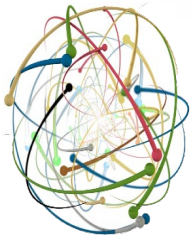

BREAKTHROUGH ENERGETICS 2022

Conference Report

EMERGING TECHNOLOGIES INSTITUTE

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Together with the National Defense Industrial Association, Emerging Technologies Institute, and Purdue University, Energetics Technology Center (ETC) hosted the 2022 Breakthrough Energetics Conference on 4-5 May 2022 on the campus of Purdue University in West Lafayette, Indiana. More than 200 participants attended sixteen panels, which – together with featured speakers and networking events – amounted to a comprehensive review of the state of the U.S. Department of Defense (DoD) energetics enterprise. Experts in government, military, industry, and academia discussed the current state of energetics technology, manufacturing and supply chain capabilities, workforce issues, and the elements of the so-called "business model" by which the DoD develops explosives, propellants, and pyrotechnics. Considering the attendance, Michael Holthe, the Director for Platforms and Weapons Technologies in the Office of the Secretary of Defense (OSD), could not recall "the last time [such a] breadth of energetics expertise was in the same room."

The impetus behind the conference lay in broad recognition that the nation's ability to develop, manufacture, and deploy state-of-the-art energetic materials is in urgent need of reform. Accordingly, the U.S. Congress initiated a multi-pronged review of the energetics enterprise with a specific instruction, Section 253 of the FY20 National Defense Authorization Act (NDAA). The review consisted of an intra-governmental report by OSD and an extra-governmental report by the Energetics Technology Center. Both served as fundamental inputs to the conference. Dr. Jason Jouet, Munitions Technology Director at OSD (R&E), was assigned the task of synthesizing the studies with inputs from the conference to create a National Energetics Plan. This report, along with associated background information, is being provided to Dr. Jouet as the analytical result of the 2022 Breakthrough Energetics Conference.

The conference yielded the following broad recommendations, which are presented in fuller form at the end of this report.

- *Strong unitary leadership of the energetics enterprise is needed to revitalize the role of energetics in the Department of Defense.*

- *A baseline operating picture of the entire energetics enterprise – spanning research and development, test and evaluation, acquisition, and the industrial base – is essential to linking and providing coherence to the activities of all parts of the enterprise.*

- *Rigorous operational and tactical modeling to clarify the significance of advanced energetic materials for the lethality and effectiveness of U.S. forces is a priority.*

- *New mechanisms and approaches are essential for qualifying advanced energetics materials and making them available for system consideration without imposing additional burdens on program budgets.*

- *Researchers and engineers must become familiar with the tactical and operational scenarios and military problems against which services' x8s, combat developers, requirements generators, Program Executive Officers and Program Managers plan.*

- *Similarly, researchers and engineers must become more familiar than is presently the case with the technologies, processes, standards, and constraints of energetic material processing and manufacturing, especially at scale.*

- *The DoD must emphasize the development of robust domestic supply chains for critical chemicals and a flexible and distributed manufacturing capability responsive to rapid changes in demand.*

- *The standards according to which material qualification and testing take place must be urgently modernized and rationalized.*

This report breaks the conference presentations and discussions into several key themes and highlights their most important insights.

THE NEW PEER-COMPETITIVE ENVIRONMENT AND ITS IMPLICATIONS FOR DEFENSE ACQUISITION

Driving the overall review are the stark operational challenges facing the U.S. Joint Force in key strategic theaters, especially the western Pacific, along with the growing conviction among defense planners that acquisition should be oriented more around "lethality" and magazine-depth than efficiency, minimum cost, or force optimization. ***Tony Garcia*** of Systems Planning and Analysis (SPA) and ***Tim Walton*** of the Hudson Institute provided conference attendees with detailed briefings that laid bare the tactical and operational disadvantages to U.S. forces in certain scenarios. Future conflicts, they made clear, will likely involve extensive use of longer-range, faster, and harder-hitting precision weapons. All aspects of effective operations – from logistics to Intelligence, Surveillance, and Reconnaissance (ISR) for planning and executing kill chains – will unfold at iterative speeds faster than previous conflicts. Incorporating advanced energetic materials into their weapons systems, among other things, has allowed potential adversaries to best many of the systems on which the U.S. Joint Force relies. The briefings, reinforced by accounts of the conflict in Ukraine, underscored that U.S. forces need larger numbers of affordable munitions of greater range and lethality than ever. The urgent challenge to the defense acquisition community is to improve means for implementation of advanced energetics technologies to meet warfighter capability requirements.

In his address to conference participants ***Brigadier General Heath Collins***, Program Executive Officer for Weapons and Director of the Armaments Directorate at Air Force Materiel Command, clarified the operational context in which improved energetics would figure. U.S. forces have begun a difficult transition from decades of operating in permissive, target-rich environments to a peer competition against a highly sophisticated adversary. The Chinese have demonstrated an "uncanny ability" to develop, test, and field with stunning speed a new generation of highly-capable anti-access, area-denial weapons. Moreover, U.S. forces face an inherent disadvantage in the geography of the western Pacific, which makes necessary longer ranges and deeper magazines for American forces. These factors together suggest that the capacities and capabilities of current U.S. weapons portfolios are grossly unbalanced.

His point was amplified by a point made later by ***Dr. Bruce Simpson***, Vice President for Systems at Integrated Solutions. Building on the "volume of fire" concept favored by Brigadier General Bill Hix (Ret.), Simpson argued that the U.S. Joint Force cannot presently afford the tens of thousands of sophisticated munitions required for any plausible military scenario against China. New weapons development is constrained by the fact the DoD is already fully committed to certain 5th and even 6th generation delivery platforms, which will irrevocably constrain munitions capacities for a half-century to come. To Simpson's way of thinking, there is no mathematical way to generate the requisite numbers of sorties based on the available weapons. Thus, improved weapons are the only answer. He speculated that energetics could have a positive multiplier effect on the range and lethality of next-generation weapons, but only if the services get around to deciding that they need and want to develop them.

THE JOINT FORCE CURRENTLY LACKS SUFFICIENT NUMBERS OF THE HIGHLY LETHAL, STAND-OFF PRECISION STRIKE WEAPONS ESSENTIAL TO SUCCESS IN A PEER-COMPETITIVE CONFLICT.

The complications of doing so are tremendous. BG Collins spoke about shifting funding from large-scale "bomb lines" to long-range stand-off fires, with particular focus on hypersonics, precision, and survivability. He highlighted the issues associated with industrial base obsolescence, the loss of critical knowledge when legacy producers exit the industry ("losing the recipes," as he put it), and the tough decision to shut down less capable programs. Lack of visibility into resource supply chains and their fragility are of particular concern. Many, if not most of the crucial ingredients for major systems are sourced from insecure countries, BG Collins pointed out, and the supply chains themselves have multiple points of potential failure. Numerous other speakers echoed his concerns over the two days of the event.

But the strongest point BG Collins emphasized was the relevance of cost. In view of the sheer quantity of munitions required for U.S. forces to deter credibly or win a major conflict, he stressed that he cannot justify – speaking hypothetically – a five percent greater system performance at twice the cost, especially if definitions of system performance do not take adequate account of lethality and target damage. As the DoD must purchase thousands and even tens of thousands of expensive weapons, cost and scalability must guide the energetics reform program. In a response to a question from a different session, ***Dr. Bob Wardle***, former Senior Director of Advanced Programs at Northrop Grumman, offered specific insight into the problem. When asked why even well-established materials such as CL-20 do not feature more prominently in current U.S. systems, he patiently explained that much more complicated manufacturing processes increased the cost of that material by a factor of multiple tens, far outstripping the margin in performance that program managers can normally justify. Clearly, more expedient routes to less costly materials must be found, perhaps through advanced manufacturing or production plans at scale.

COST AND SCALEABILITY, IN ADDITION TO IMPROVED LETHALITY, MUST DEFINE THE NEXT GENERATION OF AMERICAN WEAPONS SYSTEMS, WHICH ARE URGENTLY NEEDED IN LARGE NUMBERS.

THE RELEVANCE FOR ENERGETIC MATERIALS OF NEW APPROACHES TO DEFENSE ACQUISITION

Perhaps the centerpiece of the conference was a whirlwind review by ***Christopher O'Donnell***, the Deputy Assistant Secretary of Defense for Platform and Weapons Portfolio Management, of major changes in DoD acquisition processes over the last three decades. He tracked their evolution after the Cold War from a "standard model"- wherein DoD cooperated with industry to work up system designs and then competed them for development and production – to one which has devolved more discretion to industry. The War on Terror after 9/11 has turned out to be an interlude, based on *ad hoc* problem-solving to cope with the requirements of counterinsurgency and partnership support. Over the last decade, the U.S. has gradually awakened to the reality of a strategic competition with China based on a new model of rapid, iterative innovation, dependent less on original R&D than in the rapid translation of new technology into fielded systems. The speed and scale of technological competition is forcing the DoD to find "driving, enduring advantages across the acquisition enterprise" to "stop the erosion of our technical edge," as O'Donnell put it, even as support for Ukraine has stimulated a scramble to rekindle U.S. conventional munitions production at scale.

STRATEGIC COMPETITION WITH CHINA WILL BE BASED ON RAPID, ITERATIVE INNOVATION, WITH AN EMPHASIS ON HIGHLY EFFICIENT AND MODERN PRODUCTION CAPABILITIES AND ON THE SPEED WITH WHICH NEW CAPABILITIES CAN BE FIELDED IN SYSTEMS.

Part of the DoD's new approach to acquisition is the concept of Mission Engineering, which O'Donnell described as a subset of Capability Portfolio Management. Acquisition planners focus not on discrete, isolated capabilities but on the larger "system of systems," or the attainment of overall effect through the integration of dozens of smaller capabilities. Mission Engineering magnifies the importance of tertiary items from smaller programs at the ACAT II or III levels (such as Link 16 and Precision Navigation and Timing). Without them, marquee programs would be moribund. Several speakers took up the same point, as when Bruce Simpson admonished attendees to bear in mind that the DoD is in the business of acquiring not energetic materials, but the systems in which those materials are just a part, and sometimes not even the primary part. The point was further illustrated by ***Mike Vandenboom***, Director of Agile Acquisition, Air Force Lifecycle Management Center Armament Directorate. Systems are integrated bundles of capabilities, he said, based on things like sensors, data links, targeting with route adaptability, and energetic materials. The latter must be seen in context, and their "value proposition" cannot be formulated in isolation. For the cruise missiles that Vandenboom oversees, a vast improvement in energetic performance would be required before he would place at risk other capabilities the system needs to meet program targets. Hypersonics might well present a different value proposition, he said. The requirement to make those systems smaller, faster, and farther-ranging places heavier emphasis on the energetic materials involved and may expand the tolerance for system risk in other ways.

Like other speakers, O'Donnell stressed the importance of military-operational analysis as the most persuasive way to convey the value of advanced energetic materials. The most compelling case for investment in advanced materials, he argued, is based on how they enhance the lethality and effectiveness of the Joint Force in concrete tactical and operational scenarios. Modeling and campaign

analysis based on even marginal hypothetical increases in speed, range, and destructive effect, or the multiplication effects of advanced energetics on weapon load-outs, magazine capacities, and sortie rates speak directly to the combat developers and service representatives who build the acquisition requirements. O'Donnell's emphasis was probably the most articulate plea at the conference for more concerted and focused efforts to that end.

O'Donnell also made a strong case, echoed by other speakers, that the S&T and R&D communities need to be aware of the results of capabilities-based operational analysis. The strategic, operational, and tactical circumstances which justify investment in more lethal capabilities are too often unfamiliar to scientists and engineers. Thinking about their work in conversation with operational planners and system developers will lead to more mission-focused S&T and generate upstream improvements to lethality, especially for the DoD's highest warfighting priorities. As a model O'Donnell highlighted the Competitive Advantage Pathfinders, an initiative in the DoD to align requirements, acquisition planning, and resourcing by creating a common dialogue among the Comptroller, Cost Assessment and Program Evaluation (CAPE), and the service x8s who set requirements and direct resources. The hoped-for result will be opportunities to develop technology in joint focus areas, like long range fires, counter-C5ISR, and joint all-domain command and control. The department has made increasingly good use of the Adaptive Acquisition Framework and non-traditional contracting mechanisms to leverage cutting-edge work in programs like Conventional Prompt Strike, which has led incongruously to the Army developing launchers, fire control systems, and a glide vehicle based on a Navy propulsion unit for deployment on Pacific islands. That an important new capability can emerge from the largely uncoordinated efforts of multiple services he takes to be an encouraging sign.

> TO ACHIEVE MORE RAPID AND LESS COSTLY TRANISTION OF NEW MATERIAL, SCIENTISTS AND ENGINEERS SHOULD BE CONVERSANT WITH THE STRATEGIC AND OPERATIONAL CIRCUMSTANCES THAT JUSTIFY THOSE MATERIALS IN DEFENSE SYSTEMS.

UNIQUE DETERMINANTS OF THE DEFENSE ENERGETICS PROBLEM

Dr. Christine Michienzi, Chief Technology Officer for the Deputy Assistant Secretary of Defense for Industrial Policy, devoted her lunchtime talk on the second day of the conference to what she called "the national emergency" of a stagnating defense energetics enterprise. The longtime lack of a coherent framework to develop and mature energetics for weapons systems stimulated the formation in 2012 of the Critical Energetic Materials Working Group (CEMWG) as an overall point of reference in the DoD for critical chemicals and obsolescence issues, especially for industry. The group's activities have provided insight not just into the overall state and risk profile of energetics, but the precariousness of the supply chain and industrial base. It has also led to new levels of information-sharing and collaboration across firms and organizations. Interestingly, as Michienzi stressed, Congress has increased funding for the materials identified by the CEMWG to some $460 million as a partial result of substituting the term "critical chemicals" for energetic materials, even at the expense of the specificity and focus that many in attendance would prefer.

Michienzi spotlighted the obstacles that reformers face in efforts to rekindle the enterprise. Production capacity over the last three decades has been sheared to the bone for the sake of maximum efficiency and a stable margin for manufacturers at the expense of robustness and depth.

WEAK AND INCONSTANT DEMAND SIGNALS - TOGETHER WITH THE HIGH COSTS OF ENTRY, COMPLIANCE, AND MATERIAL QUALIFICATION FOR NEW MANUFACTURERS - HAVE LED TO AN ENERGETICS PRODUCTION BASE THAT IS UNBALANCED AND ANTIQUATED.

Because the demand signal for defense energetics is comparatively small and unsteady, large chemical firms are disinclined to compete in the space, even as the barriers to new entry remain prohibitively high for smaller producers. Defense energetics require expensive equipment, complicated processes, and sophisticated skillsets in the labor force, to say nothing of the organizational, accounting, and financial management expertise required to do business with the DoD. Similarly, there is scant progress toward finding reliable international partners. The push for cost minimization drove programs over the last three decades to source many of the most important precursors and ingredients from China, a fact unlikely to change soon due to the expense and environmental impact of doing otherwise. Although equipped with the nominal authority to dictate sources of supply, the DoD has been reluctant to do so, mindful of the cost disruption that would result.

At the same time, Michienzi pointed out, production capacity and demand are grossly unbalanced across entire categories. Ammonium perchlorate production has a capacity many times that required, while HMX and RDX production is badly capacity-constrained and backlogged for years. To make matters worse, shifting sources of supply under current guidelines is exorbitantly expensive. Testing and qualifying new material – or even requalifying a material for conventional systems – can run to many millions or tens of millions of dollars; doing so for strategic systems can run into the *hundreds*. Like BG Collins, Michienzi argued that the DoD's qualification specifications and methodologies for energetic materials and their inputs are woefully outdated, in some cases dating back to the 1940s, and there is little appetite to do the hard work of revising them. Michienzi cited an initiative to leverage the DoD labs to modernize testing specifications and share the resulting data and pointed to an effort to begin stockpiling critical chemicals. These are first steps, but success, she argued, must begin with a renewal of the formula that underwrote American military-technical dominance for a century: a close partnership between the DoD, academia, and industry.

THE POTENTIAL FOR IMPROVED GOVERNMENT-INDUSTRY COOPERATION

Several speakers over the two days of the event engaged with perhaps the most impactful topic of the conference, namely how the energetics enterprise is organized and should operate. ***Dr. Bob Wardle*** explained that working on defense programs imposes significant burdens on commercial industry to comply with Defense Contract Management Agency (DCMA) requirements for budget disclosure on R&D, IRAD, capital borrowing, overhead, fees, and so forth. Compliance costs are high and have the effect of pushing out smaller firms. Moreover, when companies become involved in programs which the government oversees closely, such as the Air Force heavy-lift launch program, they may find it difficult to allocate capital sensibly across other activities. They are also often left with only modest remainders, which limits their ability to take on additional risk or invest in other promising initiatives. Government

officials do not often seem to appreciate how working with the DoD depresses corporate margins and makes it impossible to adapt to market opportunities and technology as nimbly as other firms. Naturally, private companies orient toward Return-on-Investment, Wardle admitted, but when incentivized, they can achieve results with astonishing speed and decisiveness. When Northrop Grumman's propulsion systems group decided recently to diversify away from a single supplier of ammonium perchlorate and invest $80 million in a brand-new operating plant – without prior DoD approval or guarantee of a market – it began producing some 5 million pounds of material annually in only 24 months. That kind of ingenuity and resourcefulness could be at the DoD's disposal, he pointed out, if it could only figure out how to access it. The better industry and government understand the process and "decision-points" of the other, the better they can partner to accomplish mission goals.

However different the operating dynamics of government and industry may be, each faces the same larger challenge, argued ***Dr. Greg Quarles***, Chief Operating Officer at Applied Energetics. How can organizations – federal or commercial – underwrite discovery and technology development in a domain defined overwhelmingly by a single, overriding source of demand and virtually no dual-use potential? He cited the terrific example of DoD's constructive approach to defense-related laser innovation thirty years ago, which – like energetics – turns out to have few dual-use applications. The DoD subsidized private capital investment and permitted commercial partners to retain rights to intellectual property, which stimulated firms to invest internally in new research and manufacturing potential. The Joint Technology Office assembled what amounted to a "community of interest" – small and large businesses, academic and federal labs, and FFRDCs, among others – and built incubators and accelerators to superintend collaborations. Only a handful of the funded lines of effort bore fruit, but overall innovation in laser and related technologies surged over the next two decades. For the last few years the DoD has reaped the harvest from those long-ago investments, recently deploying cutting-edge, off-the-shelf 300kW capability to deal with a range of new ISR threats, none of which could have been foreseen when the initial investments were made. More importantly, the underlying technology ecosystem which the DoD did so much to create continues to evolve and thrive.

> TO REBUILD DOMESTIC PRODUCTION AND SUPPLY CHAINS, THE DEFENSE DEPARTMENT MUST LOOK TO HISTORICAL MODELS AND LEVERAGE NEW CONTRACTING AUTHORITIES TO HARNESS THE DRIVE AND INGENUITY OF AMERICAN INDUSTRY.

More sobering perspectives on the structure of the defense energetics enterprise were offered by panelists who currently work for the DoD. Much time and effort are wasted talking about partnership and collaboration, but little is devoted to actually partnering and collaborating, opined ***Ashley Johnson***, the Technical Director of Naval Surface Warfare Center, Indian Head Division. The mandate to run technical centers like Indian Head according to a working capital model – whereby it functions like a business focused on net result with zero profit – means that they must be optimally organized and budgeted to do what is required in the present, not lean into a hazy future. The fact of the matter, Johnson asserted, is that acquisition managers are disinterested in improved capability based on energetics, and until they are, little will meaningfully change. That same point was put more strongly by ***Chris Grassano***, Deputy Program Executive Officer of the Joint Program Executive Office for Armaments and Ammunition. New materials impose additional costs and risks which cannot be justified if existing

materials satisfy requirements, especially if the latter do not adequately take into account increases in lethality and target damage. Advanced energetics are simply too immature for incorporation into existing systems at acceptable levels of risk in cost, performance, manufacturing process, or sensitivity, among other factors. In many cases, acquisition officials lack methods even to assess those levels of risk. Grassano cited a mantra repeated by several other speakers: if the manufacturing readiness level (MRL) of a material does not outpace its technology readiness level (TRL), then the "value proposition" for adopting it fails, independent of cost. More strongly, Grassano rejected outright even considering new material if it exacerbates the vulnerability of the supply chains for critical chemicals, a telling point to which there was no easy response.

CONFERENCE PARTICIPANTS NOTED THE IMPORTANCE OF SYNCHING MANUFACTURING READINESS LEVELS (MRL) WITH TECHNOLOGY READINESS LEVELS (TRL) THROUGH TARGETED INVESTMENT AND IMPROVED QUALIFICATION AND TESTING STANDARDS.

The business model for defense energetics is brittle, Grassano concluded, because it reflects the risks and priorities of what amounts to a peculiar problem. Current high costs result from the inability of the DoD to maintain a deep market with a constant demand signal and the simultaneous need to surge production in the event of a crisis. The government has no choice but to absorb the cost of that redundant margin in production capability, however much it distorts its ability to collaborate well with industry because of limited peacetime budgets. There are undoubtedly points in the value chain – especially on the level of small-scale production – where it might make sense for industry to invest with an eye on market-level returns, but even in those cases companies typically require close partnership either with a prime contractor or the government itself to manage risk. Grassano expressed some optimism that building a "common operating picture" and "integrated data environment" will permit everybody – government and industry alike – to "determine the maturity of where things are" and help to "make better decisions and understand where the risk level actually is." If the case for collaboration looks compelling, Rick Dunn, a leading expert on defense contracting, offered the view that the tools required to achieve deeper cooperation between DoD and industry are at hand. The Acquisition Council of the House Armed Services Committee, he pointed out, has ensured that the DoD has the contracting authorities to bring about a more constructive and flexible working relationship. Mechanisms like Other Transaction Authorities for prototype projects and even – through Middle Tier Acquisition – for major programs offer ways around the strictures of the formal requirements process, and they could do much to transition promising materials into defense systems that are otherwise process-constrained.

PROSPECTS FOR AN ENERGETICS COORDINATING AUTHORITY

The question of whether the energetics enterprise needs overall direction has been a contentious one. The ETC study stressed the need for an interagency coordinating function at the highest level of national policy to make a case for the concept of Advanced Energetics as it applies to Joint Enhanced Lethality. It argued for including energetic materials in the National Defense Strategy and other policy statements, and for a more holistic understanding of energetics-based system lethality in the acquisition community. At the conference, ***Dr. Steven Wax*** spoke about the overall OSD perspective on the role of energetics for

national defense in the context of the recent reorganization of OSD A&S (Acquisition and Sustainment) and OSD R&E (Research and Engineering). Couching energetics as a "Critical Core Competency," he revealed that OSD intends to implement the recommendations of the official study even without a system-wide advocate by pressing the military services to bend their efforts to that end. Several conference attendees, including Ashley Johnson, voiced concerns regarding the mission portfolio of OSD (R&E), arguing that it gives short shrift to the importance of lethality and grouped propellants and explosives under the amorphous category of "Advanced Materials." Dr. Wax underlined that OSD is nevertheless well-positioned to support the improvement of the S&T infrastructure, manufacturing, and workforce development, even if it lacks authority to set budget priorities and the services retain full authority over their top lines. The appropriate role of OSD, he stressed, lies in oversight and coordination, not direction and allocation. He left dangling the possibility – without being specific – that working toward a designated authority – or "principal director" – responsible for uniting and overseeing the energetics enterprise might make sense at some point.

AN OVERALL AUTHORITY FOR DEFENSE ENERGETICS WOULD IMPROVE S&T INFRASTRUCTURE, MANUFACTURING ENGAGEMENT, AND WORKFORCE DEVELOPMENT TO OVERCOME THE SYSTEM RISKS IN ADOPTING MORE EFFECTIVE MATERIAL.

One of the broader goals of an overall coordinating function would be to reassert the U.S. lead in primary science and research in the field. Before observing dryly that energetics research has made little progress since his departure from the field decades ago, ***Dr. John Fischer*** of ETC spoke to how Chinese research in energetics has outpaced that of the international community in general, and the U.S. in particular. It is arguable whether U.S. research in energetics can any longer be considered the cutting edge, and certainly doubtful – in view of the scale of Chinese investment – whether it will be in the future. Looking ahead, ***Kathleen Bubniak*** and ***Dr. Mike Lindsay*** both addressed, from different perspectives, the importance of moving beyond tired paradigms of research policy and praised diverse and unorthodox approaches to material synthesis and advanced processing. Noting that Federal Acquisition Regulation-based processes slow transition, Bubniak, a Science and Technology Associate for Energetics and Warheads at the DEVCOM Armaments Center, echoed Chris Grassano in observing that the Manufacturing Readiness Level (MRL) of candidate materials must mature faster than the Technology Readiness Level (TRL) for system demonstration purposes, not least because funding for manufacturing development cannot be programmed until they achieve TRL 6. As manufacturing processes will not be able to mature until product technology and product designs are stable, Grassano's insight points to a basic inconsistency in the system acquisition process. If ways can be found to speed those trajectories of development, researchers will see an open field ahead for bringing laboratory science into fruition.

Lindsay, who serves as Technical Advisor for the Energetic Materials Branch in the Munitions Directorate at the U.S. Air Force Research Laboratory, sketched two case-studies for transitioning energetics research into actual systems: one which followed the "ideal" conventional model and resulted in failure, and another which unfolded in an unpredictable and non-linear succession of fortuitous breaks and resulted in success. Scientific researchers must understand, he said, that transition is a function of understanding operators' real-world needs and the risk calculus of program managers as much as it is simply delivering a material that is nominally more effective. Bruce Simpson graphically illustrated the

same point with the case of the Next Generation Area Attack Weapon (NGAAW). It was intended originally to feature a new energetic material, AFX-139, which offered higher fragmentation energy and velocities (energy and flux being the two primary factors in lethality calculations) and much improved performance. But the fact that the material had to be processed in the form of a very fine powder necessitated large investments in manufacturing technologies and methods, which are counted as costs under program budgets and could not be accommodated. The new material was abandoned for a ready, less costly, and lower performing alternative. When the question was raised of the warfighter impact from selecting the lower performing material, the response was the system met requirements – again illustrating that target damage effects are not a meaningful driver of requirements.

OBSTACLES AND SOLUTIONS FOR BETTER GOVERNMENT COOPERATION WITH INDUSTRY

A stark light was shone at different points on the challenging but essential partnership between government and industry in the defense energetics space. Broadly, panel discussions and feedback displayed agreement that participation by nontraditional businesses should be encouraged, but that the difficulties of adapting to defense contracting and acquisition requirements are formidable. Moreover, the DoD over the last three decades has often been seen as an inconsistent and unreliable counterparty, and the scale of its demand signal for chemicals and finished energetics is too small to sustain a marketplace in which competition and efficiency could flourish. ***Dan Hartman***, Director of Business Development for Spectra Technologies, criticized the inefficiencies and misplaced incentives involved in government ownership of any part of the production enterprise. It is precisely government ownership of the production of the most important energetic materials, Hartman argued, that has led to the present condition of brittle supply-chains with single points-of-failure and antiquated process technology. Just as competition enhances athletes, the lack of it in the energetics marketplace has made the government "fat and slow," as he put it. In perhaps the most radical proposal of the conference, Hartman recommended that the government sell off its manufacturing to private industry against contractual obligations to remain in the market. "Ordering explosives at Holston," he quipped, "is kind of like being in a restaurant where all of the entrée items on the menu are 'market price' and the maître d' gets to decide if he can sell it to you or not." Because of these circumstances, his firm – which manufacturers energetic materials and loads warheads for DoD prime contractors – cannot compete for work mandatorily earmarked for McAlester Army Ammunition Plant in Oklahoma.

> UNTIL THE GOVERNMENT REFORMS THE RULES FOR CONTRACTING AND ALLOWABLE PROFIT MARGINS, EXPECTING PRIVATE COMPANIES TO INNOVATE UNDER SUCH CIRCUMSTANCES IS UNREALISTIC, IF NOT IMPOSSIBLE.

Government officials acknowledged the peculiarities – if not dysfunctionalities – of the defense market for chemicals and energetic materials. Christine Michienzi pointed out that defense energetics represent a high-risk, low-volume, and low-revenue business, only somewhat leavened by certain niche markets like commercial ammunition, space launch, and mining. For strategic reasons, the DoD cannot rely on foreign sourcing even from allies in regions of geopolitical risk, like South Korea. Unfortunately, Michienzi pointed out, an energetics industrial base dependent on producing large amounts of legacy materials on dedicated production lines in 1950s-era facilities has

been shown to be inadequate to the requirements of peer competition. For that reason, modernization of the energetics industrial base is a "problem in search of a solution," as ***Jay Brannam***, Executive Director of the Munitions Industrial Base Task Force, said. He encouraged participants to reflect on the fact that 70 percent of munitions in the DoD inventory are made in Contractor-Owned, Contractor-Operated (COCO) facilities which operate on razor-thin margins inadequate for reinvestment in new processes and capabilities. Until the government changes the rules for contracting and allowable profit margins, expecting private companies to innovate under such circumstances is unrealistic, if not impossible. Occasional exceptions do little more than prove the rule.

Still, there are glimmers of hope, according to ***Anthony Di Stasio***, Director of the Defense Production Act Title III Office, OSD (A&S). He pointed to the steep growth of the Title III budget over the past several years as evidence that the Congress takes seriously the need to revitalize the energetics value stream. The budget of his office has exploded over eight years from $32 million to $388 million, and should hit $659.9 million next year, although that sum must admittedly address numerous priorities other than energetic materials. The problem is how to devise a system that translates such resourcing into better materials which, in turn, end up in weapons in the hands of the warfighter, preferably quickly. Pointing to the five-year spending roadmaps which the DPA Title III office has promulgated, Di Stasio said that any answer should involve "bundling" defense energetic materials with commercial products and building market scale to produce multiple chemicals simultaneously. Because of the peculiarities of the defense marketplace for chemicals and energetics, the government should focus on smaller and medium-sized firms and to help them cross-pollinate their defense lines with commercial lines-of-activity. In a similar vein, ***Dr. Paritosh Dave***, Senior Program Manager at Leidos, argued that success in bringing new firms into the fold may not be a function solely of circumstance and demand signal, and pointed to community mentorship and collaboration to foster ideas and facilitate transition.

THE GOVERNMENT SHOULD WORK EFFECTIVELY WITH SMALLER AND MEDIUM-SIZED FIRMS, HELP THEM CROSS-POLLINATE DEFENSE WITH COMMERCIAL LINES-OF-ACTIVITY, AND FOSTER A CLOSE RELATIONSHIP BETWEEN R&D AND MANUFACTURING.

Others saw the scope of industry involvement differently. Lamenting that industry interacts with government R&D and S&T organizations much less than it should, ***Charlie Zisette*** of the National Armaments Council argued that the integration of researchers who develop and synthesize material with the organizations which scale it for production should be "not a baton pass, but a relationship to be capably managed." His view was echoed by ***Mike Ervin*** of BAE Systems, who suggested that good R&D derives from a close interrelationship between scientists, engineers, and manufacturers. The result should be a "production mentality," meaning due regard for the downstream costs and the complexities involved in producing energetic material at scale. With some exception, participants expressed broad agreement throughout the conference that industry involvement in energetics R&D should be not just more intensive, but deeper. Some advocated bolder steps, as when Zisette challenged attendees to think about a defense energetics enterprise redefined by deep industry involvement in the primary science, synthesis and transition processes, and all of the steps involved in developing new materials and scaling them to production.

NEW DIRECTIONS IN RESEARCH AND PRODUCTION OF ENERGETIC MATERIALS

Adjacent technologies, or the adoption and optimization of technologies from unrelated domains for the field of energetics, featured prominently in conference discussions about modeling and production methodologies. An excellent example is the natural-language processing techniques developed by ETC to harvest legacy energetics research, an important step towards modernizing and rationalizing S&T and qualification activities. Machine-learning (ML) models for molecular and formulation discovery promise to enhance the pace and efficiency of research and enable the rapid transition of new materials into systems. But machine learning – admittedly a broad concept, with countless potential applications – is not a panacea, as ***Dr. Suhithi Peiris***, Senior Energetics Scientist at Battelle, made clear. Machine learning depends heavily on the relevance and quality of the underlying data, a view echoed by ***Dr. Pat Carrick***, former Chief Scientist at the U.S. Army Research, Development, and Engineering Center, and much of the available data is "dirty," so to speak. Applications of ML techniques to highly energetic new molecules, especially for predictive purposes, rely on different underlying datasets, as do any ML-driven attempts to look at syntheses, formulations, and ensuing physical characteristics. Much as Peiris would like to see ML-driven, AI-directed synthesis and formulation processes remove humans entirely from the dangerous business of testing and scaling materials by, we are years from practical implementation of that approach. That said, the technologies have the potential in the near term to make certain elements of those processes faster and cheaper.

ACKNOWEDGING ITS LIMITATIONS AS WELL AS POTENTIAL WILL HELP THE ENERGETICS COMMUNITY TO REALIZE THE IMMENSE CAPABILITIES OF MACHINE-LEARNING TO SPEED AND CLARIFY R&D AND TESTING PROCESSES, THUS SHORTENING TIME TO TRANSITION AND REDUCING COST.

The conference dealt only obliquely with the related issue of system integration as either promising or limiting for the profile of advanced energetic materials. ***Jill Smith***, former Director of Communication and Electronics Research at the U.S. Army's Development and Engineering Center, spoke about the importance of understanding the place of energetics at the system level. Separating energetic materials from human operators, especially in armored vehicles, opens promising design space for more powerful and effective weapons based on possibly riskier versions of them. Improved autonomy, remote technologies, and AI therefore stand to make more advanced energetics a priority. Her remarks contrasted with those of Robert Pulver of General Dynamics, who addressed the physical and engineering constraints that existing gun technology imposes on the use of more powerful materials. Until overall system constraints are redefined, he and others agreed, hard limits bound the potential of advanced energetics to enhance capability in some domains.

A major theme of the conference was the promise of state-of-the-art methods, such as continuous flow processing and others inspired by the pharmaceutical industry, for improving the manufacturing of energetics. Paritosh Dave suggested that processing smaller quantities of certain materials across a network of distributed smaller-scale plants, so characteristic of pharmaceutic chemicals, offers a valuable opportunity to deploy superior process analytics, achieve higher-quality at lower marginal cost, and flexibly meet changing demand profiles. Among other topics in her lunchtime talk on the second day, Chris Michienzi referred to a strategy to make domestic manufacturing cost-competitive by fostering the growth of single-firm, production-agile "toll houses" able to shift across product categories

IS IT APPROPRIATE TO THE SOW THE SEEDS OF A REVITALIZED ENTERPRISE IN SMALLER-SCALE DISTRIBUTED MANUFACTURING, OR IS IT UNREALISTIC IN THE CURRENT ENVIRONMENT TO MOVE AWAY FROM CENTRALIZED, LARGE-SCALE *GOGO* AND *GOCO* PRODUCTION FACILITIES?

based on changing demand. She also suggested that the acquisition community explore ways to "smooth" the demand signal for certain commodities, even at higher costs over time, for the sake of safeguarding the integrity of the production base. Others were skeptical that such a model could work. ***Dr. Shawn Phillips***, Chief of AFRL's Rocket Propulsion Division, pointed out that with a profit margin of 70 percent in some cases, the agility and innovativeness of the pharmaceutical industry will be a tough example to follow, and that manufacturing in the pharmaceutical industry reflects a fundamentally different business model. Short of radically inflating commercial producers of energetics with additional public funds – which is hardly likely – a different answer will need to be found. Suhithi Peiris pointed out that continuous-flow processing is not a one-size-fits-all, as energetic formulations often require different flow systems and the scale of output is often larger. Mike Ervin of BAE Systems expressed doubt that a highly flexible, distributed production system is possible in a financial environment defined by things the DoD cannot change, namely inconsistent demand signals and unpredictable budget cycles, regardless of what defense planners might hope for. The most crucial elements of reliable and high-quality production, in his view, are retention of quality personnel and multi-purpose manufacturing systems, especially for the very large-scale output the country needs in a crisis. Collectively, the ideas and doubts about energetics manufacturing pointed to a basic question: is it appropriate to sow the seeds of a revitalized enterprise in smaller-scale distributed manufacturing, or is it unrealistic in our current financial and political environment to deemphasize centralized, large-scale GOGO and GOCO production facilities?

Speakers suggested a host of answers. Anthony Di Stasio highlighted the untapped potential for innovative PPPs to nurture new kinds of production paradigms, together with the cultivation – echoing Ashley Johnson – of a "true collaborative environment" between government and industry. His office is investing in mobile, micro-scale agile energetic manufacturing capabilities based on a 'factory in a box' concept for smaller producers to access technologies and expertise. ***Dr. T. Yong Han*** of Lawrence Livermore National Laboratory discussed the efforts of the National Nuclear Safety Administration (NNSA) to leverage its unique position relative to academia and industry to transition low TRL materials into finished systems. Like others in attendance, Han lamented the ignorance of researchers for the latest "science of manufacturing" and the "science of scale," as he put it. Because large-scale producers frown on complex, multi-step synthesis requirements, NNSA has resorted to adjacent technologies like additive manufacturing, agile processes, and continuous-flow processing to meet its requirements. Han stressed that the largest challenge facing government agencies is working with commercial firms with the latest synthesis and manufacturing expertise, as the latter have scant incentive to collaborate on the government's terms. Because the agency is not bound by defense program constraints, Han claimed,

THE GOVERNMENT SHOULD DRAW ON PRECEDENT AND TAKE ADVANTAGE OF NON-TRADITIONAL CONTRACTING MECHANISMS TO WORK MORE EFFECTIVELY WITH COMMERCIAL FIRMS POSSESSING THE LATEST SYNTHESIS AND MANUFACTURING EXPERTISE.

NNSA has cut ten-year timeframes for system readiness in some cases to a couple of years through rapid prototyping. In other words, some of the key ideas in the OSD and ETC reports about industry partnership and manufacturing innovation have met with success in real-world applications.

WORKFORCE DEVLOPMENT

The energetics workforce, defined broadly as the specialized scientists, engineers, and technicians who shepherd the development and qualification of material through transition to system integration, has contracted drastically over the past thirty years and is an abiding concern to policy officials. According to ***Dr. Tom Russell***, Former Deputy Assistant Secretary of the Army for Research and Technology, the DoD has a decidedly thin foundation today on which to rebuild. Fortunately, a number of government programs to identify and cultivate STEM talent, not least in underserved and underrepresented communities traditionally poorly represented in the U.S. scientific establishment, are making progress. ***Dr. Jagadeesh Pamulapati***, Director of the Defense Laboratories Office, Office of the Assistant Secretary of Defense for Research and Engineering, explained that scholarships and fellowships are the largest component of the program, followed by collaboration with the nine DoD manufacturing innovation institutes which implement workforce development plans involving certification and training in STEM-related fields. Pamulapati explained that engaging with prospective STEM-oriented students early and often, especially through the SMART Scholarship Program, is producing a new generation of talented researchers and technical experts for the DoD community. To the more vexing problem of ensuring that defense laboratory work is sometimes unappealing to young scientific talent for bureaucratic and practical reasons, Pamulapati stressed that the DoD is striving to reduce the bureaucratic burdens of purchasing equipment and facilitating better collaboration.

> THE TECHNICAL AND INTERDISCIPLINARY CHALLENGES OF ENERGETICS R&D AND MANUFACTURING MAKE IT ESSENTIAL TO LEVERAGE EXISTING DEVELOPMENT PROGRAMS AND REDUCE THE BUREAUCATIC HURDLES TO RETAINING NEW TALENT AND REVITALIZING THE WORKFORCE.

Dr. Steve Beaudoin, Director of the Purdue Energetics Research Center and Professor of Chemical Engineering, described the pivotal role of universities succinctly: “we make the people who make the molecules with the requisite expertise, develop the manufacturing methods in energetics and pharmaceuticals, the process modeling, inline metrology, the developmental methodology.” But three key challenges complicate the ability of the nation’s universities to generate not just the foundational research on which defense energetics is based, but the people qualified to work in such a highly specialized field. Nearly every facet of energetics-related research in the United States depends heavily on foreign students, especially graduate students from China. A second problem – taken up by ***Dr. Peter Chung***, Professor of Mechanical Engineering at the University of Maryland – is that the most important energetics-related research often faces restrictions on publication and dissemination, a dilemma for universities built on principles of openness and collaboration. Young, mostly untenured scholars’ careers depend on the ability to publish openly in peer-reviewed journals, and research under classification may not always be considered for academic promotion. Finally, the interdisciplinarity inherent in the

advanced chemistry, chemical engineering, and manufacturing technology of energetics makes the development of new talent just plain hard. Contemporary researchers require not just foundational disciplinary competence, but often a working knowledge of computer programming, AI, machine learning, and/or or material science, as well. In other words, it is becoming more difficult not just to find and attract new talent, but to grow it in a way that allows young researchers to make progress in the field.

The outlook on broader workforce-related issues across the commercial and manufacturing landscape was brighter. ***Mary Ann Pacelli*** of the Hollings Manufacturing Extension Partnership Program at the National Institute for Standards and Technology described the role of the MEP's public-private partnerships supporting fifty-one cooperative agreement-based extensions centers. Small and medium-sized manufacturers in a diverse range of circumstances across the country gain assistance through the MEP program with technology transfer, process improvement, business development, and product development. The greatest challenges, however, are workforce-related: identifying, recruiting, training, and retaining the high-caliber people essential for process efficiency and outcomes. The extension program leverages diverse resources and expertise on behalf of firms that often struggle in their regional ecosystems, matching talent to enterprise across geographic and other barriers. Pacelli suggested that collaboration between the extension program and smaller firms in the Defense Industrial Base to collaborate with the MEP, not least in cybersecurity-related matters and other areas is sometimes challenging for smaller- and medium-sized firms.

OVERALL RECOMMENDATIONS

The core challenges identified by the conference amplified those from the official and unofficial reports:

1. the absence of coordinated advocacy and direction for the dispersed and uncoordinated energetics enterprise;

2. the challenges of maturing – or "de-risking" – new materials to the point at which they can be produced at acceptable cost and considered for use in systems;

3. an overall business model that is neither efficient nor an asset for inducing commercial actors to lean into the enterprise with more IRAD and production investment;

4. fragile and uncertain supply-chains;

5. and an antiquated and inflexible industrial base poorly suited to the scale of the nation's strategic challenges.

Participants raised other issues, as well, but the foregoing remained at the forefront.

Not all participants shared the same sense of urgency or conviction that the issue merits a strong response. As one participant remarked, stakeholders should be somewhat cautious about "over-selling" an issue that resembles other systemic problems across the defense enterprise, and perhaps across the entire federal government. "[A]t this point," Ashley Johnson said, "it feels like the band has been on tour

for a while and is looking to take requests." But such views were decidedly found among only a minority of attendees. Most speakers and attendees shared the conviction that revitalizing the development and production of cutting-edge energetics was both possible and offered a rare opportunity to enhance U.S. tactical and operational prospects in important ways.

Taken together, conference speakers and discussion yielded the following recommendations.

- *Dedicated leadership at the senior-most, strategic level of the DoD will be essential for breaking down service parochialisms and bureaucratic barriers, and ensuring that S&T, R&D, engineering, and acquisition priorities are intently focused on leveraging advanced energetics to address the operational problem of U.S. inferiority in key weapons categories. The problem itself is common across the services and operating domains, and no single service or office will suffice to address it. The significance of inspired and inspiring leadership of the energetics campaign cannot be exaggerated, and many participants suggested that unitary leadership of the energetics enterprise is the single most important measure for revitalizing the role of energetics in the DoD.*

- *The conference made clear that a baseline operating picture of the entire energetics enterprise – spanning research and development, test and evaluation, acquisition, and the industrial base – is essential. In addition to providing leadership with global awareness of developments and status and stakeholders with a sense of purpose to their efforts, a common information space will link the S&T community more strongly to downstream manufacturing and engineering, and offer visibility into how energetics bear on Service, Joint, and OSD activities and plans. Just as important as indicating what the energetics community is doing, a common operating picture can provide insight into what is not happening, and help to clarify what should be.*

- *Relatedly, there must be a focus on realistic warfare modeling and clarifying the influential role of advanced energetic materials in specific systems and specific tactical scenarios. As Chris O'Donnell put it, "[p]eople don't understand what energetics can bring to capabilities that the [DoD] needs, and there needs to be a lot of energy put into making people understand that 'if you did this…I can have five bombs on the wing vs. two bombs on a wing and I can reduce the number of sorties by three, that is what is going to sell things in the building not 'I've got a 25 percent greater energetic material." Doing so on a widespread basis – and in combination with realistic cost estimates for the capabilities, produced at scale – would address BG Collins' concern not just with enhanced capabilities derived from energetics, but their affordability in the enormous numbers required for a campaign which hold not dozens or hundreds, but thousands or tens of thousands of enemy targets at risk from U.S. long-range, stand-off precision strike.*

- *A virtual mantra for conference participants from across the acquisition spectrum was that if the manufacturing readiness level (MRL) of a candidate material does not outpace its technology readiness level (TRL), then the value proposition for adopting it fails. A major priority – articulated clearly in the OSD and ETC studies – should be to devise mechanisms whereby materials are qualified and made available for system consideration without burdening imposing additional burden on program budgets.*

- *Derivatively, there should be mechanisms or fora whereby members of the broad, upstream acquisition community (6.1-6.4) become intimately familiar with the tactical and operational scenarios and problems against which services' x8s, combat developers, requirements generators, PEOs and PMs are planning. Repeatedly voiced at the conference, by government and industry alike, was the view that familiarity with the practical challenges of warfighting leads to superior S&T/R&D and manufacturing processes, and that the feedback loops connecting them should be continuous and strong.*

- *Similarly, there should be mechanisms or fora whereby members of the broad, upstream acquisition community (6.1-6.4) become intimately familiar with the technologies, processes, standards, and constraints – financial and otherwise – of downstream material processing and manufacturing, especially at scale. Repeatedly voiced at the conference, by government and industry alike, was the view that familiarity with the practical challenges of manufacturing advanced materials at scale leads to superior S&T and R&D, and that feedback loops connecting them should be continuous and strong.*

- *Several conference attendees and speakers spoke to the urgency of drawing into the ecosystem smaller commercial producers who can speak to the costs and practicalities involved in building a more flexible and distributed manufacturing capability. Much discussion at the conference focused on the contracting and partnership mechanisms at the disposal of OSD and the acquisition community to build a flourishing manufacturing base around more modern production concepts, along with a desire on the part of attendees from industry to collapse tradition distinctions between the acquisition budget activities and develop more compressed development trajectories from laboratory to system integration.*

- *The modernization and rationalization of the qualification and testing standards that hamstring more expeditious transition of candidate materials was emphasized by key speakers (Michienzi and BG Collins, among others), but with only tentative solutions proposed, such as revisiting guidelines and standards long outdated or clarifying and eliminated redundancies. Considerable value could be added to the prospects for advanced energetics by implementing concrete measures to shortcut or speed those processes.*