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Flying Laboratories, Prototyping, and Dem/Val: The Crucial Role of Technology Demonstration in Advancing Military Innovation and Its Relevance for the Department of Energy

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The AEIC Scaling Innovation Project

This paper is one in a series of case studies examining the role of demonstration projects in the commercialization of new clean energy technologies.

In the first AEIC report, *A Business Plan for America's Energy Future (2010)*, a New Energy Challenge Program was proposed as a way for the U.S. government to support the demonstration and eventual commercialization of new energy technologies. For the United States to meet aggressive mid-century decarbonization commitments, a technology-inclusive portfolio of clean and innovative technologies, including advanced nuclear and renewable energy systems, zero-carbon fuels, long-duration electricity storage, and carbon capture and storage, must be deployed commercially at scale. The initial demonstration of complex technologies is a well-recognized challenge in the energy sector where first-of-kind risks are difficult to manage and projects must operate in highly regulated commodity markets, many of which may not yet appropriately value their advanced attributes. Because of this, the AEIC and many other experts have concluded the federal government has a role to play in overcoming this so-called demonstration "valley of death."

The AEIC believes there is an opportunity – and a need – to strengthen federal policy frameworks in support of scaling innovation to more effectively accelerate the commercialization of new energy technologies. The case studies in this series look back to notable policy efforts in the past to help inform a new policy agenda for the future.

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Key Recommendations

Technology demonstrations play a crucial role in the U.S. military's innovation process, which has been the driver of innovations ranging from GPS to the internet. Below are nine lessons from the Department of Defense approach to demonstrations that may have relevance for the ongoing policy debate over whether, and if so, how, the federal government should support large-scale energy technology demonstration projects.

1. **Recognize the Critical Importance of Technology Demonstration to Innovation**
   DoD has "fifty words for technology demonstration" – a reflection of the crucial role demonstrations play in DoD's development of mission-essential advanced technology, including commercial technology. Demonstrations conducted in a real-world environment provide insights that are not otherwise attainable.

2. **Know Your Customer**
   DoD's heavy reliance on demonstration and testing is one manifestation of its close focus on the needs of the military customer. This customer orientation is the single most important explanation for DoD's history as a powerful engine of technology innovation. The Department of Energy lacks a similar orientation to commercial customers.

3. **Put Mission over Market Philosophy**
   The controversy surrounding federal support for large-scale DOE demonstration projects reflects competing views on the role of government versus industry. In DoD, mission, not market philosophy, drives decision making.

4. **Give Demonstration Projects Political Cover**
   In contrast to the political interference many DOE demonstration projects have experienced, DoD's innovation system, including its technology demonstrations, is largely insulated from politics. Creation of an independent entity to manage energy demonstration projects would provide a similar level of political insulation.

5. **Limit the Impact of Non-Commercial Requirements and Practices**
   Many past DOE demonstration projects failed because the use of non-commercial requirements and practices undermined investors' confidence in project results. An independent entity could manage energy demonstrations using commercial practices. DoD shields some of its innovation activity, including technology demonstrations, from government-unique requirements and practices to attract commercial firms and accelerate technology deployment.

6. **Give Industry Participants Sufficient Control**
   Although DoD closely supervises its technology demonstrations, industry conducts them and exercises considerable control over the process. Creation of an independent entity to manage energy demonstration projects would give industry participants greater autonomy from unwanted or unhelpful involvement by Congress and the executive branch.

7. **"Demonstrate like you fight" – the Value of Verisimilitude**
   As with soldier training, where the philosophy is to "train like you fight," DoD strives to conduct technology demonstrations under real-world conditions. Paradoxically, the lesson of DoD's "demonstrate like you fight" maxim is that civilian energy demonstration projects should be conducted using commercial practices.

8. **Disseminate Project-Generated Results and Possibly the Intellectual Property**
Dissemination of technical, cost, and other data is a critical function of government-supported demonstration projects. DoD places a high priority on this function where appropriate – e.g., DoD-funded demonstration of innovative commercial energy technologies on military bases. DOE's record on disseminating information from Obama-era demonstration projects was uneven.

9. **Use the Carrot of Government Procurement**
DoD has been a successful innovator because it not only develops and demonstrates new technology, it also procures the new technology, often paying a premium for novel capabilities and higher performance. Government procurement should be used strategically to enhance and expand energy technology demonstration projects.

Introduction

A lack of support for large technology demonstration projects may be the most serious gap in the federal government's clean energy innovation system. While the private sector demonstrates many new technologies at scale on its own, some advanced energy technologies—particularly supply-side technologies that must connect to the electricity grid—are considered extremely risky because of business and technical challenges, regulatory uncertainty, and the sheer amount of capital required. Absent financial support from the government for projects that can demonstrate their viability to potential users and investors, these technologies may be significantly slower to deploy.

Despite the importance of large demonstration projects, however, the U.S. Department of Energy (DOE) has a mixed track record of managing them. DOE has overseen several periods of significant demonstration activity for different technologies, including large nuclear and clean coal in the 1970s and synthetic fuels in the early 1980s. During the Obama administration, the American Recovery and Reinvestment Act of 2009 (ARRA) provided significant funds for DOE to conduct clean energy demonstration projects. Although the ARRA projects fared much better, earlier projects often suffered from poor management, technical failures, and political interference.[1]

Currently, Congress is divided over whether to resume federal support for large-scale energy technology demonstrations, with opponents citing DOE's checkered history in this area (and ignoring the many ARRA successes). While energy policy experts generally favor a resumption of support, even they want to see changes in the way projects are managed and financed to improve their performance and better leverage federal funding.

As policymakers consider this issue, it is useful to look at the innovation system that supports the U.S. military's mission. The Department of Defense (DoD) sees advanced technology as a force multiplier, and DoD has been the driver for many innovations, including radar, the gas turbine/jet engine, satellites, the Global Positioning System (GPS), lasers, computers and semiconductors, artificial intelligence and the internet. Technology demonstrations have long played a crucial role in DoD's innovation process. And although DoD and DOE pursue different approaches to innovation, DoD's heavy reliance on demonstration and testing may offer insights on whether and how DOE should conduct large-scale demonstration projects.

This paper examines the role of technology demonstrations in DoD's innovation system in an effort to capture such insights. Section I describes the various types of DoD demonstrations and where they occur in the R&D process. Section II looks at the functions demonstrations serve in three areas: advanced technology development, weapon system acquisition, and energy management on military installations. Section III draws lessons from DoD's experience that are relevant to DOE and the debate over federal support for energy technology demonstrations. Finally—and distinct from the main focus of the paper—section IV asks whether DoD can play a broader role in demonstrating new energy technologies that have civilian (as well as military) applications, and whether (and where) DoD and DOE might partner on such activities.

I. The Nature and Scale of Demonstration Activity in DoD's Innovation Process

In FY20, DoD will spend about $250 billion, or roughly a third of its total budget, on its Research, Development, Test & Evaluation (RDT&E) and Procurement programs, which together make up what is known as "Acquisition" in the DoD budget. RDT&E accounts for 43% of the acquisition budget, and demonstration and testing account for a significant share of RDT&E.

Table 1 shows how the RDT&E budget breaks down by type of activity. The first three categories—basic research, applied research, and advanced technology development (categories 6.1, 6.2 and 6.3)—are activities undertaken by DoD's science and technology (S&T) enterprise, including industry, universities and DoD's own laboratories. S&T represents 15% of DoD's RDT&E budget. Categories 6.4, 6.5 and 6.7, which account for 78% of the RDT&E budget, are associated with product development for DoD's acquisition programs—largely weapon system acquisition. (Category 6.6, not discussed here, consists of spending on RDT&E management.) Appendix A describes the RDT&E categories in more detail.

Table 1: DoD FY 2020 RDT&E Funding

Category	Percent of Funding
6.1 Basic Research	2.5%
6.2 Applied Research	5.8%
6.3 Advanced Technology Development	7.1%
6.4 Advanced Component Development & Prototypes	25.5%
6.5 System Development & Demonstration	16.0%
6.6 RDT&E Management Support	6.9%
6.7 Operational System Development	36.3%

Source: Congressional Research Service, "Defense Primer: RDT&E," January 3, 2020. Available at: https://crsreports.congress.gov/product/pdf/IF/IF10553. The terms 6.1, 6.2, etc. refer to categories of funding in the RDT&E budget, but the terms are also used to describe the corresponding functional activity (e.g., basic research).

One takeaway from Table 1 and Appendix A is that demonstration and testing occur throughout much of the RDT&E process. At the category 6.3 stage, advanced technology development, the activity consists of *concept* demonstrations and proof-of-principle demonstration and prototyping of technologies. Examples include the prototypes developed and tested by the Defense Advanced Research Projects Agency (DARPA). At the category 6.4 stage, advanced component development and prototypes—also known as demonstration and validation—the emphasis is on demonstrating the maturity of components and subsystems in a "relevant environment" prior to their integration into a weapon system. "Dem/Val," as it is often called, frequently involves a competition among different designs. Category 6.5 activity, system development and demonstration—also known as engineering and manufacturing development (EMD)—emphasizes the demonstration and testing of systems and subsystems in an "operational environment." Category 6.5 activity is designed to support a formal decision by DoD to begin producing a weapon system.

A second takeaway is the budgetary significance of technology demonstrations.[a] The three categories of activity in which technology demonstrations figure most prominently (6.3 to 6.5) account for nearly half of DoD's RDT&E budget. Focusing just on activity in categories 6.4 and 6.5, which corresponds most closely to large-scale DOE demonstration projects, the share is 42%.

II. Functions of Technology Demonstrations

The functions of technology demonstrations vary somewhat by mission area. Three areas are discussed below: advanced technology development, weapon system acquisition, and installation energy management.

1. Advanced Technology Development

Building on the basic and applied research elements of DoD's S&T triad, advanced technology development (category 6.3) serves to advance the maturity of new and disruptive technologies and help them transition from the laboratory to the field. Over time, DoD has put more emphasis on technology demonstrations as a way to accomplish these ends. Category 6.3 demonstrations (like advanced technology development more generally) are *opportunity-driven*: the goal is to show a potential military customer (e.g., the Navy) the value of a new technology or system that the customer may not know it needs. DARPA activities largely fit this description.

A key function of category 6.3 demonstrations is to *determine whether a new technology has military utility*. Because advanced technology development is opportunity- rather than requirement-driven, it must be shown to provide some operational advantage, and demonstrations serve as the primary way to do that.

A closely related function of category 6.3 demonstrations is to *advance potentially disruptive technologies* without having

a The military has many terms to describe demonstration and testing, depending on what is being tested and where in the RDT&E process it occurs. Strictly speaking, a technology demonstration occurs relatively early in the process – after concept demonstration but before system demonstration and production prototyping. However, for ease of exposition, this paper uses "technology demonstration" to refer to the full range of demonstration activities. In addition to technology demonstrations, which are typically conducted by contractors, DoD has a highly formalized test and evaluation (T&E) process. Operational T&E, or OT&E, is conducted internally and overseen by an independent director of OT&E who reports directly to the secretary and deputy secretary of defense. An analysis of the T&E process is outside the scope of this paper.

to make the commitment associated with an acquisition program (category 6.4 and beyond). A classic example is DARPA's efforts during the 1980s to develop a high-altitude, long-endurance unmanned aerial vehicle (UAV) for intelligence, surveillance, and reconnaissance (ISR) missions. By 1990, DARPA's 740-pound Amber aircraft, equipped with sophisticated sensors for photographic and intelligence missions, was recording flights of more than 38 hours.[2]

The Amber flights were the culmination of years of technical advances, many of them involving prototypes and technology demonstrations. From 1980 to 1982, DARPA's TACIT RAIN program investigated a host of ways to keep UAVs aloft for days or weeks, including nuclear-, solar- and microwave-powered motors, as well as exotic materials and designs. According to a study led by DARPA historian Richard Van Atta, "these were unfettered, technology-push studies seeking to generate new ideas." DARPA's work on enabling technologies, such as miniature sensors, anti-jam data links, and an integrated communications-navigation system, went back to the early 1970s.[3]

Amber's success also helped, eventually, to *overcome internal resistance* to the new technology—another function of 6.3 demonstrations. The Army and Navy wanted to see more short-range, mini-UAVs that could be forward deployed, while Amber was conceived as a larger system (size was necessary for long-duration, high-altitude flight and to accommodate sensor payloads) that required proficient operators and prepared landing sites behind the combat zone. The Services dismissed Amber as a science project, while DARPA faulted the Services' inability to envision new operational concepts. This impasse led to Amber's termination, although the program was revived after the first Gulf War revealed serious deficiencies in U.S. airborne ISR, and quickly led to the deployment of the game-changing Predator and Global Hawk UAVs.[4]

Whether or not a new technology faces resistance, a demonstration serves as a way to *gather the views of end users and other stakeholders and experts*. This process yields valuable information as to a technology's operational utility and where additional research may be needed. DARPA often employs demonstration-based grand challenges to bring together disparate experts and organize them around a specific goal. For example, DARPA's "Colosseum," a virtual wireless arena in which teams compete to transmit data amid simulated congested radio traffic, challenged innovators to produce breakthroughs in a set of complementary fields.

In recent decades, demonstrations have become a way to *get mature technologies into the field more quickly*, bypassing the formal acquisition process. In 1994, DoD established the Advanced Concept Technology Demonstration (ACTD) program, which provided for streamlined management and oversight, and early participation of the user community. It also allowed for operational prototypes to be sent to combatant commanders for experimental use. (One of the first beneficiaries was the Predator, which was deployed in Bosnia less than two years after DARPA's program was revived.) Although some of the acronyms have changed—ACTDs are now Joint Capability Technology Demonstrations, or JCTDs—the use of demonstrations to field technology more quickly remains a priority: since 2012, DoD has established seven offices to further innovation through rapid prototyping, demonstration, and experimentation.[5]

2. Weapon System Acquisition

The acquisition of a weapon system is a lengthy and complex process, structured around a series of formal milestones and DoD approvals. Although the process is often criticized for taking too long and costing too much, new weapon systems require highly advanced technologies, and system designs often push the performance edge. In contrast to the opportunity-driven demonstrations described above, technology demonstrations at the acquisition stage (category 6.4 and beyond) are requirement-driven: they are designed to help a military customer who recognizes the need for a new capability or system but does not know the best way to achieve it. As two RAND experts concluded in a 2009 study of prototyping, "Demonstrations in realistic operational environments consistently produce information about system performance not otherwise obtainable, and fabrication of a prototype … exercises skills that design activities alone cannot."[6]

The primary function of weapon system demonstrations is to *identify and reduce technical risk*. The military officers who set the requirements for a new system often lack a sophisticated understanding of what the technology can and cannot do in a reasonable time frame. By building and testing representative items and systems, contractors can resolve known technical uncertainties and identify uncertainties they did not anticipate, or what military planners refer to as "unknown unknowns."[7]

Box A describes the famed Dem/Val contest between Lockheed and Northrop over the Advanced Tactical Fighter (ATF), which became the F-22 Raptor, the U.S. military's first stealth fighter aircraft. The ATF represented a technological leap over earlier fighter jets, and the seven companies that bid to compete in the Dem/Val phase of the ATF program were told to focus their proposals on risk reduction and technology development plans rather than on specific aircraft designs. The entire program was oriented toward "proving technologies and concepts, refining requirements, and reducing risk."[8]

Box A: The Advanced Tactical Fighter Program

The ATF was a concept development and Dem/Val program that the Air Force undertook as part of its development of a fighter jet to replace the F-15 and counter a new generation of Soviet aircraft. The program is remembered for its successful demonstration of stealth technology and integrated avionics on a supersonic platform; the resulting F-22 Raptor is considered by many to be the best U.S. air superiority fighter ever produced.

The Dem/Val phase of ATF development began in October 1986, when the Air Force selected Lockheed and Northrop from among seven bidders to undertake a 50-month effort that would culminate in the flight test of their respective prototype air vehicles (PAVs), designated the YF-22 and the YF-23. Losing bidders Boeing and General Dynamics teamed with Lockheed, and McDonnell Douglas paired with Northrop. Each team built two copies of its PAV—one each to fly with the competing engines being developed by General Electric and Pratt & Whitney under a parallel program.

The Dem/Val phase of the ATF program consisted of three principal activities:

- **System specification development:** In addition to testing what was technically feasible, the contractors conducted "trade studies" of how specific performance requirements affected cost, weight, and technical risk. This enabled the Air Force to continually refine its requirements.
- **Integrated avionics:** The ATF called for a central computer network able to integrate multiple streams of data (radar, communications, flight controls, electronic warfare) onto a single cockpit display. This capability—the ATF's most ambitious requirement—required a core processing speed 100 times that of earlier fighters,

demonstration of which entailed an unprecedented software development effort and the use of an avionics flying laboratory.

- **PAVs:** The air vehicles were built not as operational prototypes but to demonstrate that the projected performance was achievable and the technology was mature. The Lockheed team, supported by 650 subcontractors in 32 states, conducted 18,000 hours of wind-tunnel testing to meet the requirements for supercruise capability (sustained speed of Mach 1.5 without use of afterburners) and high maneuverability. At a point when designs were to have been "frozen," the team spent three months developing a new one.

After 50 months of Dem/Val activity, including four months of flight testing, the teams submitted their proposals for full-scale development in late 1990. In April 1991, the Air Force announced Lockheed's YF-22 with the Pratt & Whitney engine as the winner.[9]

Technology integration is the biggest source of risk in weapon system development and one that large-scale demonstrations are uniquely suited to address. Flight testing of PAVs was not initially part of ATF Dem/Val; the Air Force added it only after concluding that the expense, which would reduce the number of competitors it could support, was justified. Contractors reached a similar conclusion with respect to integrated avionics. The avionics ground demonstrations began with a prototype of the core processing system and added progressively more functions and interfaces. Both teams then opted to perform flight demonstrations using a dedicated avionics flying laboratory (Lockheed used a Boeing 757 outfitted for research and Northrop a modified BAC 111) even though the Air Force's solicitation had not specified one.[10]

A second, closely related function of weapon system demonstrations is to *explore tradeoffs between cost and system performance*. Ambitious performance requirements are usually achievable at some price but even DoD is budget constrained; by allowing the contractor to isolate and quantify the cost drivers, demonstrations help the military customer evaluate and refine its system requirements.

For the ATF contractors, a large part of their early work involved identifying requirements that had marginal operational value but imposed high cost or risk. Lockheed's team leader summed up the process:

> Many initial "requirements" which seemed to be no problem turned out to be major drivers of weight and/or cost…. [Eventually] the appropriate [Air Force] generals got involved, and based on trade study data, adjusted the requirements to achieve the acceptable balance of system performance and cost, with weight as a surrogate for cost….[11]

Among other things, the Air Force deleted the requirement for side-looking radar and downgraded infrared search and tracking from a requirement to a goal.

Demonstrations can serve to tighten as well as relax performance requirements. The Space Fence Ground-Based Radar is a planned facility on Kwajalein Atoll in the Marshall Islands that will dramatically improve the way the Air Force identifies and tracks objects in low-earth orbit. A system-level prototyping effort helped persuade the Air Force that the use of one rather than two radars was feasible and that the single radar could be 15% smaller than specified.[12]

Performance requirements are not the only driver of costs. The production and "sustainment" (operation and support) stages account for most of the life-cycle costs of a weapon program, and thus improvements to those activities can have huge budget implications. For the Future Vertical Lift (FVL) program, which will replace the Army's family of military helicopters with more advanced versions, the Army plans to use production prototypes to identify ways to reduce the cost of manufacturing aircraft structures and subsystems. Flying technology demonstrators are being used, among other things, to help develop design standards and systems that are common to the entire FVL fleet, facilitating interoperability and reducing dependence on specific vendors for sustainment.[13]

A third function of weapon system demonstrations is to *leverage competition*. Contractors participate in a demonstration process to increase their odds of being selected as the prime contractor. If the process is competitive, contractors are more likely to invest their own money, often outspending DoD.[b] A competitive demonstration can also incentivize contractors to reveal their latest technical advances and/or features to reduce life-cycle costs—particularly those that differentiate their system from the competition.

DoD actively exploits this dynamic, canceling demonstrations that do not attract multiple bids. The Army recently delayed its solicitation for the Dem/Val phase of its program to replace the Bradley Fighting Vehicle (known as the Optionally Manned Fighting Vehicle, or OMFV) because it received only one prototype submission. The lack of submissions was also a red flag, as the Army chief of staff acknowledged when he said publicly that the Army's "aggressive timeline did not permit industry to meet the requirements."[14]

3. Installation Energy Management

While most of the demonstration and testing activity it sponsors occurs as part of advanced technology development and weapon system acquisition, DoD uses demonstrations to advance other mission objectives as well. For example, after estimates showed that DoD would need to spend $20 billion to remove unexploded ordnance buried on former military training sites, DoD spent a decade developing a technology that could "distinguish bombs from beer cans." Following a multi-year DoD initiative to demonstrate and validate the new technology on increasingly complex sites, contractors are now using it.

Demonstrations also figure prominently in DoD's strategy for managing energy needs at military installations. With 300,000 buildings and two billion square feet of building space, DoD's 500-plus "fixed installations" (permanent military bases as opposed to those in forward locations) are major energy consumers: DoD's annual utility bill is $3.5 billion. Energy security is an even bigger challenge: fixed installations rely almost entirely on the commercial grid, and because of their outlying locations, bases are disproportionately affected by the growing number of major outages in the United States. DoD's Environmental Security Technology Certification Program (ESTCP) is using bases as test beds to demonstrate advanced technologies that can address these challenges (Box B).

b In the ATF program, the Air Force awarded each team $691 million to perform the Dem/Val phase. The Lockheed team invested $675 million of its own money and the Northrop team spent almost as much. David C. Aronstein, Michael J. Hirschberg, and Albert C. Piccirillo, *Advanced Tactical Fighter to F-22 Raptor: Origins of the 21st Century Air Dominance Fighter* (Reston, VA: American Institute of Aeronautics and Astronautics, 1998), pp. 103 and 164.

Box B: ESTCP's Installation Energy Test Bed

DoD created ESTCP in 1995 to fund the demonstration of innovative environmental cleanup technologies on its military bases; the initial focus was treatment of contaminated groundwater. Armed with hard data from these demonstrations, technology developers were able to transition their technologies to market, where DoD could purchase them as a commercial customer. Nearly all the groundwater cleanup technologies now in commercial use received funding from ESTCP.

In 2009, ESTCP established an Installation Energy (now Energy and Water) program to perform a comparable function for building energy technologies, which (like environmental cleanup technologies) face major impediments to commercialization.[c] As the country's largest real property owner, DoD has an interest in seeing these technologies transition to market so that it can purchase them commercially. DoD facilitates the process of commercialization by serving as a test bed for the demonstration and validation of technologies that meet its needs.

ESTCP's test bed is "distributed"—i.e., demonstrations take place on individual bases—which allows the testing to occur under real-world conditions with involvement by staff whose buy-in is critical. A competitive process is used to select the technologies to be tested; ESTCP then funds the developer to conduct rigorous testing and assessment of the performance and life-cycle costs of the technology while addressing DoD-unique security issues. The developer must also provide guidance and design information for future deployment of the technology across installations.

ESTCP has funded 156 completed or ongoing demonstrations of largely pre-commercial technologies—i.e., technologies that are "out of the garage but not yet on the shelf." Although new funds are going principally to advanced microgrid and energy storage technologies, ESTCP has previously supported demonstrations in four additional areas: (1) components to improve building energy efficiency, such as advanced lighting controls, high performance cooling systems, and technologies for waste heat recovery; (2) building energy management and control systems; (3) tools and processes for design, assessment and decision-making on energy use and management; and (4) onsite generation, including solar photovoltaics (PV), geothermal, waste-to-energy, and building-integrated systems.

c I was directly involved with ESTCP and the Installation Energy Test Bed from 2009 to 2012. As deputy undersecretary of defense for installations and environment, I was responsible for overseeing ESTCP and made the Installation Energy Test Bed a priority.

DoD's demonstration of advanced energy technologies serves some of the same functions as category 6.3 and weapon system demonstrations—but in a different context: As described in Box B, ESTCP demonstrations are designed to advance the commercialization of technologies so that DoD can purchase them in the commercial market (by contrast, for weapon systems, DoD *is* the market). That makes cost considerations far more important.

To elaborate, under its traditional innovation model, where DoD invests in new capabilities that will give warfighters a performance edge, cost is secondary at least until the production stage. By contrast, when it comes to investment in DoD's military-base infrastructure—including advanced energy and environmental technology—cost considerations are critical from the beginning, as Jeffrey Marqusee, who ran ESTCP for many years, describes:

> …DoD is highly sensitive to both performance and cost when it comes to [facility] energy technology. DoD's mission is national defense, not energy efficiency or environmental protection; as a general matter, DoD does not do something differently just because it's green—the technologies have to be cheaper and better than the technologies and methods that DoD is currently using.[15]

Like weapon system demonstrations, the energy technology demonstrations carried out on military bases serve primarily to *identify and reduce risk*. Advanced energy technologies do not move directly from small-scale development to the market; vendors need to demonstrate their technologies at scale, under realistic conditions. Whereas opportunities for such learning-by-doing are rare in the energy sector, DoD, with its large energy needs and deep culture of demonstration and testing, represents a unique resource.

As one example, General Electric's (GE) commercial microgrid control system uses dynamic real-time algorithms and an energy management dashboard to control complex interactions between electrical demand, heat and power generation, energy storage, and power distribution. GE perfected the system during a three-year, ESTCP-supported demonstration at 29 Palms Marine Corps base in the Mojave Desert, leading directly to the product's commercial release.

The GE demonstration is one of more than 30 microgrid demonstrations that ESTCP has funded at bases around the country; in addition, some bases have funded their own demonstrations. The performance of a microgrid is affected by site-specific factors such as the predictability of the load and the variability of intermittent renewable energy. On-base demonstrations give vendors the real-world experience they need to validate and refine their engineering designs.[d] Demonstrations also allow potential buyers to analyze how the systems perform from an economic and technical perspective.[e]

The sheer number and variety of DoD bases facilitates energy technology demonstrations in other ways as well. For example, 3M developed a film that can redirect up to 80% of the natural light from a window to interior space as far as 40 feet away. With ESTCP support, the company installed the window film in six DoD buildings, scattered across three climate zones (the buildings were selected in part based on the availability of "control" space that would allow for a side-by-side comparison). After spending months resolving a

d Microgrid "vendors" is a catch-all term that includes firms that build the components used in microgrids (controllers, switches, batteries, communication devices, etc.), firms that design and build the microgrid system but do not manufacture components, and firms that do both.

e For an analysis of the business case for microgrids on military bases, see Jeffrey Marqusee, Craig Schultz and Dorothy Robyn, "Power Begins at Home: Assured Energy for U.S. Military Bases," Noblis, January 2017. Available at: https://www.pewtrusts.org/~/media/assets/2017/01/ce_power_begins_at_home_assured_energy_for_us_military_bases.pdf.

problem with light glare that the demonstration revealed, 3M released its product commercially.

A second function of DoD's energy technology demonstrations is to *disseminate information about the performance and cost of the technology*. ESTCP requires each project team to produce a detailed report on the results of the demonstration, and the reports are publicized. By contrast, the results of vendor-funded demonstrations are almost never made public. The dissemination of performance and cost data helps inform other technology developers and investors, stimulating investment and competition on the supply side. On the demand side, it addresses one of the major impediments to customer adoption.

To elaborate, new building energy technologies have been slow to deploy in part because potential users lack information about how the technologies perform under real-world conditions. For example, component technologies are highly cost sensitive: to be of value, a light-emitting diode light fixture or a condensing boiler must provide the same or better service at reduced life-cycle cost than traditional technologies. Life-cycle cost, in turn, depends on factors such as the level of skill required to operate the technology, maintenance requirements, and tenant acceptance. To evaluate life-cycle cost, potential users need performance data that addresses these and other variables.

The same is true for new systems approaches to energy control and management, which integrate component technologies across an entire building or campus of buildings. Although these approaches promise dramatic gains in energy performance, their effectiveness depends on a host of conditions, such as the nature of building operations (e.g., working hours of 9-to-5 versus 24/7), load variability, and human interactions, to name a few.

Demonstrations such as those that take place on military bases are one of the few ways to collect this type of granular information. Large-scale energy storage systems face some of the same impediments to broad adoption as microgrids: electricity markets are volatile, the technology is new and costly, and there is no independent data on its technical and economic performance. ESTCP's energy storage demonstrations are collecting performance data that will allow would-be buyers and investors to assess the risks and value of these technologies. And because of the scale of DoD's installation footprint, these demonstrations will provide a data base that covers every energy market in the country.[f]

DoD's energy technology demonstrations yield this granular information in part because they *allow for direct interaction and collaboration with end users and other stakeholders*. Tim Tetreault, who manages ESTCP's Energy and Water program, describes the benefit to the people who operate military bases:

> DoD staff and O&M contractors often get hands-on experience operating and maintaining the new equipment. These [individuals] tend to be conservative in their outlook toward new technology, as their primary mission is to keep energy equipment/systems operating.… Getting hands-on experience is far more convincing [to them] than a technical report or sales pitch from a vendor.[16]

Building occupants can be important stakeholders as well. ESTCP supported a project that installed electrochromic windows—windows that tint electronically to reduce solar-

f In addition to field demonstrations, ESTCP is funding technology developers to model full-scale prototypes of new stationary energy storage technologies and gather data on their technical and economic performance under operational conditions. ESTCP has released the results of the first phase of this project.

heat gain—on three sides of a building at a Marine Corps base in San Diego. In addition to testing the technology at scale, the demonstration assessed occupant acceptance.

Regulators and local utilities are critical stakeholders for some technologies. ESTCP funded the demonstration of a new waste-to-energy system, Infoscitex's (IST) Green Energy Machine, at Edwards Air Force Base, in California. Unforeseen complications with state and local permitting, along with an unresponsive local utility provider, significantly delayed the project and required IST to narrow its scope.[g] The project underscored just how many stakeholders need to be involved when a new energy technology has environmental implications.

III. Lessons from DoD's Approach to Technology Demonstrations

Any effort to draw lessons for DOE from DoD's approach to innovation must start by acknowledging fundamental differences between the two agencies. First, DoD develops technology for its own use: supply and demand are under one institutional roof, to use John Alic's phrase. DOE faces a more difficult challenge because the technology it develops must ultimately compete in commercial markets. Second, DoD not only develops new technology, DoD procures the new technology, often paying a premium for its performance-enhancing capability. DOE has no such leverage. Third, DoD demonstrations are focused on technical performance, while DOE demonstrations must also show that a technology is commercially viable. Commercial viability (which includes other "ilities" such as scalability and reliability) is harder to prove than technical viability, particularly if the technology must be integrated into an existing system such as the electricity grid.

These differences may limit the value of DoD as an innovation model for DOE, but they do not negate it. For one thing, DoD institutions and methods can be adapted to non-defense missions. For example, DARPA's approach to advancing breakthrough technologies with potential military value has been modified for a commercial environment by DOE's highly regarded Advanced Research Projects Agency–Energy (ARPA–E), among other civilian agencies. Moreover, DoD innovates even in those parts of its operation, such as infrastructure (military bases), that are business-like in nature and dependent on commercial technology and commercial markets. Thus, ESTCP, much like DOE, conducts demonstrations to facilitate the transition of technology to the commercial market.[h] Finally, DOE's approach to innovation is strong on "technology push" and weak on "market pull," resulting in low uptake of its R&D by commercial firms. Thus, DoD's customer-pull innovation model represents the direction in which DOE should be looking to move.

With that qualified caveat in mind, the next section highlights nine insights, or lessons, from DoD's approach to technology demonstrations that may have relevance for DOE or for

g Although Infoscitex (IST) obtained an experimental exemption from the local air quality regulator with relative ease, the local utility (Southern California Edison) did not respond to IST's request for an interconnection agreement, forcing IST to install a load bank to receive electricity generated by the Green Energy Machine (GEM). Load balancing issues associated with the load bank put GEM's operation at odds with state air quality standards, and the placement of GEM next to the Edwards Air Force Base landfill raised concerns with state and local solid waste regulators."
Demonstration and Validation of a Waste-to-Energy Conversion System for Fixed DoD Installations," ESTCP Project EW-200932, August 2013. Available at: https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Distributed-Generation/EW-200932.

h The comparison is not perfect. ESTCP demonstrations are much smaller in scale than the controversial DOE demonstration projects. In addition, ESTCP is seeking to meet the needs of the military customer, whereas DOE is trying to anticipate the harder-to-gauge needs of commercial customers.

policymakers debating federal support for commercial-scale energy technology demonstration projects.

1. Recognize the critical importance of technology demonstration to innovation

Like cold-climate populations that are said to have "fifty words for snow," DoD has many terms for demonstration and testing—a reflection of the crucial role these activities play at many points in the innovation process. Whether the demonstrations are opportunity-driven or requirement-driven (or a combination), they provide the kind of insights that come only from building and testing representative items and systems. As the RAND experts put it, "Demonstrations … consistently produce information about system performance not otherwise obtainable..."

The crucial role of demonstration and testing in military innovation was the starting point for this paper but it is also a concluding lesson. As policymakers prepare to debate whether DOE should be allowed to resume support for large-scale energy technology demonstration projects, DoD is, if anything, ramping up its already extensive reliance on technology demonstrations.

DoD has not consistently invested in ATF-type technology prototypes that can undergo extensive testing before procurement contracts are awarded—perhaps the closest analog to a commercial-scale DOE demonstration project. Although competitive "flyoffs" were common in the 1940s and 1950s, when the military was developing highly sophisticated supersonic jet-powered fighter aircraft, in the 1960s, Defense Secretary Robert McNamara substituted "paper competitions" to reduce the expense of funding both the development and prototyping of new systems. However, some of those efforts failed to produce systems that met the military's requirements, contributing to a renewed reliance on prototype competitions and flyoffs.[17] The problem-plagued F-35 Joint Strike Fighter program can be seen as an exception to this proven approach. While DoD did compete the coveted contract—Lockheed Martin bested Boeing in the multiyear design and flyoff contest—the plane was allowed to enter production before prototype testing was complete, a controversial decision that contributed to major cost overruns and program delays.[18]

Not all DoD demonstration activity is large in scale, as section II of this paper shows. One DoD expert observed that "the issue is less scale than that the demonstration occurs in real-world conditions, in collaboration with end users and other stakeholders." Smaller-scale demonstrations can lay the groundwork, and sometimes eliminate the need, for larger-scale projects. While an analysis of DOE's entire portfolio is outside the scope of this paper, anecdotal evidence suggests that small demonstration projects are likewise underfunded. If Congress renews support for large-scale demonstration projects, it should ensure smaller-scale projects receive additional support as well.

2. Know your customer

DoD is unique among federal agencies in developing technology for its own use. The tight link between technology spending and military requirements is the single most important explanation for DoD's strong record of innovation. Warfighter requirements impose a discipline on DoD's pursuit of advanced technology comparable to what private firms face in seeking to satisfy commercial customers.

DoD's extensive reliance on technology demonstrations is one manifestation of this customer-pull approach to innovation. DoD is a demanding, data-driven customer, and its relentless demonstration and testing of prototypes and systems ensures that they will function effectively for warfighters in an operational environment. Even Dem/Val programs such as ESTCP, which focus on accelerating commercial technology development, do so to meet the needs of the military customer, based on a deep understanding of those needs.

DOE has long been criticized for an approach to innovation that is more technology-push than customer-pull. This approach reflects the dominance of DOE's Office of Science as well as DOE's weak connections to commercial customers. To be fair, ARPA–E and DOE's applied R&D offices have more of a market orientation, but the department as a whole shies away from talk of commercial applications.

Many of the problems that have plagued DOE demonstration projects reflect the lack of customer orientation, and several of the lessons discussed below echo this theme. Next to Lesson #1 (on the critical link between technology demonstration and innovation), the need to know one's customer is the most important lesson DoD has to offer DOE and its congressional overseers.

3. Put mission over market philosophy

The controversy surrounding federal support for large-scale energy technology demonstrations reflects competing views on the role of government versus industry. Most energy economists would agree that industry is underfunding such projects in part due to the presence of two classic market failures: the negative environmental spillovers that occur because carbon emissions are not priced, and the spillover of knowledge that, while good for society, limits entrepreneurs' ability to fully appropriate the benefits of their discoveries. However, skeptics warn that federal support for an activity so far "downstream" in the innovation process amounts to government picking winners and losers.

In the defense community, by contrast, the concept of "market failure" is rarely debated. Demonstration projects and other DoD "interventions" in the defense market are not controversial because DoD *is* the market for weapon systems. A program like ESTCP, which facilitates the productization of technologies that DoD wants to buy commercially, is potentially more suspect. But even there, the attitude in DoD is that markets are not perfect, and the military should act to accelerate or facilitate market forces to meet its commercial needs. (The current administration has actively maintained ESTCP's energy program, a creation of the last administration, although it did narrow its scope.) In short, mission, not market philosophy, drives decision making.

4. Give demonstration projects political cover

Those skeptical of large-scale DOE demonstration projects typically counter the market-failure argument by pointing to a history of "government failure." They invariably cite *The Technology Pork Barrel*, an account of how politics undermined the design and operation of a half dozen large demonstration projects in the 1970s and 1980s.[i] In addition to keeping white elephants alive because they provided local economic benefits, political actors influenced where projects were sited and when they were undertaken. For example, during the energy crisis of the 1970s, Congress pressured DOE to demonstrate clean coal technologies before they were sufficiently mature. Although DOE demonstration

i Cohen and Noll studied six projects funded by DOE, the U.S. Department of Transportation, and the National Aeronautics and Space Administration. They concluded that "the goal of economic efficiency – to cure market failures in privately sponsored commercial innovation – is so severely compromised by political forces that an effective, coherent national commercial R&D program has never been put in place." Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel* (Washington, D.C.: The Brookings Institution, 1991).

projects funded during the Obama administration amassed a far better track record, the pork-barrel image persists.[j]

Military technology development has experienced its share of waste and mismanagement, and DoD is hardly immune from distributive politics. However, DoD's innovation system is largely insulated from political influence, which a 2009 report on clean energy innovation traces to the power of a compelling mission:

> …at least while the Cold War continued, the deeply felt threat posed by the Soviet Union kept the military innovation system largely on track, creating a compelling sense of mission in government and, if less urgently felt, in defense firms and universities.[19]

The report cites close scrutiny by the U.S. Government Accountability Office (GAO) and other watchdog institutions as another reason DoD's innovation process has been able to remain politically insulated.

Among other virtues, the insulation of innovation from politics allows for greater risk taking. The high failure rate of DARPA projects has long been seen as a positive indicator of the agency's necessarily ambitious ("DARPA-hard") agenda, and DoD tells its Dem/Val contractors that an absence of failure is a sign that they are not taking enough risk. By contrast, many in Congress treated the failure of the solar startup Solyndra as an indictment of DOE's entire loan guarantee program, even though the program came out in the black overall. If anything, the high success rate of DOE's loan guarantee program suggests that its risk profile was too conservative.

To succeed, large demonstration projects need political cover. DOE's mission will probably never be as compelling as DoD's, which has the advantage of being written into the Constitution. Structural separation is another way to give demonstration projects political cover (among other benefits). Congress created the Synthetic Fuels Corporation (SFC) in 1980 both to assist projects that produced synthetic gas and fuel from coal, and, more controversially, to subsidize domestic production to achieve a target production level by a date certain. Although the SFC foundered when oil prices dropped—proving the folly of government-set production targets—its structure provided considerable insulation from congressional pressure.[20] While policymakers can debate the best approach, DoD's example makes clear the value of insulating innovation from political influence.

5. Limit the impact of non-commercial requirements and practices

"Government failure" is not limited to political interference. According to the Congressional Budget Office's 2014 analysis of federal support for innovation, "At least part of the problem with large federal demonstration projects…is the fact that federal agencies are not usually equipped to oversee the commercial and business aspects of new product introduction."[21]

> The commercial success of [products being demonstrated] often depends less on the novel technologies they incorporate and more on product design and broader business factors. In those areas, federal employees generally have no special expertise; indeed, the very mission of many federal agencies often militates against such considerations.

In his analysis of why many earlier DOE demonstration projects failed, John Deutch faults DOE's inability to manage projects using commercial practices, which undermined potential investors' confidence in the results. Deviations from

j For a rigorous analysis of the Obama-era projects, see David M. Hart, "Across the 'Second Valley of Death': Designing Successful Energy Demonstration Projects," Information Technology & Innovation Foundation, July 2017. Available at: http://www2.itif.org/2017-second-valley-of-death.pdf.

commercial practice included the government's imposition of federal acquisition regulations, known as "the FAR"; direct DOE involvement in the design of, and payment for, the cost of a demonstration plant; a government staff that lacked sufficient technical and financial expertise; and congressional interference. Deutch also highlights the absence of clear agreement on the purpose of technology demonstrations, leading to the adoption of multiple, competing objectives in addition to technology deployment (e.g., reducing oil imports, increasing jobs, and lowering energy costs for consumers).[22]

DoD faces some of the same challenges. Its involvement in the demonstration process is obviously not a problem, since DoD is the customer, and the direct cost of FAR requirements simply gets rolled into the price of the weapon system. However, idiosyncratic government requirements and restrictions such as the FAR impose large indirect costs, even as they facilitate oversight: most significant, many commercial firms will not do business with the Pentagon, which limits DoD's access to advanced technologies critical to developing future weapon systems.[23]

This problem became acute at the end of the Cold War—defense budgets dropped just as civilian products were becoming both less expensive and more sophisticated than their military counterparts—and DoD has tackled it ever since with mixed results. The ACTD (now JCTD) process was an early effort to exempt certain technology demonstrations from the FAR and other burdensome oversight, and it continues to function today. More recently, DoD has increased its use of "other transactions authority" (OTA), which substitutes commercial contracting for FAR contracting, for rapid prototyping and early stage demonstrations, among other purposes.[k]

In the short run, creation of a DOE version of DoD's ACTD/JCTD office would allow for more commercial management of energy technology demonstration projects. Longer term, such projects need a level of autonomy beyond what is appropriate for DoD technology demonstrations. While an analysis of alternative options is beyond the scope of this paper, one option worth noting is Deutch's proposal to create a quasi-independent Energy Technology Corporation (ETC), modeled after the SFC, to select and manage all (civilian) energy technology demonstration projects. To more closely simulate commercial conditions, the ETC would provide indirect financial incentives rather than DOE's traditional direct payments for plant construction.[l]

k OTA contracts are not new, but they were traditionally reserved for R&D and/or prototyping, where failure is contemplated and considered acceptable. Recently, in addition to significantly increasing their use for those purposes, DoD has begun using OTA contracts for production activities, which some procurement experts worry is a recipe for failure. See Frank Kendall, "The New Other Transactions Authority Guide: Helpful, But Not Enough," *Forbes*, January 3, 2019. Available at: https://www.forbes.com/sites/frankkendall/2019/01/03/the-new-other-transactions-authority-guide-helpful-but-not-enough/#4dee300e41cf.

l The ETC would be able to finance projects using a variety of indirect incentives, including guaranteed government purchases, production payments, loans and loan guarantees, and tax credits. It would also be able to replace non-germane FAR requirements with commercial practice and hire and compensate a staff with the technical and financial expertise needed to administer the program. Because it would receive one-time funding, the ETC would avoid the annual budget process and congressional hearings that encourage political interference. An alternative to ETC would be an independent office inside DOE that is charged with managing and financing demonstrations. In this context, there is also renewed discussion of the concept of a "clean energy deployment administration" (CEDA), which would be an independent federal financing agency designed to leverage private investment to accelerate U.S. clean energy deployment. Although CEDA would serve an important function, as currently designed it would not be a substitute for an ETC-type entity.
John M. Deutch, "An Energy Technology Corporation Will Improve the Federal Government's Efforts to Accelerate Energy Innovation," The Hamilton Project (The Brookings Institution), May 2011. Available at: https://www.hamiltonproject.org/assets/legacy/files/downloads_and_links/05_energy_corporation_deutch_paper_1.pdf.

6. Give industry participants sufficient control

Although DoD funds and closely oversees its technology demonstrations, industry conducts them and exercises considerable control over the process. The role of contractors in the ATF program was typical:

Every aspect of Dem/Val was oriented toward proving technologies and concepts, refining requirements, and reducing risk. The specific risk reduction activities and plans were formulated by the contractors, not the government. The Air Force specified goals for the Dem/Val phase, but the contractors were given the freedom to determine how best to achieve those goals.[24]

ESTCP demonstrations are likewise dominated by private participants. By design, most ESTCP projects are led by a private firm—specifically one with the motivation and capacity to take the technology to market. Industry-led teams are responsible for designing and carrying out project assessments, subject to ESTCP oversight and guidance.

Creation of an ETC-type structure would give industry participants in energy technology demonstration projects greater autonomy from unwanted or unhelpful involvement by Congress and DOE. This is important because even highly regarded government technical experts can unwittingly steer a demonstration project in a non-commercial direction. To take a recent example, the DOE laboratories were active participants in the SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security) project, which was led by DoD in collaboration with DOE and the Department of Homeland Security. SPIDERS demonstrated ever more complex microgrids in sequence at three military bases in Colorado and Hawaii, with a primary focus on cybersecurity. Unfortunately, SPIDERS encouraged defense-unique solutions (the DOE labs figured prominently in some of them). As a result, the project did little to advance either commercial *or* military deployment of microgrids.

7. "Demonstrate like you fight" – the value of verisimilitude

"Train like you fight" – the notion that peacetime training should reflect battlefield conditions—is foundational to the U.S. military. DoD applies the same philosophy to its demonstration and testing activities. Military test ranges provide conditions that mimic the battlefield, and as a weapon system moves through the acquisition process, demonstration and testing become increasingly operational. Similarly, ESTCP-supported demonstrations take place on active bases, some of which are like small cities in terms of their geographic coverage; the number and variety of residential, industrial, and commercial structures they include; and their associated energy usage profiles.

A distributed testing capability is key to achieving verisimilitude. Recall that GE demonstrated its microgrid controller on a Marine Corps base in the Mojave Desert, and 3M installed its daylight-redirecting film in multiple DoD buildings across three climate zones. By contrast, DOE's former Energy Efficient Buildings Hub, established in 2010 at the former Philadelphia Naval Shipyard, served as a dedicated site for the demonstration of advanced building energy technologies. The use of a dedicated test bed has certain advantages: for example, VIPs can visit a single, central site. But for technologies whose performance depends on climate conditions and other site-specific variables, a distributed test bed—particularly one that uses operational facilities such as active military bases or occupied government buildings—is a far better approach.

More broadly, the "government practices" discussed above—the FAR, federal employment restrictions, direct DOE involvement in plant design, congressional interference—reduce the level of verisimilitude, making it harder for advanced energy projects to demonstrate their commercial viability. Paradoxically, reliance on commercial practices is the best way to follow DoD's maxim to "demonstrate like you fight."

8. Disseminate project-generated results and possibly the intellectual property

While the results of DoD's weapon system demonstration and testing are kept secret for obvious reasons, ESTCP places a high priority on dissemination of technical, performance, and other data generated in the course of any demonstration it funds. This communication of highly granular data (most reports run hundreds of pages) allows prospective customers, investors, and competitors to assess the value of the technology, facilitating both commercialization and competition. In comparison, DOE's record on dissemination of data from the Obama-era demonstration projects was uneven, according to David Hart's analysis.[25]

ESTCP does not, however, generally require the technology developer to share project-generated intellectual property, which typically consists of trade secrets as opposed to patentable technology. The argument for requiring developers to share project-generated intellectual property is that it facilitates adoption of the technology by other private firms, thereby increasing competition and deployment. Several prominent experts insist a grant of exclusive intellectual property rights is fundamentally inconsistent with the goal of government sponsorship of demonstration projects.[26] The counter argument is that a requirement to share project-generated intellectual property impedes the developer's ability to commercialize the technology.

ESTCP's position is pragmatic: most technology developers it deals with will not agree to participate in ESTCP demonstrations if they have to share resulting trade secrets. However, for commercial-scale energy technology demonstration projects, which receive more substantial government funding, a requirement that project-generated intellectual property be shared may well be the appropriate public policy.

9. Use the carrot of government procurement

DoD has been a successful innovator because it not only develops and demonstrates new technology, it procures the new technology. The military often chooses to pay a premium for novel, higher performing technologies; as these technologies mature and improve with use by, and feedback from, the military, they become cost competitive. The scale of DoD's buying power can also attract new entrants to an embryonic industry, stimulating competition. DoD's role as an early customer for new innovations was critical to the development of integrated circuits, computers, and satellite imagery and communications, among other technologies.

Technology demonstration and procurement are inextricably linked. With 500 active-duty installations and hundreds of smaller National Guard bases, DoD is on track to be, in addition to one of the first, one of the largest customers for advanced microgrids. Military bases will also be a significant customer for large-scale storage systems.[m] This customer mentality informs DoD's selection and management of Dem/Val projects: for example, ESTCP has supported multiple (commercial) microgrid vendors to ensure DoD can capture the benefits of competition.

Policymakers should consider how the carrot of government procurement can be used to enhance and expand energy technology demonstration projects. Deutch's proposed ETC would be able to guarantee government purchases as one form of indirect payment. For example, ETC might commit to

m DoD's 500 fixed bases will need at least 1 megawatt of energy storage, and the bigger bases could need as much as 10 MW. The current U.S. market for large-scale energy storage is small: In 2017, new large-scale storage installations totaled only 107 MW.

purchasing a fixed amount of power from an experimental off-shore wind facility, fuel from an advanced biorefinery, or cement from a first-of-a-kind low-carbon cement production plant.[n]

DOE's Federal Photovoltaic Utilization Program (FPUP), which ran from 1978 to 1981, illustrates the challenges of using the tool of government procurement effectively. FPUP was designed to expand federal government purchases of solar photovoltaic, or PV, cells to accelerate the development and adoption of PV technology. However, DOE's decentralized implementation of FPUP—it gave federal agencies the funds to purchase PV cells that met their respective requirements—reduced the desired impact. A number of the applications agencies pursued (e.g., remote installations in national parks) had only modest commercial potential. Moreover, because the agencies sought to minimize the price they paid for PV cells, the government purchases did not reward advances in technology performance, as NASA/DoD purchases of semiconductors had done two decades earlier.[27] Although DOE's R&D efforts significantly advanced solar PV technology in the 1970s, before funding was slashed in the 1980s, FPUP was not a success story.

IV. Can DoD Play a Broader Role in Demonstrating Advanced Energy Technologies?

As we've seen, DoD is already active in demonstrating advanced energy technologies, to speed their transition to market so that military users can purchase them commercially. This last section asks whether DoD can play a broader role in the demonstration of advanced energy technologies that have civilian (as well as military) applications. It also asks whether (and where) DoD and DOE might partner on such activity. The short answer to both questions is "yes."[28]

First, DoD could certainly play a broader role in demonstrating advanced commercial energy technologies, assuming (a) these technologies support DoD's mission, and (b) DoD has the necessary funding. For example, ESTCP's energy portfolio initially included a broad range of technologies for the built environment, including building energy efficiency, building energy management and control, on-site generation, and microgrids and storage (see Box B). Although new funding is going largely to microgrids and energy storage, the program could resume work in the other areas if its budget allowed.

More broadly, DoD has unparalleled resources for demonstration and testing. For example, DoD's Defense Innovation Unit, whose main office is in Silicon Valley, has encouraged "flying car" startups to test their prototypes on military bases. DoD's vehicle platforms can also serve as test beds. As one example, the Navy's Electric Ship R&D Center allows commercial firms and DOE laboratories to test electric power systems in a hardware-in-the-loop environment. DoD's physical assets, together with its culture of testing and evaluation, make it an ideal host for

n Even the possibility of a government market can serve as a carrot. In 2012, DOE's SunShot program awarded $25 million to French semiconductor manufacturer Soitec to operate a large factory in southern California as part of SunShot's effort to foster a competitive U.S. solar PV manufacturing base. ESTCP agreed to demonstrate the technology at the 1 MW scale on two separate military bases. (Ultimately, the demonstration went forward at only one base, Fort Irwin, in California's Mojave Desert.) Under the arrangement between DoD and DOE, SunShot provided the PV modules to the military at no cost, and ESTCP paid for the balance of the system and its installation. Although Soitec subsequently exited the solar business, it continued to support the demonstration at Fort Irwin.

public and private sector innovators to conduct technology demonstration and validation.[o]

In a 2019 report for the Information Technology & Innovation Foundation (ITIF), Jeffrey Marqusee and I examine DoD's investments in energy RDT&E, which totaled $1.6 billion in FY19.[29] We conclude that, despite being driven entirely by warfighter needs, these investments—combined with DoD's ability to be an early, price-insensitive customer—have significant potential to catalyze civilian clean energy innovation.

We look in detail at four technologies where the military's needs are particularly well aligned with those of commercial users:

Solar PV: The military needs solar PV materials that are more lightweight, flexible, and efficient than silicon, which is currently the dominant PV material, for use in the field, on drones, and possibly on arrays in space. DoD is funding R&D on alternatives to silicon and seeking to slash their fabrication costs. As an early, cost-insensitive adopter, DoD can give new, higher-cost technologies the chance to gain a commercial foothold.

Microgrids: Stationary microgrids are a must-have for fixed bases. DoD's rigorous demonstration process is helping manufacturers overcome the impediments to commercialization, and with 500 active-duty bases and hundreds of smaller National Guard bases, DoD will be a major customer for microgrids. Mobile (tactical) microgrids are essential for contingency bases; for this technology, DoD's early-adopter role can help lower cost and facilitate deployment in the developing world.

Energy Storage: DoD needs better batteries for mobile missions and large-scale energy storage for its bases. It is funding R&D on commercial batteries to meet its stretch goals for battery performance, and as an early adopter can help finance their progress along cost and learning curves. It is supporting demonstrations of large-scale storage systems to facilitate commercialization; as an early adopter it can absorb non-recurring engineering costs, and as a customer (500 bases) significantly expand the market.

Wide Bandgap Semiconductors: Wide bandgap (WBG) devices have the potential to revolutionize power electronics, but only if their costs come down. DoD has supported advances in WBG technology for 50 years, and its next-generation hybrid vehicles require a level of performance in power electronics that only WBG devices can provide. As an early adopter and major purchaser, DoD can help producers ramp up production and reduce costs based on economies of scale and learning by doing.

Our 2019 report for ITIF also highlights other technologies where DoD RDT&E and procurement could advance clean energy innovation, including wireless power transmission,

o The Defense Innovation Unit is itself located on a former Navy base, Moffett Field, which NASA now controls. Moffett Field is the site of three historic airship hangars that the Navy built in the 1930s and 1940s to house dirigibles and other aircraft. In 2014, NASA leased the hangars and the surrounding site to Google, which is using the hangars as laboratories for developing drones and other technology. Dorothy Robyn and Jeffrey Marqusee, "The Clean Energy Dividend: Military Investment in Energy Technology and What It Means for Civilian Energy Innovation," Information Technology & Innovation Foundation, March 5, 2019. Available at: https://itif.org/publications/2019/03/05/clean-energy-dividend-military-investment-energy-technology-and-what-it.

fuel cells, advanced composites, fuel-efficient propulsion, building energy technologies, and very small modular nuclear reactors (SMRs). Although DoD's role as we envision it is not limited to technology demonstration, demonstration and testing figure prominently in it.

Second, DoD and DOE can and should partner on the full range of energy innovation opportunities. DoD's customer-pull and DOE's technology-push approaches to innovation are highly complementary, meaning collaboration would yield significant synergy. Most important, a partnership with DoD in areas where the military's needs are aligned with those of commercial users would introduce much-needed demand pull into DOE's innovation process.

Despite the potential for synergy, DOE and DoD interaction on energy innovation is currently limited, which we argue is a major missed opportunity. We recommend ways DOE and DoD can partner in a half dozen different areas, including the four technologies we look at in detail (solar, microgrids, storage, and WBG semiconductors). This excerpt from our recommendation on microgrids is suggestive of the value we see in greater collaboration:

> A DOE-DoD partnership would speed military and civilian deployment of microgrids in key ways. First, DOE's understanding of and ability to model grid services would help DoD better determine the economic value microgrids offer when operating in grid-tied mode. Second, DOE has unique hardware-in-the-loop facilities that would allow DoD and others to test microgrid controllers and optimize their design in a fraction of the time it now takes. Third, DoD's microgrids offer an ideal test bed for experimentation with robust cybersecurity systems, which should be of interest to DOE's new office of Cybersecurity, Energy Security, and Emergency Response, as it tries to accelerate the development of such systems.[30]

One encouraging development is a pilot initiative to demonstrate ARPA–E funded technologies on military bases. In collaboration with ESTCP, ARPA–E issued a solicitation to several current and former ARPA–E project teams working in areas relevant to DoD installation energy needs. ARPA–E (with advice from ESTCP) selected four proposals to support. Appendix B provides more detail on the "Collaboration Pilot" and the projects selected.

V. Conclusion

DoD might seem to be an unlikely source of insights into the question of whether the federal government should resume support for large-scale DOE technology demonstration projects. After all, the two agencies pursue innovation very differently, with DoD funding industry to develop technology in response to the "pull" of warfighter requirements, and DOE "pushing" technology developed in its laboratories toward a distant commercial market. However, DoD is a useful model in part because of its differences from DOE.

The most important lesson DoD has to offer is that innovation and technology demonstration are inextricably linked. The military has fifty words for demonstration because that activity is so critical to DoD's development of mission-essential advanced technology (including commercial technology in some cases). This is a lesson, not for DOE, but for policymakers who question the need for DOE to support large-scale energy technology demonstration projects.

DoD's heavy reliance on demonstration and testing is one manifestation of its close focus on the needs of the military customer, and this customer orientation is the single most important explanation for DoD's history as a powerful engine of innovation. Thus, the importance of knowing one's customer is the second most important lesson DoD has to offer DOE and its congressional overseers.

Granted, DOE faces a harder challenge in that its customers are external. Nevertheless, DoD's approach to technology demonstrations—conducting them under real-world conditions ("demonstrate like you fight"), giving contractors significant control, insulating the activity from political interference—are directly relevant. Paradoxically, DoD's experience underscores the need for the federal government to make energy technology demonstration projects as commercial as possible, including by creating an independent entity to manage them and by relying on indirect incentives rather than direct government payments to finance them. Government purchases are one such indirect incentive, and DoD's experience shows it can be a powerful tool, particularly if procurement is used strategically, to give technology developers customer feedback and help them descend the cost and learning curves.

Finally, precisely because the innovation models DoD and DOE pursue are so different, greater collaboration between the two agencies promises significant synergy. Most important, a partnership with DoD would introduce much-needed demand pull into DOE's innovation process. It could also give DOE the cover it needs to make politically unpopular choices. If exploited effectively, the complementarities between these two agencies could have enormous benefits for the nation and the world.

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Appendix A: Department of Defense Research, Development, Test, and Evaluation Budget Activities

Basic research (6.1): Scientific study and experimentation focusing on increasing fundamental knowledge which may address long-term national security needs. Includes pre-Milestone A efforts.

Applied research (6.2): Research focuses on the expansion and application of knowledge and is directed toward general military needs to determine the initial feasibility and practicality of proposed solutions. Includes pre-Milestone B efforts.

Advanced technology development (6.3): Concept and technology demonstrations that assess the technological feasibility, operability, and producibility of components, subsystems, or system models. Demonstrations evaluate general military utility or cost reduction potential of the technology. Projects in this category should have the goal of moving out of science and technology and into the acquisition process within 5 years. Includes pre-Milestone B efforts and technologies generally having a Technology Readiness Level (TRL) of 4, 5, or 6.

Advanced component development & prototypes (6.4): System specific evaluations of integrated technologies, representative models, or prototype systems in a realistic operating environment. Focuses on proving component and subsystem maturity prior to integration into major systems. Includes pre-Milestone B efforts and TRL 6 or 7 should be achieved.

System development & demonstration (6.5): Engineering and manufacturing development tasks aimed at meeting requirements prior to full-rate production. Prototype performance is near or at planned operational system levels. Conduct live fire and initial operational test and evaluation. Includes post-Milestone B efforts to support Milestone C decisions.

RDT&E management support (6.6): Efforts to sustain and/or modernize installations or operations required for RDT&E such as test ranges, military construction, and studies and analyses in support of RDT&E.

Operational system development (6.7): Efforts to upgrade systems that have been fielded or will soon enter fullrate production. Includes post-Milestone C efforts.

Source: U.S. Government Accountability Office, *Defense Science and Technology: Adopting Best Practices Can Improve Innovation Investments and Management*, June 2017, Available at: https://www.gao.gov/assets/690/685524.pdf.

Notes: Milestones A, B, and C are the reviews that precede the start of technology development, system development, and production, respectively, for a DoD acquisition program.

Appendix B: ESTCP/ARPA-E Collaboration Pilot

Overview

In coordination with ESTCP, ARPA–E issued a solicitation to several past and current ARPA–E project teams working on technologies relevant to DoD installation energy requirements. ARPA–E (with advice from ESTCP) selected four proposals to support. The technology demonstrations will be performed on DoD installations and will be funded by DOE with 50% cost share provided by the selected project teams. Total funding from DOE for the four projects is approximately $3.5 million. ESTCP will provide technical review and assist with oversight of project performance, as well as coordination with demonstration sites and funding for any DoD-related costs (permits, approvals, etc.).

Awarded Projects

- Company: The Mackinac Technology Company – Grand Rapids, MI
  Product/Title: Mackinac Window Energy Management Systems (WEMS™)

  The Mackinac WEMS™ technology is engineered to improve the insulating properties of single-pane windows. In addition to improving the energy efficiency of single-pane windows, the WEMS™ units will be tested to demonstrate compliance with DoD blast protection requirements for building occupants. Two demonstration sites, Fairchild Hall at the U.S. Air Force Academy in Colorado Springs, CO, and the Engineering Building at the Selfridge Air National Guard Base near Mount Clemens, MI, will be used to validate their performance.

- Company: SkyCool Systems, Inc. – Mountain View, CA
  Product/Title: Reducing Energy and Water Usage by Cooling DoD Facilities with the Sky

  SkyCool Systems has developed a rooftop cooling panel that improves the efficiency of air conditioning and refrigeration systems. The core technology in the panels is a multilayer optical film that passively radiates heat to the sky, day and night, and stays cool even under direct sunlight. The panels cool without evaporating water and only require electricity to run a water pump. The cooling panels are well matched to the 24/7 operation of refrigeration systems and air conditioning systems in data centers and data closets. The proposed project involves deploying SkyCool panels at four DoD facilities in different climate zones to demonstrate energy and operational savings when panels are connected to refrigeration and data center cooling systems. Demonstration sites are still being evaluated for feasibility.

- Company: Switched Source LLC – Vestal, NY
  Product/Title: Solid State Transformer for Increased Distribution System Reliability

  Switched Source's Tie Controller (TC) will be deployed on a DoD base's primary electric distribution system. The technology enables electric distribution system operators to dispatch and balance power flow, similar to a controllable valve or an Internet router but for power. One circuit can "borrow" capacity from another, enabling better load balancing, fuller use of intermittent and distributed energy resources, and built-in redundancy to minimize outages.

Demonstration sites under consideration are Fort Bliss in El Paso, TX and Rock Island Arsenal in Rock Island, IL.

- Company: Case Western Reserve University – Cleveland, OH
  Product/Title: Demonstration and Validation of a Virtual Energy Audit Tool for DoD Buildings

  Case Western will demonstrate and validate a virtual energy audit software tool called EDIFES (Energy Diagnostics Investigator for Efficiency Saving) on approximately 500 DoD buildings without setting foot in the buildings or requiring building/energy managers to complete lengthy questionnaires. Case Western has found a way to map a building's "energy DNA" through a rigorous statistical and machine learning analysis of time-series electricity consumption data compared with other buildings. The project team will: (1) use the EDIFES portfolio screening tool to produce a prioritized list of buildings with the highest energy savings opportunities and an interactive visualization of results, (2) identify and quantify energy and cost savings opportunities in these buildings throughout the project, and (3) validate EDIFES predictions of savings.

Source: ESTCP, March 2020.

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