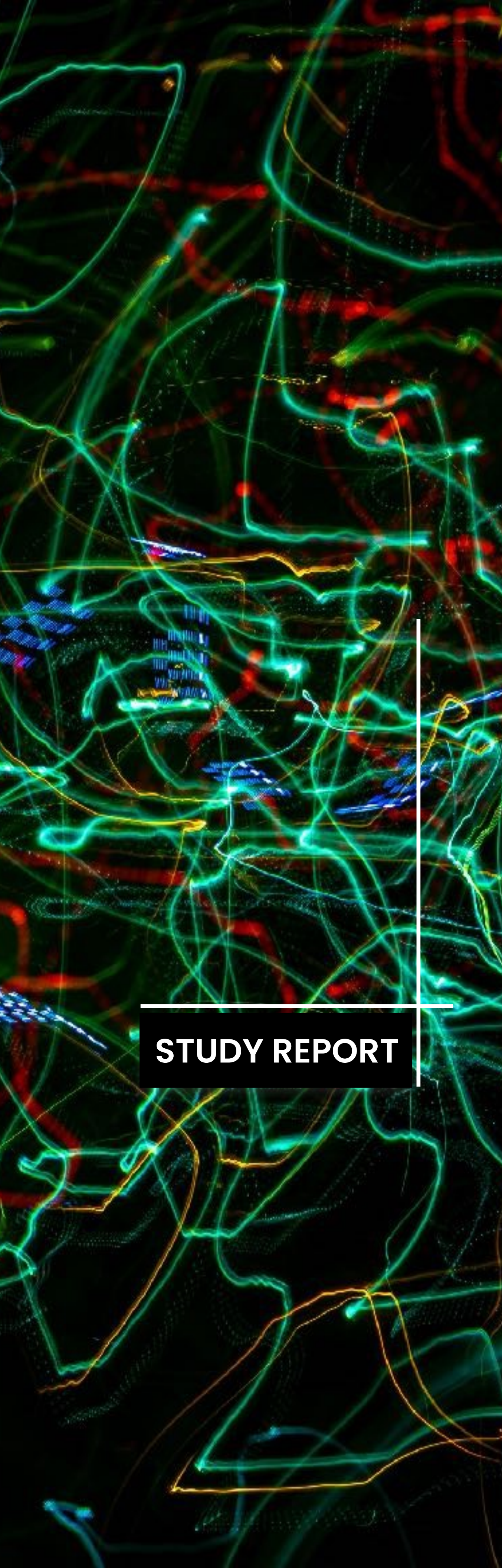

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energetics
technology center

Energetics and Lethality:
The Imperative to Reshape the U.S. Military Kill Chain

AUTHORS
Marcus Jones
Robert Kavetsky
Theresa Mayer

etc Report

This report is in response to FY2021 NDAA Section 253. The DoD was tasked with developing an energetics plan to:

- Maintain the United States superiority in energetics technology, which is critical to national security.
- Create efficient new energetics technologies and transition them into operational use.
- Maintain a robust industrial base and workforce to support the Department of Defense requirements for energetic materials.

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AUTHORS
Marcus Jones
Robert Kavetsky
Theresa Mayer

CONTRIBUTING AUTHORS
Sheri Bennington
Paul Braithwaite
Patrick Carrick
Ruth Doherty
John Fischer
Jose Gonzalez
David Jimenez
Emerson Keslar
Eugene Lauer
Matt Martin
Dale Moore
Jennifer Perkins
Bruce Simpson
Jill Smith
Jim Thomsen
Robert Wardle
Bill Wilson

DESIGN AND LAYOUT
Luiz Lobo

etcmd.com

A Report by The Energetics Technology Center

A Report in response to FY2021 NDAA Section 253 - DoD was tasked with developing an energetics plan to maintain United States technological superiority in energetics technology critical to national security; efficiently develop new energetics technologies and transitions them into operational use; and maintain a robust industrial base and workforce to support Department of Defense requirements for energetic materials.

About ETC

The **Energetics Technology Center** provides engineering and data analytics services, policy development, and technology development to the government, academia and private industry.

ETC is a 501 (c) (3) non-profit organization incorporated in 2006.
It conducts work on research and Development, innovation and R&D Policy Creation, and Technology-Based Ecosystems.

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1.0 Executive Summary

A Future Energetics Enterprise Capable of Lethality at Scale

The Imperative to Act Now - It has become apparent that the U.S. military faces a challenge without precedent in recent history: in many cases U.S. weapons systems are overmatched by those from peer- or near-peer competitors, including China and Russia. Wargaming and campaign analyses illustrate the severity of the problem, indicating plausible scenarios wherein the U.S. cannot project power or influence operational outcomes, largely due to weapons systems that are outranged or inferior to those of the notional enemy. These limitations cannot be overcome through the networking of current or more precise capability, nor can they be effectively addressed by acquiring additional more of our existing systems, platforms, and personnel. For the enterprise to deliver the required capability, leaders must acknowledge the limitations of the current force to meet the challenges posed by our adversaries and the imperative of energetics to address these and future challenges.

The U.S. military has long ignored the essential role of energetic materials (EM) in the lethality of its weapons systems and has instead focused on greater precision to achieve desired effects against targets in low-intensity forward environments. Propellants and explosives developed nearly a century ago continue to serve as the mainstays of U.S. systems, and were sufficient as long as U.S. forces enjoyed significant advantages in precision and delivery from forward-deployed platforms. But the strategic context has changed. Competitors operate systems capable of denying U.S. forces the access necessary for their current weapons. U.S. forces require the additional margin in range and destructive effect that improved energetics can provide. This study provides a framework and recommendations for restoring the U.S. advantage in energetic materials and ensuring that the lethality of the military's weapons systems exceed those of the nation's adversaries.

The Current State of Energetics - The U.S. energetics enterprise provides the Joint Force with critical explosive, propellant, and pyrotechnic materials for a wide range of military systems. Energetic materials remain the most important element in the lethality of military systems. *Lethality* refers to the ability of a weapon system to achieve a desired destructive effect. U.S. National Defense Strategy identifies lethality as the first of three priority areas for the military to develop. In contrast to other kinds of technology and systems, considerations of lethality are unique to defense organizations and must be viewed as a critical core competency. Unlike microelectronics – for which vibrant commercial markets exist – the U.S. government assumes near-total responsibility for nearly every stage of the value chain for energetic materials, including the science and technology (S&T) innovation of new molecules and formulations, the large-scale production of bulk quantities of energetic materials, and their applications in weapons and other systems. It cannot readily leverage dual-use applications from the private sector.

The energetics enterprise built in the 1940s and 1950s contributed to U.S. victory in the Second World War, military competitiveness throughout the Cold War, and helped to give rise to the crucial advances in the other elements that comprise lethality in weapons. The precision-strike-reconnaissance complex of the 1970s is the best example of the latter: the ability to strike individual targets with individual weapons yielded a far higher margin of lethality with fewer weapons than ever before. In recent decades, however, the priorities of the defense establishment have shifted from increasing lethality to delivering materials and weapon systems that are less sensitive at lower risk and lower cost. Although limited investments in S&T led to the development of new materials with enhanced performance, the demand signal for more lethal systems has been weak when coupled with higher sensitivity and/or cost. That dynamic has been a significant barrier to transitioning new materials into existing systems. Other factors, such as the mismatch between the time required for S&T efforts to come to fruition and the development schedules for programs of record, also hamper efforts to build more effective EM into systems.

Severe funding reductions and too little investment in upgrading energetics production facilities or building new ones has led to a fragile industrial base. The production process that supports the overall EM enterprise depends on vulnerable supply chains of critical raw materials. In many cases, the primary inputs to the EM production process are either single-sourced or foreign-sourced. In some cases, the foreign sources are countries viewed as current or potential adversaries. The DoD has limited authority to find, prevent, or create a source of these raw materials.

Finally, the energetics workforce has suffered from decades of under-investment and lost the opportunity to educate and build a new generation of scientists, engineers, and technical personnel to fulfill the core task of expert program support. There is very limited current demand signal to attract a new generation of scientists and engineers to enter this field. For those interested in advanced technology degrees, the barriers to transition technologies in the DoD acquisition system mean there is scant prospect for use-inspired work. When an enterprise is simply “turning the crank,” there seems little need for innovation, and innovatively-minded people look to other domains.

Two Specific Examples - The two most important energetic materials used by the U.S. military originated more than 120 years ago (RDX) and 70 years ago (HMX). Also 70 years ago, the first plastic bonded explosive (PBX) was developed by Los Alamos National Laboratory to reduce the sensitivity of energetic materials used in conventional and nuclear weapons. RDX and HMX together represent the last significant innovations in EM to have found widespread use in U.S. systems. In the 1980s a far more powerful material, CL-20, was developed at the Naval Surface Weapons Center, China Lake. The explosive and propellant properties of CL-20 exceed those of RDX and HMX by significant margins. Unfortunately, the dissolution of the Soviet Union redirected program priorities away from greater lethality to enhanced safety and lower cost and risk, and the EM community – lacking specific funding or a requirement – was in no position to mature CL-20 for incorporation into systems. Meanwhile, the Chinese military devised processes to manufacture CL-20 on an industrial scale and built it into weapons systems. The discrepancy in performance is enormous: compared to U.S. HMX-based explosives, CL-20 has a 40% increase in penetration depth, which is a significant increase in overall warhead lethality for specific applications.

Other energetic material S&T developments have been demonstrated, but not transitioned into programs of record. For example, using new mechanisms produced by combinations of thermobaric-type formulations and reactive materials, a 400-pound bomb would have the same lethality as a current 1000-pound bomb, allowing for the prosecution of five targets instead of two based on the same overall mass, and thereby addressing current concerns about capacity overmatch, as well. The research and development behind these new materials should long ago have given rise to more powerful and more compact systems. However, senior decision-makers, the combat developers responsible for generating requirements, and particularly program managers were neither aware, incentivized, nor empowered to consider these more effective mechanisms.

Without high-level leadership and coherent advocacy to overcome institutional barriers and focus resources at the most critical points, it is questionable whether the nation's current energetics enterprise can address the changing needs of the Joint Force, or factor decisively in the growing peer- and near-peer-competitive strategic competition with China and Russia. This is an unacceptable situation for the DoD, and it needs to find new ways to ensure greater "lethality at scale" – referring to larger numbers of more powerful and longer-range weapons – against established and emerging peer competitors.

A Plan for a Robust Future "Lethality Enterprise"

A program to modernize and revitalize the researching, development, and production of more effective EMs begins with leadership at the highest level. Meaningful change requires a "whole of government" approach, which starts with forging substantive relationships between the DoD and agencies, including the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and the Department of Homeland Security (DHS), that depend upon a healthy national energetics enterprise. Specifically,

1. Establish a National Level Energetics Coordination Group within the White House Office of Science and Technology Policy (OSTP) NSTC and form an "Energetics Caucus" on Capitol Hill. Both are necessary to ensure continued awareness, advocacy, and oversight of the nation's energetics enterprise at the highest levels of the U.S. government, along with academic and other institutions importantly connected to the enterprise.

2. Create a Joint Energetics Agency with budget programming authority within DoD to provide coherent strategic guidance and resource direction. This agency would work with the DOE, NASA, and DHS to develop a National Energetics Strategic Plan.

3. Adjust the DoD's relationship with the industry sector of the enterprise, and divest or radically reform its approach to manufacturing EMs more nimbly while taking advantage of the wider ecosystem of private industry for smaller-scale chemical engineering and more flexible production methods based on robust, diversified supply chains. An updated approach to intellectual property-based innovative contracting and licensing models and wider exploitation of public-private partnerships will go far in redefining how industry interfaces with the government in the production process and other parts of the value chain.

4. Prepare the EM R&D pipeline and address the time scale mismatch to mature EM technology and manufacturing readiness levels, it is recommended that the DoD:

    i. Allocate a BA 6.4 line of R&D funding, managed by the Services under the programming authority of the Joint EM Agency, to ensure new EMs are qualified and matured prior to consideration for a program of record, removing the onus on resource-strapped program managers to shoulder the high costs and uncertain risks of transition; and have each of the services provide $50 million annually for five years from current S&T investments to revitalize the EM research and discovery process by aggressively leveraging adjacent technologies such as Digitization, Virtualization, 3D Additive Manufacturing, Nanotechnology, and Machine Learning/Artificial Intelligence, which has the added benefit of rejuvenating the technical workforce.

ii. Provide funding to support Program Office Acquisition Strategies for preplanned product improvement program with an additional line of BA 6.7 funding for enhanced EM in existing systems, where feasible, managed by the weapons/systems PEOs via the programming authority of the Services.

5. Emphasize that program management place a categorical emphasis on maximum lethality as a key performance parameter in weapon systems' requirements and capabilities, to include the margin of effectiveness and increased system capacities afforded by improved EM.

6. Develop a state-of-the-art, resilient and agile energetic material manufacturing base and supply chain by developing a plan for a future network of facilities capable of producing a range of energetic materials. As a first specific step, invest in two or three pilot scale plants to address current critical specialty chemical needs that are either single and/or foreign-sourced. The emphasis should be not on selective upgrade of existing facilities, but the implementation of industrial best-practice and integrated adjacent technologies.

These recommendations – together with the subsidiary recommendations outlined in the body of the report – are intended to leverage the deep institutional resources of the DoD, motivate greater investment from, and involvement of private industry, facilitate the development of newer and more effective EMs, expedite their transition into systems – both current and prospective – and better support the acquisition process with a manufacturing and industrial base that is more modern, agile, efficient, and robust. The outcome will be a DoD that can depend on EM to enable "lethality-at-scale," which is indispensable for future high-end military conflict.

2.0 Background

The U.S. Congress initiated this study in Section 253 of the FY20 National Defense Authorization Act, which stipulates that

> [t]he Under Secretary of Defense for Research and Engineering shall, in coordination with the technical directors at defense laboratories and such other officials as the Under Secretary considers appropriate, develop an energetics research and development plan to ensure a long-term multi-domain research, development, prototyping, and experimentation effort that maintains United States technological superiority in energetics technology critical to national security; efficiently develops new energetics technologies and transitions them into operational use, as appropriate; and maintains a robust industrial base and workforce to support Department of Defense requirements for energetic materials.

To answer that instruction, the Office of Naval Research performed a complementary independent analysis and assessment of the energetic enterprise. A separate study from the government perspective was accomplished under the leadership of OSD UD(R&E). This report satisfies the independent assessment requested through ONR to address the section 253 language.

The intention at the outset was for the study to take a "whole of government" approach and provide a basis for a National Energetics Roadmap, which would address DoD-specific energetics issues and those faced by the Department of Energy (DoE), the National Aeronautics and Space Administration (NASA), and the Department of Homeland Security (DHS).

3.0 Introduction

The Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E]) defines energetic technologies to include basic and applied research, development, prototyping, and experimentation of Energetic Materials (EMs) and systems containing energetic materials, and technologies associated with the manufacture and sustainment of such materials. In this report, energetic materials and reactive materials are molecules, composites, oxidizers, fuels, binders in three broad categories: propellants, explosives, and pyrotechnics. Propellants and explosives rely on many of the same fundamental ingredients and design techniques, differing principally on whether the charge consists of a thermal ignition to bring about a particular rate of deflagration (burning) or a sudden shock to initiate rapid detonation. Pyrotechnics include thermites, intermetallics, fireworks, gas generators, delay compositions, and others. The effectiveness of many of the U.S. military's capabilities depends heavily on energetic materials. A 2004 report by the National Academy of Sciences states that "[t]here is no modern defense system or type of weaponry that does not rely on energetic materials," and EM remain the primary component in the systems on which U.S. forces most rely to close kill chains in kinetic situations. Superior energetics achieve the crucial first effects of U.S. initiatives in operational scenarios across the spectrum of peer and asymmetrical adversaries. That often means outranging and overtaking enemy systems at great distances, and delivering lethal effects against targets in every domain: on land, at sea, undersea, in the air, and in space.

Within the technical paradigm of the precision-strike regime since the 1970s, the sheer effects of superior energetic materials were not a prioritized characteristic of weapons systems. The value of greater precision – which depended on superior guidance and control technology, on-board sensors, faster processing speeds, and dispersed networked systems – was thought to eclipse the value of weight and intensity of fire, or greater range and destructive effect. As the power and effectiveness of energetic materials increased, the reasoning ran, so too increased their relative sensitivity, difficulty of manufacture, storage, and handling, and hence the level of technical risk they introduced into systems. Moreover, in the absence of a pacing competitor in any military operational domain, there seemed scant reason to accept that risk or to invest in the research and development to overcome the risk. National investment in the state-of-the-art in advanced munitions research, development, testing, and evaluation plummeted a startling 45 percent in the "long decade" between the fall of the Berlin Wall in 1989 and the terrorist attacks of 9/11, according to a 2001 study by the Department of Commerce. The wars in Iraq and Afghanistan – based as they were on counterinsurgency and state-building against asymmetrical opponents – offered little impetus to adapt the energetics enterprise.

As the focus of the U.S. defense posture returns to military competitions with peer and near-peer nations, the energetics enterprise is ill-equipped to support weapon system capabilities to win these competitions. While the U.S. has been absorbed in irregular wars focused on non-state actors, other nation-states have not been idle. China and Russia, in particular, by studying recent U.S. conflicts, developed a thorough understanding of U.S. systems and limitations. These countries have developed offensive and defensive capabilities that deny U.S. forces the ability to safeguard the integrity of our alliances and the security of the commons, and to project power in a crisis. The strategic context has shifted, and U.S. forces can now expect to operate against opponents who enjoy significant superiority in some weapons systems capabilities. China and Russia have leveraged the same technologies found in U.S. precision weapons and continued to improve the energetic materials built into their systems. Consequently, China now commands mass and range overmatch capabilities in certain domains that prevent U.S. platforms from engaging at the proximity necessary to place China's assets at risk. Similarly, Russia possesses mass and weapon capabilities that outrange those of the U.S. and have heavily armored their maneuver platforms to withstand the effects of U.S. weapons. Inadequate range and lethality limit the options U.S. commanders have in many scenarios, including their ability to build overwhelming force in theater before attempting offensive operations. The situation is made worse by mass and logistics problems that the Joint Force, distant from its bases, cannot easily or quickly address. Replenishing U.S. weapons inventories gives adversaries the critical time necessary to target command, control, and logistics, leaving the Joint Force vulnerable in all domains. Although U.S. capabilities in other areas – including electronic warfare, cyber, and directed energy – may influence an adversary, create opportunities to avoid engagements or may mitigate aggression, kinetic effects based on EM remain the principal deterrent, and the most direct means of compelling enemy behavior and degrading enemy forces, and the last line of defense.

4.0 Current State of the Energetic Materials Enterprise

As the strategic context has shifted, so must DoD's institutional priorities in developing advanced energetic materials and lethal systems. Thirty years of low-intensity counter-insurgency warfare against asymmetric opponents in two theaters resulted in only marginal improvements in the effectiveness of weapons systems, realized largely through improved precision or design, given the priority of lower cost and lower technological and sensitivity risk. Program officers, facing increasing cost and delivery schedule requirements, pivoted to a risk-adverse approach to weapons system development. In this timeframe, insensitive munitions (IM) requirements have been the only substantial drivers for EM development for the past several decades. DoD technology investments are overwhelmingly focused on system-specific requirements in the form of upgrades and spiral development; EM have effectively become commoditized and are not even considered as part of the trade space in systems development.

Concurrently, increases in EM service life and the costly regulatory burdens associated with changing ingredients and processes pushed a fragile manufacturing supply toward obsolescence and single-point failures. The lack of diverse, stable, and sufficient EM manufacturing has resulted in a deteriorating and diminished infrastructure, leading to substantial product lead times, an inability to meet surge demands, loss of subject-matter expertise, and overall shrinkage of the EM enterprise. The U.S. workforce has dwindled due to attrition and is not being replenished. In contrast, a survey of open literature reveals that China has governmental, semi-government, and commercial entities devoted to producing EM and heavily supports four top academic institutions to perform energetics research and develop their workforce. Similarly, Russia is returning to the country's impressive tradition of basic scientific research and rejuvenating its EM facilities and workforce.

In most U.S. government research, development, and acquisition activities, the government does not execute the entire range of functions in a notional value chain (basic research through technology development, production, fielding, sustaining, and decommissioning systems). More typically it handles key roles: underwriting the discovery and refinement of knowledge (S&T/R&D); performing regulatory oversight (devising policies that foster and direct the course of innovation, competition, and public/user safety), and certification activities (establishing standards for testing, licensing, and approval of activities). As a result of the trends outlined above, the contraction of the industrial base and commoditization of its output, the prevailing "business model"– or the U.S. government's approach to creating and capturing value on behalf of the public through its investments and the organizations it oversees – has come to entail the actual execution of virtually each function, or the decisive part of each function in the value chain. The government bears the entirety of the risk for the development and operationalization of energetic materials, rather than developing a model wherein industry shoulders a greater share of the risk against a cost premium acceptable to the government. This has a couple of related consequences: it forces dozens of uncoordinated organizations across government and within the defense bureaucracy to defend incremental parts of the value chain in a piecemeal fashion, and disincentivizes non-governmental investment in parts of the value chain where it could have the most salutary effects, as investors see the lack of coordination as risky and unstable.

Theoretically, the current model can produce new and better energetic materials, and find ways to transition them into more effective capabilities. The evidence, however, shows that the U.S. still relies on decades-old EM technology, seemingly without regard for leading commercial practice in related fields such as the pharmaceutical industry and the potential to exploiting adjacent sciences, particularly machine learning. Furthermore, the practice of stockpiling large quantities of munitions has left the U.S. with an arsenal of less effective munitions as the threat changes and stifles product improvement and transition of new EM. It also drives up the cost of sustainment at the expense of newer technology. There is a lack of coordination across the overall EM enterprise, including a lack of a common operating picture and misaligned S&T/acquisition timelines. More advanced materials have not adequately demonstrated an acceptable level of increased performance or manufacturability at cost and scale, undoubtedly a result of insufficient, targeted resources to develop and mature new EM.

4.1/2 Lack of Advocacy & Coordinated Management of the US Energetic Enterprise

DoD is the major responsible agency for the energetic materials enterprise. However, there is limited agency coordination with other governmental entities, namely the Department of Energy (DoE), the National Aeronautics and Space Administration (NASA), and the Department of Homeland Security (DHS). Even within DoD there is limited coordination to include basic and applied research, development, prototyping, and experimentation of EM and systems that depend on it, and technologies associated with their manufacture and sustainment. This has a couple of related consequences: it forces dozens of uncoordinated organizations across government and within the defense bureaucracy to defend incremental parts of the value chain in a piecemeal fashion, and disincentivizes non-governmental investment. Unfocused and uncoordinated effort dilutes resources across a multitude of potentially redundant efforts and hindering the advancement of technologies. It also points to the second consequence, namely that EMs are currently treated like commodity products, essentially delivered to programs of record as a black-box GFE. No senior defense leader, product leader, or operational advocate is driving requirements for greater performance such as range, speed, effect, and size. Absent this operational advocacy, efforts solely in DoD's EM research, development and acquisition enterprise are likely to have a marginal effect. Neither is there an entity solely responsible for the development and maturation of a commodity which is, again, absolutely essential for all kinetic weapon systems advancement. And just as the current system lacks a product leader or office for the EM value chain as a whole, it also lacks a unifying resource sponsor. EMs are not planned, programmed, and budgeted like every other Defense acquisition concern. They result from dozens of functions spread over different parts of the DoD, leading to a fractured, sub-optimized, and decidedly thin multiplicity of actors responsible for different segments of the value chain. Today, there is no formal active EM S&T community of interest to foster knowledge creation and exchange.

4.3 Existing Government/Commercial Sector Roles within the Energetic Ecosystem

A handful of basic structural shortcomings – all of which have the adverse effect of disincentivizing private investment or co-investment – are manifest in the current state of the EM enterprise. Research and development cycles are badly misaligned with the programs in which newer and more effective EM could make a difference. There is little private investment, moreover, at the front end of the value chain (i.e. synthesis, compounds, formulations). Had the government a clear integrated plan for the modernization of EM in existing or emerging weapons systems based on volume production, it would almost certainly stimulate more private investments at the front end of the process, especially for systems currently on contract or under development. This is in mild contrast to downstream energetic materials activities, where industry plays a larger role; even so, Government Owned – Government Operated (GOGO) munitions plants are in serious disrepair, and lack the production flexibility characteristic of more modern chemical manufacturing operations. Lately, private industry has invested in the improvement of some of the facilities it oversees, which are generally in better condition than those owned by the government. It still relies, however, on government owned – and often operated – facilities for the production of basic energetic ingredients.

The driving point here is that the market for missiles and munitions production ($15 billion in 2020) is non-trivial, but the government has done little to leverage it to attract deeper industrial and academic interest and investment for a range of potential activities. With the right incentives in place, private market actors could move into and out of different segments in the value chain, refining and enhancing innovations borne from knowledge originated or steered along the developmental path by the government, particularly in scaled-up pre-production activities.

4.4 The Current State of the Energetic S&T/R&D to Production Pipeline

The basic research behind the nation's defense EM enterprise derives from a range of governmental, academic, and industry sources supported and directed by numerous agencies with varying directions, priorities, and goals. Innovation and most of the candidate ingredients for EM come from basic research, much of it from academia. Development of new EM depends on the ability of defense science and technology organizations to interact with researchers outside of DoD, and then do applied research that can bring materials to a technology readiness level adequate for consideration by a program of record. S&T organizations investigate novel materials, characterize them, and publish the results of scientific findings for consumption by the broader community. Experimentation at that level is small in scale and devoted to demonstrating the characteristics and potential of different materials. But integrating material into actual systems is not their task. Although S&T organizations would ideally like to have new materials included in PoRs, they mature EM technologies only to a Technology Readiness Level (TRL) of 5 or 6 at the component level, short of the TRL 7 required at the subsystem or system level in a PoR. For an EM to be included in a weapons system it must be Type Qualified or at least Initially Qualified, which costs from $1.5 to $2 million and takes approximately two years. And, once the EM is established, managers for the programs of record face resource considerations that generally make them unable to accept the cost or schedule risk to insert a new EM.

In addition, research efforts often address near-term and incremental requirements to transition EM into programs. Unfortunately, without a requirement to include new EM, there is scant incentive for PoRs to consider them. Generally, fundamental system designs are determined prior to EM development and militate against changes based on newer materials with different characteristics. Therefore, the need to pursue basic research in advanced EM or to select it is not a factor in weapons systems development. Government contractors may choose to consider the incorporation of new EM, subject to qualification and suitability, but are seldom or never mandated to do so. Rather, they aim to fulfill requirements on the basis of best possible value, which is often synonymous with the lowest cost and risk. Value-driven decisions default to cost and risk in the absence of clear demands from leaders and combat developers for significant improvements in operational performance and effect.

Especially since programs bear the cost of making new materials suitable for use, PMs and contractors do not consider new EM as urgent for enhancing the performance of systems. New material must be tested and qualified, and the necessary processes are expensive, time-consuming, and arguably outdated. Qualification testing requires quantities of new material which are inherently difficult and expensive to produce. Contractors provide analytical inputs to support the analysis of alternatives prior to Milestone A, develop prototypes during the Technology Maturation & Risk Reduction phase to support Milestone B, and make source selection for engineering and manufacturing development. Development testing generates design modifications, and the resulting system then migrates to Production Qualification Tests (PQT), where it is subjected to operational testing before large-scale procurement. As systems are likely to be used for many years, any new EM is carefully evaluated for the safety and efficiency of production processes and its safety and effectiveness over the system's entire lifecycle. Unfortunately, the mechanisms for performing tests and validating the outcomes are fragmented across the services and use outmoded methodologies and equipment. When interviewed, stakeholders throughout the value chain expressed confusion over where responsibility for funding the testing lay, as well as how testing requirements and procedures may overlap or conflict, and why qualification testing takes so long.

4.5 Requirements and Risk: Factors Complicating Development and Transition of New Energetic Materials

The overriding consideration for lethal systems is greater range and destructiveness at the point-of-impact, giving U.S. forces the ability to strike adversaries before adversaries can strike them and a higher probability of kill (Pk) against targets of interest (in a manner specific to each system and accounting for accuracy and precision). In a typical Request for Proposal (RFP), a program manager issues contracts to selected vendors, stipulating only the performance parameters and key attributes of the finished system. The sub-systems or underlying technologies derive from requirements, and analysis has shown that few requirements officers grasp the potential of newer and more capable EM to offset the performance advantages of enemy systems. In many of the systems in which EM features prominently, probability of kill (Pk) is *the* critical parameter for understanding and improving system performance, especially when it combines with volume and the definition of effectiveness in campaign analyses.

Unfortunately, there are almost no incentives for DoD's acquisition professionals to see the potential of EM to improve probability of Pk. In addition, absent clear demands from warfighter communities, program managers are conditioned to conceive of requirements strictly along schedule and cost parameters. Although laudable in themselves, those parameters may come at the expense of willingness or ability to shoulder greater risk (especially technological risk) to achieve major improvements in capability and lethality. Senior defense leaders must demand improvements in range and lethality and ensure that they feature in mandated requirements.

Notionally, requirements derive from identified mission performance gaps. The mission gaps are translated into performance requirements to the S&T/R&D institutions, who strive to address them by investing research and development. The acquisition corps rely upon the S&T/R&D community to make sense of technology gaps and to offer guidance on what is possible, ensuring a link between operational needs and the underlying technologies. The S&T/R&D community offers technical solutions to problems, and advances options for emergent possibilities, which allows the requirements process to produce innovative systems. Acquisition specialists colloquially describe this tension as requirements pull vs. technology push. But as the S&T community has been marginalized by lack of requirements, so too have requirements-bound PMs become less amenable to the risks that new technology presents to the demands of cost, schedule, and minimal performance compliance. Because of this, the process has not resulted in meaningful new EM factoring into new systems, not least because the requirements officers are unaware that new EM could offer meaningful improvements in performance. If senior leaders do not prioritize new EM research and require underwriting of program risk, there is little incentive for the S&T community to prioritize EM research and for the acquisition community to include new material in systems.

Of course, determining whether to include newer and more capable EM into defense programs must assess the risks they represent fully, and the higher costs and longer schedules. Program managers – and the systems engineers who define the risk levels associated with EM – must reconcile risks and resources with sensitivity and safety as well as effectiveness. The requirement for energetic materials to conform to stringent insensitivity guidelines is a factor complicating technology transition. The services seek to ensure that EMs are reasonably safe to transport, handle, and store under adverse conditions in a variety of environments, and to decommission them safely should they not be expended. Due to the inherently hazardous properties of energetic materials and the special handling required at every stage of their lifecycle, authorities have promulgated laws and regulations to make them safe to handle and minimally susceptible to external hazards. In December 2001, Congress enacted a law devoted to "[e]nsuring safety regarding insensitive munitions" and mandated that the Secretary of Defense "ensure, to the extent practicable, that insensitive munitions under development or procurement are safe throughout development and fielding when subject to unplanned stimuli." Laudable as the law's intentions were, it is fair to claim that its requirements – when combined with the implications of limited resources and personnel – have come to dominate energetic materials development more than any other. Sensitivity concerns have led to the discontinuation of research into new energetic materials before the performance advantages could be fully explored and weighed against safety hazards, and before the acquisition community could develop mitigations. The trends driving the December 2001 law led to the Joint Insensitive Munitions Technology Program (JIMTP) in 2007, which provided funding that focused EM development on safety considerations ahead of higher performance or greater lethality. The imperative of ensuring insensitivity and the safety of existing energetics obscures the fact that safety is a function of the overall system.

These factors means that EM is understood and managed differently from other aspects of a system's design and removed from a program manager's typical decision trade-space. Knowing that, potential private sector contributors to defense acquisition perceive it as yet another disincentive for investment in the development of new EM and related innovations. Program managers have learned to choose the safest or least objectionable course, which is to use already qualified and off-the-shelf EM as a GFE-like commodity. It is simply easier and less risky to use a long-standing EM like an undifferentiated end-item with a given set of characteristics and capabilities, and not as an input over which program managers have discretion, even when a new EM may apply.

4.6 Current State of Energetic Materials Manufacturing and Supply Chain

The supply chains and production processes on which the nation's defense EM enterprise depend are outmoded, vulnerable to disruption, and inadequate to compete with a peer- or near-peer competitor. The stability and origin of supply are factors of particular concern. Propulsion, pyrotechnic, and warhead manufacturing facilities depend on a reliable supply of materials to run efficient production lines. Many relevant inputs are complex compositions requiring modification in production to accomplish mission requirements.

On July 21, 2017, President Donald J. Trump signed Executive Order (EO) 13806, "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States." It directed the Secretary of Defense to conduct a whole-of-government effort to assess risk, identify impacts, and propose recommendations to support a healthy manufacturing and defense industrial base, a critical aspect of economic and national security. The resulting report identified risk archetypes that threaten the U.S. manufacturing and defense industrial base. Regarding chemicals critical for DoD missiles and munitions, the risks include single source, sole source, and fragile suppliers; fragile markets; foreign dependency; and diminishing manufacturing sources and materials shortage. In addition, DoD has identified a list of 53 chemicals used to manufacture missiles and munitions, many of which have foreign or single sources of supply. Relying on foreign sources poses a risk to the Department's readiness to deter and defeat adversaries. In cases where alternative sources are available, the Department's ability to prevent suppliers from using of materials from hostile nations is limited. The clear implication is that the domestic industrial capability to produce materials used in DoD munitions is essential for national security.

The materials considered essential to the defense EM enterprise include AP, HMX, RDX, NC, NG and TNT. Producers of those EM have found it difficult to maintain a stable network of qualified vendors from which to source inputs that meet military specifications. Even in times of peace, companies that rely on government production of RDX, HMX, and related formulations have encountered difficulty procuring those materials in a timely manner and have been forced to defer contracts. All companies involved in producing EM depend to some degree on sole-source suppliers, making them vulnerable to disruptions in production and distribution. Moreover, a high percentage rely heavily on materials sourced abroad and would not be able to meet contractual requirements were they compelled to source materials strictly from domestic sources.

Most DoD programs mandate that RDX and HMX be sourced from a single U.S. GOCO. NC is produced for the DoD at a single GOCO, but is used extensively in both DoD and commercial applications. NG, often combined with NC in propellants and rarely cited as a stand-alone EM, is produced at several locations in the United States. Until a second commercial producer of AP entered the market (based on commercial investment and oriented to outside markets) and a second contract was arranged for TNT, *five of six fundamental EM were sourced to a single producer*. That illustrates the fragility of a supplier base that needs to be robust, resilient, and diversified. Currently, the industrial base for munitions is vulnerable to a range of potential risks: foreign and domestic political decisions, natural disasters, industrial accidents, corporate insolvency, and/or targeted sabotage. Any one risk could conceivably shut down the ability to source and prevent the DoD from producing critical munitions. It is reasonable to expect in the present political climate that more restrictive environmental regulations will make the production and supply chains more challenging to safeguard than is already the case, and perhaps drive smaller and more marginal companies from the market.

EM are synthesized, formulated, and loaded into systems at diverse locations throughout the United States. With few exceptions, these locations are smaller, aging facilities. DoD and Congress face the dilemma to continue piecemeal maintenance of smaller, aging facilities or build new facilities to fit newer technological and manufacturing paradigms. Unsurprisingly, policymakers have opted for the former. As a result, production of energetic materials relies on a sprawling network that is heavily dependent on a small number of Government Owned-Government Operated (GOGO) and Government Owned-Contractor Operated (GOCO) facilities to produce, mix, load, and pack EM prior to delivery and installation into weapon systems. Additional work is performed by large corporations like Northrop Grumman and Aerojet Rocketdyne and small businesses like Reynolds Systems Inc. and Mach I, which depend on specialty equipment, tooling, and facilities, which are often customized, costly, and require time to construct. Similar equipment used by commercial industry often lacks the safeguards, reliability, and precision needed to produce the relevant product to appropriate standards.

Modernization activities have focused on manufacturing so-called legacy energetics, traditional propellants, and explosive formulations. Recent investments of $500M have somewhat addressed acid processing, NC, and AP manufacturing, but there has been no significant investment in capabilities aimed at manufacturing new energetic materials. An often-cited (and undoubtedly credible) reason for continuing to use legacy EM is the unavailability of newer materials at the scale required for cost-efficient production, and the lack of financing for diversifying the production base to accommodate more modern and flexible methods.

Financing for the facilities is largely carried on the DoD's Military Construction (MILCON) budget, which historically accords a low priority to technology base infrastructure, production facilities, and laboratories. Predictably, this low prioritization has led to the gradual disrepair of facilities, affecting their ability to produce legacy materials (urgently or not) and is a block to retooling the plants for newer and better materials. Note that monies from MILCON are usually allocated to the refurbishment of broader infrastructure, not production equipment. Although program managers have the authority to invest in equipment, it invariably requires budget planning and coordination among programs that stand to benefit. In the case of EM, while modest recent funding has led to some improvements, there has not been nearly enough to address shortfalls. Funding for acquisition programs, which are generally platform oriented, is not generous enough to upgrade underlying infrastructure or the manufacturing base unless their shortcomings threaten the ability of the program to meet requirements.

Overall, the state of the GOGO/GOCO facilities has a dampening effect on the willingness of potential industry partners to participate in all parts of the EM value chain. Put plainly, DoD has not provided sufficient funding to justify capital investments by contractors to replace existing GOGO/GOCO facilities or to construct more modern ones for the production of new EM. Although demand for materials like AP, NG, and NP remains fairly constant, the complications inherent in primarily government-owned production pathways are prohibitive and the business case for Return On Investment (ROI) is too weak to vindicate more commercial investment.

4.7 Challenges to Maintaining an Adequate Energetics Workforce

A highly trained, specialized technical workforce is instrumental to the health and success of the defense energetic enterprise. The range of activity – from discovery and synthesis, formulation and system design, production, fielding, and to the retirement of systems – depends on the intelligence, vitality, and engagement of overlapping generations of scientists and engineers. Unfortunately, the same doleful circumstances that have eroded all segments of the scientific and technical workforce in the U.S. over the past three decades have impacted the energetics field.

Research in EM-related chemistry and chemical engineering suffers from generational attrition (together with insufficient replacement hiring), competition from more lucrative technical fields, and the minimalization of STEM at all levels of American education. It is, of course, easy to conclude that the EM enterprise – like the DoD in general – struggles to recruit and retain STEM talent because it does not pay well enough. However, surveys reveal that STEM talent is disgruntled with the defense enterprise for reasons other than total compensation packages. STEM professionals are motivated by mission and a drive to solve hard problems. Consequently, they leave the defense enterprise if they lack have the necessary skills, tools, and opportunities to solve problems in support of defense missions, and because investment in the EM field barely maintains current workforce capabilities, to say nothing of building new ones. Young scientists and engineers quickly identify outmoded facilities and undermotivated and poorly incentivized workforce. Although bursts of funding may appear for specific lines of inquiry and often cease after a few years, they give rise to unstable patterns in workforce development and retention. Scientists and engineers with competencies in fields like machine-learning and artificial intelligence can earn as much initially in the private sector as a senior manager with decades of experience in government. Perhaps most tragic is the loss of knowledge, experience, and institutional memory when retirements and workforce attrition does not involve the generational transmission of professional cultures and priorities. As is true in research associated with nuclear weapons, the largely defense-specific character of energetics means that the DoD cannot draw on a pool of dual-use competency in the private sector.

5.0 Recommendations/Future State

The future of U.S. dominance in Energetic Materials and Energetic Materials Systems is an “EM Innovation Ecosystem” that functions across industry, academia, and government, with aligned incentives that streamline and integrate research, development, testing, evaluation, and production. There is a clear need to revitalize and deepen partnerships with industry at all levels of the value chain, not just as integrators of narrowly conceived systems. The ecosystem is a broad and diverse network of stakeholders, coordinated by government authority, responsive in unscripted ways to clear, sustained demand signals for improved EM. In breadth and diversity is to be found fresh impetus to innovation in research and development; the potential for greater flexibility in production, especially of niche and more rarified EM at scale smaller than the large quantities of legacy materials currently produced; and potentially greater resilience and robustness in the supply chain and industrial base, offering the potential to flex and shift priorities appropriately as circumstances dictate. To establish the ecosystem DoD must work to create a strong relationship with private industry, and reopen lines of communication and re-establish trust with other stakeholders. Although the new ecosystem will retain infrastructure and institutions, future investments need to build out ownership for parts of the value chain that are functionally moribund or unproductive. The U.S. government retains primary investment in and buying power for EM-related activities and production, and should leverage that power pointedly to cultivate an array of industry partners and non-traditional participants and to stimulate the creation of a modern, digitized acquisition space.

5.1 Establish National Advocacy

The EM enterprise requires a whole of government approach. High-level agency coordination must address DoD-specific energetics issues, as well as those faced by the DoE, NASA, and DHS. A National Energetics Coordination Group is required to provide overall direction, established as a part of the White House Office of Science and Technology Policy (OSTP), for the identification, development, transition, and implementation of a new generation of advanced energetic materials. In addition to serving as an advocate and point for reference for the important role of EM in national and DoD innovation policy, it will advocate for the political guidance required to rectify supply-chain and industrial-base vulnerabilities.

As the lead among agencies concerned with EM, DoD needs to emphasize the concept of Advanced Energetics as it applies to Joint Enhanced Lethality. DoD must advocate for EM in the National Defense Strategy and other policy statements, and push for a more holistic understanding of system lethality and effectiveness across the range of capabilities. USD(R&E) should add Advanced Energetics to its roster of urgent modernization needs, and emphasize the importance of its development and use in as many current and future systems as is feasible. Similar to what has been done with the Joint Command and Control Domain, it is recommended that the Service's and Joint Staff leadership conduct a Joint Domain Lethality Summit to discuss the current and future state of lethality as it relates to a combination of technology areas including directed energy, precision guidance, hypersonics and advanced energetic materials.

To ensure an integrated view of the competitive threat and operating environment, the Office of the Secretary of Defense (OSD) should work closely with the National Defense Industrial Association to build a forum to unify industry, academia, and the broad range of government stakeholders in support of a focused agenda to revitalize the EM enterprise. Such an effort would certainly take advantage of – if not supplant – existing efforts among members of the NDIA, academic institutions, and nonprofits to develop conferences, workshops, and distributed digital mechanisms for information sharing and collaboration. The forum would also serve as a consolidated source of demand signals for the expanded role of industry in the EM value chain and as a clearinghouse for identifying and developing the next generation energetics workforce.

5.1.1 Recommendations:

5.1.1.1 Major:

1. Create a National Level Energetic Coordination Group within the White House office of Science and Technology Policy (OSTP) NSTC group.

2. Emphasize Next Generation Advanced Energetics in the National Defense Strategy as they relate to supporting Joint Enhanced Lethality

> **A.** Add Next Generation Advanced Energetics to USD(R&E)'s modernization priorities
>
> **B.** Conduct a combined Joint Domain Lethality Summit to Address "State of the Lethality Domain"
>
> **C.** Reiterate lethality as a DoD- wide priority, recognizing the challenge posed by U.S. adversaries, and the imperative for improved lethality to restore US superiority

3. Establish a new industry, academia and whole of government community forum

> **A.** Utilize NDIA and existing consortia, academia, and nonprofits to develop conferences and workshops focused on information sharing, communicating demand signals, and developing the next generation energetic workforce.

5.2 Unitary Management and Supervision of an US Energetic Materials Enterprise

The incoherence of the current EM enterprise is an active drag on enhancing the effectiveness of the Joint Force. The first step is for DoD to establish a high-level, program-like authority with responsibility to define goals, set budget, define resourcing, and provide managerial oversight of defense EM development from BA 6.1 through 6.4. A high-level joint office for EM will promulgate strategies, communicate their goals and priorities, delineate the transition pathways for prototyping initiatives, and ensure that investments in the BA 6.1-6.4 areas do not lead to unproductive or poorly coordinated outcomes. Such an agency would craft a National Energetics Strategic Plan to prioritize the development, transition, and integration of new EM into systems, even as the systems themselves – weapons, platforms, launch vehicles, and vessels – remain the responsibility of the appropriate government agencies or departments. This single authority would conform approximately to that of a Direct Reporting Program Manager (DRPM), responsible for the lifecycle management of the EM from S&T through production and sustainment. Such an authority would have the specified task of delivering weapons-ready EMs to PEOs, a marked contrast with current circumstances. Although owning and controlling every stage in the value chain, the government is not currently organized to fulfill that specified task.

Establishing a clear owner and advocate for the entire value chain would attract additional industry investment, funding, and resourcing, ideally stimulating involvement at every level. Coherent, ends-directed, longer-range supervision of planning for EM ensures that program managers are both aware and risk-incentivized to include improvements in current and future capabilities. The Joint Munitions Command will be subordinate to the new authority, safeguarding a clear owner and advocate for the

EM value chain. The authority will serve to link government, industry, and academia on EM issues across budget activities 6.1 to 6.7 to foster collaboration and sharing of information and production resources, and provide a dedicated EM consortium for the integration of the enterprise. Joint S&T initiatives, uniform characterization testing protocols, and a basis for consolidating and rationalizing standards offer the most promising means of overcoming the technology transition conundrum – that is, identifying and exploiting pathways for moving the products of a revitalized S&T culture into actual programs of record.

A joint energetics program authority would be able to exploit a range of technologies to support a "digital thread" integrating the entire end-to-end DoD EM acquisition life cycle. Adopting digital technology systems, as industry does now, would allow rapid and efficient the transfer of knowledge and data across and through entire value chains for product research, development, production, and support. The data and information, stored in a national Advanced Energetics Integrated Data Environment, would be managed and accessed by stakeholders who are linked through public-private partnership (PPP) frameworks and the consortium. A common data environment permit selective use of big-data analytics and data visualization, and make possible digital manufacturing, 3D additive manufacturing, advanced modeling and simulation, and other innovative digital expedients. A common data informational framework offers government, academic, and industry stakeholders improved resource planning across the enterprise. Machine learning and artificial intelligence could be applied to gain new understandings of the EM research process, identify new patterns and relationships, create new materials, and dramatically shorten product development times. Again, using available technologies to digitize, integrate, and share the knowledge and practices among stakeholders presents the most ambitious possibilities for dramatically speeding the cycle of innovation, design, engineering, and fielding of EM.

The joint energetics program authority is also charged with rationalizing the scattered testing and qualification regime. The DoD requires standardized advanced multiscale modeling and simulation (M&S) to address all Joint service needs throughout the EM lifecycle. The M&S should leverage codes for EM characterization and performance managed by the Joint Munitions Program (JMP). The agency would also coordinate the development – through an interagency working group – of uniform energetics characterization protocols and the multiscale experimental data needed to validate and feed M&S with expanded involvement from the Test and Evaluation community. The resulting tools and standardized data dictionary would provide a uniform characterization framework and exercise a unifying effect across government, industry, and academia. Standard characterization reduces the number of test trials needed to create durable insights into advanced energetics behavior and reduces the time and barriers to weaponization. The role of specifications in bringing new materials into systems is equally critical to standardize. Many specifications and forms of verification testing are outdated and require revision. A joint authority would direct synthesis and formulation producers to identify and update those standards.

5.2.1 Recommendations:

5.2.1.1 Major:

1. Create a Joint Energetics Agency, a high-level, program-like authority with responsibility to define goals, budget, resourcing, and provide managerial oversight of defense EM development from BA 6.1 through 6.4.

2. Establish a Next Generation Advanced Energetic Integrated Data Environment (IDE)

A. Devise a common EM-based operating picture, enterprise resource planning data for facilities, wargaming, and modeling & simulation

3. Have DoD, DOE, DHS, and NASA develop a National Energetic Strategy Plan.

5.2.1.2 Additional:

1. Set Joint EM S&T initiatives in areas such as Modeling & Simulation and Joint Efforts between ARPA-e and DARPA in Advanced Energetics

2. Create an interagency working group to develop uniform energetics characterization testing protocols.

3. Direct a DoD-wide energetics-based Mil-Standard/Mil-Spec Review to update, reduce, or eliminate unnecessary standards.

5.3 Revisit Government & Commercial Roles within the Energetics Material Ecosystem

S&T institutions may very well develop new EM and succeed in making it available, but if a program manager or vendor does not judge it expedient to meet stipulated parameters, it will not be used in a finished system. The DoD's 62 service laboratories (with their roughly 35,000 scientists and engineers), Federally Funded Research and Development Centers (FFRDCs), University Affiliated Research Centers (UARCs), and the Department of Energy's (DOE) national laboratories support the EM acquisition process, but they are not expected to deliver products for incorporation into systems. It is most frequently industry that delivers products to acquisition programs for testing, evaluation, advanced prototyping, and eventual production and sustainment. Industry is both a major resource sponsor for the defense technology base as well as the "performer" in many cases. One of the keys to revising the government and commercial relationship is to establish knowledge transfer, or some mechanism whereby information, competence, innovations, and expertise flow between governmental and commercial entities in the pursuit of complementary objectives.

Along with establishing a joint authority for EM, the DoD should cease directly managing or executing a range of functions. The DoD's EM enterprise is shaped by a reduced threat environment. Consequently, it focuses on producing a core set of EMs and has winnowed redundancies and variabilities to reduce cost and deliver prescribed amounts of safe, predictable, and reasonably effective propellants and explosives. It exemplifies the manufacturing model of the modern economy: clean, efficient, sterile, and reliable. In manufacturing, perfect process, full compliance, and predictable outcomes based on linear management are prized. Innovation, however, is based on increasing variation, leading to less predictable processes (more risk, meaning that some investments in BA 6.1-6.4 will not pan out or prove viable); messiness (the incentivization of greater industry participation and investment means more activity outside of DoD's oversight and acquisition pathways, and the appearance of new, unanticipated processes and technologies, some of them potentially disruptive); and chaotic (innovation and development cycles may not conform with acquisition timelines and budget parameters established years in advance).

This report recommends that the government disengage from the ownership of EM production – except for end-to-end pilot and synthesis-to-production facilities for scaling new materials – and refocus on the early phases of R&D and those stages in the value chain where transition falters. It is important to point out the impetus behind privatizing production facilities derives not from an abstract concerns. The Arsenal Act (Title 10 USC $4532) and Army Regulation AR 700-94 allows SECDEF and the Army to assess which roles and missions are essential government functions and which can be divested. Of course, this recommendation is based on the optimistic assumption that the government will devise ways to make EM production profitable and safe for industry; regardless, the configuration of government involvement and management is manifestly irrational and entirely inadequate for the challenges the United States faces. The current EM model is an inefficient distribution of finite resources among the Services, too thinly applied across too many efforts and facilities to achieve the pace necessary for innovation and transition. The government's efforts should focus on the front end of the acquisition budget activities: performing and underwriting discovery; sponsoring collaborative partnerships among federal laboratories with industry and academic stakeholders, including in the use of test facilities; wringing prohibitive risk from the transition of EM into systems engineering and production; modernizing and speeding the test and evaluation regimen; and setting standards for the enterprise.

An improved operating model will ensure maximum investment from both the taxpayer and private investors (including academia) in the front end of the value chain in order to maximize the output in the second half of the value chain. Therefore, the recommendation is for the sensible and orderly transfer of EM production to the private sector, and the fostering of public/private partnerships that maximize collaboration on EM development (not the competitive, IDIQ-based contracting typical of EM Consortia/OTAs). The government must incentivize industry co-investments at the front end of the value chain with cost-recovery mechanisms such as offsetting insurance premiums or underwriting the risk of liability. It must also open the products of DoD's EM S&T to transition through industry rather than relying on internal government transition processes, and provide industry with IP protections for time-limited production runs of certain EM compounds and mixtures.

5.3.1 Recommendations:

5.3.1.1 Major:

1. Review the roles and missions of the government in EM enterprise under the terms of the Arsenal Act (Title 10 USC $4532) and Army Regulation AR 700-94 to assess at which points government involvement is most essential and those from which resources and emphasis can be redirected.

1. Strengthen technology transfer via Public Private Partnerships (PPP)

A. Reconfigure current consortia to realign PPP and avoid IDIQ Competitive Model

B. Implement an NIH-like model for next generation advanced energetics, shifting federal labs' focus toward stronger industry collaboration

C. Reform guidelines and rules governing industry access to energetics-related intellectual property to maximize investment and development potential.

2. Stimulate additional commercial investments, IRAD reform, matching tax credits, and cost recovery reforms.

5.3.1.2 Additional:

1. Implement venture capital-inspired model for government investment in EM-related companies

2. Incentivize and promote government test facilities for small business, industry, and academic use.

3. Increase incentives by structuring long-term contracts to maximize industry investment in facilities and equipment

5.4 Prime the Pipeline for Next Generation Advanced Energetics S&T/R&D

The majority of EM RDT&E funding passes through system program offices, which are driven by low-to-minimal risk tolerance. In the earliest stages of a system, even before development, the program offices consider EM production quantities and integrate EM and systems into a bigger acquisition framework, requiring approvals from dozens of offices. When experimental concepts (EM and systems) are to be put toward operational use, they transition to dedicated system program offices. Unfortunately, these program offices cannot unilaterally authorize spending untethered to requirements for specific program elements.

The resulting risk aversion, based on lock-in effects, is almost certainly premature for systems entering development and severely limits potential advancements from an S&T technology-push approach. Few – if any – of these enablers are evident in the case of new energetics today. S&T institutions performing research and early forms of experimental prototyping are naturally oriented around a technology-push approach. Similar to private sector innovation, key enablers for bringing technologies to bear in systems are working through an innovation strategy, aligning investments with specific goals, and protecting funding for riskier projects. S&T programs should pursue interesting EM mission-oriented technologies on their own merits, believing that operational use cases will make themselves apparent through iterative prototyping and demonstration.

The problem arises when program offices rely on a requirements-pull approach. In this case, EM technologies from the labs must be in a clearly-scripted operational context and one against which budgets can be authorized. Because there are few funds available for new technologies without years of budget justification, technology maturation of advanced energetics without a requirements signal never takes place. Unfortunately, the program offices do not accomplish iterative EM prototyping and demonstration. Essentially, their timelines are mismatched with the readiness of new EM technologies. So the failure to build in new EM makes sense: programs of record are set up to accept already qualified and matured EM as a commodity with predictable production, cost, schedule, and performance risk.

To ensure that new EM technologies become a part of future systems, DoD must set up a 6.4 funding line for pre-program prototyping and experimentation. This recommendation is consistent with a high-level, program-like authority with the responsibility to define goals, budget, resourcing, and to provide managerial oversight of defense EM development. The authority provides a forum and semi-annually convenes a prototyping steering group to review and coordinate funding requests for promising 6.4-

level, EM-based prototyping programs. The steering group is an array of stakeholders from academia, industry, and DoD, and it identifies prototyping investments, ensures alignment with modernization priorities, and deconflicts them from other ongoing or proposed activities across DOD and the military services.

A preprogram prototyping and experimentation campaign devoted to pushing new and viable EM to program offices is the most promising way to highlight potential value in the programs manager's decision trade-space. The campaign will mature next-generation EM technologies, evaluate their role in systems, and prototype those systems in realistic operating environments to overcome the inability or reluctance of program managers and contractors to shoulder the cost and risk. Without such an effort, there is a lower likelihood of moving EM technology from the laboratory to operational use. Experience has shown the current pathways are insufficient for proving EM-component and EM-subsystem maturity, achieving the highest possible technology readiness level, and mitigating program risk, therefore the DoD must inject funding to experiment and refine at this level.

Small businesses are a potentially fruitful part of this energetic transformation. Using Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, topics can be created and issued relevant to new EM discovery, development, and improvement. A portion of DoD's SBIR funding could be assigned specifically for the EM domain, and provide a clear signal to industry of the department's emphasis and priority in this area.

5.4.1 Recommendations:

5.4.4.1 Major:

1. Establish a 6.4 preprogram of record prototyping and experimentation program ($150M per year) to be managed by the new Joint Energetics Agency.

2. Increase investments in S&T ($50M per year/per service for 5 years) in combined energetics and adjacent technologies initiatives.

5.4.4.2 Additional:

1. Direct $50M per year over 5 years for DoD SBIR/STTR Programs toward energetics and leverage it with DOE, NASA SBIR/STTR investments.

5.5 Address Operational/Requirement Gaps - Ensuring Mechanisms Infuse Advanced Energetics into Current & Future Weapons Systems

Evidence shows that U.S. forces face a multifaceted problem: insufficient numbers of inadequate weapons anda realistic set of requirements for weapons that include advanced energetic materials are lacking. To address this problem, and aligned with the current National Military Strategy, lethality (a combination of precision, range, and maximum effect at point of impact) needs to be a mandatory performance parameter in all new systems that include propellants and explosives. To clarify the indispensability of this requirement, this report recommends that the OSD Cost Assessment and Program Evaluation (CAPE), in partnership with the Office of Net Assessment, conduct a rigorous analysis of the materials, capabilities, capacity, and affordability of increasing investment in munitions superior to those under development or being produced. The DoD also needs to develop munitions computation engineering design tools for enhanced acquisition design and for operational assessments.

To ensure that new energetics materials are incorporated into weapon as quickly as possible, this report recommends establishing a DoD-wide EM preplanned product planned improvement (P3I) program along with a dedicated 6.7 Research and Development funding line managed by the weapons system Program Offices (PEOs). The program would fund the incremental transition of new, advanced EM into existing weapons systems and those under development. Of course, the capabilities offered by any new technology must be balanced with program cost and schedule considerations; like the recommended line of 6.4 funding, this measure would afford program managers the flexibility to consider more advanced EM and factor it into their decision trade-space during the acquisition process. The Value Adjusted Total Evaluated Price (VATEP) tool should be used to build more latitude for these improvements in the contracting process. Finally, qualification standards based on agile acquisition principles and methods are the most promising way to ensure that program managers have access to the EM they can use as early in systems development as possible. As outlined in the previous recommendation, a combination of 6.3 for testing and formulation optimization and 6.4 funds for scaling new material in the manufacturing process are utterly essential to qualify new energetics materials.

5.5.1 Recommendations:

5.5.1.1 Major:

1. Establish DoD-Wide next generation advanced energetics modernization/P3I for current weapons. Establish a 6.7 funding line managed by PEOs to address modernization.

2. Set lethality as a Key Performance Parameter (KPP) for new weapon systems that include explosives or propellants.

3. Develop munitions computation engineering design tools for enhanced acquisition design and operational assessment.

4. Use of Value Adjusted Total Evaluated Price (VATEP) to provide trade space latitude to weapon and platform contracts

5.5.1.2 Additional:

1. Have OSD CAPE perform an analysis of materials, capabilities, capacity and affordability of investments in improved munitions.

2. Promulgate qualification standards that use Agile Acquisition methods.

5.6 Create a State-of-the-Art, Resilient and Agile Energetics Manufacturing and Supply Chain Capability

One of the first tasks of a joint EM authority will be to promulgate a plan (perhaps based on the agile production capabilities for pharmaceuticals pioneered by the Biomedical Advanced Research and Development Authority of HHS) to build a robust network of smaller, adaptable, and more technically dynamic manufacturing facilities for EM, capable of surging production and shifting based on demand and capability. Ample evidence in the chemical engineering and production industrial base shows that sophisticated, smaller-scale production possibilities abound, but at a cost. A distributed, diverse network allows greater flexibility, redundancy, and technical sophistication at the expense of efficiency and cost control. The Congress and DoD must accept that a more innovative and robust EM ecosystem cannot flourish inside sclerotic institutions and processes, and that faster progress and agility demands looser constraints.

The joint EM authority should undertake an immediate review to identify and reduce or eliminate the most notable barriers to market entry for new manufacturers. It should begin by investing in two or three pilot-scale plants to address critical specialty chemical needs and invite investment and involvement from smaller chemical engineering firms. In addition, the authority needs to develop additional domestic production of core EM requirements like HMX, RDX, and nitrocellulose. Also, those provisions of the Arsenal Act that mandate "directed source" are decisive barriers to new commercial entry and should be eliminated.

The National Defense Technology and Industrial Base Council should explore partnership possibilities with allies and among federal agencies (DoD/DoE/NASA/DHS) to harmonize common interests and align supply chain sourcing. More urgently, DoD must take immediate action to direct investment and organize efforts to restore domestic sources of supply and production of crucial chemical and energetic materials. Key allies must be included in these efforts, despite worries about insularity and security.

5.6.1 Recommendations:

5.6.1.1 Major:

1. Develop a plan for a future network of robust, agile, state-of-the-art energetic production facilities that are adaptable and technically dynamic manufacturing facilities for EM, capable of surging production when required and shifting among different materials based on demand and capability

2. Invest in two-three pilot scale plants addressing critical EM specialty chemical needs

3. Take immediate action towards on-shoring or near-shoring critical chemical and EM production

5.6.1.2 Additional:

1. Charge the National Defense Technology and Industrial Base Council with investigating partnership possibilities with allies and among DoD/DOE/NASA/DHS for next generation energetic material development and manufacturing and supply chain sourcing alignment.

2. Explore second sources for current single source EM materials (HMX, RDX, and Nitrocellulose (NC) manufacturing capability

3. Review the policy of mandating government-directed sources to reduce barriers to entry for new commercial sources of production.

5.7 Creating the Energetics Workforce of the Future

A focused, strategic effort to rejuvenate the workforce of the EM enterprise is critical to the defense of the United States. Efforts especially at the BA 6.1-6.4 levels require greater support for researchers both inside and outside the DoD, because much of the basic science on which new EM depends has its origins in university and research institute staff, on whose efforts the DoD S&T organizations draw. The future EM workforce depends on attracting academically well-prepared and motivated scientists and engineers, which demands investment in STEM education and university programs to provide students with guidance, mentorship, and practical experience in energetics and adjacent fields. DoD support for academic institutions in the discovery of new energetic molecules will provide new options for defense applied research and development of new EM, and train new scientists and engineers who can be hired by the DoD and industry to work in the EM field. The challenge is steep. The DoD must be competitive with dynamic private-sector tech industries to win the nation's top intellectual talent.

Building and retaining a new generation of the talent depends on increasing wages based on agency authority to match or exceed premium compensation and bonuses offered by industry and academia; decreasing time-to-hire and related burdens like security clearances for all potential qualified hires from the U.S. and allied countries; delegating meaningful decisions to appropriate stakeholders; investing in cutting-edge enterprise tools and methods; and focusing budgets and oversight on the work of organizations rather than stove-piped weapon systems acquisition processes. Even partial success in the foregoing recommendations will give results. Research has demonstrated convincingly that for the most highly educated talent in the economy – and especially in the federal technical workforce – work-life balance and quality factor as much in hiring and retention as compensation. Empowering and supporting researchers and engineers will pay vast dividends in the future.

5.7.1 Recommendations:

5.7.1.1 Major:

5.7.1.2 Additional:

1. Create an energetics Workforce Development Plan to create a war reserve of deep technical talent in energetics. Ensure the U.S. has a stable workforce of subject-matter experts in energetics from R&D to production

2. Leverage existing SMART and NDSEG programs by allocating 25 billets per year in each program for energetic-focused projects

3. Direct part of NDEA ($10M per year) to energetics-related projects and themes, especially those focused on energetic and adjacent technologies.

6.0 Conclusion

The DoD cannot afford to field weapons systems according to the precepts that have governed the requirements and acquisition processes for the last thirty years. The long post-Cold War period of strategic hegemony has ended, and the United States is in direct military competition with peer- and near-peer states. Those competitors enjoy significant advantages in key capabilities, based in part on superior energetic materials. The lethality of U.S. forces – their ability to achieve the desired effect – no longer depends entirely on precision delivery of munitions and warheads by platforms operating in a low-intensity forward environment. Enhanced networking of existing capabilities will likewise fail to address adequately the performance gap. To be effective, U.S. systems require much greater range and destructive effect than is possible with legacy energetic materials, and it is incumbent on the DoD to remove the barriers to developing, transitioning, and fielding a new generation of far more powerful explosives and propellants. The DoD must address the grave deficiencies in the supply chains and industrial base which are necessary to produce the inputs and manufacture the materials. Those networks and infrastructure are brittle, outdated, and highly vulnerable to disruption; rejuvenating the manufacturing base will require novel ways to leverage the dynamic expertise of private industry. This report has drawn from former officials and subject-matter experts in government, industry, and academia to diagnose the state of the EM enterprise and to produce realistic recommendations. But senior leaders must act immediately and decisively if conventional deterrence of the nation's competitors is to succeed.

STUDY TEAM Organization

STUDY LEAD
Mayer

Study Support Team
Programmatics: Keslar, Bennington
Contracts/Admin: Martin
FSO/IT: Gargano, Finson
Report: Jones
Communications: Lobo, Wade

Advisory Group
Chair: Tom Russell, Former DASA R&T
Bill Hix (MGen Ret.) (Army)
Mark Ferguson (Adm, Ret.) (Navy)
Gary Kessler (Former NAWC AD TD) (Navy)
Andy Busch (LtGen, Ret.) (Air Force)

	TECHNOLOGY DEVELOPMENT DOMAIN		TRANSITION DOMAIN		ACQUISITION & SUSTAINMENT DOMAIN		
PANELS	**MODERNIZATION OF ENERGETICS**	**PLAN DEVELOPMENT R&D**	**BARRIERS TO ENERGETICS TRANSITION**	**BUSINESS & INVESTMENT MODEL**	**ACQUISITION PLAN**	**TEST & EVALUATION**	**PRODUCTION & SUPPLY**
Panel Chair	Carrick	Gonzalez	Smith	Thomsen	Simpson	Jimenez	Wardle/ Braithwaite
Panel Members	Rogers Chung Wilson Danek	Wilson Schuette Butler	Danek Doherty Bennington	Jones Martin	Lackey	Melendez Bowen Dellarocco	Dawley Ervin Price Sanderson
Panel Executive Secretary	Doherty	Moore	Wilson	Lauer	Fischer	Bennington	Martin
Panel Administrator	Crespo	Crespo	Crespo	Crespo	Shingleton	Shingleton	Shingleton

Study Advisory Board

- **Dr. Tom Russell – Advisory Board Chair**
  Former Deputy Assistant Secretary of the Army for Research & Technology/ Army Chief Scientist, Director of Army Research Labs, Director of AF Office of Scientific Research

- **Admiral (R) Mark Ferguson III**
  Former Commander of Allied Joint Force Command & Commander of US Naval Forces Europe and Africa

- **Lieutenant General (R) Andrew Busch**
  Former Commander of Four Major Air Force & DOD Logistics Activities

- **Major General (R) William Hix**
  Former Army Chief Strategy Officer

- **Mr. Gary Kessler**
  Former Deputy Assistant Secretary of the Navy (Air Programs)

Study Panel Chairs

- **Dr. Theresa Mayer,** Chair - Executive VP for Research & Partnership for Purdue University
- **Dr. Patrick Carrick,** S&T Panel - Former Chief Scientist for DHS S&T & HSARPA Director
- **Mr. Jose Gonzalez,** R&D Panel - Former Senior Official in DOD Acquisition Community
- **Ms. Jill Smith,** Barriers - Former Director of US Army CERDEC; Former Director, Weapons & Materials Directorate, ARL
- **Mr. James Thomsen**, Business/Investment - Former Principal Deputy Assistant Secretary of the Navy, Research, Development & Acquisition
- **Dr. Bruce Simpson,** Acquisition - VP for Integrated Solutions for Systems (IS4S). Former Executive Director of Air Fore Air Armament Center, Eglin AFB
- **Mr. David Jimenez**, T&E - VP C5ISR Programs, SAIC, Former Army Deputy Under Secretary for Test & Evaluation & Technical Director/Deputy to the Commander of the Army Test & Evaluation Command
- **Mr. Paul Braithwaite,** Production/Sustainment - Northrop Grumman Fellow at Space Systems
- **Dr. Robert Wardle,** Production/Sustainment - Senior Director of Advanced Programs for Propulsion Systems at Northrup Grumman Innovation Systems