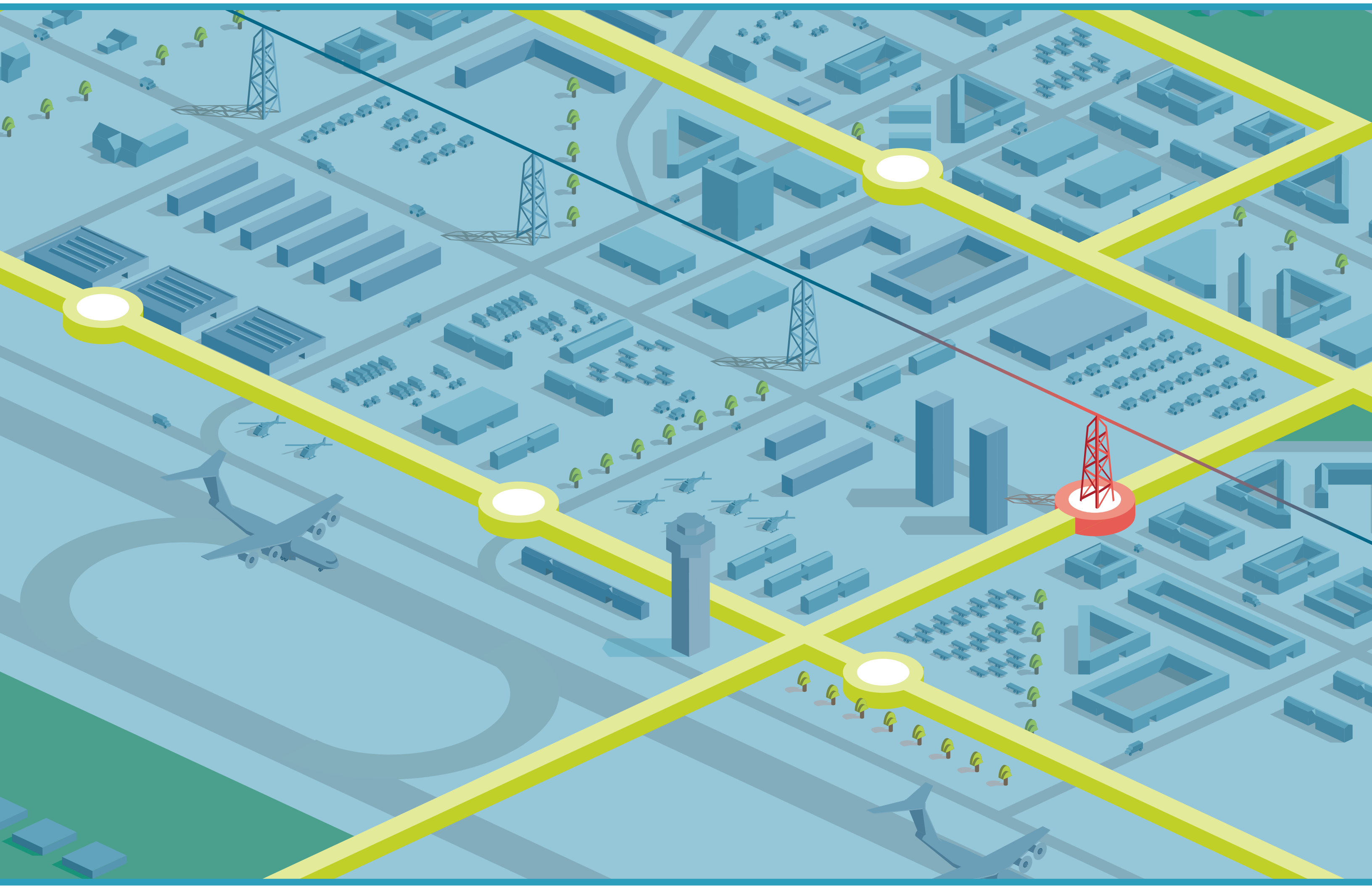
# Power Begins at Home:

## Assured Energy for U.S. Military Bases



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## Assured Energy for U.S. Military Bases

Commissioned by The Pew Charitable Trusts
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| **AEMR** | Annual Energy Management Report |
| **BTU** | British Thermal Unit |
| **CBECS** | Commercial Building Energy Consumption Survey |
| **CHP** | Combined Heat and Power |
| **DCI** | Defense Critical Infrastructure |
| **DER** | Distributed Energy Resource |
| **DoD** | Department of Defense |
| **ESPC** | Energy Savings Performance Contract |
| **ESTCP** | Environmental Security Technology Certification Program |
| **EUI** | Energy Use Intensity |
| **GAO** | Government Accountability Office |
| **GSA** | General Service Administration |
| **kW** | kilo Watt |
| **MED** | Major Event Days |
| **MILCON** | Military Construction |
| **MW** | Mega Watt |
| **MWac** | Mega Watt of AC power |
| **NREL** | National Renewable Energy Laboratory |
| **O&M** | Operations and Maintenance |
| **OSD** | Office of Secretary of Defense |
| **RPAD** | Real Property Asset Database |
| **SAIDI** | System Average Interruption Duration Index |
| **SAIFI** | System Average Interruption Frequency Index |
| **SCADA** | Supervisory Control and Data Acquisition |
| **SRM** | Sustainment, Restoration, and Modernization |
| **UESC** | Utility Energy Savings Contract |
| **VOLL** | Value of Lost Load |

# Acknowledgments

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# Executive Summary

## The Challenge of Energy Security

The U.S. Department of Defense's (DoD's) fixed installations are the backbone of American military readiness. Although U.S. military bases have long supported the maintenance and deployment of weapons systems and the training and mobilization of combat forces, increasingly, they provide direct support for combat operations and serve as staging platforms for humanitarian and homeland defense missions. Energy is the lifeblood of military bases: in FY 2015, DoD's fixed installations, which contain 284,000 buildings and 2 billion square feet of space, consumed 1 percent of the total electric energy consumed in the United States, at a cost of almost $4 billion. The military's use of installation energy entails risk as well as cost. Installations are dependent on a commercial grid that is vulnerable to disruption due to aging infrastructure, severe weather, and physical and cyberattacks. Major power outages are growing in number and severity in the United States, and military bases experience more and longer duration outages than typical utility customers because many bases are located in outlying areas.

## Current Strategy: Standalone Backup Generators

The military has long relied on standalone generators with short-term fuel stockpiles to provide emergency backup power for buildings with "critical loads"—functions related to housing, life safety and health, public safety, communications, environmental systems, and critical mission support. A large base has 100-200 standalone generators, each hard-wired to a single building. Many individual tenant-operators on the base purchase and maintain their own generators with little or no coordination with one another or with the base's central staff.

Standalone generators have endured as the military's strategy for energy security because of the high degree of operator control they afford and because they are affordable. However, the limitations of the current strategy are becoming increasingly problematic:

- Efficient Sizing: Because standalone generators are disconnected from one another, each one must be sized to meet a building's peak load. Although DoD guidance calls for generators to be sized at 200 percent of their estimated peak load, in practice, many generators exceed that standard, resulting in higher capital costs, excessive fuel use, and unnecessary wear and tear.
- Maintainability: Maintenance, inspection, and testing of standalone generators on military bases are inadequate; for example, only 60 percent of bases perform the required testing.
- Reliability: Inadequate maintenance and testing causes standalone generators to fail at a higher than expected rate. Even more problematic is the lack of N + X reliability, where "X" is the number of independent backups to the first line of defense (standalone generators).
- Flexibility: Standalone generators cannot accommodate the inevitable changes in the military's electric power needs. Because generators are hardwired to the buildings they support, the process of moving one to a new location is costly and time-consuming, requiring de-commissioning, transport, and re-commissioning.
- Coverage: The reliance on standalone generators forces operators to make an "all or nothing" decision: critical loads get 24/7, highly reliable backup power, and non-critical loads get no (assured) backup power. However, energy security needs are not binary. Certain intermediate loads could advance the mission during an emergency if they had backup power, and some critical loads could get by with a lower level of backup protection.

Although the benefits of the current energy security strategy certainly outweigh its costs, the more relevant question is whether the strategy is cost-effective. Stated differently, would an alternative energy security strategy yield more benefits for the same cost?

## An Alternative Strategy: Large-Scale Microgrids

A microgrid is a local system of distributed energy resources (DERs) and electrical loads that can operate as a single entity either in parallel to the commercial grid or independently (“island” mode). Microgrids have major advantages over standalone generators for providing energy security:

- Efficient Sizing: A microgrid shares resources across a large number of buildings on an installation which dramatically reduces the volume of power currently needed to back up a base’s critical loads.
- Maintainability: A microgrid relies on a few, large generation units that often have standardized features, making it far easier and less expensive to maintain.
- Reliability: A microgrid can readily provide a high level of reliability (N+1 or N+2) because the networked structure ensures that if any single generation asset fails, another one can instantly take its place, and it takes little additional backup power to provide even greater reliability.
- Flexibility: Because microgrids are networked, they can respond to changes in electricity needs at no cost as missions change and requirements evolve. Unlike standalone generators, microgrids can integrate the power from renewable energy sources.
- Coverage: Because a microgrid is sized to meet the annual critical peak loads of a base, excess generation is almost always available and can serve any load to which the microgrid is connected, including those loads whose priority falls between “critical” and “non-critical.”

Microgrids have one drawback: if an installation’s distribution system is unreliable, power will not reliably flow to critical loads. However, the base can address the problems with its distribution system—for example, by trimming trees and putting certain wires underground.

## Cost Comparison of Microgrids and Standalone Generators

To compare the cost of microgrids and standalone generators, we carried out a detailed modeling exercise based on a hypothetical large military installation with a peak demand of 50 megawatts (MW), of which 20 MW is critical. We calculated the cost per kilowatt (kW) to protect the installation’s critical loads under two nearly identical standalone generator scenarios (base cases) and two microgrid scenarios. The microgrid scenarios differed solely with respect to the DERs employed to power the microgrid: all large diesel generators versus a mix of large diesel and baseload natural gas generators. We modeled each of the four energy security scenarios in each of three regional electricity markets (Mid-Atlantic/Northeast, Southeast, and California).

Under the two base cases (standalone generators), the annual cost to protect a kW of critical load is $80 to $85. The cost is the same in all three markets because the major cost drivers (capital and operations and maintenance, or O&M) do not vary by region.

Under the microgrid scenario with large diesel generators only, the comparable figure ranges from $31 (Mid-Atlantic/Northeast) to $61 (California). This means that an installation anywhere in the country will save money by replacing its standalone generators with a diesel-only microgrid, and the savings will range from $8M to $20M over the 20-year life of the microgrid.  The biggest source of savings in all three regions is O&M, followed by the ability to participate in demand response programs where they are available, and peak shaving.

Under the hybrid microgrid scenario (large diesel and natural gas generators), the annual cost to protect a kW of critical load ranges widely—from negative $80 in California, to positive $93 in the Mid-Atlantic/Northeast and positive $195 in the Southeast. These results reflect the price of conventional power in the three regions; the lower that price, the less attractive it is to replace conventional power with power from baseload natural gas generators. While this particular microgrid scenario is more expensive than standalone generators in the Mid-Atlantic/Northeast and the Southeast, in California, this scenario is not only less expensive than standalone generators, its net cost is negative. The result means that at bases in California, the military could protect its critical load for free and create additional savings of $1.6M, a year or $32M over 20 years.

These compelling results nevertheless understate the case for microgrids. First, by design, we ignored the non-cost advantages of microgrids (e.g., greater reliability and coverage). Second, by limiting our analysis to large diesel and natural gas generators, we omitted a host of other DERs, some of which would allow microgrids to demonstrate even higher performance and lower life-cycle costs. Third, to keep our analysis simple, we omitted asset uses (e.g., sophisticated load shedding across an entire base) that would yield additional savings.

## Implementation Issues

A Service faces a choice as to whether to own and operate the microgrid or purchase the stream of benefits as a service from a private owner-operator. We argue that private provision is preferable. First, the microgrids used on fixed installations are not unique to the military; by taking advantage of commercial practices, DoD can leverage advances in the technology and the corresponding cost reductions. Second, the energy markets are volatile. Although a microgrid can generate significant revenue, the amount can vary widely depending on market conditions that DoD is not sufficiently nimble to exploit. Third, the design and operation of a microgrid require sophisticated knowledge that DoD lacks, and the two activities benefit from a proper alignment of incentives. By buying energy security as a service, DoD can take advantage of more integrated solutions. Finally, the acquisition of microgrids as a service is a prerequisite to the use of third-party financing.

Despite their desire to host microgrid demonstrations, the Services are only rarely acquiring large-scale systems (whether as an asset or a service). One barrier to microgrid implementation is DoD technical guidance on energy security, auxiliary power, and the design of backup power systems. Such guidance is diffuse and dated, and some of it restricts the use of the very technologies we have modeled for microgrid systems. A second barrier is the lack of guidance on how to define energy security requirements. Microgrids make possible a more nuanced approach—one that defines "security" along multiple dimensions and sets different requirements for different loads. Military staff, accustomed to an "all or nothing" approach to the specification of critical loads, will need education and formal guidance to shift to a new approach. A third barrier is DoD's approach to funding standalone generators. Although our analysis shows that microgrids can generate sufficient savings to attract third-party financing, the Services report that their proposed projects do not "pencil out." The difference is accounting: whereas we took into account all of the costs that standalone generators impose (capital, O&M, etc.), DoD's ledger provides no such recognition, because those costs are paid out of multiple budget activities and by dozens of tenants. For third-party financing to pencil out, DoD needs to recognize these costs.

## Renewable Energy and Energy Security

Renewable energy can enhance the energy security of a military installation. Although the Services have been aggressive in working with the private sector to develop renewable generation assets, energy security has not been a major consideration; rather, the Services' driving goal has been to reduce their utility costs and meet their respective goals to produce or procure 1 gigawatt (GW) of renewable energy. A notable exception to this pattern is the Navy's Enhanced Use Lease (EUL) projects, where the Navy is declining monetary lease payments for the land in favor of in-kind consideration in the form of upgrades to the base's electrical distribution system and equipment such as controls and transformers. These upgrades, when combined with a microgrid, will enable renewable energy to contribute to energy security.

More broadly, DoD needs to apply the lessons learned by the Services in pursuit of their 1 GW goals to the mission critical pursuit of energy security—strong Service leadership; measurable goals with a foreseeable deadline; and an enterprise approach using central management offices to oversee execution and work closely with industry.

## Energy Efficiency and Energy Security

Energy efficiency and energy security are inextricably linked. The cost of providing energy security on a military base is a function of the peak power required for protected loads; thus, when the base reduces those power needs through energy conservation and efficiency, its energy security costs drop proportionately. To date, the Services have made only limited improvement in their energy efficiency, in large part because they view energy efficiency as a way to comply with statutory goals and executive orders rather than as an essential element of energy security.

We compared the energy efficiency of DoD buildings, commercial buildings, and buildings owned by the General Services Administration, controlling for building size, function and, geographic location. Based on our analysis, we estimate that DoD could reduce its energy consumption by 15-35 percent. Taking the mid-point of that range as our point estimate, we conclude that DoD is leaving $1 billion a year (25 percent of its $4 billion-a-year utility bill) on the table.

Two factors largely explain DoD’s failure to take advantage of energy conservation measures that are commercially available and that would pay for themselves through energy savings. One is the lack of utility meters in individual buildings. As of last year, only 23 percent of DoD’s electric load was being captured by an advanced metering system. While the Services cite budget constraints and cybersecurity concerns as impediments to metering, neither justification withstands scrutiny. The second reason DoD is missing opportunities to improve energy efficiency is the constraints that Congress and DoD place on the process for investing in building upgrades. The key problem is the inability to combine third-party financing from energy-savings contractors with funding for capital improvements, which precludes the Services from capturing the important synergies between energy conservation measures and capital investment.

## Should DoD “Put a Value on Energy Security”?

There is growing support for the idea that DoD should “put a value on energy security”—i.e., pay a premium for renewable energy and microgrid projects that do not appear to make sense purely on business grounds so as to attract third-party financing. Based on the analysis presented in this report, we believe proposals to “put a value on energy security” are misguided. First, implicit in these proposals is a belief that DoD does not already assign such a value. However, DoD puts a value on energy security now—namely, the cost (properly calculated) of its current strategy of installing and maintaining a standalone generator at every building that houses a critical load. Second, while DoD should incorporate security considerations into its energy investment decisions, that means using the cost of standalone generators as the measure of the value of energy security. Third, our analysis demonstrates that in most parts of the country, microgrids provide more energy security for less money than the Services are currently paying for standalone generators. In short, the Services do not need to pay a premium for energy security.

## How Much Energy Security Should DoD Buy?

Bases provide backup power for critical functions as a matter of policy. By contrast, the decision to back up “intermediate loads” should be made purely on business grounds. We calculated the relative costs and benefits of standalone generators to protect non-critical loads from outages of varying durations. Over a 20-year period—the life of a generator—a base can expect to experience an outage lasting one to three days, and it has a 50/50 chance of experiencing a week-long outage. For any of those outage scenarios, the benefits of standalone generators outweigh the costs, and for outages of more than a day, that benefit-cost ratio is very high. (Given their superior economics, the benefit-cost ratio for microgrids would be even higher. ) Stated differently, purely from a business standpoint, DoD is currently underinsuring many non-critical loads on its military bases, including its R&D laboratories, industrial facilities, and many other important functions. While these activities are not “critical” in the sense of meriting emergency backup power, they are economically important—and thus expensive to suspend in the event of an outage.

# I Introduction

The U.S. Department of Defense's (DoD's) fixed installations—or military bases—are the backbone of American military readiness. U.S. military bases have long supported the maintenance and deployment of weapons systems and the training and mobilization of combat forces. Increasingly, they perform "reachback" functions in direct support of combat operations. For example, DoD operates remotely-piloted aircraft or drones in Afghanistan from a facility in Nevada and analyzes battlefield intelligence at data centers in the United States. In addition to their combat support role, U.S. military installations are becoming more important as staging platforms for homeland defense missions.[1]

Energy is the lifeblood of military installations. Just as the Armed Forces rely on petroleum and other forms of "operational energy" to drive ships, fly aircraft, and support troops in combat zones, they depend on "facility energy"—largely electricity—to power their fixed installations. In Fiscal Year (FY) 2015, DoD's fixed installations in the United States and overseas consumed more than 200,000 billion BTUs, which represents 29 percent of total DoD energy consumption and is equal to just over 1 percent of all the electricity consumed in the United States. [2]

The military's use of facility energy carries a hefty price tag: DoD's utility bill is almost $4 billion per year. That cost reflects the sheer size of the military's real property portfolio: DoD owns 284,000 buildings and nearly 2 billion square feet of building space—more than four times the area of all of the commercial office space in Manhattan.

The military's use of facility energy entails risk as well as cost. Installations are dependent on a commercial grid that is vulnerable to disruption due to aging infrastructure, severe weather, and physical and cyber-attacks. The Defense Science Board warned in 2008 that DoD's reliance on a fragile national transmission grid to deliver electricity to its bases places critical missions at risk.[3] Military bases are subject to more and longer duration power outages than typical utility customers because many bases are located in outlying areas.

### DoD's Massive Infrastructure

**BUILT**

**284K** buildings

*located on*
**523** installations

*with a plant replacement value* **> $800B**

**ENERGY CONSUMPTION**

**$4B per year** *installation energy*

**1%** of U.S. Commercial

Energy security is not a new issue. DoD has long relied on diesel generators with short-term fuel stockpiles to provide backup power for critical loads during a power outage. However, the generators are not connected to one another, and that, combined with chronic under-maintenance, reduces their reliability. Moreover, the lack of an assured fuel supply limits the value of generators for sustained outages, which represent the major threat to energy security.

The deployment of on-site generation—when combined with a microgrid and upgrades to the local distribution system—can enhance energy security by allowing a base to "island" critical loads during a power outage. However, while the Office of the Secretary of Defense (OSD) has supported over two dozen demonstrations of microgrid systems, few large-scale systems have been deployed because the Services are still examining the business case for microgrids.

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[1] The military operates fixed installations in the United States and in other countries. Fixed installations are distinct from forward operating bases, which are located in combat zones and are considered temporary.

[2] Department of Defense Annual Energy Management Report (AEMR) Fiscal Year 2015, June 2016.

[3] More Fight-Less Fuel, Report of the Defense Science Board Task Force on DoD Energy Strategy, February 2008.

OSD has issued several directives on energy security, largely in response to recent major weather events. One memorandum, issued a year after the extreme weather events of 2012, instructed the Services to identify those functions that require a continuous supply of energy during an emergency ("power resilience requirements") and determine the policies and procedures needed to protect those functions.[4] A recently issued instruction defines installation power resilience requirements and directs DoD Components to ensure that they have "available, reliable, and quality power to continuously accomplish DoD missions." [5]

Despite these actions, there is growing concern about whether military bases can maintain critical functions during an outage that lasts for days or weeks, as opposed to hours. Officials in DoD and Congress are asking what other steps they can take to address this concern. Among other things, policymakers on both sides of the political aisle have begun to question DoD's practice of paying no more for secure on-site power. Stated differently, there is a growing belief that DoD should "put a value on energy security," so as to be able to finance distributed generation and microgrid projects that do not appear to make sense purely on business grounds.

This report seeks to answer the question of what DoD can do to ensure that military bases have the power they need to sustain critical functions during long-term outages. The remainder of the report is structured as follows. Section II briefly describes the challenge, including the nature and severity of the threat to the electric grid and the vulnerability of military bases in particular. Section III evaluates DoD's current energy security strategy—reliance on standalone backup generators—in terms of technical criteria. Section IV examines an alternative strategy—the use of microgrids—and provides a detailed comparison of the costs of microgrids and the current strategy under different market conditions. The next two sections look at DoD's performance in two areas that significantly affect energy security—the diversification of supply in the form of renewable energy generation (Section V) and the reduction of demand through improved energy efficiency (Section VI). Section VII takes up two cross-cutting questions having to do with the value of energy security.

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[4] Memorandum from the Acting Deputy Under Secretary of Defense for Installations and Environment, *Department of Defense Electric Power Resilience* (Dec. 16, 2013).

[5] Department of Defense Instruction 4170.11, *Installation Energy Management,* March 16, 2016.

# II Challenges

The U.S. electric grid is an engineering marvel that generates, transmits, and distributes power to 150 million end-user customers. Although the efficiency of the grid has steadily improved over the last century, power outages remain a fact of life. Outages can range in duration from minutes to weeks, and their impact can be geographically limited (a failure in a single feeder line in a distribution system that shuts off power to one neighborhood) or widespread (a failure in the bulk transmission system that affects hundreds of thousands of people in multiple states).

Major power outages—outages that affect 50,000 or more people—are growing in number and severity in the United States, and severe weather is the leading cause. According to a 2013 White House report, severe weather (such as thunderstorms, hurricanes, and blizzards) accounted for 87 percent of the major power outages that occurred between 2003 and 2012.[6]

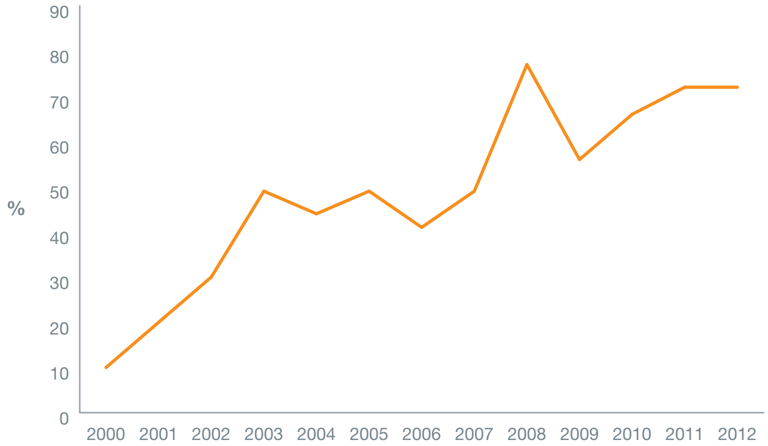

**Figure 1. Percentage of US Utilities that Experience 3 or More Outages a Year that are Classified as a Major Event Day (MED)**

Moreover, according to the U.S. Energy Information Administration, the number of weather-related outages has increased significantly since 1992—a trend that reflects the increased incidence of severe weather as well as the growing vulnerability of an aging grid.[7] The National Climate Assessment predicts that the incidence and severity of extreme weather will continue to increase as a result of climate change.[8]

> **"…it is only a matter of when, not… if, you are going to see a nation state, a group, or actor engage in destructive behavior against critical infrastructure of the United States. On the 23rd of December … an actor penetrated the Ukrainian power grid and brought large segments of it offline in a very well-crafted attack. That isn't the last we are going to see of this."**
>
> Admiral Michael S. Rogers, Director of the National Security Agency and Commander of the U.S. Cyber Command, March 1, 2016 [9]

Consistent with the trend in weather-related outages, U.S. utilities are experiencing a statistically significant increase in the number of Major Event Days (MEDs), referring to days when the reliability of the power distribution system is significantly worse than normal. (Major events are typically, but not necessarily, weather-related.) As shown in **Figure 1**, in 2000, only 10 percent of all U.S. utilities experienced three or more MEDs; by 2012, more than 70 percent of utilities fit that description.

In addition to natural hazards, the commercial grid is vulnerable to manmade

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[6] Executive Office of the President (EOP), *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*, August 2013, p. 8.

[7] EOP, op. cit., p. 8.

[8] EOP, op. cit., p. 9.

[9] Remarks by Admiral Michael S. Rogers, RSA Conference March 1, 2016, https://www.rsaconference.com/events/us16/agenda/sessions/2751/remarks-by-admiral-michael-s-rogers-u-s-navy.

threats, both physical and cyber.[10] The fastest growing threat to the electric grid are cyberattacks, in which hackers try to manipulate industrial control and SCADA (Supervisory Control and Data Acquisition), systems to disrupt the flow of electricity.[11] Hackers can potentially manipulate SCADA systems to disrupt the flow of electricity, transmit erroneous signals to operators, block the flow of vital information, or disable protective systems. Industry has reported a large increase in SCADA attacks in the United States—from 91,676 in January 2012 to 163,228 in January 2013, and 675,186 in January 2014.[12]

The first known large-scale power blackout triggered by a cyberattack occurred last year in Ukraine, when hackers stole the credentials of system operators and switched off the breakers, shutting down power to 225,000 Ukrainians. Ironically, the damage was limited by the fact that Ukraine's grid still ran on old technology, which power authorities were able to operate manually.[13]

Physical attacks can also disrupt electric services, and devices as simple as a homemade explosive or a high-powered rifle can do serious damage. Large high-voltage transformers at substations are particularly vulnerable; they are sometimes only protected by a chain link fence and their recovery times from outages can be significant.

## II.1 Vulnerability of Defense Installations

Defense installations carry out a wide range of functions, almost all of which require reliable electric power. Tactical unmanned aircraft systems in theater are piloted from U.S. bases, and many bases have enhanced intelligence, surveillance, and communications capabilities that support critical missions. Military bases are home to laboratories that perform high-value research and development (R&D), test and training ranges used to demonstrate multibillion-dollar weapon systems, and industrial facilities (such as aircraft maintenance depots and specialized ammunition plants) that directly support mission readiness. Hospitals, fire stations, and emergency management centers on military bases typically operate 24/7, and bases increasingly provide support to civil authorities during national emergencies here at home.

Military bases rely almost entirely on the commercial grid for their electric power, and a base is often the largest customer served by its local utility. No two bases are the same; as facility experts often say, "When you've seen one base, you've seen one base." However, a typical large military base has a peak electricity demand of about 50 megawatts (MW), of which about 20 MW (40 percent) represents "critical loads". Critical loads are those functions that must have emergency backup power under OSD's power resilience requirements. Although the Services define the term somewhat differently, critical loads generally include activities related to life safety and health (e.g., hospitals), public safety (e.g., policing and firefighting), communications, environmental systems, and critical mission support.

Despite the presence of backup generators, power outages are a serious problem for military bases. Outages that last just a few hours are not the major concern, although even they can be costly. For example, at one facility, the Navy had to postpone a long-planned test of a weapon system because of a short-term loss of power; Navy officials estimated that the schedule interruption cost more than $1 million.

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[10] Some analysts are also concerned about "black swan" events, such as an electromagnetic pulse (EMP) or a direct coordinated attack on the United States, which could cause multiple month-long outages in large parts of the country. Such events are outside the scope of this report.

[11] SCADA systems gather real-time measurements from and send out control signals to equipment and are the most vulnerable component in electric distribution systems and microgrids.

[12] *Dell Security Annual Threat Report*, 2015.

[13] David E. Sanger, *Utilities Cautioned About Potential for a Cyberattack After Ukraine's*, New York Times, Feb. 29, 2016.

The real concern is power outages that last days or even weeks, which can cost DoD tens of millions of dollars and jeopardize the mission of the facility and/or the health and safety of its personnel. For example:

- In April 2011, a tornado swept through northern Alabama leaving the Army's Redstone Arsenal base in Huntsville, which is home to the U.S. Army Material Command and NASA's Marshall Space Flight Center, without power for eight days.[14] The base, which employs 35,000 people, was closed to all but a few essential activities, such as a Marshall Space Flight Center unit that supports the space shuttle liftoff and one that communicates with the Space Station. The NASA units relied on several large backup generators that they maintained for just such an emergency; but by the time that power was restored, the generators were, in the words of one base official, "running on fumes."
- Following the failed coup in July 2016, the government of Turkey cut off commercial electric power to the U.S. Air Force's Incirlik Air Base in that country for nearly a week. Incirlik Air Base is key to the U.S. military's operations against ISIS: the 2,700 DoD personnel who are stationed there operate both manned and unmanned sorties from the base. Although the Air Base made use of standby generators, the Air Force was forced to reduce the number of sorties flown; had the power outage continued, it would have had to stop flying altogether.

Just how vulnerable are military bases to these kinds of outages? As a starting point, consider the reliability of those utilities that serve the 30 largest military bases in the United States, as measured by their energy consumption—a sample that is typical of U.S. utilities nationwide. The two most common indicators of utility reliability are the System Average Interruption Frequency Index (SAIFI), which measures the average number of sustained interruptions in power (more than 5 minutes) that a customer would experience, and the System Average Interruption Duration Index (SAIDI), which measures the average length of those interruptions. (SAIFI and SAIDI are based on utility-reported data.)

As shown in **Figure 2**, in 2013 and 2014, for customers served by these 30 utilities, the average number of power interruptions a year (SAIFI) ranged from 1-3 (on the y-axis), and the average duration of those interruptions (SAIDI) ranged from 1-7 hours (on the x-axis). These reliability measures illustrate two points. First, there is significant variability in the (average) reliability of U.S. utilities. Second, outages are a genuine problem. To illustrate, if the *average* duration of outages for a given utility is seven hours, the distribution of outage durations will likely include multi-day outages.

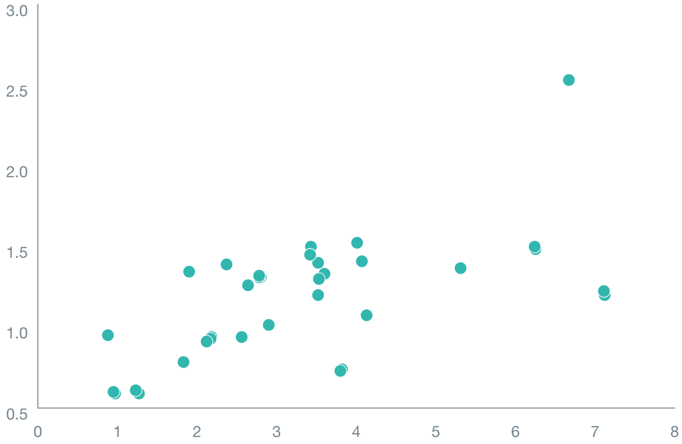

**Figure 2. Reliability of Utilities That Serve Major Military Bases**

While SAIFI and SAIDI measures are a useful reference, they understate the threat of outages to military bases in three ways. First and most important, military bases experience more frequent power outages and longer-duration outages than other customers served by a given utility. Many military bases are located in remote areas, and that fact, combined with their size, means that bases are often situated at the end of utility distribution feeders. That leaves them particularly vulnerable to service disruptions from downed power lines and other natural hazards.

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[14] Redstone Arsenal is also home to the Army's Aviation & Missile Command; the Aviation & Missile Research, Development & Engineering Center; and Redstone Test Center. Non-Army tenants include the Defense Intelligence Agency-Missile & Space Intelligence Center; the Alcohol, Tobacco and Firearms National Center for Explosives Training & Research; and the Federal Bureau of Investigation's Terrorist Explosive Device Analytical Center.

Second, whereas SAIFI and SAIDI reflect hazards outside the perimeter of a base, military bases also experience power outages because of problems within the on-base distribution system. The focus of this report is on outside-the-fence hazards, which are the responsibility of the local utility. Although inside-the-fence problems account for some (unknown) share of all outages, on-base problems can generally be solved through improved maintenance of the base and straight forward investments (e.g., keeping trees trimmed and putting wires underground).

Third, DoD has a significant number of fixed installations outside of the United States—in foreign countries and U.S. territories such as Guam and Puerto Rico. Although the reliability of the electric grid in host countries like Germany and Japan is comparable to that of the United States, in other host countries and some U.S. territories, the grid is less reliable.

## II.2 Data on DoD Power Outages

Unfortunately, DoD lacks comprehensive data on the number of power outages and their duration, much less the cost of the outages.[15] In part, this information gap reflects the fact that most DoD buildings do not have individual utility meters—a topic we discuss in Section VI. However, several recent surveys provide useful information.

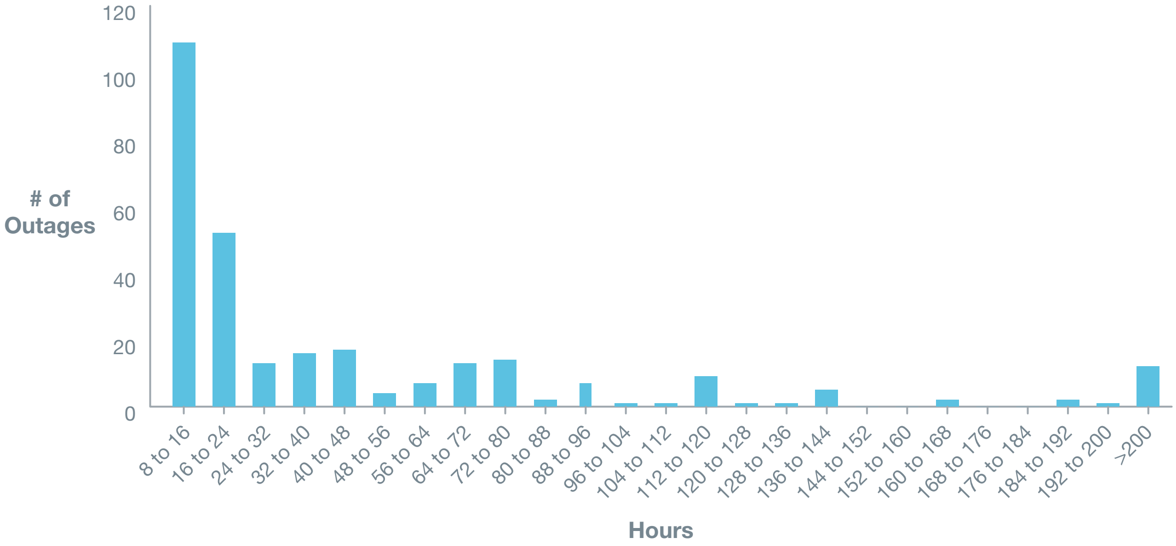

**Figure 3. Number of Outages at U.S. Military Bases as a Function of Duration (Hours) From 2012 Through 2014**

First, the Navy has recently begun to extract data on utility outages from its maintenance management system, Maximo, which tracks the occurrence and resolution of building maintenance and repair issues on an enterprise-wide basis. Based on Maximo entries, Navy bases experienced more than 900 outages in FY 2015. For bases in the Atlantic region, the average duration of an outage was around 15 hours; for bases in the Navy's Pacific region, the average duration was close to 32 hours.[16]

Additional information on the frequency and duration of outages comes from OSD. According to OSD's Annual Energy Management Report (AEMR), in FY 2015, DoD Components experienced 127

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[15] In a recent report on defense infrastructure, GAO reported that "DoD's collection and reporting of utility disruption data is not comprehensive and contains inaccuracies, because not all types and instances of utility disruptions have been reported and there are inaccuracies in reporting of disruptions' duration and cost." GAO, *Defense Infrastructure: Improvements in DoD Reporting and Cybersecurity Implementation Needed to Enhance Utility Resilience Planning*, GAO-15-749, July 2016.

[16] Data provided by Naval Facilities Command, Department of the Navy.

utility outages that lasted eight hours or longer, compared to 114 such outages in FY 2014.[17] Although the AEMR did not provide information on the duration of those outages, one can infer that from data OSD made available on prior outages.

**Figure 3** shows the distribution of eight-hour-plus outages that U.S. bases experienced from 2012 to 2014.[18] While most of the outages lasted for only 8-16 hours, roughly 25 percent lasted for 24-72 hours; another 15 percent of the outages lasted for more than 120 hours (five days), including a non-trivial number that lasted for more than 200 hours.

Finally, to supplement the AEMR, GAO recently gathered additional information from 20 installations on DoD utility disruptions caused by hazards.[19] Of the 20 installations, 18 (or 90 per cent) reported that they had experienced a disruption that lasted 8 hours or longer during the three-year period covered by GAO's investigation (2012, 2013, and 2014). The 18 affected installations reported a total of 150 such disruptions, of which about 110 (73 percent) were electric-utility disruptions.[20]

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[17] AEMR 2015.

[18] *DoD Energy Resilience Initiatives*, Ariel Castillo, Energy Exchange, August 2015.

[19] GAO, op. cit.

[20] GAO also surveyed for disruptions in water, wastewater, and other utility systems.

# III Current Approach: Standalone Backup Generators

DoD has long relied on standalone generators with short-term fuel stockpiles to provide emergency backup power for buildings with critical loads. Although this approach has endured for good reason, its limitations are becoming increasingly problematic. In this section, we look first at how military bases acquire and use standalone generators as their strategy for ensuring energy security. Then, we evaluate the advantages and limitations of this strategy using a scorecard that incorporates key technical and economic criteria.

## III.1 How Installations Acquire and Use Standalone Generators

Standalone generators are a staple of U.S. military bases. At every building housing a critical load, a single (standalone) backup generator is hard-wired directly to the building. Most backup generators found on fixed installations are powered by diesel fuel, although some of them run on natural gas, propane, or jet fuel. A base typically has centrally managed stockpiles that contain enough fuel to allow the generators to run for two to seven days.

During peak demand periods, a typical large military installation requires about 50 MW of electric power, of which about 20 MW represents critical load. Because of the large number of buildings that house critical loads, bases of this size often have 100 to 200 generators or more positioned to provide the power required to support critical loads.

The standalone generators on a typical base are diverse as well as numerous. **Table 1** provides information on the diesel-powered standalone generators found on one (unnamed) military base. There are 42 diesel generators, ranging in size from 10 kW to 1,035 kW. The generators were manufactured by 11 different companies over a broad spectrum of time (one unit dates back to 1968).

| Manufacturer Name | Year Manufactured | Generator Capacity (kW) | # of Generator Units On-Installation |
|---|---|---|---|
| Company A | 2006 | 50 | 1 |
| Company B | 1992 | 100 | 1 |
| Company B | 2005 | 1035 | 2 |
| Company B | 2009 | 500 | 2 |
| Company C | 2003 | 200 | 1 |
| Company C | 2003 | 20 | 1 |
| Company C | 2009 | 300 | 2 |
| Company C | 2009 | 175 | 2 |
| Company C | 2009 | 150 | 2 |
| Company C | 2009 | 100 | 4 |
| Company D | 1968 | 30 | 1 |
| Company E | 2006 | 94 | 1 |
| Company E | 2010 | 118 | 2 |
| Company F | Unknown | 60 | 1 |
| Company F | 1996 | 40 | 1 |
| Company F | 2003 | 350 | 2 |
| Company F | 2003 | 74 | 1 |
| Company G | Unknown | 20 | 1 |
| Company G | Unknown | 10 | 1 |
| Company H | 1996 | 12 | 1 |
| Company I | 1986 | 15 | 1 |
| Company I | 2003 | 200 | 1 |
| Company I | 2003 | 62 | 1 |
| Company I | 2005 | 30 | 1 |
| Company J | 2009 | 125 | 2 |
| Company J | 2009 | 100 | 2 |
| Company J | 2010 | 125 | 2 |
| Company K | Unknown | 10 | 1 |
| Company K | 2003 | 15 | 1 |

**Table 1. Example of the Diversity in Age, Manufacturer, and Size of Diesel Generators at a Military Installation**

The diverse makeup of the generators found on a typical military base reflects the highly decentralized way in which they are procured and maintained. A large base supports dozens of missions, and may contain multiple tenant commands. For example, Fort Belvoir—an Army base located less than an hour's drive from the Pentagon—has 90 tenants.[21]

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[21] http://www.belvoir.army.mil/tenant/all.asp.

Tenants consist largely of units from the same military Service, but they can include units from other Services and even other federal agencies. Many tenants have their own backup generators, which they buy and maintain with little or no coordination with the base.

Generators are often bought using military construction funds during the construction or major retrofit of a building. They can also be bought using Operations and Maintenance (O&M) funds, either by individual tenants or at the base level. Generators are characterized as real property and not managed by the organizations that are responsible for the base's utilities. While military bases typically have a central department responsible for public works and utilities that charges tenants for services such as electricity, there is no central account for "energy security."

## III.2 Advantages of Standalone Generators as a Strategy for Energy Security

It is easy to see why the military has adhered to the paradigm of building-tied generators as its strategy for facility energy security. The key reason is the degree of operator control this strategy affords. A tenant-operator can select the type and size of generator that best suits its needs and install it in any location that has a nearby fuel supply. Because the generators are independent of the on-installation electric distribution system, the tenant need not interact with the system operator (the base's engineering department or a private utility). Nor does the tenant need to coordinate with other tenant-operators on the base. In short, the current strategy allows a collection of autonomous operating units on a base to eliminate a significant risk to their individual missions.

If operator control is the major appeal of the current strategy, cost is a close second. It costs only about $100,000 to purchase a typical 250 kW standalone generator and $6,500 a year to maintain it. The acquisition process, using MILCON or O&M funds, is relatively straightforward, and the annual expenditures involve small, predictable outlays.

As a third key advantage, standalone generators are also independent of the state of the on-installation (inside-the-fence) power grid. They are not vulnerable to problems with the installation's electricity distribution system which are the source of some outages on bases.

## III.3 Limitations of Standalone Generators as a Strategy for Energy Security

Relying on dedicated, standalone generators as a strategy for facility energy security has limitations as well as advantages.

We explore these limitations below in terms of five key technical attributes: efficient sizing, maintainability, reliability, flexibility, and coverage. (We look separately at a sixth attribute—overall cost—which is a focus of the quantitative analysis we present in Section IV.)

> **"Activities and tenant commands rely primarily on diesel generators for backup power. (Quantico) maintains a short-term backup supply of diesel onsite and relies on the availability of resupply of diesel for long-term outages. Therefore, if there is a long-term disruption to the diesel fuel supply, day-to-day operations would be impacted severely. Furthermore, aging and under-maintained generators are prone to malfunction. These malfunctions could create additional power issues."**
>
> Marine Corps Base on Reliance and Vulnerabilities of the Current Paradigm[22]

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[22] Marine Corps Base Quantico, Marine Corps Base Order 4100.1B, Subject: Energy and Water Management Program, April 2011, http://www.quantico.marines.mil/Portals/147/Adjutant/SSIC/04000/MCBO%204100.1B%20-%20ENERGY%20AND%20WATER%20MANAGEMENT%20PROGRAM.pdf

**Efficient Sizing:** The standalone nature of backup generators contributes to their appeal, but it also limits their efficiency on an installation-wide basis. Because the generators are disconnected from one another, each one must be sized to meet a building's peak load. DoD guidance directs generators to be sized at 2X the current engineering estimate for their peak load (oversizing accommodates possible increases in the building's future load.). In practice, they are often sized even larger. **Table 2** provides information on the generator capacity and corresponding critical load at an actual (unnamed) military installation. The base has 15 standalone generators with a capacity of 100 kW or more. Although two of the generators are undersized (the generator capacity is less than 200 percent of the expected peak load it currently serves), the other 13 generators exceed the 2X capacity-to-load ratio—some by a significant amount. On average, the generator capacity exceeds the peak demand of the corresponding load by 427 percent. Oversizing results in higher-than-necessary capital costs. It also leads to excessive diesel fuel use and causes unnecessary wear-and-tear on the generators, which do not perform efficiently at low load levels.

| Unit # | Generator Capacity (kW) | Building Demand (kW) | Generator Size as a % of Building Demand |
|---|---|---|---|
| 1 | 2,000 | 260 | 769% |
| 2 | 600 | 230 | 261% |
| 3 | 600 | 230 | 261% |
| 4 | 600 | 96 | 625% |
| 5 | 600 | 71 | 845% |
| 6 | 500 | 90 | 556% |
| 7 | 400 | 160 | 250% |
| 8 | 400 | 120 | 333% |
| 9 | 300 | 220 | 136% |
| 10 | 250 | 158 | 158% |
| 11 | 250 | 33 | 758% |
| 12 | 200 | 96 | 208% |
| 13 | 200 | 58 | 345% |
| 14 | 160 | 40 | 400% |
| 15 | 125 | 25 | 500% |

**Table 2. Generator Sizing vs. Building Electricity Demand at Mid-sized Military Installation**

**Maintainability:** Maintenance and testing of standalone generators on military bases is often inadequate, although that is less of an issue on bases that have a private utility operator who maintains and test the generators. Proper maintenance requires monthly testing of each unit and semi-annual or annual testing if the monthly tests do not meet the appropriate benchmarks.[23] Only about 60 percent of military installations perform the required testing, according to OSD.[24]

Beyond the military's testing protocols, there are many other components of a well-designed maintenance program that are important for good long-term asset performance. These additional maintenance activities for larger generators include comprehensive inspection, replacement of cooling system fluid, engine inspection and adjustment, and battery replacement.[25] According to military base staff and energy contractors we interviewed, such comprehensive planned maintenance programs are often not followed.

> **As evidence of the weak state of diesel generator maintenance that can occur at installations, the company operating the privatized grid at Fort Belvoir has replaced all of the generators it inherited at that location because of past poor maintenance. Speaking more broadly about the military, the company indicated that "installations have significant reliability issues with generators that they own. This is usually due to a lack of maintenance, inspections, and testing."**
>
> Utility Privatization Experience with Diesel Generators

The lack of adequate maintenance and

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[23] See, for example, Air Force Civil Engineer Center, Engineering Technical Letter (ETL) 13-4 (Change 1): *Standby Generator Design, Maintenance, and Testing Criteria*, May 2014, http://www.wbdg.org/ccb/AF/AFETL/etl_13_4.pdf.

[24] *DoD Energy Resilience Initiatives,* Ariel Castillo, *Energy Exchange,* August 2015.

[25] Electric Power Research Institute (EPRI), *Cost of Utility Distributed Generators, 1-10 MW: Twenty-Four Case Studies*, 2003, pages 4-3 and 4-4, http://www.publicpower.org/files/Deed/FinalReportCostsofUtilityDistributedGenerators.pdf.

testing is a direct result of the current, decentralized approach to facility energy security. Installations do not invest in staff training and high-quality maintenance. (As one senior Service official in charge of energy told us, "Maintenance of generators is underfunded and no one checks.") The diversity of generators—with up to dozens of different types of equipment on a base—compounds the problem because it makes it impossible to implement standardized and efficient maintenance approaches.

**Reliability:** The reliability of an energy security system is a function of the reliability of both the first line of defense and any secondary independent backup systems. In this case, a single standalone generator is the first line of defense, and an independent backup system would consist of a second redundant standalone generator.

The lack of adequate maintenance and testing—attributable to the factors described above—results in a higher than expected failure rate for the first line of defense. An even bigger reliability deficit stems from the lack of an independent power source to provide backup if the original backup generator fails.[26] In reliability parlance, there is no N + X reliability, where "X" refers to the number of independent backups that exist to cover a failure.[27] Moreover, because standalone generators are disconnected from one another, N+1 reliability would require that every backup generator on an installation have its own dedicated backup unit.

**Flexibility:** An energy security strategy needs the flexibility to serve an installation's power needs over time. Electric power needs can change even over the course of a multi-day outage; they will almost certainly change over time, as the missions carried out on a facility expand, contract, and evolve.

Standalone generators can meet changing needs only insofar as the initial oversizing can accommodate an increase in the peak critical load. Because generators are hardwired to the buildings they support, the process of moving one to a new location is costly and time-consuming, requiring de-commissioning, transport, and re-commissioning.[28]

**Coverage:** Coverage is a variant of flexibility that refers to the ability to cover a range of power needs at a given point in time. The reliance on standalone generators—a 20-year asset purchased on the basis of its (fixed) capacity—forces operators to make an "all or nothing" decision about whether a load is critical or non-critical: critical loads get 24/7 backup with high reliability, and non-critical loads get no (assured) backup power. However, the military's energy security needs do not fit neatly into those binary categories. Certain "intermediate" loads, while not mission-critical, could nevertheless advance the mission during an emergency if they had backup power. Moreover, some critical loads could get by with a lower level of backup protection. For example, short outages (say, an hour) are not a threat to "critical" refrigeration and HVAC systems in essential buildings because of the time it takes for the relevant conditions (refrigerator and room temperatures) to deteriorate.

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[26] The Army's reliability goal for a C4ISR utility system is 0.999999, or 'six nines,' representing the probability the system will be available at any given time. For facilities serving a command center, the redundancy would need to be N+2.

[27] For a review of various levels of generator reliability (N+1, N+2, etc.), see Daniel Barbersek, *Generac Power Systems, Inc., Engine Generator Paralleling Concepts*, http://www.ewh.ieee.org/r3/atlanta/ias/2012-2013_Presentations/IEEE%20Engine%20Generator%20Paralleling%20Concepts.pdf.

[28] The Navy's Mobile Utilities Support Equipment (MUSE) division does offer some flexibility in system location by being able to move supplemental generators to areas of need. While valuable, MUSE does not approach the scale that would be required to offer the type of flexibility described in this sub-section. Likewise, MUSE generators could offer limited reliability enhancement by providing backups to the original backup generators.

## III.4 Overall Cost of Standalone Generators

A final criterion for evaluating an energy security strategy is its overall cost. (Although sizing and maintainability are elements of cost, overall cost is a more inclusive attribute.) For standalone generators, the major costs include capital acquisition and O&M. A military installation with 20 MW of critical loads will spend approximately $16 million to buy the 40 MW of standalone generator capacity it needs and $1 million a year to maintain it.

It is a safe assumption that the benefits of the current energy security strategy outweigh its costs, because the strategy has endured for so long (it would be difficult—but not impossible—to measure those benefits, which equal the value of the critical loads that are protected). Thus, the more appropriate question is whether the current strategy is cost-effective—that is, would an alternative energy security strategy yield more benefits for the same cost? In the next section, we try to answer that question with respect to one very promising alternative strategy—namely, microgrids.

# IV A Resilient Alternative to Standalone Backup Generators: Microgrids

A microgrid is an alternative way to provide secure power to a military base. While microgrids offer significant non-cost and cost advantages over standalone generators as the basis for an energy security strategy, they also face impediments to widespread implementation.

In this section, we explore the potential for microgrids to replace standalone generators as the military's strategy for base energy security. We look first at how microgrids function and at some examples of where they are already in use on military bases. Next, we compare microgrids to standalone generators on the five non-cost criteria identified in Section III. Third, we provide a detailed cost comparison of microgrids and standalone generators, using actual data from military bases and regional energy markets. Finally, we look at implementation issues, including alternative procurement strategies (the "make or buy" issue) and impediments to broader use of microgrids by the Services.

## IV.1 Triple-Play Appeal of Microgrids

A microgrid is a local system of distributed energy resources (DERs) and electrical loads that can operate as a single entity either in parallel to the commercial (macro) grid or independently ("island" mode). It can be used to provide emergency backup power during commercial grid outages, or when connected to the grid be a source of revenue and savings. Any on-site power source can serve as a DER, including renewable, fossil-fuel generators, combined heat and power (CHP) plants, waste-to-energy facilities (e.g., gasified landfills), and batteries and other forms of stored energy.

Microgrids have been in use since the days of Thomas Edison, whose concept of electricity distribution was based on a form of power (direct current) that could not be sent over long distances.[29] Many microgrids in use today are relatively unsophisticated, with limited ability to integrate intermittent DERs, little or no storage capability, and no ability to gain revenue through participation in energy markets or exploit savings through energy management while grid-tied. By contrast, advanced or "smart" microgrids can operate seamlessly both in parallel to the grid and in island mode and integrate intermittent renewable DERs. The current interest in microgrids reflects the ability of these advanced systems to achieve an energy triple play—reducing utility costs, incorporating renewable energy, and enhancing energy security and independence.

Although the technology for advanced microgrids is still relatively young, dozens of commercial systems are now operating.[30] The first advanced microgrid deployed by the federal government is located at the U.S. Food and Drug Administration (FDA) campus at White Oak, Maryland, a former Navy base that is run by the U.S. General Services Administration (GSA). The microgrid, which GSA procured though an Energy Savings Performance Contract, is powered by both diesel and natural-gas generators. It routinely operates in island mode in anticipation of outage-causing weather events, such as Hurricane Sandy and periods of high grid demand. Use of the microgrid ensures that FDA's research labs have assured power and allows GSA to save several million dollars a year by selling

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[29] The first utilities formed by Edison's company in New York were simple microgrids, with locally connected generators and loads. With the development of transformers, George Westinghouse's alternating current (AC) systems were able to send power over long distances. When Westinghouse won the AC-DC "current war," Edison's microgrids largely disappeared.

[30] EPRI. *Microgrid Implementations: Literature Review*, January 2016

excess power to the grid and avoiding costly peak demand charges.[31]

The military has expressed strong interest in advanced microgrids, and DoD has sought to further their development by serving as a testbed for pre-commercial systems. OSD's Environmental Security Technology Certification Program (ESTCP) has funded two dozen demonstrations of advanced microgrid and energy storage technologies on military bases.[32] These demonstrations allow the Services to evaluate alternative technical approaches and configurations and help vendors transition technologies to market that DoD can then purchase as commercial systems.[33]

Although most of the microgrids on military bases consist of small demonstration projects, there are a few large systems. The largest one is at Marine Corps Air Ground Combat Center Twentynine Palms, where the microgrid controls generation assets that can provide for a significant portion of the installation's peak electricity requirements. Located in California's Mojave Desert, Twentynine Palms covers an area almost the size of Rhode Island. Its power demand ranges from 10 MW in off-peak winter hours to 26 MW on summer days. The Twentynine Palms microgrid was developed based on the lessons learned from an ESTCP-sponsored demonstration project. The microgrid matches energy use on the base with output from generation sources to maximize efficiency. It uses an 8-MW CHP plant that can produce more or less power as needed, including ramping up quickly during a heat spike or a power outage.

Another large-scale microgrid is being built at Marine Corps Air Station Miramar in San Diego, California ( the location of another ESTCP-sponsored demonstration), at a cost of nearly $20M. The project is an advanced microgrid integrating renewable energy and conventional generation from diesel and natural-gas generators. The microgrid will be able to power mission-critical and support facilities during a utility grid outage, as well as provide peak shaving and demand response capability when connected to the utility grid.

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[31] Tariq Samad, Edward Koch, and Petr Stluka; *Automated Demand Response for Smart Buildings and Microgrids: The State of the Practice and Research Challenges*, Proceedings of the IEEE, Vol. 104, No. 4, April 2016.

[32] https://serdp-estcp.org/Program-Areas/Energy-and-Water/Energy/Microgrids-and-Storage

[33] Toward that end, ESTCP focuses on technologies developed by commercial vendors; the program supports multiple vendors to ensure competition. DoD's SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security) program, carried out in collaboration with DOE and the Department of Homeland Security, also funded on-base demonstrations of microgrids. The SPIDERS' demonstrations focused on cybersecurity.

In addition to the small number of large-scale systems that function as true microgrids, with the ability to balance supply and demand and operate in parallel to the grid, DoD has a number of large systems that provide advanced energy solutions short of that goal.

- At Fort Drum, New York, the Army partnered with a private firm, ReEnergy, to convert the base's coal-fired plant to biomass and connect it to the Fort's electric substation, so that the plant can disconnect from the civilian grid during a power outage. ReEnergy will operate the plant under a 20-year contract with the Army, producing enough renewable energy to meet all of Fort Drum's electricity needs and some of the local community's.[34]
- At Schofield Barracks, Hawaii, the Army is teaming with Hawaiian Electric Co. (HECO), to connect three Army posts and a community hospital to the only baseload power plant on Oahu that will be above the tsunami strike zone. The 50-MW plant will use a combination of bioenergy and conventional fuels and will have "blackstart" capability (the ability to restore power without help from the external grid). HECO will operate the plant through an easement on Army property situated 900 feet above sea level. As at Fort Drum, power not needed to meet Army needs will go to support the wider grid.[35]

DoD's interest in microgrids is continuing to grow. In addition to the planned system at Miramar the Army intends to install a microgrid at Fort Bliss in Texas (another site of an ESTCP demonstration). Although impediments remain, the technology itself is sufficiently mature for wide scale adoption.

## IV.2 Microgrids versus Standalone Generators: Non-Cost Criteria

Microgrids offer a fundamentally different way of providing energy security than standalone, building-tied generators.

**Figures 4 and 5** provide graphic representations of the two systems (**Figure 5** illustrates a very simple microgrid, which relies solely on large diesel generators for backup power).

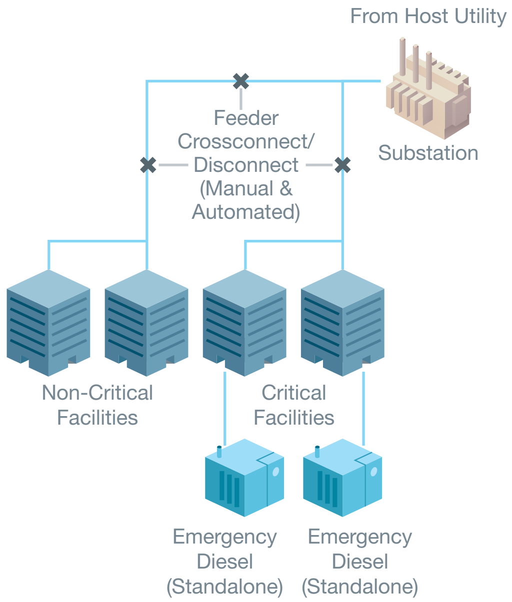

**Figure 4. Current Paradigm of Small Building-Tied, Standalone Generators**

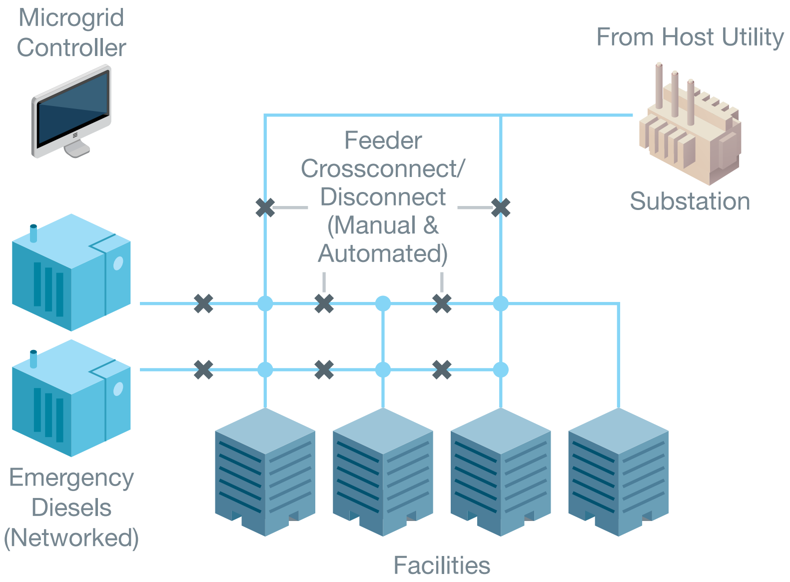

**Figure 5. Microgrid with Larger Networked Generators**

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34 U.S. Army, Office of Energy Initiatives, *Army Guide: Developing Renewable Energy Projects by Leveraging the Private Sector*, 2014, p. 6. See also, *Fort Drum Officially Connects into On-Post ReEnergy Biomass Site*, Watertown Daily Times, October 19, 2015.

35 In addition to Schofield Barracks, this project will serve Field Station Kunia and Wheeler Army Air Field. U.S. Army, Office of Energy Initiatives, et al., *Schofield Barracks Large-Scale Renewable Energy Project*, July 2016. http://www.asaie.army.mil/Public/ES/oei/docs/Schofield%20Barracks%20Renewable%20Energy%20Project.pdf.

Below, we compare microgrids to standalone generators in terms of the five non-cost criteria that we examined in Section III, after which we undertake a detailed cost comparison.

- **Efficient Sizing:** Whereas each standalone generator is sized for the peak load at an individual building, a microgrid shares resources across an entire installation, thus taking advantage of the diversity of non-coincident peak power needs at hundreds of buildings. This dramatically reduces the volume of power needed to back up a base's critical loads.
- **Maintainability:** A microgrid relies on a few, large, physically centralized generation units that often have standardized features. Such a system is far easier and less expensive to maintain than 100 or more standalone generators that represent a hodgepodge of makes and models.
- **Flexibility:** Because microgrids are networked, they can respond to changes in electricity needs at no cost—whether over the course of a multi-day grid outage or over months and years as tenants and missions change and requirements evolve. By contrast, standalone generators—which are hard-wired—must be relocated or replaced if power needs change over time (there is no ability to respond in the short-term). In addition, microgrids can integrate the power from renewable energy sources.
- **Coverage:** Because a microgrid is sized to meet the annual critical peak loads of a base (and potentially more), excess generation is almost always available and can serve any load to which the microgrid is connected. This excess coverage is valuable because installations have many loads whose priority falls somewhere between "critical" and "non-critical." By contrast, standalone generators represent an "all-or-nothing" solution.
- **Reliability:** A microgrid can readily provide a high level of reliability (N+1 or N+2) because the networked structure ensures that if any single generation asset fails, another one can instantly take its place. Moreover, because the large assets that power a microgrid rarely fail, it takes little in the way of backup generation to provide for enhanced reliability. In sharp contrast, standalone generators must be individually backed up to achieve N+1 reliability.

Microgrids have one drawback: if the installation's (on-base) distribution system is not fully functioning, power will not flow to critical loads covered by the faulty portions of the system. For that reason, an installation with a problematic distribution system is not a good candidate for a microgrid. That said, a microgrid need not cover an entire base: it can be designed to avoid areas where the distribution system is faulty. Moreover, because problems with the distribution system are under the control of the base, they can generally be addressed by better maintenance (e.g., tree trimming) and often modest investments (e.g., putting certain wires underground).

## IV.3 Microgrids versus Standalone Generators: Comparison of Costs

While a microgrid offers inherent advantages over standalone generators on the non-cost criteria, it is less obvious how the two approaches compare with respect to overall cost. To make this comparison, we carried out a detailed modeling exercise based on a hypothetical large military installation with a peak demand of 50 MW, of which 20 MW is deemed critical—a realistic hourly load profile for a military installation (unnamed)—and electricity-industry cost data. We calculated what it would cost per kW to protect the installation's critical loads under two standalone generator scenarios (Base Case A and B) and two microgrid scenarios (Microgrid Case A and B) in three regional electricity markets, for a total of 12 scenrios. We used a comprehensive measure of (net) cost that took into account differences in regional energy prices and the potential revenue from peak shaving and participation in energy markets that a microgrid makes possible.

Although the cost and revenue drivers are analyzed at an hourly level of granularity, by consolidating the business case results into a single metric, the military can compare its current, all-in cost for energy security to alternatives. We selected annual "cost per kW" of critical load as our basic metric because it allows for a direct comparison between standalone generators, which must be sized for peak demand as measured in kilowatts, and the alternative. This value represents the annual cost of protecting each kW of critical load, i.e. the cost of adding emergency backup for the critical load after netting out all associated capital, fuel, and O&M costs; changes in utility costs; and market revenues, where available. In other analyses of facility energy security [36], analysts have used cost per kW-hour as their metric. The cost of a kW-hour, the metric used when assessing the purchase of a renewable energy, is misleading when looking at energy security solutions. We rejected the kW-hour metric because it combines the cost of energy a base buys during normal operations independent of security benefits with the cost of energy security. Thus, two energy solutions that are identical can appear as having a different cost because of the rate the base pays for electricity from the commercial grid unrelated to the energy security solution.

Below, we describe the scenarios we analyzed, the analytic approach we used, and the results we obtained.

### IV.3.1 Scenarios

In the two Base Cases, the installation has 160 diesel-fueled, backup generators, each connected to an individual building, with no redundancy (no backups for the backup generators). Each generator produces 250 kW of power, and the generators collectively produce an amount of power equal to twice the total peak critical load on the base (40 MW). These two cases differ only on the timing of the purchase of the generators: in Base Case A, the generators are purchased in Year 1, whereas in Base Case B, they are purchased in Year 10. While Base Case A allows for an apples-to-apples comparison with the Microgrid Cases, in which the microgrid is purchased in Year 1, we included Base Case B in recognition of the fact that many installations will not retire their existing standalone generators until they reach the end of their asset lives, which we approximate at ten years, or half of the asset life of a standalone generator.

**Experience of Storm Sandy in 2012: New York State Energy Research and Development Authority (NYSERDA) found that "among the sites that lost (utility) grid power, and where the CHP unit was designed to operate during a grid outage, all of the CHP systems did perform as expected." In another study, it was found that during Storm Sandy "at Princeton University, 50 years of genetic research was saved because (the university's) microgrid kept the freezers running where DNA samples were kept." It is essential that a microgrid powered by natural gas generators be served by more expensive firm (non-interruptible) gas contracts to avoid being cut off during emergencies.**

Energy Reliability with On-Site Natural Gas Generators

The two Microgrid Cases differ solely with respect to the DER employed. In Microgrid Case A, the microgrid relies entirely on a dozen large (2,000 kW) diesel generators. In Microgrid Case B, the microgrid gets roughly equal amounts of power from large diesel generators and large (7,000 kW) baseload natural-gas generators. Natural gas is available to most DoD bases, and a hybrid microgrid may be preferable to an all-diesel microgrid because it spreads the risk of a disruption in the supply of either type of fuel. (The text box above describes two examples in which on-site natural gas generators proved critical to maintaining energy security.[37] )

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[36] MIT-Lincoln Laboratory's analysis in *Application of a Resilience Framework to Military Installations*, N. Judson, A.L. Pina, E.V. Dydek, S. B. Van Broekhoven, and A.S. Castillo, Lincoln Laboratory 121-A, 23 September 2016

[37] The NYSERDA information is from ICF International for the Oak Ridge National Laboratory of the U.S. Department of Energy, Combined Heat and Power: Enabling Resilient Energy Infrastructure for Critical Facilities, March 2013, page 7, https://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_critical_facilities.pdf. The Princeton University example is from Electric Infrastructure Security (ESI) Council, Electric Infrastructure Protection (EPRO®) Handbook II, Volume 1 – Fuel: Resilient Fuel Resources for Power Generation in Black Sky Events, July 2016, page 95

In other respects, the two Microgrid Cases are identical: The generators are sized to cover the installation's total peak critical load and configured to provide N+1 reliability. The microgrid can support peak shaving and limited participation in local electricity markets where available while grid-connected (activities that are not possible with standalone generators and thus excluded from our Base Cases); it also performs stably while in island mode.

Note that neither Microgrid Case includes renewable energy or battery storage, even though both would be potential additions to the type of microgrid we analyzed. This omission simplifies the comparison to the Base Cases, since standalone generators cannot make use of either of these. In addition, by omitting renewable energy, we avoid conflating the savings in utility costs with the benefits of improved energy security. Although renewable energy can contribute to both goals,[38] and the Services are seeing the cost savings from their deployment of on-base renewable generation assets, they have not yet made the investments necessary for those same assets to provide for energy security.

We situated our hypothetical installation in three electricity markets that we selected so as to capture differences in relevant market and climate variables:

- Mid-Atlantic and Northeast: moderate power prices, a deregulated market for energy generation, and well-developed markets for demand response
- Southeast: low power prices and vertically-integrated power markets with limited opportunities for participation in demand response markets
- California: high power prices, a partially deregulated energy generation market, and demand response markets that will be foreclosed to generators powered by fossil fuels

Our 12 scenarios (two Base Cases and two Microgrid Cases deployed in three regional markets) represent a realistic if simplified cross-section of opportunities available to the military (see Appendix B for more information on the assumptions underlying our 12 scenarios).

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[38] As discussed in Section V, intermittent renewable energy such as solar can contribute to energy security but at today's battery prices it cannot cost effectively serve as the primary source of energy security.

### IV.3.2 Analysis

Each of the 12 scenarios was analyzed on the basis of its 20-year net present value (NPV).[39] The NPV calculations included all generator capital, O&M, and incremental fuel costs, as well as changes in the military base's monthly electric utility bill caused by the scenario and, where applicable, demand response (DR) revenues.[40]

Because capital and O&M cost data on large-scale microgrids are not widely-available, we interviewed multiple microgrid providers knowledgeable about military energy to obtain cost estimates for the modeled technology.

To introduce appropriate precision into the analysis, we calculated military basewide electricity volumes for every hour of the year and applied realistic utility rate structures to those hourly volumes.[41] The sequence of how the energy security assets were used (or "dispatched') in the two Microgrid Cases is shown in **Figure 6**.[42] That is a logical order to maximize revenues and minimize fuel costs to DoD.

Appendix A provides further description of the analytic methods. Appendix B summarizes 34 key modeling assumptions.

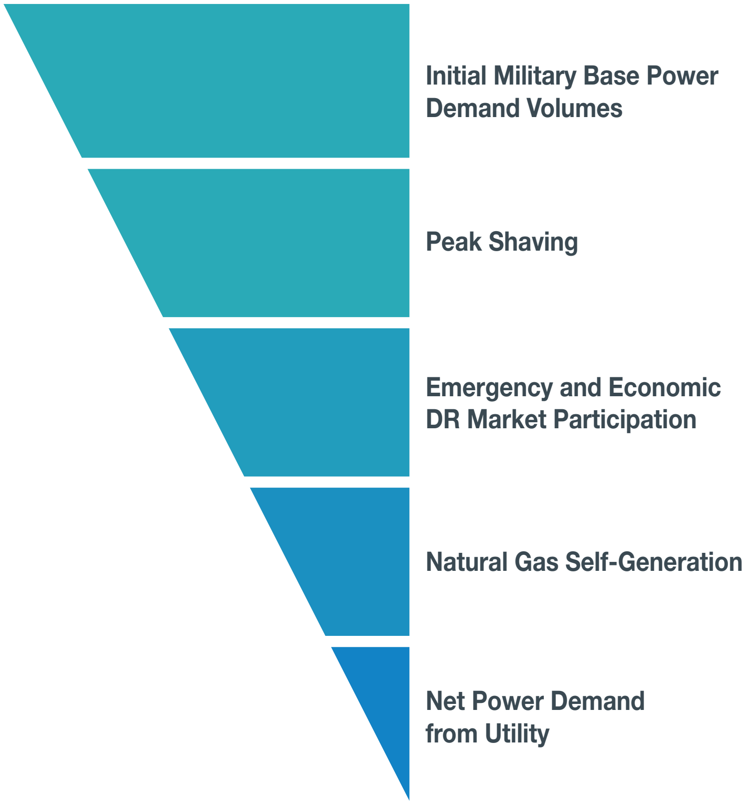

Figure 6. Top to Bottom Sequencing of Power Volumes on an Hourly Basis in the Test Cases

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[39] That duration aligns well with the useful life of the assets involved and how an external provider would capture investment value.

[40] The cost of bulk fuel storage tanks is not included in this analysis. It is a minor cost when amortized over the 40-year life cycle of the tanks, and tanks already exist at almost every military installation. In addition, tank costs would be identical for all the business cases analyzed in this report.

[41] Many analyses of electricity assets use the simple, but generally mistaken, assumption that the average per-kWh electricity price over a month or year is sufficient. That can lead to mal-investment because energy users like the military do not pay a single average per kWh price. That average per kWh price is simply a shorthand sum of many, distinct types of charges. Instead of a single rate, electricity users often pay fixed monthly fees, peak demand charges that may differ by season (summer vs. winter), on-peak and off-peak energy charges, taxes, and, when they have baseload on-site power, standby charges. This report's analysis applies all of this distinct types of utility charges in its economic modeling.

[42] DR market participation only applied in the Mid-Atlantic/Northeast scenarios and natural gas self-generation only applied in Microgrid Case B.

**Figure 7. The Annual Net Cost of Protecting each Kilowatt of Critical Load**

### IV.3.3 Results

**Figure 7** shows the results of our analysis. To summarize:

Under the two Base Cases (building-tied standalone generators), the annual cost to protect a kW of critical load is $80 to $85, depending on whether the generators are replaced in year 1 ($85) or year 10 ($80). The cost is the same in all three electricity markets because the major cost drivers for standalone generators (capital and O&M) do not vary widely by region.

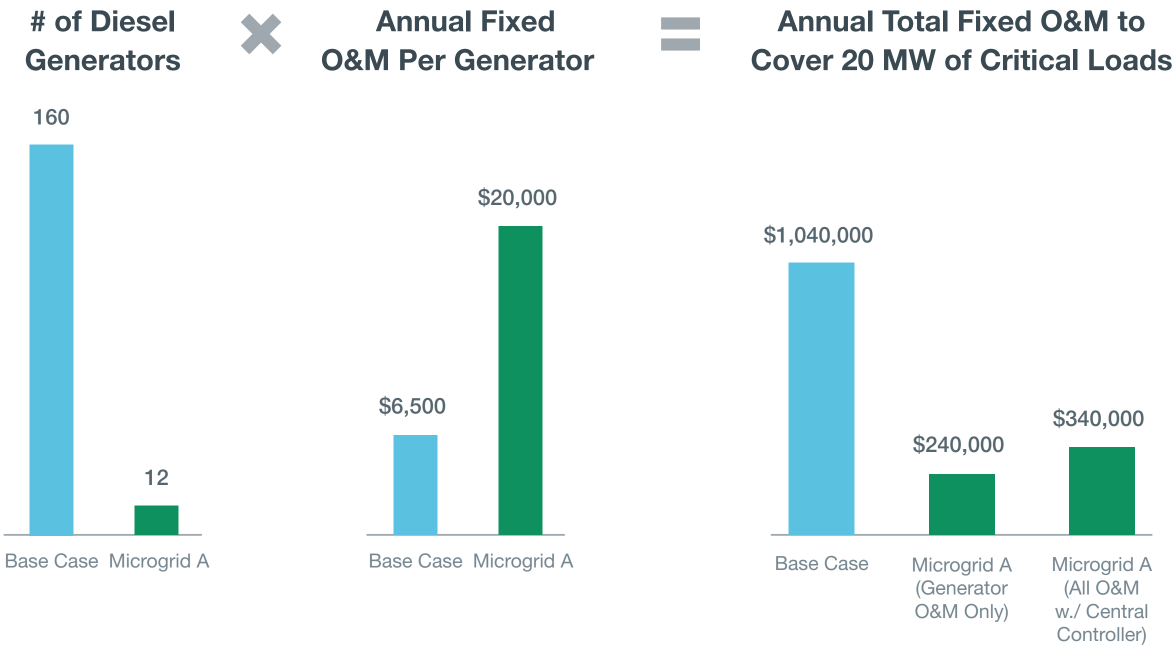

**Figure 8. Largest Source of Microgrid Savings: Lower Fixed Annual O&M Costs**

Under Microgrid Case A (microgrid with large diesel generators only), the comparable all-in energy security cost per kW ranges from $31 (Mid-Atlantic/Northeast) to $61 (California). ***This means that an installation anywhere in the country will save money by replacing its standalone generators with a large diesel-only microgrid, and the savings will range from $8M to $20M over the 20-year life of the microgrid.*** The biggest source of savings in all three regions is O&M. This is logical: While it costs more to maintain a large (2,000 kW) diesel generator than a small (250 kW) standalone generator, there are many fewer of them to maintain (12 units in the microgrid scenarios versus 160 units in the base cases, see **Figure 8**). After O&M, the next biggest savings from the all-diesel microgrids is revenue from DR, though only in the Mid-Atlantic/Northeast. The final significant source of savings in this case is peak shaving of demand charges on the utility bill. The importance of peak shaving revenue is an indication that demand charges are often a high fraction of an installation's utility costs.[43]

Under Microgrid Case B (microgrid with large diesel and baseload natural gas generators), the annual cost to protect a kW of critical load ranges widely—from negative $80 in California, to $93 in the Mid-Atlantic/Northeast, to $195 in the Southeast. Stated differently, in two of the three regions, this microgrid alternative is more expensive than standalone generators ($80-85) on an annual per-kW basis. By contrast, in California, this microgrid alternative is not only less expensive than the base case, ***its net cost is negative[44]. The result means that at an installation in California, the military could protect its critical load for free and create additional savings of $80/kW, or $1.6M, a year.***

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[43] One of the installations interviewed as part of this project is aggressively pursuing a large-scale microgrid and has identified peak shaving benefits as a substantial part of the value proposition. That is because peak demand charges comprise at least 40% of the installation's total utility power costs.

[44] This is consistent with the fact that the military is seeing some of its first large microgrids in California (e.g., Twentynine Palms and Miramar mentioned earlier in this section), and those microgrids have hybrid-generation configurations with a heavy reliance on natural gas generators.

For Microgrid Case B, as for Microgrid Case A, reduced O&M is a source of savings in all three regions, and DR revenues is a source of savings in the Mid-Atlantic/Northeast. But the major determinant of the cost savings (or lack thereof) is the price of conventional power. In two of the three regions, that price is moderate (Mid-Atlantic/Northeast) or low (Southeast) by national standards. Thus, the replacement of conventional power with power from baseload on-site natural-gas generators imposes costs on the installation that exceed the savings in other areas (O&M and DR). By contrast, in California, conventional power prices are high by national standards, which makes on-site natural gas powered generation more attractive.

Economic modeling results are provided in greater detail in Appendix C.

## IV.4 Microgrids: Significant Value, Many Opportunities

These results are compelling in and of themselves; they point to a way for installations in large parts of the country to get more and better energy security for less by substituting a microgrid for a collection of standalone generators. However, the case for microgrids is even better than our analysis suggests. Specifically, our results understate the case for microgrids in three important ways.

- By design, our cost analysis ignored key non-cost advantages of microgrids relative to standalone generators, such as their greater flexibility and coverage. (Sizing, maintainability and reliability are captured indirectly in the cost analysis.) Although we did not quantify these non-cost advantages, they too have economic value to an installation.
- Second, by limiting the generation assets that we analyzed to traditional fossil fuels, we stopped short of looking at a host of other DERs, some of which would allow microgrids to demonstrate even higher performance and lower life-cycle costs. For example, CHP plants, which generate both electric power and thermal energy, are another attractive source of backup power, as the microgrid at Twentynine Palms demonstrates. To take another example, large centralized power stations, such as the bio-power plant at Fort Drum, can serve as generation assets during an outage if supported by a microgrid.
- Third, in an effort to keep our analysis simple, we omitted asset uses that would have resulted in greater savings. For example, the DR strategies that we modeled involved relatively simple, binary choices, such as whether to turn the diesel generators on or off. In reality, with a microgrid, a base energy manager could engage in sophisticated load shedding across the entire installation, yielding additional savings and revenue.[45]

## IV.5 Path to Microgrid Implementation

Once a military Service has decided to take advantage of the security and other benefits that a microgrid provides, it faces a choice of how to procure those benefits. One option is buying the microgrid from a commercial vendor (using a design-build contract and military construction funding) and operating the asset itself. The other option is to purchase the stream of benefits as a service from a private entity that owns and operates the microgrid.

Many in DoD believe that the military needs to have direct control of an asset as mission-critical as a microgrid, which is another way of saying that ownership and/or operation of a microgrid on a military base is inherently governmental. However, anecdotal evidence suggests otherwise. The Services rely on the commercial grid for conventional power; on many military bases, the distribution system is also privately owned and operated (“utilities privatization” represents a decision by a base to go from being an owner-operator to a service customer). Moreover, some of DoD’s most critical backup power systems are privately provided, including the one that protects Fort Detrick’s biodefense campus, which

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[45] ESTCP Special Study, *Financial Optimization of Electricity Security Assets at Military Installations: Including Case Studies of Dover Air Force Base, Fort Benning, and MCAGCC Twentynine Palms,* January 2014.

houses some of the most dangerous biological agents that exist and cannot afford to lose power.

More generally, whether an activity is inherently governmental boils down to a single question: Can you write a contract? That is, can the function be reduced to an operational description such that a contractor can perform it and the performance of the contractor can be evaluated? The operation of a microgrid meets that test because a military base can identify the electric loads that require secure power and specify what "secure" means in terms of duration, availability, reliability, and flexibility. (In fact, the base should set such requirements even if it self-operates the microgrid.) Moreover, the base can monitor precisely the performance of the operator (including its own performance, if it is the operator) in meeting those requirements.

In short, the operation of a microgrid is not inherently governmental, and provision of microgrid services by the private sector is feasible on policy grounds. Beyond being feasible, we believe that private provision of microgrid services is preferable for several reasons.

First, the microgrids used on fixed installations are not unique to the military.[46] Although the military's operational requirements may differ from those of the private sector, their respective technologies are identical. Moreover, the market for commercial microgrid systems is growing rapidly. By taking advantage of commercial practices when it comes to the operation of microgrids, DoD can leverage advances in the technology and the corresponding cost reductions.

Second, the energy markets are volatile. As our analysis shows, a microgrid has the potential to generate significant revenue; but the exact amount can vary widely from year to year, depending on fuel prices, weather, and the demand response market. Like any federal agency that operates off of annual appropriations, DoD cannot easily respond to and exploit changing markets.

Third, the design and management of a microgrid require sophisticated knowledge that DoD lacks. These activities also benefit from a proper alignment of incentives: the life cycle costs of a microgrid are sensitive to how it is operated, and an understanding of operational goals for a system should inform its design and construction. By buying energy security as a service, DoD can take advantage of more integrated solutions.

Finally, the acquisition of microgrids as a service is a prerequisite to the use of third-party financing. As we discuss in Section V, the Services' deployment of renewable energy has been possible only because of private financing by developers and utilities. Third-party financing will be key to microgrid deployment as well.

## IV.6 Barriers to Implementation

Despite their desire to host microgrid technology demonstrations, the Services by and large are not taking the next step and acquiring commercial systems (whether as an asset or a service). Several barriers appear to be impeding the implementation process.

One barrier is DoD's technical guidance on energy security, auxiliary power, and the design of backup power systems. Such guidance is diffuse and dated, scattered throughout many Service-level engineering technical letters and other documents, some going back to 1996. Moreover, because it is so dated, some of the guidance restricts the use of the very technologies we have modeled for microgrid systems. For example, the Air Force prohibits the use of natural gas for emergency power generation. Air Force guidance also specifies that a generator being used to support an essential

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[46] Microgrids planned for forward operating bases are military unique. They are constrained by the military requirements for transportation, setup and operation in a war time environment. They must all be the same and allow for easy and rapid integration with other military hardware.

mission can be connected only to that mission load. Guidance matters in a command-and-control organization like the military, which is why, as a first step, the Services need to review all of their technical guidance and eliminate barriers to the use of microgrids.

An even bigger barrier to microgrid implementation is the lack of guidance on how to define energy security requirements. Microgrids make possible a more nuanced approach—one that defines "security" along multiple dimensions (duration, reliability, and flexibility) and sets different requirements for different loads. As noted above, a military base should go through that exercise under any circumstances, but it is an essential undertaking if the base plans to purchase microgrid security as a service, because commercial bidders will need that level of specificity to determine the optimal tradeoffs between cost and performance. However, military facilities staff, accustomed to a decentralized "all or nothing" approach to the specification of critical loads, will need both education and formal guidance in order to shift to a new approach.

More broadly, few staff at military bases currently have the knowledge and expertise required to manage the procurement of a microgrid, given the complexity both of the technology and of the electricity markets in which microgrids will enable participation.[47] Thus, the Services will need to provide higher level support for such procurements.

DoD's current approach to the funding of standalone generators represents another major barrier to the implementation of microgrids. Although our cost analysis shows that microgrids can generate sufficient savings and revenue to make them attractive to Energy Savings Performing Contract (ESPC) and Utility Energy Savings Contract (UESC) vendors, the Services report that their proposed microgrid projects do not "pencil out" for private vendors.[48] The difference is accounting: whereas our calculation took into account all of the costs that standalone generators impose on a hypothetical base (capital, O&M, etc.), DoD's accounting system provides no such recognition; the costs of standalone generators on a base are paid out of multiple budget activities and by dozens of tenants. For third-party financing to "pencil out," DoD needs to recognize the costs that it already pays for energy security.

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[47] One additional complexity is the role of the private utility provider on bases that have privatized their electric distribution systems. Although utility privatization is not an impediment to the acquisition of a microgrid (whether as an asset or a service), few of the contracts that transferred ownership of the distribution systems from military bases took energy security issues into account. While the private utility providers will necessarily have a role in the implementation of a microgrid solution, the nature of that role will be site-specific and contractor-specific.

[48] There is no legal barrier to third-party financing of microgrids: the statutory language and guidance for ESPCs and UESCs clearly countenance the use of these authorities for such a purpose, and Congress has encouraged DoD to use them in this way.

# V Role of Renewables

Renewable energy can enhance the energy security of a military installation. Although the Services have been aggressive in working with the private sector to develop renewable generation assets, energy security has not been a major consideration; rather, the Services' driving goal has been to reduce their utility costs and meet their respective goals to produce or procure 1 gigawatt (GW) of renewable energy.

In this section, we examine the issue of renewable energy and energy security. First, we briefly review the ways that on-site renewable energy can cost-effectively contribute to energy security. Next, we look at how the Services' are meeting their 1 GW goals, the positive lessons from that experience, and the need to apply those lessons to the challenge of facility energy security.

## V.1 Role of Renewables

DoD bases, which occupy 28 million acres of land, are well situated to support solar, wind, and other forms of renewable energy generation. In response to a congressional directive, OSD commissioned a study of the potential for solar energy development across six million acres on military bases in the Mojave and Colorado Deserts in California and Nevada. The year-long study looked at seven installations in California and two in Nevada. It found that, even though military activities and the presence of endangered species and other factors made 96 percent of the surface area of the nine bases unsuitable for solar development, the solar-compatible area on the California bases was large enough to support the generation of 7,000 MW of solar energy—equivalent to the output of seven nuclear power plants.[49]

Although renewable energy can be an element of a facility energy security strategy, some of the most attractive forms of renewable energy are intermittent in nature. Solar energy is only available during the daytime, and the amount of electricity produced varies greatly depending on time of day and cloud cover. Wind energy is likewise intermittent due to changes in wind speed. Intermittency is a challenge if the goal is to have assured energy for critical loads at all times.

For intermittent renewable energy such as solar and wind power to serve as the primary backup power for mission critical needs, it will need to be coupled with energy storage. However, a typical military base would need batteries capable of storing at least 16kW-hr of energy for every kW of power, and bases in some regions of the country would require considerably more.[50] Given the high cost of batteries, intermittent renewable energy with batteries is not cost-competitive with traditional generators, which store energy in the form of diesel fuel.[51]

Even without storage, however, a microgrid can perform better if it

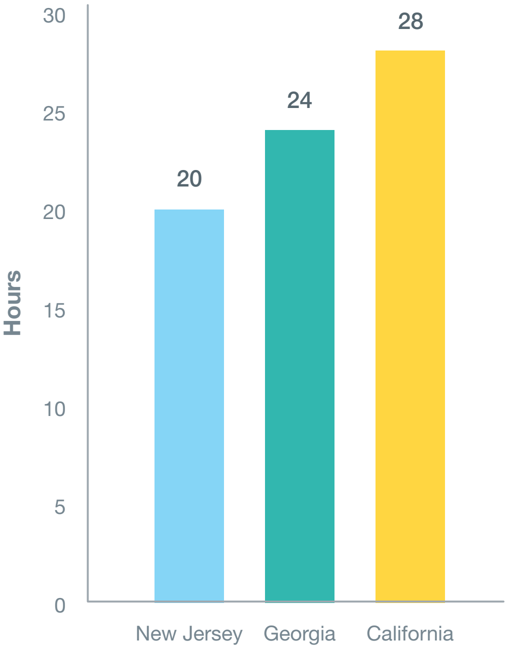

**Figure 9. Extended Protection with 5 MW of Configured PV**

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[49] ICF International for ESTCP, *Solar Energy Development on Department of Defense Installations in the Mojave and Colorado Deserts*, January 2012.

[50] Estimates over 24 hours were predicted for certain locations, MIT-LL report op cit.

[51] The capital costs of commercially available batteries today with storage duration of 16 or more hours are an order of magnitude or more greater than those for diesel generators.

can take advantage of renewable energy. One measure of performance is the duration of the backup power available to an installation. As shown in **Figure 9**, a ground-mounted 5 MW solar photovoltaic (PV) system with no battery storage can extend the supply of backup power available by 4-6 hours per MWac of PV capacity depending on the strength of the solar resource, providing 20-28 additional hours of emergency power for mission-critical functions.

The addition of renewables (without storage) can also extend the scale of backup power provided by a microgrid. Most of the renewable energy assets currently deployed on military bases do not generate electricity during a power outage because they are connected solely to the civilian power grid. With a microgrid, a military base could take advantage of renewable generation resources that would otherwise go unused. Because this is effectively a free resource, it could be used to provide backup power to intermediate loads that would not otherwise receive it.

## V.2 The Services' Renewable Energy Initiatives

DoD has made a significant commitment to the development of renewable energy. In 2012, each of the three Military Departments announced that it would produce or procure 1 GW of renewable energy capacity by 2020 (Navy) or 2025 (Army and Air Force). Less than five years later, the Navy—with 1.25 GW of off-site and on-site capacity in place or in the pipeline—has already surpassed its goal; and the Army and Air Force are making steady progress toward their goals, largely by developing large-scale, on-site solar projects.

Three factors have been key to the Services' success:

- The renewable energy initiatives have had strong support from Service leadership. Navy Secretary Ray Mabus played a particularly important role, but other Service leaders embraced the cause of renewable energy as well.
- Service leadership set measurable goals and relatively near-term deadlines for reaching them.
- Each service established an enterprise-level organization to turn these commitments into real projects on the ground. The Navy's Renewable Energy Program Office (REPO) and the Army's Office of Energy Initiatives (OEI) have for several years been identifying cost-effective projects for their respective Services, providing centralized oversight of project execution, and working with industry to improve the project analysis and contracting process. Recently, the Air Force established an Office of Energy Assurance (OEA) in partnership with the Army's OEI.

Although the Services cite energy security as a rationale for their 1 GW initiatives, other goals—largely the desire to reduce their utility costs—have been the major driver for project decisions. For example, when a Service contracts to procure off-site renewable energy, it counts toward the 1 GW goal and may lower the Service's utility costs; however, it does not enhance the energy security of the base(s) to which the power will be wheeled via the commercial grid. Moreover, even those projects that are located on-base are often not sited, sized, or designed based on security considerations. In many cases, the generation assets are connected directly to the grid, leaving the base with no ability to access the renewable energy during a power outage.

Importantly, the Services now routinely include a contractual provision that specifies that the military gets "first dibs" on power generated on base in the event of a grid outage. However, the Services are not making even the initial investments needed to enable islanding, starting with upgrades to the base's electrical distribution system and culminating in a microgrid. The Army's claim that it is making its projects "microgrid-ready" can be limited to the use of smart inverters, which have become standard on new solar arrays. In other respects, the Army is negotiating its projects with a primary focus on getting the best possible deal on the cost of power.

A notable exception to this pattern is the Navy's Enhanced Use Lease (EUL) projects, where REPO is declining monetary lease payments for the land in favor of in-kind consideration in the form of upgrades to the base's electrical distribution system and equipment, such as controls and transformers. These upgrades—when combined with storage and a microgrid—will enable islanding of critical loads. Although the Services need to do more to site, size, and design their renewable energy projects with energy security in mind, the Navy's innovative use of EULs to enhance facility energy security is a very positive step.

More broadly, DoD needs to apply the programmatic lessons learned by the Army, Navy, and Air Force in pursuit of their 1 GW goals to the mission-critical pursuit of energy security: strong Service leadership, measurable goals with a foreseeable deadline, and an enterprise approach that uses centralized management offices to oversee execution and work closely with industry. Energy security is the most important energy challenge that U.S. military installations face, and the same approach that has proved successful with respect to renewable energy is now needed to tackle that challenge.

# VI Energy Efficiency and Security

Energy efficiency and energy security are inextricably linked. Because the cost of providing energy security on a military base is a function of the peak power required for protected loads, when the base reduces those power needs through energy conservation and efficiency, its energy security costs drop proportionately. To date, the Services have made only limited progress in reducing their energy consumption, in large part because they view energy efficiency as a way to comply with statutory goals and executive orders rather than as an essential element of energy security. Our analysis suggests that, by aggressively metering energy consumption and making cost effective investments that would pay for themselves through energy savings, DoD could reduce its utility bill by 25 percent, or $1 billion a year, and its energy security bill by the same proportion.

This section looks at the linkage between energy efficiency and energy security. First, we briefly describe DoD's built infrastructure and the (facility) energy it consumes. Next, we compare the energy efficiency of DoD buildings, GSA-owned buildings, and commercial buildings, controlling for function and location, and use the results to estimate the reduction in its energy consumption that DoD could achieve. Finally, we look at the impediments that DoD needs to overcome to capture those savings.

## VI.1 DoD's Built Infrastructure Energy Needs

DoD's 284,000 buildings consume nearly 200,000 billion BTUs a year, about half of which is electricity (see **Figure 10**). This represents one percent of the total electric energy consumed in the United States and more than all of the electric energy consumed by a country such as Ireland.[52] DoD's utility bill (which includes all the energy sources shown in **Figure 10**) is about $4 billion a year.

The buildings on DoD's fixed installations contain almost 2 billion square feet (sf) of space—nearly nine times the 220-million sf footprint of GSA-owned buildings (GSA leases an equivalent amount of space in commercially owned buildings). Although DoD buildings range from the very small to the very large (more than 2 million sf), the portfolio is dominated by mid-size buildings that have from 10,000-100,000 sf. The rest of the portfolio is split equally between large buildings (more than 100,000 sf) and small buildings (less than 10,000 sf). This size distribution, which is shown in **Figure 11**, is remarkably similar to the size distribution of commercial buildings in the United States.

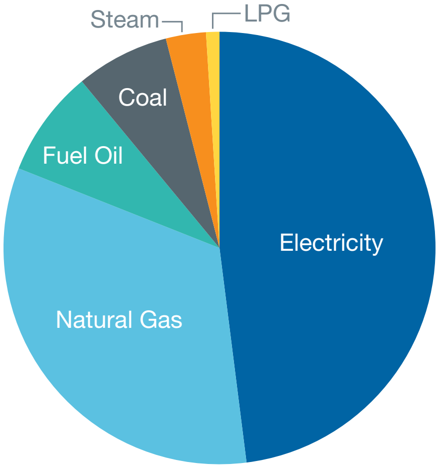

**Figure 10. Sources of DoD's Energy to Operate Bases**

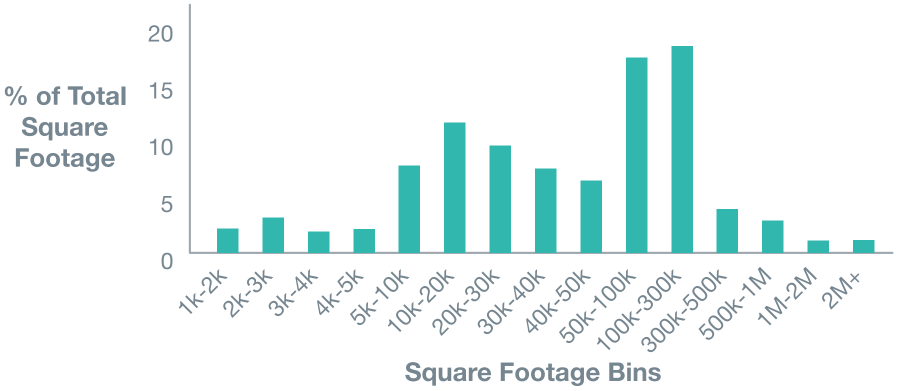

**Figure 11. DoD's Building Portfolio as a Function of the Size of Buildings**

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[52] *World Fact Book*, CIA

## VI.2 How Efficient is DoD?

To evaluate the energy efficiency of DoD's buildings, one needs both to measure improvements over time in the DoD portfolio and to compare the (static) performance of the DoD portfolio to that of other federal and commercial portfolios. The standard metric for measuring the energy efficiency of buildings is energy consumed per square foot, known as Energy Use Intensity, or EUI.

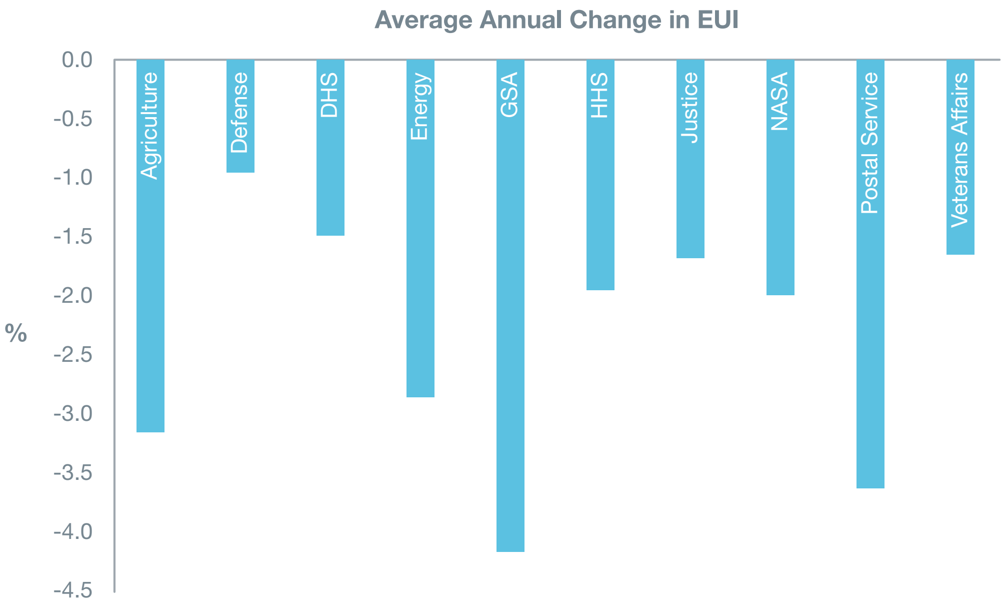

**Figure 12. Annual Average Energy Reduction Over the Last Ten Years**

Data on improvements in EUI for DoD and other federal agencies are readily available, because various statutes and executive orders directed agencies to reduce their EUI by 3 percent a year relative to a 2003 baseline, for a total reduction of 30 percent by 2015. As shown in **Figure 12**, from 2005 to 2015, DoD reduced its EUI by less than one percent a year on average—the worst record of the ten federal agencies that consume the largest amounts of facility energy. By contrast, GSA, with the best record of the ten agencies, reduced its EUI by more than 4 percent on average.[53]

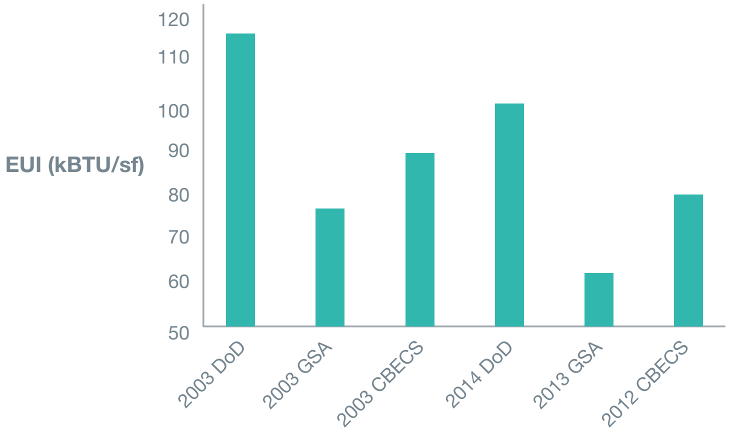

**Figure 13. Comparison of Energy Use Intensity in 2003 and Today**

**Figure 13** presents a somewhat different comparison of changes in EUI for DoD and GSA buildings in the United States. In 2003, the EUI for GSA buildings was fully 35 percent below that for DoD buildings. A decade later (11 years, in the case of DoD), that gap was even wider.[54] **Figure 13** also shows the EUI for commercial

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[53] "Federal Comprehensive Annual Energy Performance Data", http://energy.gov/eere/femp/federal-facility-annual-energy-reports-and-performance. These statistics, from the Department of Energy's Federal Energy Management Program (FEMP), reflect changes in "pure" energy efficiency (the ratio of total BTUs consumed to total square footage). For our purposes, this pure EUI measure is a better indicator than the EUI statistics that are often reported, based on the federal government's sustainability scorecards, which reflect certain actions that are not strictly energy efficiency (e.g., on-site consumption of certain types of alternative energy).

[54] Data from DOE's Federal Energy Management Program.

buildings in the United States as a whole, as measured by the Energy Information Administration's Commercial Buildings Energy Consumption Survey (CBECS) from 2003 and 2012.[55] At both points in time covered by CBECS, DoD's EUI was significantly higher—and GSA's significantly lower—than that of commercial buildings.

| FAC Title | CBECS Building Type |
|---|---|
| General Administrative Building | Office |
| Covered Storage Building, Installation | Warehouse and Storage |
| Reserve Training Facility | Public Assembly |
| Enlisted Unaccompanied Personnel Housing | Lodging |
| Aircraft Maintenance Hangar | Other |
| Covered Storage Building, Depot | Warehouse and Storage |
| Ammunition Storage, Depot and Arsenal | Warehouse and Storage |
| General Purpose Instruction Building | Education |
| Vehicle Maintenance Shop | Service |
| Applied Instruction Building | Education |

**Table 3. Ten Largest DoD FAC Title Categories by Square Footage Mapped to CBECS Building Types**

The information presented in **Figure 13**, while useful, does not control for differences in the geographic location or function of buildings in the different portfolios. This is relevant because, for example, DoD buildings might house more energy-intensive activities than GSA or commercial buildings, or they might be disproportionately located in climates with more (or fewer) heating-degree and cooling-degree days.

Beginning with a comparison of DoD and commercial buildings, we controlled for function by identifying the predominant use of every DoD building located in the United States using OSD's Real Property Asset Database (RPAD) and assigning each building, with its corresponding square footage, to the equivalent CBECS building-type category.[56]

**Table 3** shows the 10 largest facility analysis categories (FAC), which account for about half of DoD's footprint. We eliminated those buildings that either do not use power or whose power is paid for by a party other than DoD.[57]

**Figure 14** presents the results of this portion of the analysis. The CBECS building type that accounts for the largest fraction of DoD square footage is "Other," which reflects the fact that many DoD buildings, such as aircraft hangars and ammunition plants, have no commercial counterpart. "Warehouse and Storage" accounts for second largest amount of DoD square footage, followed by "Office" and "Lodging."

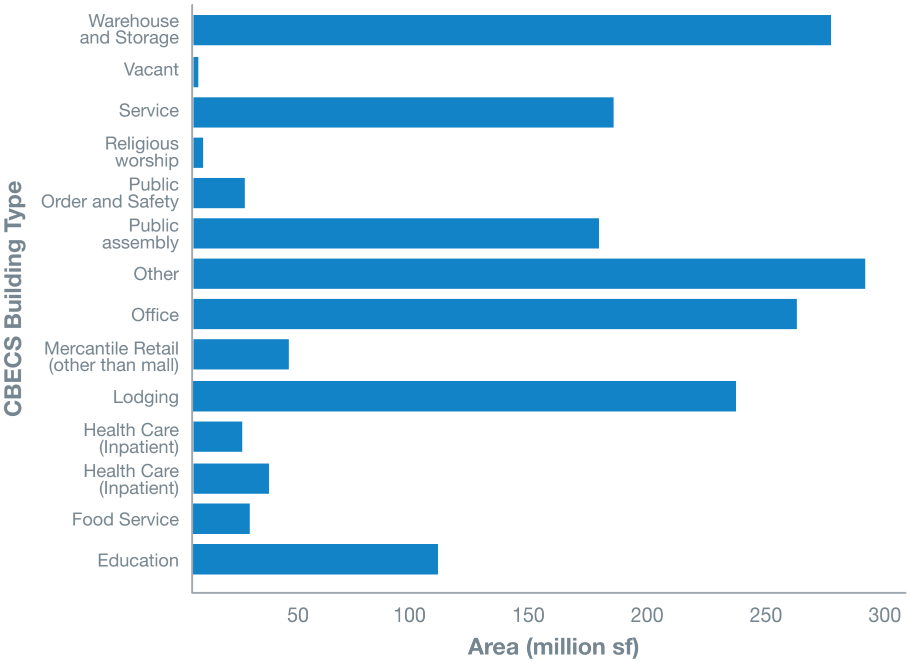

**Figure 14. Total Square Footage of DoD Portfolio in the United States by CBECS Building Type and Service**

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[55] Commercial Buildings Energy Consumption Survey (CBECS), http://www.eia.gov/consumption/commercial/

[56] Many DoD buildings have direct commercial counterparts: DoD buildings used for administration, housing, education, health, storage and community activities are very similar to commercial buildings devoted to those same activities. RPAD assigns a "Predominant Current Use FAC Code" to every building on a military base. RPAD also records the size and location of every building.

[57] We removed buildings with less than 1000 square feet from the data because these tend to be sheds that lack electricity. We also removed privatized family housing, because DoD does not pay for the power to these homes. Finally, we removed "closed, disposed, or surplus" buildings as designated in RPAD.

Next, we used CBECS data on average EUI by building type and climate zone to estimate what the EUI of every DoD building would be if performed like a commercial building in that location.[58] As shown in **Figure 15**, our analysis indicates that, if DoD buildings in the United States were as efficient today as commercial buildings were in 2012 (the last year covered by CBECS), DoD's energy consumption would be 15 percent lower than it is—a significant amount.

To test the robustness of this result, we focused on the 40 largest bases and identified and excluded from our data 22 bases that house large facilities that have R&D labs, industrial operations, and data centers.[59] When we repeated our analysis on the remaining bases, the results we obtained were essentially the same.

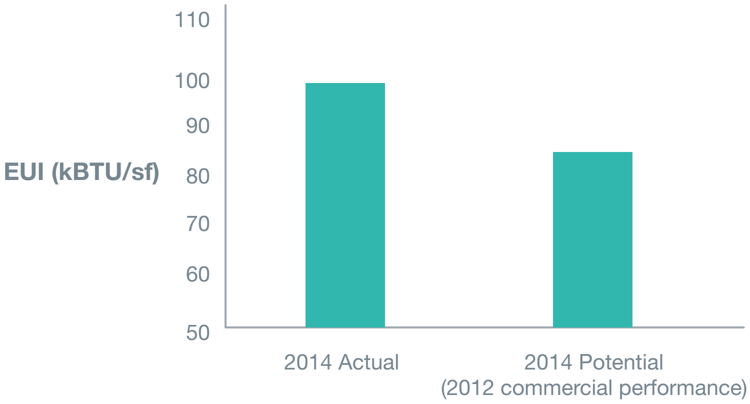

**Figure 15. Comparison of DoD's Actual Energy Use Intensity and what it would be if it Performed as Well as Commercial Buildings in 2012**

Using detailed data on GSA-owned buildings, we conducted a similar analysis to determine how GSA's buildings would perform if they operated at the same level of energy efficiency as commercial buildings. The vast majority of GSA's square footage falls into the CBECS "Office" category, as shown in **Figure 16**. Thus, the comparison of GSA and commercial buildings is more straightforward.

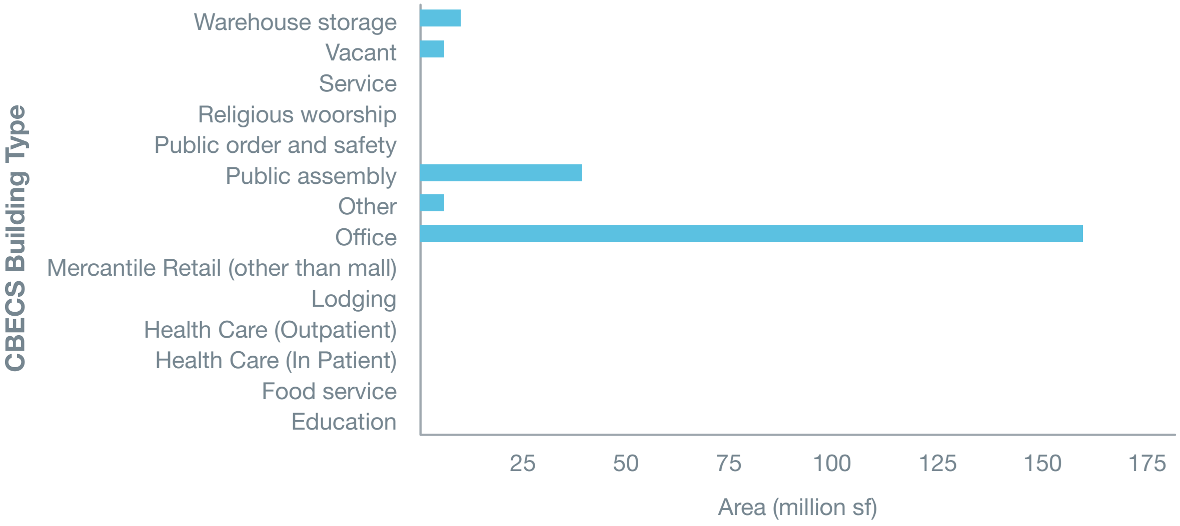

**Figure 16. Total Square Footage of GSA Portfolio in the United States by CBECS Building Type**

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[58] Using the CBECS data on average EUI by building type and climate zone, we determined the average CBECS EUI for each DoD building (kBTU/sf). Multiplying the EUI by the square footage of the building gave us an estimated energy usage for each building (kBTU). We summed these estimated energy usages across all buildings on an installation to calculate an estimated energy usage for the entire installation; we also calculated an estimated energy usage for all installations—i.e, DoD-wide. We then divided each of these estimates of energy usage by the corresponding figure for square footage (e.g., the sum of buildings on individual installations and DoD-wide) to produce an estimate of what the EUI would be if all buildings performed like commercial buildings.

[59] We selected bases from among the 40 domestic military bases that consume half of all of DoD's facility energy. Our goal in excluding bases was to reduce the amount of square footage that fell into the "Other" category, since that category includes activities that have no commercial counterpart. After excluding those bases for the reason described above, we were left with 18 bases that account for about 25 percent of total annual energy consumption. We achieved our goal: for the 18 remaining bases, "Other" accounted for only a minor portion of the square footage.

Our results indicate that GSA's buildings today are 20 percent more efficient than the equivalent commercial stock was in 2012. This finding should not come as a surprise: rather than a "gold standard" for energy efficiency, commercial buildings are in the mediocre middle, for reasons that economists and others have explored.[60] Nevertheless, the finding provides reassuring evidence that the federal government (GSA) is capable of managing a building portfolio that is well above average in energy efficiency.

The results of our comparison of GSA and commercial buildings also demonstrate what DoD could potentially achieve. GSA and commercial building owners have significantly improved their energy efficiency by deploying commercially available technologies that are cost effective and that pay for themselves though energy savings. By contrast, DoD is failing to take advantage of these opportunities, as reflected in the marginal improvement in its EUI since 2005.

Based on our analysis, we estimate that DoD could reduce its energy consumption by 15-35 percent. The lower bound estimate is based on our analysis of how DoD buildings would perform if they were as efficient as equivalent commercial buildings. The upper bound estimate is based on the revealed gap between the energy efficiency of DoD and GSA buildings. Taking the mid-point of that range (25 percent) as our estimate, we conclude that DoD is leaving $1 billion a year (25 percent of its $4 billion-a-year utility bill) on the table.

## VI.3 Meeting DoD's Efficiency Potential

Why has DoD failed to take advantage of energy conservation measures that are commercially available and cost effective? Two impediments largely explain these "sins of omission." One is the lack of advanced meters in DoD buildings, and the other is constraints on the Services' ability to combine energy conservation measures (ECMs) and capital investment.

**Metering:** DoD today lacks the ability to analyze its energy consumption at the building level because relatively few buildings have meters that measure energy use on a regular interval (typically every 15 minutes) and that disseminate that information periodically and automatically to a central data collection point on the installation (**Figure 17**). As of last year only 23 percent of DoD's electric load was being captured by an advanced metering system, either because no meter had been installed or because the meter was not networked (i.e. the data had to be collected manually). By contrast, GSA captures 90 percent of its electricity consumption with advanced meters. The adage that "you can't manage what you can't measure" applies directly to DoD's facility energy consumption.

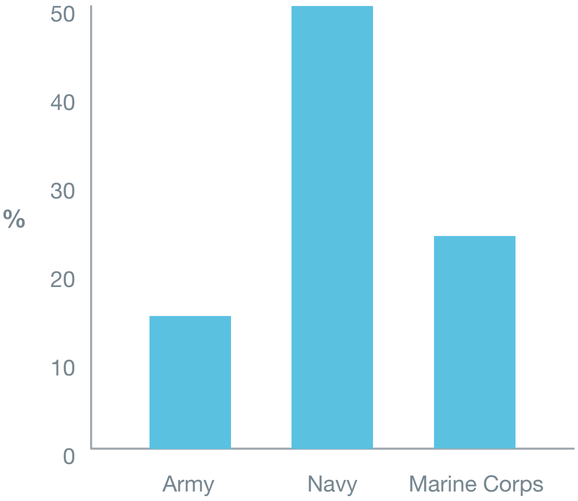

**Figure 17. The Percent of Electricity Consumption Captured by Advanced Metering System in 2015**

The lack of advanced meters in DoD buildings precludes the use of remote audits, among other management tools. Using a year's worth of interval utility data, remote audit firms can provide a detailed assessment of the energy performance of a building and identify low-cost and no-cost improvements that the building manager can take. Remote audits are an important tool in GSA's arsenal, and an ESTCP demonstration in 100 DoD buildings indicated that remote auditing could

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[60] For a review of impediments to the adoption of cost-effective investments in energy efficiency, see Todd D. Gerarden. Richard G. Newell, and Robert N. Stavins, *Assessing the Energy-Efficiency Gap*, Harvard Environmental Economics Program January 2015.

identify savings of 14 percent per building, and half of the savings would result from actions that would require no investment or extremely low-cost investments.[61] Remote audit firms and/or ESPC contractors can also identify opportunities for larger savings if they have meter data on the energy performance of individual buildings.

More broadly, if meter data were widely available, DoD's ESPC contractors could create a highly efficient market in which companies would compete to offer DoD the best energy saving opportunities at the lowest price. Absent this data, contractors must depend on the local knowledge of the base or engage in other workarounds. In short, the lack of meter data imposes high transaction costs on every energy conservation opportunity, ensuring that many of those opportunities are lost.

A 2013 OSD policy memo directs the Services to capture 60 percent of their energy use in the near term and 85 percent by 2020.[62] Although the Services are far from reaching even the immediate goal, a 60 percent requirement is far too low and 2020 too far off as a "deadline" for the more ambitious goal. DoD is missing out on major savings by not metering more aggressively more quickly. Following GSA's lead, the Services should be measuring over 90 percent of their energy consumption at the building level today.

What are the barriers to implementing a comprehensive metering program? One response from the Services is that metering is not cost effective in buildings below, say, 30,000 sf because they do not consume enough energy. A simple return on investment calculation, with conservative assumptions, shows that metering is cost effective even for buildings as small as 5,000 sf and yields a large return on investment for the average size DoD building.[63]

The second barrier to metering is concerns about cybersecurity. To be sure, cybersecurity is an important issue and DoD must protect its networks. But utilities have connected millions of advanced meters in a way that provides protection against cyberattacks. Cyber experts both inside and outside of the government stressed to us that there is no technical impediment to cyber-secure metering of buildings. Rather, the impediment is "people"—specifically, the lack of experience on the ground and the lack of support from Service leaders at the top. Moreover, the parties who must fund and approve advanced metering systems often do not recognize their importance and value.

**Energy and Capital Investments:** The second reason DoD is missing opportunities to improve energy efficiency is the constraints that both Congress and DoD place on the process for investing in building upgrades. The key problem is the inability to combine third-party financing from ESPC contractors with funding for capital improvements.

> **The availability of meter data for DoD's ESPC contractors would create a highly efficient market where companies compete across all installation to offer DoD the best energy saving opportunities at the lowest price.**
>
> An Efficient Energy Conservation Market

It is well established that investments in energy efficiency should be coordinated with capital improvements wherever possible. Often, an ECM will not "pencil out" if done as a standalone investment, but it makes economic sense as part of a larger renovation of a building. A $500 million renovation of the Empire State Building that began in 2008 has become a textbook example of this synergy. The owners undertook a large number of

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[61] https://serdp-estcp.org/index.php/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201261/EW-201261.

[62] *DoD Utilities Meter Policy*, April 16, 2013.

[63] Assuming a $5000 cost of a meter, a $50 per year maintenance cost for the meter, and the average energy cost per square foot for DoD buildings ($1.60/SF) yields a return on investment over 10 years of greater the 2 for buildings larger than 5000 sf. There are three sources of savings, reduction in the cost of auditing ever four years, a 7% reduction in energy costs with little or no investments, and an additional 7% reduction that requires a capital investment that requires 5 years to payoff.

ECMs, including replacement of 6,500 windows, in part to make the Empire State Building more appealing to future tenants. The combination of ECMs was so effective that the building owners were able to get by with a smaller replacement chiller—a savings that more than paid for all of the ECMs.[64]

Under current rules, the Services cannot easily exploit this natural synergy between ECMs and capital investment. To elaborate, the Services use two sources of appropriated money—military construction (MILCON) funds and Sustainment, Restoration, and Modernization (SRM) funds—to pay for the large capital projects that are required to upgrade or restore basic building functions. However, under current DoD policies, the Services cannot combine MILCON or SRM funds and third-party funds from an ESPC contractor into a single contract, which is what is required to align the incentives of the various parties and coordinate the funding streams.[65]

Other federal agencies have figured out how to capture the synergy between ECMs and capital investment. GSA has done this as part of its "deep retrofit" approach to ESPC projects, generating significantly larger reductions in energy consumption compared to standard ESPCs.[66] In effect, GSA identifies buildings that are slated for capital improvements in the future and makes them the candidates for a deep retrofit ESPC. Another example is the work to redevelop the Intelligence Community Campus–Bethesda where full scale renovation of three large buildings is required to meet aggressive energy goals. However, given the obstacles that the agencies and the ESPC contractor had to overcome, this is probably not a replicable model.[67]

> **Current DoD policies and Congressional rules for the authorization and appropriation of military construction funding constrains DoD from fully achieving deep energy retrofits as achieved in commercial practice.**
>
> Needed Policy Changes

DoD can do much more to capture the synergy between ECMs and capital projects even with its current legal authority. There are no legal impediments to funding a project with a mix of third- party ESPC funds and appropriated SRM or MILCON funds but Service policy prohibits it. Like GSA, DoD could identify buildings scheduled to undergo capital improvement and make them candidates for ESPCs. A Service could use SRM or MILCON funds to pay for ECMs such as a new roof or new windows that do not pencil out as part of the ESPC itself (i.e., that cannot be paid for out energy savings alone).

Although the Services can do more today, there are limits. SRM projects cannot exceed $1 million, and MILCON projects above $3M must receive specific authorization and appropriation from Congress. Thus only modest investments with appropriated dollars can be leveraged easily with non-appropriated third party funds. Legally required building-specific authorization and appropriation for projects over $3M makes coordination with third party energy conservation funding extremely complicated. The long time required and uncertainty associated with Congressional actions is a significant barrier to leveraging private sector investments. Congress could alter the current MILCON funding process to give DoD the needed flexibility to combine appropriated MILCON funds with third party financing.

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[64] "Project Case Study: Empire State Building", Eric Harrington and Cara Carmichael, 2009 (http://www.rmi.org/Content/Files/ESBCaseStudy.pdf). In some cases, the synergy between ECMs and capital improvements reflects the ability to use the same workers to accomplish both jobs.

[65] Department of the Army Policy Guidance for Implementation of an Energy Savings Performance Contract Nov. 2008; Air Force Engineering Technical Letter (ETL) 13-13: Energy Savings Performance Contracts (ESPC) 15 Aug. 2013

[66] "Energy Savings from GSA's National Deep Energy Retrofit Program", John Shonder, ORNL/TM-2014/401

[67] "Extending the Reach of Campus Renovation Through Combined Financing", Mark Wheeler, Eric James, Phillip L. Smith, and Luis Ayala; ASHRAE Transactions, Volume 121, Part 1 Page 332

# VII Value of Energy Security

In this last section of the report, we address two cross-cutting questions having to do with the value of energy security. Question one asks: Should DoD put a value on energy security (and if so, what)? Based on the analysis presented in earlier sections we argue that the logic behind increasingly popular proposals to "put a value on energy security" is flawed in several ways. Question two asks: Given the cost of energy security, how much of it should DoD buy? We provide an economic framework for analyzing the issue, and we describe our preliminary conclusion that, purely on business grounds, DoD should provide assured power routinely for many non-critical functions on military installations, including but not limited to R&D and industrial operations.

Below, we consider each question in turn.

## VII.1 Should DoD Put a Value on Energy Security?

There is growing support for the idea that DoD should "put a value on energy security." Groups calling for this action by DoD range from CNA's Military Advisory Board to the American Council on Renewable Energy (ACORE). Most recently, the Senate Armed Services Committee seemingly joined the ranks of those who advocate this position:

> The committee remains interested in the capability of the Department of Defense (DoD) to assign a value to energy resiliency and mission assurance for its installations ….[68]

The idea of putting a value—i.e., a price—on energy security began as an argument that the Services' should relax their self-imposed "grid parity" policy, which precludes them from paying more for "green power" than for "brown power." This policy has limited the Services to renewable energy projects that third-party developers or utilities will finance purely on business grounds. The authors of a supportive think tank report describe how paying a premium for secure power could expand the Services' project pipeline:

> DoD should develop guidance for bases to procure secure renewable energy systems in a replicable way. This could include the adoption of cost-benefit analyses that recognize the value of energy security and enable resilient renewable energy systems to be procured at a premium above the price of non-secure energy.[69]

One specific proposal calls for the authorization of an "energy security [power purchase agreement]," which would allow the military to pay the conventional rate for renewable power and a fixed payment for "security services" provided by the resilient infrastructure—analogous to capacity payments for standby generators.[70]

The argument that the Services should "put a value on energy security" has gone beyond renewable energy, and it is gaining traction in the discussion over how DoD can finance microgrids. Richard Kidd, who was at the time the Army's deputy assistant secretary for energy, told a Capitol Hill audience that appropriated funds were needed to pay for microgrids because they were not attractive purely on business grounds:

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[68] *National Defense Authorization Act for Fiscal Year 2017*, Senate Report 114–255, May 18, 2016. "…the committee directs the Secretary of Defense to report to the congressional defense committees no later than March 30, 2017 with established metrics to evaluate the costs, risks, and benefits associated with energy resiliency and mission assurance against energy supply disruptions on military facilities and installations."

[69] Andrea Marr and Wilson Rickerson, *Generating Security: Resilient, Renewable Power for U.S. Military Installations*, Center for National Policy, April 2014, p. 1.

[70] Marr and Rickerson, op cit., p. 9. A power purchase agreement (PPA) is a contracting tool commonly used in the private sector to finance the development of a new energy system. With a PPA, a developer installs a system to supply power to a customer facility in exchange for an agreement from the customer to buy a specified amount of power generated by the system at an established price. Under Section 2922a of Title 10 of the U.S. Code, DoD can enter into PPAs with terms of up to 30 years.

> Right now, all of our appropriated energy funds have to go through a cost-benefit analysis….But a microgrid to provide energy security on our installations should be thought of as an investment in military capability. We buy it, not necessarily to use it every day, but to have it in the event of a conflict or emergency. So … it will not necessarily have a positive internal rate of return.[71]

Based on the analysis presented in Sections III and IV of this report, we think that proposals to abandon grid-parity and "put a value on energy security" are misguided. Specifically, the logic behind those proposals is flawed in three ways.

First, implicit in the argument that DoD should "put a value on energy security" is a belief that DoD does not already assign such a value. However, as we described in Section III, DoD has a strategy now for ensuring the energy security of its bases—namely, the installation of a standalone generator at every building that houses a critical load. That strategy entails a set of budgetary costs, and those costs (properly calculated) represent the value (price) that DoD currently places on energy security.

Second, while we agree with the argument that DoD should incorporate security considerations into its energy investment decisions, in our view, that means using the cost of standalone backup generators as the measure of the value of energy security. To elaborate, if one is analyzing alternative investments designed to ensure that a military base has sufficient electricity when there is a power outage (i.e., energy security), the value of energy security should be determined by the least-cost method of providing that security—i.e., of avoiding damage from the outage in the first place.[72] Currently, standalone generators represent that least-cost method.

This approach to measuring the value of energy security reflects an economic framework. It differs from the more commonly used approach in the energy security literature, which equates the value of energy security with the potential damage that a power outage could cause. Though less often employed in the energy security debate, the economic framework—with its emphasis on cost avoidance—makes intuitive sense: Based on the analysis we presented in Section IV, **Figure 21** shows the 20-year cost to protect a kW of load using backup generators is modest, between $80 and $85 per kW (per year) for a standalone generator.

Granted, standalone generators are not the optimal approach to ensuring energy security for the reasons we spelled out in Section III. Thus, one might argue that DoD is justified in paying a premium to get a higher quality approach to energy security, in the form of a robust microgrid. However, the analysis we presented in Section IV demonstrates that in most parts of the country, microgrids provide more energy security for less money than the Services are currently paying for standalone generators. In short, the Services do not need to pay a premium for energy security (flaw number three in the logic of proposals to "put a value on energy security").

We recognize that, however compelling our analysis, the Services have failed to make the business case to private developers for many if not most specific microgrid projects. However, as we discussed in Section IV, that reflects DoD's failure to account for standalone generators in a way that captures and makes transparent their full budgetary cost (nevermind the non-budgeted costs). DoD needs to address that problem rather than paying a premium for secure power.

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[71] "Army Needs Appropriated Funds to Ensure Energy Security," Army New Service, Feb. 11, 2016.

[72] Glenn H. Ackerman and Daniel N. Carvell, "Quantifying the Value of Energy Security: Methodology and Estimates," CNA, October 2013.

## VII.2 How Much Energy Security Should DoD Buy?

While DoD does not need to pay a premium for secure power, it should carefully consider how much secure power—i.e., energy security—to buy. Bases provide backup power for critical functions as a matter of policy. (The economic benefits of national security, warfighter operations, life, safety, and health are difficult to quantify.) By contrast, the decision to back up non-critical functions, or "intermediate loads," should be made purely on business grounds. Currently, while the treatment of these loads is inconsistent across bases, most non-critical functions have little to no backup power.

The decision to back up intermediate or non–mission-critical loads depends on three factors which we review below: the Value of Lost Load (VOLL); the likely frequency and duration of power outages; and the annual cost of assuring power (today, the cost of standalone generators). If the probability of an outage is extremely low, then VOLL would need to be extremely high to justify the cost of energy security. The higher the probability of an outage, the lower the VOLL needs to be to justify the provision of assured, or secure, power.

**Value of Lost Load (VOLL):** VOLL is a measurement of the economic value of electricity that is not delivered to consumers as a result of an outage. It is commonly calculated using survey-based methodologies, which ask electricity customers to evaluate hypothetical outages and identify the economic losses they would incur.[73] Estimates of the VOLL are typically expressed as the economic loss in dollars per peak kW for an outage of a given duration. Plotted as a curve, with the duration of the outage shown on the horizontal axis, VOLL estimates reveal a common pattern: initial losses are limited, but losses steadily accrue over time as the duration of the outage increases.

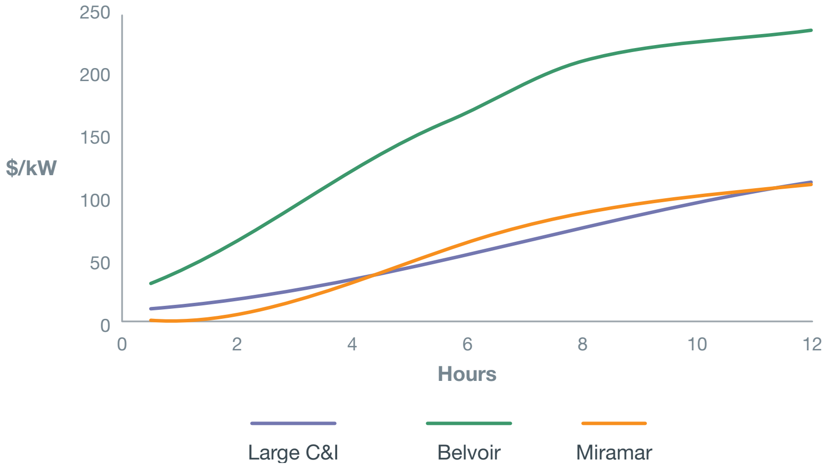

Figure 18. Value of Lost Load (VOLL) in $/kW Versus Time in Hours

**Figure 18** presents three such VOLL curves showing the estimated economic loss for outages lasting up to 12 hours, based on studies by DOE laboratories. The highest estimate, which shows losses of nearly $250/kW at hour 12 of an outage, is from an assessment by NREL of non-emergency power outages at Fort Belvoir.[74] The two lower estimates are from NREL's analysis of Marine Corps Air Station Miramar [75] and a meta-analysis of commercial and industrial customers in the United States conducted by Lawrence Berkeley National Laboratory.[76] Those two studies, whose VOLL curves are remarkably parallel, estimate losses of just over $100/kW at hour 12 of the outage. The VOLL estimates shown in **Figure 18** are consistent with DoD's own, more informal estimates of economic losses at military industrial facilities, such as one following an outage at the Portsmouth Naval Shipyard in Kittery, Maine.

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[73] There is a large amount of literature on the economic impact of electric outages on commercial and industrial operations. See London Economics International LLC. *Estimating the Value of Lost Load* (2013).

[74] *Valuing Energy Security: Customer Damage Function Methodology and Case Studies at DoD Installations*, J. Giraldez, S. Booth, K. Anderson, and K. Massey, NREL/ TP-7A30-55913, October 2012.

[75] Op. cit.

[76] *Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States,* Michael J. Sullivan, Josh Schellenberg, and Marshall Blundell, LBNL-6941E, January 2015.

**Likely Frequency and Duration of Outages:** In addition to estimating the economic loss that outages of varying durations would impose, it is essential for the military to take into account the likely frequency (i.e., the probability) of such outages. Based on the literature on grid reliability as well as actual data on outages on DoD bases (**Figure 3** in Section II), we estimated the frequency of annual outages of varying durations. The frequency of outages differs by location because it depends on the reliability of the commercial grid in the local area. To be conservative, we based our estimates on geographic areas with reliable electric services.

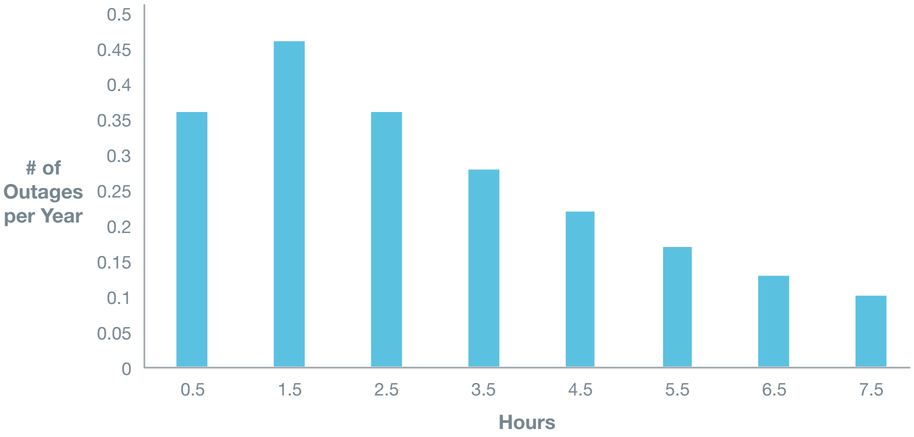

**Figure 19. A Hypothetical Annual Outage Frequency up to 8 Hours**

**Figures 19** and **20** present these probabilistic estimates. **Figure 19** shows the likelihood of outages lasting from 0.5 to 8 hours, calculated in hourly increments. **Figure 20** shows the likelihood of outages lasting from 12 hours to 168 hours (a week), calculated in 8-hour increments.[77] Based on the estimates presented in these two figures, one would predict that a typical military base would experience about two outages per year on average (SAIFI), with an average outage duration of seven hours (SAIDI). Through simple multiplication, we can show that, over the course of 20 years, a base is almost certain to experience an outage that lasts from one to three days, and there is a 50 percent probability that it will experience an outage that lasts a week.

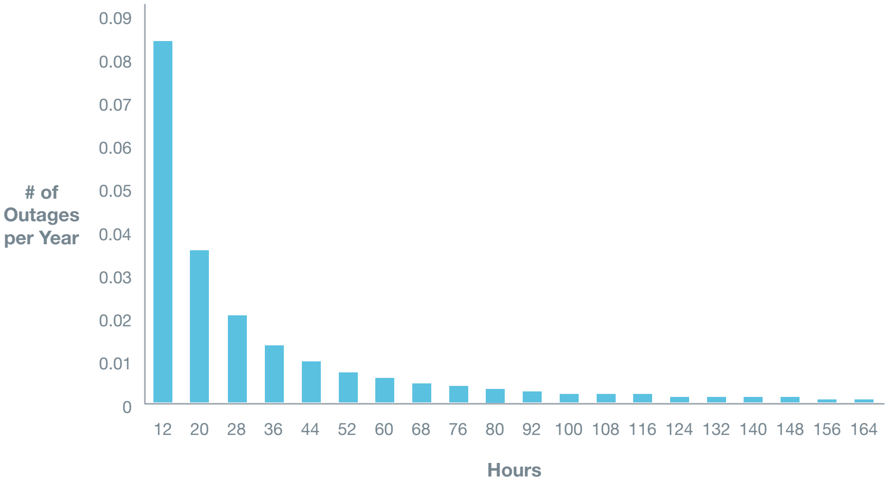

**Figure 20. A Hypothetical Annual Outage Frequency up to a Week**

The estimates presented in **Figures 19** and **20** are conservative in part because we used data from areas with above-average grid reliability. In addition, the estimates ignore long-term trends. As we discussed in Section II, with major weather events and other threats to the commercial grid increasing, outages are likely to increase in frequency and duration over time.

**Cost of Energy Security:** The cost of energy security is straightforward to calculate. **Figure 7** in Section IV shows the annualized cost of a standalone generator with a 20-year life. The cost of a standalone generator or other energy security asset as discussed above is largely insensitive to the duration of the outage.[78]

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[77] The estimates presented in Figure 20 are based on data on long-duration outages as reported to DoD; see Figure 3 in Section II.

[78] Only the cost of increased fuel storage depends on the duration.

**Calculation of How Much Energy Security to Buy:** With the information presented above, we can calculate the relative costs and benefits of using standalone generators to protect non-critical loads from outages of varying durations. The cost is equal to the annualized cost of a standalone generator (**Figure 7**). The benefit is equal to the estimated economic loss (VOLL) from an outage of a given duration (**Figure 18**) multiplied by the probability that such an outage will occur (**Figures 19** and **20**).

**Figure 21** presents the costs and benefits of energy security solutions that protect four different outages durations: eight hours, one day, three days and seven days. The results show that if one only is concerned about outage of up to eight hours, the annualized cost of a standalone generator is slightly higher than the benefits from the protection that the generator provides (the avoided economic loss). However, if one wants to protect against outages up to a day or longer, the benefits that a generator provides far exceed its costs. Moreover, that benefit-cost ratio increases dramatically with the duration of the outage, because while the cost of generators is flat, the benefits (i.e., the economic loss that generators prevent) rise sharply.

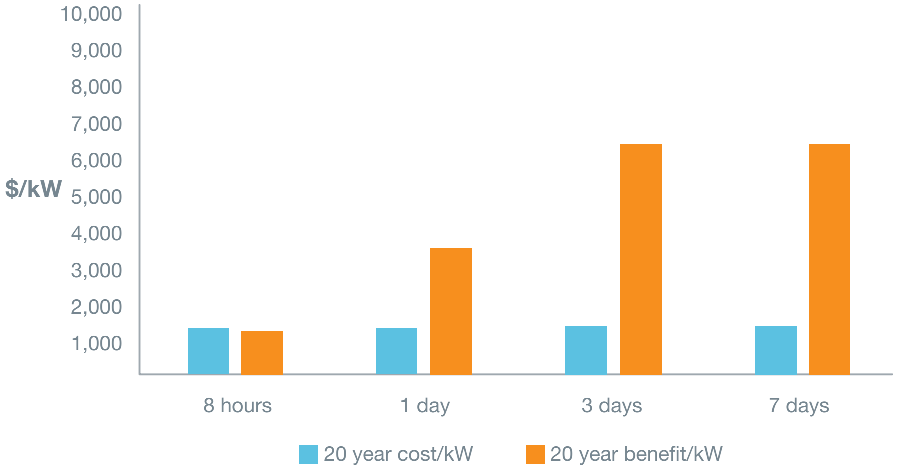

**Figure 21. Comparison of Estimates of an Energy Security Asset's Economic Benefit ($/kW) and the Cost of a Standalone Generator as a Function of the Duration in Days of Protection Required for a 20-Year Lifecycle**

These results argue strongly for greater use even of the existing energy security solution—namely, standalone generators. (Given their superior economics, the case for microgrids is even more compelling.) As we noted earlier, over a 20-year period—the life of a generator—a base can expect to experience an outage lasting one to three days, and it has a 50/50 chance of experiencing a week-long outage. For any of those outage scenarios, it would be wise to have the protection of standalone generators—and foolish to be without it.

Stated differently, purely from a business standpoint, DoD is currently underinsuring many non-critical loads on its military bases, including its R&D laboratories, industrial facilities, and many other important functions. While these activities are not "critical" in the sense of currently requiring emergency backup power, they are economically important—and thus expensive to suspend in the event of an outage.

This conclusion, while based on analysis of model data, is consistent with real-world experience. GSA acquired the microgrid at White Oak, Maryland, to protect the high-value research that FDA conducts there. Similarly, the Navy made a business decision to install multiple large-scale diesel generators at its warfare center in Dahlgren, Virginia, which had been forced repeatedly to shut down because of power outages.

Note that DoD's long-term time horizon is key to this analysis. For a commercial firm that may relocate every few years, it may not be cost effective to invest in a standalone generator. By contrast, most military bases have been in operation for decades if not centuries, and most of them will continue to operate for decades more. Today, DoD is underinsuring for energy security at its facilities on military bases. Non–mission- critical loads' economic benefits justify greater energy assurance. DoD should consider providing energy security routinely for its R&D, industrial, and many other functions that take place on a military base.

# VIII Findings

Military bases require large volumes of electricity to execute their critical missions, but their reliance on the commercial grid and a decades-old backup power paradigm can put their critical missions at risk. Already, DoD experiences multi-day power outages and pays a high cost for these outages in dollars and mission risk. The triggers for outages severe-weather, physical terrorism, and cyber-attacks – are only expected to increase in the near future.

Against that backdrop, some bases are moving towards more advanced energy security solutions. Instead of solely relying on the existing paradigm of having one standalone generator tied to each building with a critical load, they are putting in place the building blocks of smart microgrids.[79] They are making that move because they are able to achieve "triple play" benefits – more energy security and independence from the commercial grid, lower power costs, and an enhanced ability to integrate renewable energy. This reflects a real change in DoD's approach to energy security. That change is enabled by improvements in technology cost and performance. This alternative to longstanding energy practice is finally viable, at DoD and in other commercial settings.

| Criteria | Standalone Generators | Microgrid |
|---|---|---|
| Efficient Sizing | Oversized by design (2x)<br>As executed often worse | Optimal sizing<br>Advantage from the diversity of non-coincident peak power needs |
| Maintenance | Large O&M costs<br>Inadequate testing occurs and many of the 100 or more generators on large bases are poorly maintained | Easier and less expensive to maintain<br>Relies on a small number of large, standardized and physically centralized generation units |
| Reliability | Often poor due to inadequate maintenance and testing<br>N+X reliability is rare and expensive | Readily provides a high level of reliability (N+1 or N+2)<br>Networked structure makes it cost-effective |
| Flexibility | No realistic ability to meet changing requirements<br>Established at procurement | Can respond to changes in electricity needs, even during an outage<br>At no additional costs |
| Coverage | Forces all or nothing solution for loads (critical or non-critical)<br>Needs are more nuanced | Excess generation capacity can serve any load to which the microgrid is connected<br>Intermediate loads can be supported |

**Table 4. Summary of Standalone Generators and Microgrid Technical Performance**

Microgrids, even in the relatively simple configurations modeled in this report, can outperform the existing standalone generator paradigm on each of five non-cost energy security criteria and can do so at a materially lower lifetime cost of ownership. A summary of performance on the five non-cost factors is shown in **Table 4**.

Over their 20-year lifetimes on a net cost basis, an all-diesel microgrid can save large military installations from $8 to $20 million in energy security spending. The savings within that range are dependent on the region of the U.S. – savings are greatest in the Northeast/Mid-Atlantic and lower in

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[79] A smart microgrid can integrate distributed energy resources such as fossil-fuel and renewable generators, load management systems, and battery storage and operate seamlessly both in parallel to the grid and in island mode. Although the technology for advanced microgrids is still relatively young, dozens of commercial systems at large scale are now operating across the U.S.

the Southeast and California in our analysis of the all-diesel microgrid. Further savings are possible in California by integrating natural gas generators with diesel generators. In that case, it is possible to achieve better energy security and have it yield a positive revenue (not just lower costs) compared to today's backup power paradigm.

There are no technical or financial barriers to the implementation of microgrids on military bases. A Service that wants to take advantage of a microgrid faces a choice as to whether to be an owner-operator, or to purchase the stream of benefits as a service from a private entity that owns and operates the microgrid. Buying microgrid services is the preferred alternative and allows for the Services to benefit from third party financing by avoiding capital outlays and putting performance incentives and operational responsibilities on firms that are experts in managing such systems.

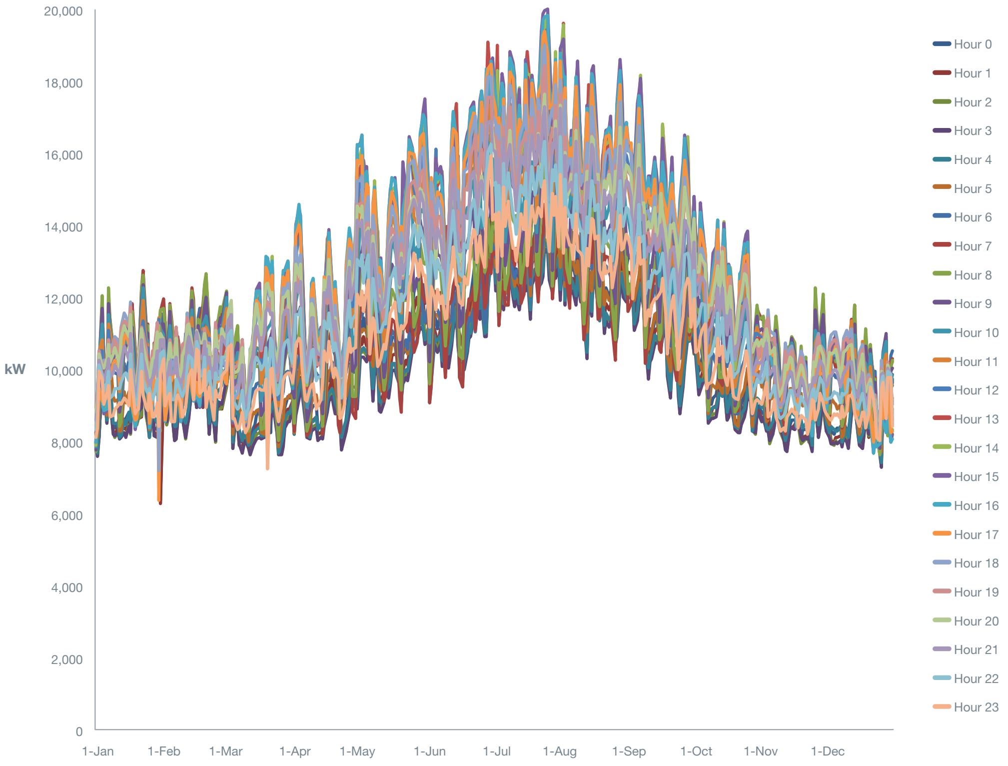
Energy efficiency can enhance the energy security of a military installation. When a base reduces its critical power needs through energy conservation and efficiency, its energy security costs drop proportionately. To date, the Services have made only limited progress when it comes to energy efficiency, and they are leaving $1 billion a year of outright energy cost savings (25 percent of its $4 billion-a-year utility bill) on the table and paying additional costs for the security of loads that would otherwise be much lower.

While renewable energy can certainly enhance energy security, the current cost of energy storage (e.g., large-scale batteries) means that intermittent sources of renewable energy (wind and solar) cannot yet cost effectively provide the primary source of energy security for critical loads.

Our analysis demonstrates that microgrids provide more energy security for less money than the Services are currently paying for standalone generators. The Services do not need to pay a premium for energy security. From a business perspective, DoD is currently underinsuring many non-critical loads on its military bases, including its R&D laboratories, industrial facilities, and many other important functions, and paying more for critical load insurance than need be.

# Appendix A Analytic Methods

The case studies began with 8760-hour/year load profiles drawn from military installation data. The graph below displays the hourly data used to represent the critical loads with a 20,000 kW (20 MW) annual peak demand at two of the bases.



**Analysis Starting Condition: Projected Hourly Critical Loads at Military Installation**

For each hour, on-site electricity production was lined up against electricity consumption to create realistic financial outcomes that are not based on extrapolating average conditions, but instead on calculating the hourly net costs of power to the military installation. That hourly analysis was applied to future years through the use of annual price and cost inflation variables. Annual cash flows were then converted into current (net present value) dollars through the use of an investment discount rate.

| Billing Component Name | Unit of Measure | Billing Rate in Year 1 | % of Annual Bill (for Status Quo Scenario) |
|---|---|---|---|
| Fixed Monthly Fee | $ | $2,500 | 0.1% |
| On-Peak Energy | $/kWh | $0.0821 | 33.2% |
| Off-Peak Energy | $/kWh | $0.0521 | 35.0% |
| Winter Peak Demand | $/kW | $8.00 | 9.4% |
| Summer Peak Demand | $/kW | $16.00 | 13.1% |
| Taxes | % of prior items | 10% | 9.1% |
| Standby/Departing Load (including taxes) | $/kW | $8.00 | *N/A – not applied in status quo, but only for microgrid with natural gas generators* |

**Table A-1. Electric Utility Rate Categories Modeled: Example for Mid-Atlantic/Northeast**

Conservative assumptions on how assets would operate in markets were applied, and outright prohibitions on DR participation by fossil-fuel generation in certain markets were incorporated. Market data on fuel (diesel and natural gas) costs and DR prices are regionally-specific to distinguish how outcomes can differ by location.

An example of the utility rate structure applied is in **Table A-1**. This reflects a realistic, though somewhat simplified rate structure. Just as with fuel costs, regionally-specific electric utility rate levels were applied to each business case. Appendix B summarizes additional key variables applied in the analysis.

# Appendix B Business Case Inputs

The main input assumptions for Chapter IV's business case analysis are summarized in **Table B-1**. These assumptions were established based on consultation with energy industry officials experienced with the existing military energy security paradigm (standalone diesel generators) and with military applications of microgrids and commercial microgrid applications in similar large campus-type environments.[80] The sources of the assumptions are provided in footnotes to the table.

| Row # | Input Name | Input Value | Unit of Measure |
|---|---|---|---|
| | Asset Cost and Performance Inputs *(applied in year 1 of investment)* | | |
| 1 | Small Diesel (250 kW) Generator Capital Cost [81] | $400 | $/kW |
| 2 | Large Diesel (2,000 kW) Generator Capital Cost [82] | $600 | $/kW |
| 3 | Natural Gas (7,038 kW) Generator Capital Cost [83] | $1,783 | $/kW |
| 4 | Microgrid Capital Cost [84] | $3,000,000 | $ |
| 5 | Small Diesel (250 kW) Generator Fixed Annual O&M Cost [85] | $6,500 | $ |

**Table B-1. Main Inputs for Business Case Analysis**

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[80] It is assumed in this analysis that the existing on-base distribution system is of sufficient quality to not require an upgrade.

[81] This cost reflects the all-in capital cost of installing new standalone (building-tied, non-networked) 250 kW diesel generators without the physical configuration nor permits to participate as dispatchable assets in electricity markets. The cost was determined by consulting distributed generator industry professionals. 250 kW is an approximation of the average size of backup generators at military installations.

[82] This cost reflects the all-in capital cost of installing new 2,000 kW diesel generators fully capable of being networked into a microgrid, operable in islanded or parallel mode within the microgrid, and with the physical configuration and permits allowing the generation units to participate as dispatchable assets in electricity markets. This cost was determined by consulting distributed generator industry professionals. It is similar to the average costs (after inflation to 2016 dollars) in Electric Power Research Institute (EPRI), *Costs of Utility Distributed Generators*, 1-10 MW, March 2003, http://www.publicpower.org/files/deed/finalreportcostsofutilitydistributedgenerators.pdf.

[83] The generator selected has nominal turbine capacity of 7,500 kW and net power output of 7,038 kW. Its installed capital cost is based on U.S. Environmental Protection Agency (EPA), *Catalog of CHP Technologies*, March 2015, page 3-14, https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf. The installed cost was calculated by removing the cost of specific heat recovery equipment in the combined heat and power (CHP) configuration (that are not needed for a power-only application like modeled here) in the EPA document as well as removing 25% of construction, engineering, and other soft costs (e.g., development and financing) and applying an inflation rate to convert the EPA data into 2016 dollars.

[84] This cost was obtained by averaging estimates for a microgrid configured to the modeling specifications in this report. The costs are consistent with a microgrid that can both (i) island, and (ii) peak shave and participate in demand response markets while grid-connected. The costs include switchgear upgrades (electrically-operated breakers), metering improvements, the microgrid controller hardware and its software configuration, systems engineering, cybersecurity implementation, factory testing, training, and commissioning. The cost estimates were obtained from multiple major providers of microgrids for large campus electricity users that also have experience with military microgrids. Investments in substation or distribution network upgrades beyond those listed above are not included in this microgrid capital cost, nor are costs to integrate distributed energy resources that are outside of this report's modeling (e.g., energy management control systems, battery storage, electric vehicle-to-grid, and intermittent renewable generation).

[85] This cost was determined in consultation with a provider of military privatization services and other distributed generation professionals and reflects a comprehensive O&M program including parts and labor used in reliability testing. Diesel fuel consumption during regular reliability testing is not included in this cost. On a per-kW basis, this O&M cost is similar to that estimated by the National Renewable Energy Laboratory (NREL), though NREL modeled much smaller diesel generators. See J. Kurtz et al., NREL, *Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison*, September 2014, pages 4-5, http://energy.gov/sites/prod/files/2014/10/f19/fcto_backup_pwr_cost_of_ownership_analysis_report.pdf.

| Row # | Input Name | Input Value | Unit of Measure |
|---|---|---|---|
| 6 | Large Diesel (2,000 kW) Generator Fixed Annual O&M Cost [86] | $20,000 | $ |
| 7 | Natural Gas (7,038 kW) Generator Variable O&M Cost [87] | $0.01244 | $/kWh |
| 8 | Microgrid Fixed Annual O&M Cost [88] | $100,000 | $ |
| 9 | Heat Rate for Large Diesel (2000kW) Generator [89] | 14,404 | Btu/kWh |
| 10 | Heat Rate for Small Diesel (250 kW) Generator [90] | 10,618 | Btu/kWh |
| 11 | Heat Rate for Natural Gas (7,038 kW) Generator [91] | 11,807 | Btu/kWh |
| Energy Price Inputs *(applied in year 1 of investment)* | | | |
| 12 | Diesel Fuel Price (Northeast/Mid-Atlantic Region) [92] | $3.39 | $/gallon |
| 13 | Diesel Fuel Price (Southeast Region) [93] | $3.17 | $/gallon |
| 14 | Diesel Fuel Price (California) [94] | $3.47 | $/gallon |
| 15 | Natural Gas Price (Northeast/Mid-Atlantic Region) [95] | $5.11 | $/MMBtu |

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[86] This cost was determined in consultation with a provider of military privatization services and other distributed generation professionals and reflects a comprehensive O&M program including parts and labor used in reliability testing. This cost is similar, when adjusted for inflation to 2016 dollars, to the cost of Caterpillar's *Watchguard Generator Service Program* described in EPRI, *Costs of Utility Distributed Generators, 1-10 MW*, March 2003, pages 4-3 to 4-5, http://www.publicpower.org/files/deed/finalreportcostsofutilitydistributedgenerators.pdf. Diesel fuel consumption during regular reliability testing is not included in the fixed O&M cost applied in this report. Diesel fuel costs of peak shaving and market participation in the Microgrid Cases, however, are captured in the modeling, and the diesel fuel prices applied for each region are described later in this table.

[87] This cost was calculated by applying an inflation rate to convert variable O&M costs for a 7,038 kW natural gas generator to 2016 dollars. For source data, see EPA, *Catalog of CHP Technologies*, March 2015, page 3-15, https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf.

[88] This O&M cost applies to the microgrid controller and related software updates and licensing, but not to O&M for individual generation assets connected to the microgrid (O&M costs for the generation assets in the microgrid are provided on the two prior rows of this table). The microgrid O&M cost was derived from exchanges with electricity industry officials familiar with selling and procuring microgrids of similar size and capabilities to those modeled in this report.

[89] This reflects the higher heating value heat rate calculated for the Generac 250 kW backup diesel generator (Model SD250). See Generac, Industrial Diesel Generator Set, http://www.generac.com/generaccorporate/media/library/content/all-products/generators/industrial-generators/diesel/0185780sby-c-sd250-8-7l.pdf?ext=.pdf.

[90] This reflects the higher heating value heat rate calculated for the Caterpillar 2,000 kW backup diesel generator (Model 3516B). See Caterpillar, http://www.cat.com/en_ZA/products/new/power-systems/electric-power-generation/diesel-generator-sets/18331799.html.

[91] This reflects the higher heating value electric heat rate for the 7,038 kW unit in EPA, *Catalog of CHP Technologies*, March 2015, page 3-6, https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf.

[92] The average of prices for a 3-year period (June 10, 2013, through June 6, 2016) for No. 2 Diesel in the Central Atlantic Region was used from Energy Information Administration (EIA), U.S. Department of Energy (DOE), *Gasoline and Diesel Fuel Update*, http://www.eia.gov/petroleum/gasdiesel/.

[93] op. cit. for Lower Atlantic Region.

[94] op. cit. for California Region.

[95] The average of annual day-ahead natural gas prices for the Transco Zone 6 Non-New York hub over the period 2013 to Mid-Year 2016 (with results for 2016 weighted as a half-year) plus $1.00/MMBtu for local utility distribution was used. The hub price was from Federal Energy Regulatory Commission (FERC), *Northeast Natural Gas Market: Annual Hub Prices* (updated 7/15/2016), https://www.ferc.gov/market-oversight/mkt-gas/northeast.asp.

| Row # | Input Name | Input Value | Unit of Measure |
|---|---|---|---|
| 16 | Natural Gas Price (Southeast Region) [96] | $4.37 | $/MMBtu |
| 17 | Natural Gas Price (California) [97] | $4.41 | $/MMBtu |
| 18 | All-in Average Electricity Price (Northeast/Mid-Atlantic Region) [98] | $0.0928 | $/kWh |
| 19 | All-in Average Electricity Price (Southeast Region) [99] | $0.0675 | $/kWh |
| 20 | All-in Average Electricity Price (California) [100] | $0.1234 | $/kWh |
| 21 | Utility Standby Charges (applicable to natural gas generators) [101] | $8.00 | $/kW (monthly) |
| 22 | Emergency Demand Response Capacity Payment (Northeast/Mid-Atlantic Region) [102] | $120 | $/MW-day |
| 23 | Emergency Demand Response Capacity Payment (Southeast Region) [103] | N/A | $/MW-day |
| 24 | Emergency Demand Response Capacity Payment (California) [104] | N/A | $/MW-day |
| 25 | Emergency Demand Response Annual Event Hours (only applicable to Northeast/Mid-Atlantic Region) [105] | 12 | # of Hours |

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[96] The average of annual day-ahead natural gas prices for the Florida Gas Transmission (FGT) Z3 hub over the period 2013 to Mid-Year 2016 (with results for 2016 weighted as a half-year) plus $1.00/MMBtu for local utility distribution was used. The hub price was from FERC, *Southeast Natural Gas Market: Annual Hub Prices* (updated 7/15/2016), https://www.ferc.gov/market-oversight/mkt-gas/southeast.asp.

[97] The average of annual day-ahead natural gas prices for the SoCal Border hub over the period 2013 to Mid-Year 2016 (with results for 2016 weighted as a half-year) plus $1.00/MMBtu for local utility distribution was used. The hub price was from FERC, *West Natural Gas Market: Annual Hub Prices* (updated 7/15/2016), https://www.ferc.gov/market-oversight/mkt-gas/western.asp.

[98] The average retail electricity price for industrial customers in Maryland, New Jersey, and Pennsylvania (simple average of the three states) for 2014 was used from EIA, Average Price (cents/kilowatthour) by State by Provider, 1990-2014, www.eia.gov/Electricity/Data/State/avgprice_annual.xls. See Section IV of this report for a discussion of how these average per-kWh electricity prices were converted into the more complex rate structures applied in the report's financial modeling.

[99] op. cit., using the average retail electricity price for industrial customers in Alabama, Florida, Georgia, and South Carolina (simple average of the four states).

[100] op. cit., using the average retail electricity price for industrial customers in California.

[101] See ICF International, Inc. for the California Energy Commission (CEC), *Combined Heat and Power: Policy Analysis* and *2011-2030 Market Assessment*, February 2012, http://www.energy.ca.gov/2012publications/CEC-200-2012-002/CEC-200-2012-002-REV.pdf. On page 72 of that report, the high end of the range for capacity reservation (i.e., standby) charges for baseload distributed natural gas generators was $7.70 to $7.95/kW. Due to inflation that has occurred since the publication date of the CEC report and to be conservative in modeling the Microgrid Cases, the high end of the standby cost range was chosen for this report.

[102] This equals the price in the PJM auction for capacity in 2017/2018. See PJM, 2017/2018 *RPM Base Residual Auction Results*, page 18, http://pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2017-2018-base-residual-auction-report.ashx. No annual escalator was applied to the capacity price for future years as there has been no clear upward trend in these capacity prices at the RTO level. For economic demand response, which was a very small factor in the financial results in this report, 2011-2012 hourly day-ahead prices from PJM were used as representative for the Northeast/Mid-Atlantic region. Economic demand response was assumed to be unavailable in the Southeast and California regions for diesel generation assets.

[103] It was assumed that suitable emergency demand response programs are not available in the Southeast region.

[104] It was assumed that enrolling diesel generators in emergency demand response (DR) programs will not be allowed in California over the investment horizon contemplated in this report (2017 and after) due to strengthened emissions requirements in the state. In past years, diesel generators could participate in some utility emergency DR programs in California.

[105] Emergency DR events are rare, and this variable has minimal effects on the financial results in this report. The 12 hour assumption is on the high end of the historical experience in PJM. See PJM, *Summary of PJM-Initiated Load Management Events*, www.pjm.com.

| Row # | Input Name | Input Value | Unit of Measure |
|---|---|---|---|
| **Escalator and Investment Rate Inputs** | | | |
| 26 | Annual Escalator of Capital and O&M Costs [106] | 1.96 | % |
| 27 | Annual Escalator of Diesel, Natural Gas, and Electricity Prices [107] | 1.96 | % |
| 28 | Discount Rate [108] | 3.20 | % |
| **Generator Unit Availability and Dispatch Inputs** | | | |
| 29 | Small Diesel (250 kW) Generators in Base Cases [109] | 160 | Number of Generators |
| 30 | Large Diesel (2,000 kW) Generators Included in Microgrid Cases [110] | 12 (all diesel case) and 8 (half diesel/ half natural gas case) | Number of Generators |
| 31 | Natural Gas (7,038 kW) Generators Included in Half Diesel/Half Natural Gas Microgrid Case [111] | 2 | Number of Generators |
| 32 | Large Diesel (2,000 kW) Generators Used for Peak Shaving in Microgrid Cases [112] | 3 | Number of Generators |
| 33 | Large Diesel (2,000 kW) Generators Used for Demand Response for Microgrid Cases [113] | 10 (all diesel case) and 6 (half diesel/half natural gas case) | Number of Generators |
| 34 | Duration of Annual Planned Maintenance for Natural Gas (7,038 kW) Generators [114] | 9 | Days |

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[106] 20-year inflation expectations are from the Federal Reserve Bank of Cleveland as of June 1, 2016. See https://www.clevelandfed.org/our-research/indicators-and-data/inflation-expectations.aspx. The 20-year inflation expectations were applied because the investment horizon in this report is 20 years.

[107] op. cit..

[108] U.S. Office of Management and Budget (OMB), *Budget Assumptions*, November 20, 2015, https://www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist-2016.pdf. The 20-year OMB assumption for 2016 was used to match the 20-year investment horizon in this report.

[109] This number of generators was obtained by using the common practice at military installations of sizing backup generators at two times the peak requirements of the critical loads to which they are connected. Twice the 20 MW critical peak load used in this report is 40 MW. Dividing that figure by the generator size of 250 kW results in 160 generators. Given the significant over-sizing (200% versus critical loads) of building-tied generators under the energy security status quo, power factor considerations (i.e., power factor below 100%) were not applied in determining the number of small generators to model in the Base Cases. If power factor was considered, the number of standalone generators would increase.

[110] The number of networked generators in the Microgrid Cases was determined by dividing the critical load requirements (20 MW) by an assumed power factor of 90% (which is typical for blended commercial and industrial electricity uses such as those occurring at military installations) and, then, determining the minimum number of diesel generators required to achieve N+1 reliability. Power factor is defined as the ratio of real power to apparent power (the percentage of the current provided that is converted into real work). There is a need to over-size generation solutions to account for power factors under 100% because not all generator output will be converted into real power used by installation electricity equipment.

[111] This is the minimum number of natural gas generators required to serve at least half of the critical loads after adjusting for power factor. In the half-diesel, half-natural gas Microgrid Case, there is 14.076 MW of natural gas capacity and 16 MW of diesel capacity.

[112] This number of generators was selected because peak shaving a larger number of generators would have minimal additional impact on monthly peak demand charges for the 50 MW peak demand military installation modeled in this report without greatly increasing the number of peak shaving hours required. The same number of diesel generators were used for peak shaving in both the all-diesel microgrid and the half-diesel, half-natural gas Microgrid Cases.

[113] Two diesel generators were reserved for non-performance. This variable only applied in the Northeast/Mid-Atlantic region because it was assumed in the modeling that suitable emergency DR programs would not be available in the Southeast region and that enrolling diesel generators in DR programs will not be allowed in California over the investment horizon contemplated in this report (2017 and after).

[114] This level of planned maintenance is within industry norms for distributed natural gas generators. For example, see EPA, *Fuel and Carbon Dioxide Emissions Savings Calculation Methodology for Combined Heat and Power Systems*, February 2015, page 28 https://www.epa.gov/sites/production/files/2015-07/documents/fuel_and_carbon_dioxide_emissions_savings_calculation_methodology_for_combined_heat_and_power_systems.pdf.

# Appendix C Detailed Case Study Results

This Appendix summarizes the results, and economic drivers, of the Chapter IV economic analysis. The results illuminate where centralized microgrids do and do not bring long-term economic advantages over the status quo of decentralized, standalone diesel generators.

The economic results for microgrids using all-diesel generation and for those using half-natural gas, half-diesel generation are presented in distinct sub-sections of the Appendix. Within each sub-section, results are presented separately for each of the three regions modeled because utility power costs, fuel costs, and energy market participation options can vary widely by region:

- Mid-Atlantic/Northeast
- California
- Southeast

This report does not quantify the substantial, additional non-economic benefits that microgrids can deliver, including much higher levels of reliability (N+1 versus N) and the flexibility to match changing mission requirements. Nor do the economic results quantify the value of being able to use the microgrid itself for renewables integration, load management, or other purposes. Therefore, the economic results presented below can be interpreted as the minimum, or most conservative, business case for microgrids.

## C.1 All-Diesel Microgrid Compared to Status Quo

Tables C-1 to C-3 show how the status quo of decentralized standalone generators compares on 20-year economics to a centralized microgrid with large diesel generators.[115] The all-diesel microgrid is more cost-effective over 20 years than the status quo, with net savings of approximately $8 to $20 million depending on the region.

| Cost or Revenue Category | Status Quo (Base Case) | Microgrid with All Large Diesel Generators | Net Savings (or Cost) of Microgrid vs. Status Quo |
|---|---|---|---|
| Diesel Generator Capital Cost | $13,905,655 | $14,400,000 | ($494,345) |
| Natural Gas Capital Cost | $0 | $0 | $0 |
| Microgrid Capital Cost | $0 | $3,000,000 | ($3,000,000) |
| Diesel Fuel Cost | $0 | $4,330,421 | ($4,330,421) |
| Diesel Non-Fuel O&M Cost | $18,012,102 | $4,156,639 | $13,855,463 |
| Natural Gas Fuel Cost | $0 | $0 | $0 |
| Natural Gas Non-Fuel O&M Cost | $0 | $0 | $0 |
| Microgrid O&M Cost | $0 | $1,731,933 | ($1,731,933) |
| Utility Power Cost | $407,382,836 | $403,665,988 | $3,716,848 |
| Emergency Demand Response Revenues | $0 | ($11,171,172) | $11,171,172 |
| Economic Demand Response Revenues | $0 | ($476,261) | $476,261 |
| Total Cost of Electricity | $439,300,593 | $419,637,548 | $19,663,045 |

**Table C-1. Status Quo Versus All-Diesel Microgrid Results for Mid-Atlantic/Northeast Region (Data in 20-Year Net Present Value)**

| Cost or Revenue Category | Status Quo (Base Case) | Microgrid with All Large Diesel Generators | Net Savings (or Cost) of Microgrid vs. Status Quo |
|---|---|---|---|
| Diesel Generator Capital Cost | $13,905,655 | $14,400,000 | ($494,345) |
| Natural Gas Capital Cost | $0 | $0 | $0 |
| Microgrid Capital Cost | $0 | $3,000,000 | ($3,000,000) |
| Diesel Fuel Cost | $0 | $5,169,847 | ($5,169,847) |
| Diesel Non-Fuel O&M Cost | $18,012,102 | $4,156,639 | $13,855,463 |
| Natural Gas Fuel Cost | $0 | $0 | $0 |
| Natural Gas Non-Fuel O&M Cost | $0 | $0 | $0 |
| Microgrid O&M Cost | $0 | $1,731,933 | ($1,731,933) |
| Utility Power Cost | $485,876,504 | $481,752,793 | $4,123,711 |
| Emergency Demand Response Revenues | $0 | $0 | $0 |
| Economic Demand Response Revenues | $0 | $0 | $0 |
| Total Cost of Electricity | $517,794,261 | $510,211,212 | $7,583,049 |

**Table C-2. Status Quo Versus All-Diesel Microgrid Results for California Region (Data in 20-Year Net Present Value)**

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[115] The "base case" assumes that standalone generators are replaced in 10 years; if standalone generators were instead replaced now, the long-term capital costs for the status quo would be approximately 6% worse (see Figure 7).

| Cost or Revenue Category | Status Quo (Base Case) | Microgrid with All Large Diesel Generators | Net Savings (or Cost) of Microgrid vs. Status Quo |
|---|---|---|---|
| Diesel Generator Capital Cost | $13,905,655 | $14,400,000 | ($494,345) |
| Natural Gas Capital Cost | $0 | $0 | $0 |
| Microgrid Capital Cost | $0 | $3,000,000 | ($3,000,000) |
| Diesel Fuel Cost | $0 | $2,803,425 | ($2,803,425) |
| Diesel Non-Fuel O&M Cost | $18,012,102 | $4,156,639 | $13,855,463 |
| Natural Gas Fuel Cost | $0 | $0 | $0 |
| Natural Gas Non-Fuel O&M Cost | $0 | $0 | $0 |
| Microgrid O&M Cost | $0 | $1,731,933 | ($1,731,933) |
| Utility Power Cost | $296,083,444 | $293,318,447 | $2,764,997 |
| Emergency Demand Response Revenues | $0 | $0 | $0 |
| Economic Demand Response Revenues | $0 | $0 | $0 |
| **Total Cost of Electricity** | **$328,001,201** | **$319,410,443** | **$8,590,758** |

**Table C-3. Status Quo Versus All-Diesel Microgrid Results for Southeast Region (Data in 20-Year Net Present Value)**

## C.2 Half-Natural Gas, Half-Diesel Microgrid Compared to Status Quo

Tables C-4 to C-6 show how the status quo of decentralized standalone generators compares on 20-year economics to a centralized microgrid powered half by natural gas (NG) generators and half by large diesel generators.[116]

Because the natural gas generators are used for nearly continuous baseload power to the military installations, there are substantial fuel and O&M costs to their operation over 20 years and a substantial reduction in power costs that are paid to the utility. That is why the results for the half-natural gas, half-diesel microgrids are very sensitive to the relationship between natural gas costs and utility power prices in each region. In California, the spread between the cost of power from on-site natural gas generation and grid power is attractive, which is why the economic results for this microgrid configuration are so favorable in California ($64 million in savings over 20 years) and why it is already being implemented by military installations in that state. In the other two regions, the pure economic case for a half-natural gas microgrid is unfavorable ($5 million net cost over 20 years in the Mid-Atlantic/Northeast and $46 million net cost in the Southeast)

| Cost or Revenue Category | Status Quo (Base Case) | Microgrid with Half-NG & Half-Diesel Generators | Net Savings (or Cost) of Microgrid vs. Status Quo |
|---|---|---|---|
| Diesel Generator Capital Cost | $13,905,655 | $9,600,000 | $4,305,655 |
| Natural Gas Capital Cost | $0 | $25,097,316 | ($25,097,316) |
| Microgrid Capital Cost | $0 | $3,000,000 | ($3,000,000) |
| Diesel Fuel Cost | $0 | $3,754,232 | ($3,754,232) |
| Diesel Non-Fuel O&M Cost | $18,012,102 | $2,771,093 | $15,241,010 |
| Natural Gas Fuel Cost | $0 | $125,670,120 | ($125,670,120) |
| Natural Gas Non-Fuel O&M Cost | $0 | $25,911,464 | ($25,911,464) |
| Microgrid O&M Cost | $0 | $1,731,933 | ($1,731,933) |
| Utility Power Cost | $407,382,836 | $253,901,831 | $153,481,005 |
| Emergency Demand Response Revenues | $0 | ($6,661,137) | $6,661,137 |
| Economic Demand Response Revenues | $0 | ($285,756) | $285,756 |
| Total Cost of Electricity | $439,300,593 | $444,491,095 | ($5,190,501) |

**Table C-4. Status Quo Versus Half-Natural Gas, Half-Diesel Microgrid Results for Mid-Atlantic/Northeast Region (Data in 20-Year Net Present Value)**

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[116] The "base case" assumes that standalone generators are replaced in 10 years; if standalone generators were instead replaced now, the long-term capital costs for the status quo would be approximately 6% worse (see Figure 7).

| Cost or Revenue Category | Status Quo (Base Case) | Microgrid with Half-NG & Half-Diesel Generators | Net Savings (or Cost) of Microgrid vs. Status Quo |
|---|---|---|---|
| Diesel Generator Capital Cost | $13,905,655 | $9,600,000 | $4,305,655 |
| Natural Gas Capital Cost | $0 | $25,097,316 | ($25,097,316) |
| Microgrid Capital Cost | $0 | $3,000,000 | ($3,000,000) |
| Diesel Fuel Cost | $0 | $5,169,847 | ($5,169,847) |
| Diesel Non-Fuel O&M Cost | $18,012,102 | $2,771,093 | $15,241,010 |
| Natural Gas Fuel Cost | $0 | $108,455,035 | ($108,455,035) |
| Natural Gas Non-Fuel O&M Cost | $0 | $25,911,464 | ($25,911,464) |
| Microgrid O&M Cost | $0 | $1,731,933 | ($1,731,933) |
| Utility Power Cost | $485,876,504 | $272,030,247 | $213,846,257 |
| Emergency Demand Response Revenues | $0 | $0 | $0 |
| Economic Demand Response Revenues | $0 | $0 | $0 |
| Total Cost of Electricity | $517,794,261 | $453,766,934 | $64,027,327 |

**Table C-5. Status Quo Versus Half-Natural Gas, Half-Diesel Microgrid Results for California Region (Data in 20-Year Net Present Value)**

| Cost or Revenue Category | Status Quo (Base Case) | Microgrid with Half-NG & Half-Diesel Generators | Net Savings (or Cost) of Microgrid vs. Status Quo |
|---|---|---|---|
| Diesel Generator Capital Cost | $13,905,655 | $9,600,000 | $4,305,655 |
| Natural Gas Capital Cost | $0 | $25,097,316 | ($25,097,316) |
| Microgrid Capital Cost | $0 | $3,000,000 | ($3,000,000) |
| Diesel Fuel Cost | $0 | $2,803,425 | ($2,803,425) |
| Diesel Non-Fuel O&M Cost | $18,012,102 | $2,771,093 | $15,241,010 |
| Natural Gas Fuel Cost | $0 | $107,471,316 | ($107,471,316) |
| Natural Gas Non-Fuel O&M Cost | $0 | $25,911,464 | ($25,911,464) |
| Microgrid O&M Cost | $0 | $1,731,933 | ($1,731,933) |
| Utility Power Cost | $296,083,444 | $195,522,798 | $100,560,646 |
| Emergency Demand Response Revenues | $0 | $0 | $0 |
| Economic Demand Response Revenues | $0 | $0 | $0 |
| Total Cost of Electricity | $328,001,201 | $373,909,344 | ($45,908,142) |

**Table C-6. Status Quo Versus Half-Natural Gas, Half-Diesel Microgrid Results for Southeast Region (Data in 20-Year Net Present Value)**

# Authors

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