Army Research Laboratory Technical Implementation Plan 2015 – 2019

U.S. ARMY RESEARCH LABORATORY

MISSION: Discover, innovate, and transition science and technology to ensure dominant strategic land power.

VISION: The nation's premier laboratory for land forces.

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INTRODUCTION

The U.S. Army Research Laboratory (ARL) is the Department of the Army's corporate laboratory as well as the Army's sole fundamental research laboratory, dedicated to scientific discovery, technological innovation, and transition of knowledge products. ARL, *the nation's premier laboratory for land forces*, is strategically placed within the Army Research, Development, and Engineering Command (RDECOM) – an Army Materiel Command (AMC) Major Subordinate Command (MSC). ARL influences and impacts the Army as well as the broader DoD science and technology (S&T) communities, primarily, through transition of knowledge products to its sister organizations within RDECOM. Explicitly, ARL's mission is to *"Discover, innovate, and transition science and technology to ensure dominant strategic land power"*; to accomplish this mission, ARL executes fundamental research, defined as Basic Research (BA 1) and Applied Research (BA 2), to address enduring S&T challenges that have been identified by the Assistant Secretary of the Army for Acquisition, Logistics, and Technology [ASA(ALT)] and priorities articulated by the Chief of Staff of the Army (CSA). In addition, the laboratory conducts research and analysis in emerging fields that hold promise in realization of novel or vastly improved Army capabilities into the deep future (2030 – 2040).

Emerging trends suggest that the future Army's operational environment will likely be dominated by decreasing domestic budgets and reduced force structure; increased velocity and momentum of human interaction and events; potential for adversarial capability overmatch; proliferation of weapons of mass destruction; spread of advanced cyberspace and counter-space capabilities among our adversaries; and increased likelihood of operations among populations, in cities, and in complex terrain. Within the context of this highly non-linear and complex operational environment, the Army – America's principal land force – must shape the security environment; set the theater of operations; efficiently project national power; effectively execute combined arms maneuver in the air, land, maritime, space, and cyberspace domains; initiate and maintain wide area security; conduct cyberspace operations in the land domain; and integrate special operations across the Army's mission set. These core competencies, the Army's strengths and essential contributions to the Joint Force of the deep future, will strongly rely on S&T developments. To address the S&T-driven imperatives mandated by the deep future Army's complex operational environment and its core competencies, ARL has structured 24 Key Campaign Initiatives (KCIs) – *substantive, long-lived, primarily in-house technical programs focused on pursuing scientific discoveries, innovations, and knowledge product transitions that are expected to lead to greatly enhanced capabilities for the operational Army of 2040.* These KCIs are the cornerstone efforts of ARL's S&T Campaign – defined in the ARL Technical Strategy[1] (April 2014) and ARL S&T Campaign Plans[2] (September 2014) – and are the foundation of the ARL Implementation Plan.

This document defines ARL's KCIs; each of which is described by a long range (FY15 – FY30) plan identifying the 1) expected impact on the operational Army of 2040; 2) technical goals; 3) requisite increase in personnel above existing staffing levels; 4) infrastructure enhancements needed; and 5) alignment with the Army Warfighting Challenges[3] (AWFCs) and Army Centers of Excellence (CoE) S&T needs[4]. The laboratory's KCIs reflect a robust yet aggressive approach, delineated by a near-term (FY15-FY19), mid-term (FY20-FY25) and long-term (FY26-FY30) trajectory, which is anticipated to lead to capabilities that are critical to the Army in the deep future.

[1] Army Research Laboratory Technical Strategy

[2] Army Research Laboratory S&T Campaign Plans

[3] U. S. Army Operating Concept; TRADOC Pam 525-3-1; http://www.tradoc.army.mil/tpubs/pams/tp525-3-1.pdf

[4] Prioritized Technical Objectives; https://www.us.army.mil/suite/files/43196236

COMPUTATIONAL SCIENCES CAMPAIGN

MISSION: To discover, innovate, and transition S&T capabilities that (1) harness the potential of computational sciences and emerging high-performance computers (HPC) to maintain the superiority of Army materiel systems through predictive modeling and simulation technologies; (2) facilitate information dominance, distributed maneuver operations, and human sciences through computational data intensive sciences; and (3) significantly increase and tailor advanced computing architectures and computing sciences technologies on the forefront to enable land power dominance.

VISION: Computational science and the applications of advanced computing technologies will accelerate the United States Army's strategic land power dominance through critical research developments. Strategic and transformative developments in Computational Science will poise the Army of 2030 and beyond as the world's dominant land force. The desired end state is to leverage the full range of S&T enablers to position the Army to excel in distributed operations and increasingly complex operational environments.

TACTICAL HIGH PERFORMANCE COMPUTING (HPC) [CS-1]

EXPECTED ARMY IMPACT: This effort will provide 100 Petaflop computing power in the battlespace to enable real-time processing for Soldiers operating at the tactical edge and improve mission effectiveness and mitigate risk in hostile environments. Computing power of this magnitude is also an enabling technology for autonomous systems and real-time data analytics for Soldiers and intelligence analysts. Achieving such a system with current computing devices which are constrained devices by power and performance is untenable. By aggregating the computing processing power of deployed friendly computing devices through distributed computing, supplemented by the projection of mobile customized HPC platforms operating at the tactical edge (tactical cloudlets), a new level of capabilities is possible for mounted and dismounted Soldiers.

DESCRIPTION: Tactical High Performance Computing integrates four primary research areas including I) advanced computing research to facilitate the efficient use of emerging architectures – new algorithm design and analysis approaches must be developed to boost the computing capacity of fixed and deployed devices; II) research in provisioning these systems within a distributed computing architecture – this work includes novel concepts to schedule computing tasks over friendly networked processors to limit network hop to appropriate resources; III) dynamic binary translation to limit software re-writes and facilitate optimization in a runtime environment to achieve maximum performance; and IV) power- and architecture-aware computing for enhanced intelligence of provisioning systems – to design systems that have greater awareness of their computing capacity and mission appropriateness. The critical, mobile ad hoc networks that will form the connections in tactical cloudlets to the large-scale databases and complex applications that will be performed by these resources make this research uniquely military and Army in nature. Numerous applications are envisioned for this system in the future and include artificial intelligence aids for decision making, processing large-scale datasets (text, video), and navigation systems for autonomous vehicles (HPC-enabled autonomous vehicles providing on-demand processing).

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):
   a. Develop models that can accurately couple computational performance with communication infrastructure.
   b. Explore and develop scalable algorithms to optimize power for computing and networks.
   c. Explore scalable and distributed algorithms for quantum networks, bio-computing, heterogeneous, quantum annealing, and neuro-synaptic computing architectures.
   d. Establish a hierarchy of parameters for optimization of asset provisioning (strategicand tactical).
   e. Develop scalable algorithms based on emerging models.

ii. Mid-term goals (FY20-FY25):
   a. Scalable algorithms and software development moving from static compile-based code to real-time, dynamic binary translation for optimization and architecture re-mapping.
   b. Take advantage of the quantum network paradigm and integrate computing and communication for specific non-deterministic human-centric applications.
   c. Identify key elements of algorithm signatures to determine power-drain limiting instruction sets with required precision.
   d. Develop battle command applications utilizing scalable and distributed algorithms for quantum networks, bio-computing, heterogeneous, quantum annealing, and neuro-synaptic computing architectures.

iii. Far-term goals (FY26-FY30):
   a. Incorporation of novel processing paradigms and hardware (Quantum, neuro-synaptic, and bio-computing) as part of a broader distributed computing solution for Soldiers.
   b. Ad hoc network and quantum network planning and resiliency based on offered computing load and available resources to service these requests (coupled communication and computation).
   c. New application spaces (autonomous HPC, audio and visual processing, red and blue force analysis) and capabilities for Soldiers.

b. PERSONNEL REQUIREMENTS: This work will, ideally, be carried out by a team of researchers from the computer science, computer engineering, and mathematics disciplines as appropriate. Mathematics will be required to develop heuristics for solution spaces that span into Non-deterministic Polynomial-time Hard (NP-Hard) and NP-Complete problems. New methods of solving optimization problems dealing with temporal and spatial data will need to be developed. Computer scientists and engineers will work closely with colleagues from academia and industry as fabrication technologies continue to converge on paths of pervasive parallelism. Representative test cases will be developed on key application kernels and signatures to determine optimal binary instruction scheduling on heterogeneous architectures and identify ways to overcome key performance inhibitors including memory access patterns and spin-idle cycles from merging architectures of difference computing capacity. Identifying and discovering new capabilities from fielded HPC level performance will require inputs from across DoD and will ideally be carried out by computational scientists who understand varying domain areas and the new capacity offered by tactical HPC.

i. Near-term (FY15-FY19): Expertise in scalable algorithm development on heterogeneous parallel computing, neuro-synaptic, quantum annealing, and distributed. (4-6 FTEs)

ii. Mid-term (FY20-FY25): Personnel who understand how to bridge the capacity and capability gaps of new computing hardware and software. (4-6 FTEs)

iii. Far-term (FY26-FY30): Expertise on emerging computing paradigms and network modeling to explore and develop new scalable algorithms and software. (5-8 FTEs)

c. INFRASTRUCTURE NEEDS: Continued access to emerging processor designs and High Performance Computing platforms for development and testing of new approaches in algorithm design, code mapping (compilation), and benchmark suite analysis.

i. Near-term (FY15-FY19):
   a. Small-scale developmental computing hardware to test emerging low-power and alternate design approaches.
   b. Testbed to evaluate battle command applications including real-time complex sensor and heterogeneous data processing.
   c. Neuro-synaptic and quantum annealing emulation architectures and small scale systems to explore algorithms.

ii. Mid-term (FY20-FY25):
   a. Laboratory space to develop customized architectures and enhanced ad hoc network emulation facilities.
   b. Heterogeneous computing with multi-core and neuro-synaptic architectures.
   c. Mobile systems to test functionality at tactical edge settings.

iii. Far-term (FY26-FY30):
   a. Access to emerging systems including quantum, neuro-synaptic, high-density core, and heterogeneous systems.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
1	Develop and sustain a high degree of situational understanding.
7	Assure uninterrupted access to critical communications and information links.
11	Conduct effective air-ground combined arms reconnaissance.
15	Conduct combined arms air-ground maneuver.
17	Coordinate and integrate Army and joint, interorganizational, and multinational fires and conduct targeting across all domains.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	Capability Area Need
MCoE	3.c – Small Unit Lethality.
MCCoE	2.a – Fully interoperable, simple Mission Command systems.
FCoE	4.c – Next Generation Mission Command.

VERY LARGE-SCALE DATA ANALYTICS FOR THE ARMY
[CS-2]

EXPECTED ARMY IMPACT: This effort will aid in the U. S. Army's information supremacy by pursuing concepts that enable analysis of big data in realistic timeframes, limit tactical surprise, improve situational awareness, and facilitate intelligence for autonomy. Data from battlefield networks, sensors, experiments, observations, human factor aspects, and large-scale numerical simulations are generating exabytes, yottabytes, and beyond quantities of data. This effort focuses on understanding and exploiting the fundamental aspects of large-scale, multi-dimension, multi-modal, dynamic, inconsistent, and incomplete data and performing analytics in almost real-time exploiting emerging and next generation hierarchical computing architectures. Real-time predictive large-scale data analytics will provide decisive advantage to commanders across a range of military operations in the homeland and abroad. Expected impacts include information supremacy and vastly improved situational awareness to aid warfighters and intelligence analysts; predictive analytics for decisions; enhancing autonomy technologies; accelerated Soldier training trough live and virtual data analytics; and catalysts for new innovations for Army materiel systems utilizing observational, experimental, and simulations data.

DESCRIPTION: The overarching goal of this effort is to develop scalable computational methods on massively parallel hierarchical computing architectures to realize extraordinary potential for scientific advance inherent in large-scale complex data. Specific technical goals include scalable mathematical algorithms, data enabled science, predictive computational methods, real-time data analytics, model order reduction, human cognition based mathematical approaches, neuro- and biologically-inspired methods, science analyzing large-scale data from wearable electronics/technologies, large-scale data sensing/compression methodologies, large-scale visual analytics, live-virtual methods for training, data mining/learning mathematical algorithms for distributed heterogeneous computing systems. Computational scalable algorithmic research in cognitive behavior, artificial intelligence, human-machine interactions and autonomous networks is also integral to this work.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

   a. Theory and algorithms for numerical and non-numerical large-scale data analytics – mathematical approaches for data reduction exploring mathematical model order reduction methods, data sensing/compression algorithms, graph analytics, and scalable data mining methods.
   b. Scalable model order reduction methods for assisting fast running design models, live-virtual training for Soldiers, and interdisciplinary methods.
   c. Computational methods for large-scale complex experimental data analytics to support Army Network Integration Evaluation, wearable electronics, and network sciences experimentation.

ii. Mid-term goals (FY20-FY25):
   a. Develop scalable algorithms for numerical and non-numerical large-scale data analytics on heterogeneous computers.
   b. Develop innovative computational mathematical algorithms for distributed large-scale data analytics to take advantage of heterogeneous computing architectures.
   c. Real-time experimental data processing coupled to assist in developing predictive computational methods on high performance computers. Scalable machine learning algorithms and next generation stochastic based data mining techniques.
   d. Scalable model order reduction methods for assisting fast running design models, live virtual training for Soldiers, and interdisciplinary methods.
   e. Implement uncertainty quantification methods to improve predictability of large-scale structured and un-structured large-scale data analytics.
   f. Explore and implement new computational methods for large-scale complex experimental data analytics to support live-virtual simulations and Soldier training.

iii. Far-term goals (FY26-FY30):
   a. Cognition-based computational approaches for large-scale data analytics.
   b. Quantum computer based approaches for solving complex data analytics especially visual and incomplete data.
   c. Improved autonomy and decision based approaches exploiting neuro-synaptic computing concepts.
   d. Develop real-time predictive data analytics taking advantage of next generation heterogeneous computing architectures.

b. PERSONNEL REQUIREMENTS: This work will be carried out by an interdisciplinary team of researchers from computational mathematics, computational informatics, computer science, computer engineering, engineering, and other subject matter experts as appropriate.

i. Near-term (FY15-FY19): Expertise in scalable algorithm for large-scale graphs, data organization on distributed computers, large-scale information visualization, computing architectures for data intensive sciences, and distributed computing environments. (4-6 FTEs)

ii. Mid-term (FY20-FY25): Expertise in scalable algorithm for evolving complex graphs, data organization on distributed heterogeneous computing systems, real-time large-scale information visualization, distributed and heterogeneous computing architecture for data intensive sciences, and applications based computing environment. (4-6 FTEs)

iii. Far-term (FY26-FY30):
   a. Expertise in scalable algorithm for dynamic complex and evolving large-scale graphs, data organization on distributed next generation computers, cognition based visualization, and computing models for next generation computing architectures (quantum, neuro-synaptic, biological, DNA). (6-9 FTEs)

c. INFRASTRUCTURE NEEDS: Continued access to emerging processor designs and High Performance Computing (HPC) platforms for development and testing of new approaches in algorithm design, code mapping (compilation), network mapping, and benchmark suite analysis.

i. Near-term (FY15-FY19):
   a. Peta-scale computing, experimental HPC architecture designed for large-scale data analytics.
   b. Experimental heterogeneous computing architecture for live-virtual training application.

ii. Mid-term (FY20-FY25):
   a. Large-scale heterogeneous architecture for distributing different data types on different systems for real-time data analytics.
   b. Exascale computer system.

iii. Far-term (FY26-FY30):
   a. Heterogeneous computer with next generation computing architecture (exascale, quantum, neuro-synaptic, DNA, biological).

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	**Description**
1	Develop and sustain a high degree of situational understanding.
11	Conduct effective air-ground combined arms reconnaissance.
15	Conduct combined arms air-ground maneuver.
17	Coordinate and integrate Army and joint, interorganizational, and multinational fires and conduct targeting across all domains.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	**Capability Need Area**
MCoE	3.e – Robotics/Autonomy.
CASCOM	3.a – Autonomous Ground Resupply.
CASCOM	3.e – Autonomous Aerial Resupply.
USAICoE	4.a – Intelligence Analysis.

COMPUTATIONAL PREDICTIVE DESIGN FOR INTERDISCIPLINARY SCIENCES [CS-3]

EXPECTED ARMY IMPACT: Predictive computational modeling significantly shortens development cycle and substantially improves performance of lethality, protection, electronics, power, and dismounted Soldier gear utilizing lightweight, multi-functional, cost effective, optimized innovative materials by design exploiting high performance computers. Rational design of such materials through predictive modeling can significantly shorten the development cycle and result in cost effective solutions for multifunctional materials. The materials engineered through predictive design computational methods can be fabricated according to Army specification and with optimized performance at every spatial and temporal scale. Materials subjected to extreme conditions such as mechanical shock, pressure and electromagnetic fields are of particular importance to the Army and require advanced multi-scale and multi-physics computational strategies for successful engineering design.

DESCRIPTION: Fully validated, large-scale parallel software will simulate multi-component complex systems in multiple technology areas. This software will integrate diverse sub-system models, some running concurrently for highly coupled system components, and others sequentially, as dictated by the system functionality. The highly coupled model components may be separate executables, running at different time scales and potentially on different computational platforms. Some of the components may be commercial or third-party software packages where only the executable is available. The data exchange and particulars of the execution would be transparent to the user. Multi-scale analysis and material by design are supported through this scalable computational methodologies and software. The system software would be integrated with optimization algorithms and capabilities for determining design sensitivity and uncertainty quantification. Use of reduced order models will provide varying levels of computational speed and fidelity for different needs and facilitate coupling through reduced data sets and across distinct physical representations of system components.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Multi-scale and Interdisciplinary computational Framework to couple field and deformation codes.
b. Enhance hydrocode frameworks for better physical representation of interfaces and fracture; fluid-thermal-structural interactions; uncertainty quantification and verification validation methods; large-scale network modeling including cyber and Electronic Warfare (EW).
c. Multi-scale methods for particle dispersion in realistic urban weather/ battlefield environments.
d. Create reduced order models of select computationally intensive simulations.
e. Identify and characterize the sets of component models and the data interactions needed for each system level software suite including component multi-scale models and bridging strategies to explore materials by design strategies.

ii. Mid-term goals (FY20-FY25):
   a. Develop generalized and extendable bridging methodologies for connecting models using data analytics and statistical approaches.
   b. Incorporate physiological data into system simulations.

iii. Far-term goals (FY26-FY30):
   a. Robust, efficient, validated, large-scale parallel design and analysis software suites serving lethality and protection platforms, integrated sensor and material design, maneuver systems and war fighter assessment.
   b. Integrated software relating source, effect and consequences for cyber and electronic warfare.

b. PERSONNEL REQUIREMENTS: One segment of the personnel should be well-versed in numerical methods for scientific software--solving sets of coupled differential equations. They should also have some knowledge of the physics behind the equations they are programming, and the application space. They would work closely with colleagues from other campaigns on software verification and establishing comprehensive test suites for software quality assurance. Another aspect of the programming is software coupling in large scale parallel environments and potentially working with large quantities of data. Here information compatibility, efficiency and robustness would be concerns. Expertise on platform-specific performance is required to ensure software efficiency. A third personnel area would be needed to keep the simulation software up to date and running efficiently on evolving DoD computer platforms. Mathematical expertise is also needed for data-analytics to connect models and statistics because the model connections could be through ensemble averages and moments.

i. Near-term (FY15-FY19): Computational scientist team with expertise in computational mathematics and associated scientific fields. Personnel familiar with computing system architectures and scalable algorithmic knowledge for determining efficient software integration and interdisciplinary strategies. Computational mathematics with model order reduction expertise. (4-6 FTEs)

ii. Mid-term (FY20-FY25): Computational scientists with a good understanding of mathematical, numerical and specific discipline expertise to develop innovative coupling approaches at large scale and providing efficient parallel implementations. Scientists with experience in uncertainty quantification and software quality assurance to establish and maintain verification and validation suites. (4-6 FTEs)

iii. Far-term (FY26-FY30): Computational scientists that can take advantage of evolving hardware platforms and software models. Computational scientists with mathematical and specific discipline expertise to enhance capabilities as new models and new computing algorithms come available. Personnel with mathematical and statistical backgrounds for data analytics. (6-10 FTEs)

c. INFRASTRUCTURE NEEDS: Continued access to emerging high performance computing platforms for large scale testing and evaluation and ready access to small numbers of nodes (unfettered by lengthy queue times) for efficient software development. Access to moderate size parallel platform with reconfigurable communications that would not interfere with production computations.

i. Near-term (FY15-FY19):
   a. State of the art petascale computer system.
   b. Experimental computer platforms to create and exercise novel communication and data transfer schemes.

ii. Mid-term (FY20-FY25):
   a. Traditional exascale computer.
   b. Experimental heterogeneous computers.

iii. Far-term (FY26-FY30):
   a. Heterogeneous exascale computer.
   b. Quantum and biological-computing for diverse classes of interdisciplinary applications.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
5	Prevent, reduce, eliminate, and mitigate the use and effects of weapons of mass destruction.
7	Assure uninterrupted access to critical communications and information links.
15	Conduct combined arms air-ground maneuver.
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.

Army Capability Need Proponent	Capability Need Area
CASCOM	4.e – Advanced Materials.

MATERIALS RESEARCH CAMPAIGN

MISSION: Perform fundamental interdisciplinary research in materials and manufacturing science to ensure rapid and affordable development of materials, from discovery to delivery, critical to the Army of 2030.

VISION: Discovery and unparalleled innovation of devices and Materials By-Design and On-Demand across all Army domains. Understand, exploit, and demonstrate diverse material sets with exceptional quality and capabilities relevant to the Army of 2030 via advances in manufacturing science. The desired end state is to enable the Army of 2030 to succeed in distributed operations and increasingly complex environments through realization of superior materials.

ALTERNATIVE ENERGY
[MR-1]

EXPECTED ARMY IMPACT: Tactical energy independence, relevant to individual dismounted Soldiers as well as expeditionary contingency bases, will posture tactical units to operate for indefinite periods without resupply in austere environments. Energy harvesting from multiple sources will be combined with the ability to produce fuels on the battlefield and fuel flexible high energy dense power sources to nearly eliminate the need for logistics fuel resupply. Onsite fuel production will use readily available resources such as solar energy, CO2 from generator exhausts, grey water, waste or ambient thermal energy, and other ambient electromagnetic radiation to produce a broad range of fuels for generators, fuel cells, or Soldier portable power sources. Soldier's will have high energy dense power sources using efficient thermal energy conversion (thermophotovoltaic, thermoelectric, pyroelectric, or other novel method) of combusted fuels that can outlast or reduce the weight of platforms using existing rechargeable batteries by more than 10 times. Energy harvesting will include extremely efficient solar photovoltaic devices integrated into the materiel and gear to provide greatly extended or unlimited mission times for the individual Soldier and the ability to combine power sources from many Soldiers to support the activities required for large remote outposts. Multifunctional materials will simultaneously store energy and provide structural support and protection to dramatically reduce size and weight of platforms.

The Soldier will operate within an intelligent power network with tools for automated allocation of the best energy resources and wireless channels for energy to be dynamically redistributed down to the individual Soldier on-the-move. Advancements in wireless energy transfer will enable distribution of power amongst power sources, multimodal energy harvesters, and loads to occur wirelessly on the Soldier as a platform, so that all carried equipment will be powered and ready for operation at all times without thought to replacing individual equipment power sources. A combination of wireless power transmission, energy harvesting, and high energy dense power sources will enable the Soldier to possess numerous integrated, low power sensors to provide enhanced situational awareness and performance monitoring. Soldier electrical loads will be minimized by integrated power management as well as incorporation of low power electronics, sensors, and computing.

Radioisotope power sources will enable drop-and-forget battlefield sensing (motion, radiation, photographs, periodic communications) or built-in infrastructure health detection (vibration, corrosion) for durations ranging from 10 – 100 years or whose output power can be switched between low and high levels for persistent sensing or directed-energy applications.

DESCRIPTION: Alternative Energy focuses on improving and developing new material and devices for novel sources of energy; energy conversion; energy storage; and energy transmission and distribution to enable tactical unit energy independence. This goal requires multidisciplinary approaches, personnel, and infrastructure to make significant advancements in the areas of water splitting, CO_2 reduction, microcombustion, thermophotovoltaics (TPV), photovoltaics, thermoelectrics, pyroelectrics, wireless energy transfer, micropower management, multimodal energy harvesting, radioisotope power sources, and multifunctional materials.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Determine if solar and other ambient radiation can enhance catalytic rates of particular reactions of interest such as carbon-carbon bond cleavage, CO_2 electroreduction, O_2 electroreduction and water splitting.
b. Investigate techniques to fabricate high efficiency, light weight, rollable or foldable solar photovoltaic sheets based on currently available III/V semiconductor materials.
c. Identify and synthesize combustion catalysts with increased sulfur tolerance and increase the efficiency of liquid fueled combustion thermal sources for use in TPV energy conversion.
d. Investigate sophisticated optical coupling structures integrated on TPV cells and thermal management systems to enhance the total efficiency of TPV conversion.
e. Reduce the leakage current of lead zirconium titanate materials and determine the ability of pyroelectric generators to convert thermal energy from waste heat, combustion sources, or laser sources.
f. Demonstrate transfer of 10W for Soldier-vehicle and point-of-load connections using inductive wireless transfer and determine feasibility of alternatives including electromechanic and laser-photovoltaic transmission. Novel power materials will be developed to enable enhanced transfer efficiencies.
g. Investigate new power materials, devices, microfabrication processes, and new power circuits to enhance the power density of lightweight power-management units and explore novel materials for development of new multi-transduction-mode energy harvesting devices.
h. Demonstrate weight and volume savings using multifunctional materials to integrate structure and protection function with energy storage (batteries, supercapacitors, and electrostatic capacitors).
i. Evaluate tritium radionuclide power sources capable of 10 years of operation and determine the fundamental physics by which energy-release rates may be controlled for isomers to enable a switchable power source.

ii. Mid-term goals (FY20-FY25):

a. Determine if engineered structures such as metamaterials can enhance the effect of electromagnetic fields on catalysis of reactions of interest and determine if CO_2 can be directly reduced to methanol for use as a fuel.
b. Increase thermal efficiency of combustion platforms and evaluate the durability, such as sulfur tolerance and carbon formation, of catalysts over a wide range of fuels including JP-8.
c. Develop new materials to enable operation of TPV cells at higher temperature and with a spectral response matched to emitter spectra to eliminate the need for costly optical filtering.
d. Evaluate near-field TPV to increase power density for lower emitter temperatures.
e. Reduce the materials cost of solar photovoltaic devices using hybrid materials and develop integrated novel optical structures to allow high solar concentration, reducing the volume of PV material needed for the required power.
f. Integrate semiconductor nanowires for solar energy conversion into the fabric of the Soldier's uniform to provide wearable power.

g. Increase power transmission and distance for body-scale and inter-Soldier wireless power sharing.
h. Develop high-speed power circuits for adaptable and intelligent chip-scale power management and develop multimodal energy harvesting devices exploiting new materials with multiple transduction mechanisms leading to high-power density portable energy harvesters.
i. Investigate new materials manufacturing techniques, such as additive manufacturing, and improved multiphysics models and simulation to increase the energy density and mechanical properties of multifunctional, structural power materials and to allow tailoring of material microstructure for simultaneously maximizing energy storage and structural functions.
j. Extend the duration of radioisotope power sources to 10 years of operation using tritium radionuclide sources, develop the capability to use ^{63}Ni for higher power and duration, develop isomers to enable storage at minimal power levels and activation to operational levels prior to deployment for long-duration sensors or directed energy applications.

iii. Far-term goals (FY26-FY30):
a. Determine if more complex fuels than methanol, such as ethanol and butanol, or heavy hydrocarbons can be synthesized from water and CO_2 on a tactical scale and directly used as fuels in high energy density power sources. Determine if grey water can be used as a fuel source in water splitting.
b. Improve the durability of combustion catalysts for multi fuel capability and develop combustion-based thermal sources with integrated balance-of-plant to enable portable thermal sources in a lightweight, small form factor package.
c. Enhance the total efficiency and power density of TPV systems and new thermal conversion methods at lower temperatures to enable harvesting from wasted thermal energy in the environment or on platforms.
d. Develop entirely new materials and material combinations to yield photovoltaic systems that far exceed the current efficiency limits at a cost that allows deployment throughout the Army.
e. Increase both wireless power and transfer distances to enable robotic and intersquad operational energy distribution requiring advanced wireless power management and power beaming media.
f. Integrate multimodal harvesters with small-scale power management units for low- or no- power sensors and wearable electronics as well as exploit new materials and transduction phenomena for new power conversion topologies.
g. Develop design tools and materials reliability data sets and investigate repair techniques to enable integration of multifunctional materials into a broad range of systems. Increase the performance of dielectric and structural electrolytes to enable multifunctional materials with energy densities approaching those of conventional energy storage materials.
h. Extend the duration of radioisotope power from 10 to 100 years of operation and provide a broad array of isotope sources including switchable isotope sources that can be chosen on the basis of power and duration required.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Experts in radiation and nuclear physics, microcombustion, power and microelectronics, electromagnetic, ferroelectrics, semiconductor physics, plasmonic spectroscopy, nano-material synthesis, and photonics. (10-12 FTEs)

ii. Mid-term (FY20-FY25): Experts in near-field radiation heat transfer, flexible and large-area packaging, interdisciplinary electro mechanics and physicists, materials science, metamaterials, materials synthesis and microfabrication, and combustion modeling. (6-8 FTEs)

iii. Far-term (FY26-FY30): Experts in nuclear physics, power systems, power electronic materials, quantum physicists, and radio frequency. (6-8 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
  a. Simulation and design software.
  b. Facilities onsite to fill tritium capsules.
  c. Update radiation generators and measurement instrumentation.
  d. Hydride vapor phase epitaxy system to grow relatively thick semiconductor layers.
  e. Laboratory space, fume hood, and equipment for catalyst synthesis and characterization.
  f. Laser, light sources, and detectors (IR, Raman, optical), gas chromatography/mass spectrometer and Differential Electrochemical Mass Spectrometry.

ii. Mid-term (FY20-FY25):
  a. Equipment and facilities for TEM and XPS analysis, 3D printing of materials, enhanced surface analysis tools, synthesis of novel transduction materials, high-frequency power devices, solar cell characterization including a pulsed solar concentrator, and materials growths including III/V – silicon molecular beam epitaxy, metal-organic chemical vapor deposition, or liquid phase epitaxy.
  b. Enhance capabilities to enable testing of ^{63}Ni power sources and matched energy-conversion technologies.
  c. Update radiation generators and measurement instrumentation.
  d. Outdoor test facility with regulatory approval for high power transmission in frequency bands of prevailing interest.

iii. Far-term (FY26-FY30):
  a. Test beds for qualification of wireless energy transfer in multi-user, high interference environments and low-power electronics and platforms.
  b. Equipment and facilities to run 24 hour durability tests on catalytic materials; develop new material systems; and test and characterize new ultra-energetic materials, energy-conversion technologies, transduction materials, power materials, and to run material durability tests 24 hours a day.
  c. Update radiation generators and measurement instrumentation.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
7	Assure uninterrupted access to critical communications and information links.
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.

Army Capability Need Proponent	Capability Need Area
MCoE	3.d – Unburden the Soldier.
CASCOM	3.c – Intelligent Power Management and Distribution System.
CASCOM	4.a – Hybrid Power Capabilities.
USAICoE	3.b – Collection Modernization.

BEYOND NOVEL MATERIALS
[MR-2]

EXPECTED ARMY IMPACT: The United States Army's mission is to fight and win our Nation's wars by providing prompt, sustained land dominance across the full range of military operations and spectrum of conflict in support of combatant commanders. To fulfill this mission in the complex operational environment of the future, a ready, robust, regionally engaged, expeditionary, globally responsive, and mission-tailored Army force that is uniquely positioned to shape events in peace, prevent, and rapidly end conflict at the speed at which it unfolds is needed. Many of the capabilities required by the Army of deep future will significantly depend on substantial improvements over the current state-of-the-art in materials synthesis, fabrication, and processing methodologies. In particular significant advances that go beyond current state-of-the-art materials are expected to impact the future Army's capabilities through high performance electronic components for reliable communications and enhanced situational awareness; reduced logistical burdens afforded through point-of-use fuel generation and high efficiency, high power density energy storage devices; light weight, high strength, and chemical resistant appliqués that facilitate operation in a chemical, biological, radiological, nuclear, and explosives (CBRNE) environment; and high strength, low erosion alloys to facilitate realization of high penetration munitions.

DESCRIPTION: ARL aims to discover, design and develop future materials in topological phases of matter, two dimensional materials, active heterogeneous interfaces, and materials fundamentally altered by external fields to meet the demands of a transforming battlefield. Topological phases give access to unique electronic, magnetic, and superconducting functionalities, as well as other not yet known. They also give rise to charge carriers that can be fractional and or that do not obey normal quantum statistics. Their phase transitions go beyond the standard paradigms, and the materials fundamentally deviate from the standard semiconductor energy constraints. Similarly, two dimensional materials and their heterostructures offer unprecedented electronic/optoelectronic properties that are not possible in their 3D counterparts due to the unique quantum confinement effects of two dimensions. Known topological and two dimensional materials will be optimized and explored for novel electronic functionalities while those that have yet to be realized or envisioned will be developed and characterized. Heterostructures of disparate materials, topological and otherwise, will be theoretically studied and experimentally realized to explore both novel physics and unique devices that function beyond the reach of evolutionary advances in the technology of today.

Energy coupled to matter (ECM) is an emerging technology that goes beyond the traditional process optimization factors of scale, composition, temperature, and pressure. Materials developed by processing under high energy fields enable creation of materials that break the current pressure-temperature phase relations and exploits materials substructure orientation capability permitting exceptional structural and functional materials properties. ECM enabled materials become a powerful tool in creating materials on-demand and by design. It holds great promise in facilitating the realization of transformational materials through the aid of externally applied fields, including electric, magnetic, acoustic, microwave, and gamma radiation used singularly or in combination. The application of high intensity and/or ultrafast fields may alter phase transformation pathways; create new microstructures; shift equilibrium favoring new metastable alloys or electronic materials with novel functions; align phases; manipulate and shape nanoscale architectures; and produce materials with revolutionary structural and multifunctional properties otherwise unattainable using traditional processing and fabrication methods. These fields may either be used to induce a permanent material property improvement or to selectively activate enhanced time-dependent properties via dynamic stimulation.

Due to the cross-cutting nature of materials research, significant ECM developments can be applied to a number of vastly different areas, including discovery of new materials, enhancement of manufacturing processes, and the expansion of capabilities for advanced weapons and protective systems. Novel equilibrium and metastable materials with high combined strength, fracture toughness, and ductility will be developed using field-enhanced processing methodologies to overcome established material property limitations. Enhancement of standard processing and manufacturing techniques and equipment through the use of energetic fields will enable fabrication of materials at significantly lower temperatures and shorter times, resulting in highly efficient production, extended tool life, significant energy savings, reduction in operating and manufacturing costs, and improved final products. Materials developed using ECM will be integrated into protection technologies for diverting, bending, and fracturing ballistic threat projectiles with greater efficiency, thus reducing system weight and volume. Conversely, higher strength projectiles fabricated through ECM materials advancement will be utilized for enhanced penetration and defeat of enemy protection systems.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Thin film growth of one or more known topological insulators with surface-to-bulk conductivity ratio of 10:1 or better.
b. Employ these high quality materials to determine thermoelectric parameters and the figure of merit for the thermoelectric effect mediated by surface states. Theoretically determine a maximum figure of merit.
c. Synthesize lead-based topological materials such as topological crystalline insulators, characterize the basic electronic structure, and determine the primary defects that may obscure the unique materials function. Devise strategies for mitigating these defects.
d. Devise strategies to grow and stabilize unique topological materials such as two-dimensional tin (stanene) to demonstrate unique electronic functionality.
e. Devise, demonstrate and seek novel functionality in new heterogeneous interfaces between topological materials and topologically trivial materials.
f. Conceptualize modeling approaches suited to topological and 2D heterostructures to employ in the prediction of new materials and novel functionality.
g. Theoretically determine the distinguishing characteristics of topological plasmonics.
h. Design and demonstrate prototypes of novel devices exploiting the unique properties offered by novel topological materials, 2D materials and heterostructures.
i. Study polarization-induced topologically protected states at InN/GaN interfaces.
j. Grow and characterize the properties of highly mismatched alloys such as GaNSb, as well as active heterogeneous interfaces involving III-N/III-Sb heterostructures.
k. Engineering of Escherichia coli for improved binding to metal (e.g., gold) and dielectric/semiconductor surfaces for living circuits.
l. Design and demonstrate prototypes of novel photodetectors exploiting the unique properties of active heterogeneous interfaces between III-N/SiC heterostructures to achieve high efficiency single photon counting across the ultraviolet spectrum.

m. Advancements in the understanding of coupling energetic fields with matter.
n. Development of computational modeling capabilities that predict materials structure and properties and describe the field characteristics.
o. Develop in-situ methods for measuring the fields and the evolution of material structure.
p. Application of ECM technologies to traditional processing and manufacturing methods to retrofit existing processing systems with improved capabilities.
q. Provide state-of-the art modeling capabilities for modeling at multiple scales.

ii. Mid-term goals (FY20-FY25):
a. Achieve near room temperature functionality in one or more thin film topological materials.
b. Demonstrate the unique functionality of at least two topological materials such as topological crystalline insulators or other topological materials discovered at ARL that distinguishes them from standard topological insulators.
c. Utilize modeling approaches devised in the near-term goals and further refined in the mid-term to predict at least one material new to science that also provides a unique functional opportunity. Adopt earlier advances in synthesis techniques to realize the material(s) for the first time.
d. Refine the synthesis techniques of the near-term to achieve a surface-to-bulk conductivity in a known topological material that exceeds 100:1. Employ similar techniques to begin refining other devised topological materials to attain properties that are not obscured by defects or other trivial aspects.
e. Demonstrate reliable/reproducible electronic switches and circuits that can duplicate and exceed the functionality of CMOS technology.
f. Devise and demonstrate the simultaneous exploitation of two or more electron degrees of freedom in an electronic device.
g. Demonstrate polarization-switchable topological materials such as InN/GaN heterostructures.
h. Demonstrate enhanced alternative energy harvesting and routes to fuel through functional active heterogeneous interfaces between highly mismatched alloys/inverted polarity heterostructures and liquids such as water.
i. Demonstrate autonomous and directed patterning and reconfigurable binding at bio/non-bio interfaces for living circuits, self-healing properties, and responsive properties.
j. Development of new materials specifically for processing, use and exploitation in energetic fields.
k. Synthesis, production, and scale-up of materials capable of high energy absorption or dissipation for on-demand defeat of ballistic threats.
l. ECM produced materials for energy harvesting applications.
m. Development of materials which can change their electromagnetic signature in energetic fields which provide new capabilities in low observable materials to prevent detection, disorient enemies or provide camouflage.
n. Development of a simultaneous multi-field manipulation capability which can apply a combination of magnetic, acoustic, and other diverse fields for suspending and printing matter in three-dimensional space for net-shape additive manufacturing applications.
o. Development of ruggedized portable high field generators.

p. Develop true concurrent multi-scale based materials-by-design capability for materials in high rate environments to enable significant advances in energy dissipation and damage tolerance

iii. Far-term goals (FY26-FY30):
a. Demonstrate electronic and computational function with efficiency 10X greater than state of the art in 2015.
b. Observe evidence for Majorana Fermions and/or other quasiparticles, demonstrating that the observed particles do not obey Fermi or Bose quantum statistics.
c. Devise and establish the braiding of topological quantum quasiparticles suited for exploitation for quantum computing and related technologies.
d. Develop a "unified field theory" combining biology, chemistry, physics, and materials science to design, predict, and experimentally verify the function of bio/non-bio active heterogeneous interfaces for bioadhesives and bioelectronics.
e. Identification, development, and exploitation of a novel class of ECM materials which provide unprecedented physical and mechanical properties.
f. Produce transformational materials that can on-demand, rapidly and actively transition from one state to another when alteration is desired for offensive of defensive purposes by the user.
g. Provide ultralightweight damage tolerant materials for protection systems.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19):
a. Training in the unique physics of topological phases and the connection to materials structure and characteristics will be optimal. (5 re-trained FTEs)
b. Materials scientists, biologists, engineers, chemists, and physicists with multi-disciplinary skills in computational modeling or materials synthesis and processing, and mechanical and microstructural characterization are critical for developing predictive multi-scale computational models and providing experimental validation of those models in order to make new materials and creating novel applications. (5-10 FTEs)

ii. Mid-term (FY20-FY25):
a. Mechanical, materials, ballistic and electrical engineers to design, build, and apply multi-field ECM systems for new materials development. New additive manufacturing capabilities exploiting ECM will require manufacturing engineers. (6 – 12 FTEs)

iii. Far-term (FY26-FY30):
a. Materials scientists and engineers, supported by the research contributions of computational scientists, physicists, biologists, and chemists are critical expertise to make, characterize and integrate new materials or new material properties that are predicted. Mechanical and electrical engineers, aerospace and aeronautical engineers, manufacturing engineers, for developments in high field processing will necessitate transition to commercial production. (6 – 12 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Dedicated growth facilities for the exploration of unique materials predicted.
   b. High magnetic field, ultra-low temperature (sub 1K) magneto-transport characterization facilities for verifying transport characteristics.
   c. Angle-resolved photoemission for the verification of topological band structures.
   d. Low-temperature (sub 1K) scanning tunneling microscopy/spectroscopy to characterize the electronic structure of materials.
   e. Develop a state-of-the-art in-house ECM laboratory with:
      i. High magnetic field thermomagnetic processing system capable of high temperature and pressure application
      ii. Single mode microwave sintering technologies.
   f. Access to existing facilities with high magnetic field sources such as the National High Magnetic Field Laboratory should be leveraged for research on paramagnetic and diamagnetic materials.

ii. Mid-term (FY20-FY25):
   a. Materials processing and device fabrication facilities suitable for the wet and dry chemistries necessary to manipulate topological materials.
   b. Establishment of custom multi-field ECM equipment with additive manufacturing functionality for fabricating net-shape components in three-dimensional space through the use of one or more fields.
   c. In-situ characterization tools capable of providing analysis of the material's properties and the energetic field's characteristics during field application.
   d. Ex-Situ characterization of materials while in performance of their function.
   e. Access to existing space based microgravity facilities for ECM experimentation.

iii. Far-term (FY26-FY30):
   a. Dedicated growth facilities for the exploration of unique materials predicted.
   b. Practical facilities and equipment for reproducing microgravity environments on Earth.
   c. Multi-field ECM equipment adapted for in-theater use, capable of recycling scrap and indigenous materials into useful components to enable a self-sufficient environment that does not rely on delivery or shipment of critical items.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
5	Prevent, reduce, eliminate, and mitigate the use and effects of weapons of mass destruction.
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive.
13	Establish and maintain security across wide areas (wide area security).
15	Conduct combined arms air-ground maneuver.
17	Coordinate and integrate Army and joint, interorganizational, and multinational fires and conduct targeting across all domains.
18	Deliver fires and preserve freedom of maneuver.

Army Capability Need Proponent	Capability Area Need
MCoE	3.a – Combat Vehicle Development.
MCoE	3.d – Unburden the Soldier.
MSCoE	3.i – The Capability to Protect from the Effects of WMD Hazards.
CASCOM	4.a – Advanced Materials.
USAACE	4.d – Mitigants to “chance encounter” threats.

DESIGNED MICROBIAL CONSORTIA FOR MATERIALS SYNTHESIS AND SUSTAINABILITY [MR-3]

EXPECTED ARMY IMPACT: Many of the commodity chemicals that the Army utilizes to produce critical materials originate from non-renewable sources. These resources are typically petroleum based and the security of crude oil feed stocks is directly related to the Army's ability to produce and/or procure materials beyond fuels and lubricants to precursors for advanced polymer systems such as Kevlar. There is a need to replace petroleum based precursors with biologically derived materials which could be produced from waste or renewable resources and that could be employed in additive manufacturing processes. This drive for the biological production of commodity chemicals will also allow for designer materials with fine control of desired functionality (reactivity, resiliency, biodegradability, recyclability, and reduced weight), which are expected to facilitate new and improved Army capabilities such as equal or greater protection at significantly lighter weights. In addition, understanding microbial consortia and engineering them for biological processing / manufacture would also provide the Army with the ability to produce complex chemical intermediates/feed stocks for material synthesis, bioremediation of toxic materials in the environment, probiotics for enhanced Solider health / performance, waste mitigation, and novel routes to energy generation for reduced logistics loads.

DESCRIPTION: Natural microbial communities are capable of completing highly complex tasks such as water purification or waste remediation but many of these processes are not currently well understood. Presently it is possible to monitor, enhance, predict, and control only select single organisms to perform engineered tasks. To achieve the goals of functionality, flexibility, efficiency, and usefulness requires a deeper understanding of symbiotic consortia from a few to a few thousand organisms. Synthetic biological approaches frequently require the modification of 10s-to-100s of genes which need to be timed and controlled perfectly in a single organism. Recently, there have been great advances in this area of research, making it now possible to utilize simple genetic constructs designed for singular functions in a set of organisms which could then be utilized ex vivo. Proper design and implementation engineered ex vivo constructs could reduce complexity and cost for fully functional systems. Advanced concepts also include the use of cybernetic systems to control biological consortia output. Ideally, the desired output of the entire microbial system will be used to establish a balance between the desired function of the organisms and survival of the organisms within the system. This would facilitate robust systems with lasting engineered results rather than the transient results common with current technology.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Develop methods to measure metabolic flux from individual species in multi-organism systems to understand their contribution toward total the total natural and engineered ecologies.
b. Leverage existing state-of-the-art and develop new transcriptomic and proteomic methods to measure individual species in multi-organism systems to understand their contribution toward total the total natural and engineered ecologies.
c. Systematically study designed consortia via bottom up assembly to understand and develop universal design principles for artificial ecology engineering.
d. Advance state-of-the-art in modeling multi-organism systems to include interactions with other organisms and ecological parameters.

e. Iteratively develop and validate advanced models with increasing organism and ecological complexity.
f. Examine mechanistic responses of natural and engineered bacterial consortia to stress and environmental stimuli including feed stocks, pH, and temperature.
g. Use understanding of stress response to improve robustness of ecological systems.

ii. Mid-term goals (FY20-FY25):
a. Characterize genetic circuitry used in natural and artificial consortia to determine mechanism through which individual species modulate responses to ecological conditions such as location in ecology, presence of other organisms, and nutrient levels.
b. Develop advanced tool sets for studying individual cells in ecologies to better understand the impacts of natural phenotypic heterogeneity on complex multi-organism consortia and systems.
c. Develop genetic engineering and synthetic biology tools to alter organisms in ecologies.
d. Manipulate ecologies through genetic modifications of individual species using newly developed synthetic biology tools.
e. Determine minimal metabolic pathways for desired function of ecologies
f. Develop a-cellular systems based on minimal metabolic pathways to reduce system complexity.
g. Explore synthetic systems to produce critical polymer precursors from renewable starting materials.
h. Iteratively develop and validate advanced models with increasing organism and ecological complexity.
i. Develop advanced design principles for ecologies and a-cellular systems
j. Determine critical criteria for scaling the processes.

iii. Far-term goals (FY26-FY30):
a. Understand natural and designed consortia as well as cell free synthetic systems to the point where engineering complex mixtures of natural organisms under controlled conditions will facilitate low-cost, low-energy waste mitigation and bio-manufacturing is possible.
b. Delineate limitations of engineered consortia and cell free systems and explore hybrid approaches.
c. Develop synthetic pathways and ecologies for production of advanced compounds.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Individuals with expertise in metabolomics, systems biology, bio-derived materials, and computational biology would be recruited / developed. Also, expertise in microbial ecology for investigation of environmental, human, and industrial microbial consortia for scalable, robust and safe bio-manufacturing and bio-processing is required. (6 to 10 FTEs)

ii. Mid-term (FY20-FY25): Individuals with engineering expertise in scaling biological processes (biological, chemical, process engineering). (5 to 10 FTEs)

iii. Far-term (FY26-FY30): Modernization and advancement of the science is expected at ever increasing rates and training, replacement and hiring new skill sets / talent will need to be programmed as a continual process. (6 to 10 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Increase capabilities in metabolomics.
   b. Advanced chromatographic instrumentation.
   c. Advanced mass spectrometric instrumentation.

ii. Mid-term (FY20-FY25):
   a. Expanded laboratory space for biological, chemical, and materials science / engineering facility with single to hundreds of liters bio-processing capacities.
   b. Access to ARL's Center of Advanced Polymer Processing.

iii. Far-term (FY26-FY30):
   a. Modernization of instrumentation is expected at ever increasing rates and replacement / upgrade / new developing characterization will need to be programmed as a continual process.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
5	Prevent, reduce, eliminate, and mitigate the use and effects of weapons of mass destruction.

Army Capability Need Proponent	Capability Need Area
CASCOM	3.b – Alternative Sources of Water.
CASCOM	3.d – Additive Manufacturing.

QUANTUM SCIENCES
[MR-4]

EXPECTED ARMY IMPACT: Quantum Sciences will provide game-changing capabilities for Command, Control, Communications, Intelligence, Surveillance and Reconnaissance for stationary and mobile Army elements. Exploitation of quantum phenomena, including distributed quantum systems, will ultimately provide the enabling foundation for many capabilities and applications that are impossible or impractical to achieve through classical means, including quantum teleportation-based information transfer for tamper-evident, secure, long-haul communications and quantum information distribution; enhanced information processing that exponentially exceeds the current classical limits enabling the Army to process information collected from the battlefield in near-real time; assured positioning, navigation, and timing in GPS denied environments; and a network of high-precision globally-synchronized atomic clocks for secure timing capabilities in contested environments. Additionally, exploiting quantum phenomena will lead to new generations of quantum sensors that provide unprecedented sensitivity in field detection, including gravitation fields for locating underground structures and tunnels.

DESCRIPTION: One major initiative of the in-house Quantum Sciences program within the Materials Campaign and the Center for Distributed Quantum Information (CDQI) will be a collaborative fundamental research effort connecting ARL, academic, industrial and other government researchers to develop the physical layer of a multi-site, multi-node, modular quantum network based on resilient distributed quantum entanglement preserved by quantum memory and quantum error correction. Great advances have been made to increase the fidelity of critical quantum components needed to establish a resilient network of quantum entangled resources in various atomic and solid-state systems. Although several research groups have demonstrated point-to-point quantum teleportation, entanglement distribution, quantum error correction, and quantum memory, no scalable, integrated, modular architecture exists by which one can connect three or more small quantum nodes and through which quantum information may be processed. The in-house Quantum Sciences effort working cooperatively with academia and industry will develop and demonstrate such a scalable architecture for an entanglement-based distributed quantum network; establish the physical-layer protocols and algorithms for this architecture composed of integrated, modular components; implement quantum error correction applicable to quantum repeaters and memories; explore Army-relevant applications for such a network; and identify performance limitations of a distributed heterogeneous quantum network that must be overcome or are fundamental. Specific material components include quantum memories, quantum registers, quantum processors, quantum switches, quantum frequency conversion devices, entangled photon sources, single-photon detectors, matter-photon interfaces, quantum sensors, as well as other technologies enabling the realization of integrated, chip-scale and/or modular components for robust, mobile distributed quantum information networks.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Develop the physical architecture of a scalable, modular quantum network where the quantum nodes generate, process, and locally store quantum information and are resiliently connected by fiber-based or free-space photonic links. This includes exploration into heterogeneous system interfaces.

b. Investigate quantum entanglement creation, efficiently converted to and from photons, distributed among three or more quantum nodes, protected through error correction, and locally stored and recovered on demand with high fidelity using quantum memory.
c. Develop network algorithms and protocols, including efficient entanglement management protocols with experimental validation in the context of a multi-site (three or more quantum nodes) distributed quantum network. Quantum entanglement management takes into account entanglement routing, characterizing and manipulating multi-site entanglement, and entanglement verification.

ii. Mid-term goals (FY20-FY25):
a. Improve quantum control, fidelity, entanglement rates, frequency conversion efficiency, and storage times of a heterogeneous quantum network.
b. Refine quantum error correction and purification protocols to protect quantum information from decoherence, and develop entanglement management protocols to coincide with advances to the physical quantum network.
c. Efficiently scale the number of nodes within a quantum network to increase range and performance capability.
d. Develop novel components and technologies to enable scalability and robustness appropriate for the physical implementation to address application requirements.

iii. Far-term goals (FY26-FY30):
a. Investigate and integrate novel modular quantum components for enhanced distributed quantum system performance.
b. Implement basic quantum operations to explore capabilities beyond what is possible classically, such as secure information processing and ultraprecise positioning, navigation, timing and sensing.
c. Explore new applications for which the quantum sciences can perform Army-relevant operations in a manner impossible or impractical for commensurate classical systems.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Expertise in quantum theory and modeling, quantum entanglement, entanglement distribution, entanglement purification, quantum error correction, quantum networking protocols, quantum information processing, quantum teleportation, quantum optics, quantum frequency conversion, quantum memory, quantum control, material growth/synthesis and characterization for quantum applications, fabrication of quantum components, laser-cooling and atomic physics. (8-12 FTEs)

ii. Mid-term (FY20-FY25): Expertise in quantum information management, quantum error correction, quantum purification, quantum logic, heterogeneous quantum interfaces, topological quantum systems, quantum networking, quantum communication, and integrated modular quantum technology. (8-12 FTEs)

iii. Far-term (FY26-FY30): Expertise in quantum networking, quantum operations, quantum engineering, hybrid quantum system integration, quantum repeaters, quantum communication, quantum simulation, and quantum applications. (8-12 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Laboratory space and equipment to develop quantum nodes based on ions, neutral atoms, and solid-state materials.
   b. Design and fabrication facilities to develop modular, integrated components.
   c. Characterization tools and software for assessing performance of quantum systems.
   d. Access to ARL's Center for Distributed Quantum Information

ii. Mid-term (FY20-FY25):
   a. Equipment and facilities for heterogeneous quantum network integration.
   b. Expanded laboratory space for hybrid quantum network with increased range and performance capability.
   c. Leverage existing facilities across the quantum science community for quantum control.

iii. Far-term (FY26-FY30):
   a. Test beds for basic quantum network operations through both optical fiber and free-space.
   b. Modernization of instrumentation, including replacement, upgrade, and new capability development.
   c. Access to emerging quantum systems.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
1	Develop and sustain a high degree of situational understanding.
7	Assure uninterrupted access to critical communications and information links.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	Capability Need Area
MCoE	2.b – Agile, robust, resilient network.
MCoE	4.b – Control the electronic environment.
USAACE	4.e – Assured communications.
Cyber CoE	3.d – Assured Position, Navigation, and Timing (PNT).
Cyber CoE	4.b – Quantum Computing.

SCIENCES-FOR-MANEUVER CAMPAIGN

MISSION: To discover, innovate, and transition S&T enabled capabilities that significantly increase the force effectiveness and global responsiveness of the Army - America's primary ground force.

VISION: Air and ground platforms available to commanders of the Army of 2030 are designed and built that make it possible to rapidly respond to emerging conflicts at any location around the globe. Based on vastly improved materials, logistical support needs of the fighting force are greatly reduced. A globally responsive, lethal, and resilient force serves as a significant deterrent to rising conflict. The desired end state is to leverage the full range of S&T enablers to prepare forces.

FORCE PROJECTION AND AUGMENTATION THROUGH INTELLIGENT VEHICLES [ScMVR-1]

EXPECTED ARMY IMPACT: The Army Operating Concept (AOC) states that "Army development of autonomous and semi-autonomous operational capabilities will increase lethality and protection, and augment, enable and, in some cases, replace Soldiers, thus freeing them to maneuver and operate to their advantage." ARL is focused upon providing the fundamental understanding that will enable future unmanned vehicle systems (UVS) operating in the air, ground, or maritime environments – through greatly improved platform perceptual, learning, reasoning, and communications capabilities to facilitate effective interaction with Soldiers and the local populace thereby engendering trust essential to forming efficient teams. In addition, technological advances in this area are envisioned to create "the potential for affordable, interoperable autonomous and semi-autonomous systems that improve the effectiveness of Soldiers and units. Robotics will deploy as force multipliers at all echelons from the squad to the brigade combat teams. Future robotic technologies and unmanned ground systems (UGS) augment Soldiers and increase unit capabilities, situational awareness, mobility, and speed of action."

DESCRIPTION: ARL research is centered on creating the machine cognition and behaviors that can, in certain scenarios, replace the operator (driver or pilot) in future unmanned vehicles. Our focus includes the perceptual, learning, reasoning and communication skills that are required to effectively interact with both Soldiers and the local populace, and engender the mutual trust necessary for effective teaming.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Cognitive architecture and supporting technologies to model the world in semantic terms, permit reasoning based upon abstractions, and allow interactive communication with Soldiers using structured natural language.

b. Semantic labeling of an increasingly larger vocabulary of objects and behaviors to permit a richer, more detailed description of the environment. Includes the determination of critical scene elements, actions, and relationships to be remembered for future use in machine planning, learning, and reasoning; recognition of changes in the physical and tactical environment as a cue to significant activity requiring reaction; and incorporation of contextual information and life-long learning into reasoning.

c. Expansion of research activities from a primary focus on ground vehicles to fully encompass unmanned air systems.

ii. Mid-term goals (FY20-FY25):

a. Creation of the ability to infer purpose from the relationships between objects in the environment and behaviors (activity) exhibited by people (teammates, adversaries, and non-combatants) and place objects and behaviors into context.

b. Enhanced ability of machines to generalize and rapidly learn from a limited number of exemplars; monitor execution; and identify conditions requiring reconsideration of plans and modification of behavior and autonomously initiate the replanning process.

c. Enable machines to explain knowledge, actions, and predicted outcomes enabling rapid redistribution of tasks between Soldier and robot, enhancing transparency, and engendering greater trust by human collaborators.

iii. Far-term goals (FY26-FY30):

a. Cognitive architectures and algorithms to create unmanned vehicles that possess the situational awareness, cognitive skills, learning capabilities, and reasoning prowess associated with tactical or support vehicle operators.

b. Systems capable of reasoning on an abstract level possessing basic tactical skills and knowledge.

c. Machines able to generalize, adapt, and successfully apply their knowledge base to synthesize new solution approaches to previously unknown situations.

d. Robots able to rapidly and autonomously adapt to changes in human teammate actions--operate effectively as wingmen within a manned-unmanned team without a need for direct control by a Soldier.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Expertise required in computer science, applied mathematics and engineering associated with the creation and integration of software algorithms. Emphasis on cognitive architectures modeling human behavior also requires individuals with backgrounds in social sciences and psychology. Emphasis on the use of natural language for communication calls for additional leveraging of existing expertise in natural language processing. Over the course of five years, expect a net increase of between 12 and 18 Government employees, augmented through partnership arrangements with additional personnel from academia and industry.

ii. Mid-term (FY20-FY25): As the scope of dedicated facilities and testbeds increase, hire 3-4 new Government engineers and technicians, releasing S&T staff to focus on research and experimentation. Consider rotating personnel from Research, Development, and Engineering Centers to ARL for extended periods to facilitate technology transition to concept demonstration projects. Hire 1-2 S&T staff per year to explore and implement the increasing number of research topics, especially as the research focus turns towards empowering robots with more "human-like" cognitive capabilities.

iii. Far-term (FY26-FY30): As technology matures and an increased focus is on empowering systems with cognitive skills, there will be a requirement for 1-2 subject matter experts working with computer scientists and software engineers to create and explore exemplar complex tactical behaviors.

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):

a. A set of representative testbed vehicles, both air and ground, on which to integrate, exercise, and explore integrate component technologies at appropriate scales in a relevant, reconfigurable environment. This could be accomplished in collaboration with appropriate partners (Government, academic, or industrial).

b. Upgraded component sensing and computational hardware to maintain relevance with readily available technology.

ii. Mid-term (FY20-FY25):
   a. Expanded facilities for simulated and live experimentation for increasingly complex physical and tactical outdoor environments for air, ground, and hybrid vehicles. Given the scope of this activity, potential partnering with the Test & Evaluation community, other Government agencies, or industrial partners should be explored.

iii. Far-term (FY26-FY30):
   a. Additional laboratory space to house the larger number of personnel and testbeds in the program.
   b. Additional software development facilities.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
1	Develop and sustain a high degree of situational understanding.
3	Provide security force assistance.
5	Prevent, reduce, eliminate, and mitigate the use and effects of weapons of mass destruction.
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive.
13	Establish and maintain security across wide areas (wide area security).
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.

Army Capability Need Proponent	Capability Need Area
MCoE	3.e – Robotics/Autonomy.
CASCOM	3.a – Autonomous Ground Resupply.
CASCOM	3.e – Autonomous Aerial Resupply.
USAACE	3.d – Improved Manned-Unmanned Teaming and Autonomy.
USAACE	3.h – Joint Force Commonality.
MSCoE	4.e – The Capability to Conduct Operations with Autonomous Systems.

ADVANCED, ELECTRICAL POWER TECHNOLOGIES AND COMPONENTS [ScMVR-2]

EXPECTED ARMY IMPACT: With the demand for higher efficiency and performance, the Army has, traditionally, migrated from mechanical systems to electronic systems. In the future, this evolution will be even more attractive and necessary as networked power management holds the promise of enabling additional capabilities, benefits and cost savings. The Advanced, Electrical Power Technologies and Components effort addresses the development of a broad spectrum of materiels and devices that will be required by Army systems developers in the coming years. Of special focus are high-voltage components that will accelerate the realization of compact, high-energy (sub-) systems.

This research effort is expected to have the following Army impacts:

- Improving mission effectiveness of Army platforms through the development of necessary energy and power underpinning devices and circuits that are required to enable electric-based component technologies.
- Reducing logistics burdens through the development of more efficient electrical power generation, distribution, and conversion components and systems.

DESCRIPTION: This research effort will focus on pursuing advanced, electrical power technologies and components to enable efficient Army platforms. The goals of this work are to overcome barriers to realization of intelligent, solid-state alternatives to selected electro-mechanical components; components and techniques for improved thermal management of transient heating events in electronic systems; high voltage components based on advanced wide band-gap semiconductors; intelligent power conditioning modules and interfaces for power conversion and inversion; and induction-based, electrical energy storage devices that approach 20 J/cc capacities.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):
   a. Develop intelligent, solid-state replacements for selected electro-mechanical components.
   b. Develop a compact, high-voltage power source for plasma applications such as aerodynamic control of smart munitions.
   c. Develop components and techniques for improved thermal management of transient heating events in electronic systems.

ii. Mid-term goals (FY20-FY25):
   a. Develop high voltage components based on advanced wide band-gap semiconductors (such as aluminum nitride or gallium nitride) that allow higher voltage (>25 kV) operation for expanded power control
   b. Develop intelligent power conditioning modules and interfaces to demonstrate power converters and inverters with adaptive circuit topology capability for improved efficiency and reliability
   c. Develop high-slew rate electrical machines, drives, and power sources.
   d. Investigate the use of three-dimensional (3-D), silicon carbide (SiC), metal-oxide-semiconductor field-effect transistors (MOSFET) for improved efficiency of power conversion circuits.

e. Demonstrate high-action, high-voltage opening switches for inductive storage devices. These components are critical for the development of energy storage based on superconducting inductors.

iii. Far-term goals (FY26-FY30):
   a. Develop dielectric-based, electrical energy storage devices that approach 3 J/cc capacities to decrease the volume of energy storage capacitors by one-half.
   b. Develop inductive-based, electrical energy storage devices that approach 20 J/cc capacities to provide substantial volume reductions over competing approaches.
   c. Complete reliability/manufacturability validation of a vertical power transistor using, the wide band-gap semiconductor, gallium nitride (GaN).

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Seventeen (17) S&Es (2 ME, 3 Phys, 12 EE) with advanced education (e.g., M.S., Ph.D.) and at least 5-years of experience in applied research and development environments. External partnering with university and industrial researchers will be required.

ii. Mid-term (FY20-FY25): Eighteen (18) S&Es with advanced education (e.g., M.S., Ph.D.) and at least 5-years of experience applied research and development environments. External partnering with university and industrial researchers will be required.

iii. Far-term (FY26-FY30): Sixteen (16) scientists & engineers (S&Es) with advanced education (e.g., M.S., Ph.D.) and at least 5-years of experience in applied research and development environments. External partnering with university and industrial researchers will be required.

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Renovation of laboratory space and implementation of advanced high-voltage packaging capability.

ii. Mid-term (FY20-FY25):
   a. Renovation of laboratory space for the study of electrical machines. Energy storage using rotating mass requires a containment structure and diagnostic equipment.
   b. Upgraded instrumentation for circuit characterization.

iii. Far-term (FY26-FY30):
   a. Renovation of ARL Bldg. 500's 4160 VAC switch yard at the Adelphi Laboratory Center.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
7	Assure uninterrupted access to critical communications and information links.
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.

Army Capability Need Proponent	Capability Need Area
CASCOM	3.c – Intelligent Power Management and Distribution System.
CASCOM	4.a – Hybrid Power Capabilities.

DAVINCI: DISCOVER & ADVANCE VTOL INNOVATIONS, NOVEL CONCEPTS, AND IDEAS [ScMVR-3]

EXPECTED ARMY IMPACT: By 2040, the Army Aviation Center of Excellence has identified that the Army needs an expanded area of operation, improvements in aviation responsiveness, and minimization of vulnerabilities. Higher vehicle speed, range and payload are three performance attributes required in a Vertical Take Off and Landing (VTOL) vehicle to achieve these needs. Platform configurations capable of meeting such performance goals will be fundamentally different from the current fleet of Army helicopters. Research efforts by ARL will specifically impact:

- Development of technologies to enable fielding of the next generation of VTOL platforms and transfer capability to current platforms to produce significantly increased speed without degradation in hover efficiency.
- Development of technologies to enhance maneuverability in complex environments and at higher operating speeds.
- Development of next generation micro and small unmanned autonomous air vehicles.

DESCRIPTION: The technical goals are to develop algorithms, methods, and tools for flight mechanics, dynamics predictions, and performance assessment; develop new technologies to achieve revolutionary improvements in vehicle performance (including active flow control and active structural shape control to minimize performance tradeoffs across different flight conditions); and explore innovative vehicle configurations for VTOL and micro/small autonomous air vehicles. This effort will leverage analytical, computational, and experimental efforts to achieve the goals. In the far-term (FY26-FY30), high performance computing is expected to reach the exascale levels and sufficiently miniaturization to facilitate embedding into vehicle platforms to provide significant onboard computing power. Additionally, technological advances in materials science are expected to create extremely light weight, strong materials to significantly reduce system weight. The combination of these improvements will enable active shape-morphing vehicles that are optimized using developed tools, methods, and embedded computing. Exascale computational tools will manipulate the structural deformations along with active flow control to generate necessary forces in each flight regime.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Develop computational algorithms and methods to significantly enhance and improve accuracy and efficiency of predictions for loads, stability and performance of platform mechanics.
b. Develop multi-fidelity approaches to understand aerodynamic interactions and exploiting them for performance benefits.
c. Develop methods and algorithms to evaluate system utilizing emerging materials by integrating multi-physics simulations with different time and space scales.

ii. Mid-term goals (FY20-FY25):

a. Demonstrate mature active flow control and structural shape control technologies in model scale experiments.
b. Develop algorithms to couple sensors with the control mechanism to predict aeromechanics characteristics and configuration management for specified flight mission.

c. Develop models of biologically-inspired or smart materials and systems for application in design and comprehensive analysis tools.
d. Develop performance models of potential VTOL platforms.

iii. Far-term goals (FY26-FY30):
a. Virtual demonstration of fusion of advanced aerodynamic, structural and control technologies on VTOL platforms.
b. Develop models of enabling technologies – active flow control, active shape control, configuration morphing – across the flight spectrum.
c. Develop tools and methods for load, stability, and performance prediction of next-generation VTOL platforms.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): The project requires additional personnel resources with background and experience in the general area of rotorcraft aeromechanics. Personnel are also required to support teams engaged in utilizing high performance computing for fundamental fluid dynamics and structural dynamics. (5 FTEs).

ii. Mid-term (FY20-FY25): The project requires personnel with expertise in multiple disciplines to influence next generation analysis tools and methods. Such needs may be met by new hires or by leveraging personnel from material science, information science, and computational science campaigns. (6 FTEs)

iii. Far-term (FY26-FY30): Multi-disciplinary expertise to impact studies of VTOL platforms possessing significant interactions between several systems. (7 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
a. High Performance Computing resources (25 Million CPU hrs per year).
b. Access to Transonic Dynamic Tunnel.

ii. Mid-term (FY20-FY25):
a. Access to Petascale High Performance Computing resources. (100 Million CPU hrs per year)
b. Access to Transonic Dynamic Tunnel.

iii. Far-term (FY26-FY30):
a. Access to ExaScale High Performance Computing resources.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
12	Establish and maintain security across wide areas (wide area security).

Army Capability Need Proponent	Capability Need Area
USAACE	3.a – Range, speed, payload, and capacity consistent with maneuver force lift demands and mission needs.
MSCoE	4.a – The Capability to Facilitate Early Entry Operations.

INFORMATION SCIENCES CAMPAIGN

MISSION: To discover, innovate, and transition S&T capabilities that (1) facilitate the availability and effective use of high assurance and high quality information and knowledge at the tactical edge in a timely manner; and (2) facilitate the development of offensive information systems to limit adversary command-and-control capabilities.

VISION: Intelligent information systems available to the Army of 2030 provide reliable, timely, valuable, and trustworthy information and knowledge at the most appropriate force echelon, especially to the tactical edge – significantly mitigating tactical surprise. Army offensive information systems significantly limit the adversary's command-and-control capabilities. Intelligent information systems support and team with the force, forming an underlying socio-technical base for all things in the battlespace, from munitions targeting to maneuver to command-and-control. The desired end state is to leverage the range of S&T enablers to prepare forces to succeed in distributed operations and increasingly complex environments where information plays an ever increasing role.

CYBER FIRE AND MANEUVER IN TACTICAL BATTLE [IS-1]

EXPECTED ARMY IMPACT: The Army battlefield of 2040 will be a highly converged virtual-physical space, where cyber operations will be an integral part of the fight. As stated in the Army Operating Concept, "The cyberspace and space domains will take on added importance in the future. Global and regional competitors have invested heavily in all aspects of cyber and space operations". Cyber Fires will degrade, disrupt, deny, deceive and destroy not only informational, computational and communication resources of the adversary, but also the physical capabilities of its platforms, weapons, robots, munitions, and even of personnel. "Land-based cyber operations generate and exert combat power in and through cyberspace utilizing combined arms leaders, staffs, and formations to enable freedom of maneuver and action to deliver decisive effects." Cyber maneuver will rapidly move and/or transform (in the cyber space, but also in conjunction with physical maneuver) the friendly informational-computational resources to deny the adversary an opportunity to attack, while imposing on him a new unsolvable problem. Cyber Fires and Maneuver will rely on effective Cyber Intel capabilities. "The capability to conduct cyberspace information collection to find and identify cyberspace threats inside and outside of friendly force networks, and forensically collect, analyze and exploit an attack or intrusion, is critical to conducting friendly or enemy assessments." Operating on multiple time scales, often far faster than human cognitive processes, in a highly dynamic, non-contiguous field (as opposed to today's largely static cyber defense perimeters), these fires and maneuvers will be inseparably integrated with kinetic fires and movements. "The complexity of unified land operations further requires an expanded notion of combined arms that fully integrates physical, cyber, and electronic means." Our research will support continuous (real-time, not just deliberate) creative planning and execution control of highly agile, daring, aggressive cyber fires and maneuvers of this complex nature, in a necessarily highly automated, machine-intelligent fashion, yet responsive to human intent and in accord with slower kinetic actions.

DESCRIPTION: This research effort will focus on developing the models, methods, and understanding to overcome existing barriers to realization of effective cyber fires and maneuvers in a tactical environment. The goals of this work are to pursue near-autonomous detection and identification of malicious activity directed at friendly networks; methods to rapidly respond to adversarial activities; predictive characterization of network vulnerabilities; and a robust framework to assess networks. In addition, this research program will focus on realization of methodologies for the reliable reconfiguration of friendly cyber assets to evade or recover from attack; convert means for collection and predictive analysis of enemy actions; and methodologies to destroy cyber assets with high certainty and predictable probabilities of kill.

a. TECHNICAL GOALS:

- i. Near-term goals (FY15-FY19):
  - a. Techniques for near-automated generation of tools for detection and identification of malicious activities and malware using machine learning and other automated techniques with limited human supervision; including theoretically grounded methods for characterizing the detection and identification capabilities.
  - b. Methods of active responses to adversary presence on friendly networks, with measurable and quantitative means to select and configure a response, and to anticipate the effects of the response on adversarial behavior.

c. Approaches to predictive characterization of risks to a network imposed by adversary, by network features and by human factors.
d. Theoretical frameworks for quantifying effects of cyber maneuvers.

ii. Mid-term goals (FY20-FY25):
a. Theoretically-grounded methods for robust autonomous detection of malicious activities, with adaptive collection and self-learning modifications of collection-detection agents.
b. Techniques to move effectively and predictably through friendly and enemy cyber space using wired and wireless access means.
c. Approaches to reliable reconfiguration of friendly cyber assets to evade or recover from an attack.

iii. Far-term goals (FY26-FY30):
a. Autonomous techniques where collaborative teams of cyber agents under human oversight conduct focused collection and predictive analysis of enemy actions, while maintaining self-concealment.
b. Approaches to agent-based integrated collaborative planning and wargaming; communicate and coordinate actions in execution.
c. Methods to destroy enemy cyber assets with high and predictable probability of kill; autonomously re-synthesize and re-deploy the agents when defeated by adversary, taking into account the observed defeat mechanism.

b. PERSONNEL REQUIREMENTS:

i. Far-term (FY26-FY30): Computer scientists with skills in agent-based systems, artificial intelligence, autonomous negotiation, planning, game-theoretic approaches, and formal methods in software synthesis. (3 FTEs)

ii. Mid-term (FY20-FY25): Computer scientists with skills in detection theory; adaptive systems; electrical engineers with skills in electromagnetic applications in cyber; control theory for execution of cyber maneuvers. (5 FTEs)

iii. Near-term (FY15-FY19): Computer scientists with skills in machine learning mathematicians with skills in advanced statistics and mathematics for applications for large-scale data analysis and mining; risk theory; system scientists with skills in human factors in application to cyber. (4 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
a. Framework for large-scale collection, analysis, tagging and storage of real-world cyber data suitable for further research utilization.
b. Laboratory for efficient study of integrated, heterogeneous techniques for detection and analysis of malicious activities using large volumes of pre-collected cyber data.
c. Facility for realistic emulation of cyber data of enterprise, tactical, and cyber-physical nature.

ii. Mid-term (FY20-FY25):
   a. Laboratory for emulation and extensively instrumented experimentations for study of realistic dynamics and effects of individual cyber fire actions and cyber maneuver of adversarial cyber environments. Minimal human input or manipulation should be required for experiments. Includes cyber-physical systems. Highly automated, continuous adoption of latest observed adversarial TTPs from real-world cyber defense operations.

iii. Far-term (FY26-FY30):
   a. Research-focused facility for emulation of cyber battlefield, and automated experimentation in realistic wargames, controllable and repeatable, with adjustable time-scale, in large-scale, high-fidelity scenarios; able to represent activities of friendly and hostile teams of cyber agents, in the context of combined arms operations.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
1	Develop and sustain a high degree of situational understanding.
3	Provide security force assistance.
7	Assure uninterrupted access to critical communications and information links..
11	Conduct effective air-ground combined arms reconnaissance.
13	Establish and maintain security across wide areas (wide area security).
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	Capability Need Area
USAICoE	4.a – Intelligence Analysis.
Cyber CoE	3.e – Cyber Situational Awareness (Cyber SA).
Cyber CoE	4.a – Autonomous Active Cyber Defense

TAMING THE FLASH-FLOODS OF NETWORKED BATTLEFIELD INFORMATION [IS-2]

EXPECTED ARMY IMPACT: The Army battlefield of 2040 will be a complex dynamic heterogeneous network involving multiple interacting actors and agents (humans, robots, robo-sensors, robo-munitions, and intelligent agents). Their interactions and implications of these interactions have many dimensions (military, economic, social, political and legal). "Operating in complex environments, including dense urban areas, and against enemies that intermingle with civilian populations and avoid long-range detection, Army forces develop situational understanding through action and are prepared to fight for information while applying firepower with discipline and discrimination." In this complex environment, massive volume and complexity due to variety, velocity and veracity of distributed information - the bulk of it machine-generated - will rise, surge, morph, collapse and pulsate through this network, overwhelming and incomprehensible to humans. Our research will provide means of controlling, channeling, directing, reshaping this dynamic, cluttered information field – in accord with the underlying dynamic network of humans and machines - in a manner that meets the needs of human minds relevant to the mission context at the precise time and for their precise needs. Highly automated collective intelligence of the network will comprehend the information field; know the rapidly evolving cognitive needs and situational context of Soldiers. This will enhance the security, accessibility, and utility of information while simultaneously shifting the burden of technological complexity from the user to the overall mission command system. The collective intelligence of the network will proactively access, shape, correlate, organize, clarify, distill and deliver to each Soldier the right, precisely meaningful content.

DESCRIPTION: This research effort will focus on developing the models and methods to overcome existing barriers to realization of analytical approaches to better understand the dynamics that characterize complex, multi-genre networks. The goals of this work are to pursue quantitative models of information semantics trust and quality; methodologies to creating coherent information networks from distributed information sources; approaches to partially centralized and semi-autonomous control of large complex networks; and approaches to autonomously recognizing, modeling, and anticipating dynamic changes in network processes.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

   a. Modeling and analysis of dynamics in complex multi-genre networks, including impacts of mobility in disruptive terrain, and of context-sensitive and social-sensitive information caching and routing.
   b. Quantitative models of information semantics trust and quality, and approaches to applying these characteristics in networked information delivery.
   c. Approaches to creating coherent information networks from distributed yet implicitly linked information sources, including analysis, summarization and linking heterogeneous information such as video and textual information, and network-distributed data mining for trends, patterns and anomalies.

ii. Mid-term goals (FY20-FY25):

   a. Approaches to partially centralized and semi-automated control of large complex networks, including stabilization after a major disruption and degradation, while accounting for information semantics, value and trustworthiness.

b. Methods to discover, retrieve, extract, fuse relevant information from large, distributed, dynamic storages of heterogeneous, unstructured info – adaptive to situation, mission, communications resources, and cognitive state – of the individual Soldier or collaborative group.

iii. Far-term goals (FY26-FY30):
   a. Theoretically-grounded, robust techniques for autonomous and distributed control of large multi-genre networks, including large scale self-reconstruction under conditions of extensive ongoing disruptions and destruction, mobility, social and organization dynamics.
   b. Approaches to autonomously recognizing, modeling and anticipating dynamic changes in network processes, such as changes in connection and data flow patterns, including social, group and collaboration dynamics, understanding of friendly situation, adversary plans, social and political environment.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Computer scientists and computational social scientists with skills in multi-genre network modeling; mathematicians and information theorists with skills in large-scale data mining and semantic information theory. (3-4 FTEs)

ii. Mid-term (FY20-FY25): Computational cognitive and behavioral scientists with skills in modeling individual and group cognitive requirements; computer scientists with skills in multi-media information extraction and fusion. (3-5 FTEs)

iii. Far-term (FY26-FY30): Control theory scientists with skills in robust distributed control; artificial intelligence and computational social scientists with skills in agent-based system dynamics and predictive modeling of complex socio-technical systems. (2-4 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Laboratory for extensively instrumented study of emulated mobile communication networks with realistic automated portrayal (largely through computer-assisted scripting) of effects of mobility, EW attacks, and organizational-social and cognitive effects.
   b. Framework for analysis, linking, integration and evaluation across large collections of heterogeneous information sources.

ii. Mid-term (FY20-FY25):
   a. Facility for experimentation with human-driven control mechanisms of emulated and partially physical networks, enabling both computer-simulated human agents along with human-in-the-loop and autonomous robots; red-teaming for disruption and degradation of the network.
   b. Interoperability capabilities with the laboratory for retrieval, extraction and fusion of distributed heterogeneous unstructured information.

iii. Far-term (FY26-FY30):
   a. Framework for emulation and automated experimentation of autonomous control of integrated information and communication network, in realistic wargames, controllable and repeatable, with adjustable time-scale, in large-scale, high-fidelity scenarios; able to represent extensive adversarial impacts and realistic reactions of red, blue and civilian actors.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	**Description**
1	Develop and sustain a high degree of situational understanding.
3	Provide security force assistance.
7	Assure uninterrupted access to critical communications and information links..
11	Conduct effective air-ground combined arms reconnaissance.
13	Establish and maintain security across wide areas (wide area security).
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	**Capability Need Area**
MCCoE	2.d – Units that can function in spite of degraded networks (cyber, EW, space, etc.).
USAICoE	3.b – Collection Modernization.
USAICoE	4.a – Intelligence Analysis

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ACTING INTELLIGENTLY IN A DYNAMIC BATTLEFIELD OF INFORMATION, AGENTS, AND HUMANS [IS-3]

EXPECTED ARMY IMPACT: The Army Operational Environment of 2040 will be a complex dynamic environment of interacting heterogeneous agents, actors, and adversaries (humans, robots, sensors, information systems, and software agents). Their interactions, and implications of these interactions, have many dimensions (military, economic, social, political, legal). "Operating in complex environments, including dense urban areas, and against enemies that intermingle with civilian populations and avoid long-range detection, Army forces develop situational understanding through action and are prepared to fight for information while applying firepower with discipline and discrimination." In this complex environment, understanding and exploiting the interactions between information systems and intelligent systems will be critical to mission success by providing automated intelligence in the form of intelligent perception, reasoning, planning, collaboration, and decision making. Our research will provide the means with which to understand, fuse, and act upon the information to support the Soldier in accomplishing the tactical mission. Highly intelligent information understanding will extract and combine data from disparate information sources that transform the information into computationally tractable and more Soldier useable formats. Highly intelligent information fusion will integrate data from human and physical sensors by incorporating contextual and semantic information to provide Soldiers with trustworthy, high quality information on which to act. Computationally feasible techniques and theory will synergistically integrate information with the behavior of intelligent agents acting upon the world. This will support and augment the Soldier in accomplishing tactical missions.

DESCRIPTION: This research effort will focus on developing the models, methods, and understanding to overcome existing barriers to realization of robust and reliable intelligent agents. The goals of this work are to pursue concepts for processing large-scale text and speech of low-resource languages; concepts for determining visual saliency in large scale imagery and video data sets; militarily-relevant pattern recognition and mapping methodologies; techniques to enable real-time decision making; approaches to develop new world-models of recently encountered spaces; algorithms to infer relationships between disparate elements and events; and approaches to autonomously recognize, model, and anticipate dynamic changes in information processes.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Concepts for processing large-scale text and speech of low-resource languages drawing on machine learning techniques.
b. Data mining and analytics techniques for rapid exploitation of large-scale data sets.
c. Innovative concepts for determining visual saliency in large scale imagery and video information.
d. Robust object detection via varied modalities incorporating contextual and semantic cues.
e. Recognition and classification of simple activity in non-cluttered environments.
f. Multi-sensor information fusion of EO/IR videos, acoustic signals, and passive RF in context of semantic information.

g. Pattern recognition and mapping in relevant complex military environments to understand and incorporate newly encountered physical and abstract spaces into the knowledge representation of existing information sources.
h. Planning and execution of agent behaviors to explore the unknown and incorporate it into a known framework.
i. Intelligently control physical and software information agents by coupling sensing, communications, intelligence, and user constraints across the information science enterprise.
j. Enable real-time decision making by tasking and allocating resources across the environment with an emphasis towards long-duration missions.

ii. Mid-term goals (FY20-FY25):
a. Approaches to extract explicit meaning in social media based on contextual and semantic cues.
b. Video summarization, scene understanding, and perception of complicated dynamic scenes by incorporating multi-modal and situational contextual information.
c. Recognition and classification of activity in cluttered environments.
d. Approaches to recognize and understand the world in terms of cognitive modeling as a framework for representing and computing information across complex interacting agents.
e. Approaches to recognize patterns and develop a world model of newly encountered spaces in military environments.
f. Algorithms and representative paradigms that enable intelligent agents to infer relations between disparate elements and events, thus enabling improved situational awareness and forecasting of future events.
g. Estimates of adversarial actions based on disparate sources of data and predictive models to reason about intent.
h. Novel techniques for distributed and decentralized decision making by heterogeneous physical and software agents.

iii. Far-term goals (FY26-FY30):
a. Theoretically-grounded, robust techniques for autonomous, multi-agent information exploitation by physical and software agents, including intelligent behaviors by physical agents that can actively gather and extract information from the environment.
b. Approaches to autonomously recognize, model, and anticipate dynamic changes in information processes, including intelligent agents that can manipulate information to the detriment of adversarial agents and to the benefit of Soldier mission effectiveness, including social, group and collaboration dynamics, understanding of friendly situation, adversary plans, social and political environment.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Control theorists, computer scientists, and computational linguists with skills in machine learning, semantic information theory and adaptive control; and statisticians and mathematicians with skills in, large-scale data mining. (3-5 FTEs)

ii. Mid-term (FY20-FY25): Computational social scientists and social linguists with skills in modeling social, political and cultural context; computer and information scientists with skills in multi-media information extraction and fusion; and computer engineers with skills in prototyping agent behaviors. (3-4 FTEs)

iii. Far-term (FY26-FY30): Artificial intelligence and multi-agent reasoning scientists with skills in agent-based system dynamics and predictive modeling of complex intelligent systems. Control theory scientists with skills in robust distributed control. (3-4 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):

a. Laboratory for study of intelligent systems in militarily relevant environments including varied static and dynamic agents with ground truth capacity.

ii. Mid-term (FY20-FY25):

a. Facility for large scale experimentation with multi-agent, heterogeneous teams of human, physical agents, software agents, and simulated semantic and contextual information paradigms.

iii. Far-term (FY26-FY30):

a. Framework for large scale experimentation with extended temporal capabilities by physical agents, software agents, and high-fidelity information system simulation.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
1	Develop and sustain a high degree of situational understanding.
2	Shape and influence security environments.
3	Provide security force assistance.
11	Conduct effective air-ground combined arms reconnaissance.
13	Establish and maintain security across wide areas (wide area security).
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	Capability Need Area
USAICoE	4.a – Intelligence Analysis.
Cyber CoE	3.a – Hardware Software (HW/SW) Convergence.
Cyber CoE	3.e – Cyber Situational Awareness (Cyber SA).

SENSING AND INFORMATION FUSION FOR ADVANCED INDICATIONS & WARNINGS [IS-4]

EXPECTED ARMY IMPACT: The goal of this research is to provide the foundational elements needed for future Army systems to: 1) sense and discover the presence of friendly and enemy assets and activities; 2) predict future activities for situational understanding. If successful, these improved capabilities will significantly extend the time (weeks instead of hours) that US forces, and particularly those at the tactical edge, will have to respond to threats and enable them to engage under the most favorable conditions for our warfighters. The research will focus on enabling a high fidelity common operational picture while simultaneously shifting the burden of technological complexity away from the user. The battlefield of 2040 will likely be saturated with sensor assets and information sources (both friendly and enemy) since they are readily available and interconnected. The challenge will be to fully exploit all those sensors and information sources, regardless of data provenance, reliability, or relevance and synthesize conclusions relevant to individual missions. Sensors must also keep pace with enemy camouflage, concealment and deception (CCD) techniques and be able to operate under all environmental conditions. Future information generation and exploitation will exploit not only traditional sensors but the full range of information sources including sensors (US, allies, neutrals and enemy), text sources, cyber sources, human experts, etc. The ultimate consumer of these technologies would include the Army, the Marine Corps, and USSOCOM for combat operations as well as stability and humanitarian operations. From TRADOC PAM 535-3-1: "Future Army forces require the capability to develop and sustain a high degree of situational understanding while operating in complex environments against determined, adaptive enemy organizations." This research is consistent with the following TRADOC Emerging Technology Focus areas:

- "Maximize Demand Reduction and Improve Reliability" by adding significant automation to the information generation process.
- "Maintain Overmatch" in the areas of protection and intelligence.
- "Enhance Expeditionary Capabilities" by enabling US forces to seize the information initiative and offset enemy advantages.

Key research areas include:

- New sensors and sensor processing for long range, early warnings.
- Technologies to overcome environmental impediments to sensing.
- Sensor and information fusion algorithms and architectures to reduce all available relevant data into information consumable by analysts.
- Sensor and information processing at the tactical edge in a spatially distributed networked environment.

DESCRIPTION: This research effort will focus on shifting the burden of technological complexity away from the user which will rely heavily on making information sources such as sensors more capable and more easily interconnected. Fusion of multiple information sources, not only sensors, is essential and much of the program is focused on foundational work aimed at facilitating that fusion. Fundamental research in physical phenomenology is also critical since it can lead to new sensing opportunities, enable full exploitation of sensor data, and lead to realization of new sensors which can provide more robust input to fusion algorithms.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Make the Improved Sensor Integration (ISI) standards into a Standardized Agreement (STANAG).
b. Exploit vector (particle velocity) sensors for acoustic detection & localization & integrate with atmospheric models for accurate localization.
c. Algorithms for image & video analysis that leverage co-occurrence of textual information for combined exploitation.
d. Object classification and scene understanding for LIDAR data.
e. Soft and hard data fusion for anomaly determination.
f. Agile, distributed service oriented architecture for networking and interoperability of disparate sensor assets.
g. Policy management tools for sensor asset control and sensor data/information dissemination.
h. Controlled natural language techniques for metadata representations and mission programming.
i. Fusion of physics based sensor data & human generated social media data.
j. Physics-based RF clutter models for urban, rural, and forest environments.
k. RF interference mitigation techniques Development of automatic target detection, tracking and classification algorithms for low signature and/or concealed targets.

ii. Mid-term goals (FY20-FY25):

a. Accurate classification of impulsive acoustic events.
b. Context aware algorithms for multi-sensor fusion.
c. Robust, low level sensor meta-data standards to enable all source fusion.
d. Ontology and semantic processing algorithms for matching sensors & processing to missions.
e. Identification of video alphabet classes and action grammars for robust & accurate behavior determination.
f. 3D scene reconstruction methods from passive, near sideways-looking airborne image sensors to gain situational awareness on access denied terrain.
g. Ontology and semantic processing algorithms for matching sensor assets & processing resources to dynamic missions.
h. Distributed and integrated fusion for situational understanding; distributed composition of sensor, data and information services.
i. Unstructured data fusion and analytics with focus on video and text
j. Adaptive context-aware predictive analytics.
k. All-weather ground-based and airborne wideband penetrating radar for close-in and wide-area standoff detection of concealed targets in urban and rural environments.
l. Combined multi-function foliage penetration synthetic aperture radar (SAR) imaging and moving target indication (MTI).

iii. Far-term goals (FY26-FY30):

a. Surface and sub-surface imaging from mechanical waves.
b. Managing, processing and exploiting the growing volume and complexity (variety, velocity and veracity) data and information at the tactical edge.

c. Highly collaborative sensor to sensor and sensor to human interactions.
d. Extreme low power image & video scene analysis algorithms with the power of reliable prediction or spatiotemporal demarcation of dangerous and threatening objects and events.
e. Fully cognitive and integrated radar and EW functionality.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19):
   a. Additional experts in image understanding. (5 – 7 FTEs)
   b. Social science researchers with sensor & data analytics skills. (4 – 7 FTEs)
   c. Build team to develop robust meta-data for sensors & other data sources. (1 – 2 FTEs)

ii. Mid-term (FY20-FY25):
   a. Ontology researchers (Government, contractors, collaborators). (5 – 8 FTEs)
   b. All-source intelligence experts (Government, contractors, collaborators). (3 – 5 FTEs)

iii. Far-term (FY26-FY30):
   a. Expert ARL Ontology research team. (5 – 8 FTEs)
   b. Data analytics team. (8 – 12 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Collaborative networked sensor test bed facility– including networking for sensors, lab facility for algorithm development and offices for guest researchers to come to ARL to perform research experimentations.
   b. Links to big data storage and analytic capabilities.

ii. Mid-term (FY20-FY25):
   a. Tightly integrated, distributed networked sensor research capability in conjunction with universities and other laboratories.
   b. Robust collaborative work environment to link all ARL & collaborators.
   c. Organic big data storage and analytic capabilities for Army problems.

iii. Far-term (FY26-FY30):
   a. Networked sensing test bed integrated with operational Army elements for real time experimentation.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
1	Develop and sustain a high degree of situational understanding.
3	Provide security force assistance.
11	Conduct effective air-ground combined arms reconnaissance.
13	Establish and maintain security across wide areas (wide area security).
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.
19	Understand, visualize, describe, direct, lead, and assess operations.

Army Capability Need Proponent	Capability Need Area
MCoE	3.b – Advanced Sensors Technology and Integration.
USAICoE	3.b – Collection Modernization.
USAICoE	4.a – Intelligence Analysis.
Cyber CoE	3.c – Defensive Cyber Operations-Tactical.
Cyber CoE	3.e – Cyber Situational Awareness (Cyber SA).

SCIENCES FOR LETHALITY-AND-PROTECTION CAMPAIGN

MISSION: To discover, innovate, and transition S&T capabilities that (1) facilitate the development of discriminant lethality across a broad range of missions; (2) facilitate the development of protection systems that are effective, fieldable, and affordable against a broad array of threats; and (3) enable robust technical tools and methodologies for evaluation and combat decision aids.

VISION: Lethality systems available to commanders of the Army of 2030 are precise, long range, and highly mobile. Protection systems are light weight, low burden, affordable, and resilient towards a broad array of threats. A fundamental understanding of injury mechanisms is exploited for a safer, more effective force. A globally responsive, lethal, and resilient force serves as a significant deterrent to rising conflict. The desired end state is to leverage the range of S&T enablers to provide forces with the right lethality at any place and time without increased warfighter risk and warfighter protection against the continuum of threats without degrading combat power.

SCALABLE LETHAL ADAPTABLE WEAPONS CONCEPTS [ScL/P-1]

EXPECTED ARMY IMPACT: These efforts will provide continued lethal overmatch across the full range of weapons for both direct and indirect fires. Systems will be employed in expanding roles such as light and heavy armor with increased range and fire power as well as new lightweight manned and unmanned combat vehicles/systems and dismounts. New types of gun and missile technologies will be enabled with new launch mechanisms to deliver increased muzzle energies and new lethal mechanisms capable of defeating the toughest targets at reduced energy, reduced caliber, or reduced missile size while working with other research areas to provide necessary standoff range. Futuristic lethal mechanisms will be pursued and validated to provide a range of incapacitation effects against personnel and combat vehicles/systems. Disruptive energetic and propulsive materials will be investigated and tested to provide the Army with weapons with orders of magnitude enhancement in performance.

DESCRIPTION: This program will lead to unprecedented enhancements in lethality for the mounted and dismounted soldier against a spectrum of personnel and manned and unmanned ground and aerial combat systems.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Demonstrate medium caliber munition concept that can defeat personnel in the open and behind double reinforced concrete structures.
b. Demonstrate concept capable of breeching urban structures (double reinforced concrete, triple brick) to produce a man-sized hole.
c. Demonstrate proof of concept of new launch mechanisms that enable significant increases in muzzle energies from current launch package sizes – Advanced Kinetics.
d. Demonstrate proof of concept of new mechanisms that take advantage of target vulnerabilities to reduce the required energy to the defeat of targets (extending range).
e. Synthesis and characterization of novel energetic materials which have performance characteristics that exceed RDX by 30%.
f. Develop novel methods for differentiating the effects of thermal loading, shock loading, and optical excitation in order to develop a fundamental understanding of initiation mechanisms.

ii. Mid-term goals (FY20-FY25):

a. Maturation and transition of warhead concepts and mechanisms that provide the lethality of legacy systems using a fraction of the energy currently required.
b. Proof of concept demonstration of single munition capable of defeating multiple threat target types.
c. Investigate and characterize viable directed energy mechanisms and concepts to defeat combat vehicles.
d. Development and implementation of small-scale experiments to predict full-scale performance of novel energetic and propulsive materials.
e. Develop computer-based simulation environment for the virtual design of weapons and robust models for the prediction of effects.
f. Maturation of revolutionary disruptive energetic and propulsive materials with performance characteristics significantly greater than current capabilities.

g. Demonstrate proof of concept for cannon-type effects with a man-portable system.
h. Develop a model to correctly predict failure of brittle materials and organic materials.

iii. Far-term goals (FY26-FY30):
a. Proof of concept demonstration of non-lethal reversible incapacitating effects.
b. Proof of concept demonstration of high energy warhead with scalable lethal effects (0-150%).
c. Maturation of adaptable directed energy weapon concepts that provide spectrum of lethal effects against personnel and vehicles.
d. Maturation and transition of disruptive and propulsive materials with performance characteristics with orders of magnitude greater than FY15 capabilities.
e. Proof of concept demonstration of sensing capabilities to detect hostile targets and assess levels of incapacitation at extended ranges, thereby identifying if the detected personnel is a continued threat.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19):
a. Expansion of research teams investigating far-term lethality solutions that include physical and biomedical scientists and mechanical, materials, electrical, and electronics engineers.
b. Retraining of current personnel to acquire new experimental and computational skills.

ii. Mid-term (FY20-FY25):
a. Rebalancing and retraining of current personnel to meet rapidly evolving research challenges.

iii. Far-term (FY26-FY30):
a. Retraining of current personnel to acquire new experimental and computational skills.

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
a. Modernization of facilities and equipment to support state-of-the-art experimentation necessary to develop disruptive energetic and propulsion materials. Modernization of experimental facilities to include precision measurement tools, diagnostic instrumentation capable of capturing ballistic events in higher spatial and temporal resolution, and software upgrades (integrated and intermediate) to increase speed and accuracy of data acquisition, reduction, and analysis.
b. New facility dedicated to high-pressure synthesis and scale-up of disruptive and propulsive materials.
c. New facility to accommodate leading-edge lethal mechanism research.

ii. Mid-term (FY20-FY25):
   a. Modernization of experimental and computational facilities and equipment to support development of advanced lethal weapons. Modernization of experimental facilities to include precision measurement tools, diagnostic instrumentation capable of capturing ballistic events in higher spatial and temporal resolution, and software upgrades (integrated and intermediate) to increase speed and accuracy of data acquisition, reduction, and analysis.
   b. Development of facilities which permit seamless integration of multiple experimental and modeling/simulation teams.

iii. Far-term (FY26-FY30):
   a. Modernization of experimental facilities to include precision measurement tools, diagnostic instrumentation capable of capturing ballistic events in higher spatial and temporal resolution, and software upgrades (integrated and intermediate) to increase speed and accuracy of data acquisition, reduction, and analysis.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive operations.
15	Conduct combined arms air-ground maneuver.
17	Coordinate and integrate Army and joint, interorganizational, and multinational fires and conduct targeting across all domains.
18	Deliver fires and preserve freedom of maneuver.

Army Capability Need Proponent	Capability Area Need
MCoE	3.c – Small Unit Lethality.
USAACE	3.b – Multi-purpose weapons capable of lethal and non-lethal options.
MSCoE	3.j – The Capability to Immediately Neutralize or (Temporarily) Incapacitate Targets.
FCoE	3.c – Long Range Precision Fires.

DESIRED LETHAL EFFECTS AT STANDOFF RANGES IN CONSTRAINED ENVIRONMENTS [ScL/P-2]

EXPECTED ARMY IMPACT: The expected impact that this research will have on the operational Army's capabilities in the 2040-timeframe is significant enhancements in assured delivery of the lethal payload. Assured delivery implies that munitions will be brought to bear on the battlefield more precisely (lower collateral damage, reduced logistics burden), with more mission space (extended range, moving targets, defilade targets, smaller caliber weapons for lighter platforms), in a more complex environment (GPS denied, countermeasures) at low cost.

DESCRIPTION: Assured delivery of the lethal payload is underpinned by ballistic launch and flight sciences. Guided delivery is composed of two enabling technologies: maneuverability and navigation. Navigation provides information to understand the dynamic states relating the target and the munition and maneuverability is necessary to deliver the payload to the target. Goals are defined with these sciences and enabling technologies in mind.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Demonstrate proof of concept of high maneuverability airframe flight required to intercept moving or defilade targets.
b. Understand flight behaviors critical to formulating control mechanism technologies and guidance and control algorithms that accommodate large uncertainties characteristic of low cost actuators and sensors.
c. Achieve image-based navigation for simple ground targets to advance the state-of-the-art in navigation in access denied environments and interception of moving targets.
d. Demonstrate proof of concept for a feasible system approach that can address the multi-shot man-portable defilade kill capability that can 1) be safely fired (recoil and noise constraints); 2) reach extended ranges (2km); 3) implement highly effective navigation and guidance approaches; and 4) implement effective lethal package.
e. Proof of concept demonstration of technologies that provide increased muzzle energies while maintaining or lowering recoil compared to current weapon systems.

ii. Mid-term goals (FY20-FY25):

a. Exploit nonlinear physics to devise flight control mechanisms and algorithms to overcome scientific barriers to maneuverability of atmospheric flight vehicles spanning Mach regimes from subsonic to low hypersonic (omnisonic speeds).
b. Enable initial swarming behaviors of modular munitions by extending physics-based algorithms, embedded computing, and low cost measurements in navigation research. The focus will be on efficient algorithms for multispectral measurements in countered environments.
c. Proofs of concept demonstration of advanced man-portable defilade kill capability.
d. Proof of concept demonstration of advanced kinetic weapons via muzzle pressure management for reduction of key ballistic launch and flight system errors.

iii. Far-term goals (FY26-FY30):

a. Development of methodologies to elicit large forces and moments at high bandwidth (0~1000Hz) based on arbitrarily arranged sensing arrays on the skin of the flight body over omnisonic flight regimes.
b. Devise means of navigating to complex, mixed targets based on advanced algorithms using available techniques such as flash LIDAR, redundant low cost imagers, or high-speed, low-latency communications.
c. Maturation of compact and robust form factor technologies to facilitate the widest proliferation of technologies in the battlespace (small caliber weapons for light platforms).
d. Proof of concept demonstration of advanced swarming behaviors for guided munitions based on understanding of omnisonic aeromechanics and control.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Experienced researchers in aeromechanics, munitronics (diagnostic measurements and telemetry for munitions), propulsion, and structural dynamics (3 computer scientists, 3 electrical engineers, 3 physicists, 2 mathematicians, 2 aerospace engineers, and 2 mechanical engineers, at least half of which have PhDs). (13 FTEs)

ii. Mid-term (FY20-FY25): Multidisciplinary researchers with backgrounds in electrical engineering (5), computer science (5), and aerospace engineering (5). (15 FTEs)

iii. Far-term (FY26-FY30): Acquire, re-train, and cross-train personnel in physical sciences (5), electrical engineering (5), computer science (5), aerospace engineering (5), and mechanical engineering (5) with more than half possessing advanced degrees. (25 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):

a. Access to theoretical infrastructure, in the form of models and numerical tools, to better understand the nonlinear dynamics and stability and state estimation of controlled ballistic systems should be formulated.
b. Control design tool infrastructure would also facilitate GNC algorithm development.
c. Experimental facilities to more readily measure launch and flight dynamics, and implement control theories in embedded systems for validation and demonstration are necessary.
d. Access to high fidelity computational tools.

ii. Mid-term (FY20-FY25):

a. Modernized experimental range facilities with low cost, highly accuracy instrumentation (high speed digital photography) and data analysis techniques to enable launch and flight research.
b. New experimental facilities to understand controlled flight behaviors, such as omnisonic wind tunnels with motion capture, flow visualization, and particle image velocimetry.

c. Laboratory facilities for novel control mechanisms studies and feedback measurements; and applied research of guidance, navigation, and control (GNC) techniques, and launch dynamics.

iii. Far-term (FY26-FY30):

a. Upgrades to theoretical, experimental and computational infrastructure identified in the near-term and mid-term.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
13	Establish and maintain security across wide areas (wide area security).
15	Conduct combined arms air-ground maneuver.
17	Coordinate and integrate Army and joint, interorganizational, and multinational fires and conduct targeting across all domains.
18	Deliver fires and preserve freedom of maneuver.

Army Capability Need Proponent	Capability Area Need
FCoE	3.c – Long Range Precision Fires.

HUMANS IN EXTREME BALLISTIC ENVIRONMENTS
[ScL/P-3]

EXPECTED ARMY IMPACT: Primary injury mechanisms can be categorized into two types of insults – blast (injuries caused by shock waves including accelerative loading and TBI; and ballistic (impact of bullets, fragments and spall). Research efforts in each of these mechanistic areas will yield scientific understanding and lead to new protection concepts. Approaches will be realized to mitigate injuries from blast and ballistic insults and may include improved body armor, helmets and other forms of PPE. The long-term approach is to de-convolve the current ensemble of PPE and start from the basic human form taking into consideration the bio-diversity of the future Army. Concepts for mounted Soldiers are similar, but extend to include the coupled vehicle structure/occupant response and energy-absorbing techniques employed along the entire load path.

DESCRIPTION: The goal of this research is to provide a mechanism based understanding of the human response to blast and ballistic insults that will lead to advances in protection sciences and, ultimately, Army capabilities. This research will enable technologies that substantially enhance Soldier Personal Protective Equipment (PPE) capabilities while increasing mobility for dismounts, survivability, and overall combat effectiveness.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):
   a. Failure models for hard and soft tissue suitable for massively parallel computations that enable rapid execution and exploration of parameter space.
   b. First generation physics-based human model for HPC simulations for mounted and dismounted threat environments.
   c. Understanding of the loading mechanisms which lead to injuries to the lower extremities and spine during accelerative loading events.
   d. Develop high fidelity models, understanding, and data correlation based on dynamic injury assessment experiments.

ii. Mid-term goals (FY20-FY25):
   a. Develop second generation physics-based human model capable of handling arbitrary threat and loading environments.
   b. Identify new proactive protection mechanisms that can be exploited for increased protection from underbody blast events.

iii. Far-term goals (FY26-FY30):
   a. Understanding of individual soldier unique response to specific blast and ballistic events and personalized model of each combat soldier.
   b. Knowledge and understanding sufficient to individualize protection for the Soldier (size, shape, biometrics) in response to given threats.
   c. Nano-bio convergence capable of enabling breakthroughs in biologic response to threats.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Grow current staff with expertise in biomechanics and biomedical engineering to bridge the gap between traditional mechanical engineering design and injury mechanics. Plan to hire 3-4 new scientists and engineers / year in this area. Personnel work closely with experts in the ballistics and medical fields to study human response to ballistic loading and research appropriate protection mechanisms. (5-7 FTEs)

ii. Mid-term (FY20-FY25): Technical staff with engineers and scientists with advanced degrees in multiple disciplines. Staff will collaborate daily with medical and academic research institutions; and expand focus to include bio-materials. (5-7 FTEs)

iii. Far-term (FY26-FY30): Technical staff works seamlessly across traditional scientific, medical, and engineering disciplines to research human response and protection technologies. (5-7 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. Development of multi-scale experimental facilities to characterize human and PPE damage mechanisms from blast and ballistic insults.
   b. Leverage existing facilities across medical and DoE communities.

ii. Mid-term (FY20-FY25):
   a. Enhanced diagnostic mechanisms for biological materials to detect tissue damage coupled with experimental ballistic facilities to provide enhanced visualization and insight into biological response. Facilities will include wide angle x-ray scattering, expanded micro computer-tomography, magnetic resonance imaging, and utilization of advanced photon source imaging.
   b. Access to expanded computational infrastructure to enable seamless multi-scale analysis of human response.
   c. Realize a Joint Center of Excellence for Human Response Research for Military and Civilian Traumatic Events.

iii. Far-term (FY26-FY30):
   a. Experimental facilities to detect micro-structural damage mechanisms in both organic and inorganic materials during blast and ballistic events. Experimental approaches such as advanced photon source imaging will be routinely used as part of ballistic rate experiments.
   b. Human performance experimental facilities to determine real-time response of Soldiers to virtual conditions. Computational capabilities will be closely tied to experimental data collection for real-time identification of experimental anomalies. Co-lead, with the medical community, the Joint Center of Excellence for Human Response Research for Military and Civilian Traumatic Events.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive operations.

Army Capability Need Proponent	Capability Area Need
AMEDD	3.a – Brain Health and Fitness Optimization.

ADAPTIVE AND COOPERATIVE PROTECTION
[ScL/P-4]

EXPECTED ARMY IMPACT: The operational threat environment that our troops face continues to grow in both capability and complexity. From near-peer adversaries to terrorist groups, the landscape is constantly evolving. The ability of our troops to exercise freedom of maneuver under these contested conditions will dictate mission success or failure. Developing a suite of technologies that provide the highest level of protection, in austere conditions, is the goal of this research. These efforts will result in transformational protection capabilities for Army platforms (ground, air, Soldier, and maritime) focused on increased levels of protection and the ability to rapidly adapt to new and unforeseen changes in threat environment at a reduced weight burden.

DESCRIPTION: This research effort combines technologies from across numerous disciplines to include technical intelligence, environmental sensing, dynamic threat characteristics, high speed signal processing, signature modification, and counter-measures in addition to conventional armor. All of these elements and combinations are linked through an intelligent agent to provide a real-time response decision that can proactively adapt. This methodology is capable of learning and applying new approaches as it evolves. An optimized combination of hard and soft protection techniques will provide a robust and redundant solution that will reduce inherent susceptibilities of current active protection systems to a variety of counter measures. It will also allow new techniques and responses to be deployed in real-time as dynamic software upgrades. This approach is seen as the only feasible means to maintain pace as the rate of threat evolution and proliferation is accelerated by globally available technologies such as digital design and additive manufacturing. The resulting advantages of this approach include; reduced weight when compared to current methodologies, increased reliability, ability to counter new threats in real-time and the ability to learn, adapt and improve.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Shift from traditional protection methods based upon specific threats to holistic approach by fusing individual capabilities of armor, underbody blast protection, active protection systems (APS), signature control, advanced soft kill methods and conceal, camouflage and deception techniques into one solution to maximize survivability and minimize weight.
b. Develop real-time threat sensing, identification and localization with extreme reliability for all threat classes.
c. Real-time sensor fusion of multiple sensor modalities such as imaging, RADAR, LIDAR, relying upon high speed digital signal processing, adaptive signature techniques, and pulse power defeat mechanisms.
d. Develop intelligent agent algorithms that learn from each encounter, share information across the network with other platforms, and continuously improves effectiveness of response.
e. Develop understanding of the fracture and failure of current ballistic protection materials, such as lightweight Magnesium alloys and ultra-hard ceramics, using a combination of modeling and experimental techniques.
f. Incorporate new electromagnetic physics in existing modeling tools to allow proper evaluation and validation of EM armor concepts.

ii. Mid-term goals (FY20-FY25):
   a. Generate a suite of protection technologies that combine aspects of active protection, camouflage, concealment, and deception with traditional armor.
   b. Conceive novel threat defeat mechanisms that take advantage of postulated materials using Materials by Design approach.
   c. Develop and apply advanced physics-based M&S tools to evaluate new defeat mechanisms including electromagnetic armor and other energy coupled to matter protection concepts.
   d. Determine optimum set of material properties, given a specific defeat mechanism. These will include novel equilibrium and metastable materials with high combined strength, fracture toughness, and ductility to exceed existing material property limitations.

iii. Far-term goals (FY26-FY30):
   a. Develop an intelligent framework containing a collection of protection technologies, connected via an intelligent agent, which determines the most effective defeat mechanism, or combination of mechanisms, to employ against a broad array of threats.
   b. Develop capability to autonomously engage protection options, monitor results in real-time, adjust response on-the-fly to improve outcome and communicate results to other platforms for awareness and adaptation.
   c. Develop algorithm to predict future activities to maximize situational understanding; fully exploit sensor capabilities to determine the most likely outcome; and minimize functional damage and crew injuries prior to impact and respond accordingly to minimize mission degradation.
   d. Incorporate various postulated and synthesized materials into ballistic application concepts.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Expertise in solid dynamics, EO/IR & EM signatures and sensors, impact physics, high speed digital signal processing, control theory, explosive effects, real-time embedded implementation, decision theory (12 FTEs)

ii. Mid-term (FY20-FY25): Personnel with knowledge across disciplines in solid dynamics, electro-magnetics, pulse power, scalable algorithms, and control theory (6-8 FTEs)

iii. Far-term (FY26-FY30): Personnel that understand electro-magnetic phenomena and approaches towards fully exploiting emerging computational assets as the lines between hardware, firmware and software blur and the ability to convert between various forms of energy reach high levels of efficiency (10 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. HPC-based simulation environment able to capture multi-physics problems (EO/IR interactions, flight dynamics, impact physics) at appropriate level of fidelity.
   b. Embedded real-time hardware/firmware.
   c. Expansion of shock physics capabilities at Dynamic Compression Sector of Advanced Photon Source.

d. Classified research facility with secure communications assets to facilitate interactions with the intelligence community.
e. High Energy Laser and Ultra-short Pulse Laser metrology laboratory to study directed energy effects on Army protection technology concepts.
f. RF metrology facility to expand capability to acquire RF signatures.

ii. Mid-term (FY20-FY25):
a. Signature control facility to include formulation, implementation, and measurement capabilities.
b. Advanced shock physics facility coupled with experimental diagnostics.
c. Experimental ballistic diagnostic facility to allow probing of ballistic events on short time scales and unprecedented length scales.
d. Directed Energy effects facility containing representative DE threats.

iii. Far-term (FY26-FY30):
a. Access to classified quantum computing assets for multi-physics simulations.
b. Pulse power facility for electro-magnetic research, experimental validation, and simulation effects.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	**Description**
16	Set the theater, provide strategic agility to the Joint Force, and maintain freedom of movement and action.

Army Capability Need Proponent	**Capability Need Area**
MCoE	3.a – Combat Vehicle Development.
MCoE	3.g – The Capability to Protect from the Effects of Explosion Hazards.

DISRUPTIVE ENERGETIC MATERIALS
[ScL/P-5]

EXPECTED ARMY IMPACT: Improved models, concepts, and new energetic materials for propulsion are expected to provide enhanced range, speed of engagement, and maneuverability while maintaining weapons safety and surety. Additionally, game-changing energetic concepts with an order of magnitude more potential than conventional energetics are being pursued and are expected to enable new approaches to lethality, particularly when partnered with emerging accuracy and precision advances.

DESCRIPTION: These efforts will focus on the exploration and maturation of novel energetic and propulsive materials which are expected to provide revolutionary performance capabilities that are unachievable today. Research in this area seeks to understand very high energy density storage and release on desired timescales, methods to balance various parameters in energetic formulations, and prediction of formulation ingredient compatibility.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Development of sustainable energetic materials with performance characteristics which exceed those of RDX by 30%.
b. Formulation of novel energetic ingredients for transition to weapons applications.
c. Optimization of multi-phase explosive and initiation concepts to maximize energy transfer to target.
d. Develop novel methods for differentiating the effects of thermal loading, shock loading, and optical excitation in order to develop a fundamental understanding of initiation mechanisms.
e. Development of techniques to control muzzle overpressure and quantification of factors controlling dispersion in small-caliber weapons.
f. Extend quantum mechanical-based modeling tool set for prediction of key performance key performance and vulnerability properties.
g. Develop performance libraries for traditional explosives characterized using conventional and small scale testing.

ii. Mid-term goals (FY20-FY25):

a. Identify, characterize, and formulate extended solid energetic materials, such as polymeric CO, which are expected to have energy densities an order of magnitude higher than RDX.
b. Explore Structural Bond Energy Release Materials for use as novel energetic components.
c. Develop propellants with 10 -15 % improvement in Specific Impulse levels.
d. Develop computational models which accurately capture salient features of reacting, heterogeneous systems and physical phenomena.
e. Develop methodologies to control muzzle overpressure and quantify factors controlling dispersion in medium and large-caliber weapons.
f. Develop predictive models for both traditional and novel explosives over a broad range of loading conditions.
g. Develop new techniques to facilitate optimization of non-ideal explosive performance concomitant with full explosive characterization from a single test.

iii. Far-term goals (FY26-FY30):
  a. Identify and characterize extended solid energetic, organometallic, and metal cluster materials with projected energy densities orders of magnitude (> 10x) higher than RDX.
  b. Enable a fully coupled multiscale modeling approach with accurate predictive capability of macroscale response which has been verified through direct advanced experimentation.
  c. Determination of compatibility of novel energetics based on structure, functionality, and M&S results to identify promising energetic materials and formulations.
  d. Develop high-speed, full dynamic range of explosive imaging for novel energetics including measurement of cessation and onset of detonation.

b. PERSONNEL REQUIREMENTS:

i. Far-term (FY26-FY30): Technical staff works seamlessly across traditional scientific and engineering disciplines to execute rapidly evolving technical goals of mission. (5-6 FTEs)

ii. Mid-term (FY20-FY25): Grow current staff with expertise in chemistry, physics, mechanical engineering, and modeling & simulation. (5-6 FTEs)

iii. Near-term (FY15-FY19): Grow current staff with expertise in physical chemistry, physics, mechanical engineering, and modeling & simulation. Foster collaborative research with outside groups to promote cross-training of existing and next generation researchers. (5-6 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
  a. Modernization of facilities and equipment to support state-of-the-art experimentation necessary to develop disruptive energetic and propulsion materials.
  b. New facility dedicated to high-pressure synthesis and scale-up of disruptive and propulsive materials.
  c. Access to High-Performance Computing to support the development of ‘Materials by Design’ capabilities.
  d. Leveraging of Department of Energy (DOE) large-scale facility investments (Oak Ridge, Advanced Photon Source, National Ignition Facility) for advanced characterization.

ii. Mid-term (FY20-FY25):
  a. Modernization of existing experimental, computational facilities, and equipment to support disruptive energetic and propulsion materials development.
  b. Development of facilities which permit seamless integration of multiple experimental and modeling/simulation teams.
  c. Expanded infrastructure to enable small-scale characterization of novel energetics and propellants.
  d. New diagnostic facilities for advanced characterization of novel materials such as in-situ imaging with 1nm resolution and time –resolved methods.
  e. Creation of a Center of Excellence for Disruptive Energetics and Propulsive Technology.

iii. Far-term (FY26-FY30):

a. Continue to modernize facilities and equipment to support state-of-the-art experimentation necessary for the development of disruptive energetic materials.

b. Access to peta- and exa-scale computing environments for multi-scale simulations to enable ‘Materials by Design’ and to allow assessment of effectiveness of notional designs of lethal armaments.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive operations.
15	Conduct combined arms air-ground maneuver.
18	Deliver fires and preserve freedom of maneuver.

Army Capability Need Proponent	Capability Need Area
FCoE	3.e – Next Generation Cannon.
MCoE	4.b – Next Generation Shooters.

HUMAN SCIENCES CAMPAIGN

MISSION: To discover, innovate, and transition S&T capabilities to (1) understand and improve individual and small unit performance across the full range of military operations; (2) empower leaders with enhanced cognitive capabilities to make sound decisions quickly; and (3) enable expeditionary forces to use knowledge of societal and cultural issues and social cognitive networks to shape the operational environment.

VISION: The Army of 2030 maximizes the effectiveness of Soldiers physically, perceptually, and cognitively. Small units are capable of operating effectively and efficiently in social-cultural contexts around the globe. The desired end state is to leverage the full range of S&T enablers to poise forces to succeed in distributed operations and increasingly complex environments.

HUMAN SYSTEM INTEGRATION (CYBERNETICS)
[HS-1]

EXPECTED ARMY IMPACT: The differential advantage of the Army over its potential adversaries is derived, in large part, from the integration of skilled Soldiers with advanced technologies within a team context. Training burdens and the rapid advance of technology indicates a critical need to "fit machines to Soldiers rather than the other way around" (U.S. Army Operating Concept, TRADOC, 525-3-1, 2014). Fundamental understanding of human capabilities and human-system interactions is needed to enable more cohesive and efficient integration of future Army technologies into Army units and training to maximize their operational impact. Advances in the human sciences for cognitive, social, and physical performance and development are envisioned in new methods, models, approaches, and capabilities for enhancing human-system integration in the systems design cycle. Resultant innovations in Soldier-system interfaces and interactions are expected to augment Soldier cognitive and physical performance, enabling faster, more accurate, and more decisive actions needed to meet the demands of the future battlespace. Reduced technological complexity for users and decreased training demands will enhance Soldier readiness and enable Army forces to keep pace with rapid development and insertion of advanced technology capabilities, while staying ahead of our potential adversaries' technology transfer and system adaptation.

DESCRIPTION: Human System Integration (Cybernetics) integrates empirical and theoretical efforts that apply the concepts, insights, and methods of cybernetics to the study of dynamic, complex human systems and human-system interactions, initially at three different levels of analysis including 1) the perceptual level, examining mechanisms of multisensory integration through adaptive feedback coupling; 2) the social level, examining the impact of social variables and processes in control and communication interactions with autonomous and networked agents; and 3) the neural level, examining closed-loop brain-based technology interfaces for human-system interactions. The critical challenge for human-system integration in future technologies will be the design of solutions that adapt their capabilities to maximize the human potential of the future Soldier. Cybernetics seeks to identify general systems principles that operate across levels of analysis, providing a conceptual and modeling framework that captures the multidimensional, adaptive, and dynamic nature of human behavior in ways that current models cannot. New methodological and analytical approaches that capture the temporal dependences inherent to human data will be established to develop descriptive, mechanistic, and predictive models of real-world, human adaptive behaviors.

a. TECHNICAL GOAL(S):

i. Near-term Goals (FY15-FY19):

a. Characterizations of human unisensory and multisensory perceptual similarity based on multi-dimensional (perceptual, semantic, physical) characterizations of stimulus features.
b. Statistical analysis techniques that account for the temporal dependencies inherent in human perceptual and physical data.
c. Closed-loop models of adaptive mechanisms in multisensory integration for functional and skilled human movement and brain-computer interactions.
d. Cybernetic models of human-system interaction in sociotechnical and sociocultural contexts.

ii. Mid-term Goals (FY20-25):
   a. General theoretical framework of multisensory perceptual similarity based on multi-dimensional characterizations of stimulus features, to predict complex, and multi-modal stimulus interactions.
   b. Methodologies for the assessment of multisensory function underlying adaptive performance in real-world task environments.
   c. Algorithms for the adaptive use of multisensory information.
   d. A brain-based closed-loop framework for augmenting the integration of different stimulus features from multiple sensory sources.
   e. Proof-of-concept system demonstration of brain-based, closed-loop human-system interactions.
   f. Social cybernetic models of human-system interaction under real-world and/or operationally-relevant task conditions.

iii. Far-term Goals (FY26-30):
   a. Design principles and guidelines for adaptive, multisensory, and augmented perceptual human-system interfaces.
   b. Predictive models of human perceptual capabilities enabling multipurpose, multisensory, and adaptive decoy and deception systems.
   c. General theoretical framework for adaptive integration of multisensory information to enhance Soldier perceptual capabilities.
   d. Technologies for enhancing an individual's inherent capability to process multisensory information in perception, decision-making, and skilled movement.
   e. Design principles and guidelines for brain-based, closed-loop, and social cybernetic approaches to human-system interaction design.

b. PERSONNEL REQUIREMENTS

i. Near-term Goals (FY15-FY19): Expertise required in applied mathematics statistics, complex and dynamical systems, computational neuroscience, computational social science, control theory, or related disciplines for computational modeling and algorithm development. Expertise needed in social sciences and psychology. Engineering and technical support needed for hardware/software integration in experimental testbed platforms. (6 – 8 FTEs)

ii. Mid-term Goals (FY20-25): Expertise required in computer science and engineering for implementation of algorithms in proof-of-concept systems. Additional expertise in statistical modeling, signal processing, machine learning, and related domains to extend computational models and algorithms to real-world application domains. (6 – 8 FTEs)

iii. Far-term Goals (FY26-30): Expertise required in engineering and computer science to support technology transition to concept demonstration projects. (6 – 8 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term Goals (FY15-FY19):
   a. Re-configurable laboratory space and research-grade multisensory display testbed platforms to conduct perceptual performance research in real and augmented reality environments.

ii. Mid-term Goals (FY20-25):

a. Ruggedized multisensory display testbed platform, including multi-aspect measurement capabilities to conduct perceptual performance research in real and augmented reality environments.

b. Instrumented real-world research spaces for evaluating technologies, model predictions and algorithm performance in behaviorally-relevant environmental conditions.

iii. Far-term Goals (FY26-30):

a. Mobile laboratory and multi-aspect monitoring capabilities for real-time tracking and analysis of Soldier performance in operationally-relevant environments.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
3	Provide security force assistance.
8	Train Soldiers and leaders.
9	Develop resilient Soldiers, adaptive leaders, and cohesive teams.
20	Design Army formations.

Army Capability Need Proponent	Capability Need Area
MCoE	3.f – Human Dimension and Small Unit Leader Development Technologies.
MCCoE	4.a – Optimize Human Performance.
USAACE	3.d – Improved Manned-Unmanned Teaming and Autonomy.

OMNIPRESENT REAL-WORLD SOLDIER ASSESSMENT [HS-2]

EXPECTED ARMY IMPACT: The goal of this research is to provide the foundational elements for future Army systems to generate high-resolution, moment-to-moment, predictions of individual Soldier's internal and external behavioral and performance dynamics in mixed-agent team and social settings across training and operational environments through the use of omnipresent, multi-aspect wearable systems. These technologies will provide the foundation for future Army systems to adapt to the individual Soldier's states, behaviors, and intentions in real-time, which will provide our Soldier the most favorable conditions to train, engage in operations, and team with intelligent systems and personnel from the U.S. and other nations. Adaptive approaches will provide novel capabilities to decrease time-to-train, augment physical, cognitive, and social performance, and improve human-network interactions by providing robust predictions of Soldier state and intent to integrate with the network and are critical to the emergence of individualization of equipment and maximizing and sustaining both Soldier and unit peak performance during mission critical tasks. The research will focus on enabling high fidelity, omnipresent prediction that can account for continuous changes in Soldier's physical, cognitive, and social states, such as stress, fatigue, task difficulty, trust, and situational awareness. The goal is to exploit the array of sensors and information streams that will be present in the operational environment of 2040 to predict Soldier dynamics with sufficient resolution and robustness to adapt systems in manners to directly enhance mission performance. The ultimate consumer of these technologies includes personnel across all three services both in the operational and medical domains. From TRADOC PAM 525-3-1: "Investments in maximizing human performance focus on achieving accelerated professional development; increasing cognitive and physical performance; developing Soldiers' social and interpersonal capabilities; improving the overall health and stamina of personnel; and improving talent management. These efforts will improve the adaptability and endurance of Soldiers operating in a complex environment across the range of military operations." This research is consistent with the following TRADOC Army Operating Concept for "Human performance" that improves the adaptability and endurance of Soldiers in a range of military operations. In addition, this research feeds several TRADOC Emerging Technology Focus areas:

- "Grow Adaptive Army Leaders, Optimize Human Performance" by using omnipresent Soldier assessment.
- "Maintain Overmatch" in the areas of protection, intelligence, and mission command.
- "Continuously Upgrade, Protect, and Simplify the Network" by incorporating human state information to enable high degree of situational understanding and greater interoperability.

Key research areas include:

- Approaches and algorithms to assess and predict non-linear human states that vary on multiple time scales across training and operational environments.
- Techniques to leverage information about other individuals, sub-groups of individuals, and groups to improve prediction of an individual.
- Techniques and fusion algorithms to interpret and predict non-stationary, human actions and behaviors in complex, dynamic, artifact-rich environments.

DESCRIPTION: The goal of this research is to provide the foundational elements for future Army systems to generate high-resolution, moment-to-moment, predictions of individual Soldier's internal and external behavioral and performance dynamics in mixed-agent team and social settings across training and operational environments through the use of omnipresent, multi-aspect wearable systems.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):
   a. Algorithms for state interpretation in complex, dynamic, artifact-rich, real-world environments through omnipresent, human monitoring.
   b. Human performance prediction algorithms for pseudo-controlled environments from on data collected via monitoring through multiple body-worn and external information streams.
   c. Transfer learning, active learning, collaborative filtering approaches to interpreting and predicting individual behavior from other individuals.
   d. Moment-to-moment interpretation of individual Soldier action and behavior and the relation to other individuals and team behavior within operationally relevant small team environments.

ii. Mid-term goals (FY20-FY25):
   a. Algorithms for state and performance prediction in complex, dynamic, artifact-rich, real-world environments through omnipresent, multi-aspect integration of body-derived and external information streams.
   b. Performance prediction algorithms that require limited training data to adapt across tasks and human states via approaches that leverage existing data from other individuals.
   c. Moment-to-moment interpretation of individual Soldier action and behavior and the relation to other individuals and team behavior within operationally relevant large team environments.
   d. Moment-to-moment prediction of individual Soldier action and behavior within operationally relevant small team environments.

iii. Far-term goals (FY26-FY30):
   a. Algorithms for high resolution, moment-to-moment, real-time predictions of cognitive, physical and social states in complex, dynamic, artifact-rich, real-world environments through omnipresent, multi-aspect integration of body-derived and external information streams.
   b. Self-calibrating suites for interpreting and predicting individual actions, behaviors and intentions and their consequential influences on mixed-agent team performance and social behaviors.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Multidisciplinary expertise that spans fields including applied mathematics, physics, engineering, computer science, and statistics. (8 – 10 FTEs)

ii. Mid-term (FY20-FY25): Multidisciplinary expertise that spans applied mathematics, physics, kinesiology, engineering, computer science, statistics, social psychology, and cognitive neuroscience. (6 – 8 FTEs)

iii. Far-term (FY26-FY30): Multidisciplinary expertise that spans applied mathematics, physics, kinesiology, engineering, computer science, statistics, social psychology, and cognitive neuroscience. (4 – 6 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):

a. 100 low-resolution multi-aspect, omnipresent systems to track individual's physiological and behavioral data integrated with external sensors and information streams to capture context. Infrastructure for data storage, sharing, and real-time analysis.

b. Database capabilities and tools for 250+ individuals with minimum of 6 months data.

c. Innovation facility for novel, adaptive human-system/environment interaction technologies. The facility will merges daily technology use with technology discovery and innovation and form the cornerstone of a wearable technologies community.

ii. Mid-term (FY20-FY25):

a. 250 mid-resolution multi-aspect, omnipresent systems to track individual's physiological and behavioral data integrated with external sensors and information streams to capture context. Infrastructure for data storage, sharing, and real-time analysis.

b. Database capabilities and tools for 1000+ individuals with minimum of 6 months of data; 250+ individuals with minimum of 2 years of data.

iii. Far-term (FY26-FY30):

a. 1000 high-resolution multi-aspect, omnipresent systems to track individual's physiological and behavioral data integrated with external sensors and information streams to capture context. Infrastructure for data storage, sharing, and real-time analysis.

b. Database capabilities and tools for 5000+ individuals with minimum of 6 months of data; 250+ individuals with minimum of 5 years of data.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
8	Train Soldiers and leaders.
9	Develop resilient Soldiers, adaptive leaders, and cohesive teams.
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive.

Army Capability Need Proponent	Capability Need Area
MCoE	3.f – Human Dimension and Small Unit Leader Development Technologies.
MCCoE	4.a – Optimize Human Performance.
HD	4.d – Soldier Readiness Monitoring.
AMEDD	3.e – Health and Performance Status Monitoring.
AMEDD	4.e – The Capability for Health and Performance Status Monitoring.

TRAINING EFFECTIVENESS RESEARCH
[HS-3]

EXPECTED ARMY IMPACT: The U. S. Army Training and Doctrine Command/Army Capabilities Integration Center predicts (Strategic Trends Analysis, May 2014) predicts that by 2040 "the speed of events will unfold that will require the Army to rapidly respond (measured in hours and days vs. weeks and months) with an operationally significant force to protect vital national interests. Increased speed of information requires more rapid and discriminate responses to crises. Future crises require increased multinational and whole-of-government approaches; however, partner and interagency capacities may not be sufficient. The environment will be increasingly transparent due to widespread information technology. Mission command must be capable of handling big data. Future land forces will require the capability and capacity to gain situational understanding of complex megacity environments (physical, human, and information). As technology exponentially advances, the Army will need to replace systems more rapidly to equip the future force in an effective and timely manner."

This environment will require a real-time integration and adaptation to rapidly deployed technologies (personally worn exoskeletons, distributed unmanned systems, and cyber-warfare systems). To address these requirements, this research will demonstrate a ubiquitous, reconfigurable, fully adaptive, synthetic training environment that can quickly and accurately assess learning requirements, while reducing time required for Soldiers and their units to attain job domain competency; increasing the rate of knowledge and skill retention; increasing the rate of training transfer for mission readiness; increasing user acceptance; and reducing overall life-cycle sustainment costs.

DESCRIPTION: The main goals of this research are to: 1) discover and delineate the relationships among training environment fidelity, level of training immersiveness, and Soldier/unit performance; 2) create models of efficient training evaluation for the Army driven by relationships between training technologies/methods and training effectiveness; 3) determine relationships between training technologies and transfer of acquired knowledge, skills, and abilities to operational contexts, and 4) optimize training for autonomous, intelligent systems.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):

a. Explore necessary factors conducive to training effectiveness in immersive simulation environments.
b. Discover molecular, cellular, and computational mechanisms of multisensory information processing and cognitive adaptation during learning, simulation, and training.
c. Explore individual and unit level performance assessment technologies to integrate and produce real-time learning with intelligent agent-based systems.
d. Develop and demonstrate artificially-intelligent software-based agents that monitor and solicit learner reaction to determine influence and usability of training technologies.
e. Develop and demonstrate artificially-intelligent software-based agents that monitor individual learner and unit performance and solicit job transfer data.
f. Develop virtual humans with emotions, natural language processing, graphics and animation/ embodiment, non verbal communication and perception that can learn from others.

g. Demonstrate a framework of streamlined reusable processes, agents, models and standard interfaces to support the evaluation and validation of training transfer.
h. Demonstrate training development tools that automatically update research-based findings to recommend most effective training methods for learning and performance.

ii. Mid-term goals (FY20-FY25):
a. Explore and develop integrated individual and unit level performance assessment technologies to produce real-time learning with intelligent agent-based systems.
b. Develop molecular, cellular, and computational mechanisms of multisensory information processing and cognitive adaptation during learning, simulation, and training.
c. Develop automated unit level learning assessment technologies for augmented reality training environments.
d. Develop individual to company level human performance models to predict training effectiveness of distributed-immersive training environments with 1000's of virtual characters in the field-of-view and a real-time reconfigurable whole world terrain.
e. Develop virtual humans with emotions, natural language processing, graphics and animation/ embodiment, non verbal communication and perception that can learn from others.
f. Develop technologies that enable simulation-based tutoring systems to automatically adapt feedback and scenario challenge level during instruction based on learner states (cognitive, affective, competence) resulting in optimized learner gains (performance, retention, accelerated learning, adaptability) during self regulated learning sessions.

iii. Far-term goals (FY26-FY30):
a. Develop individual to company level human performance models to predict training effectiveness of distributed-immersive training environments with 1000's of virtual characters in FOV and a real-time reconfigurable whole world terrain.
b. Develop molecular, cellular, and computational mechanisms of multisensory information processing and cognitive adaptation during learning, simulation, and training.
c. Develop real-time assessment and training for optimizing control and communication between humans and intelligent agent-based systems.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19): Multidisciplinary expertise that training/learning, human factors, computer science, and social science. (1 – 3 FTEs)

ii. Mid-term (FY20-FY25): Multidisciplinary expertise that spans training/learning, human factors, computer science, and social science. (2 – 4 FTEs)

iii. Far-term (FY26-FY30): Multidisciplinary expertise that spans training/learning, human factors, computer science, and social science. (3 – 5 FTEs)

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19): No specialized infrastructure is required to support this effort. All software concepts developed through this work can be accommodated on common computational devices. Specialized biological and behavioral sensors may be procured/developed under this program. Specialized laboratory space is required to test training effectiveness for devices such as exoskeletons.

ii. Mid-term (FY20-FY25): No specialized infrastructure is required to support this effort. All software concepts developed through this work can be accommodated on common computational devices. Specialized biological and behavioral sensors may be procured/developed under this program. Specialized laboratory space is required to test training effectiveness for devices such as exoskeletons.

iii. Far-term (FY26-FY30): No specialized infrastructure is required to support this effort. All software concepts developed through this work can be accommodated on common computational devices. Specialized biological and behavioral sensors may be procured/developed under this program. Specialized laboratory space is required to test training effectiveness for devices such as exoskeletons.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
8	Train Soldiers and leaders.
9	Develop resilient Soldiers, adaptive leaders, and cohesive teams.
20	Design Army formations.

Army Capability Need Proponent	Capability Need Area
MCoE	3.f – Human Dimension and Small Unit Leader Development Technologies.
MCCoE	4.a – Optimize Human Performance.
CAC-T	3.a – Future Holistic Training Environment-Live/Synthetic (FHTE-LS).
CAC-T	3.c – Training Methods for Operational Dominance.
CAC-T	4.b – An Adaptive Learning/Learner Centric Enterprise.
CAC-T	4.d – Adaptive Leader Development and Unit Training.
HD	4.j – Capability to Rapidly Learn at the Individual and Organizational Level.
HD	4.k – Adaptation of Training Models.

ASSESSMENT AND ANALYSIS CAMPAIGN

MISSION: To discover, innovate, and transition S&T capabilities that (1) improve the technologies being developed to meet critical and Army-unique needs; (2) provide decision makers and Soldiers with accurate and detailed awareness of materiel's capabilities; and (3) link the institutional and operational forces by means of a powerful shared toolset that simplifies and improves their decision making.

VISION: Army decisions about technology investments, weapon systems acquisition, and operational employment are founded on rigorous, transparent technical bases that take account of the full Doctrine, Organization, Training, Materiel, Leadership & Education, Personnel, and Facilities (DOTMLPF) spectrum; the breadth of adversaries' potential actions and countermeasures; and the ultimate consequences in terms of our forces' effectiveness in completing their missions. The desired end state is that comparable analytical capabilities are built into materiel and fielded to operational units, allowing Soldiers to employ swiftly and decisively emerging Army systems.

ARCHITECTURE FOR SCIENCE-BASED ANALYSIS
[AA-1]

EXPECTED ARMY IMPACT: By serving as a medium for linking together high-fidelity scientific models, an architecture for science-based analysis will lead to the operational Army's possessing resilient systems capable of performing their intended functions in any contested environment. Resilience is the ability of organizational, hardware and software systems to mitigate the severity and likelihood of failures or losses, to adapt to changing conditions, and to respond appropriately after the fact. The architecture will integrate physics- and engineering-based models with tactics, techniques and procedures. It will allow modeling of technologies and systems of interest at an engineering and/or physics level of fidelity to understand the effects of specific technical parameters on mission outcome. This will inform investment decisions for S&T and acquisition by providing a more integrated, holistic perspective. Also modeled at the same level of technical fidelity will be the contested environment, which can include such considerations as threats, atmospheric phenomena, and terrain. This unprecedented analytical capability will provide detailed insight for the design and development of systems and technologies, as well as their integration with the operational force to produce the most resilient system.

DESCRIPTION: The goal of this technical program is to develop a medium for linking together high-fidelity scientific models from diverse disciplines to enable coherent analysis of the behavior of complex systems of interacting technologies. This single common M&S context will also incorporate operational considerations such as METT-TC and TTPs to allow analyses in terms of criteria with relevance to warfighting missions. By providing detailed insight for the design, development, and integration of systems and technologies, this will inform investment decisions for S&T and for acquisition.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):
   a. Draft requirements.

ii. Mid-term goals (FY20-FY25):
   a. Formulate requirements.
   b. Identify models.
   c. Design architecture.
   d. Develop simulation environment.
   e. Develop model interfaces.

iii. Far-term goals (FY26-FY30):
   a. Demonstrate prototype analytical model.
   b. Reach IOC (of use to the Army's S&T, analysis, acquisition, T&E, and warfighter communities).

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19):
   a. Requirements engineers. (2 FTEs; 1 new term-hire; and 1 retrained employee)

ii. Mid-term (FY20-FY25):
   a. Software architects. (4 FTEs; 2 new hires and 2 retrained employee)
   b. Software developers. (10 FTEs; 5 new hires and 5 retrained employees)
   c. Project manager. (2 FTEs; 1 new hire and 1 retrained employee)
   d. Project scientists. (3 cross-trained FTEs)

iii. Far-term (FY26-FY30): No additional manpower is required.

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. No specialized infrastructure is required to support this effort.

ii. Mid-term (FY20-FY25):
   a. No specialized infrastructure is required to support this effort.

iii. Far-term (FY26-FY30):
   a. SCIF labs at APG and ALC for simultaneous control and display of multidimensional data, including ground truth, BLUFOR and OPFOR COPs, METT-TC, RF environment, network performance, statistical roll-ups, and study-specific metrics. Assimilating these multiple perspectives is essential to assessing the subtle interactions among technologies and phenomena, which is at the heart of the framework for science-based analysis.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
12	Project forces, conduct forcible and early entry, and transition rapidly to offensive
15	Conduct combined arms air-ground maneuver.
17	Coordinate and integrate Army and joint, interorganizational, and multinational fires and conduct targeting across all domains.
18	Deliver fires and preserve freedom of maneuver.

Army Capability Need Proponent	Capability Need Area
USAACE	3.e – Improved Aircraft Operational Availability and Mission Reliability.
USAACE	4.g – Ultra-reliable designs, optimized maintenance, and reduced overall operating and support costs.

SMALL-UNIT MODELING
[AA-2]

EXPECTED ARMY IMPACT: Exponentially more effective combat power is available in small units today than ever before. Traditional Army squads or platoons have had significant technological constraints on their potentially available mobility, lethality, protection, intelligence, and battlefield sensing. Radically improved and in many cases miniaturized and lighter-weight technologies for mobility, lethality, Soldier protection, communication, sensing, and effectiveness evaluation are all either in hand or within 15-year reach. New possibilities made available by these new technologies are so numerous and richly variable that they scarcely yield to traditional optimization techniques. A modeling and simulation (M&S) environment for small-unit combat employing variable and user-specifiable levels of engineering resolution is currently under development to assist with this task. Such tools can help with the first part of research managers' two-fold dilemma by helping them determine the relative value of potential payoffs for investment in mobility, lethality, Soldier protection, communication, and sensor technology. Given an appropriate tactical vignette or vignettes, and SME-agreed constraints about plausible limits of system physical performance, our existing system-of-systems analysis tools are already proven capable of helping us rationally array a set of technological possibilities in terms of potential incremental gains in unit combat power.

Such system-of-systems analysis tools can also help with the second part of the researcher's dilemma. Emerging tools for assessment and analysis have already been used to characterize particular technologies at sufficient resolution to support quantitative assessment of their incremental impact on mission success in particular Army vignettes or scenarios. Maturation of these M&S tools will allow engineering trade-off analysis for envisioned small-unit technology improvements to be grounded in realistic Army tactical needs rather than in abstract and sometimes overly sterile specifications or technical requirements. In turn, the decisions we make in the Army about which technologies to pursue and which engineering trades we should make will for the first time ever be made with technical rigor.

DESCRIPTION: Through leveraging the architecture for science-based analysis developed under KCI AA-1, develop and demonstrate optimization capability to explore combinations of technologies to enhance the mobility, lethality, protection, intelligence, sensing, and communication for small-unit operations. This will facilitate engineering trade-off analyses for envisioned technology improvements for small-unit operations.

a. TECHNICAL GOAL(S):

i. Near-term goals (FY15-FY19):
   a. Draft list of potential technologies and begin to assess the highest payoff requirements, and the appropriate level of engineering fidelity with which the technology should be characterized.

ii. Mid-term goals (FY20-FY25):
   a. Formulate requirements.
   b. Identify specific technologies for consideration and develop ARL-wide prioritized list.
   c. Develop technical characterization of technologies under consideration.
   d. Modify the simulation environment as needed to capture the new technologies being simulated.
   e. Develop new model interfaces as needed for the new technologies.

iii. Far-term goals (FY26-FY30):
   a. Enable technology development efforts to more rapidly demonstrate prototype of most important small unit technologies.
   b. Technology pushes to RDECs and development community to expedite enhancing of small units.

b. PERSONNEL REQUIREMENTS:

i. Near-term (FY15-FY19):
   a. Requirements engineers. (1 new term hire; and 1 retrained employee)

ii. Mid-term (FY20-FY25):
   a. Software developers. (2 FTEs)
   b. Project manager. (1 new hire)
   c. Project scientists. (6 cross-trained employees)

iii. Far-term (FY26-FY30):
   a. Specific technology proponents for all types of small-unit technologies to be embedded with analysis team to study payoffs of alternative modes of technology implementation.

c. INFRASTRUCTURE NEEDS:

i. Near-term (FY15-FY19):
   a. The science-based architecture built at PSL.

ii. Mid-term (FY20-FY25):
   a. The science-based architecture built at PSL, WSMR, or APG.

iii. Far-term (FY26-FY30):
   a. SCIF labs at APG and ALC for simultaneous control and display of multidimensional data, including ground truth, BLUFOR and OPFOR COPs, METT-TC, RF environment, network performance, statistical roll-ups, and study-specific metrics. Assimilating these multiple perspectives is essential to assessing the subtle interactions among technologies and phenomena, which is at the heart of the framework for science-based analysis.

ALIGNMENT: This effort is aligned with the following Army Warfighting Challenges and Army Capability Needs.

Army Warfighting Challenge	Description
8	Train Soldiers and leaders.
9	Develop resilient Soldiers, adaptive leaders, and cohesive teams.
20	Design Army formations.

Army Capability Need Proponent	Capability Need Area
MCoE	3.c – Small Unit Lethality.
MCoE	3.d – Unburden the Soldier.


EMPLOYEE ENTRANCE

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