



SCIENCES OF EXTREME MATERIALS

ARMY RESEARCH DIRECTORATE

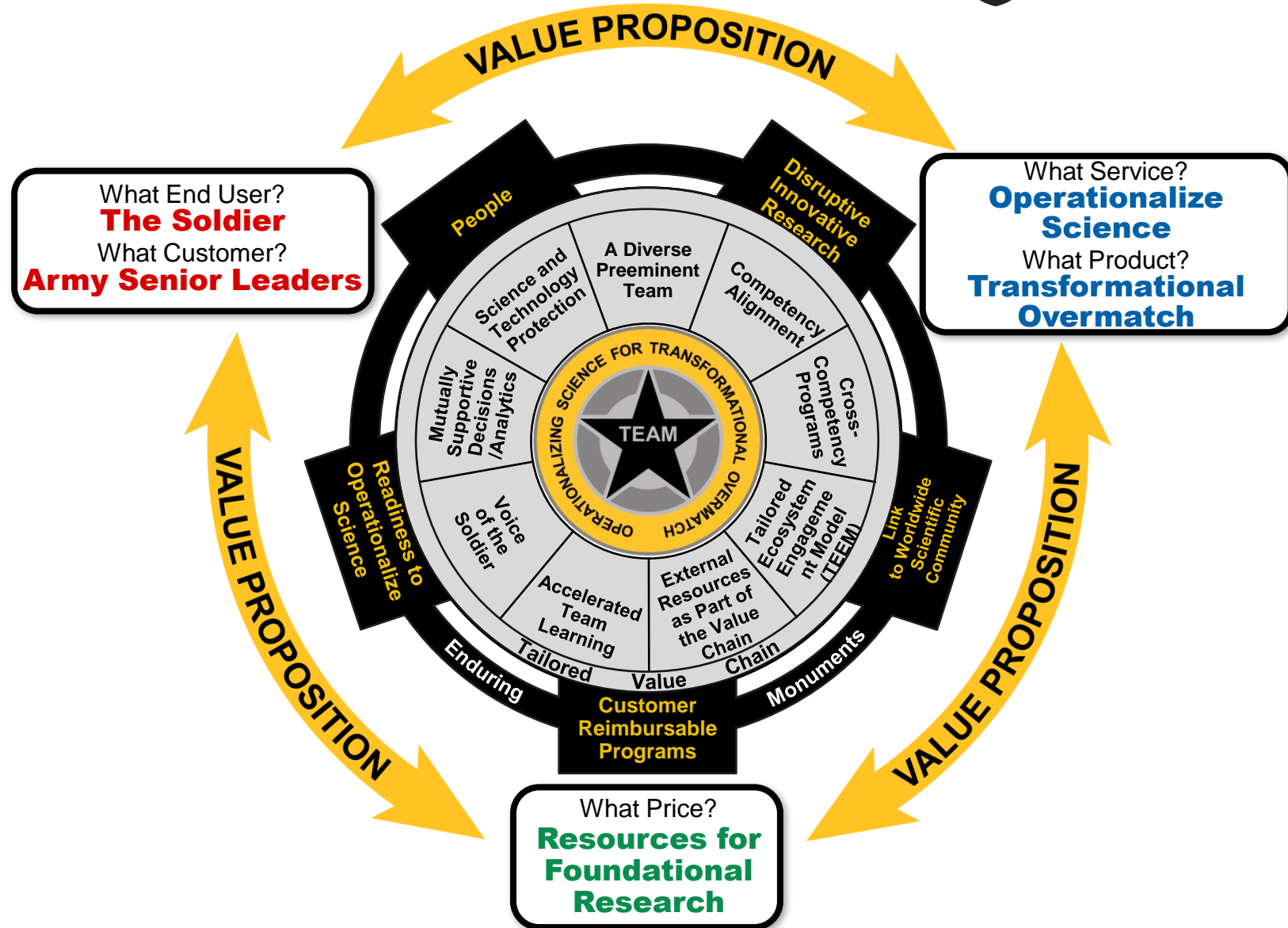
DEVCOM Army Research Laboratory

**INTRODUCTION AND
OVERVIEW**

WIN THE COMPETITION TO OPERATIONALIZE SCIENCE



- **Global competition** with global stakes
- **Competition today will define landscape in 2040+**
- **Purpose of a lab**
 - Create / Exploit scientific knowledge
 - Provide expert advice
- **Strategy: Maximize unique value delivered for Army**



ARMY FUTURES COMMAND



DEVCOM MET

- LIFE CYCLE ENGINEERING
- APPLIED S&T
- ANALYSIS
- FOUNDATIONAL RESEARCH

PURPOSE

U.S. Army Futures Command (AFC) exists to transform the Army to ensure war-winning future readiness.

FOCUS

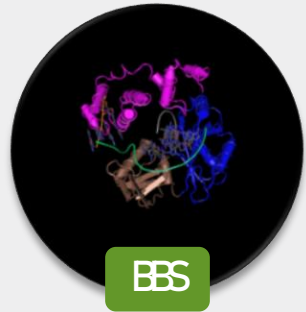
AFC currently focuses on three overarching priorities: **prioritizing people, designing Army 2040 and delivering Army 2030.**

IMPACT

The groundbreaking work of AFC's headquarters directorates, subordinate commands, research laboratories, innovation hubs and Cross-Functional Teams is **advancing the Army's six modernization priorities**: long range precision fires, next generation combat vehicle, future vertical lift, air and missile defense, network and soldier lethality.



ARL RESEARCH COMPETENCIES



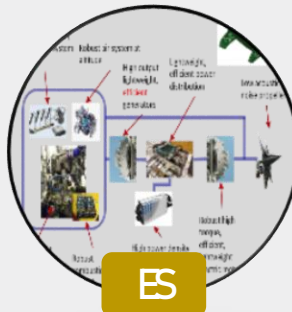
BBS

Biological and
Biotechnology
Sciences



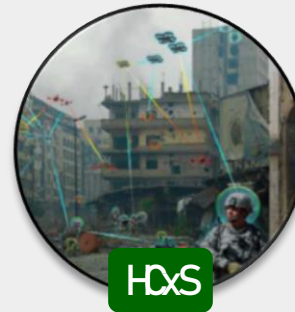
EMSS

Electromagnetic
Spectrum Sciences



ES

Energy Sciences



HCS

Humans in
Complex Systems



MS

Mechanical
Sciences



MS

Military Information
Sciences

Competency-aligned Intramural and Extramural Foundational Research



NS&CS

Network, Cyber, and
Computational Sciences



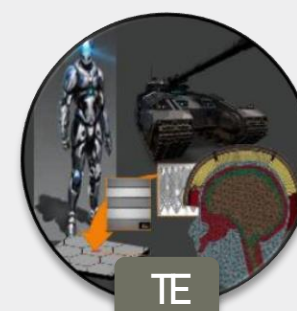
PE&QS

Photonics,
Electronics, and
Quantum Sciences



SEM

Sciences of
Extreme Materials



TE

Terminal Effects



WS

Weapons Sciences

ARMY RESEARCH LABORATORY



- ARL operates as an enterprise with three main organizational functions
- Integration by competencies is key to executing DEVCOM's foundational research mission

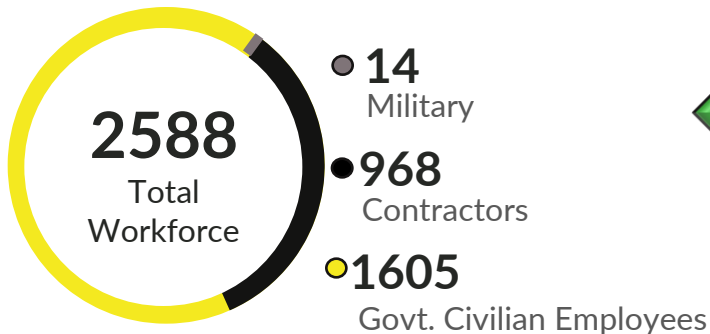
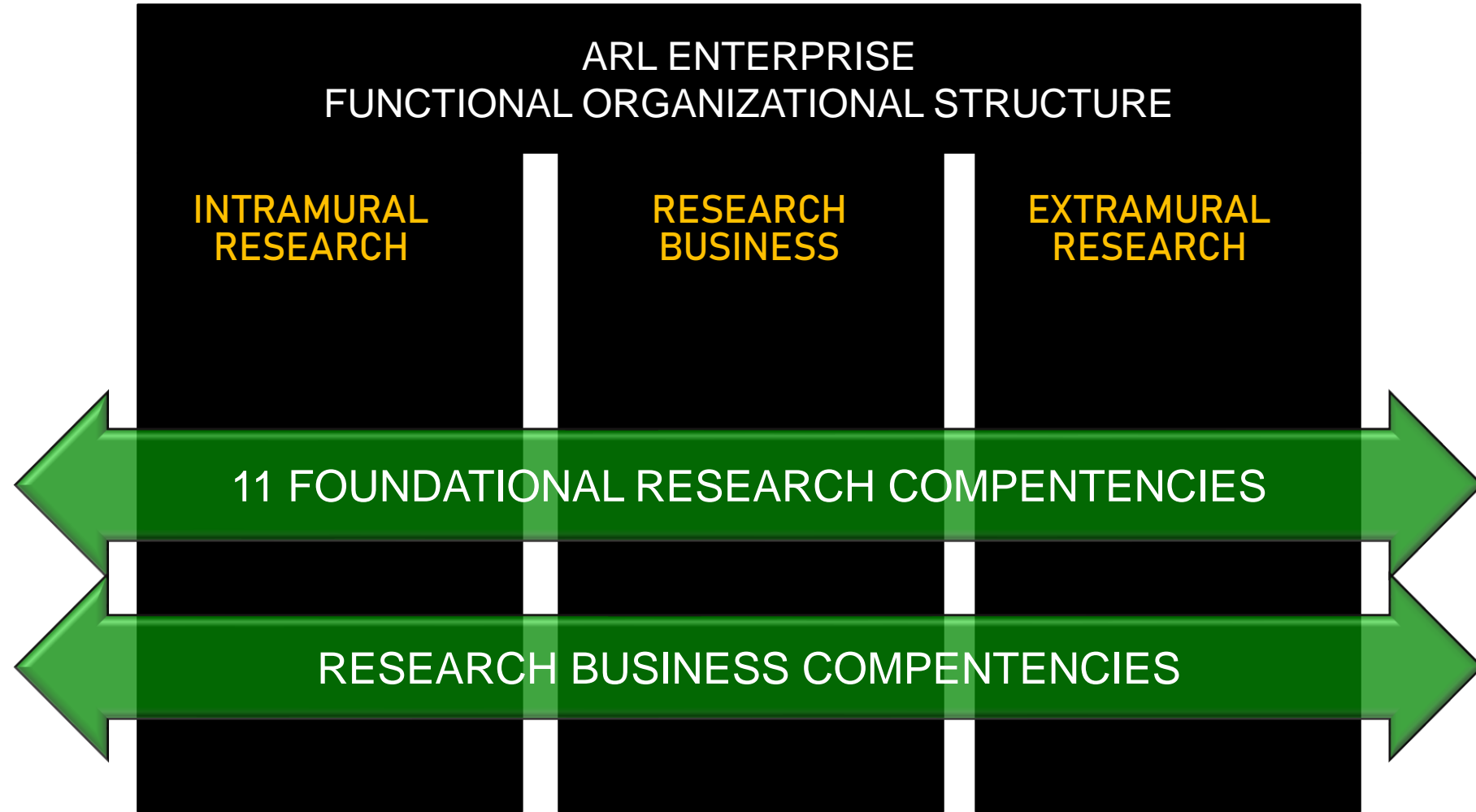


Diagram as of FY22



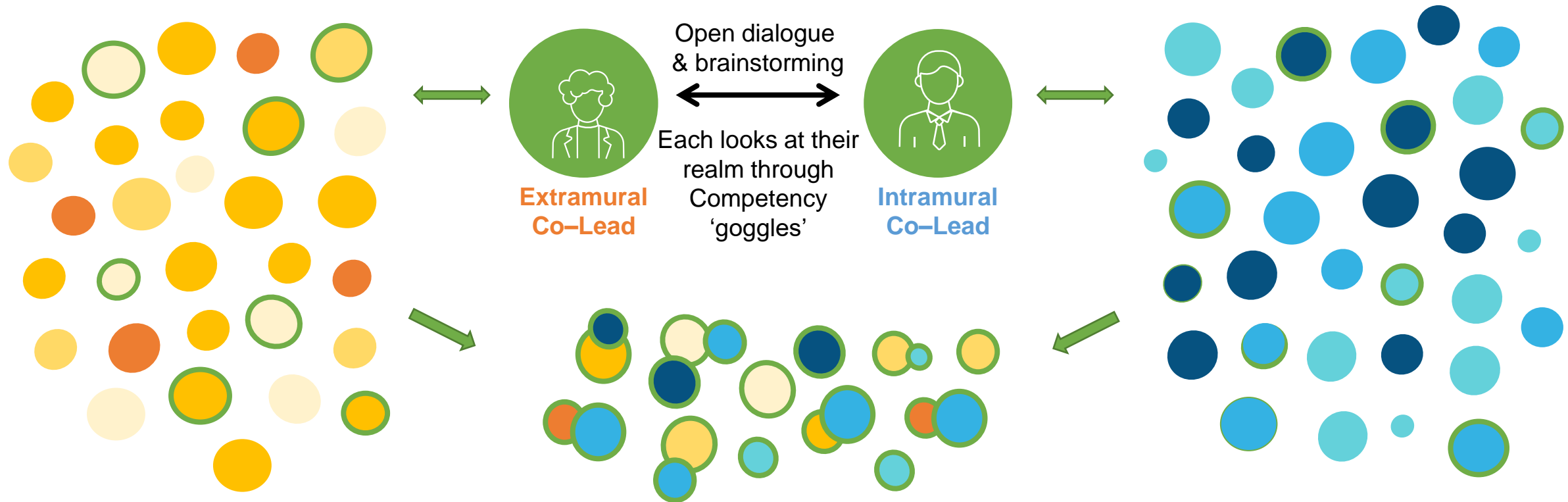
VISION: MANAGING BY COMPETENCIES



Realm of EXTRAMURAL
(Academic) Research

ARL Competency Co-Leads facilitate
Realm of INTEGRATED RESEARCH

Realm of INTRAMURAL
(In-House) RESEARCH



Each Co-Lead searches their domain for opportunities, including **talent management, research initiatives,** and new **points of interaction** from small studies to large partnerships

ARL ARMY-UNIQUE EXPERIMENTAL FACILITIES



Aberdeen Proving Ground



Materials Research Laboratory

- Human Variability and Behavior
- Human Capability Enhancement
- Integration of Humans and Systems
- Materials and Manufacturing Science
- Soldier and Vehicle Protection
- Battlefield Injury Mechanisms
- Assessment and Analysis Methodologies
- Enhanced Lethality Concepts
- Energy and Propulsion
- Platform Mechanics
- Vehicle Intelligence
- Computational Modeling of Complex Systems
- Real-Time Scalable Data Analytics



Transonic Experimental Facility



ARL Center for Advanced Polymer Processing (ACAPP) Infrastructure



Mechanical Sciences Research Laboratory



Information for Mixed Squads (INFORMS) Laboratory



Cold Spray Laboratory



Additive Manufacturing Science Center

Adelphi Laboratory Center



Zahl Physical Sciences Laboratory



Network Science Research Laboratory



Energetics Laboratory



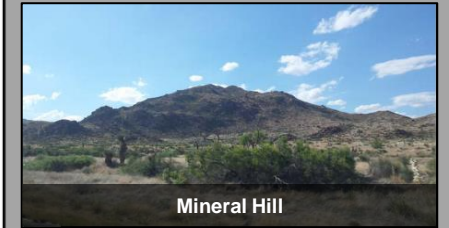
Specialty Electronic Materials and Sensors Cleanroom



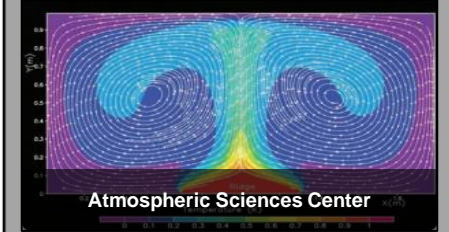
Quantum Network Laboratory

- Biotechnology
- Power and Energy
- Electronics
- Photonics
- Cyber Threat Detection and Analysis
- Autonomous Sensing
- Atmospheric Modeling
- Text and Video Analytics
- Sensor and Information Fusion
- Multimodal Sensing and Processing

White Sands Missile Range



Mineral Hill



Atmospheric Sciences Center

- Weapons Systems
- Communications & Networks
- Battlespace weather & environmental effects
- Computational science and engineering

Grace's Quarters



Robotics Research Collaboration Campus



A National asset in robotics research: A 700 Acre collaborative research campus supporting robotics, AI, autonomy, and teaming research for multi-domain operations across land, air, sea, and cyber

SEMD RESEARCH PORTFOLIOS



Super Materials

PM: Dr. Victoria Blair

- Materials synthesis, processing and characterization of structural materials which perform in high temperature, highly dynamic chemical, mechanical, and thermal environments.
- [Link to ARL BAA](#)

Invincible Materials

PM: Dr. Kris Behler

- High strain rate and impact-resistant materials, processes and advanced manufacturing
- Emerging materials for structural, chemical, biological, directed energy protection.
- [Link to the ARL BAA](#)

Invisible Materials

PM: Mr. Dan DeBonis

- Material systems with selectable/tunable radiative, convective and conductive heat transfer.
- Modeling of phononic coupling at materials interfaces using DFT-MD.
- [Link to the ARL BAA](#)

Foundational Research

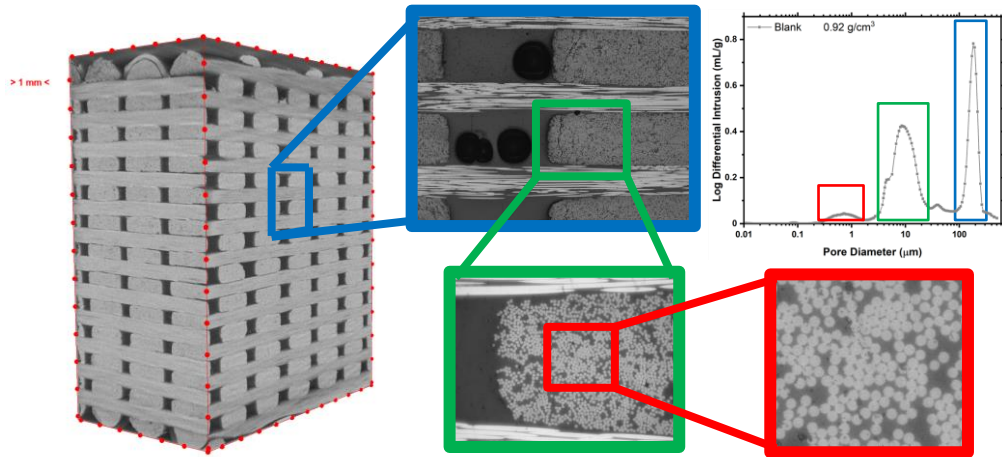
PM: Dr. Scott Weingarten

[Link to the ARL BAA](#)

Super Materials PORTFOLIO



How might we increase range, lethality and integrity through foundational materials science and manufacturing?



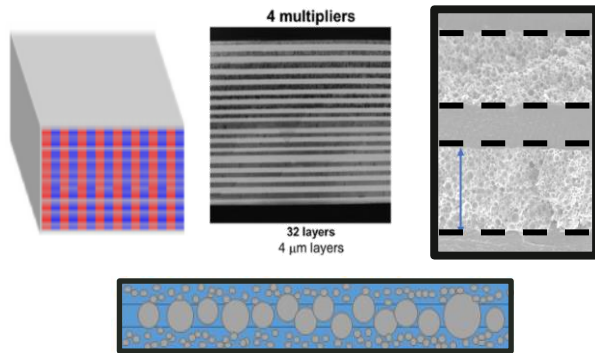
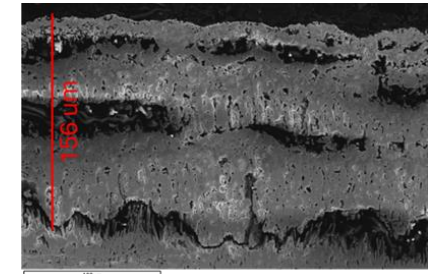
Identify processing, property and microstructural relationships of high temperature materials.



Develop near-net shape manufacturing approaches.



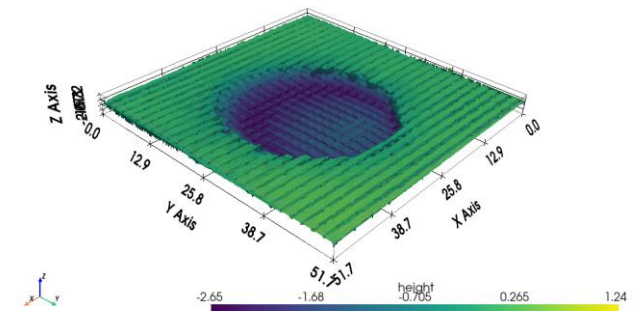
Assess materials performance at high temperatures and extreme environments.



Optimization of polymer and particulate loaded structures



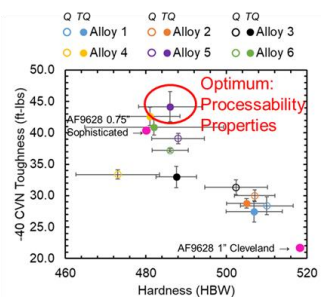
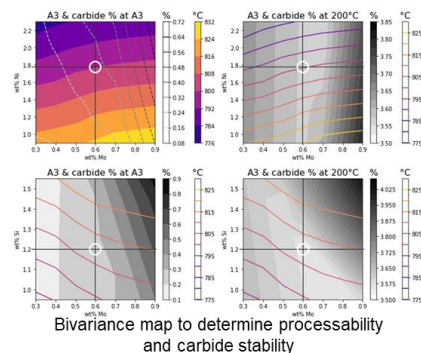
Mechanical characterization of architecture materials.



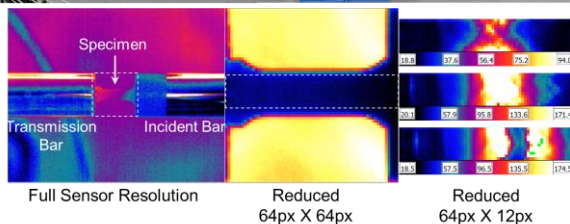
INVINCIBLE MATERIALS



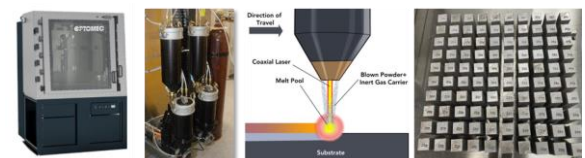
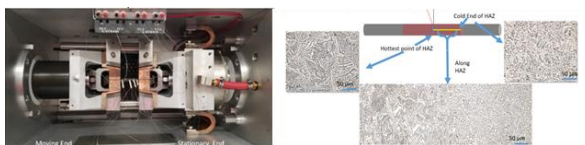
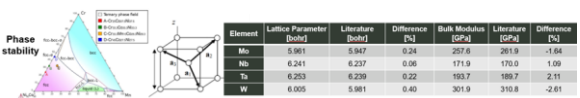
Alloys for Protection



Dynamic Failure of Metals



Metastable Functional Materials

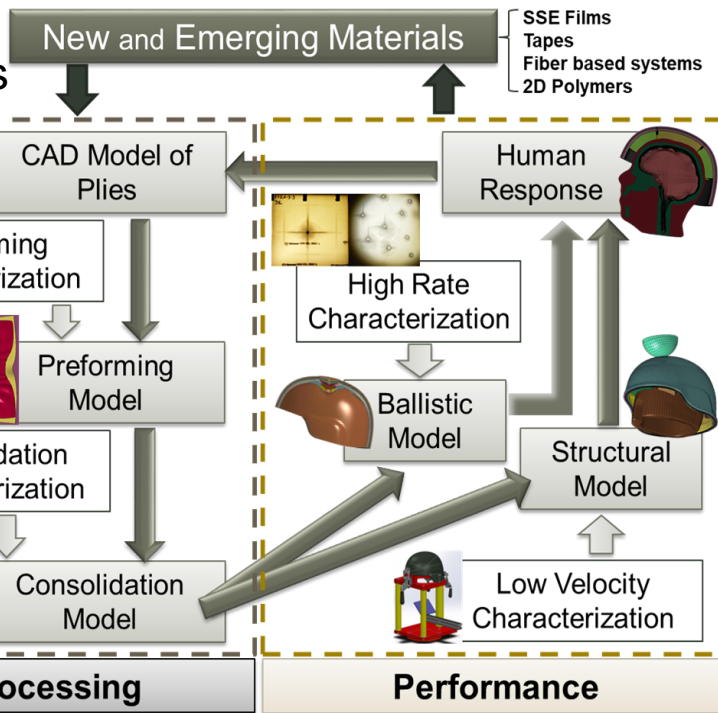


10 December 2024

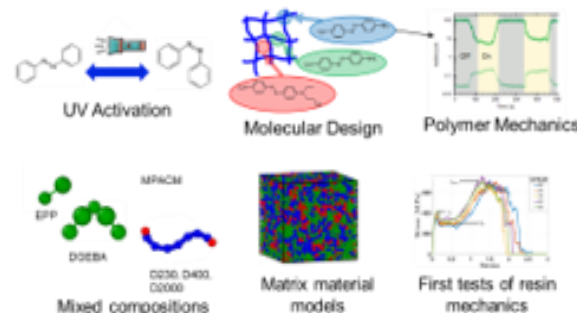
Next Gen Thermoplastics



Wikipedia.com

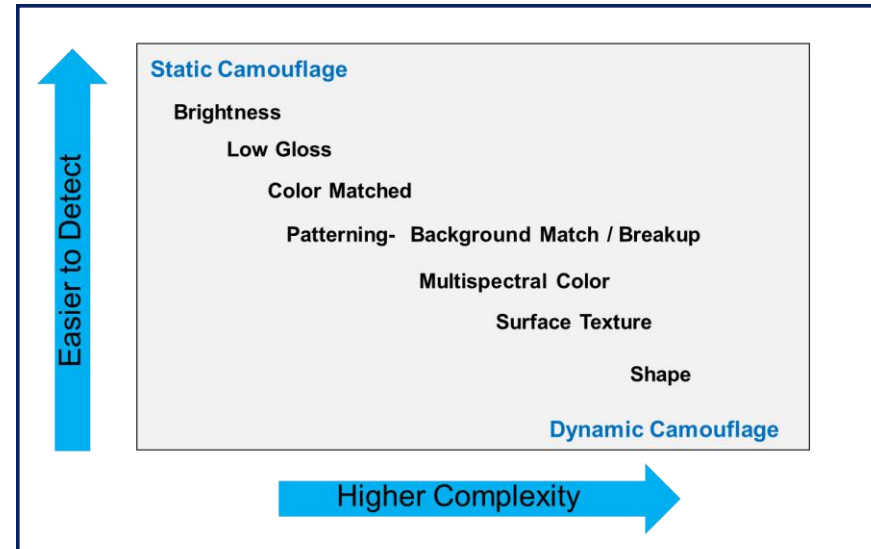
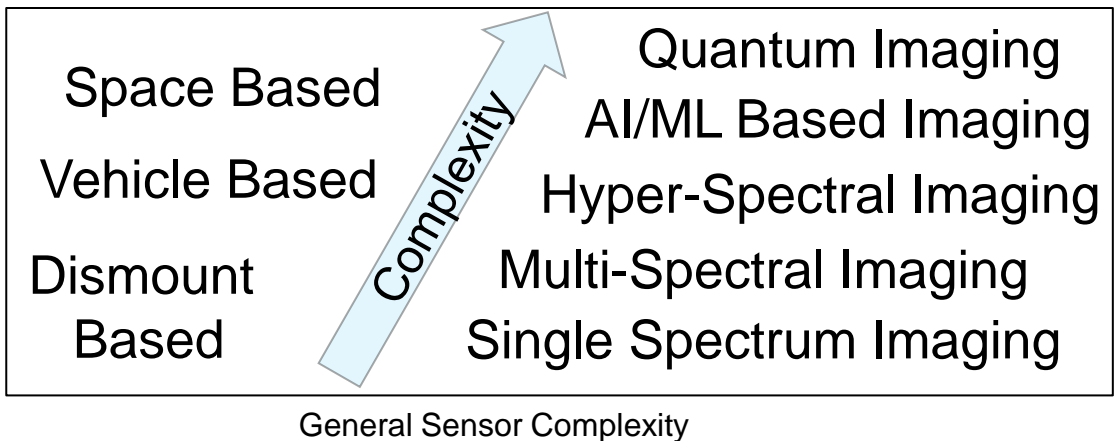
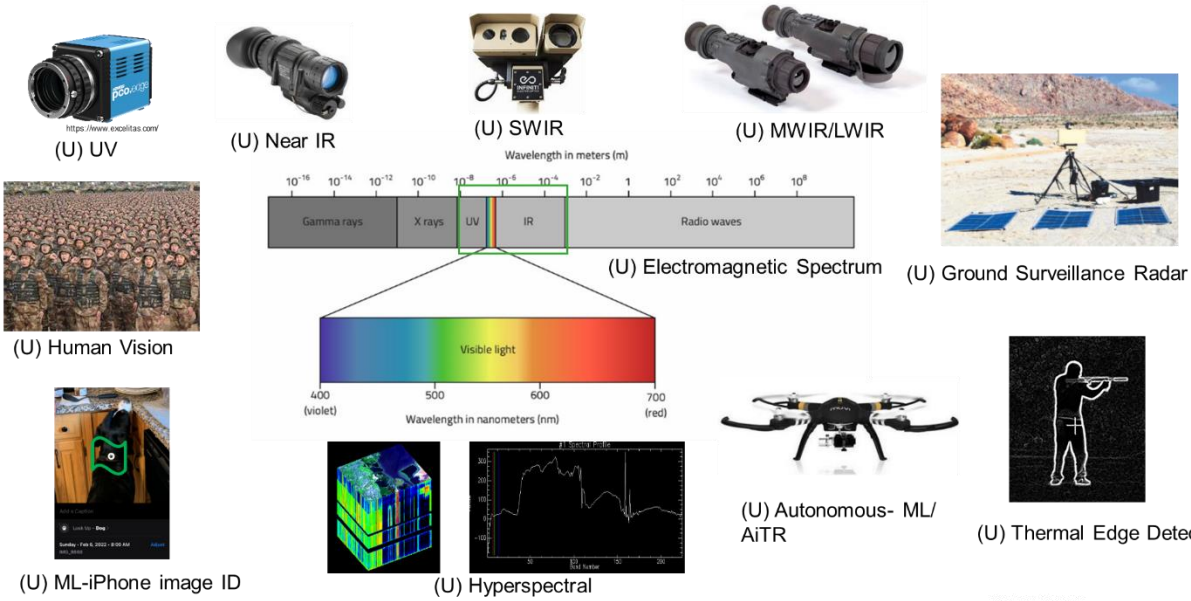


Adaptive Resins and Lightweight Composites



Invisible Materials

(U) SENSOR THREATS



- Arctic
- Counter UAV
- Counter AiTR
- Camouflage Coatings
- Thermal Materials
- SWIR/NIR Materials
- Hyperspectral Materials
- Biological Materials
- Light Weight Composites
- Advanced Surface Effects
- Autonomy
- Patterns of Life

CERAMICS AND TRANSPARENT MATERIALS

Branch Expertise

- Synthesis and processing of opaque and transparent ceramics/glasses
- Advanced manufacturing science for development of heterogeneous multi-scale ceramics and interfaces
- Thin film deposition for development of functionalized particles, coatings, and surfaces
- High-throughput simulation, ML and design optimization for processing-structure-property relationships
- High-throughput non-destructive evaluation and characterization

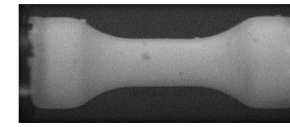
Experimental Facilities

Processing

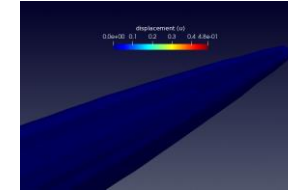
- Hot press capability (lab and pilot scale, up to 100 ton, 2200°C)
- Hot-isostatic press (HIP) capability (pilot scale, 206 MPa, 2000°C)
- Pressureless sintering capability (up to 2800°C)
- Transparent Ceramics (glove box w/ furnace passthrough)
- Additive Manufacturing (heterogeneous DIW, Binder Jetting, SLA)
- Thermomagnetic Processing System (FY24, 9 T, 2000°C)
- Laminate Processing (RF Press, Cleanroom)

Characterization

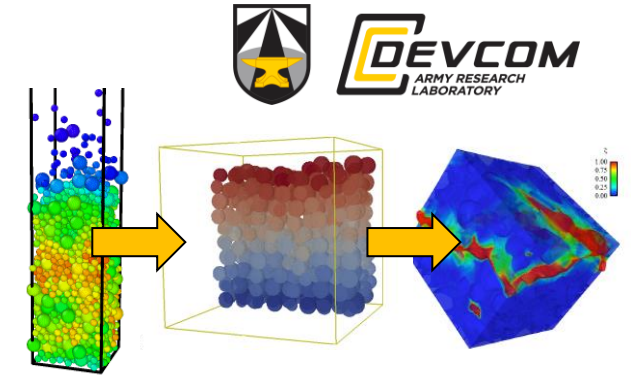
- Analytical – XRD, XRF, SEM, TEM, RBS, Raman spectroscopy
- Mechanical – Quasi-static and dynamic load frames, hardness
- NDE – Contact ultrasound, RUS, impedance spectroscopy
- Ballistic (gas-driven) range with high-speed imaging/DIC
- Automated, instrumented oxy-acetylene torch test rig (FY24)



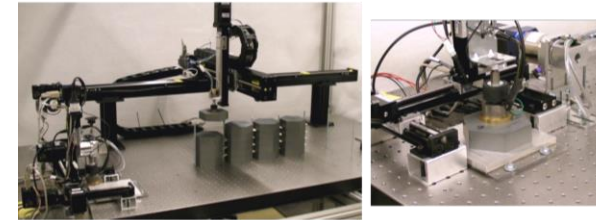
Dynamic compression testing of ceramics



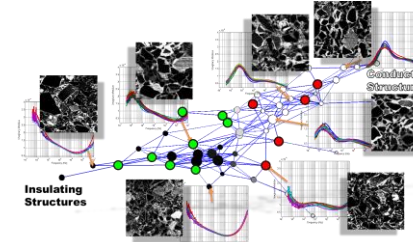
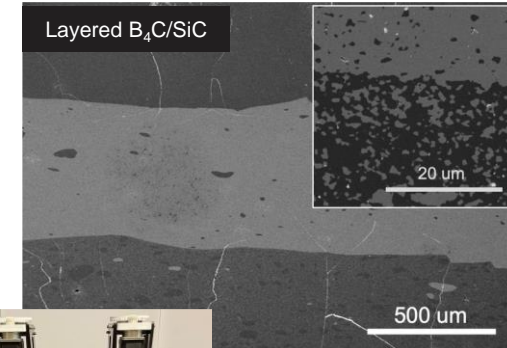
Densification Process Modeling



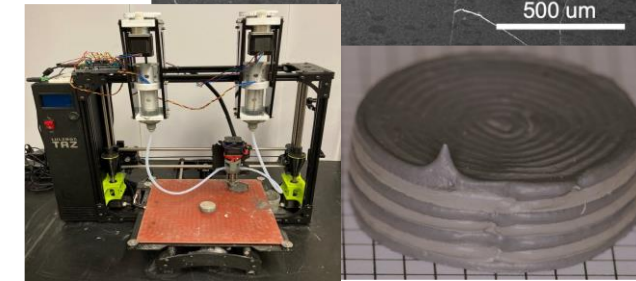
Multiscale modeling connecting processing to performance



High-throughput microstructural characterization



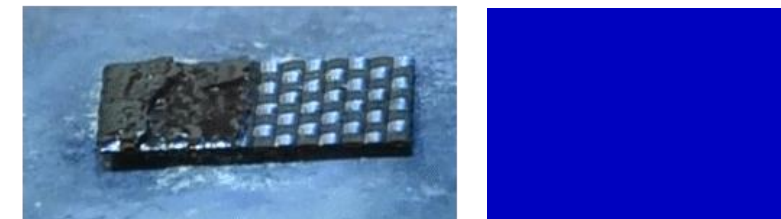
Near-net shape manufacturing of UHTCs



Advanced manufacturing of heterogeneous ceramics



UHTC plasma spray coatings



Torch testing of UHTC coatings

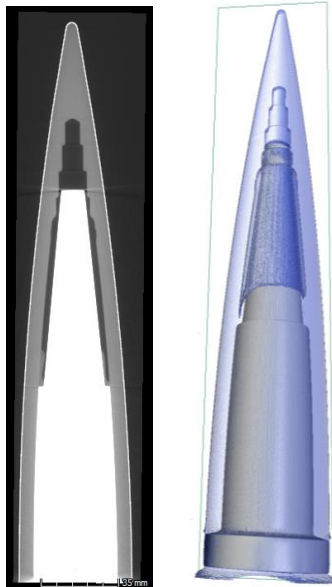
COMPOSITE AND HYBRID MATERIALS



- Concealment and Lethality

- Processing and Modeling

Hypersonic Materials Evaluation



Test Article

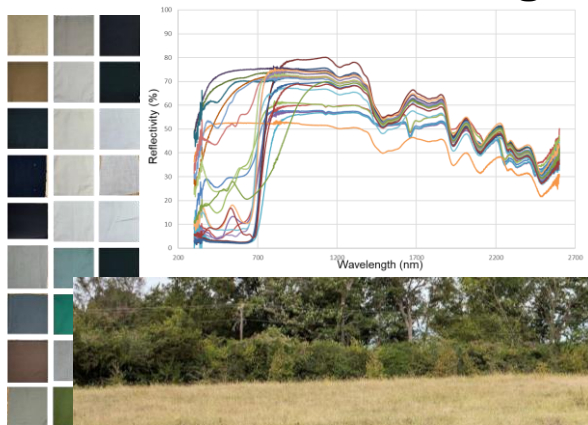


2D Polymers design + fabrication

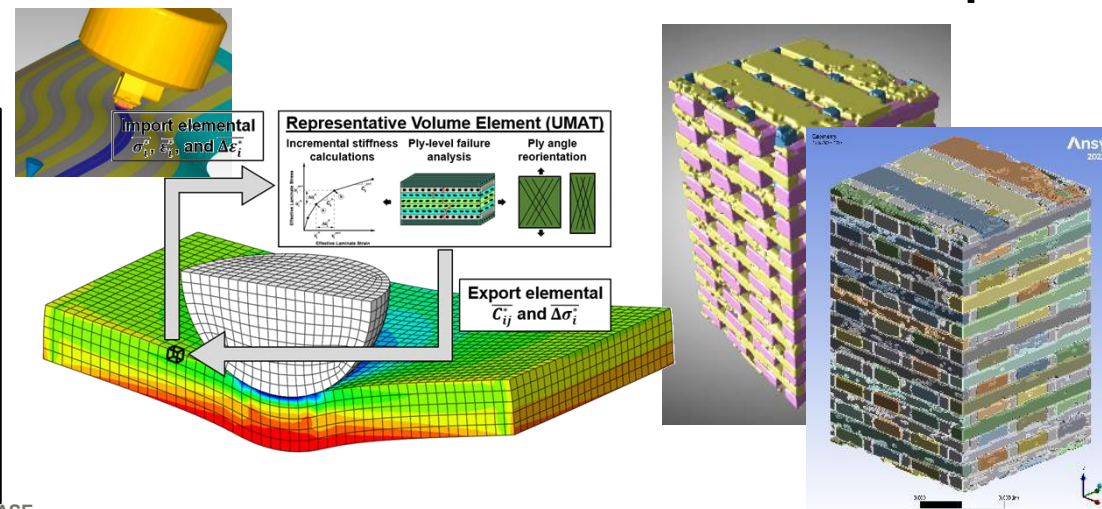


Advanced Manufacturing

Materials for Camouflage



LAMPAT UMAT Modeling Models of real components



POLYMERS



Overarching Polymer Expertise:

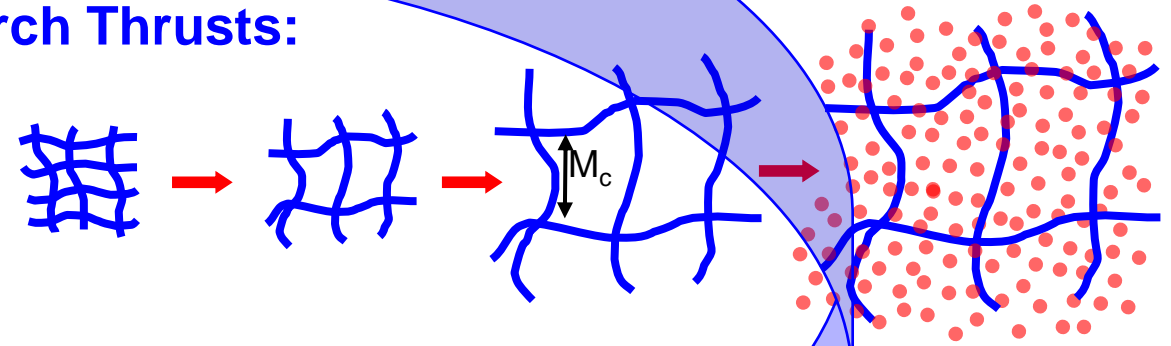
- **Physics** – structure / property relations (mechanics and functional)
- **Synthesis** – new materials through chemistry and additives
- **Processing** – new materials through chemistry and structural control
- **Modeling** – insight and guidance (quantum, molecular, meso-scales)

Current State:

- ~20 staff
- Skilled workforce (PhD)

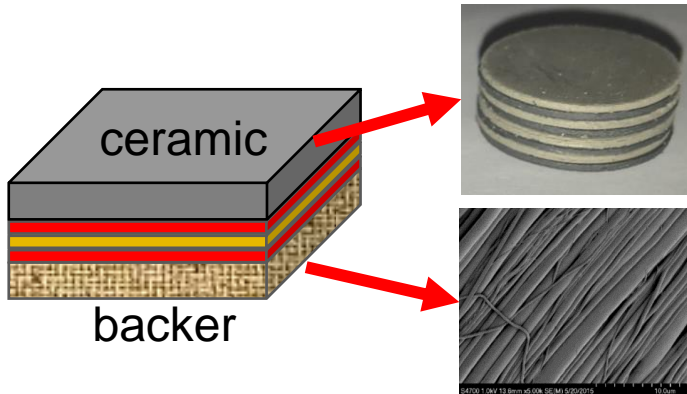
Underpinning Research Thrusts:

- Polymer Processing:** semi-crystalline, engineering thermoplastics, highly particle loaded, new feedstock



Resins / Adhesives: composite and laminate structures, dynamically responsive feedstock

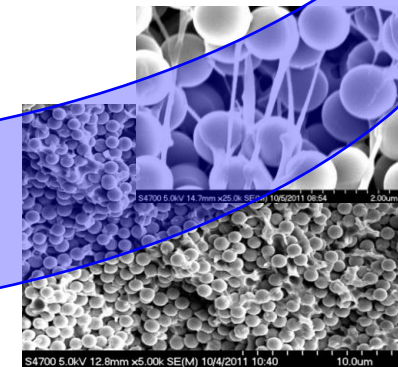
Targeted Applications:



Soldier Protection



Vehicle Protection



Weapons

Manufacturing Science and Technology



Polymer Energetics AM

- Polymer and composite feedstock formulations for energetics AM

Hybrid AM

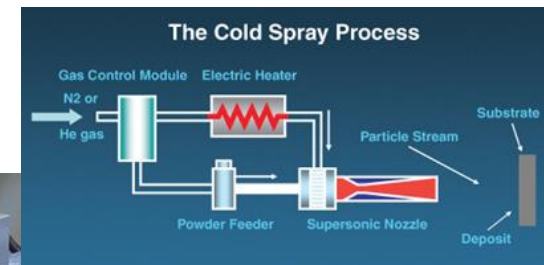
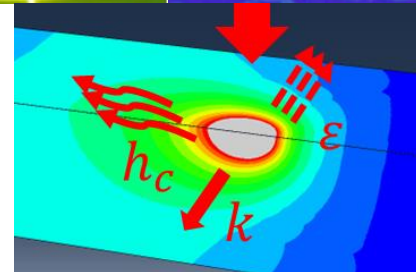
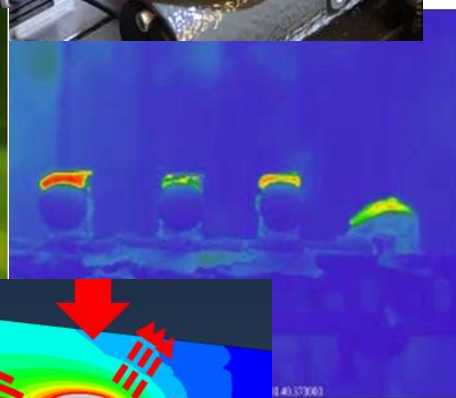
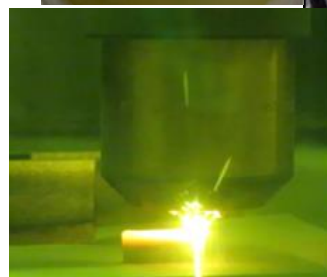
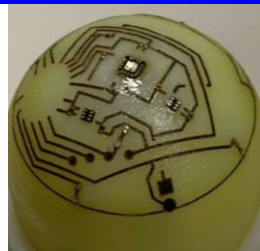
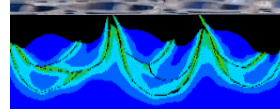
- Conformal/3D printed electronics
- Multi-material processing systems
- Novel feedstocks, e.g. high temp. inks

Metals AM

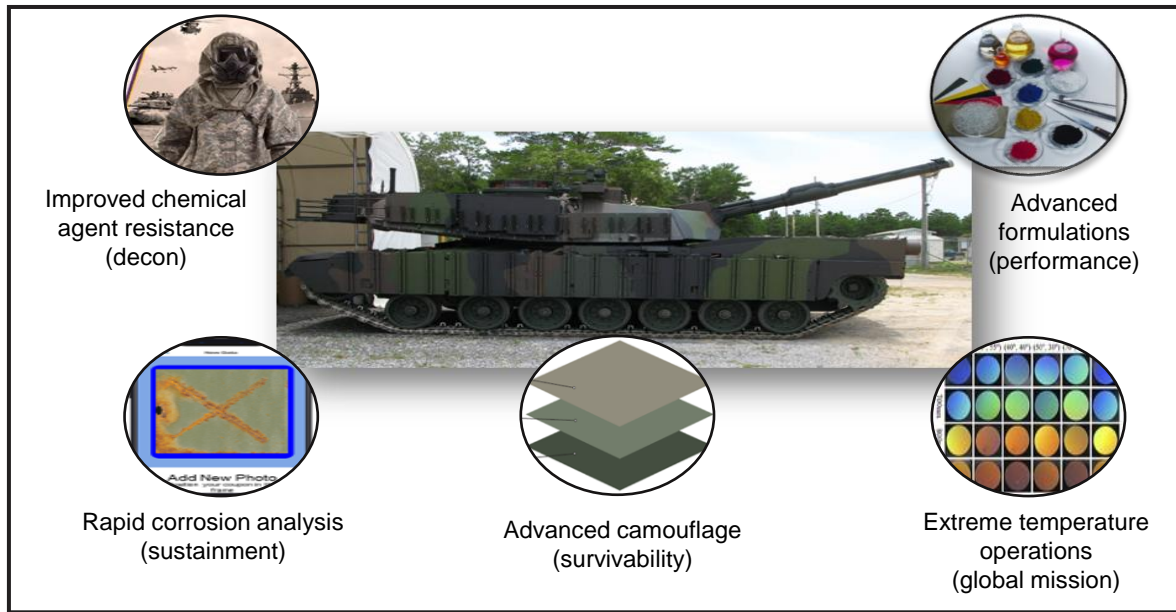
- Army centric alloy development

Plasma spray and Cold Spray Solid State AM

- Coatings for extreme environments
- Multiscale materials systems
- Nanostructured feedstocks
- Repair process development
- Tools for acceleration of adv. man
 - In-situ process sensing & feedback with ML driven analysis
 - Multiscale materials & process models linking processing to microstructure to performance in extreme environments
- Specs/standards/rapid Cert/Qual



MATERIALS DEVELOPMENT & TRANSITION

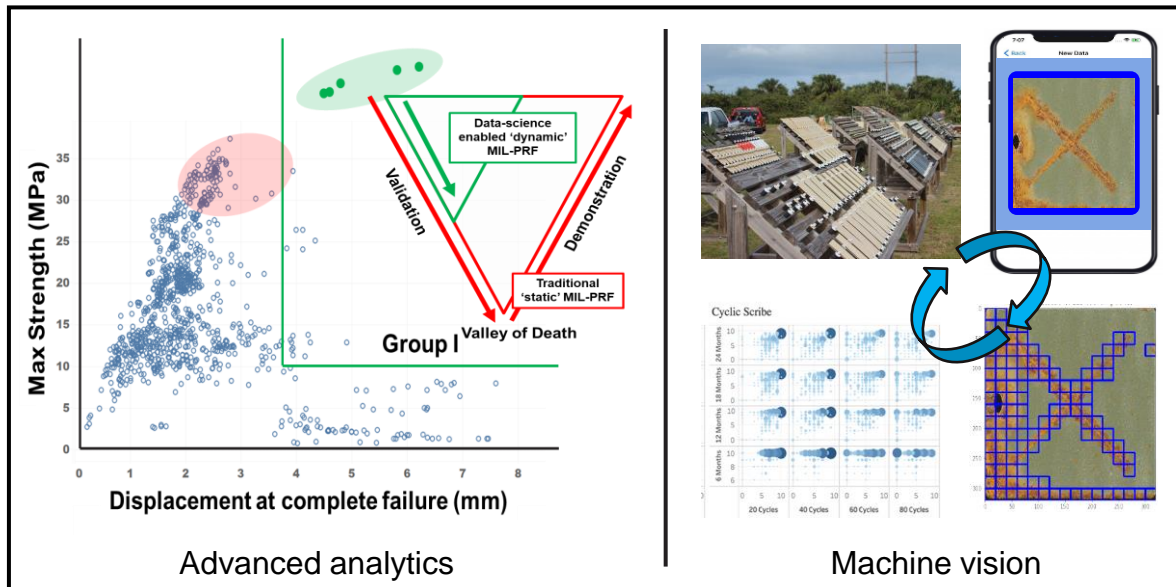


• Camouflage, Coatings & Corrosion

- Advancing the current capabilities of camouflage, chemical agent protection and vehicle sustainment in extreme operating conditions
- Expertise + transition: ARL is the DOD technical authority for CARC and executive office to approve and validate CARC coatings via AR750-1 for the DOD
- Customer efforts focus on constant need to sustain global operating capability including rapid diagnostics and predictive models for corrosion, reduced toxicity of coatings to meet environmental restrictions, and engineering antimicrobial activity

• Materials Data Science

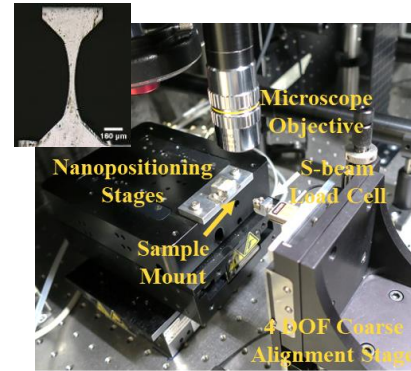
- Using machine learning (ML) models to enhance the depth and breadth of understanding of composition-process-structure-property relationships
- Developing ML tools to rapidly accelerate materials discovery using predictive physics-based models of materials for extreme conditions across relevant length-scales
- Addressing key challenges with a DoD R&D environment including isolated, air gapped data capture; minimax and multi-objective problems; multi-modal non-deterministic problems; sparse data in independent variable space but large data in dependent variable space; concept-drift; heterogeneous data practices
- Using data-driven approaches to bridge low TRL research metrics with high TRL field requirements and to accelerate the path to transition



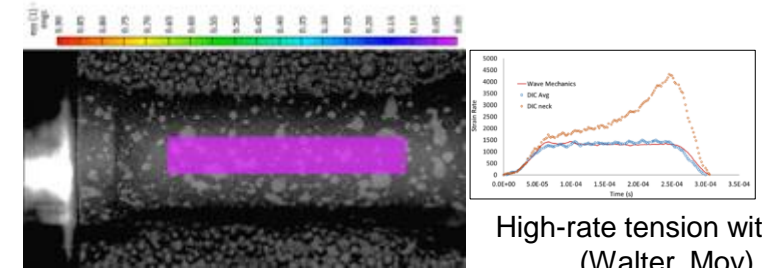
Materials Response and Design



- Home to “Mechanics of Materials” core competency
 - **Experimental Mechanics** - from micro- to macro-scale
 - Interrogating the micro-scale
 - Micro scale CT
 - FIB/femtosec-laser
 - Macro-scale: 3D, high-rate
 - Mechanical testing
 - Optical (DIC)
 - xCT
 - Novel capabilities
 - Macro, micro, nano xCT
 - FIB/laser machining with micro stage loading
 - High speed imaging (up to 10Mfps)



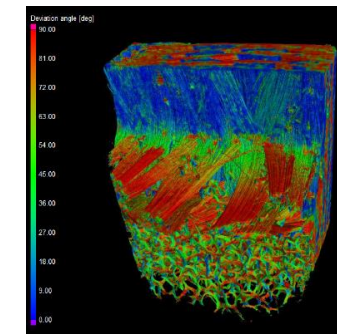
Microscale tension testing (Ligda, Magagnosc)



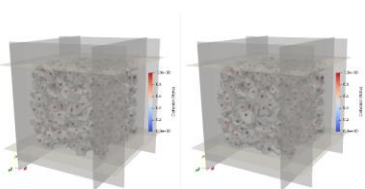
High-rate tension with DIC (Walter, Moy)

– **Computational Mechanics and Design** – Prediction and Optimization

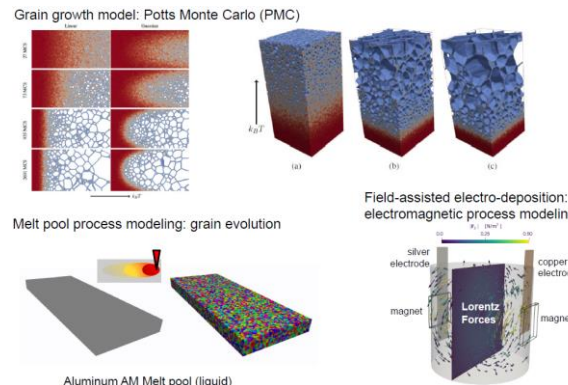
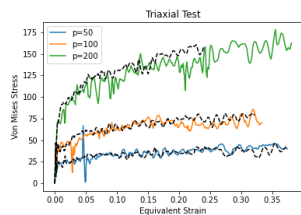
- Continuum physics-based models in Army environments (high rate, high temperature)
- Design Optimization – designing topology and/or materials to reflect multiple objectives and manufacturability



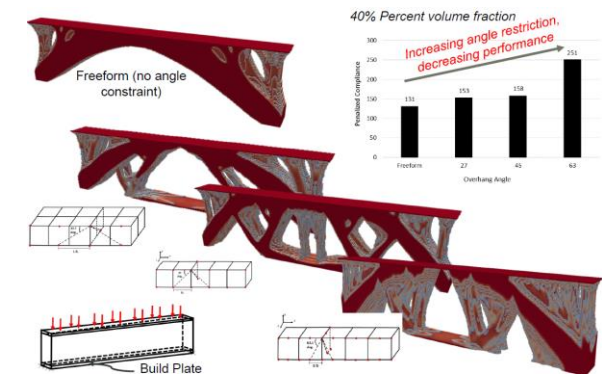
CT fiber orientation (Sietins)



DEM cracking of particles (Wilson)



Grain scale optimization (Hernandez)



AM-specific TopOp (Gaynor)

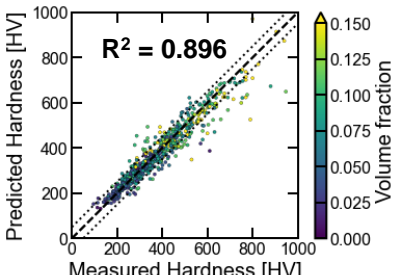
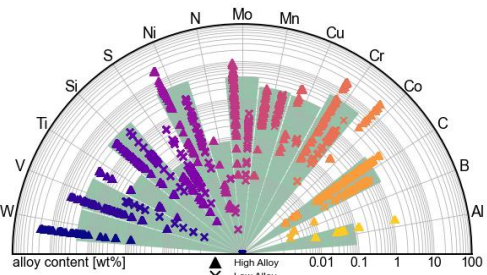
METALS RESEARCH



Revolutionizing Army capabilities through innovative metals research and processing development, enabled by high-throughput techniques

Innovative nano-structured powders with unique properties

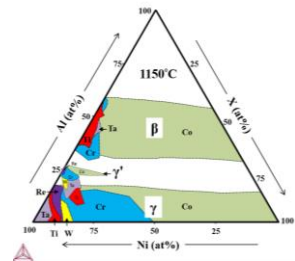
Novel steels and lightweight alloy development enabled by AI/ML predictive framework



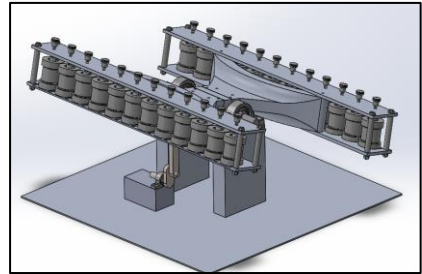
AI predicted hardness compared to measured hardness.



Hydrogen production with nanogalvanic Al powders



Tertiary phase diagram generated by Thermo-Calc



High-throughput ball-milling to accelerate discovery

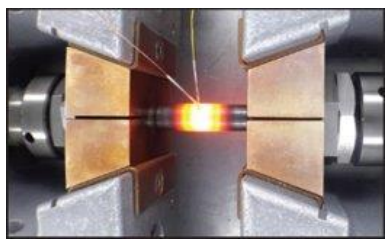
Cantor alloys for pistons



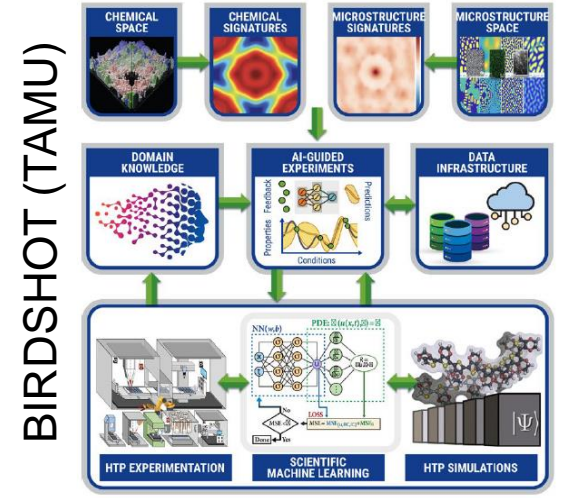
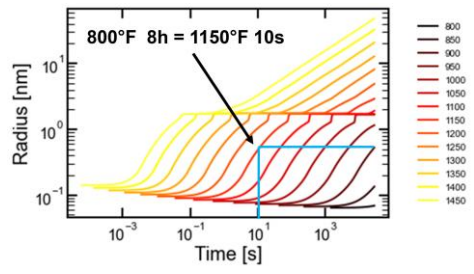
From advanced powders to near-net shape demo pieces



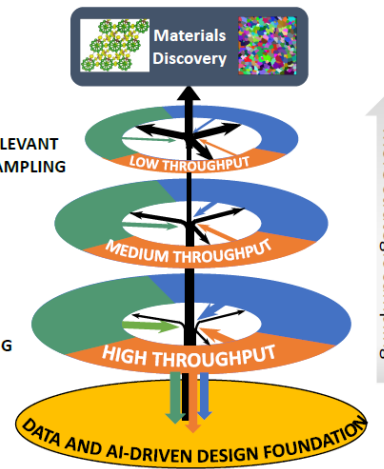
Stress-corrosion cracking of high-hard steels



Rapid tempering of steels

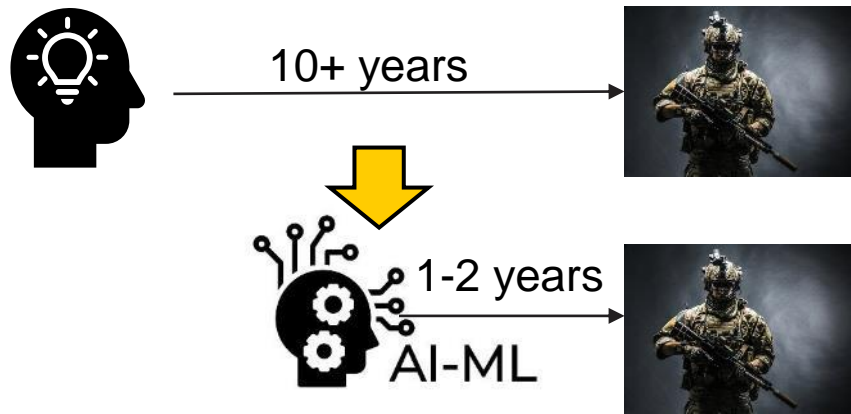


BIRDSHOT (TAMU)



HT-MAX (JHU)

HIGH-THROUGHPUT MATERIALS DISCOVERY FOR EXTREME CONDITIONS (HTMDEC)

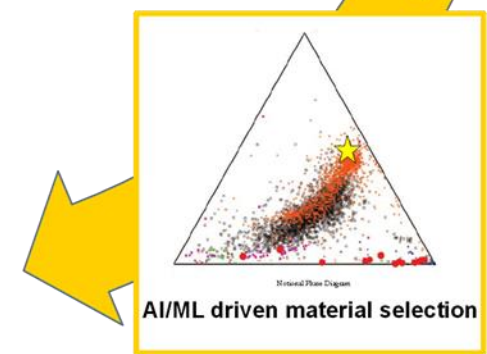
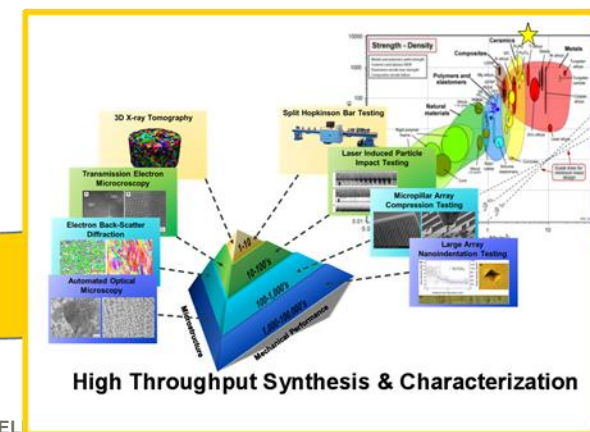
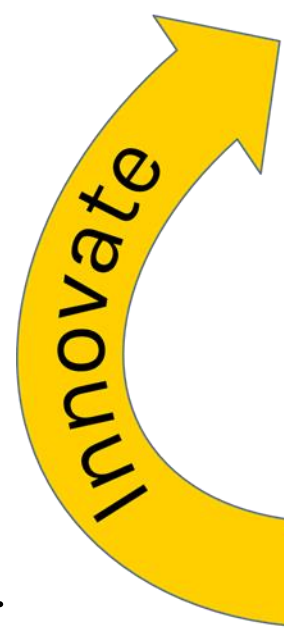
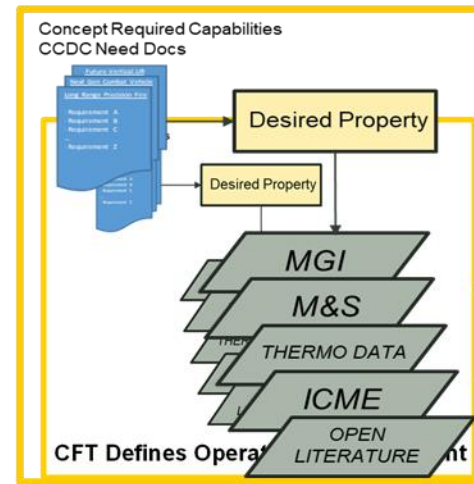


'Trial & Error' Approach

High-Throughput Materials Discovery

HTMDEC is *accelerating* materials discovery through high-throughput processes and integration of computational tools (e.g. AI, ML), and data science.

The ultimate benefit will be rapid development of new materials based on Army needs, accelerating transition of highly-optimized materials to the warfighter.



TAILORED ECOSYSTEM ENGAGEMENT MODEL (TEEM)



Researcher to Researcher



Researcher to Soldier

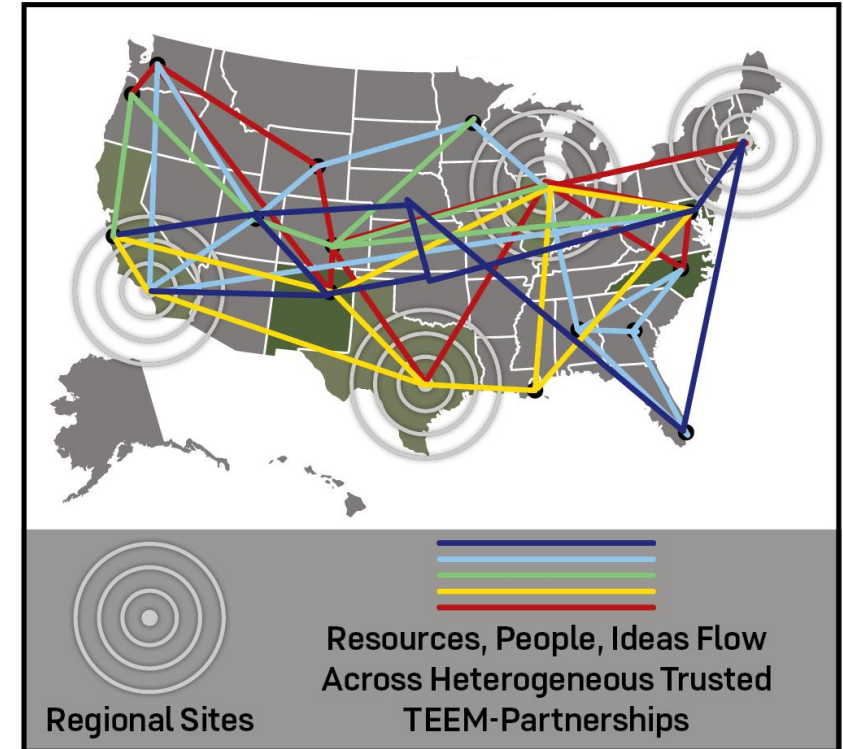


Researcher to Business

- Collaborative Research Alliances (CRAs)
- Cooperative Agreement (CAs)
- Educational Partnership Agreements (EPAs)
- Historically Black Colleges and Universities/Minority Institutions Program (HBCU/MI)
- Multi-Disciplinary University Research Initiative (MURI)
- Other Government Agencies (MOUs, MOAs)
- Single Investigator Program

- 75th Innovation Command – Tech Scouting
- Catalyst Pathfinder
- FAST Program (Field Assist Science and Technology Advisors) across the world
- Greening and Warfighter Focus/engagement
- Ignite – Science shaping Concepts, Experimentation / Wargaming / Focused Excursions

- Army xTech Prize Competition Program
- Cooperative Research and Development Agreements (CRADAs) and Collaborative Technology Alliances
- DoD and Army Manufacturing Technology (ManTech)
- Patent License, Test Service and Software Release Agreements
- Small Business Innovation Research (SBIR) and Technology Transfer (STTR)
- University Affiliated Research Centers (UARC)



Winning Requires a 21ST Century Engagement Model



THANK YOU.