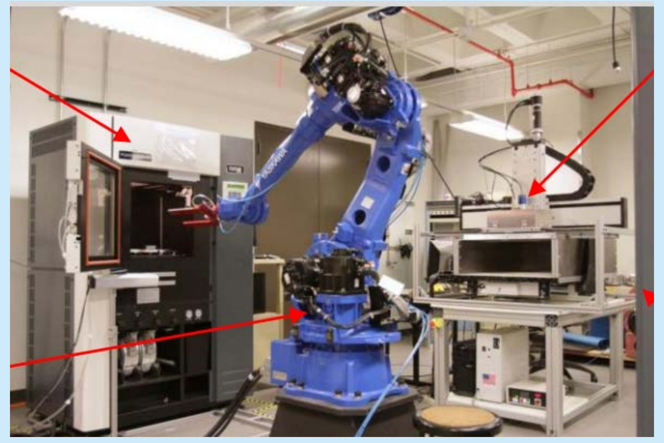
Maintenance & Calibration



Expanded Capability

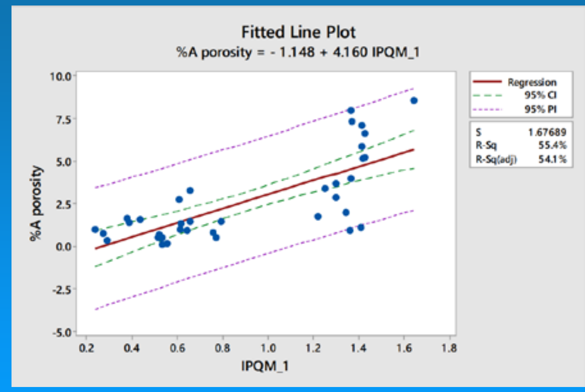


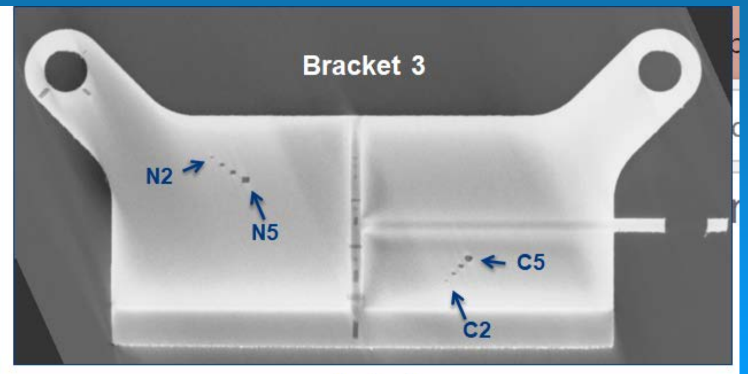



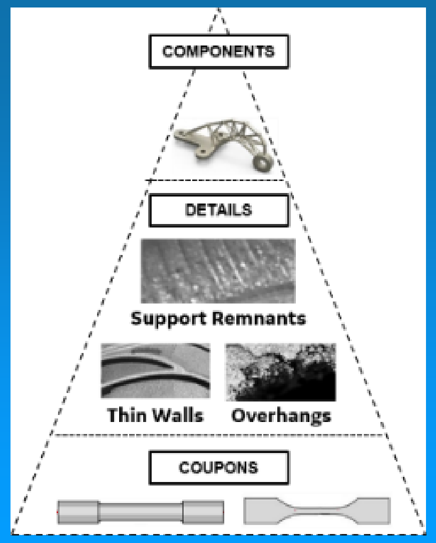
Value Chain

- Physical limits of sensing and inspection technologies
  - Probability of detection
  - Overcoming complexity
- Sourcing and acquisition technology
- Business case analysis
  - Understanding value proposition of AM
- Novel test methods needed
  - Validation
- Cybersecurity
- Rapid inspection
- Digital twins which account for:
  - Manufacturability
  - Multiple manufacturing operations
  - Product variability/quality control

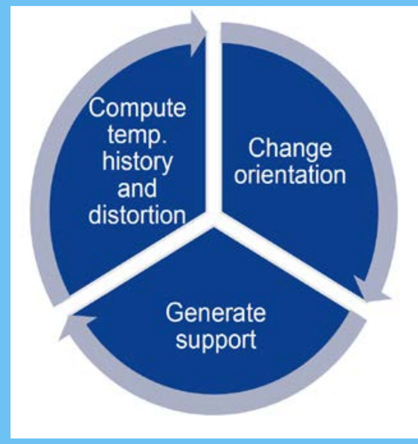
Qual/ Cert

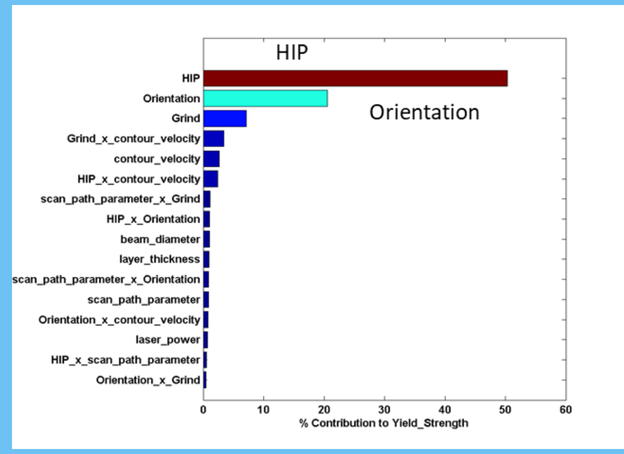


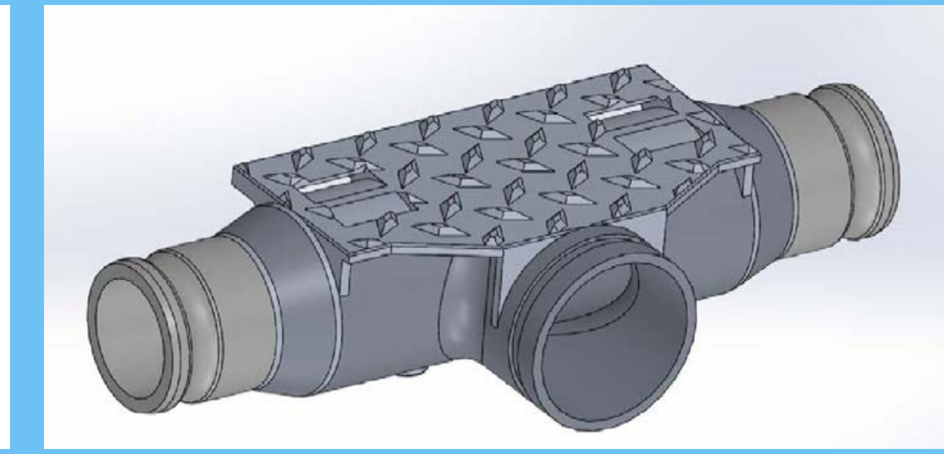




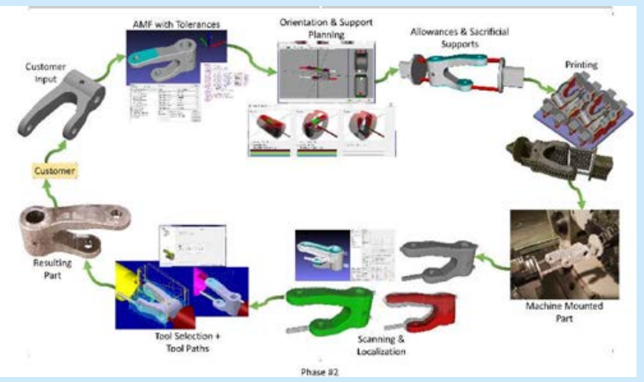
Cost







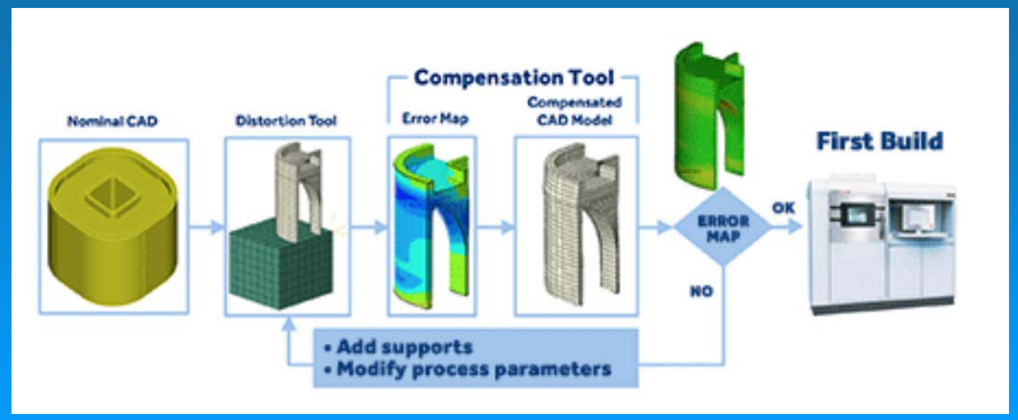
Digital Capability

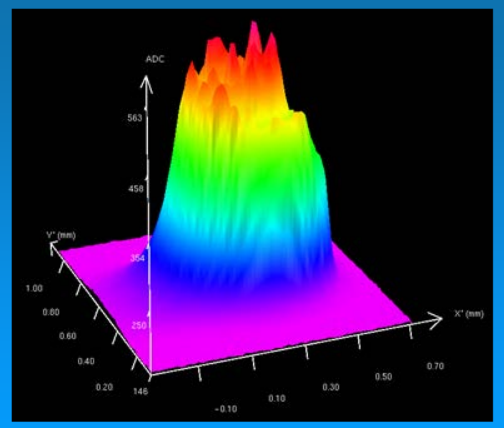


AM Genome

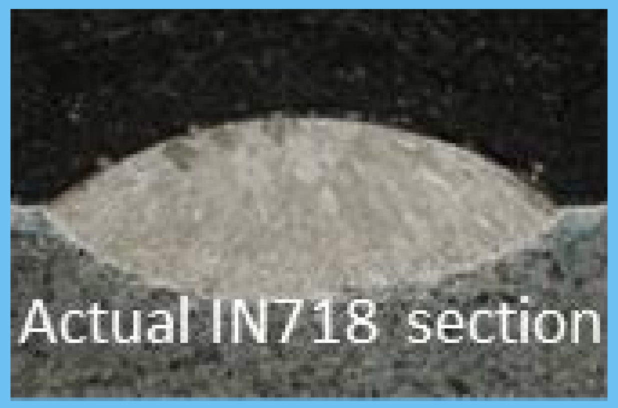
- Physics-based predictive tools
  - Track geometry
  - Surface finish and lack of fusion
  - Distortion/residual stress
- Experimental validation
- Machine learning/artificial intelligence
  - Structure and performance prediction
- Reduced demand for physical experimentation and testing
- New AM materials development

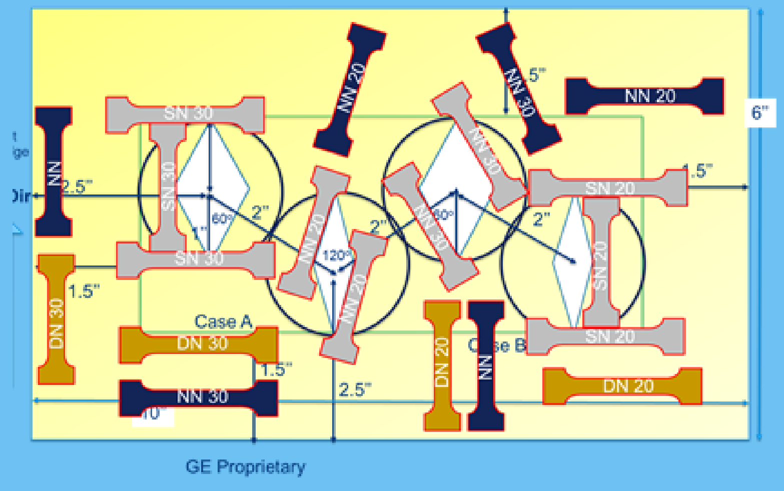
Tools

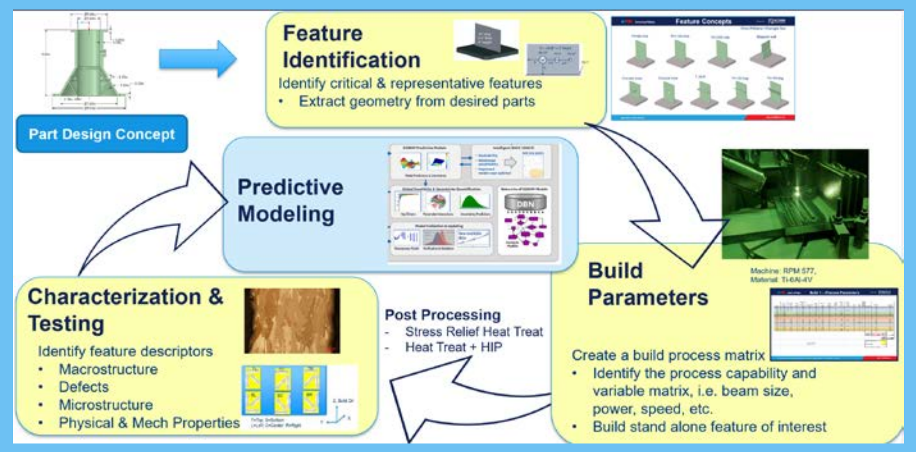




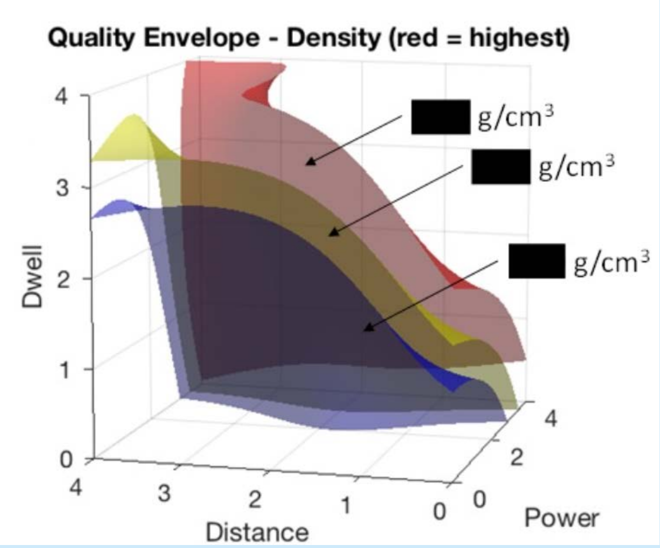
Methods

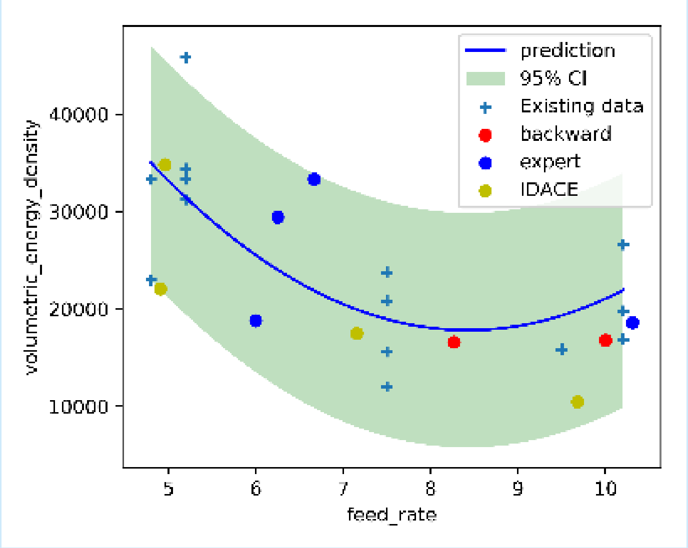


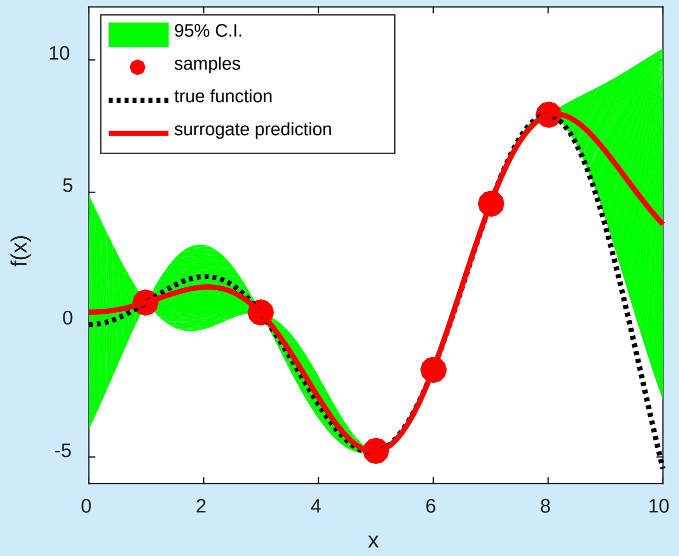




Optimization







Senvol.com

ANSYS, Autodesk, University of Louisville, Honeywell, Wright State University, GE Global Research, EWI, Applied Optimization, PennState Applied Research Laboratory, Youngstown State, GE Aviation, Optomec, TechSolve, Raytheon Technologies, Lockheed Martin, Senvol, YBI Youngstown Business Incubator, Addiguru, Connecticut Center for Advanced Technology, Inc., CTC, Rolls-Royce, University of Dayton Research Institute, Open Additive

Scaling AM Technology for Nuclear Applications

- Demand volume for nuclear application components exhibits potential for considerable benefit from AM
- Reliability and familiarity with product performance and materials behavior must be addressed to insure expanded adoption
  - Repeatability and transferability of manufacturing capability will be important
  - Supply chain resilience = potential for lead time reduction
- Inspection is a critical component of nuclear product certification and may not deter broader application of the technology
  - May not always be true, now is the time to explore
- Continued exploration and documentation of productivity and lead time improvements gained by AM
  - DED vs. GMAW
  - Repair and prototyping before super-critical applications – crawl, walk, run mentality
  - Refined cost modeling
- Compatibility with legacy sub-systems, assemblies, or manufacturing operations
  - New materials may not exhibit same compatibilities or behaviors
- Some cost and lead time savings may come immediately
  - Like for like replacement of legacy designs/material forms
  - Often realization of performance or unique benefits requires development, testing, data and investment

Regulation and Standards

- These appear to be encouraging times for advanced manufacturing in nuclear industry
  - AMT Application Guidance Draft Framework June 2020
- 10CFR 50.55a(z)(1)
  - Equivalency according to ASME Code Section III design allowables
  - This is a challenging and evolving topic within AM industry which is impact no just nuclear industry
- 10CFR 50.55a(z)(2)
  - Functional testing has served as a meaningful method to determining product function in a relevant operating environment
  - Aerospace
- Direction and recommendation of guidance mirrors much of the AM industries understanding
- The guidance suggests now is a great time to get engaged with SDO’s and share your needs with broader community
  - Opportunity to benefit your organization and your industry
  - Standards development requires data and perseverance
  - Change requires time and effort
  - There has been much learned about AM, but additional effort is required
- Take advantage of opportunities to connect with your peers and learn from others
  - Sharing information (familiarity with the technology) tends to reduce barriers to entry and uncertainty

Future Opportunities

- Additive has demonstrated value proposition for nuclear applications
  - These benefits build upon prior lessons learned across various (but similar) industries
  - Expansion of technology's recognized value
- Operating conditions and materials offer reasonable transition opportunities
- With expanded familiarity, additional validated design tools and methods are likely to follow
- Capture of key lessons learned will serve as the foundation for workforce development and new standards
  - R&D, materials data, and functional (performance based) testing will play a key role
- Successful demonstration of lower risk components can continue to serve as useful opportunities to bolster industry's familiarity with the technology
  - Scale and expand adoption for a variety of applications
- It is important to recognize the value of collaboration
  - Sharing (pre-competitive) lessons learned will allow the nuclear industry to focus on application specific challenges rather than redeveloping AM best practices from scratch
  - Accelerate primary focus/efforts to product evaluation and performance monitoring (terminology adopted from AMT Application Guidance Draft Framework)

When America Makes America Works

America Makes

AmericaMakes.us @AmericaMakes /AmericaMakes