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Lean, Mean and Clean: Energy Innovation and the Department of Defense

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The Department of Defense's long history of technological development suggests that it is well-positioned to play an important role in the energy innovation space.

In recent years, the Department of Defense has come to see excessive energy use and reliance on foreign energy sources as strategic vulnerabilities. In the words of Chairman of the Joint Chiefs of Staff Admiral Mike Mullen, "Energy security needs to be one of the first things we think about, before we deploy another soldier, before we build another ship or plane, and before we buy or fill another rucksack."[1]

To address these vulnerabilities, the Department has begun to pursue innovative activities to reduce its energy intensity and shift away from foreign fossil fuels. While clean, self-sufficient energy is a somewhat new focus, DOD has a long history of pursuing similar technology development activities to achieve mission goals, serving as developer, demonstrator, or early market creator in sectors like aviation, computing, GPS, and nuclear power. Many of these activities have led to significant commercial spillovers that have boosted innovation and technological change in the broader economy. This history suggests that DOD is well-positioned to play an important role in the energy innovation space, but must be able to count on continued Congressional support for these efforts, while also pursuing collaboration with other agencies and the private and academic sectors to achieve its own critical mission goals.

DOD'S ENERGY CHALLENGE

The national security implications of dirty, foreign energy sources have received considerable attention from a growing chorus in recent years.[2] As consulting firm Deloitte put it, "Energy security and national security are closely interrelated: threats to the former are likely to translate as threats to the latter."[3]

Perhaps the most obvious challenge is the fact that energy imports can benefit supplier nations that oppose U.S. interests, or at least complicate or constrain U.S. foreign policy choices. Geopolitical relationships and influence often hinge on securing energy access, allowing the profile of supplier states like Russia to grow at the expense of U.S. influence.[4] In some cases, the income from international trade in energy can be used to further entrench hostile or totalitarian regimes, as is the case with Iran. Beyond adversary governments are worse characters, as the Joint Operating Environment 2010 report points out: “A portion of OPEC’s windfall might well find its way into terrorist coffers, or into the hands of movements with deeply anti-modern, anti-Western goals — movements which have at their disposal increasing numbers of unemployed young men eager to attack their perceived enemies.”[5] The irony is not lost on Navy Secretary Ray Mabus, who recently said, “We would never allow these regions to produce our ships, our aircraft, our land vehicles, but because of their good fortune of having fossil fuel reserves, these very same regions get a say in whether our aircraft fly, whether our ships sail, or whether our ground vehicles operate."[6]

If DOD were a state, it would rank around 32nd in the United States, roughly equal to the entire state of Oregon, in annual energy consumption.

The importance of oil contributes to the need to protect the global supply system from disruption and scarcity, which has deep implications for American policy and the military in the Middle East and elsewhere. Oil reserves are highly concentrated and the international supply chain is subject to a handful of major choke points in volatile regions, such as the Strait of Hormuz. Colonel Gregory J. Lengyel, USAF, has written that “instability and hostility towards the United States characterizes most of the oil-producing world, and terrorist organizations have called for attacks on oil infrastructure and military supply lines.”[7] The Electrification Coalition, a project of energy- independence advocacy organization Securing America’s Future Energy, suggests that up to 15 percent of the current defense budget goes towards protection of oil supply.[8] And supply shocks can have widely destabilizing economic, social, and political effects that reach far beyond the borders of the exporting country. Indeed, the United States is not the only nation to rely heavily on petroleum imports, and access to oil fields has been a driver of strategic considerations at least since World War II, when Imperial Japan targeted Indonesia for access to Dutch oil fields there. Quoting again the Joint Operating Environment Report, “The implications for future conflict are ominous, if energy supplies cannot keep up with demand and should states see the need to militarily secure dwindling energy resources.”[9]

Beyond the realm of international politics and strategy, a very real challenge is the way our armed forces use energy and maintain supply, both on the battlefield and at fixed installations. It’s hard to understate the military’s energy appetite. In FY07, the federal government consumed roughly 1.6 quadrillion BTUs (quads), of which DOD accounted for 1.1 quads or more than 70 percent. (Figure 1)[10] This level of consumption, equal to roughly 1 percent of all energy consumed nationwide, makes DOD the single largest consumer of energy on the planet. If DOD were a state, it would rank around thirty-second in the United States, roughly equal to the entire economy of Oregon, in annual energy consumption. The FY07 consumption figure actually represents a 25 percent decline in aggregate energy consumption from 1985, due in part to downsizing.

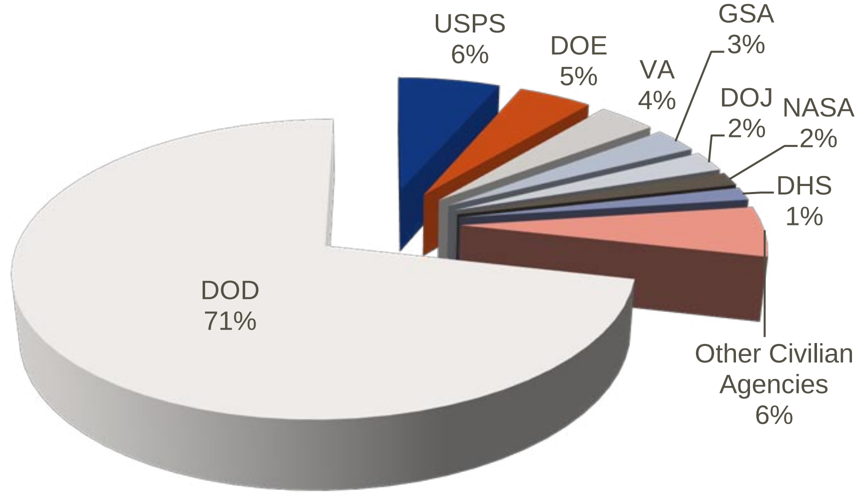

Figure 1: Percent of Total Federal Primary Energy Consumption By Agency

The vast majority of this energy consumption goes towards the military departments, with the Air Force representing the largest overall fuel consumer. (Figure 2)[11] This is mainly due to its use of fuel to power aircraft as well as tactical vehicles and equipment. In FY09, the Defense Energy Support Center (DESC), which acts as a centralized bulk energy purchaser for the entire military establishment, purchased 128 million barrels of petroleum-based fuel, with jet fuel accounting for more than 70 percent of this purchase. In turn, JP-8, the military's primary battlefield fuel, accounted for more than 84 percent of the jet fuel purchase.[12]

Unsurprisingly, such consumption comes at great cost. In FY09, DOD spent $13.2 billion on energy for fixed installation, equipment, and vehicle fuels like gasoline and jet fuel; roughly three-quarters of this is for petroleum-based fuel.[13] Such large-scale spending is highly sensitive to fluctuations in global prices of crude oil; between 2004 and 2006, for example, DESC expenditures on oil procurement doubled due in large part to the run-up in world crude prices.[14] The potential for future supply constraints to limit availability and increase costs is a very real concern. According to the Joint Operating Environment assessment, "By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly ten MBD [million barrels per day]."[15] This is not simply excessive caution, but a fear drawn directly from the industry itself. Hess Corporation CEO John Hess has predicted substantial pending price spikes, saying, "As demand grows in the next decade, we will not have the oil production capacity we will need to meet demand."[16] And the International Energy Agency has already suggested that global oil production is unlikely to reach its 2006 peak, even in the face of increasing overseas demand. The price rises from these constraints can have consequences not only for spending and budgets, but for military readiness. DESC establishes fixed prices for fuel purchases at the beginning of each year to facilitate budgeting. If market prices undergo rapid increases and exceed DESC's established rates, as they have more than once in recent years, it can result in budgetary shortfalls that constrain or delay other activities like training and maintenance.[17]

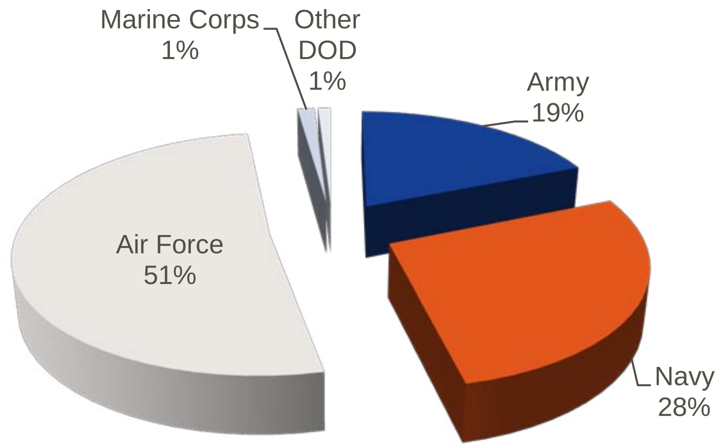

Figure 2: Purchases of Petroleum, Natural Gas, and Aerospace Energy By Branch

But the aggregate dollar amount also doesn't tell the whole story. Deloitte estimates the amount of fuel consumed per soldier per day during combat operations has increased dramatically, from less than five gallons per day during World War II and the Korean War to more than 20 gallons per day in Iraq.[18] Forward operating bases (FOBs) require hundreds of gallons each day, brigades can consume hundreds of thousands of gallons daily,[19] and hundreds of millions of gallons are supplied in-theater each year. Moving such huge quantities of fuel to the battlefield requires a major logistical effort and onerous supply chains. According to a Defense Science Board task force, 70 percent of the tonnage shipped by the Army for battlefield purposes is fuel.[20] The same task force also found that the Air Force uses 84 percent of its fuel delivery budget to deliver 6 percent of its total fuel usage through in-flight refueling.[21]

High energy intensity and a long logistics tail have serious repercussions in maneuverability, endurance — and in lives. Fuel supply convoys make attractive targets for attack through direct assault or by Improvised Explosive Devices (IEDs); nearly half of all U.S. casualties in Iraq over a six-year period ending in May 2009 were inflicted by IEDs. American casualties also show high correlation with increases in fuel consumption in Afghanistan.[22] According to one Army study, one soldier or civilian responsible for fuel transport or security is killed for every twenty-four fuel convoys in these areas.[23] The need to protect large and frequent fuel convoys can occupy units that could be redeployed to active combat operations elsewhere. According to Secretary Mabus, "Fossil fuel is the No. 1 thing we import to Afghanistan, and guarding that fuel is keeping the troops from doing what they were sent there to do, to fight or engage local people."[24]

Additionally, the need to continuously supply forward combat units can restrict war fighting capabilities, constrain maneuverability, or limit unit endurance. For example, the Army Research Lab has calculated that a 50 percent improvement in Abrams tank fuel efficiency would have reduced Operation Desert Storm force buildup time by 20 percent.[25] Greater efficiency can also mean greater range and reduced refueling needs for aircraft or vessels, much as improved jet engine performance has improved combat aircraft performance over the preceding decades.[26] The constraints of the fuel logistics tail prompted General James Mattis, former Commanding General, 1st Marine Division during Operation Iraqi Freedom, to challenge the defense establishment to "unleash us from this fuel tether."[27]

The logistical challenge means that there are hidden costs above what DESC pays for each gallon of fuel. Whereas the bulk purchasing price may be a few dollars per gallon, the "fully burdened cost of fuel" — including transportation, delivery, and security, as well as related infrastructure and hardware — is significantly higher than its purchase price, commonly by as much as a factor of ten or more in combat areas.

An implication of hidden fuels costs is that measures to reduce the logistics tail — be they investments in energy efficiency or adoption of innovative energy supply technologies, or even modified delivery practices — might appear less cost-effective to planners than they actually are.

The implication is that measures to reduce the logistics tail — be they investments in energy efficiency or adoption of innovative energy supply technologies, or even modified delivery practices — might appear less cost-effective to planners than they actually are. As the Defense Science Board has said, the purchase price of fuel "has serious unintended consequences for DOD's ability to estimate realistically the economic benefits of increased fuel efficiency."[28]

Finally, while much of the focus is on liquid fuels, DOD also has a massive appetite for electricity. The Department operates over 500 installations worldwide, with over 500,000 buildings and other structures. The global footprint includes over two billion square feet of floor space, quadruple Wal-Mart's.[29] In FY09, DOD delivered more than 200 trillion BTUs to its facilities, the bulk of which came from electricity (roughly 95 trillion BTUs) and natural gas (roughly 71 trillion BTUs).[30] The Department has been steadily building up the number of metered buildings in recent years to better track electricity consumption and thereby improve management and assess the need and role for efficient smart technology.

Even in light of cheap coal and natural gas, electricity nevertheless comes with its own set of challenges, particularly in the form of national grid vulnerability. As the non-profit analytical group CNA has said, "At military installations across the country, a myriad of critical systems must be operational 24 hours a day, 365 days a year. They receive and analyze data to keep us safe from threats, they provide direction and support to combat troops, and stay ready to provide relief and recovery services when natural disasters strike or when someone attempts to attack our homeland."[31] Installations providing such critical mission support rely overwhelmingly on commercially owned and maintained grid infrastructure provided by local utilities. The electricity supplied to that grid is likewise generated overwhelmingly by private generators. The current vulnerabilities of the grid to targeted attacks or national disasters have been well established. For example, in 2009 it was revealed by Homeland Security and Defense officials that cyber attacks originating from China, Russia, and elsewhere had penetrated the national power grid, leaving behind potentially disruptive software.[32]

Domestic grid resiliency is also a concern. The American Council of Civil Engineers gave the nation's energy infrastructure a D+ grade in its 2009 report card, writing, "The transmission and distribution system has become congested because growth in electricity demand and investment in new generation facilities have not been matched by investment in new transmission facilities. This congestion virtually prohibits outages required for proper maintenance and can lead to system wide failures in the event of unplanned outages."[33] The fragile state of the grid thus represents a major security red flag.

BOX 1: THE ADVANTAGES OF ENERGY EFFICIENCY

The Defense Science Board found several strategic reasons to seek out energy efficiency improvements. From its 2001 report:

- **Surprise:** Fuel efficiency increases platform stealth by diminishing the platform's heat signatures, exhaust, and/or wakes; and affords less chance of compromising movement by reducing the logistics tail and resupply communications.
- **Mass:** Fuel efficiency decreases the time required to assemble an overwhelming force.
- **Efficiency:** Fuel efficiency increases commander's flexibility in efficiently assembling an overwhelming force.
- **Maneuver:** Platforms will travel faster and farther with reduced weight and smaller logistics tails that improve platform agility, loiter and flexibility.
- **Security:** Fuel efficiency decreases platform vulnerability to attacks on supply lines, and reduces demand for strategic reserves.
- **Simplicity:** Fuel efficiency decreases the complexity and frequency of refueling operations and logistics planning, while reducing vulnerability to the "Fog of War."

All in all, a major increase in attention has been given to the services becoming energy efficient, self-sufficient, and independent. The 2010 Quadrennial Defense Review found that "energy security for the Department means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs. Energy efficiency can serve as a force multiplier, because it increases the range and endurance of forces in the field and can reduce the number of combat forces diverted to protect energy supply lines, which are vulnerable to both asymmetric and conventional attacks and disruptions"… "The Department is increasing its use of renewable energy supplies and reducing energy demand to improve operational effectiveness, reduce greenhouse gas emissions in support of U.S. climate change initiatives, and protect the Department from energy price fluctuations."[34] Likewise, the Defense Science Board has stated, "The payoff to DOD from reduced fuel demand in terms of mission effectiveness and human lives is probably greater than for any other energy user in the world."[35] (See also box 1).[36] Many in Congress have also taken strong notice, including House Armed Services Readiness Subcommittee Chairman J. Randy Forbes, who wrote in a recent essay, "Energy efficiency is often framed as an environmental issue, but it is first and foremost a national security issue."[37]

It's clear that DOD properly sees energy security as a fundamental strategic goal. Fortunately, this goal overlaps the broader international goal to innovate for cleaner energy sources. The world's energy challenge is simple but massive: to add fifteen terawatts (TW) or more of clean energy by mid-century,[38] thereby avoiding the worst impacts of climate change, decoupling the global economy from volatile and politically problematic oil markets, and meeting massive future energy demand in the developing world.

In light of these overlapping interests, DOD can make a major contribution to energy innovation while pursuing its own strategic goals. This contribution will come through technology development activities: to acquire the cleantech it needs, DOD will serve as a technology developer, demonstrator, and early market driver. This process will contribute to the energy technology knowledge base, provide impetus for private-sector innovation, and may even yield technologies with potential commercial application. In fact, DOD has a long history of fostering technological development that achieves important defense-related objectives while also serving an important — and, from a defense perspective, incidental — function within a larger innovation system framework. In the words of Assistant Secretary of Defense for Operational Energy Plans and Programs Sharon Burke, "We have the chance to be a major driver and innovator of change."[39]

DOD'S PLACE IN THE INNOVATION SYSTEM

It's useful to think of DOD's role in developing and using advanced energy technologies as a form of *innovation and translation policy*. What do we mean by this? The debate over innovation often focuses on two important, complementary "poles" of the technology development cycle. On one "end" of the cycle are policies like direct R&D funding for basic research and R&D tax credits, which drive the expansion of knowledge and spur the creation of radical new technologies. On the other "end" are policies that create or expand the private market for these technologies and accelerate their deployment and consumer adoption. These latter policies can include mandates, financing assistance, regulatory reform, and carbon prices. But between these two poles lies rocky ground frequently referred to as the "valley of death," and traversing this ground — moving from lab to market — can be perilous for promising but still-experimental technologies.

What exactly is the "valley of death," and why is it so perilous for new innovations? New technologies and innovations may boast significant potential as commercial products, but they also inherently carry high risks due to technological uncertainty. Development, prototyping and demonstration activities to prove commercial viability can incur substantial costs. An official from Booz Allen Hamilton, a strategy and technology consulting firm, gets at the meaning and the challenges for entrepreneurs and technology developers:

> I would define [the] Valley of Death [as occurring] when the amount of money you're starting to ask for — the bill — starts to add up to the point

> where management says, 'What are you guys up to, what are you doing, and what am I going to get out of it?' But yet it is sufficiently early in the process that you don't feel you can answer that question. If you are fortunate enough that the questions come when you have an answer, you, in fact, have scooted over the Valley. If not, you are squarely in that Valley.[40]

The valley of death is not a universal obstacle faced by all new technologies equally, and the private sector can and does regularly move products from the lab to the market through processes where risks are low and technological improvements are more incremental than radical. But the challenge tends to increase — or, one could say, the valley of death widens — with escalating risk and cost for early-stage, more radical technologies. Of course, the goal isn't to move all technologies through the valley of death — just the worthy ones. Many bad or unworkable ideas get left behind in the applied research or testing phases of development, and rightly so. Technology development requires a stringent culling process and managers able to separate the good from the bad. The goal, however, is to ensure the good ideas don't get left behind too, due to built-in obstacles in the development process. A key challenge, in many cases, is a daunting learning curve: new technologies may eventually become cost-effective, but only after significant resource and time investment has driven them down the cost curve and addressed uncertainty. Technology-related uncertainty is high for new projects, and this means that funding for early-stage technologies from private capital sources may be scarce.[41] Thus, markets may be slow to take up superior but unproven technologies when left to their own devices. Policy can help reduce this uncertainty where market activity wouldn't on its own.

If a key challenge is translating new technologies from the lab to the market, DOD is well-positioned to facilitate this translation while pursuing its own strategic challenges.

Additionally, there are some energy-specific market challenges that exacerbate technology transitions to the market.[42] Electricity is a fungible commodity, which means there is no inherent work advantage to using clean energy versus dirty energy for electricity to perform the same task. The energy sector is also marked by high up-front capital costs for new projects, and existing fossil fuel plants have decades-long life spans that allow for depreciation benefits. And limitations in supporting infrastructure can also pose barriers to adoption. As energy innovation experts Charles Weiss and William B. Bonvillian have written, entry for new technology "into the extremely complex and competitive markets" may be the toughest step.[43] Thus, radical or revolutionary energy technologies may be developed in labs in universities, private firms, or public research institutions, but can require additional policy support post-invention at market entry and perhaps beyond to become commercially useful through cost curve reductions.

If a key challenge, then, is developing new technologies and translating them from the lab to the market, DOD is well-positioned to facilitate development while pursuing its own strategic challenges outlined above. This is particularly true in the case of dual-use technologies, like energy, that are useful for both military and civilian purposes. Innovation scholars Daniel Sarewitz and John Alic put it well in testimony before Congress: "When government is responsible for providing a public good like national defense — or public health — it may choose to pursue technologies (digital computation, genome mapping) based on their potential for providing that good, rather than on strict considerations of cost. The very process of applying technologies to the solution of societal problems may then lead to accelerated innovation, improved performance, reduced costs, creation of new markets, and generation of new wealth."[44]

There are several policy mechanisms through which DOD pursues innovation and translation. Conceptually, these mechanisms can be broken into three categories, tied directly to various phases of the typical innovation process.

- Direct R&D support. DOD has commonly been a major source of funding for basic and applied research of technologies that assist mission goals, especially in the private and academic sectors. Formal military service branch activities to fund university research began with the World War II-era Office of Naval Research.[45] Research support is critical for creating new technologies; but more than just research dollars are needed. Also key is the effective management and coordination of that research. The fact that DOD is able to support research while pursuing such coordination as a more-or-less unified entity gives it a potential institutional leg up on more disparate, competitive but uncoordinated research endeavors elsewhere.

- Demonstration and validation. Once mission-critical technologies have been developed, they must be tested to ensure operational viability. The nature of DOD's mission means that it is able to request and enforce high standards for technology performance. Thus, in its testing activities, DOD can help to drive performance improvements by acting as a demanding, high-quality customer, an important ingredient in innovative success.[46] This is also a function that DOD can perform exceedingly well, where other agencies (notably the Department of Energy) have a less-than-stellar track record.

- Procurement. Large-scale purchasing of new technologies creates early markets for new technologies, allowing private firms time to grow and gain productive experience, while also driving cost reductions and technology performance improvements. This is the typical market-pull mechanism that provides assured return on investment for private firms able to produce risky new technologies that can perform. The size of the market and nature of DOD's mission goals means there are substantial opportunities for pushing technologies down the learning curve.

Jeff Marqusee, Director of DOD's Strategic Environmental R&D Program and Environmental Security Technology Certification Program, has said, "The role for DOD we see, particularly for this class of technologies that overlap the civil sector, is to be a test-bed for them: to be a place where we can take the high risk to try out new technologies, where we can partner with DOE, directly with the private sector, with the venture capital sector, to bring on technologies which haven't been used yet or widely deployed, get the lessons learned, and find out what are the winners and losers."[47] In fact, the department has deep historical roots in fulfilling exactly this translational role, by identifying strategic defense challenges and pursuing technological solutions to meet them. As Deputy Under Secretary of Defense for Installations and Environment Dorothy Robyn has said, "Although DOD has provided this support solely for national security reasons, the technologies spawned have served as key drivers for U.S. economic growth and competitiveness. The commercial success of these technologies, ranging from aerospace to the Internet, has in turn benefited DOD by allowing the military to take advantage of the cost savings and further technology advances from the private sector."[48] A brief review of some of these cases follows.[49]

Aircraft

The military's role in contributing to the development of aviation technology is clear and well-established. As early as World War I, military needs began to drive the early industry's modest growth given the obvious warfare implications of human flight. The military's translational role becomes obvious when one considers the state of the industry prior to the outbreak of war. The early industry was built on extensive experimentation by technologists, craftsmen and entrepreneurs, to some extent in the United States, but mostly within Europe, and the domestic industry remained fairly small before the war. World War I and its associated military needs for airborne combat led to greater coordination in the domestic industry and production quotas of thousands of aircraft, compared to the 300 or so aircraft produced domestically before the war.[50] Even more important than the sheer quantity of production, however, was the rapid pace of technological change that greatly increased aircraft performance. Indeed, keeping up with this pace was a major challenge for the domestic industry, unlike production efforts in Europe that drew on engineering design advances more effectively. As a result, U.S. domestic industry had only limited success in spite of the sharp jump in production.[51] Once the military's involvement dried up, the domestic industry shrank drastically, and only later intervention by the Army and the U.S. Postal Service prevented "complete collapse."[52]

A key institutional innovation directly tied to military needs was the creation in 1915 of the National Advisory Committee for Aeronautics (NACA), which served an advisory role until 1926, when it became the premier federal entity for aviation research. NACA was not a military entity nor exclusively tasked with military aviation research, but nevertheless made attention to military needs one of its primary responsibilities while also receiving substantial investment from the military to advance the state of knowledge over the next few decades.[53] NACA's experimental research centers and superior wind tunnels developed several minor and major innovations — perhaps most notably the "NACA cowling", aerodynamic housing that greatly reduced drag and overheating, thus increased fuel efficiency — prompted by military needs and put to use by the military and industry alike.[54]

Jet propulsion provides another clear instance of military strategic needs driving technology translation from lab to marketable product. Advances in the science of aerodynamics and the clear limitations of the propeller-driven paradigm induced innovative experimentation in jet engine design, much of which was pursued under a military umbrella. NACA's legacy actually fares poorly on this front, as the agency remained skeptical of the technology and thus missed out on the development opportunity, effectively ceding leadership to others. However, NACA's failure means that the world's militaries stepped in more directly. The United Kingdom and Germany took pivotal roles, sponsoring early R&D and demonstration models, and moved into large-scale acquisition. U.S. Air Force sponsorship of jet engine development and aircraft design in conjunction with General Electric, Lockheed, and other firms came shortly thereafter.[55] Military activities were thus a major driver in improving jet engine performance during the war and in the decades beyond.[56]

The commercial upshot followed with its adoption by manufacturers for private markets — and ultimately contributing to both the commercial aircraft industry as well as the gas turbine electric power sector.[57]

Electronics and Computing

The connection between early experimentation with tabulating machines and vacuum tubes, and the modern-day computer industry is almost entirely due to military purchasing and R&D. After decades of experimental work in adding machines and similar primitive technologies, the first automated calculator and the first digital computer were both designed and created for the military during and immediately following World War II. The latter was developed with the express purpose of assisting the Aberdeen Ballistics Research Laboratory in artillery calculations.

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These early years saw the formation of the original computing firms, as well as a shift into computing by business product innovators like IBM. The early industry was bolstered almost entirely by military procurement contracts. Even in instances where major advances occurred without direct DOD funding support, the promise of future demand helped to provide motivation for their development, as was the case with the invention of the transistor at Bell Labs in 1947; after this discovery, the Army Signal Corps, based in Fort Monmouth, NJ, provided substantial funding to Bell Labs and for early transistor manufacturing facilities constructed by a number of firms.[58] Meanwhile, the Air Force also funded Texas Instruments' development work in microchips following the firm's privately-funded invention of the integrated circuit in 1958 (roughly concurrent with Fairchild Semiconductor, whose integrated circuit was the first to use silicon), and later provided a substantial demand market for the firm through the Minuteman II missile program.[59] Funding for semiconductor R&D and manufacturing has continued into the modern era with DOD's Advanced Research Projects Agency-(DARPA) support of SEMATECH and the Semiconductor Research Corporation Focus Center Research Program.

The important Semi-Automatic Ground Environment (SAGE) Project drove early technology development and improvements and provided steady demand for further industry growth. A collaborative project with MIT and IBM and funded first by the Office of Naval Research and later by the Air Force, SAGE led to the development of a decentralized, digital aircraft tracking and missile defense system that spanned the continent beginning in 1961. The program represented a quantum leap in digital technology, and many of the inventions developed for SAGE are direct antecedents of technological components in modern computers.[60]

In addition to hardware and systems development, DOD also played an important role in the software industry. DOD accounted for half the software market into the 1980s, and funded up to half of all academic computer science R&D. A major initiative in this area included the Very High Speed Integrated Circuit Program, a joint undertaking of the Army, Navy, and Air Force in conjunction with private firms like Honeywell and IBM to develop advanced silicon integrated circuits for improved weapons systems. The program lasted roughly ten years and addressed the complete innovation process from design, development, and demonstration, to fabrication and manufacturing, to deployment.[61]

DARPA's Information Processing Techniques Office (IPTO) and NSF were instrumental in providing funding for the foundation of the computer sciences discipline in the latter half of the twentieth century.[62]

Space, Satellites, and GPS

When one thinks of the early space race, Sputnik is one of the things that come to mind. But it did not take the original 1957 "Sputnik Moment," to use the Obama Administration's terminology, to launch American efforts to develop space technology: those efforts had begun more than a decade before, in the acquisition of German rocket science. Later, NACA would begin performing substantial early aeronautics research into high-altitude and space-based flight through the urging of the Air Force through Air Research and Development Command.[63] Eventually NACA's astronautics work would account for a majority of its effort, leading up to its transformation to NASA in 1958. The Air Force's manned spaceflight program would evolve into NASA's Project Mercury, while the Army and Navy both also maintained an interest in manned spaceflight through proposals to the Advanced Research Projects Agency.[64]

The CORONA program produced substantial technical achievements and would lay the groundwork for NASA's later work in satellite communications, which in turn would yield massive commercial spillovers in the modern telecommunications industry.

The initial American satellite program, Project Vanguard, was approved in 1955 and tasked to the Naval Research Laboratory. Military rocket programs at the Army Ballistic Missile Agency played a major role in getting these initial satellites off the ground, so to speak. At the same time, the CIA and the Air Force began developing a top-secret program, dubbed CORONA, to create and launch spy satellites for intelligence-gathering, and which yielded substantial technical achievements.[65] These and other efforts by NASA and the military departments continued to lay the groundwork for later private-sector success.

CORONA also helped grow the technological foundations that led to global positioning systems (GPS). The global system grew initially out of military research of general relativity using atomic clocks in orbit. In the late 1950s and 1960s, the Navy and DARPA would sponsor the development of the Transit global satellite navigation system, in partnership with the Johns Hopkins Applied Physics Lab. The system would eventually be opened to commercial ocean traffic use, which increased in the 1970s with the development of affordable receivers.[66] At the same time, the Department of Defense initiated the next generation of navigation satellites under the "Navstar" rubric, which opened to public use in 1983.[67] The Navstar/GPS system is still overseen and operated by the Air Force's 50th Space Wing.[68]

Nuclear Energy

The age of nuclear weapons and energy began in the laboratories of some of the world's top scientists and rapidly developed under the planning and direction of the United States military. By the late 1930s, scientific research into splitting the atom advanced significantly enough that Albert Einstein warned President Franklin Roosevelt of the dangers of allowing adversarial countries to use this new knowledge for militaristic means. Late in 1939, the United States directed the Army (which directed the Army Corp of Engineers) to develop and construct an atom bomb. Led by Colonel Leslie Groves, the Manhattan Project not only designed a bomb, but also created an institutional complex of "entirely new scientific, engineering, and technical knowledge."[69] By the time design and testing of the atom bomb was completed, this new "complex" included universities and private industries led by the military. The Army commissioned construction of research facilities and bomb test sites under the title 'Manhattan Engineering District.' One of the project sites, at the University of Chicago (Argonne, Illinois), was the test-plant location of the first self-sustaining nuclear chain reaction. The military constructed another test plant at Oak Ridge, Tennessee that eventually housed two of the three proposed plants for producing fissionable material from uranium and plutonium (the other in Richland, Washington). The military weapons research laboratory in Los Alamos, New Mexico developed the devices to house the nuclear material for use as bombs.

A year after the end of World War II, brought on by the use of two successfully deployed nuclear bombs on Japan, Congress created the Atomic Energy Commission to transition nuclear energy technology from military to civilian control. After President Eisenhower's Atoms for Peace speech, the AEC began developing peaceful uses for nuclear energy. By 1951, the AEC developed and constructed the first nuclear power plant in Arco, Idaho in close collaboration with the military. A year later, the Navy, led famously by Admiral Rickover, began developing the first light-water nuclear submarine in Groton, Connecticut in collaboration with GE and Westinghouse. But because of low coal-generated energy costs and vast U.S. coal reserves, utilities showed little interest in nuclear power.[70] Eventually, under pressure from Congress and the power industry, the AEC developed the Power Demonstration Reactor Program to develop the first series of commercial nuclear power plants.[71] Ultimately, six reactor designs were submitted to the AEC for development, but because of the Navy's success with the light-water reactor design for submarines, AEC chose it as the industry standard.[72] Within the following forty years, 110 light-water nuclear power plants were constructed, largely by private industry, producing 22 percent of U.S. electricity.

Though civilian nuclear energy increased rapidly after control was handed over to the AEC (and later the newly created Department of Energy), military use for nuclear energy was largely relegated to weapons and submarines. The one exception was during the 1960's, when the AEC and the Army jointly studied the use of small nuclear reactors as deployable combat-energy options for bases as well as nuclear-powered airplanes. However, their development was abandoned after it was concluded that such a program would be too costly and time consuming. Ultimately, during the nuclear boom of the 1960s and 1970s, the military ignored nuclear energy and instead used more convenient, low-cost fossil fuels. But by 2009, nuclear energy — more specifically, small advanced modular reactors (SMRs) developed from the Navy's nuclear submarine program — reemerged as a viable electricity generation alternative to fossil fuels. The 2010 National Defense Authorization Act required the DOD to study the feasibility of using nuclear energy on military installations. And in August of 2010, the DOD and the DOE signed a Memorandum of Understanding (MOU) to collaborate on licensing, regulating, developing, and integrating nuclear power at DOD installations.

CURRENT DOD ENERGY ACTIVITIES

It is through policies of innovation and translation that DOD can make the greatest contribution, achieving its own strategic goals while also aiding broader societal needs. The move for a cleaner, more self-sufficient force is not purely rhetoric, as action is already under way. The below examples are not meant to be exhaustive, but serve to illustrate the range and variety of activities.

Key Drivers

Much of the current movement on energy has been driven by congressional legislation and presidential order. On the legislative side, Congress has demonstrated leadership by regularly using the annual National Defense Authorization Act (NDAA) to study the viability and often times promote green fuels and renewable power. Congress expressed its priorities on DOD's energy challenges by creating the Assistant Secretary of Defense for Operational Energy Plans and Programs in the FY 2010 NDAA. Congress has also shown a willingness to establish targets and timetables in conjunction with the White House to help direct DOD's clean energy transformation. Section 203 of the Energy Policy Act of 2005 directs federal agencies to increase their use of electricity generated from renewable energy to 3 percent beginning in 2007, 5 percent in 2010, and 7.5 percent by 2013. This requirement was modified by Executive Order 13423, signed by President Bush in January 2007, which mandates that half of all electricity counting towards the quota must come from new sources established after January 1, 1999. The 2007 NDAA established a further renewable electricity target for DOD, requiring production or procurement of 25 percent of all electricity from renewables by the end of 2025.

The department managed to meet the EPAct renewable energy goals for FY 2009, though this was partly achieved through Air Force procurement of renewable energy certificates, which credit clean energy generated and consumed elsewhere from other existing sources rather than from the establishment of new generation sources for direct consumption.[73] Deputy Under Secretary of Defense for Installations and Environment Dorothy Robyn has called the 2025 goal "a major challenge," and stated that DOD is far from meeting its internal interim target of 14 percent by FY 2011.[74]

Executive Order 13423 also established an energy intensity reduction goal of 3 percent BTUs per square foot per year for federal facilities, with the ultimate goal of a 30 percent overall reduction by 2015. These requirements were later codified in Section 431 of the Energy Independence and Security Act of 2007. The Department of Energy later excluded from these requirements "buildings and facilities in which national security is overwhelmingly the primary function of the buildings and this either 1) prevents the implementation of energy efficiency measures or 2) prohibits reporting of energy consumption, costs, or square footage data on the subject buildings because it would pose a demonstrated security risk."[75] DOD's excluded facilities amount to slightly more than 3 percent of departmental owned buildings.[76] Lastly, executive order 13514, signed by President Obama in 2009, ordered petroleum consumption reductions in non-tactical vehicle fleets by 2 percent each year through 2020. The Department has met both the petroleum reduction and the facilities energy efficiency targets as of FY 2009.

BOX 2: SELECT MILITARY BRANCH TARGETS AND GOALS

Air Force Energy Plan

- 50% of domestic aviation fuel via alternative greener blends by 2016
- 10% less aviation fuel consumption by 2015
- 25% of facility renewable energy via renewable sources by 2025
- 10% per year increases in non-petroleum fuel use in motor vehicle fleet

Navy Energy Goals

- 50% less petroleum use by commercial fleet by 2015
- 50% of onshore energy from alternative sources by 2020
- 50% of installations net-zero by 2020
- 50% of total energy from alternative sources by 2020
- "Great Green Fleet" Strike Group by 2012

Army Strategic Energy Security Goals

- ESG 1. Reduced energy consumption
- ESG 2. Increased energy efficiency across platforms and facilities
- ESG 3. Increased use of renewable/alternative energy
- ESG 4. Assured access to sufficient energy supplies
- ESG 5. Reduced adverse impacts on the environment

Marine Corps Expeditionary Energy Strategy Goals

- Systems and equipment energy use monitoring by 2015.
- 50% efficiency gains in weapons systems, platforms, vehicles and equipment by 2025.
- Increase operational energy from renewables.
- 50% of installation energy from renewables by 2020.
- 50% less petroleum use by commercial fleet by 2015

Internally, DOD has shown leadership in the clean energy transition, not least of which is demonstrated by the military branches' establishment of aggressive internal energy goals that in some cases surpass those required by law.

Internally, DOD has also shown leadership to date in the clean energy transition, not least of which is demonstrated by the military branches' establishment of aggressive internal energy goals that in some cases surpass those required by law (Box 2). To help meet these broad energy goals, the Department signed an MOU with the Department of Energy in July 2010, establishing a framework for interagency cooperation on energy technology and security issues. DOD has already begun to draw on DOE's technical expertise through program work described below. DOD leadership also initiated inclusion of fully-burdened lifecycle fuel cost calculations in planning processes in 2007, a move that gained the weight of law through the NDAA 2009.[77]

More recently, the FY2011 NDAA, signed into law in January, contains provisions for a joint microgrid pilot program spearheaded by DOE's Office of Electricity Delivery and Energy Reliability and DOD's the Environmental Security Technical Certification Program, establishes guidelines for assessing the viability of new renewable energy construct at installations, and requires each branch to develop energy performance plans.

Direct R&D

As mentioned above, sustained R&D support is an important ingredient in what is effectively a search process for new knowledge and technologies. Frequently, more fundamental science is the purview of other entities, but DOD is able to shift basic research forward to the applied phase. The divisions among R&D, demonstration, and procurement in the programs listed here are also not hard-and-fast, as the responsibilities for many of these programs and institutions cut across these categories.

TARDEC

The Army Tank Automotive Research, Development, and Engineering Center (TARDEC) has planned to invest up to $14 billion in vehicle technologies, including efforts to research and develop advanced hybrid-electric combat vehicle systems and advanced battery storage. The program, in partnership with Michigan's defense industry, aims to drastically reduce the number of vehicles that transport fuel, lengthen troop operation times without refueling, and reduce the risks for supply convoys.

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ARPA-E Battery Storage Partnership

Recently, DOD and DOE's Advanced Research Projects Agency-Energy (ARPA-E) partnered to develop two mission-oriented projects that could result in significant cleantech breakthroughs. The first, based on ARPA-E's previous work in power electronics and battery storage, aims to develop an advanced, modular energy storage system that can rapidly charge and discharge. This system would be scalable and useful in combat and at sea. The second, an offshoot of ARPA-E's Grid-Scale Rampable Intermittent Dispatchable Storage Project (GRIDS), aims to accelerate development of next-generation, large-scale grid solutions for use at bases and installations. A goal of the latter project is to find ways to combine onsite renewable electricity generation with microgrids. "Microgrids" are highly localized, base-specific grids that could give installations a level of independence from the public, civilian grid, meaning greater resiliency should the civilian grid go down due to technical failure or external attack. Both projects, which are being pursued under the interagency MOU described above, would allow DOD to reduce installations' risk of disruption to local energy supplies.

Global Solar Prediction Model

The Air Force and DOD are developing a software package that simulates the optimum renewable energy strategy for operating bases worldwide. The software package will recommend energy efficiency and renewable energy options for fixed and temporary installations, both current bases and future plans. The package is being coded to integrate with other DOD software applications, such as mission planning software, to account for the military's numerous energy needs and national security challenges.[78]

Testing and Evaluation: Efficient Installations & FOBs

Fixed installations are a major potential source of efficiency gains through building control technologies and other solutions. Forward operating bases offer a very different challenge: finding independent power sources that can reduce the need for vulnerable forward supply lines without sacrificing warfighting capabilities.

Power Surety Task Force

Recently subsumed into the Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs, the PSTF was initially developed by the Army to foster alternative energy sources in forward areas, to reduce the amount of fuel transported for power generation systems by 40 percent. Development projects were implemented with the explicit goal of deploying the technologies within eighteen months. Projects have been deployed in Afghanistan, Iraq, Djibouti, Kuwait, and the United States.
For example, in Iraq, the program aimed to make temporary structures like tents and living units more energy efficient. Along with the Army's Raid Equipping Force, PSTF demonstrated a technique for insulating temporary structures such as tents and containerized living units. Innovative spray foam was developed that saves increases the energy efficiency of the insulated structure by 40 percent to 75 percent. The technology was effective enough that Iraqi Multi-National Forces awarded a $95 million contract to insulate nine million square feet of temporary structures at a savings of 77, 000 gallons of fuel per day or equivalent to about thirteen truckloads of fuel. The associated cost savings are $230,000 per day (assuming $3 per gallon gasoline), so payback time is roughly fourteen months. The foam technology is now being used in military housing sites and as insulation for permanent military installations.

The goal of the SPIDERS project is to demonstrate a smart microgrid that incorporates numerous combinations of clean energy sources as well as energy efficiency technologies that could be deployed in numerous environments.

ESTCP

The Environmental Security Technology Certification Program, a counterpart to the Strategic Environmental Research and Development Program (SERDP), is one of the key offices in the defense energy space. Whereas SERDP, the Department's environmental science and technology program, focuses on applied research and development of high-risk environmental technologies, ESTCP provides a testing program for both new environmental and energy technologies on the verge of deployment, but in need of validation and demonstration. This function places the ESTCP program at a critical juncture in the energy technology development cycle. As ESTCP Director Marqusee has said, "We can serve as a test bed to get these technologies over the valley of death, and then we can be an early market. The calculation is pretty straightforward. If we test ten technologies, and one is highly successful, we can deploy that in a hundred places and make it profitable."[79] ESTCP works with public, private and university researchers on a similar array of projects as SERDP, and recently announced a major new initiative funding projects exploring microgrids, energy storage, renewable power, building efficiency and control technologies, and energy-use design tools. In one notable Recovery Act-funded project, ESTCP worked with GE to install new smart-grid technology at Twentynine Palms, the country's largest Marine Corps base. GE developed a new microgrid controller installed at the base's central control station. The base is connected to California's power grid, but the control technology will allow the base to function off-grid if necessary while improving coordination and management of supply and demand. The demonstration project is intended to yield insights that could apply to other bases as well as industrial facilities, college campuses, and other places where microgrids could be someday developed.

SPIDERS Microgrid Technology

In addition to the microgrid projects mentioned above, DOD has launched a joint smart-grid project concurrently with partner ARPA-E, the Smart Power Infrastructure

Demonstration for Energy Reliability and Security Program (SPIDERS), working with DHS, five national labs, and local utilities providing power to military bases. The goal is to demonstrate a smart microgrid that incorporates numerous combinations of clean energy sources as well as energy efficiency technologies that could be deployed in numerous environments (i.e. sunny, windy, etc.). SPIDERS managers believe that as the project progresses, private sector smart-grid projects can incorporate the project's system-level planning and technology development to strengthen regional smart grids. The demonstration project is slated to take place at the Marine Corps Camp H.M. Smith in Hawaii.

Afghanistan Solar Power

Remote operating bases, checkpoints, and outposts have become more common in desert warfare, like that in Iraq and Afghanistan. These isolated operations require generators and long supply lines. To reduce these challenges, the military has implemented solar system demonstration projects with deployed battalions that allow continuous power consumption without the use of a generator. These "Green Marines" utilize an innovative system of photovoltaic rechargeable batteries that provide up to 300 watts — equivalent to a small generator — of power, while saving equipment weight on patrol.

The Army is also developing innovative solar energy systems for individual soldier use. Their Rucksack Enhanced Portable Power System (REPPS) is a unique combination of rechargeable batteries and solar panels that can be used in combat to power radios, vehicles, laptops, and other high impact equipment. The goal is to reduce the number of batteries carried by troops to two small rechargeable instead of three 2.2-pound traditional batteries. REPPS is capable of charging these batteries in less than six hours.

REPPS (U.S. Army Photo)

Solar Thermal Bases

In 2009, the Army partnered with clean energy company Acciona Solar Power to build five solar thermal sites at Fort Irwin and its Army National Training Center.[80] Once completed, the solar installations would generate 500 megawatts, significantly more than the 28 megawatts of power Fort Irwin needs at its peak consumption. The remaining 470 megawatts of electricity are to be sold to the local civilian power grid.

And the deal is unique in that DOD is not playing a monetary role in the project. Instead, DOD is renting out its land to Acciona and developer Clark Energy Group, both of which are funding the project's $1.5 billion cost. The project licensing and regulatory phase is schedule to be completed by the end of 2011 and the project is expected to generate enough electricity to power all of Fort Irwin by 2014. The full project is expected to be completed by 2022.

RFAST-C

The Army's Research, Development and Engineering Command (RDECOM) recently announced the deployment of a large technical team to Bagram Airbase in Afghanistan.[81] Dubbed the RDECOM Field Assistance in Science and Technology Center (RFAST-C), the task force will provide on-the-ground assistance to address technology issues on the front lines, including in the energy realm. RDECOM is the parent unit of the Army Research Laboratory and other entities that work on an array of energy challenges from storage to conversion to intelligent management, a portfolio that also includes many of the programs listed in this overview.

Testing and Evaluation: Fuel for Vehicles, Aircraft, and Battleships

Liquid fuels for mobile units and equipment represent roughly three-quarters of DOD's energy purchases. Developing affordable alternatives could shield the military from petroleum price spikes and offer advantages in the logistics of supply.

Air Force: Synthetic fuels / Biofuels

The Air Force has several initiatives in alternative fuels. It has certified the B-52H to use a 50 percent blend of synthetic fuel and typical jet fuel. In 2007, a C-17 completed the first transcontinental flight using a synthetic fuel blend, and a B-1 flew at supersonic speeds using the same blend in 2008. Tests are underway to certify the C-17, B-1, and F-22 for a synthetic fuel mix, with an objective to certify the entire fleet by early 2011. Ultimately, the Air Force's goal is to obtain 50 percent of its fuel using greener sources, such as biofuels or those obtained through carbon capture methods.[82] In addition, the Air Force is developing an Assured Aerospace Fuels Research Facility (AFRF) to study and evaluate how alternative fuels effect jet operation, efficiency, and carbon footprint. Joint studies sponsored by the Air Force and the DOE have shown the potential of using biomass to power vehicles while significantly reducing carbon emissions. Additionally, the Air Force has partnered with DARPA and private industry to investigate the suitability of second- and third-generation biomass-derived transportation fuels like cellulosic biomass, algae oils, animal fats, and others as renewable feedstock options for aviation use.

Refueling B-52 (U.S. Air Force photo/Staff Sgt. Kamaile O. Long)

The military branches and DESC are also working closely with the Commercial Aviation Alternative Fuels Initiative (CAAFI), which represents the airlines, airports, and manufacturers, to efficiently and economically certify the commercial airline fleet. This effort builds on the fact that many aircraft in the commercial and military fleets share common platforms, systems and engines.

Navy Clean Energy

The Navy is conducting significant research on the effective use of alternative logistics fuels in naval power systems.[83] In collaboration with the Department of Agriculture, the Navy is developing advanced biofuels and renewable energy systems specifically for creating a 'Green Fleet' naval carrier strike force. Among these initiatives is the launching of the *U.S.S. Makin Island*, a carrier with a hybrid-electric engine expected to save $250 million in fuel costs over forty years.[84] These efforts will also address the impacts biofuels have on engine operation and fuel distribution, as well as optimizing fuel composition and improving the combustion process. While transitioning to biofuels would reduce the Navy's carbon emissions, it would also reduce a ship's heat signature, limiting an enemy's ability to detect it. The Navy is also moving forward with plans to deploy biofuels for air combat. In 2009, DESC awarded a contract for 40,000 gallons of Camelina-based jet fuel for use in fighter jets (Camelina is a flowering plant, not part of the United States food supply, capable of producing biodiesel and bio jet fuel), and has tested the fuel in an F/A-18 "Green Hornet."[85] The Navy also requested an additional 150,000 gallons of algae-based biofuel last September.[86] The Navy is also working to harness ocean power, via wave-energy technology. The Navy has contracted Ocean Power Technologies to develop an ocean-wave device that connects directly with an electricity grid to provide clean energy. It has also partnered with Lockheed Martin to develop breakthrough technology that taps into the stored solar energy of the ocean to power installations.

F/A-18 Hornet (U.S. Navy photo by Mass Communication Specialist Seaman Rosa A. Arzola)

Procurement

The potential for a large, stable, demanding market is an important mechanism for driving innovation and scale-up of new technologies. Many of the technologies listed above are still in their testing stages, but much of the development appeal for private sector actors is due to the potential payoff in the form of a large and stable market.

Advanced Geothermal Power

The Navy has a history of using geothermal to power some of their facilities, the earliest case being a 270 megawatt plant at the China Lake, California Naval Weapons Facility. But increasingly, the Navy has sought to build advanced geothermal plants at other facilities including bases and housing. Most recently the Navy is seeking to use procurement funds to build, in partnership with the private sector, a thirty-plus megawatt plant at Fallon Naval Air Station, Nevada. The program has been so successful that the Navy hopes to receive authority to conduct similar programs using other clean energy sources. The Army has used its procurement authority to conduct a similar program at the Hawthorne Army Depot in Nevada.[87]

Alternative Energy Vehicles

In 2009, the Army began taking steps to meet its EISA 2007 goal by replacing its non-tactical light-duty vehicle fleet on bases with Neighborhood Electric Vehicles (NEVs). The Army hopes to lease up to 4,000 of these golf-cart sized plug-in electric vehicles that can travel up to thirty-five mph for up to eight hours on one charge, and hopes to ultimately replace up to 28,000 gasoline-support vehicles at several dozen installations.[88]

LOOKING AHEAD

DOD's role in developing innovative technologies is historically significant and highly relevant to the modern energy technology challenge. Like past technologies developed with DOD involvement, in partnership with other entities and driven by strategic military needs, energy generation and efficiency represent dual-use technologies useful for both military and civilian purposes. DOD's vital and robust role in developing next-generation technology to maintain an agile fighting force, increase troop safety, and achieve its mission must continue.

DOD's vital and robust role in developing next-generation technology to maintain an agile fighting force, increase troop safety, and achieve its mission must continue.

In pursuing energy technology to fulfill its primary strategic role, DOD is also fulfilling another important role. DOD is acting as a critical bridge in the broader clean technology innovation lifecycle, helping technologies developed in public and private laboratories to hurdle the "valley of death" and begin to scale to commercial viability. Because of its mission and size, DOD is well-positioned to serve as this bridge, providing testing, demonstration and validation at a key point in the technology development cycle, and serving as a potential early market. History is clear about DOD's pivotal role in moving numerous technologies in multiple industries from concept to market, including nuclear energy, GPS, satellite communications, and aviation. We could likewise be looking back someday and commenting upon the pivotal role DOD played in developing and deploying advanced solar-thermal power plants, next-generation energy storage, and innovative smart-grid technologies.

There are two key conditions that must be met to ensure continued success. First, Congress, to its credit, has taken some significant steps to help drive this energy transformation. Continued, responsible support for DOD's efforts should continue — both through direct support, as well as by ensuring that the overall energy innovation system is robust enough to provide DOD with effective and willing partners in government, in academia, and in the private sector. This leads into the second point: historically, DOD's technological development efforts required substantial partnership activities, with NACA, NASA, NSF, and a countless legion of university researchers and private-sector firms. The lesson learned is one of collaboration and information sharing: given the complex nature of technology development and innovation, transparent partnership and collaboration is needed to maximize opportunities to innovate, identify key opportunities and overcome obstacles. The fact that DOD can both contribute to its own mission and fulfill a translational role in the technology development cycle represents a "win-win" combination for a nation in need of energy innovation.

ENDNOTES

1. Sharon Burke and Dorothy Robyn, "Empowering Defense Through Energy Security," *The White House Blog*, October 18, 2010, http://www.whitehouse.gov/blog/2010/10/18/empowering-defense-through-energy-security.
2. For example, see the 2006 report by the Council on Foreign Relations' Independent Task Force on Energy and U.S. Foreign Policy, headed by former Director of Central Intelligence and former Energy Undersecretary John Deutsch and former Defense and Energy Secretary James Schlesinger Independent Task Force on Energy and U.S. Foreign Policy, *National Security Consequences of U.S. Oil Dependency*, Independent Task Force Report (Council on Foreign Relations, 2006), http://www.cfr.org/energy-security/national-security-consequences-us-oil-dependency/p11683.
3. Deloitte, *Energy Security: America's Best Defense* (Washington, D.C., November 2009), 14, http://www.deloitte.com/us/aerospacedefense/energysecurity.
4. Independent Task Force on Energy and U.S. Foreign Policy, *National Security Consequences of U.S. Oil Dependency*, 27.
5. U.S. Joint Forces Command, *Joint Operating Environment 2010* (Suffolk, VA, February 2010), 27, http://www.jfcom.mil/newslink/storyarchive/2010/JOE_2010_o.pdf.
6. Annie Snider, "Energy, Environment Opportunities Grow Despite DOD Belt-tightening," *Greenwire*, January 26, 2011, http://www.eenews.net/public/Greenwire/2011/01/26/4.
7. Colonel Gregory J. Lengyel, USAF, *Department of Defense Energy Strategy: Teaching an Old Dog New Tricks*, 21st Century Defense Initiative (Washington, D.C.: The Brookings Institution, August 2007), 21, http://www.brookings.edu/~/media/files/rc/papers/2007/08defense_lengyel/lengyel20070815.pdf.
8. The Electrification Coalition, *Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security*, November 2009, 30, http://www.electrificationcoalition.org/electrification-roadmap.php.
9. U.S. Joint Forces Command, *Joint Operating Environment 2010*, 26.
10. U.S. Department of Energy, *Annual Report to Congress on Federal Government Energy Management and Conservation Programs Fiscal Year 2007* (Office of Energy Efficiency and Renewable Energy, Federal Energy Management Program, January 27, 2010), 90, http://www1.eere.energy.gov/femp/regulations/facility_reports.html.
11. U.S. Defense Energy Support Center, *DESC Fact Book FY 2009* (U.S. Department of Defense, 2010), 21, http://www.desc.dla.mil/DCM/Files/FY09%20Fact%20Book%20%288-10-10%29.pdf.
12. Ibid., 22.
13. U.S. Department of Defense, *Department of Defense Annual Energy Management Report: Fiscal Year 2009* (Office of the Deputy Under Secretary of Defense for Installations and Environment, May 2010), http://www.acq.osd.mil/ie/energy/energymgmt_report/main.shtml.
14. U.S. Defense Science Board Task Force on DoD Energy Strategy, *More Fight – Less Fuel* (Washington, D.C.: U.S. Department of Defense, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, February 2008), 13, http://www.acq.osd.mil/dsb/reports2000s.htm.
15. U.S. Joint Forces Command, *Joint Operating Environment 2010*, 29.
16. Clifford Krauss, "A Dark Warning on Global Oil Demand," *New York Times Green Blog*, March 8, 2011, http://green.blogs.nytimes.com/2011/03/08/a-dark-warning-on-global-oil-demand/.
17. U.S. Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting Through Reduced Fuel Burden* (Washington, D.C.: U.S. Department of Defense, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, January 2001), 9.
18. Deloitte, *Energy Security: America's Best Defense*, 3.
19. Ibid., 15.
20. U.S. Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting Through Reduced Fuel Burden*, 13.
21. Ibid., 17.
22. Deloitte, *Energy Security: America's Best Defense*, 16.
23. Elisabeth Rosenthal, "U.S. Military Orders Less Dependence on Fossil Fuels," *The New York Times*, October 4, 2010, sec. Science / Environment, http://www.nytimes.com/2010/10/05/science/earth/05fossil.html.

24. Ibid.
25. U.S. Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting Through Reduced Fuel Burden*, 13.
26. John A. Alic, *Trillions for Military Technology: How the Pentagon Innovates and Why It Costs So Much*, First Edition. (New York: Palgrave Macmillan, 2007), 112.
27. Colonel Gregory J. Lengyel, USAF, *Department of Defense Energy Strategy: Teaching an Old Dog New Tricks*, 13-14.
28. U.S. Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting Through Reduced Fuel Burden*, 15.
29. Dorothy Robyn, "Statement of Deputy Under Secretary of Defense for Installations and Environment Dr. Dorothy Robyn before the House Armed Services Committee Subcommittee on Readiness," February 24, 2010, http://www.acq.osd.mil/ie/download/robyn_testimony022410.pdf.
30. U.S. Department of Defense, *Department of Defense Annual Energy Management Report: Fiscal Year 2009*, 3.
31. CNA, *Powering America's Defense: Energy and the Risks to National Security*, May 2009, 15, http://www.cna.org/sites/default/files/Powering%20Americas%20Defense.pdf.
32. Siobhan Gorman, "Electricity Grid in U.S. Penetrated By Spies," *Wall Street Journal*, April 8, 2009, sec. Technology, http://online.wsj.com/article/SB123914805204099085.html.
33. American Society of Civil Engineers, "Energy Grade 2009," *Report Card for America's Infrastructure*, 2009, http://www.infrastructurereportcard.org/fact-sheet/energy.
34. U.S. Department of Defense, *Quadrennial Defense Review Report* (Washington, D.C., February 2010), 87, http://www.defense.gov/qdr/.
35. U.S. Defense Science Board Task Force on DoD Energy Strategy, *More Fight – Less Fuel*, 18.
36. Quotes U.S. Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting Through Reduced Fuel Burden*, 10.
37. J. Randy Forbes, "Energy security: Important to budget, national defense," *The Hill's Congress Blog*, March 23, 2011, http://thehill.com/blogs/congress-blog/homeland-security/151449-energy-security-important-to-budget-national-defense.
38. Martin I. Hoffert et al., "Energy implications of future stabilization of atmospheric CO2 content," *Nature* 395, no. 6705 (October 29, 1998): 881-884.
39. Alvin Powell, "U.S. investigating ways to conserve fuel in the field," *PhysOrg*, March 4, 2011, http://www.physorg.com/news/2011-03-ways-fuel-field.html.
40. Lewis M. Branscomb and Philip E. Auerswald, *Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development* (National Institute of Standards and Technology. Economic Assessment Office., November 2002), 35, http://www.atp.nist.gov/eao/gcr02-841/contents.htm.
41. Ibid., 63.
42. For an excellent overview of commercialization challenges in the energy sector, see Venkatesh Narayanamurti et al., *Transforming the Energy Economy: Options for Accelerating the Commercialization of Advanced Energy Technologies*, Findings of the Executive Session on Demonstrating New Energy Technologies at Harvard Kennedy School, December 1-2, 2010 (Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School, February 2011), http://belfercenter.ksg.harvard.edu/files/ETIP_Workshop_Report_Feb_2011_2.pdf.
43. Charles Weiss and William B. Bonvillian, *Structuring an Energy Technology Revolution*, 1st ed. (Cambridge, MA: The MIT Press, 2009), 34.
44. Daniel Sarewitz and John Alic, "Accelerating Technological Advance for Climate Change: Testimony before the U.S. Senate Committee on Energy and Natural Resources," December 2, 2009, 4, http://www.cspo.org/library/reports/.
45. Alic, *Trillions for Military Technology*, 78.
46. See Michael E. Porter, "The Competitive Advantage of Nations," *Harvard Business Review*, April 1990.
47. *Energy Innovation 2010 - Part 4*, 2010, http://www.youtube.com/watch?v=lUu23qyLO2M&feature=youtube_gdata_player.
48. Dorothy Robyn, "Statement of Deputy Under Secretary of Defense for Installations and Environment Dr. Dorothy Robyn before the House Armed Services Committee Subcommittee on Readiness."

49. These case studies draw heavily from Vernon W. Ruttan, *Is War Necessary for Economic Growth? Military Procurement and Technology Development* (New York: Oxford University Press US, 2006).
50. Alic, *Trillions for Military Technology*, 57.
51. Ibid., 58-59.
52. Ruttan, *Is War Necessary for Economic Growth?*, 36.
53. Ibid., 41.
54. Roger E. Bilstein, *Orders of Magnitude: A History of the NACA and NASA, 1915-1990*, The NASA History Series SP-4406 (Washington, D.C.: U.S. National Aeronautics and Space Administration, Office of Management, Scientific and Technical Information Division, 1989), 10, http://history.nasa.gov/SP-4406/contents.html.
55. Ibid., 22.
56. John Alic et al., "A New Strategy for Energy Innovation," *Nature* 466, no. 7304 (July 15, 2010): 316-317.
57. Darian Unger and Howard Herzog, *Comparative Study on Energy R&D Performance: Gas Turbine Case Study* (MIT Energy Laboratory, August 1998), 5, http://web.mit.edu/energylab/www/pubs/el98-003a.pdf.
58. Ruttan, *Is War Necessary for Economic Growth?*, 101.
59. John A. Alic et al., *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, MA: Harvard Business School Press, 1992), 258.
60. Ruttan, *Is War Necessary for Economic Growth?*, 96.
61. For a full account, see U.S. Department of Defense, VHSIC Program Office, *Very High Speed Integrated Circuits Final Program Report 1980-1990* (Office of the Under Secretary of Defense for Acquisition, Deputy Director, Defense Research and Engineering for Research and Advanced Technology, September 30, 1990), http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA230012.
62. David C. Mowery and Richard N. Langlois, "Spinning Off and Spinning On(?): the Federal Government Role in the Development of the US Computer Software Industry," *Research Policy* 25, no. 6 (September 1996): 947-966.
63. Loyd S. Swenson, Jr, James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury*, The NASA History Series SP-4201 (Washington, D.C.: U.S. National Aeronautics and Space Administration, NASA History Office, Office of Policy and Plans, 1998), 69, http://www.archive.org/details/thisnewoceanhist00swen.
64. Ibid., 99-100.
65. Ruttan, *Is War Necessary for Economic Growth?*, 135.
66. Robert J. Danchik, "An Overview of Transit Development," *Johns Hopkins Applied Physics Laboratory Technical Digest* 19, no. 1 (March 1998): 25.
67. David Braunschvig, Richard L. Garwin, and Jeremy C. Marwell, "Space Diplomacy," *Foreign Affairs* 82, no. 4 (July 1, 2003): 157.
68. U.S. Air Force, "Factsheets : 2nd Space Operations Squadron," *Schriever Air Force Base*, January 2010, http://www.schriever.af.mil/library/factsheets/factsheet.asp?id=4045.
69. Ruttan, *Is War Necessary for Economic Growth?*, 76.
70. Alic, *Trillions for Military Technology*, 166.
71. Ruttan, *Is War Necessary for Economic Growth?*, 76.
72. Alic, *Trillions for Military Technology*, 168.
73. U.S. Department of Defense, *Department of Defense Annual Energy Management Report: Fiscal Year 2009*, 6.
74. Dorothy Robyn, "Statement of Deputy Under Secretary of Defense for Installations and Environment Dr. Dorothy Robyn before the House Armed Services Committee Subcommittee on Readiness."
75. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Guidelines Establishing Criteria for Excluding Buildings from the Energy Performance Requirements of Section 543 of the National Energy Conservation Policy Act as Amended by the Energy Policy Act of 2005," January 27, 2006, http://www1.eere.energy.gov/femp/pdfs/exclusion_criteria.pdf.
76. U.S. Department of Energy, *Annual Report to Congress on Federal Government Energy Management and Conservation Programs Fiscal Year 2007*, 42.

77. U.S. Defense Science Board Task Force on DoD Energy Strategy, *More Fight – Less Fuel*, 99.
78. U.S. Department of Defense, "Near Term Energy Efficient Technologies (NTEET) Program Plan," June 2010, http://www.defense.gov/recovery/plans_reports/2010/pdfs/DoD%20NTEET%20Program%20Plan%20Update_FINAL_062110.pdf.
79. *Energy Innovation 2010 - Part 4*.
80. C. Todd Lopez, "Agreement signed at Fort Irwin to create solar power," *Army.mil*, October 16, 2009, http://www.army.mil/-news/2009/10/16/28911-agreement-signed-at-fort-irwin-to-create-solar-power/.
81. Dan Lafontaine, "Army deploys science, technology center to Afghanistan," *Army.mil*, February 10, 2011, http://www.army.mil/-news/2011/02/10/51640-army-deploys-science-technology-center-to-afghanistan/.
82. Shaun McGlaun, "USAF Certifies First Aircraft for Biofuel Use," *DailyTech*, February 14, 2011, http://www.dailytech.com/USAF+Certifies+First+Aircraft+for+Biofuel+Use/article20902.htm.
83. U.S. Department of Agriculture, "USDA, Navy Highlight New Partnership to Power Navy Fleet with Biofuels," press release, *Navy.mil*, April 6, 2010, http://www.navy.mil/search/display.asp?story_id=52437.
84. Mark Thompson, "The Navy Goes in Search of a U.S.S. Prius," *Time*, April 27, 2010, http://www.time.com/time/world/article/0,8599,1984626,00.html.
85. "Camelina Biofuel Powers US Navy F/A-18 Test Flight," *Renewable Energy World*, April 26, 2010, http://www.renewableenergyworld.com/rea/news/article/2010/04/camelina-biofuel-powers-us-navy-fa-18-test-flight.
86. Yoni Cohen, "Green Startups Target the Department of Defense," *Greentech Media*, March 11, 2011, http://www.greentechmedia.com/articles/read/green-startups-target-the-department-of-defense/.
87. Kevin Ahern, "Defense Logistics Agency: Installation Energy" (presented at the 2010 Asia Pacific Clean Energy Summit and Expo, Honolulu, HI, September 1, 2010), http://www.ct-si.org/events/APCE/sld/pdf/35.pdf.
88. Irma Avalos, "Electric vehicles help post go 'Army Green, Army Strong'," *Army.mil*, March 19, 2010, http://www.army.mil/-news/2010/03/19/36128-electric-vehicles-help-post-go-army-green-army-strong/.

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