"Some of the views expressed in this presentation are those of the author, and they do not necessarily reflect the views of the National Science Foundation or the Federal Government"

NSF Advanced Manufacturing Program and Funding Opportunities

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Program Director, Advanced Manufacturing

ENG/CMMI

National Science Foundation

NSF Workshop on Advanced Manufacturing for Industrial Decarbonization, Arlington, VA, August 3-4, 2023

Outline

Advanced & Future Manufacturing Programs

AM Research – Industrial Decarbonization

Funding and Collaboration Opportunities

Summary

Advanced Manufacturing

Application of innovative manufacturing technologies to accelerate product development, customize products, increase production efficiency, increase productivity, reduce cost

Advanced Manufacturing (AM) Program

Program Goals

- Support ***basic research*** needed to revitalize American manufacturing, to grow national prosperity and workforce, and to reshape strategic industries
- Seek ***multidisciplinary research*** that fundamentally alters and transforms manufacturing capabilities and practices
- Encourage consideration of approaches ***outside customary manufacturing portfolio*** to bring manufacturing to new applications

Manufacturing Processes

- Processes – Additive / Subtractive / Joining / Forming / Molding / Deformation
- Engineering – Materials / Surface / Interface
- Nanomanufacturing – Top-down (Printing, Imprinting) / Bottom-up (Self-assembly)
- Cybermanufacturing – Network-accessed Computation / Communication / Control
- Biomanufacturing – Bio-incorporated, Bio-inspired, Bio-compatible Structures

Note: Materials research, characterization, analysis and device design and testing will not align with AM program

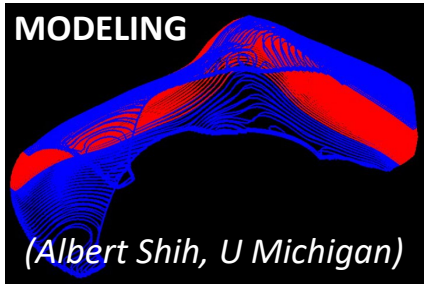
19-088Y: *https://new.nsf.gov/funding/opportunities/advanced-manufacturing-am*

Contact*: AdvancedManufacturing@nsf.gov*

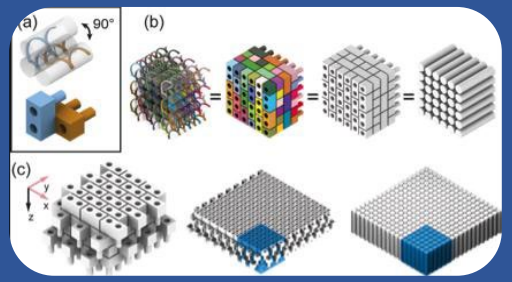
Advanced Manufacturing (AM) Program

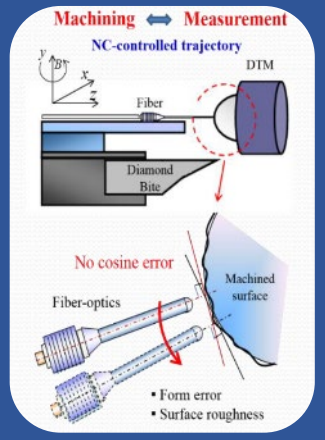
Research

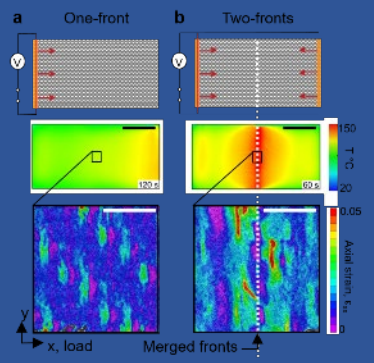
- Processing-Structure-Property Relationships
- Materials and Structure Design
- System Integration
- Modeling, Simulation, DS/ML/AI
- Characterization, Metrology, Machines, Standards



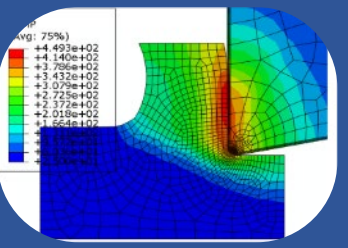
- **Process**—Efficiency, Controllability, Reproducibility, Repeatability, Sustainability, Scalability, Customizability, Affordability
- **Product**—Quality, Durability

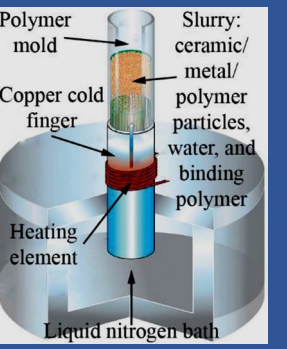

(a)
90°
(b)
(c)

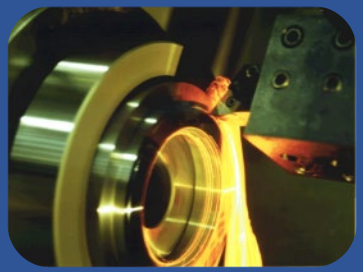

Machining ⟺ Measurement
NC-controlled trajectory
DTM
Fiber
Diamond Bite
No cosine error
Machined surface
Fiber-optics
▪ Form error
▪ Surface roughness

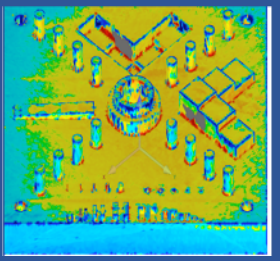

a
One-front
b
Two-fronts
150
T, °C
20
0.05
Axial strain, ε_{xx}
0
120 s
62 s
x, load
Merged fronts

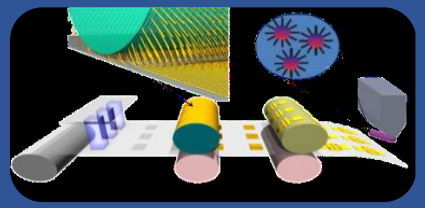

Process
Oxide
Scalable
Mechanisms
Structures
Performance
Engineering
Integrated
Design
Functional
Material
Hybrid
Nanoscale
3D-Printing
Composites
Metal
Modeling
Manufacturing
Additive
Printing
Continuous
Aluminum
Hierarchical
Atomic
Ceramic
Structure
Systems
Devices
Films
Flexible
Fabrication
Chemical
Silicon
Metals
Layer
Interfaces
Nanomaterials
Polymers
Control
Surfaces
Deformation
Assembly
Laser
Energy
Alloys
Thin
Coatings
Self-Assembly
Soft
Electrodes
Multifunctional
Metallic
Friction
Strength
Growth
Welding
Liquid
Materials
Mechanical
Surface
Multi-Scale
Formation
Carbon
Advanced
Sintering
Machining
Processing
Nanoparticles
Nanostructured
Polymer
Nanostructures
Deposition
Properties
Nanocomposites
Nanomanufacturing
Applications

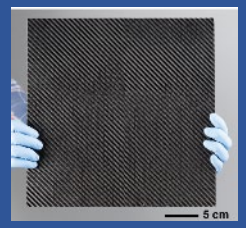


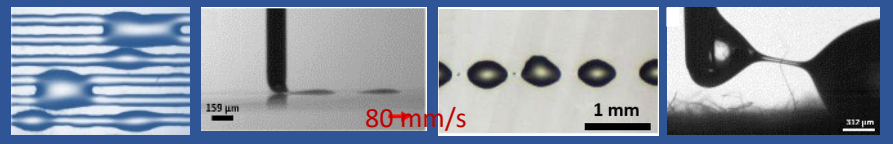

Polymer mold
Slurry: ceramic/ metal/ polymer particles, water, and binding polymer
Copper cold finger
Heating element
Liquid nitrogen bath

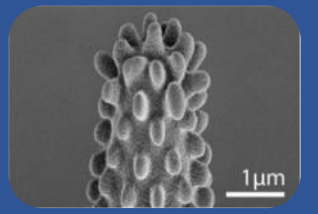


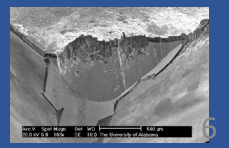





5 cm


159 µm
80 mm/s
1 mm
312 µm


1µm



Collaboration in Advanced Manufacturing (Industry)

Dear Colleague Letter: Supporting Fundamental Research to Enable Innovation in Advanced Manufacturing at Manufacturing USA Institutes

- Encourage proposals that ***address critical fundamental research needs*** in advanced manufacturing in one or more of the Manufacturing USA Institutes' focus areas
- Resulting knowledge can, in turn, ***enable new technologies that feed into the innovation pipelines*** of one or more of the Manufacturing USA Institutes
- Proposals that include a collaboration with a Manufacturing USA Institute and ***leverage the facilities, infrastructure*** and member companies of that Institute are particularly encouraged

17-088 -- *https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf17088*

Collaboration in Advanced Manufacturing (International)

Dear Colleague Letter: NSF and DFG Opportunity for Collaborations in Advanced Manufacturing

International collaborations between U.S. and German institutions in areas of interest to ***NSF's Advanced Manufacturing Program and DFG's 401 Production Technology and Materials Engineering Review Boards***

Review Criteria:

- Mutual benefit(s);
- True intellectual collaboration among all participating partners;
- Benefits to be realized from the expertise/specialized skills, facilities, sites and/or resources of the international counterparts;
- Active research engagement of students and early-career researchers, where such individuals are engaged in the project

22-013 -- *https://www.nsf.gov/pubs/2022/nsf22013/nsf22013.jsp*

Future Manufacturing (FM) Solicitation

Goal: Support fundamental research and education of a future workforce to overcome scientific, technological, educational, economic, and social barriers in order to ***catalyze new manufacturing capabilities that do not exist today***

Three Thrust Areas:

- Cyber manufacturing
- Eco manufacturing
- Bio manufacturing

Two Tracks:

- **FMRG** - up to $3,000,000 for up to four years
  - ***Fundamental, multidisciplinary, and integrative research and education*** to enable future manufacturing
  - Prospective vision for ***translation of fundamental research results to manufacturing practice***
  - ***Potential benefits and challenges*** of new manufacturing to the economy, environment, communities and to society as a whole
- **FMSG** - up to $500,000 for up to two years
  - Initiation of research and educational activities that could provide the ***basis for a subsequent proposal for an FMRG***

Inquiries: *futuremanufacturing@nsf.gov*

23-550 -- *https://beta.nsf.gov/funding/opportunities/future-manufacturing-fm*

Future Manufacturing (FM) Solicitation

- **Cyber manufacturing**
  - Research that transforms the ***predictability, security, reliability and efficiency*** of manufacturing
  - Opportunities at ***intersection of computing and manufacturing***
  - ***AI/ML/DS, CPS, IIoT,*** to rethink, reconceptualize, reinvent, and explore new possibilities
- **Eco manufacturing**
  - Research that redesigns manufacturing ***lifecycles and supply chains for sustainability***
  - Holistic manufacturing processes that account for ***energy consumption, health and environmental impact, and cost effectiveness***
  - Manufacturing processes for products that ***degrade naturally or on cue, or can be re-purposed without harmful byproducts***
  - Keep resources in use as long as possible, extract their maximum value while in use, and ***recover materials at the end of their service life***
- **Bio manufacturing**
  - Research that ***harnesses biology and/or integrates biological materials*** in manufacturing
  - Biologically based production of ***materials and biomaterials*** such as therapeutic cells, chemicals, pharmaceuticals, polymers, and fuels, and bio-based technologies for computing, signal processing and communication ***devices***
  - ***Benefit personalized healthcare, sustainable energy, environmental sustainability, and society***

AM Research - Industrial Decarbonization

Research: *Sustainability, Manufacturing Efficiency, Energy Efficiency, Less Material Waste, Environmentally-friendly Materials, Materials for Clean Energy, Zero Defects …*

Improving the sustainability of omni-present casting via 3D Sand-Printing (NSF CAREER# 1944120)
→ Reimagining the fundamentals of foundry science to reduce casting defects
PI: Guha Manogharan

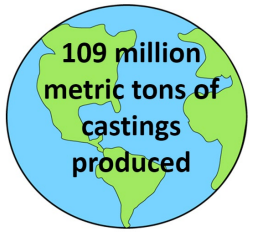
AFS industry impact report 2019

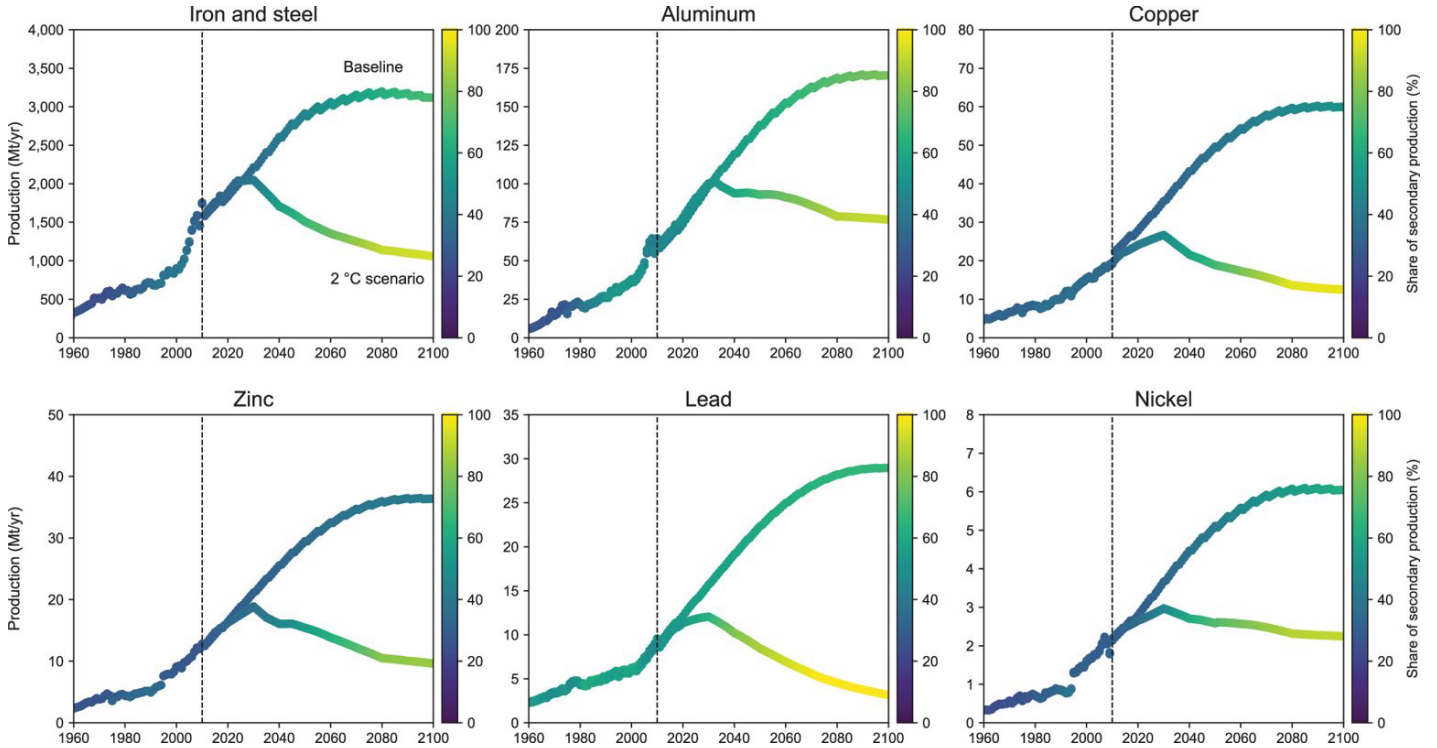
United States

Total Jobs: 490,000+

Wages: $32 Billion

Total Economic Impact: $110 Billion

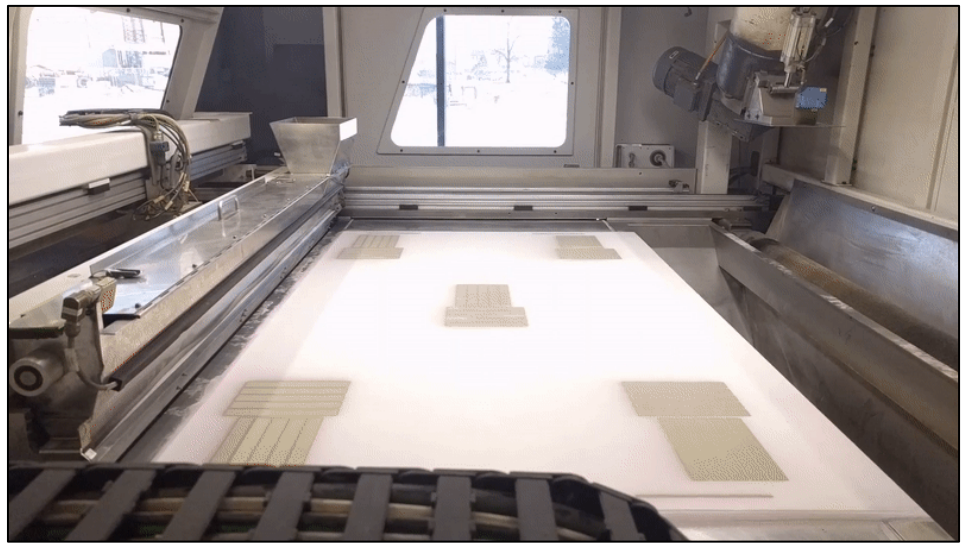


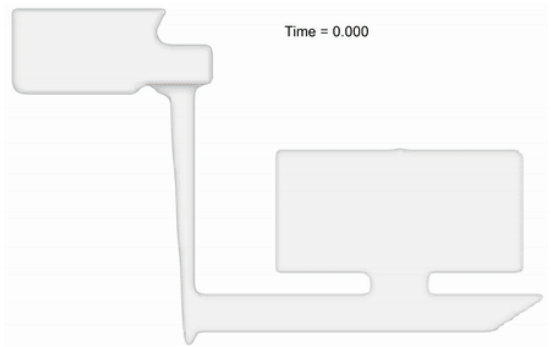


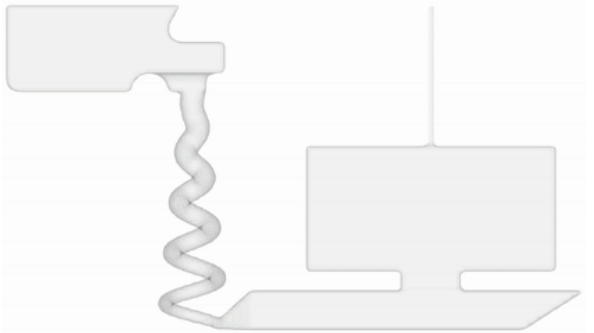
Production activities for six major metals, 1960-2100. The shade of the line color represents the ratio of secondary production to total production. The 2 °C scenario shows a case assuming increased end-of-life recycling rate and product lifetime (Ref: https://pubs.acs.org/doi/10.1021/acs.est.0c02471.)

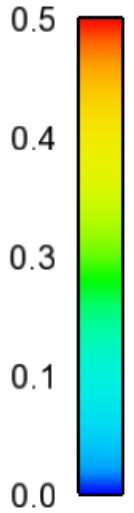
By 2025, it estimated that a loss of over 8 billion USD will be due to 87% scrap rate from casting defects caused by turbulent flow and feeding defects in conventional sand casting

3D Sand-Printing offers an economically viable method to reduce casting defects → reduce energy and cost to scrap/rework castings with defects



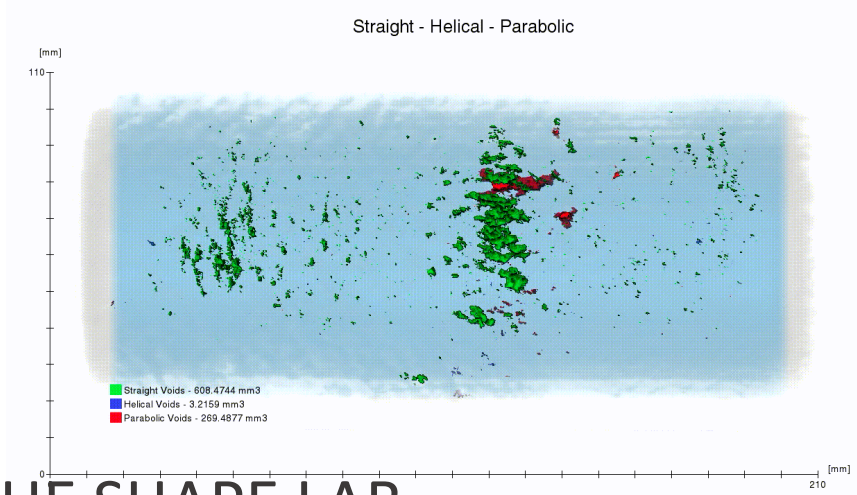




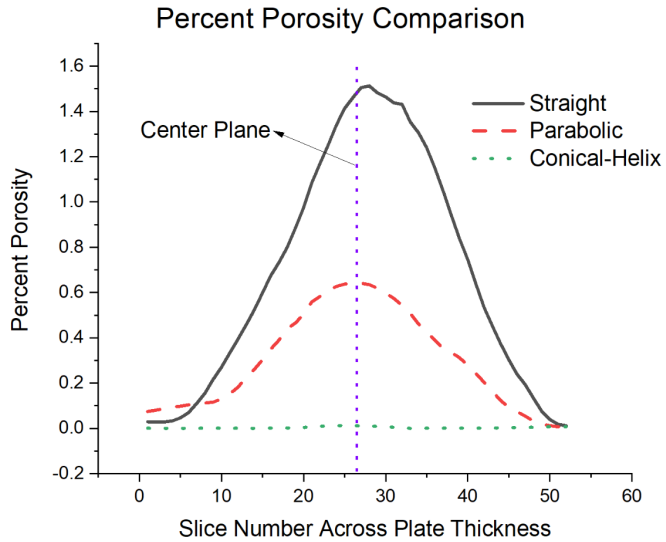


Velocity (m/s)

CFD



CT Scans



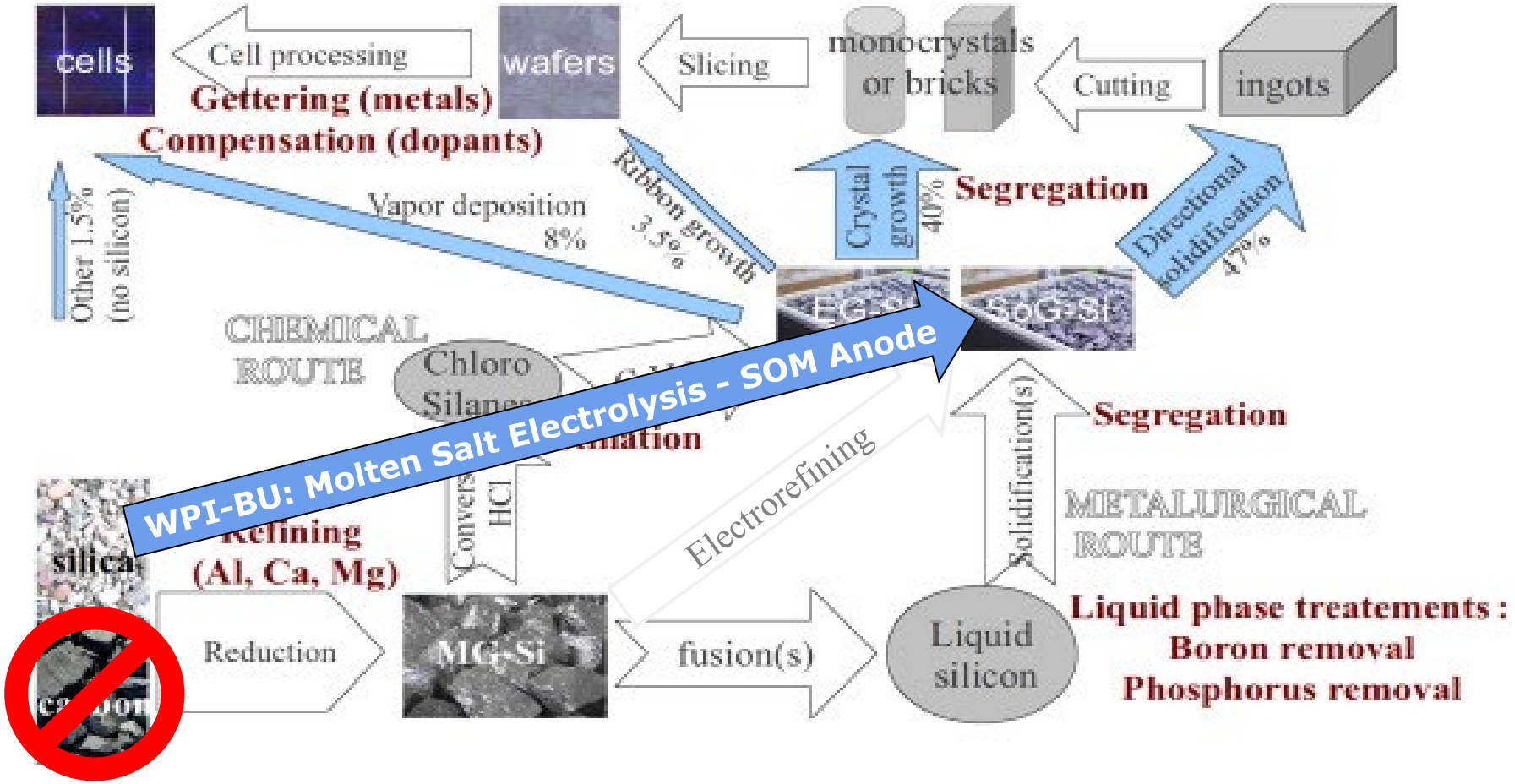
Apply digital technologies – 3DSP, in-line process monitoring, embedded sensors, real-time data analytics to lead metal casting to sustainability
- Review article

Solar Silicon Production – PI: Adam Powell (WPI)

Chemical (Siemens):
- Many steps
- Direct CO_2 emissions
- Energy-intensive
  300 kWh/kg

Metallurgical (slag, liquid metal, electrorefining):
- Fewer steps
- Direct CO_2 emissions
- 60-100 kWh/kg

WPI-BU molten salt electrolysis:
- One step
- Zero CO_2 emissions
- 30 kWh/kg



Faculty: Adam Powell, Yu Zhong (WPI), Uday Pal (BU) Postdoc: Mohammad Asadikiya (WPI → startup SilarTek, LLC)
PhD students: Aditya Moudgal, Haoxuan Kyle Yan, Yifan Zhang
Undergraduates: Sarat Buasai, Alexander McMahon, Yi-Jie Wu, Lucien Wallace, Gabriel Espinosa, Jacob Hazerjian, Ariana Ly, Vicky Luu, Alexander Alonzo, Andrew Charlebois, Evan Costa, Peter Catalino, Tyler Melo
NSF Awards 1937818, 1937829

FMRG Projects Addressing Industrial Decarbonization

Title/Objective	PI	Institution
FMRG: Eco: A Systems-Enabled Paradigm Shift for Modular Sustainable Chemical Manufacturing - Move a predominant raw material base for chemical manufacturing from non-renewable to renewable substrates	Marianthi Ierapetritou	University of Delaware
FMRG: Eco: Process-Structure-Property Relationships of 3D Printed Earth Materials and Structures - Optimal mix designs for 3D printed earth materials and structures as sustainable alternatives to cementitious materials	Lola Ben-Alon	Columbia University
FMRG: Threading High-Performance, Self-Morphing Building Blocks Across Scales Toward a Sustainable Future - Sustainable, self-morphing building blocks from nano to macro scales inspired by biological systems to devise novel manufacturing processes of highly efficient multi-scale structures and components	Shu Yang	University of Pennsylvania
FMRG: Eco: CAS-Climate: Sustainable Manufacturing Using Living Organisms and Agriculturally Derived Materials - 3D printing methods to manufacture environmentally friendly products using living organisms (algae, bacteria, and fungi) and agriculturally derived materials (biomass and corn plastics)	Zhijian Pei	Texas A&M University
FMRG: Digital Light Manufacturing for the Circular Economy - Synthesize monomers from biomass sugars, design them to make polymers recyclable, use DLM to 3D print high-quality parts	Jay Keasling	University of California-Berkeley
FMRG: Manufacturing ADvanced Electronics through Printing Using Bio-based and Locally Identifiable Compounds (MADE-PUBLIC) - Print biodegradable, and recyclable electronic devices using locally identifiable resources, such as bio-based materials derived from plants	Junhong Chen	University of Chicago
FMRG: Eco: CAS-Climate: Reimagining Cement Manufacturing for Carbon Neutrality (NeutraCEM) - Cement production through solar energy-powered, two-stage process: (1) electrochemical decarbonation process to produce lime without carbon dioxide release; and (2) ultrafast high temperature synthesis	Narayanan Neithalath	Arizona State University
FMRG: Eco: Sustainable Route to 3D Solid-State Sodium-ion Battery by Direct Ink Writing and Capillary Rise Infiltration - 3D printed Li- and Co-free 3D solid-state Na-ion batteries containing polymer composite solid electrolyte and electrodes made of Earth-abundant elements	Eric Detsi	University of Pennsylvania
FMRG: Eco: Future Eco Manufacturing of Recyclable Soft Electronics - Manufacturing of recyclable soft electronics by seamlessly integrating a select group of biodegradable, recyclable materials, guided by economic and environmental life-cycle assessment	Yong Zhu	NC State University
FMRG: Eco: Cyber Enabled Transformation to Circular Supply Chains for Sustainable Pharmaceutical Manufacturing Networks - Enable design of zero waste pharmaceutical manufacturing networks using integrative approach focused on novel process chemistry and separation methods, macroscale modeling of the networks to integrate new processes, and a dedicated cyberinfrastructure	Shweta Singh	Purdue University

Impacts of FMRG Projects

- Change chemical manufacturing
  - Sustainability
- Earth materials as alternatives to cement
  - Climate-friendly digital manufacturing of built environment
- Biology-inspired building blocks
  - Low-cost, high-performance structural components for reuse, repurposing, upcycling
- Use living organisms and agriculture biomass
  - Environmentally friendly products and their manufacture
- Recyclable polymers
  - Replace petroleum-based plastics
- Recyclable electronics
  - Resilient supply chains due to use of locally identifiable resources
- Decarbonization of cement manufacturing
  - Slash CO_2 emissions
- Earth-abundant battery materials
  - Sustainable processes such as 3D printing
- Recyclable soft electronics
  - Renewable materials using energy-efficient manufacturing processes
- Zero waste pharma manufacturing
  - Circular supply chains

Funding and Collaboration Opportunities Relevant to Industrial Decarbonization

Climate Change

Dear Colleague Letter: CiviL Infrastructure research for climate change Mitigation and Adaptation (CLIMA)

Goal: Convergent civil infrastructure research on transformative ideas that contribute equitable ***solutions to climate change mitigation and/or adaptation***

Fundamental approaches drawing from multiple fields to create pathways to ***infrastructure and community resilience, social equity, and improved long-term performance***

Topics of Interest:

- Green construction, operation, and maintenance of civil infrastructure
  - ***Locally sourced materials, distributed manufacturing, modular manufacturing***
- Smart civil infrastructure for health, security, and economic growth
  - Integration of ***engineering and nature-based solutions*** for healthier cities
- Sustainable and integrated civil infrastructure systems
  - ***Use-inspired advanced materials and manufacturing concepts***, e.g., programmable matter and structures and ***living engineered materials***
- Climate change-informed design and systems science methods
  - New systems modeling methods that accommodate climate mitigation and adaptation strategies

Participating Programs: ECI, AM, EDSE, DCSD, OE, HDBE, MoMS, CIS, MSI

23-079*: https://www.nsf.gov/pubs/2023/nsf23079/nsf23079.jsp*

Inquiry: *clima@nsf.gov*

Clean Energy

Dear Colleague Letter: Clean Energy Technology RAISE or EAGER Proposals

Definition: Clean energy (1) energy saved through increased ***energy efficiency and conservation measures*** for existing technologies, (2) energy derived from renewable sources ***(biomass, geothermal, wind, hydropower, tidal power, and solar)***

Goal: **(1)** Advances in custom-designing and producing materials for ***energy-efficient technologies, electrification*** of transportation sector and the chemical industry. (2) New approaches to ***harnessing energy from renewable sources in green and sustainable ways*** to achieve a ***carbon-neutral and equitable economy***

Topics of Interest:

- Hydrogen, fusion, and/or geothermal technologies
- Industrial heat and/or energy efficiency technologies
- Fundamental challenges of enabling offshore wind/wave technologies
- Critical materials for clean energy technologies - their recovery, reuse, and recycling
- Net-zero fuels and bioenergy
- Education and workforce development efforts

Participating Directorates: ENG, MPS, BIO, CISE, GEO, SBE, EDU, TIP

23-109: *https://www.nsf.gov/pubs/2023/nsf23109/nsf23109.jsp?org=NSF*

Inquiries: *CET_DCL_EAGER@nsf.gov.; CET_DCL_Raises@nsf.gov.*

Sustainability

Critical Aspects of Sustainability (CAS) Solicitation

- Research that improves the ***efficiency with which natural resources are used*** to meet human needs for products and services
- Sustainability research encompassing the ***design, manufacture and use of efficient, effective, safe and more environmentally-benign products and processes***

Participating Directorates: *ENG, MPS, BIO, GEO*

21-9102: *https://new.nsf.gov/funding/opportunities/critical-aspects-sustainability-cas*

Dear Colleague Letter: Critical Aspects of Sustainability: Innovative Solutions to Climate Change (CAS-CLIMATE)

Research that aids in ***Nation's goal of reaching net-zero greenhouse gas (GHG) emissions*** and approaches for adapting to change that is already occurring

Research in ***advanced manufacturing to reduce GHG emissions and energy use***

- Improved or new approaches that ***reduce energy use and energy waste relevant for manufacturing, recycling, and upcycling***
- Innovations in major ***energy-consuming technologies such as desalination, cement manufacturing, and metal production*** (refining and smelting); reduction in energy use and increased energy efficiency in manufacturing through changes in processing, use of data analytics, and ***near-final form fabrication***

Participating Directorates: *ENG, MPS, BIO, GEO*

21-124: *https://new.nsf.gov/funding/opportunities/critical-aspects-sustainability-cas-innovative*

Inquiries: *cas@nsf.gov*

Other Funding and Collaboration Opportunities

New

Manufacturing Systems Integration (MSI)

Digital integration of design and manufacturing within the larger life cycle ecosystem

New

DCL: Next Gen Supply Chains

Understand global supply chains, ability to provide industrial goods, critical healthcare, consumer products, and key services

Cross-cutting

Inter-disciplinary (LEAP HI, DMREF, EFRI); Computation (CPS, CSSI, CDS&E); Instrumentation (MRI); Infrastructure (MsRI)

Engineering Research Centers (ERCs)

HAMMER

New

International

ENG-EPSRC, US-Ireland-No Ireland, NSF-GACR, NSF-BSF, NSF-SNSF, **AccelNet**

Career Advancement

CAREER
BRITE
ERI

Industry

GOALI
IUCRC
INTERN SUPP
INTERN AFRL SUPP
SBIR/STTR
PFI

NSF Regional Innovation Engines program selects 16 teams for the final round of competition

August 2, 2023

Advanced Agriculture

Advanced Manufacturing/Building Construction

Advanced Materials

Aerospace

Bioeconomy

Blue Economy/Circular Economy

Climate and Resilience

Health & Wellness

Microelectronics and Semiconductors

Quantum

Sustainable Energy

Water Sustainability

REMADE Mission:

Reduce embodied energy and carbon emissions through early stage applied research and development and accelerating the transition to a Circular Economy

Strategic Goals:

Develop **transformational technologies** that enable U.S. manufacturers to:

- Expand Recycling, Recovery, Remanufacturing and Reuse
- Reduce Primary Materials Consumption
- Increase Utilization of Secondary Materials
- Lower Consumption and Emissions
- Achieve Cost and Energy Parity between primary and secondary materials

DCL-Supporting Fundamental Research to Enable Innovation in Advanced Manufacturing at Manufacturing USA Institutes

Summary

NSF – Fundamental Research

Advanced & Future Manufacturing

AM/FM - Industrial Decarbonization

Funding and Collaboration Opportunities

- Programs, Solicitations, DCLs
- TIP – NSF Engines
- REMADE

Thank you!

khcooper@nsf.gov