TRANSFORMING THE WAY DOD LOOKS AT ENERGY

AN APPROACH TO ESTABLISHING AN ENERGY STRATEGY

REPORT FT602T1

Thomas D. Crowley
Tanya D. Corrie
David B. Diamond
Stuart D. Funk
Wilhelm A. Hansen
Andrea D. Stenhoff
Daniel C. Swift

LMI
GOVERNMENT CONSULTING

APRIL 2007

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **APR 2007**	2. REPORT TYPE	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **Transforming the Way DOD Looks at Energy. An Approach to Establishing an Energy Strategy**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **LMI Government Consulting,2000 Corporate Ridge,McLean,VA,22102**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**138**	

LMĨ

Transforming the Way DoD Looks at Energy:
An Approach to Establishing an Energy Strategy

REPORT FT602T1/APRIL 2007

Executive Summary

In an environment of uncertainty about the price and availability of traditional energy sources, DoD is facing increasing energy demand and support requirements that it must meet if it is to achieve its broader strategic goals—notably, establishment of a more mobile and agile force. However, recent technological advances in energy efficiency and alternative energy technologies offer a unique opportunity for DoD to make progress toward reconciling its strategic goals with its energy requirements through reduced consumption of fuel—especially foreign fuel. To capitalize on this opportunity, DoD needs to implement an energy strategy that encompasses the development of innovative new concepts and capabilities to reduce energy dependence while maintaining or increasing overall warfighting effectiveness. Recognizing that DoD must change how it views, values, and uses energy—a transformation that will challenge some of the department's most deeply held assumptions, interests, and processes—the Office of Force Transformation and Resources, within the Office of the Under Secretary of Defense for Policy, asked LMI to develop an approach to establishing a DoD energy strategy.

LMI identified three areas of disconnect between DoD's current energy consumption practices and the capability requirements of its strategic goals:

- *Strategic.* DoD seeks to shape the future security environment in favor of the United States. But, our dependence on foreign supplies of fuel limits our flexibility in dealing with producer nations who oppose or hinder our goals for greater prosperity and liberty.
- *Operational.* DoD's operational concepts seek greater mobility, persistence, and agility for our forces. But, the energy logistics requirements of these forces limit our ability to realize these concepts.
- *Fiscal.* DoD seeks to reduce operating costs of the current force to procure new capabilities for the future. But, with increased energy consumption and increased price pressure due to growing global demand for energy, energy-associated operating costs are growing.

In parallel with the increase in the global demand for energy is an increase in concern about global climate change and other environmental considerations. Therefore, when identifying technical solutions to its energy challenges, DoD should also considered a fourth disconnect—environmental.

From our research, we concluded that DoD has the opportunity to address the four disconnects by fundamentally changing how it views, values, and uses energy. Many actions are required to implement this transformation, but the highest-level requirements are straightforward:

- Incorporate energy considerations (energy use and energy logistics support requirements) in the department's key corporate processes: strategic planning, analytic agenda, joint concept and joint capability development, acquisition, and planning, programming, budgeting, and execution (PPBE)
- Establish a corporate governance structure with policy and resource oversight to focus the department's energy efforts
- Apply a structured framework to address energy efficiency, including alternate energy sources, to the department's greatest energy challenges—those areas consuming the most fuel, requiring the most logistics support, or having the most negative impact on the warrior.

The following are some options for energy actions related to DoD's corporate processes:

- Apply the energy-efficiency requirements of Executive Order 13423 (3 percent reduction per year, or 30 percent reduction by 2015 from 2003 baseline) to mobility forces
- Analyze current and projected energy and energy logistics required to support operational plans and capability-based planning and incorporate findings in other corporate processes
- Assess the role of information in reducing energy requirements through improved operational and logistics effectiveness and reduced in-theater personnel requirements
- Incorporate energy considerations (energy use and energy logistics support requirements) in all future concept development, capability development, and acquisition actions
- Make energy a top research and development priority
- Improve the incentives for investment in energy efficiency

- Increase global efforts to enhance the stability and security of oil infrastructure, transit lanes, and markets through military-to-military and state-to-state cooperation
- Make reducing energy vulnerability a focus area of the next strategic planning cycle and Quadrennial Defense Review.

To coordinate the efforts of DoD components, provide strategic direction, focus research and development efforts, and monitor compliance with energy-efficiency guidelines, DoD needs an effective energy governance structure. We recommend that DoD establish a coordinating body with policy and resource oversight authority. Considering the need for collaboration among the services and DoD, we believe an empowered committee would be more effective that a single leader.

From our survey of emerging energy technologies, the department has a wide range of options for addressing energy efficiency and alternate sources of energy. Under the guidance of the coordinating body, DoD can begin a structured analysis of how to apply organizational, process, and technology changes to execute a strategy to reduce energy dependence. Although assessing the strategic, operational, fiscal, and environmental impacts of a change provides a mechanism to value potential choices, these impacts may not provide sufficient insight to be determinative.

To promote the changes that will have the greatest utility in addressing the disconnects, we recommend that the department begin by focusing on three areas:

- Greatest fuel use (aviation forces)
- Greatest logistic difficulty (forward land forces and mobile electric power)
- Greatest warrior impact (individual warfighter burden).

DoD energy transformation must begin in the near term, addressing current practices and legacy forces, while investing for long-term changes that may radically alter future consumption patterns. We recommend a time-phased approach to reduce our reliance on fossil and carbon-based fuels. This approach includes the following:

- Organizational and process changes that can be implemented immediately
- Engineered solutions, to improve the efficiency of current forces and those nearing acquisition
- Invention of new capabilities, employed in new operational concepts, for those forces yet to be developed.

Applying this approach to the three focus areas will give DoD an opportunity to develop portfolios of solutions that can reduce energy use and dependence. The coordinating body can evaluate these portfolios to against the energy disconnects to identify optimal solutions across the services, broader department objectives, and U.S. government strategic objectives and energy efforts. The coordinating body can then focus technology development as required to achieve the desired solutions.

For the energy transformation to be successful, DoD's senior leaders must articulate a clear vision for the change and must ensure—through their sustained commitment and active participation—that it becomes engrained in the organization's ethos. We propose the following vision:

> DoD will be the nation's leader in the effective use of energy, significantly reducing DoD's dependence on traditional fuels and enhancing operational primacy through reduced logistics support requirements.

Establishing a goal for mobility energy efficiency will provide near-term objectives in support of the vision, enhance operational effectiveness by reducing logistics support requirements, and free resources for recapitalization of the force. Our estimates show that implementing a 3 percent reduction per year until 2015 could result in savings of $43 billion by 2030 based on Energy Information Agency reference case price projections, without including any multiplier effects.

In view of the long period required to develop and populate the force with new concepts and capabilities, DoD should begin now to shape the force for an uncertain energy future.

Contents

Figures

Tables

Chapter 1
Introduction

Over the past several decades, the United States has become increasingly reliant on imported energy, primarily from petroleum. The Energy Information Agency (EIA) forecasts that U.S. dependence on petroleum imports will increase to 68 percent by 2025. DoD, the largest U.S. consumer of energy, also relies on foreign supplies of crude oil and the finished transportation fuels (such as military jet fuel) that are derived from it. Fuel represents more than half of the DoD logistics tonnage and more than 70 percent of the tonnage required to put the U.S. Army into position for battle.[1] The Navy uses millions of gallons of fuel every day to operate around the globe, and the Air Force—the largest DoD consumer of fuel—uses even more.

DoD's heavy operational dependence on traditional fuel sources creates a number of decidedly negative effects:

- DoD shares the nation's reliance on foreign energy sources, which effectively forces the country to rely on potential adversaries to maintain its economy and national security.[2]
- DoD's energy dependence exposes the department to price volatility, forcing it to consume unplanned resources that could be used to recapitalize an aging force structure and infrastructure.
- The availability of traditional energy supplies beyond 25 years is difficult to project. Because of the 8- to 20-year time frame of future operational concepts and a similarly long, or longer, capital asset replacement cycle for DoD platforms, DoD must begin now to address its uncertain energy future.
- The United States bears many costs associated with the stability of the global oil market and infrastructure. The cost of securing Persian Gulf sources alone comes to $44.4 billion annually.[3] DoD receives little support from other consuming nations to perform this mission although they share in the benefits due to the global nature of the oil market.

---

[1] The Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting through Reduced Fuel Burden*, January 2001.

[2] Through 2004, members of the Organization of the Petroleum Exporting Countries alone have earned $4 trillion in oil revenue. Some portion of that oil revenue has likely gone toward efforts inimical to U.S. national security interests.

[3] Milton R. Copulos, *America's Achilles Heal*, *The Hidden Cost of Imported Oil: A Strategy for Energy Independence* (Washington, DC: The National Defense Council Foundation, 2003).

In this environment of uncertainty about the availability of traditional fuel sources at a reasonable cost, DoD is facing increasing energy demand and support requirements that it must meet if it is to achieve its broader strategic goals—notably, establishment of a more mobile and agile force. However, recent technological advances in energy efficiency and alternative energy technologies offer a unique opportunity for DoD to make progress toward reconciling its strategic goals with its energy requirements through reduced consumption of fuel—especially foreign fuel. To capitalize on this opportunity, DoD needs to implement an energy strategy that encompasses the development of innovative new concepts and capabilities to reduce energy dependence while maintaining or increasing overall warfighting effectiveness.

Recognizing that DoD must change how it views, values, and uses energy—a transformation that will challenge some of the department's most deeply held assumptions, interests, and processes—the Office of Force Transformation and Resources, within the Office of the Under Secretary of Defense (USD) for Policy, asked LMI to develop an approach to establishing a DoD energy strategy. Specifically, it asked LMI to develop a process for identifying, evaluating, and implementing new energy-saving and -replacement technologies and techniques and to identify possible energy governance structures that would enable DoD to gain a system view of energy consumption, support requirements, efficiency, and costs.

STUDY APPROACH

As a starting point, LMI gathered data to understand DoD's current energy consumption practices and the capability requirements of its strategic goals and to identify any disconnects between them. We also assessed DoD's corporate processes and its energy governance structures.

Considering that initial research, LMI identified options for each of the major corporate processes, including strategic planning, analysis, joint concept and capability development, acquisition, and planning, programming, budgeting, and execution (PPBE). Some key options include applying energy efficiency goals to mobility forces; capturing energy use and support implications in analysis; including energy considerations in future concept and capability development; using the fully burdened cost of fuel and support requirements in capability, acquisition, and programming decisions; and leveraging military-to-military relations to enhance (and create cost sharing for) the security of the global energy infrastructure and transit lanes.

LMI also identified options for a DoD energy governance structure. Our own analysis and other reports have highlighted the need for such an integrating body. An effective managing body in DoD can accomplish numerous important tasks, including the following:

- Coordinating the development of opportunities across DoD and civilian agencies to minimize redundancy and to maximize complementarities

- Managing change in DoD to minimize suboptimization across organizational levels
- Establishing goals, metrics, and reporting requirements for energy efficiency across the department.

To evaluate the potential risks and rewards of different energy opportunities, LMI used two overlapping frameworks to arrive at possible solution sets: combinations of technologies and resources that will best address disconnects. One framework is based on the greatest use, greatest difficulty to supply, and greatest impact on the warrior—the Greatest Use/Greatest Difficulty/Greatest Impact framework—and is a useful tool for identifying where DoD efforts might have the most impact. The other framework—the Organize/Engineer/Invent framework—accounts for organizational changes, engineered technology changes, and invented technologies and is a useful tool for identifying optimal combinations of energy opportunities that could be implemented. Using these overlapping assessment frameworks, DoD can conduct a detailed assessment of new energy opportunities via the following steps:

- Identify a specific energy challenge in the areas of greatest use, greatest difficulty of delivery, and greatest impact on the warrior. This will focus the analysis on DoD's current needs and ensure that any action helps solve an operational requirement.
- Identify possible solutions from options in the organize, engineer, or invent categories. This will help determine the relative risk, the solution time frame, and the level at which coordination and decision making should occur.
- Identify the potential strategic, operational, and environmental benefits, which help determine the potential rewards, and the fiscal costs and benefits, which help determine potential return on investment. These benefits can be weighted by whether the opportunity is most important to the warfighter, addresses an energy source that is difficult to deliver, or addresses an urgent need.

REPORT ORGANIZATION

This report is organized as follows:

- Chapter 2 characterizes DoD's energy problem and describes four areas of disconnect between DoD's current energy consumption practices and the capability requirements of its strategic goals.
- Chapter 3 establishes a method for developing possible solution sets that will most benefit DoD and that DoD can effectively execute. It explains the use of the Greatest Use/Greatest Difficulty/Greatest Impact framework

to identify energy needs and the use of the Organize/Engineer/Invent framework to evaluate potential options to meet those needs.

- Chapter 4 discusses current DoD corporate processes and governance structures related to energy.
- Chapter 5 considers options for process and organizational changes to address the lack of a system view of energy at the DoD corporate level.
- Chapter 6 contains our high-level observations concerning research efforts and technology development. It then presents sample applications of the Organize/Engineer/Invent framework to identify potential solution sets for the areas in which change can provide the greatest impact in addressing the DoD’s energy disconnects.
- Chapter 7 proposes a vision of the outcome of the department’s energy transformation and identifies some of the key steps that DoD should take to ensure the successful transformation of how it views, values, and uses energy.

The appendixes contain supporting detail.

Chapter 2

The Need for Change

In 1911, Winston Churchill, then First Lord of the Admiralty, converted the British fleet from Welsh coal to foreign oil. The resulting gain in speed and decrease in logistics burden gave the British navy a decisive advantage over Germany's Bundesmarine. The shift toward a foreign energy source also set off a geopolitical scramble as major powers sought to secure oil supplies.

Today, the United States is the superpower. Yet, the scramble to secure access to oil continues while the availability of easily recoverable oil diminishes, putting the United States into increasing competition with other oil importers, most notably, the rapidly emerging economies of India and China.[1] As the U.S. government's energy security strategy evolves, the U.S. military, which is highly dependent on oil to fuel the engines of its overwhelming operational superiority, must develop a long-term strategy to deal with the changing energy environment.

WORLD/U.S. ENERGY ENVIRONMENT

The United States consumes about 25 percent of the world's oil. Half of this can be attributed to the country's continued demand for transportation fuels for automobiles and trucks to support our economy and standard of living. About 58 percent of the oil consumed by the United States is imported. Consistent with the worldwide trends in energy demands, it is projected that by 2025, the U.S. will have to import some 68 percent of its oil. This level of economic dependence on politically unstable energy sources such as Venezuela, Nigeria, and the Middle East creates concerns over our future security posture and vulnerability.

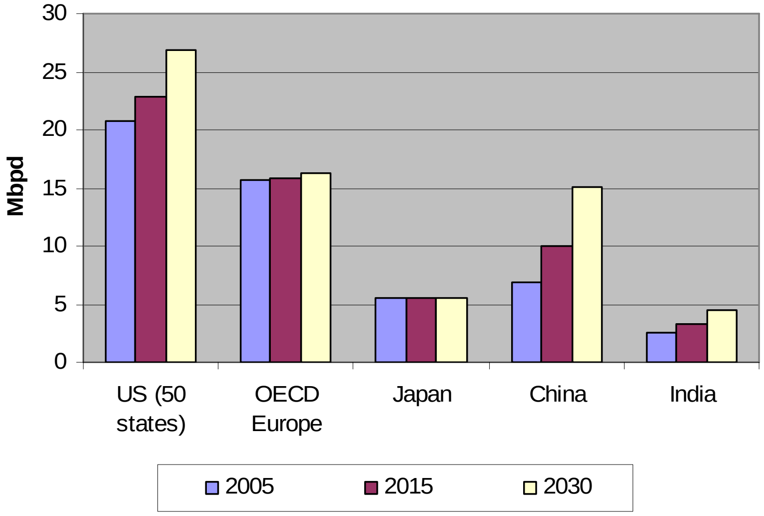
Figure 2-1 compares the projected increase in the demand for barrels of oil in the United States with that in other countries. As can be seen, the growth in the United States (using the EIA reference case) is not mirrored in Western European countries or in Japan, all of which are similar to the United States in terms of levels of industrialization. Although the pronounced growth in U.S. demand means retaining the position of the world's largest oil consumer, the 42 percent growth in U.S. demand does not approach the 130 percent increase in China or the 80 percent increase in India.[2]

---

[1] John Deutch and James R. Schlesinger, *National Security Consequences of U.S. Oil Dependency*, Council of Foreign Relations, Independent Task Force Report 58, 2006.

[2] Energy Information Agency, *Annual Energy Outlook 2007,* DOE/EIA-0383(2007), February 2007.

Figure 2-1. Projected Oil Demand Growth for Selected Countries



Source: Energy Information Administration, *Annual Energy Outlook 2007*, Appendix A, Table 20, http://eia.doe.gov.

A recent evaluation of supply and demand projections by the DoD-chartered JASON Defense Advisory Group (JASON) concluded that recoverable oil resources are sufficient to sustain 25 years of demand at a 2004 production cost of less than $30 per barrel. JASON noted that the 2004 International Energy Agency (IEA) World Energy Outlook data indicate that demand may be met at the same price for another 25 years, but questioned the value of extrapolations to 50 years. The same data indicate that additional supply resources will become available at higher prices. Consumption projections for 2030 are highly assumption dependent and vary widely from the IEA projection of 100 million barrels per day used by JASON to 117 million barrels per day for the EIA 2030 reference case.[3] The JASON report assumes a properly functioning oil market and no disruptions in supply from the Middle East.[4]

Despite this apparent near-term availability of oil supply, or perhaps associated with the caveats related to stable and functioning markets, competition for world energy supplies appears to be increasing. All over the world, importers are increasingly finding themselves in direct competition over sources and strategic shipping routes. Japan and China are continually trading diplomatic blows and threats over off-shore petroleum reserves south of Japan.[5] In 2003, China's President Hu Jintao also expressed concern over the "Malacca Dilemma," the reputed U.S. ability to control the Straits of Malacca, through which much of China's energy flows. As a result, China has taken a "string of pearls" approach to develop bases and military relationships that will improve the security of its oil supplies

---

[3] See Note 2.

[4] P. Dimotakis, N. Lewis, R. Grober, and others, *Reducing DoD Fossil-Fuel Dependence*, JSR-060135 (McLean, VA: JASON Program Office, MITRE, 2006), pp. 5–9.

[5] "The Japan-China Oil Slick," *Business Week*, November 7, 2005.

and transit lanes.[6] China has also embarked on a strategy to secure oil equity interests in Latin American, Canada, Russia, and Africa.[7]

The dependence on and competition for world energy supplies constrain the foreign policy and national security objectives of oil importers. The United States has long taken an energy-based security interest in the Middle East even though the United States receives only 17 percent of its oil from the region.[8] Meanwhile, net exporters—such as Russia, Iran, Sudan, the Central Asian republics, Venezuela, and even Saudi Arabia—are emboldened to leverage energy sources to achieve political gains that are usually inimical to many of the oil-importing states. Examples include Russia's restricting natural gas to former republics (and Europe), Iran's development of nuclear capability, Sudan's actions in Darfur, and Saudi Arabia's weak support for human rights.

Because small changes in supply or demand can have large price impacts, the dependence on oil to fuel the global economy will continue to have negative implications for our national and economic security. The Council on Foreign Relations Energy Security Task Force estimates that a 1 percent change in supply (or demand) can have a 5 to 10 percent impact on price.[9] As long as our global economic partners remain significant oil consumers, the United States would still feel oil price shocks even if it could achieve energy "independence." This shock would come in the form of higher finished good prices from our fastest growing trade partner, and potential geopolitical competitor, China. Also, our European partners, who are more reliant on Middle Eastern and Russian oil than we are, would likely suffer an economic downturn that would limit their purchase of our products.

In short, oil considerations are a key component of our economic security and a significant driver of our national security posture. As former Secretary of State George Schultz noted:

> Once more we face the vulnerability of our oil supply to political disturbances. Three times in the past thirty years (1973, 1978, and 1990) oil price spikes caused by Middle East crises helped throw the U.S. economy into recession. Coincident disruption in Venezuela and Russia adds to unease, let alone prices, in 2004. And the surging economies of China and India are contributing significantly to demand. But the problem far transcends economics and involves our national security. How many

---

[6] Dan Blumenthal and Joseph Lin, "Oil Obsession: Energy Appetite Fuels Beijing's Plans to Protect Vital Sea Lines," *Armed Forces Journal*, June 2006, accessed online February 13, 2007.

[7] "The Real Trouble with Oil," *The Economist*, April 28, 2005.

[8] Norman Kempster, "U.S. Ignores Human Rights Abuses of Saudi Arabia," *Los Angles Times*, March 20, 2000, http://www.commondreams.org/headlines/032800-01.htm, accessed February 16, 2007.

[9] See Note 1, p. 17.

> more times must we be hit on the head by a two-by-four before we do something decisive about this acute problem?[10]

Some policy observers believe competition for energy sources may lead to conflict. Others, however, believe this outcome can be avoided through alternate energy sources, enhanced energy efficiency and demand reduction, and increased cooperation to ensure the security and efficiency of international oil markets.[11]

DOD ENERGY CONSUMPTION PROFILE

In FY05, the United States consumed about 20 million barrels per day. Although the entire federal government consumed a mere 1.9 percent of the total U.S. demand, DoD, the largest government user of oil in the world, consumed more than 90 percent of all the government's petroleum (liquid fuel) use.[12] Although DoD is highly dependent on petroleum and is the largest single petroleum user, it cannot by itself, drive the market. However, because DoD's operations (the capabilities, costs, and the strategy that define them) rely so heavily on the petroleum market, they are vulnerable to the price and supply fluctuations affecting the petroleum market. Examining the impact of the future energy environment on DoD, and the options available to react to this environment, requires an understanding of the DoD energy consumption profile (how and where is energy being consumed).[13] Energy consumption falls into two categories: facility energy use and mobility energy use.

Facility Energy Use

Facility energy is the energy required to fuel bases and other stationary products. Using data from the Annual Report to Congress (FY06) issued by DoD, LMI derived the following facility energy use profiles:[14]

- Of the total DoD energy consumption (1.18 quads), facility use made up 34 percent of total consumption (0.39 quad) while mobile energy use was 66 percent (0.78 quad).[15]

---

[10] Amory Lovins and others, *Winning the Oil Endgame* (Snowmass, CO: Rocky Mountain Institute, 2004), Foreword.

[11] See Note 1, pp. 7–10.

[12] Defense Energy Support Center (DESC) Fact Book, 2005, and Energy Information Agency. http://tonto.eia.doe.gov, accessed February 16, 2007.

[13] DoD has a complicated energy consumption profile that is difficult to ascertain from the data available. In many cases, detailed energy supply data are available (what is delivered to the theater or the battlefield), but not detailed consumption data for actual military operations (how the petroleum was actually used, e.g., tactical vehicles, logistics, and generators). An overview from available data is provided to highlight the general breakdown of DoD fuel use.

[14] DoD, AT&L, Energy Costs and Consumption Data, http://www.acq.osd.mil/ie/irm/Energy/energymgmt_report/fy06/2006-0976-IE%20Tab%20C%20DataRpt.pdf (accessed March 7, 2007).

[15] One quad is an amount of energy equal to 10^{15} Btu.

- Overseas facility energy use (OCONUS) accounted for 16 percent of total DoD facility consumption, and CONUS made up 84 percent.[16]
- DoD facility energy consumption consisted of electricity, natural gas, fuel oil, coal, and other types of energy (steam). Electricity counted for only 46 percent of consumption followed by natural gas, 35 percent. Fuel oil and coal made up the remainder, about 20 percent.

DoD facilities have made extensive efforts to conserve energy. To date, this has been “the low hanging fruit” for controlling energy costs. As an example, over the last 10 years (FY95–FY05), energy usage at Air Force facilities has declined 15.4 percent. The unit energy cost has increased 42 percent, while the Air Force’s total utility bill has risen only 10.7 percent.[17] This shows that offsets made through conservation have helped keep facility energy costs down despite steep increases in the price per energy unit, but additional initiatives will be required to address the overall fiscal burden of energy costs.

Many DoD installations have shifted to a local power grid network to meet electricity needs. Although this reduces DoD’s energy infrastructure costs, it does not isolate DoD from energy market volatility, which is reflected in electricity prices. This shift has also introduced a degree of operational vulnerability due to reliance on external supplies.

Mobility Energy Use

Mobility energy is the fuel used to power DoD weapons platforms, tactical equipment, and all other types of vehicles. In contrast with facility energy, mobility energy consists almost entirely of petroleum-based products and accounts for 94 percent of DoD’s petroleum consumption. The categories of fuel used for mobility are jet fuel,[18] gasoline, distillates and diesel, ship’s bunkers, and residuals. As illustrated in Figure 2-2, about 75 percent of the mobility fuel used by DoD is jet fuel. Distillates and diesel follow with 17 percent. Many DoD platforms are multifuel capable, so it is not appropriate to consider these percentages as directly attributable to air, land, and sea platforms.

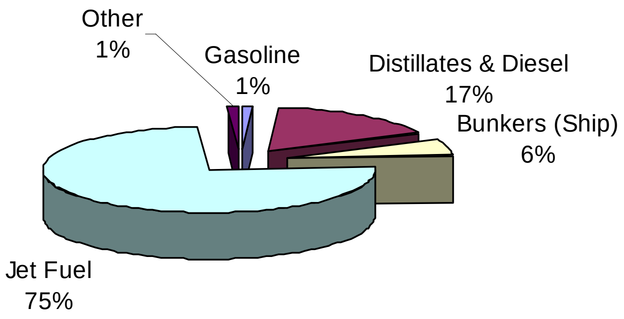
---

[16] Given the continued closure of overseas bases, it is probable that this figure will widen.

[17] Mike Aimone, “Air Force Energy Strategy for the 21st Century” (briefing, June 5, 2006).

[18] “Jet fuel” consists of JP-4, JAB, JAA, JA1, JP-5, JP-8, and JTS.

Figure 2-2. DoD Mobility Use (FY03–FY05)



Source: *Defense Energy Support Center Fact Book*, 2005.

JP-8, used primarily for air operations, makes up about 56 percent of the total petroleum purchased by DoD. The continued use of JP-8 as the fuel of choice for operations is testament to the U.S. military doctrine that relies heavily on air power as an integral part of the joint force across the whole spectrum of operations. The agility, mobility, and speed that this doctrine provides have been effective, but it comes at a high cost and further reliance on liquid petroleum.

A recent *Los Angeles Times* article noted that the U.S. military is consuming about 2.4 million gallons of fuel every day in Iraq and Afghanistan.[19] The data, provided by the U.S. Central Command, show that DoD is using approximately 57,000 barrels a day, at a cost of about $3 million per day. This equates to about 16 gallons per soldier per day. This is significantly more than the 2005 consumption rate of 9 gallons per soldier. These numbers make it clear that energy consumption for military operations has increased dramatically in the last 15 years. In Desert Storm, consumption was 4 gallons per soldier per soldier, and in World War II, consumption was only 1 gallon per day per soldier. Appendix A contains additional detail about DoD's mobility fuel use.

IMPLICATIONS OF U.S. NATIONAL SECURITY POLICY

Recent experience indicates that the nature of the threat facing the United States is changing. Today, we cannot be sure in advance of the location of future conflicts, given the threat of dispersed, small-scale attacks inherent in warfare with rogue nations and insurgent forces. In addition, the U.S. military must be prepared to defend against single strikes capable of mass casualties. This complex security environment—an environment in which a wide range of conventional and unconventional attacks can come from unpredictable regions of the world and the risk of a single attack is high—requires the United States not only to maintain a force that is forward and engaged on a daily steady-state basis, but also to ensure that it is ready for quick, surge deployments worldwide to counter, and deter, a broad spectrum of potential threats.

---

[19] Max Boot, "Our Enemies Aren't Drinking Lattes," *Los Angeles Times*, July 5, 2006.

Department-wide and service-specific strategy documents have identified solutions to navigating in this new environment. The solutions have three general themes (described in Appendix B):

- *Theme 1*. Our forces must expand geographically and be more mobile and expeditionary so that they can be engaged in more theaters and prepared for expedient deployment anywhere in the world.
- *Theme 2*. We must transition from a reactive to a proactive force posture to deter enemy forces from organizing for and conducting potentially catastrophic attacks.
- *Theme 3*. We must be persistent in our presence, surveillance, assistance, and attack to defeat determined insurgents and halt the organization of new enemy forces.

To carry out these activities, the U.S. military will have to be even more energy intense, locate in more regions of the world, employ new technologies, and manage a more complex logistics system. Considering the trend in operational fuel consumption and future capability needs, this “new” force employment construct will likely demand more energy/fuel in the deployed setting. Simply put, more miles will be traveled, both by combat units and the supply units that sustain them, which will result in increased energy consumption. Therefore, DoD must apply new energy technologies that address alternative supply sources and efficient consumption across all aspects of military operations.

DISCONNECTS BETWEEN ENERGY POLICY AND STRATEGIC OBJECTIVES

The demands placed on the armed forces have changed significantly since their current capabilities were designed and fielded and the plans and concepts for their employment were developed. The security challenges of the 21st century require a force structure that is more expeditionary, agile, and responsive. Such a force structure will consume increasing amounts of energy if current trends continue. Building this future force structure requires the application of resources, yet budgets will be increasingly constrained by operational energy demands. We call the misalignments between energy policies and strategic objectives “disconnects,” and they exist along three lines: strategic, operational, and fiscal. In recognition of the political factors associated with increasing energy consumption and some alternative energy solutions, we also identified a fourth disconnect—environmental. Table 2-1 defines the disconnects, and the following subsections discuss them in more detail.

Table 2-1. Energy Disconnects

Category	Description
Strategic	Ability to shape the future security environment favorably to support our national interests, principles, freedoms, and way of life. Requires reduced reliance on foreign energy resources.
Operational	Ability to counter projected threats, which entails increased operational mobility, persistence, and agility. Requires developing efficient technologies that can support the asymmetric combat capability needed for future operations without increased fuel consumption or logistics and support limitations.
Fiscal	Ability to procure new capabilities, which requires efficient energy consumption. Inability to control increased energy costs from fuel and supporting infrastructure diverts resources that would otherwise be available to procure new capabilities.
Environmental	Ability to conduct DoD operations and activities in a manner that protects the environment while supporting national security objectives and maintaining operational readiness.

Strategic Disconnect

The goal of our security strategies is to shape the future security environment favorably to support our national interests, principles, freedoms, and way of life. However, our nation's and DoD's current and future growing dependence on foreign energy sources and the need to ensure their continued availability limit our ability to shape the future security environment. Protecting foreign energy sources will have an increasing impact on DoD's roles and missions, at the expense of other security needs, potentially dictating the time and place of future conflict if action is not taken to change the trend and mitigate the effects of future reductions in the supply of oil.

Operational Disconnect

The security and military strategies for DoD require an energy-intense posture for conducting both deterrence and combat operations. The strategies rely on persistent presence globally, mobility to project power and sustain forces, and dominant maneuver to swiftly defeat adversaries. These current and future operating concepts tether operational capability to high-technology solutions that require continued growth in energy sources. Current consumption estimates, although based on incomplete data, validate these increasing fuel requirements and the implications for future operations.

Clearly, the skill of our logistics forces in providing fuel has grown significantly since World War II. Still, we must be mindful of the operational implications of logistics requirements. The stalling of General Patton's Third Army following its campaign across France in August and September 1944 is a telling example of the fuel "tether." Despite the heroic efforts of logistics forces, the wear and tear on supply trucks and the strategic priority for fuel and logistics support in other areas of operations limited Patton to local operations for nearly 2 months.[20]

The Defense Energy Support Center (DESC) estimates that 20,000 soldiers are employed to deliver fuel to operations (and spending $1 million per day to transport petroleum, which does not include fuel costs for contractor-provided combat support). The delivery of fuel poses such an operational and tactical risk that in July 2006, Maj. Gen. Richard Zilmer, the highest-ranking Marine Corps officer in Iraq's Anbar Province, characterized the development of solar and wind power capabilities as a "joint urgent operational need." General Zilmer cited reductions in often dangerous fuel transportation activities as the main motivation for this request: "By reducing the need for [petroleum-based fuels] at our outlying bases, we can decrease the frequency of logistics convoys on the road, thereby reducing the danger to our Marines, soldiers, and sailors."[21]

Operational capability is always the most important aspect of force development. However, it may not be possible to execute operational concepts and capabilities to achieve our security strategy if the energy implications are not considered. Current planning presents a situation in which the aggregate operational capability of the force may be unsustainable in the long term.

Fiscal Disconnect

The need to recapitalize obsolete and damaged equipment and to develop high-technology systems to implement future operational concepts is growing. At the same time, the procurement accounts for DoD are constantly under pressure from the rising costs of nondiscretionary accounts in the DoD budget (fuel, manpower) and requirements for non-defense spending (social security, health care). In this pressurized fiscal environment, controlling operating costs is essential to enable the procurement of new capability needs. However, fuel costs and consumption trends are increasing the total operating costs of the force, and projected trends will create the need to make investments in additional logistics capability. Thus, investment for future combat capability must increasingly compete with growing operating costs and logistic support requirements.

In addition to the financial planning challenge associated with energy market volatility, the inability to fully account for energy considerations in operational and force development analysis impacts the investment decisions necessary to build the future force. The real cost of fuel to DoD is more than just the DESC

---

[20] Maj Jeffrey W. Decker, "Logistics and Patton's Third Army: Lessons for Today's Logisticians," *Air & Space Power Journal*, March 20, 2003, in *Chronicles Online Journal*, accessed February 13, 2006.

[21] Rati Bishnoi, "Renewable Energy Systems Wanted in Iraq," InsideDefense.com NewsStand, August 11, 2006.

standard price used for programming, budgeting, and investment decisions.[22] To assess this difference, the Office of Program Analysis and Evaluation (PA&E) has been studying the delivered cost of fuel for the military. PA&E estimated the "wholesale" cost to each service and then added the costs incurred for "retail" delivery as well as other costs incurred by the services and agencies. For a fuel-type dependent standard cost of $2.29 to $2.32 per gallon, PA&E found that the composite costs per gallon are as follows:

- Air Force JP-8 (weighted cost)—$6.36 air delivery cost (9 percent of total)—$42.49
- Army JP-8—$5.62 (wartime delivered cost not estimated due to variance in mission and escort requirements)[23]
- Navy JP-5 (weighted cost at sea)—$3.08 (airborne delivered cost not estimated due to data availability and variance in scenarios)
- Navy F-76 (weighted cost at sea)—$2.74.

The PA&E brief emphasizes that efforts to refine the method and apply fully burdened fuel costs are ongoing and that more focus should be applied to the method than to the specific numbers.[24] The inability to estimate potential wartime costs applies a downward bias to these burdened fuel costs.

Environmental Disconnect

As we reviewed DoD's energy strategies and policy, it became increasingly apparent that the environmental impacts of energy policy needed to be considered. There is increasing national and international consensus on the effect of carbon dioxide emissions on global climate change, as well as the idea that solutions to energy challenges cannot be considered independently of the environmental impacts the solutions create.[25] Although environmental considerations are not the focus of our effort, we believe that a DoD energy strategy based on solutions that have the potential for significant adverse environmental impact may pose challenges in gaining public acceptance, delaying or diverting the department's energy transformation.

---

[22] Fully burdened costs include standard fuel price, direct ground fuel infrastructure, indirect base infrastructure, environmental costs, delivery asset operations and support, delivery asset depreciation, and other specific costs. Disagreement exists on the application of delivery asset depreciation due to the number of delivery assets not being directly scalable to fuel consumption.

[23] The JASON study (see Note 4) found that the Army's delivered costs in-theater can be $100 to $600 per gallon.

[24] OSD PA&E, *Burdened Cost of Fuel* (briefing to Energy Security IPT, February 20, 2007).

[25] John P. Holdren, "The Energy Innovation Imperative: Addressing Oil Dependence, Climate Change, and Other 21st Century Energy Challenges," *Innovations*, Spring 2006, p. 4.

Consideration of the environmental disconnect is consistent with DoD directives to “ensure that environmental programs achieve, maintain, and monitor compliance with all applicable [Executive orders] and Federal, State, inter-state, regional, and local statutory and regulatory requirements.”[26] Although some military operations are excluded from the purview of this directive, joint doctrine notes that

> while complete protection of the environment during military operations may not always be possible, careful planning should address environmental considerations in joint operations, to include legal aspects. [Joint Force Commanders] are responsible for protecting the environment in which U.S. military forces operate to the greatest extent possible consistent with operational requirements.[27]

SUMMARY

The current focus on the global energy market, global climate change, and national defense provides DoD with a unique opportunity to develop a comprehensive energy strategy that addresses these strategic, operational, fiscal, and environmental disconnects. Such a strategy would fundamentally transform how DoD views energy. While estimates vary on the availability of recoverable oil at near current prices (potentially 25 to 50 years), the long period to develop alternate sources of fuel and changes in energy infrastructure and the long capital asset replacement cycle for DoD make it imperative that the development and implementation of a comprehensive energy strategy be a matter of urgency.

---

[26] DoD Instruction 4715.6, “Environmental Compliance,” April 24, 1996.

[27] Joint Publication 3-0, *Joint Operations*, Joint Staff, September 17, 2006, p. III-32.

Chapter 3

Assessing Energy Options

The strategic, operational, fiscal, and environmental disconnects described in the preceding chapter illustrate the drawbacks of DoD's current energy profile, but the disconnects alone do not point toward a solution. Our survey of the energy technology environment identified many technologies that could affect DoD's energy dependence, but technology alone provides little investment insight. To focus a change in how DoD views, values, and uses energy, DoD must address the use of energy in specific applications as well as larger corporate issues. Arriving at a solution requires identifying energy challenges; selecting viable technological, organizational, and process options; and developing potential solution sets—the combinations of technologies and resources that best address the disconnects, that will most benefit DoD, and that DoD can effectively implement.

IDENTIFYING ENERGY CHALLENGES

To meaningfully assess its energy options, DoD must understand the specific challenges it faces: What specific energy dependence problem or "challenge" does DoD need to resolve? Answering this question—whether at the corporate level or component level—provides a context for identifying meaningful, implementable options.

In addition to addressing how DoD views and values energy at the corporate level, our review of the role of energy in DoD identified three specific challenges that DoD might address:

- *Greatest Use.* The greatest use challenge captures the areas within DoD that have the highest fuel/energy usage. An example of a Greatest Use challenge is the aviation fuel consumption by all segments of the aviation community, which equals roughly 80 percent of DoD's mobile energy usage.
- *Greatest Difficulty*. The greatest difficulty challenge captures the areas that present the greatest difficulty for logistics support. An example of a Greatest Difficulty challenge is fuel use in the operational environment by tactical and nontactical vehicles such as tanks, Humvees, and support vehicles. A second example is the transportation and support, including fuel, of mobile electric power generation equipment.
- *Greatest Impact on the warrior.* The greatest impact challenge captures areas that would improve the operational effectiveness of the individual warfighter. An example of a Greatest Impact challenge is improving

information availability while reducing the weight and number of energy storage devices (batteries) that soldiers must carry in the field for tactical missions.

These categories are not intended to be exclusive but rather to identify areas in which DoD might best prioritize action to generate energy efficiency (or replacement) impacts. The specific organizational or technological options within these categories may change over time, but focusing on these categories will highlight the issues that present the greatest opportunities for change.

SELECTING OPTIONS

The U.S. government and commercial industry are developing an astonishing number of energy-saving and -making technologies that have the potential to address DoD's energy challenges. The list is daunting, considering that most technologies have multiple applications. For example, new solar technologies have been proposed for everything from solar panels on tents to replace generators for air conditioning, to solar panels on soldiers to replace battery weight. The list becomes longer still when we, quite correctly, include energy-saving organizational and process changes, which include everything from better targeting systems (better aim = fewer bombs to hit a target = less energy used) to more efficient scheduling systems.

To help DoD select viable energy options, LMI developed a framework to distinguish between short-term organizational options and longer term engineering or inventing options. The Organize/Engineer/Invent framework helps to illustrate the time and relative level of effort associated with the different options, as well as the ability to implement changes at appropriate levels within the department.[1] This approach enables selection of multiple, time-phased options that offer a combination of benefits that best support the needs of DoD and address a wider stakeholder audience. The components of this framework are outlined below.

- *Organize.* This component consists of organizational, operational, or process changes that reduce energy consumption without changing the underlying energy-consuming technologies. Examples of options include alignment of organizational processes to promote energy efficiency or, at a more specific level, more efficient scheduling of operations, use of trainers or virtual communications, and manpower adjustments. Organizational options do not affect the underlying energy-consuming technologies of applications, but they may require other technologies—such as scheduling or optimizing software, communications links, sensors, data collection devices, and other forms of information technology—to make processes more efficient.

---

[1] This framework is also consistent with the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) assessment framework for organizational transformation.

- *Engineer*. Engineering options improve energy efficiency by adopting available new technologies or making incremental changes to existing technologies. The engineering approach makes use of technologies that are available in the marketplace or are in the research and development (R&D) pipeline to implement new methods to supply energy or improve energy efficiency. Options in this area will most likely take the form of improved equipment such as improved batteries or more fuel-efficient engines. In general, engineering options will require changes in support from the logistics community and may involve changes to existing policy or doctrine.

- *Invent.* This component includes options to reduce energy consumption by making radical changes to existing technology, using fundamentally new technology either driven by or enabling new operational concepts or concepts of operations. These new technologies will usually require new supporting infrastructures and logistics capabilities as well as changes in policy and doctrine.

This framework also illustrates the relative level of cost, risk, and degree of stakeholder coordination required in each solution category. Organizing generally costs the least and presents the least risk, because in most cases it can be done at the operational level and requires no new technologies. Engineering, on the other hand, requires up-front investment in available new technologies, while likely producing greater future cost savings. Inventing involves the greatest investment in time, expense, and technical risk, because it often requires research of basic science and technology and the subsequent development of new solutions, with the expectation that the savings will eventually be greater than the initial investment.

Grouping solutions according to the Organize/Engineer/Invent framework provides decision makers with a menu of choices from which to develop a solution set that best supports DoD’s goals. This framework presents a balanced view of the solution landscape in the context of a particular challenge and enables a first-level comparison of options and their tradeoffs.

One must be careful when considering the costs associated with a proposed change to ensure that the full cost of implementation is captured. Some solutions may require significant changes in support infrastructure and associated manpower, which must be included in any business case analysis. Solutions that provide a fundamental change in capability pose the additional challenge of trying to estimate the incremental value of this capability change.

Without an understanding of the full cost of implementation, stakeholders may “suboptimize” by defaulting to options that they can implement at a low level and that provide a more immediate payoff. For instance, compared with other types of changes, organizational changes are generally the quickest, least risky, and least expensive, and they can be carried out at the lowest organizational level.

However, organizational changes that shift the cost to another activity or level of the chain of command will neither address the strategic disconnects nor minimize energy consumption in the long term. For this reason, as a last step, proposed solutions sets should be evaluated against the strategic, operational, fiscal, and environmental disconnects to ensure that the proposed solution reduces the disconnects from an aggregate force perspective.

This framework is applicable at both the DoD corporate level and for specific energy challenges. Addressing organizational or process issues at the DoD level provides a first step in aligning the entire department to reduce energy dependence.

DEVELOPING POTENTIAL SOLUTION SETS

Selecting among the numerous technological, organizational, and process options for addressing DoD's energy challenges is a daunting task. Some options are readily available and easy to implement, but they may produce only limited savings in fuel usage and cost, particularly when viewed over the entire DoD system. Other options, including some still in the development stages or with longer implementation cycles, may offer greater promise for long-term savings. Because of this, it is unlikely that a single-point solution will deliver all of the desired energy reduction benefits. Satisfying the need both for immediate savings and for longer term sustainable reductions in energy consumption requires a portfolio of solutions.

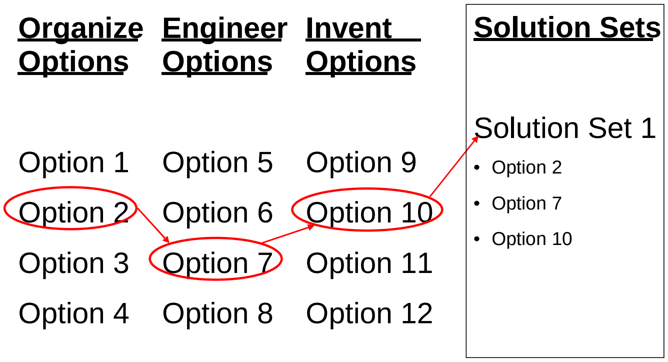
The Organize/Engineer/Invent framework can produce a menu of technology and process improvement options to address energy challenges. Table 3-1 illustrates this concept.

Table 3-1. Energy Options

Area	Organize options	Engineer options	Invent options
Technology Area 1	Option 1	Option 2	
Technology Area 2		Option 3	Option 4
Technology Area 3			
Technology Area 4	Option 5		Option 6
Process Area 1	Option 7		
Process Area 2	Option 8		

For a given energy challenge, options can be selected from the framework table to create a portfolio of solutions that together deliver the most beneficial outcomes. Figure 3-1 illustrates the notional selection concept.

Figure 3-1. Developing Solution Sets from Viable Options



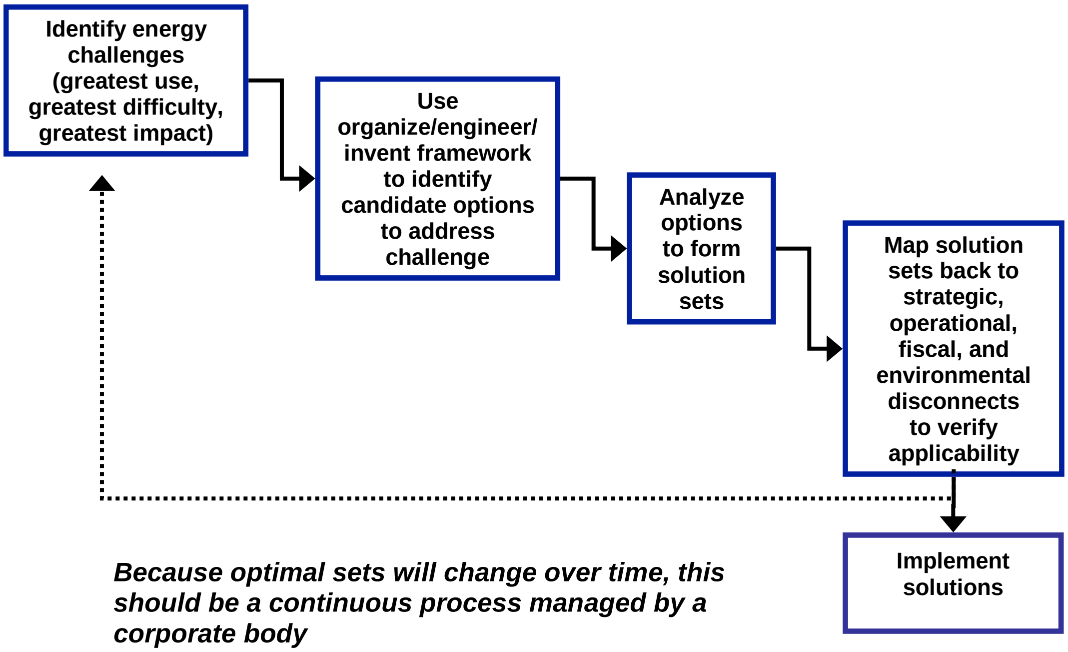
The process is relatively straightforward, but identifying viable options and selecting among alternatives requires a detailed analysis of each option. The analysis must include the relative costs and benefits in relation to the strategic, operational, fiscal, and environmental disconnects. This process requires a combination of quantitative analyses to determine the technical merits and operational and fiscal implications of each option, qualitative analyses to determine the relative importance of addressing each disconnect, and an understanding of DoD or national-level policy or organizational constraints associated with implementing the solutions. Achieving a balance between strategic, operational, fiscal, and environmental criteria will also depend on DoD policy, especially for the strategic criteria. Moreover, a good solution set might exert negative pressure on one of the evaluation criteria, but still exert enough benefit in the other categories to overwhelm any individual category.

Portfolios or combinations of investment options should be created by assessing their ability to directly address the strategic, operational, fiscal, and environmental disconnects. Creating portfolios enables the packaging of complementary combinations of organizing, engineering, and inventing options that may deliver a greater level of benefits than selecting a single option. For instance, a solution set that effectively addresses three of the four disconnects might be preferred over a solution set that improves only operational effectiveness. The portfolio approach also provides the opportunity to identify and limit investment in engineering solutions that are inconsistent with eventual implementation of a preferred long-term invented solution. Evaluation and reevaluation of combinations of investment strategies should be a continual process.

SUMMARY

Creation of a sustainable energy strategy requires a structured approach to DoD's energy challenges and targeting of the appropriate technologies and resources to address these problems. The Organize/Engineer/Invent framework provides the building blocks of such an approach and enables the development of both technical and nontechnical options for meeting DoD's most important energy challenges. Figure 3-2 illustrates the overall assessment process. At the highest level, this framework also informs DoD that the first, and perhaps most meaningful, steps may be to address DoD's corporate organization and processes to reduce energy dependence.

Figure 3-2. Process for Assessing Energy



Because optimal sets will change over time, this should be a continuous process managed by a corporate body

Chapter 4

Current DoD Energy Organization and Process

Any change in how DoD views, values, and uses energy must start by addressing DoD's organization and processes. The department itself reflects the American style of war as it has evolved since the Civil War. The American way of war has been to leverage our industrial capacity to provide sufficient forces and supplies to overwhelm and wear down our adversaries. The net result has been a heavy reliance on logistics, including energy, to provide essentially whatever support American commanders desired. In economic terms, logistics requirements have been viewed by the commander as a "free good," always available when needed. Although the U.S. military has begun a transformation to a more mobile and agile force, as evidenced by the conflict phases of Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom, the transformation has yet to be reflected by a significant reduction in logistics requirements, including energy requirements. Current DoD corporate processes and governance structures related to energy reflect this organizational view of logistics in general and energy in particular. As detailed below, energy efficiency of the mobility forces is seen as secondary to operational primacy at the point of contact, with little regard for the constraints placed on the total force as a result of its energy requirements.

ENERGY CONSIDERATIONS IN DOD CORPORATE PROCESSES

DoD corporate processes attempt to integrate all of the programs, processes, and resources necessary to support the successful achievement of DoD's mission. This integration effort is key to ensuring that all of the components work together. The corporate processes used to facilitate this integration are

- strategic planning;
- analytic agenda, including campaign analysis and mission analysis conducted by the services;
- joint concept and capability development;
- acquisition; and
- PPBE.

In view of the linkages between energy and operations, energy must be considered in DoD's corporate processes to fully address all of the components that affect mission execution. Presently, little consideration is given to sources and uses of energy, other than the use of DESC's standard prices for routine planning and programming in the operations and maintenance accounts and in required acquisition life-cycle cost analysis.

Strategic Planning

The DoD strategic planning process does not address energy considerations as a key factor in analysis, operational concept and capability development (or procurement), and the associated planning and programming phases of the PPBE processes.[1] Although recent efforts, including a Deputy Secretary of Defense Memorandum on strengthening America's security through energy efficiency[2] and the establishment of the Energy Security Task Force and the Defense Science Board Task Force on Energy Security, are examples of high-level DoD energy initiatives, they do not reflect formal incorporation of energy in the strategic planning process. Without such incorporation, these efforts may have limited effectiveness, similar to the results of 2001 and 2004 Defense Science Board efforts.

Analytic Agenda

The DoD analytic agenda is the vehicle used to synchronize strategic analysis in the department. Through the use of defense planning scenarios approved by the USD(Policy) and of Multi-Service Force Deployment (MSFD) information developed by the Joint Staff, the analytic agenda provides a baseline from which changes in assumptions or capabilities can be evaluated. Although OSD and the Joint Staff provide the common framework, the services are responsible for much of the modeling used to produce mission-level and campaign analysis. The results of this analysis are used to inform PPBE decisions, operational planning, and force development, including capability and acquisition decisions.

The analytic agenda and previous strategic analyses have not focused on the energy implications. Although the Joint Staff evaluates the services' input to the MSFD to ensure logistics feasibility, this effort is primarily limited to ensuring sufficient lift for prospective force deployments. It does not evaluate alternative future operational plans or capabilities to compare the energy support requirements. The logistics community has the ability to estimate the logistics support force requirements, but the data are not used in an iterative, near-real-time manner for total force optimization. The services are improving their ability to incorporate

---

[1] The strategic planning process, which includes the development of strategic planning guidance and efforts like the Quadrennial Defense Review, provides guidance to the OSD staff, combatant commanders, Joint Staff, services and agencies. This guidance influences the studies to be conducted in the analytic agenda as well as joint concept and capability development. The strategic planning process drives the PPBE planning phase.

[2] Memorandum from Gordon England to Secretaries of Military Departments, Chairman of the Joint Chiefs of Staff, and Under Secretary of Defense for Acquisition, Technology, and Logistics, "Strengthening America's Security and Improving the Environment," February 16, 2007.

energy considerations in war-gaming simulations, but these efforts are not uniformly reflected in DoD analyses.

Joint Concept and Capability Development

The joint operations concept development process serves as a basis for future force development by building on strategic guidance to project how a future force might operate in 8 to 20 years. The concepts developed then become a basis for capability development in the Joint Capability Integration and Development System (JCIDS). Neither process takes a system view of energy use and related impacts.

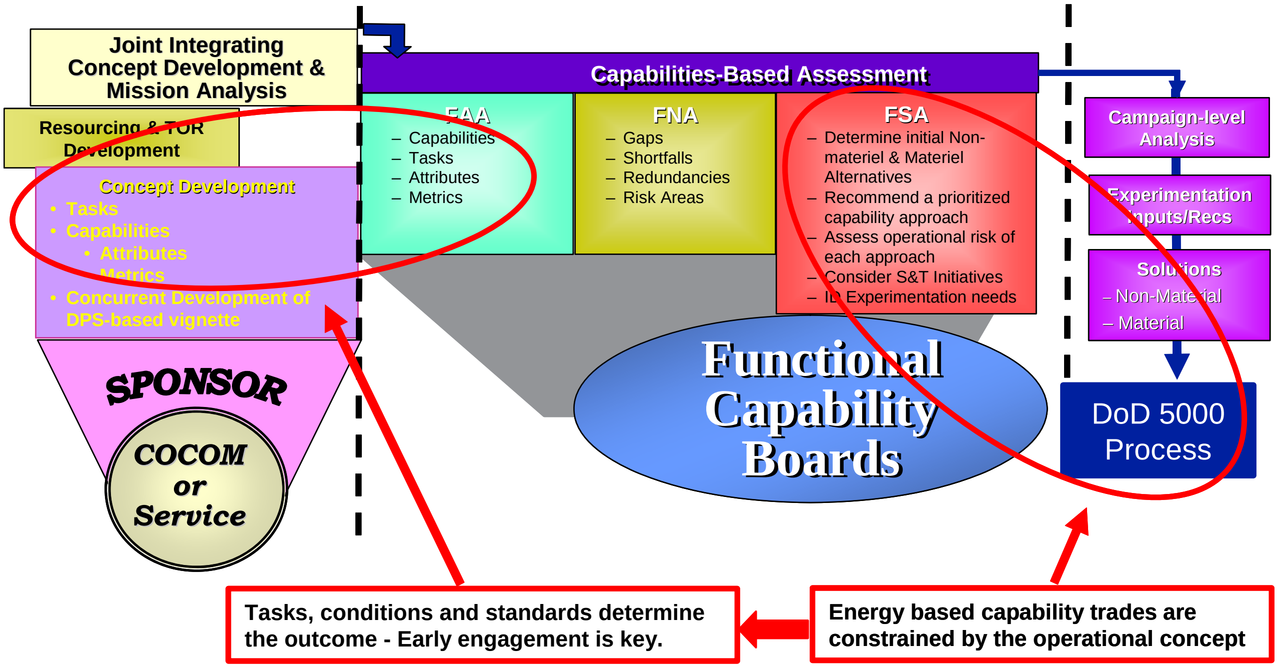
Currently, 26 joint operating, functional, or integrating concepts are approved or in development. The focused logistics and joint logistics concepts make limited reference to the desirability of reducing energy demand or providing alternate sources such as fuel cells but the remaining concepts generally are written without regard to the fuel or energy implications on the total force. For example, the major combat operations joint operating concept states: “The joint sustainment distribution subsystem must be capable of delivering all required supplies anywhere in the battlespace where supported forces are operating.”[3] This follows the long-standing practice of the warfighter assuming that the logistics community will provide whatever is required. Although this practice has worked well in the past, it may create unintended vulnerabilities if the force energy consumption trends continue. The fuel supply chain comes with an operational cost in terms of loss of agility, resources diverted to transport and delivery, and force protection requirements, as well as a fiscal cost. These costs are not considered when evaluating the aggregate force capability impact of a new concept.

While the joint concept development process and the joint capability process are independent processes, they are integrated through the capability-based assessment process developed by the Joint Requirements Oversight Council (JROC). Figure 4-1 depicts the JROC process. The broad capability requirements and operating environment of the joint concepts provide the foundation for the functional area analysis and the functional needs analysis of the capabilities-based assessment required by JCIDS.

---

[3] Department of Defense, *Major Combat Operations Joint Operating Concept*, Version 2.0, December 2006, http://www.dtic.mil/futurejointwarfare/concepts/joc_mco_v20.doc, accessed February 16, 2006.

Figure 4-1. The JROC Capability Assessment Process



Source: Joint Staff, J-8 Capabilities and Acquisition Division, “JCIDS Overview,” November 30, 2005, http://www.dau.mil/performance_support/docs/Nov_2005_JCIDS_Overview/ppt, accessed February 16, 2007.

Note: LMI annotations shown in red.

The JCIDS process is structured to consider capability alternatives developed to meet the needs identified in the functional needs analysis. These alternatives are assessed in the functional solutions analysis, which provides an opportunity to consider the energy implications of proposed solutions. Historically, these considerations have been based on the projected DESC standard price of fuel, not the fully burdened cost, which includes the cost to deliver the fuel to the operating unit. As previously noted, this fully burdened cost can be significantly higher than the standard cost, particularly for air-delivered fuel or fuel for forces forward in the operating environment.

The JROC recently agreed to

> selectively apply energy efficiency as a [key performance parameter (KPP)], as necessary, to include:
>
> - Defining “fully burdened” cost of delivered fuel to fully price the logistics fuel delivery chain (including force protection requirements);
> - Establish overarching policy mandating fuel efficiency considerations to fleet purchases and operational plans, consistent with mission accomplishment (new department wide guidance is currently pending); and

- Mandate life cycle cost analysis for new capabilities include “fully burdened” cost of fuel during analysis of alternative/ evaluation of alternatives (AoA/EoA) and acquisition program design trades.[4]

Acquisition

The acquisition process as defined by DoD Directive 5000.1, “Defense Acquisition System,” and implementing guidance provides the opportunity to consider the energy implications of a developmental system through a life-cycle cost analysis and an analysis of alternatives. In general, these analyses have been based on the projected DESC standard price of fuel, not the fully burdened cost.

Although both the JCIDS and the acquisition process provide an opportunity to address energy considerations associated with a capability, they may be “selectively applied” only at the operating unit level. Using the fully burdened cost addresses the fiscal implications of fuel supply requirements, but DoD has no provision to consider the impacts of the fuel supply chain on the aggregate force level capability, including its mobility, agility, and persistence.

Planning, Programming, Budgeting, and Execution

The fiscal impacts of energy usage become apparent in the programming and budgeting phase of the PPBE process. Rising consumption trends, if not addressed, coupled with likely gradual, and possibly sudden, price increases, will serve to increase the requirements of the operating accounts. The system aspects of energy use can also affect the procurement and other accounts. The following example highlights the ultimate impact on PPBE of systemwide energy considerations.

When new capabilities and operating systems or concepts are implemented, the logistics community evaluates the impact of these changes on the supply chain and determines if additional logistics capability is required to meet the demand of the new system or concept. This, in turn, may create new acquisition requirements for the added logistics capability. In an ideal world, if the future logistics requirements are captured in the analysis for the initial new capability, then the cost of the additional new logistics capability could be programmed at the same time. If this cost was not captured, then it competes for resources with other planned procurements (and the other accounts), creating a classic “tail” versus “tooth” situation. If the resolution of this conflict is a reduction in the planned capability purchase, unit price likely increases for either or both the warfighting and logistics capability, resulting in self-perpetuating price increases absent the introduction of unplanned funding from other sources.

---

[4] JROC Memorandum 161-06, “Key Performance Parameter Study Recommendations and Implementation,” August 17, 2006.

Once a capability has been delivered to the force, the fuel requirements are funded through the operations and maintenance accounts. Other support requirements to deliver the fuel are funded through multiple accounts. Although the services can internally allocate some of these costs to the major program, the PPBE process does not. As a result, service major program managers have little incentive to propose investment to reduce energy-related operating costs, particularly as the savings accrue to the operating accounts, not their own accounts. If other services have the requirement to deliver the fuel, the incentive is even less. In a political climate in which operating costs are viewed as readiness requirements and are essentially treated as "must pay" bills, or when operating costs are funded through supplemental appropriations, this tendency is even more pronounced.

DOD ENERGY GOVERNANCE

DoD has had an ongoing effort to monitor and reduce energy consumption since the passage of the National Energy Conservation Act in 1978. Up to 2006, the department's greatest successes have been in installation and facility energy conservation. The 2005 DoD Annual Energy Management report shows that DoD achieved a reduction in energy use of 28.3 percent (measured in Btu/gross square foot) compared to the baseline set in 1985. The department's ability to reduce its energy consumption was facilitated by the establishment of a governance structure, internal and external goals, metrics, and reporting requirements, incentives, and innovative funding mechanisms for energy efficiencies.[5]

A significant amount of legislation, along with Executive orders, directives, and instructions, dictate the need or state policy for energy conservation and efficiency. DoD energy managers in all of the services are directed to focus their energy program efforts to ensure "that DoD utility infrastructure is secure, safe, reliable and efficient; that utility commodities are procured effectively and efficiently; and that DoD Components maximize energy and water conservation efforts."[6] DoD guidance is clear and provides specific procedures to meet or exceed legislated standards for conserving energy, reducing energy consumption, and meeting environmental goals.[7] This guidance, however, focuses on facilities and installations, including fleet vehicles, and specifically exempts military tactical vehicles and activities outside the United States.[8] (Appendix C identifies key legislative and executive direction, DoD guidance, and service-specific regulations.)

---

[5] USD(AT&L), *Department of Defense Annual Energy Management Report, Fiscal Year 2006*, January 2007.

[6] DUSD(I&E), *DoD Energy Manager's Handbook*, August 25, 2005.

[7] DoD Directive 4140.25, April 2004, and DoD Instruction 4170.11, November 2005.

[8] Executive Order 13423, January 24, 2007.

Governance Structures

In December 1985, the DoD Energy Policy Council was established to provide a coordinated review of DoD energy policies, issues, systems, and programs. The instruction assigned responsibilities to various offices within DoD and allowed for a "cross-feed of information between Military Department Energy Offices."[9] Although the instruction is dated and no longer matches the current organizational framework, many of the functions and responsibilities described in the instruction are being performed by various offices within DoD.

One of the key officials is the Principal Deputy Under Secretary of Defense for Acquisition, Technology and Logistics, DUSD(AT&L), who is the DoD senior agency official responsible for meeting the goals of Executive Order 13123. (Although Executive Order 13123 was canceled by the recently issued Executive Order 13423, we presume the senior agency official required by 13423 would not change.) Another key official is the DUSD for Installations and Environment (I&E), who chairs the DoD Installations Capabilities Council. The council is chartered to address a broad spectrum of installation issues, including energy management, and to identify and remove obstacles through improved policy and guidance. The USD(AT&L), has delegated authority for managing the installation energy program to the DUSD(I&E).[10]

Energy Initiatives

The Energy Conservation Investment Program (ECIP) is an initiative to improve energy and water efficiency at DoD facilities. ECIP is a competitive-bid program that uses military construction funding to invest in energy-efficient upgrades for facilities. Annual funding has increased from $27 million in FY02 to $60 million requested in FY07, and is expected to increase $10 million annually to $100 million in FY11.

DoD uses Energy Saving Performance Contracts (ESPCs) and Utility Energy Service Contracts (UESCs) to identify and also to encourage the use of energy-efficient products and technologies. DoD uses the savings from energy-efficient actions to finance the contracts. ESPC is a contracting procedure by which a private contractor (typically called an energy services company) evaluates, designs, finances, acquires, installs, and maintains energy-saving equipment or systems for a client and receives compensation based on the energy consumption or cost savings performance of the equipment or systems. Potential retrofit projects involve

---

[9] DoD Instruction 5126.47, December 2, 1985.

[10] The DUSD(I&E) is assigned authority to establish departmental energy conservation program goals and develops procedures to measure components' energy conservation accomplishments; provide annual programming guidance and oversight for the achievement of energy goals and objectives; establish criteria, program, and budget for and monitor the execution of the Military Construction–Energy Conservation Investment Program (ECIP); and develop policy guidance, consistent with current legislation and Executive orders, to report energy use and results of energy conservation accomplishments against federal energy conservation and management goals.

lighting; heating, ventilating, and air conditioning systems; automatic controls; building envelope improvements; water conservation measures; and alternative fuel systems. These contracts can be signed for periods up to 25 years. UESCs are similar to ESPCs, but the projects are financed and implemented through utility companies.[11]

An ESPC can be an effective vehicle through which to implement energy conservation measures, especially when little or no internal funding is available. In a March 1, 1991, memorandum, “Defense Facilities Energy Management,” the Deputy Secretary of Defense directed each military department to initiate a minimum of three ESPC projects each fiscal year. The services are easily exceeding this goal. In FY06, defense components awarded 17 UESC and 19 ESPC task orders or contracts valued at $694 million, with projected annual energy savings of 1,750 trillion Btu and projected total life-cycle savings of $501 million.[12] In light of the Executive Order 13423 requirement for all federal agencies to reduce their energy consumption by 30 percent by 2015 (from 2003 baseline data) and the limited current and future internal funding, it is likely that ESPCs will facilitate a large amount of energy conservation measures for DoD installations.

In 2003, legislation was introduced for ESPC pilot programs for nonbuilding applications. Although the program was not expected to generate the same level of returns as the original ESPC program, it was a method to provide private capital to modernize DoD systems for improved energy efficiency without using appropriated funds. In 2004, however, the Administration objected to the expansion of ESPC authorities to nonbuilding applications because it was “inconsistent with Federal fiscal and procurement policies.”[13]

Installation efforts include numerous programs in energy conservation awareness, awards programs, and use of government funds to finance tools to attain shore energy goals. Success is achieved by setting reduction goals and then tracking progress to those goals. Some key areas being measured are total energy and water cost, energy consumption per square foot of facilities, greenhouse gas emissions, and resources programmed to support energy conservation plans. The philosophy behind programming resources is “smart investments in energy efficient technology yield a return on investment of 300% to 400% over their life cycle.”[14]

DoD has numerous renewable energy projects to reduce energy dependence, from an operating geothermal power plant at China Lake, CA, to wind facilities in Guantanamo Bay, Cuba. In 2005, almost 9 percent of electricity used on DoD

---

[11] USD(AT&L), *Department of Defense Annual Energy Management Report, Fiscal Year 2005*, January 2006.

[12] USD(AT&L), D*epartment of Defense Annual Energy Management Report, Fiscal Year 2006*, January 2007.

[13] Office of Management and Budget, “Statement of Administration Policy by Executive Office of the President,” May 19, 2004.

[14] *Department of Navy Shore Energy Business Plan, 2001.*

installations came from renewable sources. The Air Force is the number one purchaser of renewable energy in the United States. In the future, federal agencies must ensure that at least half of the statutorily required renewable energy consumed in a fiscal year comes from new renewable sources; to the extent feasible, agencies must implement renewable energy-generation projects on agency property for agency use.[15]

Notwithstanding the governance focus on installation energy, the services have taken some steps to improve energy efficiency in mobility applications. Because of the long capital replacement cycle, the improvements in legacy force efficiency have more significant near-term impacts than technology development for new systems.

From 1977 to 2003, the Navy has reduced fuel consumption on legacy platforms by 15.5 percent for surface combatants and by 6 percent for fixed-wing aircraft.[16] The Navy is pursuing development of hydrodynamic technologies for improved ship power and fuel savings. In 2003, the Naval Sea Systems Command's Naval Surface Warfare Center Carderock Division opened a Center for Concept Visualization dedicated to ship system analysis and design. The center is used to view, test, and manipulate highly "immersive" visualizations of new ship designs that allow engineers to examine water flow and noise transmission in and around ships and submarines. The results are faster, quieter ships that cost taxpayers less money.[17]

DoD is also pursuing enabling capabilities for lightweight vehicles and weapon systems that will be more energy efficient. A new manufacturing process for titanium may provide a cost-effective, lighter, and stronger alternative to steel for nearly all DoD platforms. Although abundant, titanium has been expensive to use in manufacturing because purifying it from ores is energy intensive.[18] The Army has an ongoing Energy and Power Technology Initiative with stable goals and funding. The initiative is achieving measurable progress in developing the advanced system components necessary to implement future energy initiatives.[19]

Incentives

All of the services are engaged with the DOE award programs—for example, the Energy Saver Showcase Award, the Federal Energy and Water Management Award, and the Presidential Award for Leadership in Federal Energy

---

[15] Executive Order 13423, January 24, 2007.

[16] Dr. Alan Roberts, Head, Energy Plans, Policy and Technology Branch, "DON Energy Management Program"(briefing to the DSB Energy Strategy Task Force, May 30, 2006).

[17] USD(AT&L), *Department of Defense Annual Energy Management Report, Fiscal Year 2006*, January 2007.

[18] John J. Young Jr., Director, Defense Research and Engineering, and Philip W. Grone, DUSD(I&E), "Joint Statement before Subcommittees on Terrorism, Unconventional Threats and Capabilities and Readiness of the House Armed Services Committee," September 26, 2006.

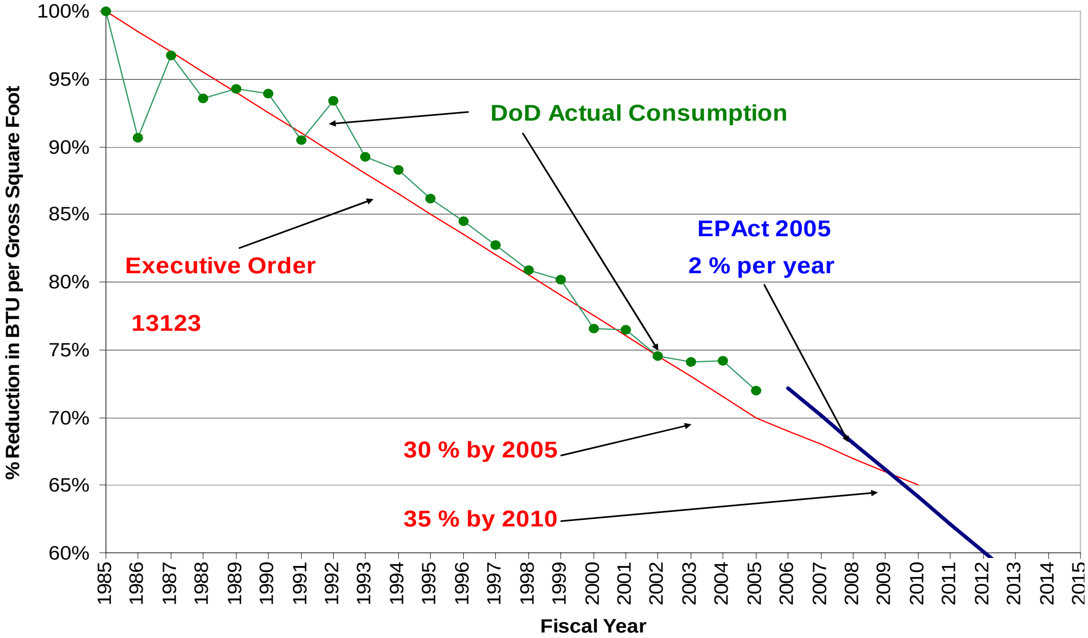
[19] Meeting with Dr. M. Freeman, Office of ASA(ALT), February 14, 2006.

Management. In addition, each service has its own award program. DoD incentives include energy conservation awards given to individuals, organizations, and installations. The services each have awards programs for outstanding individuals for overall contribution to the program, and they often incorporate on-the-spot awards and incentive awards to recognize exceptional performance and participation in the energy management program. Energy management provisions are also included in performance plans within the DoD energy chain of command, including major command, base, and site energy managers.

SUMMARY

The establishment of a single process owner, along with goals, metrics, reports, and timelines (although they may have appeared arbitrary at the time), and the development of innovative energy-savings investment mechanisms have been effective in reducing energy consumption in DoD facilities. Figure 4-2 highlights the success DoD has had in facility energy reduction over the last 10 years and the expectation for continued success in the future.

Figure 4-2. DoD Energy Reduction Progress in Standard Buildings



Source: Dr. Get W. Moy, “Department of Defense Overview of the Department’s Asset Management” (presentation, December 5, 2006).

Many of the same processes that were effective in reducing the DoD facility energy consumption by nearly 30 percent from the 1985 baseline could be applied to operational and mobility energy usage. Combined with changes in DoD corporate processes to apply a system view of energy uses and costs, particularly in the development of operating concepts and capabilities, the potential exists to significantly reduce the department's reliance on traditional energy sources.

Significant facilities energy savings did not happen overnight. They were clearly tied to long-term goals and incremental energy efficiencies developed in response to legislation and Presidential and DoD policy guidance. Because the capital asset replacement cycle is lengthy, significant changes in operational energy consumption due to new capabilities will require a long period. Investment in energy conservation methods that apply to the existing forces is essential to achieve near-term efficiencies.

Chapter 5

DoD Corporate Options for Change

DoD's current organizational processes and structure pose several challenges for transforming the way it considers energy. As discussed earlier, DoD's strategic planning, analysis, joint concept and capability development, acquisition, and PPBE processes provide few incentives to consider energy alternatives and fully burdened energy costs in resource allocation decisions, particularly when related to mobility forces. We also noted that energy responsibilities are widely dispersed among DoD and the services and that the current governance structure is highly focused on facilities and installation energy usage—a structure that does not engender a system view of energy uses, costs, and support requirements.

In this chapter, we consider options for process and organizational changes to address the lack of a system view of energy at the DoD corporate level.

OPTIONS FOR CORPORATE PROCESS CHANGE

In Chapter 4, we concluded that the potential exists to significantly reduce the department's reliance on traditional energy sources through changes in DoD corporate processes. These process changes would apply a system view of energy uses, costs, and support requirements, particularly in the development of operating concepts and capabilities, combined with application of the processes used to reduce energy consumption across DoD. To fully incorporate this approach, we evaluated how changes could be made in each of the relevant corporate processes.

Strategic Planning

In the strategic planning process, DoD leadership has influence over the analytic agenda, concept and capability development, combatant commanders' planning, and high-level resource allocation. This influence is exercised through the Strategic Planning Guidance and periodic Quadrennial Defense Review (QDR). Through this process DoD leadership could do the following:

- Establish a goal. Direct the services to apply the energy efficiency requirements of Executive Order 13423 (3 percent reduction per year, or 30 percent by 2015) to mobility forces and provide guidance to the PPBE process to ensure that appropriate initiatives to achieve these requirements are programmed, budgeted, and executed.

- Direct that the analytic agenda incorporate current and projected energy and energy logistics analysis in support of operational plans and capability-based planning.
- Provide guidance to the joint concept development process to include energy considerations in all future concept development.
- Provide guidance to the capabilities development and acquisition processes to use fully burdened fuel costs in their analysis of system life-cycle costs.
- Provide guidance to the acquisition process to make energy technology R&D (focused on significantly reducing energy dependence and implementing new energy-efficient operational concepts) a top priority (on a par with the development of stealth, precision strike, and tactical intelligence, surveillance, and reconnaissance in the late 1970s).[1]
- Make reducing energy vulnerability a focus area of the next strategic planning cycle and, potentially, the next QDR.
- Increase coordination with the Department of State to pursue international cooperation to ensure the security of energy infrastructure and transit lanes and direct the combatant commanders to leverage military-to-military relationships to enhance the stability and security of oil infrastructure, transit lanes, and markets by
  - working with the militaries of our economic partners and, to the extent possible, with potential adversaries to emphasize the global nature of the energy market and the need for stability and security in this market and associated infrastructure, and to establish cooperative efforts to ensure the security of energy infrastructure and transit lanes, and
  - working with militaries of oil-producing nations to emphasize that the ability to maintain the long-term security of their oil infrastructure depends on transparent use of hydrocarbon revenue to promote the economic and social prospects of their population.[2]

Table 5-1 summarizes some advantages and disadvantages of changing this process.

---

[1] Defense Science Board Task Force, “The Roles and Authorities of the Director of Defense Research and Engineering,” October 2005.

[2] John Deutch and James R. Schlesinger, *National Security Consequences of U.S. Oil Dependency*, Council of Foreign Relations, Independent Task Force Report 58, 2006, pp. 27–30. The report discusses how energy security can be enhanced through good governance in producer states and cooperation in infrastructure security efforts.

Table 5-1. Advantages and Disadvantages of Change: Strategic Planning Process

Advantages	Disadvantages
Strategic planning drives other corporate processes. Energy efficiency goal focuses service attention and has proven effective for facilities reduction. Incremental energy efficiency efforts are applied to mobility as well as facility uses. Combatant commanders initiate actions to promote energy security. U.S. government engagement on global energy security is promoted.	Immediate changes in operational concepts are deferred pending analysis. Proponents of traditional view may oppose the change as not applying to operational matters. Initiating military-to-military actions with strategic implications may be viewed as outside the purview of DoD.

Analytic Agenda

The DoD analytic agenda informs all of the other corporate processes. To ensure the effective inclusion of energy considerations, DoD leadership could direct the Joint Staff to work with the services to do the following:

- Capture energy use and energy logistics requirements in service campaign and mission analysis as a baseline for future analyses. Capture total joint force energy use and energy logistics requirements to ensure the logistics feasibility of analyzed plans
- Capture energy use and energy logistics requirements of future capabilities when conducting capability analysis; evaluate the aggregate impact on the total force of the projected capabilities; and quantify operational and fiscal impacts. For analyses, allow deviation from single fuel in the battlespace policy.
- Develop the capability to analyze energy implications in near real time so that model runs with variations of operational plans/concepts, MSFDs, and support forces can be optimized, including energy requirements as one of the optimization factors.
- Assess the role of information-based technologies to reduce energy dependence through the “multiplier effect” of unmanned systems, enhanced operational information provided to the warfighter, and sensors and improved energy information in operational logistics, particularly where in-theater personnel requirements can be reduced.
- Evaluate whether an immediate, focused action is required to develop a new Capstone Concept for Joint Operations and to develop alternate energy supplies, if required by the magnitude of vulnerability.

Table 5-2 summarizes the advantages and disadvantages of changing this process.

Table 5-2. Advantages and Disadvantages of Change: Analytic Agenda Process

Advantages	Disadvantages
Other corporate processes are informed by analysis. Internal DoD analysis becomes basis for new Capstone Concept and alternate energy supply development, if required. Insight into operational energy requirements and into potential benefits and costs of changes is improved. Ability to optimize warfighting plans and capabilities across all relevant key factors is greater.	Legacy analytical techniques may lack capability to capture all energy-related requirements. Additional investment in modeling capability may be required. DoD insight relies on service models. Energy logistics are difficult to model. Many assumptions are necessary and the results may not be accurate.

Joint Concept Development, Joint Capability Development, and Acquisition

Because of the linkages between joint concept development, capability development, and acquisition, energy considerations in these processes must be integrated. To put it another way, addressing energy considerations in joint capability development and acquisition will improve decision making based on an understanding of the full energy costs associated with a capability, but only changes in the operational concept can create the opportunity to evaluate the full spectrum of capability choices that may be applied in the future operating environment.

All future operational concepts should include energy considerations (such as usage, logistics requirements, and warrior burden) in their development. The focus of joint operations concepts is on 8 to 20 years in the future, and the systems developed based on these concepts may remain in the force for 20 to 50 years. Therefore, the concept development process is an ideal vehicle for DoD to begin dealing with the uncertain energy future. The requirement for immediate, focused concept development efforts to speed the reduction of the force’s reliance on traditional energy sources and logistics will be determined by the analysis undertaken as a result of strategic planning directives to assess the vulnerability of current operational plans and concepts to the embedded energy considerations.

To integrate energy considerations in the joint concept and capability development processes, DoD leadership could direct the Joint Staff to do the following:

- Develop a new concept that would make the joint force commander significantly less reliant on energy and its associated logistics support.
- Include energy considerations in all future warfighting concepts and associated joint experimentation. These considerations should be

addressed in specific capabilities, attributes, tasks, conditions, and standards

- Include energy considerations in all JCIDS capability-based assessments. These considerations should be addressed in specific tasks, conditions, and standards.

To integrate energy considerations in the solutions analysis of the JCIDS process and in the acquisition process, DoD leadership could require the Joint Staff, services, and acquisition community to do the following:

- Apply fully burdened fuel costs in all capability solutions analyses and analyses or evaluations of alternatives. Care must be taken to ensure that all energy infrastructure and logistics support requirements are captured, particularly when new requirements may be involved.
- Ensure the inclusion of energy infrastructure and logistics support requirements in the solutions analyses of operational concepts. Also ensure their inclusion in associated mission and campaign analyses of aggregate force impacts.
- Identify capability development initiatives that shift fuel support costs across service boundaries and ensure that the service responsible for providing the fuel support has a role in the associated capability and acquisition decisions.
- Require the use of energy efficiency as a KPP for those capabilities whose aggregate energy consumption is a significant contributor to life-cycle cost or energy logistics support. Achieving threshold energy efficiency should also be a Milestone B exit criterion.

Tables 5-3 and 5-4 summarize the advantages and disadvantages of changing the concept and capability development processes.

Table 5-3. Advantages and Disadvantages of Change: Concept Development Process

Advantages	Disadvantages
Operational concepts drive development of energy-efficient or alternate energy capability. Energy implications are integrated into operational concepts and associated support concepts. Conditions are set to consider full range of alternative capabilities in capability-based assessments. R&D funding can be focused on technologies required to implement concepts.	Energy use and support requirements have not traditionally been considered as drivers for operational concepts (except for single fuel on battlefield). DoD concept may not be sufficient to drive R&D to production in heavily commercial industries (e.g., vehicles).

Table 5-4. Advantages and Disadvantages of Change: Capability Development Process

Advantages	Disadvantages
Full range of alternative capabilities is considered in assessments.	Determining fully burdened cost may be difficult.
Solution alternatives would reflect full fiscal and operational impacts on DoD.	Valuing aggregate operational impact may be difficult.
Joint logistics support requirements can be integrated in the JCIDS and acquisition process.	Determining appropriate KPP metric and threshold may be difficult.

In addition to the actions that are directly linked to capability procurement, the acquisition process can make several other contributions to changing the role of energy in DoD. In particular, DoD leadership can do the following:

- Invest in S&T to provide potential breakthrough opportunities for energy efficiency or alternative energy sources, particularly those opportunities that may significantly reduce the reliance on petroleum-based fuels
- Coordinate service R&D initiatives to ensure focused efforts and avoid duplication
- Invest in commercially developed alternative energy sources as required to ensure the qualification of these products for use in DoD systems
- Consistent with the degree of vulnerability generated by analysis in the analytic agenda and the pace of commercial development of alternate energy sources, consider establishing long-term purchase agreements (and recommending associated authorizing legislation) to spur commercial investment by reducing market risk, in partnership with other consumer industries if feasible.

Table 5-5 summarizes the advantages and disadvantages of changing the acquisition process.

Table 5-5. Advantages and Disadvantages of Change: Acquisition Process

Advantages	Disadvantages
DoD-wide suboptimization and cost-shifting between operating and support forces would be minimized. Solution alternatives would reflect full fiscal and operational impacts on DoD. Future operating and logistics support requirements could be properly planned and programmed. Focused S&T and R&D efforts would be promoted. Qualified alternate energy sources for DoD applications would be ensured. If required and appropriate due to degree of vulnerability, investment in commercial alternative energy sources would be promoted.	Valuing aggregate operational impact may be difficult. DoD acquisition alternatives may be constrained by what industry is willing to provide, particularly in heavily commercial markets (e.g., vehicles). Some S&T and R&D efforts are directed by Congress. Excess focus and elimination of duplication may limit opportunity for technology breakthroughs. Alternative energy market should be developed by industry. Investment in alternative energy sources alone does not address distribution to operating forces.

Planning, Programming, Budgeting, and Execution

All of the DoD corporate processes come together in the PPBE process. If the corporate changes related to energy are fully incorporated in the other processes then little action should be required in the PPBE process. In practice, however, PPBE provides a vehicle to address situations in which cost or requirements associated with energy may not have been fully captured in the other processes. In a resource-constrained environment, it may also be necessary to use the PPBE process to prioritize among competing needs.

To ensure the full integration of energy considerations in DoD corporate processes, DoD leadership could leverage the PPBE process to do the following:

- Prioritize among competing requirements to ensure adequate funding for R&D and procurement of energy-efficient solutions and, if required, alternative energy sources. This is consistent with the highly successful “offset strategy” used in the late 1970s to develop stealth, precision strike, and tactical intelligence, surveillance, and reconnaissance.

- Improve incentives for energy efficiency investment.

    - Require services to allocate the costs of energy and energy support requirements to the supported capability programs. This information should be provided to OSD with service program and budget submissions.

- Develop formal incentive programs that allow services to retain a portion of the benefits from fuel efficiency efforts. These incentives could be applied at the service and program levels, as well as at the operating unit level (where they are currently, and successfully, applied in the Navy).
- Increase ECIP funding for services to increase energy efficiency and examine the potential for legislative changes to expand the ECIP (or create an ECIP-like program) for mobility energy efficiency.
- Work with the Office of Management and Budget and Congress to re-examine the decision not to allow DoD to enter into ESPCs for mobility (nonbuilding) applications. Increased use of ESPCs could allow energy efficiency investments to be made without or with less public investment.

Table 5-6 summarizes the advantages and disadvantages of changing this process.

Table 5-6. Advantages and Disadvantages of Change: PPBE Process

Advantages	Disadvantages
Funding of energy efficiency and alternative fuel initiatives could be ensured. Energy funding would be aligned to capability programs to improve incentives for energy efficiency investment, reducing the potential for suboptimization. Service compliance with energy-efficiency directives could be ensured. Alternative investment options and incentives for energy efficiency could be promoted.	Offsets may be required in other capability areas. Capturing full costs of energy and energy support requirements is difficult. Mobility energy savings may be difficult to capture for ESPCs. Metrics for mobility energy efficiency may be difficult to establish. No means exists of valuing alternative fuels that promote independence but are more costly than petroleum.

OPTIONS FOR GOVERNANCE CHANGE

Although DoD can articulate an overarching energy strategy and can change its processes to better address energy considerations—how DoD views, values, and uses energy—a unified energy governance structure will be essential to fully implement the changes, to coordinate DoD and service actions, and to enforce compliance. Without such a structure, the effectiveness of the process changes may be constrained. For example, in Chapter 6, we note that DoD's energy-related R&D is not well focused and that an OSD-level integrating body for energy security could enhance the effectiveness of DoD energy investments.

The concept of establishing a unified energy governance structure is not new to DoD. The DoD Energy Policy Council (DEPC) was established in 1985 "to provide for coordinated review of DoD energy policies, issues, systems, and programs… [and provide] a cross-feed of information between Military Department Energy Offices."[3] Although the directive establishing the DEPC is in effect, the DEPC does not meet, and its organization is outdated.

LMI recommends that DoD establish a new energy governance entity with centralized authority over DoD energy policies and practices. The range of authorities that this centralized governance structure could be given is wide, as are the options for its configuration and composition. We started our analysis of options for a DoD energy governance entity by addressing the following normative questions:

- Should the entity's purview include energy strategy and policy authority, as well as the ability to integrate its decisions into the relevant decision-making processes? Similarly, should it have insight into planning and analysis to inform policy refinement?
- Should it have authority across corporate processes? This authority could effectively incorporate energy efficiency considerations–including non-platform efficiency solutions—into the acquisition process and across DOTMLPF. In addition, the entity could generate and oversee strategic energy investment and synchronize R&D projects.
- Should the entity coordinate and stimulate information sharing with interagency partners such as DOE, the Department of Commerce, and the Department of Homeland Security?
- Would a single leader or committee structure be the more effective structure? If it is the latter, would a single committee—or committees for each business process represented—be the preferred solution?

An energy governance entity with the full spectrum of authorities would be able to incorporate its policies into the department's business and analytical processes, influence capability development and procurement, and direct R&D funds to the technologies that can best ensure energy security in the future. However, a structure with different qualities may be more politically feasible (implementable). Clearly, the degree of authority and the resources granted to this new entity are important considerations that will be driven by DoD leadership's sense of urgency in changing energy consumption.

After considering the normative questions, LMI developed six potential courses of action (COAs): one COA that maintains the baseline governance structure (in other words, only processes would be changed), three single-leader COAs, and

---

[3] DoD Instruction 5126.47, December 2, 1985, http://www.dtic.mil/whs/directives/corres/pdf/i512647_120285/i512647p.pdf, accessed February 2, 2007.

two COAs that employ a committee structure. We further differentiated these options by the spectrum of authorities they are granted, consisting of

- authority to create, update, and integrate policy;
- authority to oversee or directly allocate resources;
- execution authority over R&D and acquisition programs; and
- authority to procure weapon systems, equipment, and necessary support for operations.

Table 5-7 lists the six COAs, shows their authorities, and identifies organizations with similar structures.

Table 5-7. COAs for Governance

Course of action	Authority				Example organization
	Policy	Resource	R&D and acquisition	Operational	
COA 0: Process changes only					
COA 1: Single leader with full spectrum of authority	✓	✓	✓	✓	SOCOM
COA 2: Single leader with resource/ acquisition control	✓	✓	✓		NR JIEDDO MDA[a]
COA 3: Single leader with policy authority	✓				ONDCP
COA 4: Empowered committee	✓	✓			DAB JROC
COA 5: Governance committee	✓				EPC

Notes: DAB = Defense Acquisition Board, EPC = Energy Policy Council, JIEDDO = Joint Improvised Explosive Device Defeat Organization, JROC = Joint Requirements Oversight Council, MDA = Missile Defense Agency, NR = Naval Reactors, ONDCP = Office of National Drug Control Policy, and SOCOM = Special Operations Command.

[a] R&D but not acquisition.

COA 0 is a baseline organizational model. This model assumes implementation of process changes without altering DoD’s energy governance structure. These process changes may include (1) creating visibility in all business processes to meet strategic, operational, or fiscal needs; (2) establishing metrics, goals, and reporting requirements for DoD energy-efficiency efforts for mobility as well as for facility uses; (3) requiring use of fully burdened energy costs in cost estimates; and (4) establishing KPPs for energy efficiency.

COAs 1 through 5 require changes to DoD’s governance structure:

- *Single leader with full spectrum of authority (COA 1)*. Similar to authorities granted to the Special Operations Command (SOCOM) for management of Major Force Program 11, a single leader under this COA would report to the Secretary of Defense and have funding authority for policy development, R&D, and acquisition of materials and services and for the operational employment of these capabilities.

- *Single leader with resource/acquisition authority (COA 2).* Under this COA, the leader would report to the Secretary of Defense or designated subordinate with input from service points of contact (POCs) and would have policy development, R&D, and acquisition execution authority. The leader may also have streamlined acquisition authority in which acquisitions are fast-tracked through the JCIDS process. The Naval Reactors organization is a special case in that it has a co-equal, parallel organization within DOE with the same leader assigned to both organizations. The Missile Defense Agency is a different special case in that it has R&D but not traditional program acquisition authority.
- *Single leader with policy authority (COA 3).* The leader under this COA would have policy development authority, including the evaluation and coordination of DoD-wide energy security efforts.
- *Empowered committee (COA 4).* This COA would establish a committee with energy policy development and oversight authority. The oversight authority would include coordination of resource allocation for energy-related R&D, PPBE decisions, and participation in the Defense Acquisition Board’s process for Major Defense Acquisition Programs that would have potentially significant impacts on DoD’s energy consumption profile and support requirements.
- *Governance committee (COA 5).* Under this COA, the committee would have policy development authority, including the evaluation and coordination of DoD-wide energy security efforts. This committee could be similar to a revitalized DEPC but with broader influence over mobility energy and energy strategy.

After an initial assessment of the COAs, we eliminated COA 1 from further analysis because we determined that the scope of authorities assigned to a SOCOM-like organization is too broad to warrant consideration for a DoD energy governance organization. The authority to conduct operations is delegated to combatant commanders, including SOCOM for some missions. While securing or maintaining access to energy resources is a legitimate national security objective, the authority to execute such operations cannot reasonably be delegated to an energy governance entity.

Although COA 0 violates the central tenet of establishing a DoD energy governance structure, we chose to keep it because it still may have value as a short-term option as DoD prepares to transition into a new governance structure. We then evaluated the baseline (COA 0) and the remaining four COAs, which we believe are realistically implementable based on evaluation criteria drawn from a literature review and expert judgment. Table 5-8 lists the five criteria we developed, along with detailed considerations for each one.

Table 5-8. Criteria for Evaluation

Criterion	Considerations
Implementability	Will the structure be easy to implement? Is it politically feasible? What is the magnitude of change required?
Efficiency	Are lines of authority clear? Will the structure promote efficient decision-making practices? Will it build momentum from Day 1?
Effectiveness	Will it generate cost savings/avoidance? Will the structure have a positive impact on operations and readiness? Will it provide insight into planning and analysis to inform policy updates and refinement? Will the structure have authority across business processes and DOTMLPF? Will it be able to focus on a key set of priorities and generate results in a relatively short period?
Promotion of joint and interagency collaboration	Can the structure support joint and service-unique requirements? Will it promote interoperable and interdependent processes, common standards, and resource sharing? Will it be able to stimulate and coordinate with interagency partners such as DOE, Department of Commerce, and Department of Homeland Security? Will it involve services and agencies to obtain their ideas and gain ownership?
Promotion of cultural change	Will the structure be able to establish a coherent mission and broadly understood and accepted goals? Will it be able to develop a communication strategy to create shared expectations? Will it support top leadership and drive transformation and culture change?

Next, we identified advantages and disadvantages for each criterion. Table 5-9 lists them.

Table 5-9. Advantages and Disadvantages of Each Criterion, by COA

COA	Advantages	Disadvantages
Implementability		
0	◆ It is the least disruptive. ◆ Process changes may facilitate later structural changes.	◆ Transformation proponents may oppose this option as being insufficient.
2	◆ Transition to a single leader would be less disruptive than transition to a committee. ◆ Many well-functioning organizations with a similar structure exist.	◆ R&D and acquisition execution authority may be viewed as a loss of service resources and prerogative. ◆ Parties dissatisfied with similar organizations may oppose this option.
3	◆ Transition to a single leader would be less disruptive transition to a committee. ◆ Limiting authorities to oversight and policy creation may make this option more palatable than others.	◆ Those who view policy-only organizations as ineffective may oppose this option.
4	◆ Shared governance may increase buy-in.	◆ Support and coordination of all committee members is required.
5	◆ Limiting authorities to oversight and policy creation may make this option more palatable than others. ◆ Shared governance may increase buy-in.	◆ Support and coordination of all committee members is required. ◆ Those who view policy-only organizations as ineffective may oppose this option.
Efficiency		
0	◆ Results will be realized quickly.	◆ “Big moves” may reduce the level of disruption in the long term. ◆ Decentralized decision making leads to inefficiencies.
2	◆ Lines of authority will be clear. ◆ A single leader can make decisions without lengthy consultations.	◆ This option may be slow to implement and gain support.
3	◆ A single leader can make decisions without lengthy consultations.	◆ Limited authority may lengthen time to realize change.
4	◆ Ability to divide responsibilities among members may streamline processes.	◆ Because multiple parties are involved, the decision-making process may be protracted.
5	◆ Ability to divide responsibilities among members may streamline processes.	◆ Limited authority may lengthen time to realize change. ◆ Because multiple parties are involved, the decision-making process may be protracted.

Table 5-9. Advantages and Disadvantages of Each Criterion, by COA

COA	Advantages	Disadvantages
Effectiveness		
0	◆ The focus is on changing business rules and processes rather than on organizational upheaval. ◆ Quick successes may bolster support for additional transformation.	◆ Significant cost savings or change may not be generated. ◆ Misalignment/overlap of R&D will continue. ◆ Effectiveness in generating mobility energy efficiency over past 20 years has been limited. ◆ Near-term changes are unlikely to be implemented.
2	◆ Significant authority may lead to greatest influence and to cost savings or avoidance. ◆ Potential for standardization of practices is greatest for this option. ◆ Small organizational structure may lead to manpower savings. ◆ Near-term changes may be easier to implement.	◆ Without active involvement, services/agencies may feel alienated from the process. ◆ Services may resist adopting capabilities developed without buy-in.
3	◆ Small organizational structure may lead to manpower savings.	◆ Limited authority makes it difficult to fully align resources with needs. ◆ Without active involvement, services/agencies may feel alienated from the process. ◆ Control of R&D/acquisition execution is fragmented. ◆ Ability to effect near-term change is limited.
4	◆ Decisions require continuity of opinion and understanding, increasing the likelihood of implementation. ◆ Near-term changes may be easier to implement.	◆ Control of R&D/acquisition execution is fragmented.
5	◆ Decisions require continuity of opinion and understanding, increasing the likelihood of implementation.	◆ Limited authority makes it difficult to fully align resources with needs. ◆ Control of R&D/acquisition execution is fragmented. ◆ Ability to effect near-term change is limited.

Table 5-9. Advantages and Disadvantages of Each Criterion, by COA

COA	Advantages	Disadvantages
Promotion of Joint and Interagency Collaboration		
0	◆ Existing collaborative projects will not be interrupted.	◆ Potential for increased collaboration is limited.
2	◆ Control over R&D and acquisition may promote service and agency collaboration.	◆ Services may feel marginalized if not involved. ◆ Current owners of resources may resent loss of influence.
3	◆ If leader works closely with service/agency POCs, potential for collaboration/jointness is enhanced.	◆ Services may feel marginalized if not involved.
4	◆ Committee structure may promote sharing of resources. ◆ Group knowledge sharing may increase understanding of service/joint requirements. ◆ Potential for inter-entity buy-in is increased. ◆ Consensus may lead to better or quicker socialization of changes.	◆ Service parochialism may affect decision making. ◆ Gaining consensus of a committee may slow ability to take action.
5	◆ Committee structure may promote sharing of resources. ◆ Group knowledge sharing may increase understanding of service/joint requirements. ◆ Potential for inter-entity buy-in is increased. ◆ Consensus may lead to better or quicker socialization of changes.	◆ Service parochialism may affect decision making. ◆ Gaining consensus of a committee may slow ability to take action.
Promotion of Cultural Change		
0	◆ Quick successes may increase willingness to change.	◆ Mission and goals are not uniform. ◆ Communication among parties is insufficient.
2	◆ Potential for development of uniform policies and practices and a consistent mission is greatest.	◆ Some may be hesitant to support the transition of so much authority to a single leader. ◆ Lack of service ownership may limit change effectiveness.
3	◆ Policy change and strategy development may drive cultural change.	◆ Limited authority may inhibit ability to promote cultural change through goal enforcement.
4	◆ Consensus structure may promote coincident changes in attitudes and approaches.	◆ Service parochialism may affect decision making.
5	◆ Consensus structure may promote coincident changes in attitudes and approaches.	◆ Limited authority may inhibit ability to promote cultural change through goal enforcement. ◆ Service parochialism may affect decision making.

Our analysis indicates that, although implementing process changes alone (COA 0) may be a desirable interim step, DoD needs a unified energy goveranance structure if it is to effectively implement significant changes to its energy strategy. Our analysis framework provides a construct by which that goverance structure can be selected. The department may consider conducting a formal and thorough decision analysis exercise to select a COA. For instance, using a pair-wise comparison method, DoD could weight the criteria to accurately factor in their relative importance. The COAs then could be ranked in relative terms according to each criterion, resulting in a raw score that can be used to assign an order of preference to the COAs.

After a review of the many factors involved, our prima facie recommendation is to use a single leader with resource/acquisition authority (COA 2) or an empowered committee structure (COA 4). Unlike COA 3, both COA 2 and COA 4 include the authority to oversee or directly allocate resources, which greatly increases their potential to successfully initiate and enforce an energy transformation. Forced to choose between COA 2 and COA 4, we believe the importance of cooperation among DoD components suggests that the empowered committee would be the more effective.

If DoD believes that a fundamental realignment of how energy is viewed as a matter of urgency, COAs 3 and 5 are less desirable than COAs 2 and 4. If not, COA 5 may be marginally preferred over COA 3 because of the history of success of a similar energy governance structure on the installation side. However, without the formal ability to influence resourcing decisions, this COA would have limited impact on energy transformation on the markedly more complex operational side.

Regardless of the COA selected, DoD, before implementing a governance structure, must consider a number of additional questions regarding participants and resourcing. These questions include the following:

- Which organization should lead, either as a single leader or committee chair? USD(AT&L), USD(Policy), or the Office of the Director, PA&E are possible choices for this responsibility. Commander, U.S. Transportation Command, has also been raised as a possiblity because of his role as the distribution process owner.
- If a committee structure is selected, what is its proper composition?
- Should service representatives be uniformed service members or civilian leadership? Service acquisition executives may be more familiar with the acquistion and procurement issues involved, while uniformed service members may have closer ties with, and greater influence over, their respective services.
- How should the governance structure be resourced? Any committee will require a core staff and analytical resources, otherwise it is beholden to the other stakeholders, which ultimately reduces its effectiveness. A single leader will also require support staff.

Chapter 6

Energy Technology and Options for Change

To effectively plan for the future in a world with increasingly scarce low-cost fossil fuel energy resources, DoD must leverage technology to facilitate improvements in fuel energy efficiency. Demand reduction measures, combined with alternative sources of energy, including alternative fuels, offer many possibilities for reducing DoD's dependence on traditional energy sources and the associated logistics support requirements.

We used a variety of research techniques to survey the energy technology landscape. From this research, we can make some high-level observations concerning research efforts, technology development, and applicability. We can also begin to identify those that might offer the most promise to help reduce DoD's energy dependence when evaluated through the Organize/Engineer/Invent framework in the context of a specific energy challenge.[1] Finally, we provide some sample applications of the framework to some specific energy challenges.

RESEARCH OBSERVATIONS

Our key observations are as follows:

- Research is diverse and not well focused.
- DoD research investment is demand-side focused.
- Multiple solutions will likely be required to significantly reduce traditional energy dependence.
- Technologies with a multiplier effect may significantly reduce logistics and other support costs.
  - Unmanned vehicles offer significant opportunities.
  - Better information management could be as significant as energy-directed technologies.

The following subsections expand on our observations.

---

[1] Our research included web searches, informal interviews, consultation with experts, review of briefings (from various studies, meetings, forums, etc.), and a literature review.

Diverse, Unfocused Research

Numerous federal (primarily DoD and DOE) and commercial energy R&D efforts are underway. These efforts, which are at various stages of maturity, represent a large, varied portfolio, but their direction and funding—at least in DoD—are uncoordinated and not integrated with an energy-efficient future operational concept. A primary reason for this lack of strategic planning regarding energy-related R&D may be the absence of a central group in DoD that can assist the Secretary of Defense with developing a holistic energy strategy, making energy-related decisions on the basis of solid business practices, initiating DoD-wide directives, and coordinating the flow of resources to the most critical technologies required to realize energy-efficient operations.

Although the fixed installation side of DoD, through the DUSD(I&E), has an energy plan and monitors its success, DoD's operational side—where two-thirds of its energy is consumed—does not have a strategic plan with short- and long-term goals, metrics, and milestones. Although USD(AT&L) owns the functions most often associated with energy planning—infrastructure and environment, logistics management review, and defense research and engineering—the doctrinal, organizational, policy, and resource issues cut across the organization.

DoD has created an ad hoc body, the Energy Security Integrated Project Team (IPT), to study the energy issue. The IPT has recommended creation of an Alternative Fuels Task Force with some of the integrating responsibilities listed above, but questions remain regarding the lifespan of the body and its staffing and funding sources.

Demand-Side Focus of DoD Research

The technology portfolio is diverse, but most of the known dollar investment in R&D is focused on demand-side opportunities. This is a natural bias, because DoD is a platform-centric organization; that is, its acquisition and planning is based on weapon system development and support. In fact, a number of supply-side technologies are being sponsored by industry and other government agencies. Many energy policy practitioners assert that the private sector and DOE are best positioned to sponsor supply-side energy development and question DoD's role on supply-side development.

Although this division between government and commercial sources may represent the best model for advancing the consideration of alternative energy solutions, DoD could take a more global perspective in integrating energy and operations, trying to fill the gaps by leveraging supply-side technologies. One area in which additional DoD involvement is clearly appropriate is the development of what we call "cross-cutting" technologies, technologies that can supply power at the local level and reduce the demand for bulk energy supplies and the associated logistics burden.

Given that DoD's projected fuel needs can be met with conventional domestic petroleum production,[2] DoD leadership in the development of alternate liquid fuel production involves a national-level policy decision regarding the appropriateness of DoD's role as a change leader.

At a minimum, DoD should participate in supply-side technology development to the extent necessary to ensure that developed products can be applied to DoD uses with little, if any, additional modification. And, in view of the range of alternatives to provide liquid fuels being pursued by DOE and the commercial sector, DoD should be mindful of the risk of foreclosing future options by supporting capital-intensive programs that might then preclude the later development of solutions with higher source to use energy efficiency and reduced environmental impact.

Requirement for Multiple Solutions to Energy Dependence

The change associated with moving away from conventional oil-derived fuels is evolutionary, rather than revolutionary. The energy density of current fuels makes them difficult to replace within the life span of current platforms. Most technologies associated with the Energy Security IPT effort offer demand-side savings, which are valuable but will only provide savings incrementally as they are introduced to the force over time.

The life expectancies—often decades—of DoD systems increase the importance of addressing the energy demands of legacy platforms and ensuring that energy considerations are properly factored into the design of new capabilities and replacement capabilities for those platforms reaching the end of their service life.

The Multiplier Effect

As new technologies are considered, they need to be evaluated, not only for their operational effectiveness and energy efficiency, but for their multiplier effect, which occurs when the direct or indirect consequences of an action magnify its effect. In this context, a technology has a multiplier effect if it reduces fuel consumption and, in doing so, causes additional reduction in the total burden of providing fuel. For instance, delivering fuel in the deployed setting requires a long and energy-intensive logistics tail. When a technology reduces fuel consumption at the front end, the demands placed on the entire logistics tail decrease, resulting in savings beyond just the fuel acquisition costs.[3] Technologies that may have high payoff due to the multiplier effect should be given strong consideration for implementation. New operational concepts can also serve to focus technology

---

[2] P. Dimotakis, N. Lewis, R. Grober, and others, *Reducing DoD Fossil-Fuel Dependence*, JSR-060135 (McLean, VA: JASON Program Office, MITRE, 2006).

[3] The value of these savings can be significant. The 2006 JASON report calculates a fuel delivery cost of $20 to $25 per gallon for air-air refueling and a cost of $100 to $600 per gallon for fuel delivered to troops in forward areas. For efficiencies that do not result in a reduction of the air refueling infrastructure, the savings can still be up to 3.3 times the saved fuel cost.

development on capabilities that may have high payoff via a multiplier effect, particularly if they can reduce the deployed forces required to accomplish an operation.

UNMANNED VEHICLES

Unmanned vehicles offer significant opportunities to reduce energy dependence because of the multiplier effect. Because they do not have to carry humans (and the associated protection and life support equipment), they can be much lighter, require less fuel to support or have longer on-station capability (or both). They also offer cost savings that can be used to invest in additional capability. For surveillance platforms, the increased surveillance capability results in greater precision of battle space information, decreasing the number of troops, manned aircraft, or ships needed to localize a target. That, in turn, results in reduced fuel use and support requirements. Realizing opportunity from unmanned vehicles requires resisting the temptation to increase capability without considering the impact on cost and quantity, which may reduce the commander's risk tolerance, negating some of the operational benefit.

INFORMATION MANAGEMENT

Better information management is generally considered an enabler, but we are unaware of any "holistic" netting of information to make energy one of the key parameters. Current operational and logistics systems are not optimally linked. We discuss information management and the specific initiatives to transform air traffic control practices in Appendix D, but other opportunities to link planning and execution data to conserve resources (and ultimately fuel) are likely available. A recent workshop at the Defense Advanced Research Projects Agency (DARPA) and a Naval Research Advisory Committee (NRAC) study indicate that as DoD continues to merge and manage net-centric opportunities, it may be able to generate energy savings through better management and use of data in real time or near real time.[4]

The DARPA workshop noted potential energy savings through (1) developing extra-theater stand-off capabilities with increased telecommuting ability and improved satellite systems, (2) ensuring universal connectivity and increasing modeling and simulation to increase the ability to process and synthesize information and provide better streamlined and efficient supply/demand needs, and (3) using a theater-wide networking and modern telecommunication technology to provide information to those needing it.

---

[4] Naval Research Advisory Committee, "Future Fuels" (presentation, October 4, 2005) and information provided by Dr. Rosemarie Szostak, Program Manager, DARPA, workshop coordinator.

The NRAC study—commissioned in response to a challenge from Marine Corps Lt. Gen. James Mattis to "unleash us from the tether of fuel"—proposed to "untangle" the tether through a system of dynamic fuel management. It recommends

> the development of sensor and communications systems, along with resource allocation tools to enable operational commanders to manage fuel allocation and re-supply in real time during combat operations. Timely delivery of fuel is essential to maintaining operational tempo. Fuel management during combat operations can include: location and fuel status of vehicles, ability to dynamically relocate fuel assets to areas of high need, etc.

Through the development of more robust and linked information systems, DoD could ensure the optimization of the supply chain, with resultant energy efficiencies and savings. If DoD had had better-linked modeling, planning, and execution tools and information, it may have avoided some of the energy wasted in Operations Iraqi Freedom and Enduring Freedom. The current fragmented planning and execution systems (operational and logistics) have resulted in queues of fuel trucks waiting en route and at discharge points. These queues are the result of a combination of inadequacies in demand forecasting, operations awareness, and facility readiness. Not all delays might have been avoided, but a better level of data integration and use could have reduced some of this logistics burden, not to mention the risk to the operators involved in delivering fuel in a combat environment.

ENERGY TECHNOLOGY OPTIONS

LMI surveyed energy technologies—under study or in development by DoD and other federal agencies—that may facilitate energy efficiency and renewable energy or present opportunities to improve energy security for DoD. Table 6-1 summarizes the more promising technology options for DoD application, categorizing them in two ways: where they fit in the Organize/Engineer/Invent framework, and whether they are related to "supply" (they replace fossil fuels) or "demand" (they reduce consumption of fossil fuels) or are cross-cutting (they replace local supply and reduce the logistics burden). DoD may be able to implement organizing and engineering opportunities in the near-term while inventing solutions that require a longer time horizon. In general, we considered technologies that will be available for use by DoD forces by 2015 as near term, and technologies that will be available for use by DoD forces in 2015 or later as far term. These time frames generally correspond to the DoD planning cycle of the FY08 Program Objective Memorandum, which would include near-term technologies. Appendix E contains our full review of these technologies.

Table 6-1. Energy Change Options

Technology	Options		
	Near term		Far term
	Organize	Engineer	Invent
Supply (replace fossil fuels)			
Synthetic fuels		Coal and natural-gas-based fuels (Fischer-Tropsch process)	Synthetics from renewable resources
Biofuels		Replacing conventional fuels with biofuels, including biodiesel Optimizing future applications to run on biofuels	Microalgae or other high-energy biofuels
Hydrogen		Hydrogen combustion	Fuel-cell powered applications Portable soldier power
Nuclear power		Naval propulsion Nuclear power sources for synthetic fuel production	Nuclear power sources for hydrogen fuel production Advanced nuclear propulsion (reduced size, manpower)
Geothermal energy		Nontactical use in favorable geographies	
Demand (reduce fuel consumption)			
Engines/ turbines		Auto shutoff and partial engine idling Reengineering of aircraft and tanks Low-emission diesel Low-speed turbofan aircraft engines	Low-temperature combustion mode engines
Materials		Composites and lightweight metals for aircraft, ships, and vehicles	Advanced lightweight armor
Hybrid drive		Hybrid vehicles	Advanced hybrid systems
Unmanned vehicles	Increased use of unmanned vehicles in place of manned vehicles	Improved unmanned vehicles	Advanced autonomous unmanned vehicles
Aerodynamic design/ blended-wing aircraft		Aerodynamic enhancements to current airframes	Blended-wing aircraft designs
More-electric architecture		Replacing mechanical and hydraulic components with electric for aircraft, ships, and ground vehicles	

Table 6-1. Energy Change Options

Technology	Options		
	Near term		Far term
	Organize	Engineer	Invent
Information technology/ information management	Efficient scheduling Simulators and virtual training Increased reach-back	Monitoring and control systems Air traffic management	Control of hybrid systems Information capture for future improvement
Low-power computing		System on Chip (SoC) technologies	Power Aware Computing and Communication (DARPA)
Cross-cutting (replace local supply and reduce logistics demand)			
Batteries	Replacing primary with secondary batteries	Battery charge indicators Upgrading batteries to best available chemistry	Next-generation batteries
Generators		More efficient battlefield generators	Micro-turbines Portable fuel cell battery chargers
Fuel cells		Stationary power	Ship service fuel cells Reforming JP-8 for portable power Battery-sized fuel cells for portable electronics Hydrogen infrastructure
Solar		Solar collector installation	Space-based solar
Wind		Wind turbine installation	
Ocean energy		Ocean thermal energy conversion	Surface and ocean wave energy harvesting
Conversion of waste-to-energy		Direct conversion of waste to electricity	Conversion to liquid fuels via pyrolysis

Our assessment of the promising technology options was also informed by the results of an Energy Technology Assessment Workshop, held at LMI on January 24, 2007. As a follow-up to this workshop, attending subject matter experts (SMEs) ranked technology alternatives based on whether DoD should place them as a high, medium, or low priority for investment. (Appendix F contains the results of this exercise.) This analysis provided high-level insights from a technology perspective, but more detailed analysis is required to prioritize solutions from an implementation perspective.

OPTIONS FOR CHANGES IN ENERGY USE

Below, we present sample applications of the Organize/Engineer/Invent framework detailed in Chapter 3 to address specific energy-efficiency challenges. For each of these examples, we list viable technology options that, together, represent potential solution sets for addressing DoD's energy disconnects. The examples are as follows:

- *Example 1—Greatest Use Challenge: Aircraft Fuel Consumption.* One of the most important mobility fuel conservation opportunities is the reduction of aviation fuel for tactical and mobility aircraft. A solution set of viable options might include the following:
  - *Organize*: Use simulators to reduce actual training flight requirements. Minimize weight on board by carrying only mission-essential items. Optimize flight routing through GPS-aided positioning, advanced scheduling and flight planning software, and consideration of on-ground en route refueling. Increase efficient aircraft utilization based on analysis of sortie effectiveness against specific tactical and training objectives; evaluate use of flight-hours as a measure of effectiveness. Increase use of unmanned aerial vehicles. Evaluate just-in-time (airlift delivery) logistics requirements against using surface delivery to determine instances that may not justify routine use of airlift (considering both inventory and delivery costs).
  - *Engineer*: Install air traffic monitoring systems to allow access to more direct commercial flight routes. Install more efficient engines on aging aircraft.[5] Supply synthetic fuels in place of standard jet fuel. Increase fuel efficiency through aerodynamic design and use of lightweight materials and composites.
  - *Invent*: Develop unmanned aerial vehicles with advanced capability. Design future aircraft with blended wings for improved fuel efficiency.[6]

---

[5] The Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting through Reduced Fuel Burden*, January 2001, and Defense Science Board Task Force, *B-52H Re-Engining*, June 2004.

[6] DoD Energy Security IPT brief to the SSG, Energy Options, presented September 13, 2006.

- *Example 2—Greatest Difficulty Challenge: Operational Vehicle Fuel Consumption.* Another key energy conservation opportunity is reducing the amount of fuel required by ground forces deployed in the operational environment. Because this fuel is the most difficult to deliver, the cost is likely to include some of the highest multiplier effects so the total savings per gallon conserved are much higher than the DESC standard price per gallon.

  - *Organize*: Measure and monitor vehicle operating profiles and consumption patterns. Adjust operating profiles to reduce fuel consumption based on analysis of fuel consumption data.[7] Review single-fuel requirement for JP-8 to determine if supplying diesel fuel for certain applications would provide greater fuel efficiency or lower logistics costs.[8]

  - *Engineer*: Install data collection systems for vehicle usage, idling, and fuel consumption patterns. Install auxiliary power units on tanks and other vehicles to reduce power consumption during idling. Replace existing turbine engines on M1 tanks with more efficient diesel engines.[9] For other vehicles, use most efficient engines available for specific equipment usage patterns, such as the inline-6 diesel engine[10] and hybrid-electric vehicles with built-in power export capability.[11] Increase use of composite materials.

  - *Invent*: Develop real- or near-real-time reporting of vehicle consumption data to automated logistics information systems. Develop unmanned land vehicles with reduced armor and hotel loads.[12] Develop lightweight strength members and armor.

---

[7] See Note 2.

[8] Diesel fuel has a higher heat content than JP-8 and could provide greater fuel efficiency, all things being equal. The current single fuel policy of supplying JP-8 for all tactical applications has important implications for vehicle power options, because it precludes the use of low-sulfur diesel fuel that may be required for cleaner diesel engines that employ exhaust gas recirculation. However the reduced emissions from employing exhaust gas recirculation may also result in a 3-5% reduction in fuel economy, and supplying low sulfur fuel may impose additional logistics costs. Some information indicates that there is considerable use of fuel from local sources in the operational environment. A comprehensive analysis of the single fuel policy is warranted.

[9] See Note 2.

[10] See Note 2.

[11] See Note 2. Because of military vehicle operating patterns, the principal benefit from hybrid-electric vehicles may be auxiliary power rather than increased fuel efficiency while driving.

[12] See Note 5.

- *Example 3—Greatest Difficulty Challenge: Mobile Electric Power.* Another example of significant logistic burden including fuel delivery in the operational environment is mobile power generation for forward basing areas. A solution set of viable options to address this problem might include the following:
    - *Organize:* Monitor equipment usage. Ensure that temperature settings on air conditioners and heaters are adjusted to the most efficient practical levels. Insulate temporary structures. Reduce the footprint and energy consumption of deployed forces by increasing reach-back to CONUS and reducing "home station" amenities for deployed forces.
    - *Engineer*: Replace legacy generators with newer, more efficient, light weight generators.[13] Replace portable air conditioners with more efficient models for long-term fuel savings. Install hybrid electric power stations with wind turbines, solar collectors, and storage devices.
    - *Invent*: Develop waste-to-energy and fuel cell generators for forward base and remote power locations.
- *Example 4—Greatest Impact Challenge: Battery Weight for Warriors.* One of the concerns on the modern battlefield is the amount of weight warriors must carry. While every additional pound reduces the warrior's persistence (endurance), mobility, and agility, limiting the power (batteries) available reduces access to information, placing the warrior at personal risk and hindering mission accomplishment. In recent years, an increasing amount of this warrior burden involves batteries, which now average about 15 to 20 percent by weight of the burden. A solution set of viable options to address this problem might include the following:
    - *Organize*: Assess mission and equipment requirements to optimize the number of batteries required.
    - *Engineer*: Install battery charge indicators on equipment or batteries to reduce the tendency to replace batteries prematurely.[14] Provide lightweight, compact battery recharge capability. Field energy-efficient computing and communications technology.
    - *Invent*: Develop low-power chips to reduce power requirements for electronic devices.[15] Develop advanced chemical batteries with greater energy and power densities. Develop battery form factor fuel cells

---

[13] *2kW Military Tactical Generator (MTG)*. http://www.pm-mep.army.mil/technicaldata/2kw.htm.

[14] Defense Logistics Agency and DoD Power Sources Technology Working Group, *Department of Defense Technology Roadmap for Power Sources*, Workshop Data, November 24, 2006.

[15] Committee of Soldier Power/Energy Systems, National Research Council. *Meeting the Energy Needs of Future Warriors.* September 2004. http://books.nap.edu/catalog/11065.html.

> with greater power and reduced weight to replace traditional batteries. Develop man-portable fuel-cell generators that can provide battlefield power for recharging secondary batteries, which will allow a single secondary battery (or a few secondary batteries) to be used in place of a greater number of primary batteries.[16]

After potential solution sets are identified, they must be validated through rigorous, detailed cost-benefit analysis and assessment of their strategic, operational, fiscal, and environmental implications. For example, changes to tactics, techniques, and procedures that reduce fuel consumption may have an adverse effect on the ability to complete real-world missions unless they are made in the context of changes to operational concepts that leverage the efficiencies gained by the aggregate force. Similarly, the energy efficiency gain and the corresponding reduction in logistics requirements from new battery chemistries may be offset by the environmental impact of battery disposal.

When considering investments in long-term solutions, DoD must address both the cost and the probability of achieving technological objectives. The department must also consider the different stakeholders and organizations in the defense hierarchy whose support will be required to implement those options. Although local commanders can implement many organizational solutions, other solutions may require changes to policies and procedures developed by the service staffs or combatant commanders. Likewise, most engineering and inventing solutions require continued funding over multiple fiscal years and must ultimately be vetted via the PPBE process. Nevertheless, we believe that this approach can lay the foundation for a DoD energy technology strategy.

---

[16] See Note 13.

Chapter 7

Approach to an Energy Strategy: An Energy Transformation

A strategy to change how DoD views, values, and uses energy will challenge some of the department's most deeply held assumptions, interests, and processes.[1] Executing this strategy will require the development of innovative concepts and capabilities that reduce energy dependence while maintaining or increasing overall warfighting effectiveness. This change will be a transformation.

KEYS TO A SUCCESSFUL ENERGY TRANSFORMATION

Achieving an energy transformation at DoD will require the commitment, personal involvement, and leadership of the Secretary of Defense and his key subordinates. Most important, the Secretary must establish a clear vision of the outcome of the department's energy transformation and must institutionalize the processes, governance structure, and resources required to achieve that vision. As one author noted, "undercommunicating the vision by a factor of 10 (or even 100 or even 1000)" is one of the reasons that transforming organizations fail.[2]

The vision must be an articulation of the leader's view of the desired end state, but it also must resonate within the organization and with external stakeholders (in this case, Congress, the public, and the defense industry) if it is to be effective and enduring. We propose the following vision:

> To be the nation's leader in the effective use of energy, significantly reducing DoD's dependence on traditional fuels and enhancing operational primacy through reduced logistics support requirements.

A recent RAND study notes that a "clear, well-communicated vision or purpose will focus attention on innovative ideas. Employees must have a keen understanding of the organization's purpose before they can suggest improvement. Because decisions made at all levels of the organization contribute to the success or failure of innovative ideas, a clear vision or mission statement reduces the need for

---

[1] Some of these challenged assumptions, interests, and processes include (1) the operator's assumption that individual platform performance is more important than aggregate system performance, (2) the commander's assumption that the logistics community will provide required fuel regardless of cost or difficulty, (3) the logistics community's vested interest in the fuel delivery force structure, and (4) the requirements and acquisition processes for making life-cycle cost and procurement investment decisions on the basis of fuel cost which do not capture the real costs (and operational implications) of delivery in the operational environment.

[2] John P. Kotter, *Leading Change* (Boston, MA: Harvard Business School Press, 1996), p. 9.

lengthy debates on every decision."[3] If DoD is to significantly reduce its dependence on liquid fuels and their associated logistics, it is imperative that the leadership clearly and frequently articulate this objective, while establishing the processes and incentives to make the change.

A Government Accountability Office review of key practices from successful organizational mergers and transformations identified two factors commonly found in transformations that had been successful:

- Ensure that top leadership drives the transformation
- Establish a coherent mission and integrated strategic goals to guide the transformation.[4]

The diverse views and interests of the many stakeholders in a defense energy strategy make it apparent that the active, continuing involvement of the Secretary and Deputy Secretary of Defense will be necessary to achieve a successful energy transformation.

IMPLEMENTING AN ENERGY STRATEGY

The organizational vision and strategic goals for transformation lay the foundation upon which any strategy is built. A strategy outlines an approach to achieving the vision by identifying the methods to be used to achieve the established goals. An energy strategy would define the organizational process changes and technical changes to facilitate DoD's shift toward improving mobility energy efficiency.

To implement an effective, long-term energy strategy, DoD must include energy considerations in its corporate processes, guidance, and governance structure. The addition of energy concerns to the organization's key processes will raise the level of awareness about DoD's energy issues and focus the organization on identifying solutions. The following steps highlight changes that could be made in the key processes—strategic planning, analytic agenda, joint concept and joint capability development, acquisition, and PPBE—to support an energy strategy:

- Apply the energy efficiency requirements of Executive Order 13423 (3 percent reduction per year, or 30 percent reduction by 2015 from 2003 baseline) to mobility forces (which are currently exempted).

---

[3] Debra Knopman, Susan Resetar, Parry Norling, Richard Rettig, and Irene Brahmakulam, *Innovation and Change Management in Public and Private Organizations: Case Studies and Options for EPA* (RAND, 2003), p. 36.

[4] Government Accountability Office, *Results-Oriented Cultures: Implementation Steps to Assist Mergers and Organizational Transformations*, GAO Report 03-669, July 2003.

- Establish a corporate governance structure to provide strategic energy direction. A strong governance structure will help ensure the continued alignment of the DoD energy efforts.
    - Coordinate the energy efforts of DoD components.
    - Establish metrics and monitoring and reporting requirements in support of energy efficiency goals.
    - Monitor and enforce compliance.
- Incorporate energy strategy, energy use, and energy logistics in DoD's corporate processes.
    - Analyze current and projected energy and energy logistics required to support operational plans and capability-based planning.
    - Evaluate the aggregate impact of energy and energy logistics requirements for the joint force in an operational environment, and quantify operational and fiscal impacts.
    - Assess the role of information-based technologies to reduce energy dependence through the multiplier effect of unmanned systems and sensors, enhanced operational information to the warfighter, and improved energy information in operational logistics, particularly where in-theater personnel requirements can be reduced.
    - Evaluate whether an immediate, focused action is required to develop a new Capstone Concept for Joint Operations and alternate energy supplies due to unforeseen magnitude of vulnerability.
- Incorporate energy considerations (energy use and energy logistics support requirements) in all future concept development, capability development, and acquisition actions.
    - Examine, and quantify where possible, energy considerations in concept and capability analysis and experimentation.
    - Implement the use of fully burdened fuel costs in capabilities and acquisition analysis of system life-cycle costs.
    - Require energy efficiency as a KPP and Milestone B exit criterion for those capabilities with significant energy consumption or energy logistics support requirements.

- Make energy a top R&D priority.
  - Invest in S&T to provide potential breakthrough opportunities for energy efficiency or alternative energy sources, particularly those opportunities that may significantly reduce the reliance on fossil fuels.
  - Coordinate service R&D initiatives to ensure focused efforts and avoid duplication.
  - Qualify commercially developed alternative energy products for use in DoD systems.
- Improve the incentives for investment in energy efficiency.
  - Identify and allocate the costs of energy and energy support requirements to capability programs.
  - Develop mechanisms to allow the services to retain a portion of the benefits from fuel efficiency efforts.
  - Work with the executive branch and Congress to increase incentive authority and funding for energy efficiency investment programs (ECIP and ESCP).
- Increase global efforts to enhance the stability and security of oil infrastructure, transit lanes, and markets.
  - Coordinate with the Department of State to promote international cooperation in these areas.
  - Direct the combatant commanders to leverage military-to-military relationships in these areas.
- Make reducing energy vulnerability a focus area of the next strategic planning cycle and QDR.

The next step in the strategy definition process is to identify specific changes to be made to energy-supported processes and technology. A survey of the emerging energy technology landscape reveals that the department has a wide range of options for addressing energy efficiency and alternate sources of energy. In order for any strategy to fully leverage changes to processes or technological advances, the energy challenges to be addressed must be defined to enable evaluation of the options, based on their ability to respond to the stated challenges. One method that can be used to outline the energy challenges is to consider the

- greatest fuel use (aviation forces),

- greatest logistic difficulty (forward land forces and mobile electric power), and
- greatest warrior impact (individual warfighter burden).

Other categories may be worthy of investigation to address specific areas of DoD concern. Whatever categories are used, this step must be completed to enable a thorough evaluation of candidate change options.

With energy challenges identified, the next step is to identify and select potential solutions. Some solutions are easily implemented with little or no investment in technology, but produce only limited energy savings. Other solutions may require a larger investment in either time or money to produce more substantial savings. Therefore, it is unlikely that a single solution will deliver all of the desired energy-reduction benefits. Satisfying the need for immediate savings, as well as longer-term, large-scale, sustainable reductions in energy consumption, will require a portfolio of solutions.

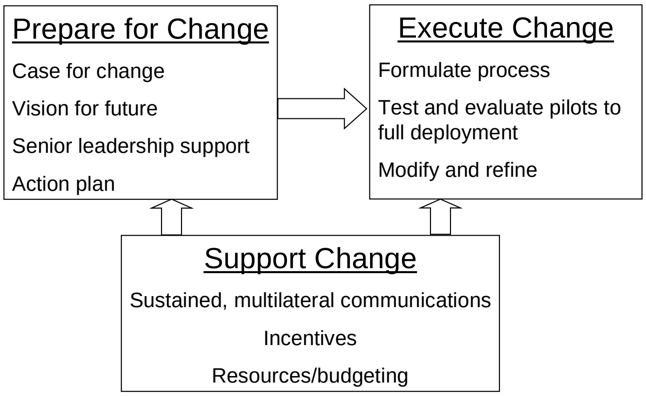
The following framework can be used to identify a range of solution options available for reducing energy consumption:

- Identify organizational and process changes that can be implemented immediately
- Identify engineered solutions to improve the efficiency of current forces and those nearing acquisition using existing technology
- Invent new capabilities, employed in new operational concepts, for those technologies yet to be developed.

Under the guidance of a coordinating body, DoD can begin a structured analysis of how to apply organizational, process, and technology changes to execute a strategy to reduce energy dependence. Establishment of a coordinating body with policy and resource oversight authority would enable integration of energy efforts across the services and DoD. The coordinating body can evaluate the identified portfolios against the energy disconnects to identify optimal solutions across the services, broader department objectives, and U.S. government strategic objectives and energy efforts. The coordinating body can then focus technology development as required to achieve the desired goals.

In evaluating the approach to implementing an energy strategy against a model for public-sector change management developed by RAND (see Figure 7-1), one can see that the proposed changes, if implemented, address the necessary attributes to prepare for and support change. We believe that an empowered corporate energy body, supported by senior DoD leadership, will provide the necessary governance to achieve successful execution of this transformation.

Figure 7-1. Model for Change Management



Source: Debra Knopman, Susan Resetar, Parry Norling, Richard Rettig, and Irene Brahmakulam, *Innovation and Change Management in Public and Private Organizations: Case Studies and Options for EPA* (RAND, 2003), p. 33.

BENEFITS OF ENERGY TRANSFORMATION

A successful transformation in how DoD views, values, and uses energy will provide a powerful catalyst for 21st century operations at all levels of the department. The 2005 DoD National Defense Strategy and the 2006 QDR call for increasing U.S. military presence globally, rather than locating en masse at static operating bases. This theme represents a "new global posture" in which smaller, joint bases, including joint expeditionary sea bases and cooperative security locations, are distributed globally and can reposition with ease in response to threats. Establishing such a posture requires forces in more regions of the world, employs new technologies, and creates a more complex logistics burden. Under current consumption patterns, such a strategy will be even more energy intensive at a time when availability of traditional energy resources is becoming increasingly questionable. The application of new operational concepts and energy technologies that address efficient use of energy and alternative supply sources increases the opportunity to achieve the vision of the National Defense Strategy.

Increasing the energy efficiency of DoD operations has the potential to increase operational flexibility by reducing logistics support requirements, while freeing resources currently dedicated to energy and associated support for recapitalization purposes. The proposed option to expand the energy consumption mandates for federal facilities to mobility operations presents opportunities for significant savings. Our analysis, described in Appendix G, indicates that this move could result in cumulative savings to DoD of roughly $43 billion by 2030 based on Energy Information Agency reference case price projections (with a range between $26 billion and $73 billion for "low" and "high" price cases). This estimate does not include the secondary savings from the multiplier effects of reducing energy consumption. While investment would likely be required to achieve these savings, the investment would be offset by the multiplier effect, which is typically larger than the associated fuel cost.

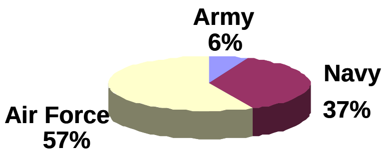
An energy transformation that leverages process change in the short term and technological innovation in the mid to long terms will provide DoD the opportunity to address the strategic, operational, fiscal, and environmental disconnects inherent in its current energy use and policies. Energy transformation will enable DoD to target its greatest energy challenges and focus change efforts on addressing them. Incorporating new energy-efficient concepts and technologies increases the potential to enhance operational effectiveness through increased reach and agility while reducing the logistics dependence of the force. From a fiscal perspective, reduction in the energy use profile will allow DoD to redirect resources formerly spent on fuel to increase investment in warfighting capability. Improved energy efficiency will also reduce DoD’s fiscal vulnerability to supply and price shocks in the energy market. More efficient use of energy and the choice of alternative energy options which minimize or mitigate environmental impact will garner the support of the public while acting in concert with national environmental goals.

Through the process of energy transformation, DoD can become a national leader in innovative and efficient uses of energy, with the potential to alter the energy landscape by changing energy demand patterns and the associated energy security requirements. To implement these important changes, an effective managing body in DoD is required. This will allow DoD to coordinate the development of opportunities across the DoD and civilian agencies to minimize redundancy and to maximize complementarities; minimize suboptimization across the organization; and establish goals, metrics, and reporting requirements for energy efficiency. In view of the long period required to develop and populate the force with new concepts and capabilities, DoD should begin now to posture the force for success in an environment of increasing energy uncertainty.

Appendix A
Mobility Fuel Use

Mobility energy—the fuel used to power DoD weapons platforms, tactical equipment, and all other types of vehicles—comprised 66 percent of the total energy consumed by DoD. In contrast with facility energy, the energy required to fuel bases and other stationary products, mobility energy is entirely petroleum-based products and accounts for 94 percent of DoD's petroleum consumption. Figure A-1 shows the distribution of mobility fuel use by service.

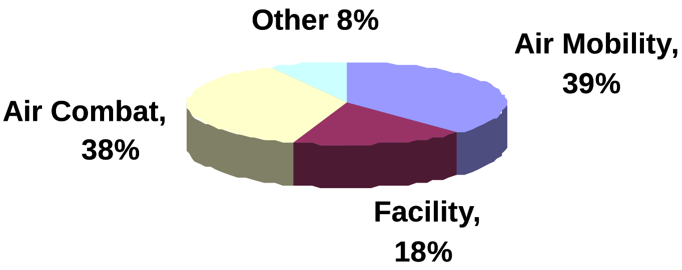
Figure A-1. DoD Mobility Fuel Use by Service



AVIATION OPERATIONS

The Air Force, the largest user of mobility fuel, spends about $5 billion on energy, with approximately 80 percent of this supporting aviation operations (Figure A-2).

Figure A-2. Air Force Energy Usage



Since September 11, 2001, the costs of energy have doubled, which has led to an energy fuel bill that exceeds $10 million a day.[1] The aviation fuel consumption rate has increased 6 percent over the last 10 years. The amount of fuel consumed over the last 3 years has decreased slightly, but this decrease has been offset by higher fuel costs. Over a 10-year period, costs per flying hour have increased a dramatic 144 percent. Total aviation fuel costs rose from about $1.8 billion in

---

[1] Mike Aimone, Assistant Deputy Chief of Staff, USAF, Logistics, Installations and Mission Support, "Air Force Energy Strategy for the 21st Century" (briefing, June 5, 2006).

1996 to about $4.8 billion in 2005.[2] The compound annual growth rate (CAGR) over this 10-year period was 9.6 percent.[3]

The Air Force has ascribed the rising costs of aviation fuel to the increased fuel consumption to support the global war on terrorism and to the fact that the standard price of aviation fuel rose substantially in FY04 and FY05. Because the military has relied on air operations to sustain and complement ground forces[4] and because the defense strategies demand increased mobility, agility, and sustainment, DoD can expect continued high energy usage and higher energy costs. This consumption and price trend clearly points to an area in which a comprehensive strategy is warranted.

GROUND VEHICLES

A study by NRAC[5] looked at petroleum usage for FY03 across the armed services. In its study, NRAC provided a profile for ground vehicles. NRAC found that 88.5 percent of Military Essential Function (MEF) ground vehicles were tactical wheeled vehicles (TMV), which included High Mobility Multi-Purpose Wheeled Vehicles (HMMWVs), medium trucks, and Logistics Vehicle Systems (LVSs). Also, the NRAC study pointed to a 2003 fuel-reduction study done by the Marine Corps. The Marine Corps concluded that its fleet of armored assault vehicles—M1 tank, Light Armored Vehicles, and Amphibious Assault Vehicles—while fuel guzzlers, consume only a minor fraction of the total MEF fuel allotment.

HMMWVs and 5-ton trucks accounted for 69.7 percent of total TMV fuel usage, and LVSs followed with 18.7 percent. The requirement for TMVs to be highly responsive and mobile and the fact that 70–75 percent of these vehicles are used off-road or on unimproved roads have made these vehicles prone to greater fuel use.

This ground vehicle consumption profile and trend may be useful for strategy development, considering the operations of insurgents in Iraq and Afghanistan and the projection that future operations may take this shape.

---

[2] See Note 1.

[3] $\text{CAGR} = (\text{FV}/\text{PV})^{1/n}-1$.

[4] Michael J. Hornitschek, Lt Col, USAF, *War Without Oil: A Catalyst for True Transformation* (Air War College, February 17, 2006), p. 20.

[5] Naval Research Advisory Committee, *Future Fuels*, April 2006.

Appendix B
Defense Strategy Themes

Recent experience indicates that the nature of the threat facing the United States is changing. Today we cannot be sure in advance the location of future conflicts, given the threat of dispersed, small-scale attacks inherent in warfare with rogue nations and insurgent forces. In addition, the U.S. military must be prepared to defend against single strikes capable of mass casualties. This complex security environment—an environment in which a wide range of conventional and unconventional attacks can come from unpredictable regions of the world and the risk of a single attack continues to be high—requires the United States not only to maintain a force that is forward and engaged on a daily steady-state basis, but also to be ready for quick surge deployments worldwide, to counter and deter a broad spectrum of potential threats.

Department-wide and service-specific strategy documents have proposed solutions to navigating in this new environment. These solutions have three general themes:

- *Theme 1.* Our forces must expand geographically and be more mobile and expeditionary so that they can be engaged in more theaters and prepared for expedient deployment anywhere in the world.
- *Theme 2.* We must make the transition from a reactive to a proactive force posture to deter enemy forces from organizing for and conducting potentially catastrophic attacks.
- *Theme 3*. We must be persistent in our presence, surveillance, assistance, and attack to defeat determined insurgents and halt the organization of new enemy forces.

This appendix describes those themes.

THEME 1: GEOGRAPHIC EXPANSION AND MOBILITY

Under the reasoning that “the United States cannot influence that which it cannot reach,” the 2005 DoD National Defense Strategy (NDS) called for a global increase in U.S. military presence. Rather than locating en masse at static operating bases, this theme represents a new global posture in which smaller, joint bases, including joint expeditionary sea bases and cooperative security locations are distributed globally and can reposition with ease in response to threats. The NDS states that such a system will enhance response to irregular, catastrophic and disruptive challenges, while simultaneously maintaining the ability to respond to traditional challenges.

This theme is reflected throughout DoD and service strategy documents. The 2006 QDR envisions ground forces that are “more modular in structure at all levels, largely self-sustaining and capable of operating both in traditional formations, as well as disaggregating into smaller autonomous units.” The 2004 National Military Strategy (NMS) states that this new environment involves “ensuring capabilities are positioned and ready to conduct strikes against time-sensitive and time-critical targets.”

The Air Force’s long-term plans call for greater coverage both globally and in outer space. Terrestrially, the Air Force’s plans are similar to those of the other services, emphasizing global mobility and the establishment of air operations from austere, cold, warm, and hot bases.[1] Additional long-term plans call for protection of the vulnerable U.S. assets located in space. The Air Force expects future space-based platforms to persist in space, which will require the refueling, repair, and relocation of assets while in orbit. The Air Force acknowledges that the transition to space-basing will require a major shift from petroleum-based fuels, suggesting that it may be able to collect or generate large quantities of energy on orbit to fuel bases.

The Navy’s strategic plan published in May 2006 similarly calls for expanded capability to counter the future threats described in the QDR.[2] It plans for an increased force size of 313 ships and a widely distributed and networked force posture to provide deterrence against transnational threats and increased persistence in surveillance for global maritime domain awareness and homeland defense. This more widely distributed force is to have expanded capability to agilely “dominate in the open ocean, littoral, coastal and internal waters, seamlessly, to influence events on the shore.” The strategy also includes the development of an expanded capability to support operations by joint forces from expeditionary sea bases to project both power and defense globally. These increased capabilities are enabled by enhanced engagement through security cooperation programs and the alignment of the shore infrastructure for force sustainment.

THEME 2: TRANSITION TO A PROACTIVE POSTURE

A theme common among the DoD and service strategy documents is the need for a more proactive and expeditionary, rather than reactive and static, military posture. The NDS remarks that, given the potentially destructive value of the weapons rogue states may yield, there now is a greater need to confront challenges

---

[1] Headquarters, U.S. Air Force/XPXC, *The U.S. Air Force Transformation Flight Plan*, 2004, pp. 42–45.

[2] M.G. Mullen, *Navy Strategic Plan in Support of Program Objective Memorandum 08,* May 2006, https://wwwa.nko.navy.mil/portal.

earlier and more comprehensively before they mature because the consequences of waiting until an attack happens are severe.

Likewise, one of the four NMS National Military Objectives is to "prevent conflict and surprise attack":

> US forces permanently based in strategically important areas, rotationally deployed forward in support of regional objectives, and temporarily deployed during contingencies convey a credible message that the United States remains committed to preventing conflict. These forces also clearly demonstrate that the United States will react forcefully should an adversary threaten the United States, its interests, allies and partners.[3]

This theme's focus on proactive rather than reactive operations has the potential to reduce military operations in the long term; however, this preventive mission also may drastically increase the range and activity of the military in the short and medium terms. For instance, a proposed effort to track terrorist networks, by using a Global Sensor Network that establishes persistent surveillance at multiple points on the globe simultaneously, implies a potentially significant increase in forces and network infrastructure. This and other new initiatives focused on preventive measures also may have the second-order effect of increasing energy consumption within DoD, particularly if conventionally powered systems are used.

THEME 3: PERSISTENCE

Because future engagements increasingly will involve stabilization of rogue states—a longer term process than traditional warfare—the ability to attack with persistence is needed. We must "ensure the global force posture and rotation support for the sustained military operations required" and we must "defend the US and its interests by conducting continuous global operations."[4]

The Strategic Planning Guidance emphasizes the need to prepare for "long duration irregular warfare." The QDR echoes this theme, stating that "long duration complex operations will be waged simultaneously in multiple countries around the world…[therefore,] maintaining a long-term, low-visibility presence in many areas of the world where US forces do not normally operate will be required."[5] This transformation to persistent global surveillance will require greater use of military capabilities and greater consumption of the fuel that powers them.

---

[3] Joint Chiefs of Staff, *The National Military Strategy of the United States: A Strategy for Today, a Vision for Tomorrow*, 2004, p. 11. Available at http://www.dtic.mil/doctrine/jel/other_pubs/nms_2004.pdf.

[4] *Global War on Terror Contingency Plan*, CONPLAN 7500 (Classified).

[5] DoD, *Quadrennial Defense Review Report*, February 6, 2005, http://www.defenselink.mil/qdr/report/Report20060203.pdf.

Appendix C
Energy Guidance

Legislation, Executive orders, policy guidance, and instructions for implementing energy conservation and efficiency programs at military installations have been key factors in the success of DoD's conservation effort. This appendix identifies key legislative and executive direction, DoD guidance, and service-specific regulations.

LEGISLATIVE AND EXECUTIVE DIRECTION

In addition to the National Energy Conservation Act of 1978 (Public Law 95-619), which was enacted by Congress in response to the energy crises of the 1970s, the following legislation and Executive orders have been key to guiding the DoD and service energy programs:

- Energy Policy Act of 1992—promulgated a comprehensive federal energy policy to facilitate end-user energy-efficiency programs and mandated a 25 percent reduction in facility energy usage by 2000.
- Public Law 109-58, Energy Policy Act of 2005—established the latest national policy on energy and a new energy baseline (2003); provided tax incentives for domestic energy production, including clean coal and nuclear; and mandated doubling the nation's use of biofuels.
- Executive Order 13123, "Greening the Government through Efficient Energy Management" (June 3, 1999)—directed consolidated agency energy reporting, extended energy and greenhouse gas reduction goals to 2010, and encouraged procurement of energy-efficient products and expanded renewable energy use. The order included a mandated energy reduction goal of 35 percent by 2010.
- Presidential Memorandum, "Energy Conservation at Federal Facilities" (May 3, 2001)—directed heads of executive departments and agencies to conserve energy use at their facilities, review their existing operating and administrative processes and conservation programs, and identify and implement ways to reduce such use.
- Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management" (January 24, 2007)—modified the annual reduction requirement specified by Public Law 109-58 to 3 percent per year or 30 percent by 2015.

- Presidential Memorandum, “Energy and Fuel Conservation by Federal Agencies” (September 2005)—directed agency heads and department heads to take appropriate actions to conserve energy use at their facilities to the maximum extent possible, thereby contributing to the Katrina relief efforts.

DOD GUIDANCE

Key DoD guidance on energy is as follows:

- DoD Directive 4140.25, “DoD Management Policy for Energy Commodities and Related Services” (April 2004)—updated the policies and responsibilities to manage energy commodities, minimize the number and complexity of fuels and maximize the use of commercial fuel, and continued the authorization to publish other energy-related guidance.
- DoD Instruction 5126.47, “Department of Defense Energy Policy Council (DEPC)” (December 1985)—established the DEPC to provide for coordinated review of DoD energy policies, issues, systems, and programs.
- DoD Instruction 4170.11, “Installation Energy Management” (November 2005)—provided procedures for DoD installation energy management and implemented DoD Directive 4140.25.
- *DoD Energy Manager’s Handbook*—issued to assist DoD installation and facility energy managers with effectively performing tasks associated with their jobs. The handbook contains basic information and references to other resources.
- OUSD Memorandum, “Installation Energy Policy Goals” (November 2005)—provided facility energy management goals consistent with current legislative requirements, Executive orders and the direction of the department.

SERVICE-SPECIFIC REGULATIONS

The following are energy-related regulations issued by the services:

- Army Regulation 11-27, “Army Energy Program (AEP)” (February 1997)—updated policies, procedures, and responsibilities for the AEP. AEP objectives are to eliminate/reduce energy waste in facilities, increase energy efficiency in new/renovated construction, reduce dependence on fossil fuels, conserve water resources, and improve energy security.
- SECNAV Instruction 4100.9A, “Department of the Navy Shore Energy Management Program” (October 2001)—dictated policy, guidance, and

responsibilities at all levels within the Navy. This instruction supplements the Department of the Navy's Energy Program Business Plan.

- Air Force Energy Program Procedural Memorandum (AFEPPM) 04-1 (November 2004)—issued as the implementation plan for the Air Force energy management program. The strategy to support energy program objectives specifically applies to installation operations, although mobility operations are mentioned. Mobility fuel energy consumption would be targeted for reduction but only when the reduction can be achieved without degrading capability.

Appendix D
DoD Energy Initiatives

DoD has undertaken several initiatives to address energy security. This appendix discusses some of them.

OSD ASSURED FUELS INITIATIVE

Stemming from growing concerns about the security and reliability of DoD's energy sources, the OSD Assured Fuels Initiative is a multi-service/agency effort, implemented through USD(AT&L), that is intended to support production of clean fuels for the military by commercial industry from secure domestic resources, while mitigating environmental effects. The initiative's key objectives are as follows:

- Form partnerships with industry, academia, and civil agencies (DOE, Department of Transportation, EPA, Department of the Interior, Department of Commerce, etc.) to encourage development and investment in energy resources
- Develop a transition plan for introducing and using alternative energy DoD-wide and a roadmap to provide fuel to the joint battle space
- Review the use of the fuels in all tactical vehicles, aircraft, and ships, and develop new specifications for fuel with non-petroleum components, for use in these vehicles.

ENERGY SECURITY IPT

The Energy Security IPT—a task force with representatives from the military services, defense agencies, USD(AT&L), USD(Policy), and U.S. Transportation Command—was formed to address growing concern for energy security.[1] Its goals are as follows:

- Address the strategic planning guidance tasking:
  - "Define an investment roadmap for lowering DoD's fossil fuel requirements and develop alternate fuels"

---

[1] Established in May 2006, the DDR&E Energy Security IPT was still operational at the time of this report. The recommendations in this report should be considered tentative: the final recommendations may differ.

    - Present “findings on the total delivered cost of fuel consumed by DoD platforms, including logistics and force protection”
    - Prepare “proposals to improve energy efficiency of DoD platforms”
    - “Develop recommendations to enable the production and use of alternate fuels, especially domestically-sourced fuels”
- Provide options to manage financial and operational challenges generated by cost and availability of oil and other forms of energy.

The IPT is specifically concerned with solutions that reduce our dependence on foreign oil, abroad and at home. The IPT divided its work into four major areas: platforms and weapons systems, future fuels, installations, and other initiatives. It developed recommendations for future work in each of these areas, putting priority on efforts that would have the greatest potential return for the least investment. The group’s overarching recommendations are to

- establish an alternative fuels task force to continue to address these issues,
- seek efforts that will increase platform efficiency, and
- work to accelerate installation initiatives.

The specific research areas supported by the IPT are

- fuel conservation for mobility platforms,
- operational efficiencies as demonstrated by commercial practices,
- facilities energy opportunities,
- domestic supply options (synfuels, algae to biomass, etc.), and
- increased efficiency of power systems.

AT&L/FT&R ENERGY CONVERSATION SERIES

The USD(AT&L) and the Deputy Assistant Secretary of Defense for Forces, Transformation and Resources have cosponsored an Energy Conversation lecture series to engage leaders across the government and other sectors in a dialogue about energy as a national security issue. Monthly, a speaker is invited to lead a conversation on an energy-related topic. Recent topics have included sustainable IT networks, conversion of waste to energy, and climate change.

DEFENSE SCIENCE BOARD TASK FORCE ON ENERGY STRATEGY

The Defense Science Board's Task Force on Energy Strategy, comprising senior DoD civilians and representatives outside DoD, was established to do the following:

- Identify DoD operational and strategic constraints and vulnerabilities created by optimizing tactical platforms and capabilities without regard to energy use.
- Identify programs and means for DoD to reduce its energy demand, particularly on petroleum-based fuels. Identify supporting infrastructure requirements.
- Identify and assess opportunities for DoD to produce energy for its own use.
- Identify synergistic opportunities for renewable and alternative energy sources common to meeting both facility/infrastructure and transportation/mobility requirements.
- Assess second- and third-order effects that may create opportunities for DoD to transition to a new energy strategy. Identify metrics and processes for determining true costs across the entire life cycle.
- Identify potential technologies to assist with the DoD transition. Assess DoD's ability to transition these technologies to achieve some level of energy independence.
- Assess the impact of the proposed strategy on force structure and the department's global posture realignment effort.
- Identify institutional and organizational barriers to this transition.[2]

Clearly, the task force, scheduled to report in 2007, faces a significant challenge. Their task—broader than that of the IPT, which did not grapple with policy—seems to be strategy and policy driven.

---

[2] Memorandum from Kenneth J. Krieg, Under Secretary of Defense, to Chairman, Defense Science Board, "Terms of Reference—Task Force on DoD Energy Strategy," May 2, 2006.

DEFENSE ENERGY SUPPORT CENTER: FISCHER-TROPSCH REQUEST FOR INFORMATION

DESC, within the Defense Logistics Agency, Logistics Operations, recently released a request for information (RFI) seeking to identify and get information from potential suppliers of synthetic aviation fuel, specifically those generated using the Fischer-Tropsch process. DoD is investigating the feasibility of delivering as much as 200 million gallons of synthetic aviation fuels—half of which is JP-8 equivalent—during 2008. The RFI also expressed an interest in the long-term manufacture and supply of increasing quantities of aviation synthetic fuels from domestic resources.

HYDROGEN RESEARCH AND DEVELOPMENT TASK FORCE

The White House Office of Science and Technology Policy established an interagency task force as an outgrowth of the President's Hydrogen Fuel Initiative. The task force's purpose is to coordinate the eight federal agencies that fund hydrogen-related R&D. The task force has the following responsibilities:

- Develop an extensive database of past, present, and potential future hydrogen activities within the federal government
- Provide agencies with guidance for the direction of their research
- Identify potential areas for interagency collaboration
- Manage the development and implementation of a 10-year interagency coordination plan.

JASON TECHNOLOGY STUDY

A recent report, *Reducing DoD Fossil-Fuel Dependence*, provided recommendations and findings regarding DoD's energy future.[3] The study pursued five major tasks, one of which was to explore technology options for reducing DoD's dependence on foreign fuels. The study also analyzed the viability of technologies to provide the performance needed by DoD platforms, an essential requirement for insertion of alternative energy options in the foreseeable future.

---

[3] P. Dimotakis, N. Lewis, R. Grober, and others, *Reducing DoD Fossil-Fuel Dependence*, JSR-060135 (McLean, VA: JASON Program Office, MITRE, 2006).

The JASON study presented the following findings, organized in overarching categories:

- *Global, domestic, and DoD fossil-fuel supplies*. DoD will have no fossil-fuel shortages in the next 25 years, assuming no major worldwide upheavals or other political changes that could change access to fossil fuels.
- *DoD fuel cost*. Fuel costs represent only 2.5 to 3 percent of the defense budget, but the JASON study suggests that DoD curb fuel use, primarily because the burden of transporting fuel adds significantly to fuel costs and, on the battlefield, can cost lives.
- *Decreasing DoD fuel use*. The greatest potential for reducing DoD fuel use is through the use of unmanned vehicles.
- *Liquid fuels from coal or natural gas*. The most favorable supply alternative for DoD is liquid fuels from stranded natural gas (a natural gas field not considered usable for economic or physical reasons). As energy prices increase, this option becomes increasingly economically viable. Underground coal gasification is the next-best alternative, but is acceptable from an environmental perspective only if the carbon dioxide is sequestered.
- *Biofuels*. Biofuels do not have much potential. If the alternatives are to be considered for DoD, the biofuels community must demonstrate sustainability through a life-cycle analysis.

The following JASON recommendations are particularly relevant to DoD energy security:

- Optimize exploitation of commercial aviation fuels
- Reengineer M1 tank, B-52 bomber, and other major materiel to exploit modern engine technology
- Leverage modern design using lightweight materials, without down-armoring
- Consider new designs in unmanned vehicles and platforms.

DARPA PETROLEUM-FREE MILITARY WORKSHOP

In 2005, DARPA convened a 3-day workshop to explore ideas for alternative energy. The workshop brought together academics, scientists, economists, and military representatives. Participants were asked to consider complete shifts in the areas of energy obsolescence, energy transfer, energy efficiency, and energy source.

Attendees generated ideas for solutions, without regard for practicality. The group concluded that no single “silver bullet” would allow the military to maintain peak operational capability while eliminating reliance on fossil fuel. Standardizing electric generation instead of using liquid fuel could increase fuel flexibility because electricity can be generated from a variety of resources. Efficiency improvements in operations, combined with those in the systems and platforms used, and more reliance on information management and discrimination could greatly reduce the need for liquid hydrocarbon fuels. Suggestions from this workshop included the following:

- Use and exploit local resources
    - Reduce the logistic burden of supporting operations
    - Exploit local energy
    - Consult with local governments
    - Secure local power generation and distribution
- Develop specialized, task-oriented systems
    - Rely more on unmanned autonomous platforms
    - Increase individual capabilities and provide personal power sources
- Develop extra-theater standoff capabilities
    - Increase telecommuting ability
    - Improve satellite systems
- Ensure universal connectivity for information flow and increase modeling and simulation
- Use a theater-wide network for timely collection and transmission of information and increase wireless telecommunications availability.

Appendix E
LMI Technology Survey

In this appendix, we provide a brief survey of technologies that may facilitate energy efficiency and renewable energy or present opportunities to improve energy security for DoD. For each technology, the discussion highlights the potential for DoD applications in each area, along with any strategic, operational, fiscal, and environmental considerations. We categorize the technology opportunities as supply-side technologies, technologies for increased efficiency, and cross-cutting technologies (batteries and power generation technologies).

SUPPLY-SIDE TECHNOLOGIES

Synthetic Fuels

Synthetic fuels are one of the most promising alternatives for DoD in the near term. Sometimes referred to as Fischer-Tropsch or FT fuels (a name based on the chemists who developed the process), they are a mixture of hydrocarbons produced in a two-step process: partial oxidation of coal or natural gas followed by reduction of the gas over a catalyst to produce straight-chain hydrocarbons. Synthetic fuel is generally designed to behave much like conventional fuel—requiring little or no change in the equipment that uses it or the infrastructure for storing and distributing it—which makes it highly desirable to DoD. Particulate emissions are also reduced because of its lack of aromatic components.[1]

Synthetic fuels present unique challenges because of their composition and must be qualified for use as a DoD fuel. Vehicles and platforms run on conventional fuels, so developers need to ensure compatibility with current fuel system designs. SASOL in South Africa has been producing a blend containing the necessary aromatics to ensure system design performance. In September 2006, DoD successfully tested a 50-50 blend of synthetic and conventional fuel in a B-52 bomber. The Air Force testing program will determine whether using mixtures with conventional oil blend stocks has any deleterious effects.

Synthetic fuels also present environmental considerations due to the production process. Without carbon sequestration, a coal-to-liquid process produces twice as much CO_2 as petroleum-based fuel for the equivalent mechanical power delivered. SASOL is reported to be the largest CO_2 producer in Africa and possibly the world. Although carbon capture and sequestration is an option, it may increase

---

[1] NREL, “Gas-to-Liquid Fuels,” *Nonpetroleum Based Fuels*, http://www.nrel.gov/vehiclesandfuels/npbf/gas_liquid.html, October 2006.

production costs by 25 to 40 percent and introduces its own set of technical uncertainties.[2]

Another challenge of synthetic fuels is cost and availability. The base cost of this fuel is up to 10 times that of conventional fuel.[3] Because of the high capital cost associated with synthetic fuel technology, few domestic companies can guarantee production of the large quantities DoD needs without a long-term contract or other commitment. As synthetic blends are increasingly used, the cost will likely fall. A recent Scully Capital report indicates that a 30,000 barrel per day plant could produce FT fuel at about $70 per barrel (plus or minus 30 percent), depending on investment assumptions and long-term delivery contracts.[4]

DESC recently issued a request for information (RFI) on industry's capability to supply 200 million gallons of synthetic jet fuel (100 million of JP-8 for the Air Force and 100 million of JP-5 for the Navy), which resulted in 28 responses. All responders proposed using either a gas- or coal-to-liquid method to create the fuel—offering no renewable source methods. Furthermore, the comments received from the RFI revealed that the industry needs longer-term contracts and some type of pricing floor or guarantees to allow recovery of their large capitalization costs. These elements may require legislative action, which DoD is preparing and discussing.

Today, viable large-scale synthetic fuels are derived from nonrenewable sources, but that is likely to change. In Germany, Shell Oil has partnered with Choren Industries to produce a biomass-derived synthetic fuel, and DaimlerChrysler and Volkswagen are supporting the technology for their diesel vehicles because no modifications are required.[5]

Biofuels

In 2004, biomass provided 2.85 quadrillion Btu of energy to the United States, making it the leading source of renewable energy in the nation for 4 consecutive years. In 2002, DOE's Energy Information Administration compiled a report detailing the uses of different renewable fuels throughout the country and found that biomass was the source of 47 percent of all renewable energy produced in the United States. Industry dominates biomass energy use.

---

[2] P. Dimotakis, N. Lewis, R. Grober, and others, *Reducing DoD Fossil-Fuel Dependence*, JSR-060135 (McLean, VA: JASON Program Office, MITRE, 2006), pp. 55–58.

[3] Alex Kaplun, "Energy Policy: DoD Research Can't Drive Alternative Energy Market, Officials Say," *Environment and Energy Daily*, September 2006.

[4] David Berg, Brian Oakley, and Andy Paterson, "The Business Case for Coal Gasification with Co-Production" (briefing for DoD's Energy Security IPT, Washington, DC, December 19, 2006).

[5] CHOREN Industries, "Shell Partners with CHOREN in the World's First Commercial SunFuel Development," http://www.choren.com/en/choren/information_press/press_releases/?nid=55.

Biofuels are considered to be net carbon-neutral, meaning they do not contribute to increasing the greenhouse gases in the atmosphere because the carbon dioxide released is recaptured as the next crop is grown. Biofuels show promise, due in large part to the diversity of options in this category.

ETHANOL AND BIODIESEL

Residues from paper mills and other wood-derived sources are the largest sources of biomass fuel, though production and use of ethanol and biodiesel from agricultural crops are increasing sharply. Ethanol and biodiesel have the potential to reduce petroleum consumption and toxic emissions. Ethanol can be blended with or substituted for gasoline, and biodiesel can be blended with or substituted for diesel fuel. These biofuels differ from gasoline and diesel because they contain oxygen, and although that decreases their intrinsic energy value, they combust more completely than the aromatic-containing, petroleum-based gasoline and diesel, reducing emissions.

Two biofuels in current use are B20 and E85.[6] These fuels will help DoD installations reach their 2005 Environmental Protection Act requirements for using alternative energy sources. All services are implementing either biodiesel or E85 in some of their installation vehicles. The Navy has a goal of increasing the use of alternative-fueled vehicles through the use of E85, biodiesel, and community electric.

In early 2006, ethanol made from corn grain displaced more than 2 percent of the gasoline in the United States. With advances in technology, cellulosic ethanol (produced from the stalk and other waste portions of the plant) is expected to offer greater efficiency and the potential to displace even more fossil fuel use.

Using crops for energy may displace their use for food, possibly causing a sharp rise in food prices. The crops needed to produce biodiesel and ethanol require substantial amounts of land. For example, 14 percent of U.S. corn production was required to produce the 2 percent gasoline displacement noted above.[7] Other concerns are the merits and challenges of using cellulosic ethanol because of its potential impact on the soil quality. Corn stover (the stalks) is routinely plowed back into the soil to replenish nutrients. Using the entire plant in fuel production would divert stover from soil replenishment, which may deplete future productivity of the land.

Current biofuels are not a suitable replacement for jet fuels. According to the National Renewable Energy Laboratory (NREL), ethanol does not have the energy density to serve as jet fuel, and biodiesel, though containing an energy density that is 90 percent that of the present jet fuel, solidifies at the low temperatures that

---

[6] NREL, "Gas-to-Liquid Fuels," *Nonpetroleum Based Fuels,* http://www.nrel.gov/vehiclesandfuels/npbf/gas_liquid.html, October 2006.

[7] See Note 2.

exist at high altitudes.[8] Therefore, other options, which satisfy the two requirements (energy density and low solidification point), must be considered for bio-based jet fuel.

BIOBUTANOL

Another biofuel that has not received much press but represents a valuable energy source is biobutanol, which is developed in a process similar to that of ethanol, but uses a bacteria rather than yeast to produce energy via a sugar fermentation process. In the United Kingdom, a DuPont–British Petroleum (BP) joint effort is focused on biobutanol development, as well as smaller ventures in the United States.

Biobutanol has higher energy content than ethanol, making its miles-per-gallon performance more similar to that of gasoline. Once developed, biobutanol can be used as a substitute for, or in conjunction with, ethanol in conventional gasoline blends. Another advantage is the reduced miscibility with gaskets and seals, which reduces corrosivity, allowing it to be used without modification to gas tanks and making it transportable via existing pipelines.

DuPont–BP researchers expect the first line of biobutanol, which will be generated using current technology, to be available by 2007; a second line—using newer, higher conversion technology—is aimed at commercial sale in 2010. Although this technology shows promise as a short-term, supply-side source of fuel, its impact on DoD would be minor. Like any non-petroleum-based fuel, its use is limited to installation use for nontactical vehicles running on conventional gasoline.

MICROALGAE

As stated previously, present jet engine technology does not allow the use of biodiesel or ethanol in place of jet fuel. One alternative that has the potential for use in planes is the fatty oil components found in microalgae. Harvesting algae for production as a fuel is an exciting technology. The oils in microalgae can be processed to make a fuel similar to JP-8 (Figure E-1).

---

[8] NREL, *Jet Fuel from Microalgal Lipids*, July 2006.

Figure E-1. Raceway Pond System in Israel Growing Microalgae

Courtesy of NREL.

NREL has researched microalgae for two decades, cataloging over 300 species.[9] In 1996—when diesel was less than 60 cents per gallon—NREL discontinued its Aquatic Species Program,[10] but is now working to reestablish it because the cost of fuel has grown and the technology has more economic potential.

DoD should continue to pay attention to this technology. NREL believes that this type of fuel could become price competitive as early as 2010.[11] But others suggest that it is a much longer-term technology, citing several major hurdles, including the landmass and water, fertilization, harvesting, and processing requirements.

DARPA BIOFUELS PROGRAM

The DARPA Biofuels Program recently arrived on the alternative fuels scene. This program seeks an affordable bio-based alternative to petroleum-derived JP-8. DARPA recently issued broad agency announcement (BAA) 06-43 for R&D efforts to develop a process that "efficiently produces a surrogate for petroleum based military jet fuel (JP-8) from oil-rich crops produced by either agriculture or aquaculture (including but not limited to plants, algae, fungi, and bacteria) and which ultimately can be an affordable alternative to petroleum-derived JP-8."[12] The primary objective of the BAA is a cost-efficient oil-to-JP-8 conversion process combined with biofuel characteristics that allow for direct substitution as an aviation fuel. If DARPA succeeds in this effort, this technology could have a substantial impact on longer-term DoD strategies.

---

[9] Olivier Danielo, "An Algae-Based Fuel," *Biofuture*, May 2005.

[10] NREL, *A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae Close-Out Report*, http://www.eere.energy.gov/biomass/pdfs/biodiesel_from_algae.pdf.

[11] NREL, "Field Test Laboratory Building," *NREL Facilities*, October 2006.

[12] FedBizOpps, "BAA06-03 BioFuels," July 5, 2006.

Hydrogen

DoD is working to develop supply-side technologies associated with the introduction of hydrogen as a fuel. Working collaboratively with other federal agencies and industry, an ad hoc group has been investigating the challenges of production, storage, and distribution. The objective is to poise DoD as an early adopter and principal demonstrator of the technology where it contributes to the mission of the department. DoD, as an energy consumer, would provide demand and help close gaps as the technology continues to advance.

The Department of Transportation (DOT), DOE, DoD, and many transportation and safety-related federal agencies participate in an interagency working group that promotes the consideration and advancement of hydrogen- and fuel-cell-related research. The DOT Hydrogen Working Group created a road map to detail the hydrogen-related initiatives in the member organizations and provide an outreach tool for other federal and civil organizations, Congress, and members of the public interested in hydrogen-based technologies. The document’s primary purpose is to describe DOT activities and discuss the infrastructure and planning necessary to establish a national hydrogen-based transportation system. It details several initiatives related to hydrogen-based transportation, some of which hold significant potential for DoD application.

Medium and heavy-duty vehicle hydrogen technology is one of the road map’s central focuses. In fact, the research DOT has done supports the idea that these larger vehicles will be the first to effectively utilize hydrogen fuel technology, possibly laying the groundwork for the transition of lightweight vehicles and infrastructure to a hydrogen-based economy. DOT is focusing in particular on the application of hydrogen technology to public buses and water-going vessels, including shuttles, ferries, and deepwater passenger and freight vessels. On maritime vessels, hydrogen use potentially applies to propulsion and onboard electrical generation.

Hydrogen technology can be more easily implemented in medium- and heavyweight vehicles than in small private vehicles for several reasons, most of which could apply to military vehicles. Vehicles that can be refueled at central locations, such as buses and defense vehicles, can be served by hydrogen fuel without a hydrogen fuel infrastructure already in place. Furthermore, these heavier vehicles, both in the civilian and military sectors, are operated by trained professionals, who will be more able to adapt to the introduction of hydrogen technology. The Federal Transit Administration is researching and developing a heavy-duty fuel cell bus, an automotive-based fuel cell hybrid bus, and a hydrogen internal combustion engine hybrid bus.

Implementation of hydrogen-based fuel technology in medium- and heavy-duty vehicles is likely a long-term proposition, though initial deployment could begin as early as 2010 to 2015.

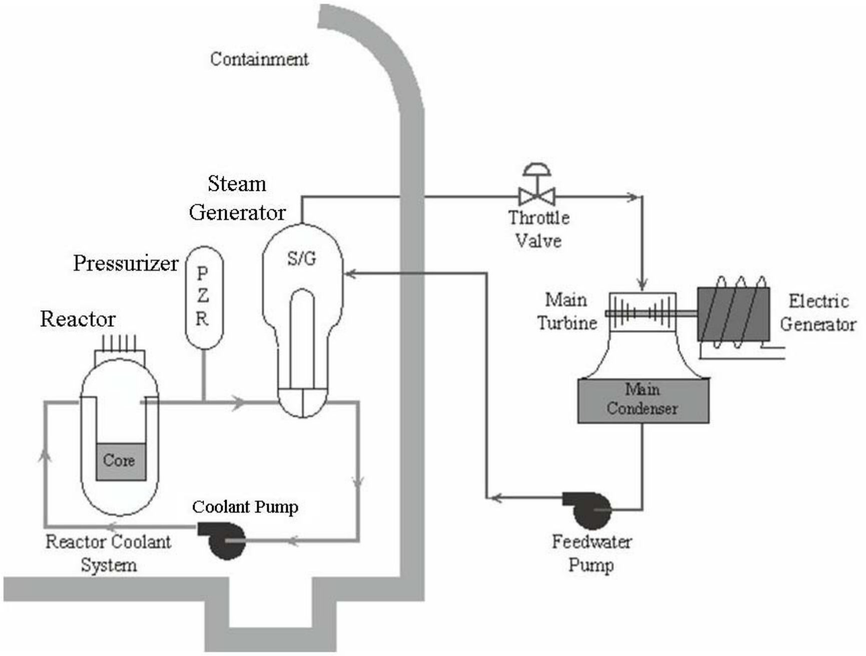
Nuclear Power

TECHNOLOGY OVERVIEW AND CURRENT TRENDS

Currently, 104 licensed power reactors in the United States are producing approximately 20 percent of the nation’s electricity supply. The U.S. Navy also maintains 10 commissioned nuclear-powered aircraft carriers and more than 60 nuclear-powered submarines. Nuclear power plants utilize the controlled fission reaction of a radioactive fuel to produce heat, which can in turn be used for electricity generation, propulsion, or powering other chemical processes that require a heat source. Nuclear power plants can generate tremendous amounts of energy from relatively compact fuel sources—usually enriched uranium and plutonium—with limited pollution or greenhouse gas emissions from the actual operation of the reactor and associated power plant. However, nuclear power plants carry other significant risks, including the safe production, storage, and disposal of radioactive fuels; control of the heat and radiation produced during reactor operation; and the threat of nuclear proliferation if highly enriched nuclear fuels (which may be used to produce nuclear weapons) fall into the hands of terrorists or enemy states. These safety and proliferation concerns limit the ability to employ nuclear power in most tactical military applications.

Power reactors (those used to generate power for commercial use) are usually classified by the type of coolant used to remove heat from the reactor and moderate (control the level of) the nuclear chain reaction. All operational U.S. reactors utilize either pressurized or boiling water as the cooling mechanism. In the most popular design, the pressurized water reactor, pressurized coolant is circulated through the reactor plant and is then used to produce steam for power generation or propulsion (see Figure E-2). The predominance of this design in the United States can be traced to the Navy’s decision to select this reactor design for submarines in the late 1940s.

Figure E-2. Typical Pressurized Water Reactor Plant



Source: Nuclear Regulatory Commission.

Other reactor designs have been employed more widely outside the United States. The Canadian CANDU reactor design uses heavy water (whose molecules contain deuterium instead of hydrogen). Several nations, including the United Kingdom, have employed high- and low-temperature gas-cooled reactors. Japan, France, and the former Soviet Union developed fast-breeder reactors, cooled with liquid sodium, which use uranium fuel but produce additional uranium and plutonium fuels as a byproduct.[13] However, breeder reactors also present significant risks for weapons proliferation because the fuel produced is suitable for nuclear weapons use. The former Soviet Union also developed a class of graphite-moderated and water-cooled breeder reactors, including the one involved in the Chernobyl accident.

Reactor plant protection and containment systems have been considerable improved in recent decades, but most traditional reactor designs are still not inherently safe. Rather, they require some form of active protection system to cool the reactor and prevent it from meltdown even after the critical reaction stops. These inherent safety concerns, highlighted by the accidents at Three Mile Island and Chernobyl, have led to a considerable worldwide backlash against nuclear power. Following Three Mile Island and Chernobyl, nuclear plant construction has been severely curtailed in most other countries, either through outright moratoriums or increasing regulatory and political obstacles that limit the financial viability of new power plant construction. The last successfully completed nuclear power

---

[13] International Atomic Energy Agency, “Advanced Reactors Fact Sheet,” 1999, http://www.iaea.org/Publications/Factsheets/English/advrea.html.

plant order in the United States was placed in 1974. Most recent power plant construction has occurred either in Asia or in the former Soviet Union. According to the International Atomic Energy Agency, only 13 countries—Argentina, Bulgaria, China (including Taiwan), Finland, India, Iran, Japan, Korea, Pakistan, Romania, Russia, Taiwan and the Ukraine—were planning new reactor construction.[14] Nuclear power continues to constitute a significant source of power in the United States, but electricity generation capacity has generally been maintained by extending the life of existing plants and increasing their power ratings.

Despite the dearth of new plant construction, increasing concern over greenhouse gas emissions, coupled with rising cost of petroleum fuels, has led to a renewed interest in civilian nuclear power in the past decade. The 2001 National Energy Policy called for increasing nuclear power generation capacity to enhance energy supply diversity and reliability.[15] In 2002, the Department of Energy instituted the Nuclear Power 2010 program, a public-private partnership to promote new power plant development in the United States.[16] The program has focused on a number of advanced light water power plant designs with the potential for future commercialization.

One of the most promising new reactor designs outside the United States is the Pebble Bed Modular Reactor (PBMR), which uses a helium coolant and is classified as a high-temperature gas-cooled reactor. A distinctive feature of the PBMR is the inherent safety of the fuel design. Unlike traditional reactors, the PBMR fuel is contained in thousands of small pellets that are dispersed inside the reactor vessel and cannot melt down in the event of a loss of reactor coolant. The PBMR has a relatively low power rating (165 kW), but is designed for modular operation with multiple units operating in parallel. The high operating temperature also provides the potential for its use in extracting hydrogen from fossil fuels or generating synthetic fuels, applications that may be of interest to the military. The PBMR is being developed by the South African Pebble Bed Modular Reactor Company, PBMR (Pty) Ltd. The company plans to begin construction on a prototype reactor in 2007, with commercialization anticipated in 2013.[17]

TRADITIONAL MILITARY APPLICATIONS

All three services experimented with nuclear reactor designs for propulsion and power generation following World War II, but only the Navy continues to build power reactors. The Army Corps of Engineers operated a nuclear power program from 1952 to 1979, producing portable reactors for power in remote areas, including Sundance, WY; Camp Century, Greenland; and McMurdo Sound in

---

[14] International Atomic Energy Commission. “Nuclear Reactor Information System,” 2006, http://www.iaea.org/programmes/a2/index.html.

[15] National Energy Policy Development Group, *National Energy Policy*, 2001, http://www.whitehouse.gov/energy/National-Energy-Policy.pdf.

[16] DOE Office of Nuclear Energy, “Nuclear Power 2010 Fact Sheet,” 2006, http://np2010.ne.doe.gov/np2010.pdf.

[17] See https://www.pbmr.com/.

Antarctica. The Army also developed plans in the 1960s for a military compact reactor that would be used as part of a portable energy depot to produce synthetic fuels for the battlefield, but later abandoned this design due to concerns about cost-effectiveness and the uncertainty of developing enabling technologies.[18] The Air Force also experimented with nuclear power for aircrafts and satellites, but has largely abandoned those efforts.

The cost, size, manpower requirements, and safety considerations of nuclear power have largely relegated its use by the U.S. military only to situations in which it provides a unique benefit or attribute. Nuclear power provides the ability for ships to transit long distances at high speed and stay on station indefinitely without refueling, and it provides the unique benefit of high-speed air-independent propulsion for submarines.[19] The ready availability of seawater for reactor cooling and shielding also simplifies naval nuclear power plant design.

In addition, successful nuclear power plant operation requires a cadre of skilled operators and the development of an organizational culture that emphasizes safety and reliability. The Navy maintains a rigorous nuclear power training program and has created these “high-reliability organizations” aboard its ships, but it would be difficult to replicate this environment for land-based reactor plants in an operational environment.[20]

POTENTIAL NEW MILITARY APPLICATIONS

The Air Force Research Lab recently examined the feasibility of nuclear-powered unmanned aerial vehicles (UAVs) using a quantum nuclear reactor that releases power from a radioactive source (hafnium 178) using x-rays.[21] This design could be inherently safer than a conventional fission reactor, because hafnium 178 is much less radioactive than other nuclear fuels and because the nuclear reaction would subside quickly if the x-ray source were removed. However, the potential would remain for long-lived radioactive contamination if the UAV were to crash.

The most promising new military applications for nuclear power might come about in conjunction with the employment of alternative fuels, such as hydrogen or FT fuels, which require high temperatures to produce. In a 2001 article in *Army Logistician* magazine, Robert Pfeffer from the Army Nuclear and Chemical Agency and William Macon Jr. from the Nuclear Regulatory Commission advocated the renewed development of the Army’s remote “energy depot” designs from the 1960s, using a high-temperature PBMR to produce hydrogen as a fuel

---

[18] Robert A. Pfeffer and William A. Macon Jr., “Nuclear Power: An Option for the Army’s Future,” *Army Logistician*, Sept–Oct 2001, http://www.almc.army.mil/alog/issues/SepOct01/MS684.htm.

[19] Other air-independent power sources have emerged in the last decade, but they do not provide enough power for high-speed, long-endurance operations.

[20] Robert Pool, *Beyond Engineering* (Oxford: Oxford University Press, 1997), pp. 249–278.

[21] Duncan Graham-Rowe, “Nuclear-Powered Drone Aircraft on Drawing Board,” *New Scientist*, February 19, 2003, http://www.newscientist.com/article.ns?id=dn3406.

and potable water.[22] Northrop Grumman Corporation has proposed a demonstration initiative for land or sea-based synthetic fuel production based on using a nuclear reactor to provide the thermal energy and hydrogen for the FT process.[23] One advantage of this method of FT production is that it uses less carbon-based fuel and produces less CO_2 than a conventional FT plant. Although these efforts would require a significant new investment, DoD could leverage existing nuclear power R&D efforts by the Navy and DOE's Nuclear Power 2010 program.

Geothermal Energy

Geothermal energy provides a viable alternative energy supply, but only for installations located near a geothermal source. The Navy, in particular, has major efforts in geothermal energy and established a plant at the Naval Air Weapons Station, China Lake, CA (Figure E-3) as a step in its effort to convert Navy shore facilities to alternate energy.[24]

Figure E-3. Geothermal Plant at China Lake

Courtesy of Naval Air Warfare Center Weapons Division, Technology Transfer website.

The Navy indicates that geothermal energy reduced the Navy's electricity bill by $24.2 million. In 1993, it saved $4.2 million, which equates to a 33.3 percent reduction in electrical energy cost.

---

[22] See Note 18.

[23] William Laz, Douglas Law, and Charles Smith, *Assured Fuel Initiative* (briefing, Northrop Grumman Corporation, July 2006).

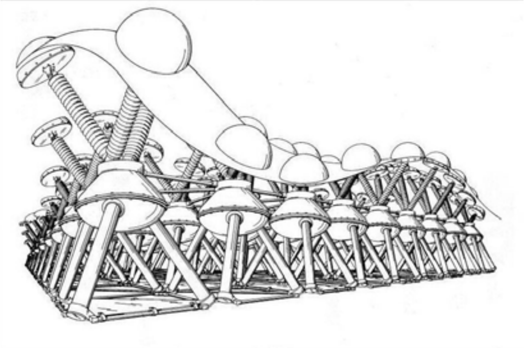
[24] NAWCWD Technology Transfer website, https://www2.nawcwd.navy.mil/techTrans/index.cfm?map=local.ccms.view.aB&doc=home.1), August 2006.

The limiting factor of this technology is that it is location specific, although efforts are in progress to expand the range of suitable locations. This inhibits geothermal energy's ability to displacing petroleum, especially in the tactical environment, but will help increase DoD's renewable portfolio.

Ocean Energy Harvesting

Similar to geothermal, this technology could be useful in specific locations, especially in support of military sea-basing efforts. This technology is not widely used, but several innovative companies are working on it, and it has potential for DoD in contributing to the renewable energy portfolio in stationary power. The Ocean Wave Energy Company (OWEC), working under a Coast Guard small business innovation research contract, completed bench-top trials with full-size components in 2000. Figure E-4 shows the OWEC module array.[25]

Figure E-4. OWEC Module Array



DARPA is working on a project in surface wave energy harvesting as well. The program objective is to "develop and demonstrate a hierarchy of wave and motion energy harvesters to enable long endurance tactical missions and test and evaluation programs." The program has successfully demonstrated a wave-powered autonomous buoy.

NREL has also been evaluating ocean thermal energy conversion (OTEC), which converts solar radiation to electric power by using the ocean's natural thermal gradient to generate electricity. As long as the temperature between the warm surface water and the cold deep water differs by about 20°C (36°F), the OTEC system can produce a significant amount of power.[26] The Office of Naval Research is currently developing an OTEC facility to provide power to Diego Garcia in the Indian Ocean. This local application, which might also be effective for a future sea base, also falls under our category of a cross-cutting technology.

---

[25] Ocean Wave Energy Company, http://www.owec.com/index.html, September 2006.

[26] NREL, "What Is Ocean Thermal Energy Conversion?" *Ocean Thermal Energy Conversion*, http://www.nrel.gov/otec/what.html, October 2006.

TECHNOLOGIES FOR INCREASED EFFICIENCY

Engines and Turbines

Improvements in engines—for both ground and aviation use—are an important demand-side opportunity for reducing energy consumption. Corresponding reductions in pollutants and greenhouse gases result from these fuel efficiency gains, but additional engine technology improvements may also address the environmental impact of engine operation. Because these engines are used in tactical applications, efficiency improvements could help conserve fuel where it is most expensive and places the largest burden on the DoD logistics system.

AIRCRAFT

Improved airplane jet engine efficiency is of interest not only to DoD, but also to the civil aviation sector, which has felt the impact of rapid increases in fuel prices. DoD has established the Versatile Affordable Advanced Turbine Engine program as a multi-service R&D effort involving turbine engine technologies to provide improved fuel efficiency and the ability to use alternative fuels in DoD aircraft.

Incremental improvements in jet engine technology and aircraft construction have already led to a 34 percent increase in average aircraft fuel efficiency between 1973 and 2002. Further advances are possible by increasing engine bypass ratios (achieving more airflow into the turbine for the amount of fan power expended) and increasing turbine air pressure ratios.[27]

One area of engineering improvement is the efficiency of the intake fan that pulls air into the turbine for combustion. Pratt and Whitney is developing a geared turbofan engine, which features a gearbox between the fan and shaft to allow for the use of a larger, slower moving, and more efficient fan. The company is hoping to introduce this engine into the Boeing 757, for which it projects a 12 percent reduction in fuel consumption over current engine technologies, with corresponding reductions in noise and environmental impact. Engine maker Rolls Royce is seeking a similar reduction in fan speed and increase in fuel efficiency via a three-stage intake fan.[28]

Even if more fuel-efficient aircraft engines are available, the high up-front cost of replacing or retrofitting legacy aircraft with new engines tends to slow the diffusion of this technology. A 2003 Defense Science Board study concluded that the cost of retrofitting the B-52 would be made up by the fuel savings during the remaining lifetime of the aircraft, but the Air Force has yet to go forward with the

---

[27] Aeronautics and Space Engineering Board, *For Greener Skies: Reducing Environmental Impacts of Aviation*, 2002, http://books.nap.edu/catalog/10353.html.

[28] Dominic Gates, “Pratt Hoping to Power the 737’s Replacement,” *Seattle Times*, August 10, 2006.

retrofit due to the estimated cost of over $3 billion.[29] Similar legacy fleet considerations have also slowed the adoption of new, more fuel-efficient aircraft models by the commercial sector.

GROUND VEHICLES

The Department of Energy has promoted improvements in automobile engine efficiency under the Advanced Combustion Engine research program, part of the FreedomCAR and Vehicle Technologies office. According to DOE, "specific goals are to improve, by 2012, the efficiency of internal combustion engines for (1) light-duty applications from 30 percent to 45 percent and (2) for heavy-duty applications from 40 percent to 55 percent—while meeting cost, durability, and emissions constraints."[30] Near-term engineering improvements to conventional engines include the implementation of continuously variable transmissions, variable valve timing, auto shut-off and start-up when the vehicle is stopped, and idling a number of engine cylinders when not needed. These enhancements have already been incorporated into a number of production vehicles, with the auto shut-off and start-up feature used in all hybrid-electric models. In the longer term, DOE advocates advanced internal combustion engines that are capable of low-temperature combustion modes that can provide greater fuel efficiency under certain engine-loading conditions, as well as turbochargers, thermoelectrics, and other technologies to recapture waste heat.

Most medium- and heavy-duty applications already employ diesel (vs. gasoline) engines due to their superior fuel efficiency and durability, although they emit higher levels of pollutants and particulate matter. Improvements to engine emission controls and combustion regimes would also allow diesels to compete in the light car and truck market, where they could achieve fuel efficiencies on par with hybrid gasoline-electric vehicles. Particulate traps, lean nitrous oxide traps, and catalytic reduction are promising technologies, but must be improved to avoid sacrificing fuel efficiency gains for emissions reduction.[31]

In addition to improvements in internal engine combustion characteristics, DOE has also focused simultaneously on exhaust after-treatment technologies and fuel formulation. Flex-fuel vehicles (already offered by domestic automakers) can operate on either gasoline or E-85 (a combination of 15 percent gasoline and 85 percent ethanol), while diesel engines are being built to operate on low-sulfur diesel fuel. Flex-fuel vehicles might provide DoD with the option of using alternative fuels where they are available without requiring the adoption of a new logistics fuel infrastructure for tactical applications.

---

[29] Amory Lovins and others, *Winning the Oil Endgame* (Snowmass, CO: Rocky Mountain Institute, 2004).

[30] Department of Energy, *Advanced Combustion Engines*, http://www1.eere.energy.gov/vehiclesandfuels/technologies/engines/index.html, accessed February 8, 2007.

[31] Department of Energy, *Progress Report for Advanced Combustion Technologies*, 2005, http://www1.eere.energy.gov/vehiclesandfuels/pdfs/adv_engine_2005/2005_advanced_engine.pdf.

Like aircraft engines, the up-front cost of replacing engines in legacy vehicles is also an obstacle to improving fuel efficiency. The Army considered replacing the 1960s vintage AGT 1500 turbine engines on the Abrams Tank—with an estimated fuel efficiency of less than 1 mile per gallon—with more efficient diesel engines, but it abandoned the effort in favor of refurbishing existing turbines due to the anticipated cost of the development effort.[32]

Hybrid Vehicles

Hybrid-electric ground vehicles have a traditional internal combustion engine and an electric motor (powered by rechargeable batteries or ultracapacitors) that recharges during vehicle operations. With improved fuel efficiency, hybrid vehicles could also contribute to a reduced logistics tail and related fuel costs. They can provide an operational advantage through reduced noise and thermal signatures. However, DoD tactical land-based vehicles usually maneuver over the terrain that requires high engine power, which reduces fuel savings.[33] Thus, military nontactical vehicles may be a more realistic in the short term.

Hybrid-electric land-based vehicles have other uses, to fulfill “silent watch” and other stationary power needs, but the increased weight of batteries needed to support lengthy stationary missions may offset any fuel savings.[34] Further refinement of battery storage capacity and other aspects of this technology is needed before DoD can realize substantial vehicle fuel savings in the tactical sphere. The savings analysis becomes more complex if hybrid-electric vehicles are used to supplement or replace mobile electric power sources. A detailed analysis in this area may show a savings in aggregate force fuel requirements even if individual vehicle savings are not achieved.[35]

Unmanned Vehicles

Unmanned aerial and land-based vehicles offer substantial fuel savings through weight reductions stemming from their smaller overall size and removal of armor and other human support systems.[36] Both guided (remote-controlled) and autonomous land-based vehicles can be made lighter, more fuel efficient, and operationally more effective than their manned counterparts, in addition to utilizing composite and lightweight materials, as discussed previously. In addition, the removal of the pilot reduces not only the associated aircraft weight but also the fuel-intensive infrastructure required to train and maintain pilot proficiency, resulting

---

[32] Steven Komarow, “Military’s Fuel Costs Spur Look at Gas-Guzzlers,” *USA Today*, March 8, 2006.

[33] Ocean Wave Energy Company, http://www.owec.com/index.html, September 2006.

[34] See Note 2.

[35] Dr. Michael E. Canes, *Estimated Costs of Projecting Electric Power onto a Battlefield* (briefing, NDIA 30th Environmental and Energy Symposium, April 8, 2004).

[36] Ocean Wave Energy Company, http://www.owec.com/index.html, September 2006.

in additional energy savings—a classic example of the multiplier effect. DoD is actively pursuing unmanned aerial and land-based vehicles.

Among unmanned vehicles, UAVs are the most mature.[37] Integrated into operations in missions traditionally flown by manned aircraft, their lighter weight can bring substantial fuel savings.[38] For example, Sensorcraft aircraft being designed by the Air Force Research Lab could save as much as 97 percent of the fuel used by three manned systems it could replace: Joint Surveillance and Target Attack Radar System, Airborne Warning and Control System, and rivet joint surveillance aircraft.[39] Although this example may be the extreme case, it shows that unmanned aerial and land-based vehicles hold much promise for reduced fuel consumption and consequent cost savings for DoD.

Lightweight Metals and Composites

Using nontraditional materials for land-based vehicles and the fuselage of aircraft can reduce weight and thus conserve fuel. Two broad categories of materials being used are lightweight metals and composites.[40] Lightweight metals include aluminum, titanium, and metal alloys. Composite materials, such as carbon fiber reinforced plastics, are made of two or more substances that are used together without blending or homogenizing, so that the appealing characteristics of both are maintained.[41] The manufacture of composites has been automated, and prices are lower than when they were first introduced.

Composites have been used for some time in military aircraft to reduce their weight and improve characteristics of the aircraft body. They are now being used extensively in commercial aircraft as well; Boeing and Airbus are launching new models (787 Dreamliner, A350, and A380) that will use composites more extensively.[42] For land-based vehicles, such as Humvees and tanks, vehicle weight is also important with regard to fuel use. Decreasing the weight of the structural components (frame) of vehicles like these can lower fuel use.[43] This must, however, be accomplished without increasing vulnerability to enemy fire. If achievable, the main benefit from a fuel perspective is that land-based vehicles and aircraft built with composites weigh less than traditional vehicles and aircraft, thus conserving fuel; extending range, persistence, and operational effectiveness; and reducing emissions. This option is viable for reducing fuel use in the near and far terms, and can continue as new fuels are developed.

---

[37] See Note 2.

[38] See Note 2.

[39] See Note 2.

[40] Stanley Holmes, "A Plastic Dream Machine," *Business Week*, Issue 3938, 2005, p. 32.

[41] Jim Lorincz, "Composites Fly Lighter, Stronger," *Manufacturing Engineering*, Volume 136, Issue 3, 2006, p. AT1.

[42] Valerie Browning, "DARPA's Energy Related Programs" (presentation, May 31, 2006).

[43] See Note 2.

More-Electric Architecture

More-electric architecture (MEA) is a concept for building the components of an aircraft in a way that maximizes efficiency.[44] It involves synchronizing and balancing energy use and production within the aircraft, including redesigning the traditional engine to produce thrust and electric power, while the power needs of the pneumatic, hydraulic, and other mechanical systems are met by smaller electric engines.[45] The technical design of an MEA is already in use, with components designed by Honeywell.[46]

An important aspect of the MEA concept is that it can be applied to any aircraft, military or commercial. Its main benefits are environmental and fiscal, because the integration of systems can reduce fuel use, which reduces emissions and overall cost. However, implementing MEA on existing aircraft involves investment up front, with the benefits of reduced cost coming in the long term. MEA is of possible use to DoD to conserve fuel in the near term, but implementing MEA will not move DoD much closer to its strategic goals of energy independence or a petroleum-free existence. In the long term, this concept could be applied to other types of vehicles.

Aerodynamic Design

Aerodynamic design can be used to achieve reductions in fuel use through more reduced turbulence in air flow. Boeing's wing-tip program (Figure E-5) is an example. By changing the shape of aircraft wingtips, Boeing can reduce fuel use and emissions, as well as noise. Boeing's data suggest that winglets used on the 737-800 aircraft could reduce fuel use by 2 to 3 percent.[47] The Energy IPT has analyzed the adoption of this design aspect for long-haul tactical and nontactical aircraft and found that it could bring 6 percent fuel savings, or $1,000 per flight.[48]

---

[44] Robert Wall, "Better Buzz," *Aviation Week & Space Technology*, Volume 164, Issue 19, 2006, p. 52.

[45] "The 'More Electric' Architecture Revolution," *Military Technology*, Volume 29, Issue 10, p. 60.

[46] Steven Komarow, "Military's Fuel Costs Spur Look at Gas-Guzzlers," *USA Today*, March 8, 2006.

[47] M.M. Goetz, "Commercial Aviation—Noise and Emissions Developments" (presentation at the ICAO-ACI/LAC Seminar on Bird Hazards, Environmental Protection and Land Use at Airports for the NAM/CAR/SAM Regions, Miami, FL, April 24–27, 2000).

[48] DoD Energy Security IPT, "Energy Options" (briefing, SSG, September 13, 2006).

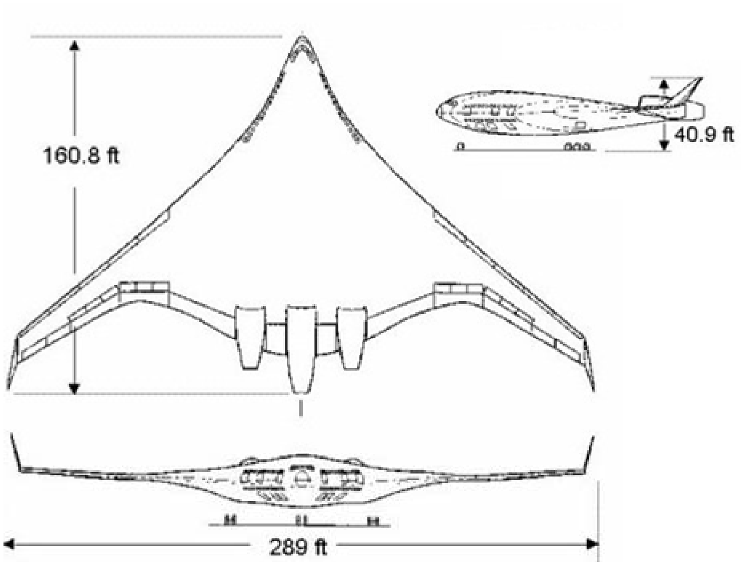
Figure E-5. Boeing Wing-Tip

Source: DoD Energy Security IPT, “Energy Options” (briefing, SSG, September 13, 2006).

Blended-Wing Aircraft

In a long-term aerodynamic effort, Boeing, the Air Force, and NASA are testing the blended-wing body (BWB) concept at NASA’s Langley Research Center in Hampton, VA. The Air Force has named the aircraft the X-48B, and the project team began testing an 8.5 percent-scale prototype in April 2006.[49] Figure E-6 shows a drawing of the aircraft.

Figure E-6. Blended-Wing Body Design



Source: Al Bowers (presentation at “The Wing Is The Thing” meeting, September 16, 2000).

---

[49] U.S. Fed News Service, “Team Uses Historic NASA Tunnel to Test Blended Wing Body,” Washington, DC, 2006.

The Air Force is evaluating the BWB as a multirole, long-range military aircraft. Boeing reports that the BWB could be ready for military use in 10 to 15 years.[50] A BWB can carry the same weight of cargo and twice as many people as a Boeing 747, but will use less fuel. The BWB is estimated to be 20 to 30 percent more fuel efficient than a conventional aircraft of similar size carrying the same amount of fuel.[51] BWB benefits also include a reduced environmental impact through lower emissions due to reduced fuel consumption to carry the same weight. However, depending on size, the BWB design has a larger wing span for the same cargo weight capacity and may require investment in airport infrastructure as well as the aircraft.

Information Technology and Information Management Systems

Information technology and information management (IT/IM) systems can serve as enablers for energy efficiency, aiding both in the design of energy efficiency technology and in managing operations more energy efficiently. Collectively, IT/IM refers to systems, technologies, or methods for collecting and disseminating information. Examples are data acquisition and control systems, communications technologies, databases, knowledge management systems, and the Internet. These systems can be used both to reduce energy consumption with existing technologies and to enable the employment of newer energy efficiency technologies that require control and interoperability between component technologies. IT/IM systems can be used to help optimize operational processes to minimize fuel consumption. Examples are automatic control of industrial processes and computerized scheduling of transportation and logistical operations. In addition, IT/IM systems may cut down on the need for energy use by accomplishing tasks through virtual rather than physical interaction.

AUTOMATED CONTROL SYSTEMS

Automated control systems save energy by systematically monitoring and adjusting equipment so that it operates efficiently. Most new “intelligent” commercial buildings employ some type of automated sensor and control systems for lighting, heating, cooling, and other applications that involve energy usage over time. In a daylight harvesting system, sensors monitor the level of daylight entering a building and reduce the level of artificial lighting to maintain a desired level of brightness. These systems vary in sophistication from basic systems that turn lighting banks on and off to systems that enable continuous variable monitoring. Wal-Mart reported a 2-year payback from installation of continuously variable daylight harvesting systems, which resulted in energy savings of approximately $100,000 per store.[52] In addition to intelligent controls of individual processes, these

---

[50] “Air Force Studies Blended Wings,” *Machine Design*, Volume 78, Issue 12, 2006, p. 30.

[51] See Note 50 and Al Bowers (presentation at The Wing Is The Thing meeting, September 16, 2000).

[52] Charles Zimmerman, Wal-Mart Vice President (presentation at EnergyConversation.org meeting, January 16, 2007).

systems have the potential for even greater gains when they are interoperable. For example, motion and light sensors to detect building occupancy can provide inputs to automated systems for both lighting and heating, ventilating, and air conditioning.[53] In addition to installing daylight harvesting and other automated systems in its stores, Wal-Mart also controls these systems centrally, making it easier to fine-tune performance.[54] The American Society of Heating, Refrigerating and Air-Conditioning Engineers publishes comprehensive energy efficiency and intelligent control standards for both commercial and residential buildings.

Automakers have also implemented intelligent control systems to reduce unnecessary fuel consumption. Many vehicles now employ monitoring systems that sense the demand for power and can reduce the number of engine cylinders in operation when full engine capacity is not required. Other energy-saving techniques, such as shutting down the engine at stoplights and shifting between two- and four-wheel drive, also depend on automated monitoring and control systems. Hybrid electric vehicles, which provide improved fuel efficiency over internal combustion engines, require sophisticated control systems to manage the distribution of power between the gasoline engine, electric motor, and storage battery. Trucks are able to reduce energy lost due to idling through the integration of auxiliary power units that allow for continued use of heating, cooling and loading/unloading equipment without running the engine.[55]

These IT/IM system principles also have potential for energy saving in tactical DoD applications. Most ships, airplanes, and ground vehicles already incorporate extensive monitoring and control systems that capture performance data. This includes the Navy’s “smart ship” technologies, a suite of seven control and monitoring systems that include the Integrated Bridge System, Integrated Condition Assessment System, the Damage Control System, the Machinery Control System, the Fuel Control System, a fiber optic local area network, and the Wireless Internal Communication System.[56] The Army’s future combat system is also being designed as a “system of systems” that will allow interoperability and communications between a wide variety of ground vehicles, UAVs, and individual soldiers. Although not designed specifically to manage fuel economy, these systems provide the interoperability and data collection capability that could provide real-time data and feedback on energy consumption to allow for more efficient operation.

---

[53] Abigal Gray, “How Smart Are Intelligent Buildings,” *Building Operation Management,* September 2006, pp. 61–65.

[54] Charles Zimmerman, Wal-Mart Vice President (presentation at EnergyConversation.org meeting, January 16, 2007).

[55] U.S. EPA SmartWay Transport Partnership, “Fleet Strategies,” 2004, http://www.epa.gov/otaq/smartway/smartway_fleets_strategies.htm.

[56] Scott Freedner, John Imbesi, and Leslie Spalding, *Smart Ship Installations in Full Swing* (David Taylor Research Center, 2000), http://www.dt.navy.mil/pao/excerpts%20pages/2000/smartship_Nov.html.

IMPROVED SCHEDULING AND LOGISTICS

In addition to facilitating energy efficiency of individual buildings, systems, or vehicles at the tactical level, IT/IM technologies can also reduce energy consumption by optimizing routing, scheduling, and logistics. For vehicles, energy consumption is largely proportional to the time operated or miles driven, so any routing changes to minimize the amount of mile traveled will reduce the overall amount of fuel consumed. The trucking and airline industries have both employed IT/IM systems in this manner. Automated logistics systems for the freight industry optimize routing and match loads with available trucks to reduce back-hauling empty trucks.[57] These systems include computerized routing and scheduling software integrated with GPS tracking systems and wireless Internet connections on individual trucks. Systems allow for centralized control by trucking companies but can also allow drivers to update their availability and request real-time updates. Web-based wireless information systems can also provide drivers with real-time information on fuel prices, allowing them to make informed decisions about fuel purchases.[58]

The aviation industry is also exploring how improvements in air traffic management (ATM) can be used to reduce fuel consumption of individual aircraft by allowing more efficient management of aircraft routes, horizontal and vertical spacing of aircraft, and landing and takeoff timing. The FAA and the European Commission both have programs in place to improve ATM; the FAA is creating the Next Generation Air Transport System, while the European Commission is heading the Single European Sky Air Traffic Management Research program.[59]

The move toward the next generation of ATM primarily applies to commercial flight, but the same concepts could be applied to military aircraft. The benefits are reduced fuel use and emissions, and possible cost savings due to the retiring of costly older technologies used to manage aircraft.[60] DoD compatibility with new ATM systems may also be required to ensure that military aircraft have full access to commercial airspace. Without this access, military aircraft could be forced to avoid congested airspace and use longer (and therefore less fuel efficient) flight routes.[61]

---

[57] U.S. EPA SmartWay Transport Partnership, “Improved Freight Logistics,” 2004, http://www.epa.gov/otaq/smartway/documents/loadmatching.pdf.

[58] See Note 29.

[59] U.S. Fed News Service, “U.S./Europe Seek Seamless, More Efficient Air Traffic Management,” Washington, DC, 2006.

[60] David Hughes, “Global ATM Vision,” *Aviation Week & Space Technology*, Volume 162, Issue 22, 2005, p. 42.

[61] Global Security.org, “KC-135R Stratotanker,” http://www.globalsecurity.org/military/systems/aircraft/kc-135r-pacer-crag.htm.

INFORMATION CAPTURE FOR FUTURE IMPROVEMENTS

IT/IM systems can also be used to collect and process information on long-term usage and energy consumption patterns for feedback into future designs or operating procedures. Even if current systems are designed with energy efficiency in mind, empirical operating data may point out unanticipated problems or opportunities for further improvement. Empirical data are also important in highlighting changes in energy-consumption profiles due to unanticipated missions or operating environments. DoD vehicles and systems are designed to provide optimal performance in an anticipated operating scenarios, and changes in operating patterns may have a significant effect on fuel consumption. This is particularly true in Iraq, where equipment has been used continuously in a combat environment. Humvees and other military vehicles have been modified with additional armor, which increases the weight and changes vehicle performance characteristics. A recent JASON study noted the lack of comprehensive Army data on vehicle mix, number of vehicle hours used per day, idling rate, fuel consumption, and other routine statistics. A GPS-based vehicle-monitoring system, equivalent to the commercially available "On-Star" system installed on GM cars, could help collect such information.[62]

DoD can also use empirical data to recommend best operating practices for existing technology, in the form of lessons learned or revised operating procedures. The Navy established a Shipboard Energy Conservation Team to train personnel on reducing energy consumption during normal operations, and it uses annual energy conservation awards as a means of raising awareness of energy-saving practices.[63]

VIRTUAL TRAINING

Simulation software and communication systems can reduce energy consumption in a different way, by accomplishing tasks virtually that would otherwise have required energy expenditures for travel or system operation. DoD has used flight and battle simulators for decades, but recent advances in computer processing and networking allow for much more sophisticated scenarios and real-time interaction between participants in different locations. The Navy employs the AN/USQ-T46 Battle Force Tactical Trainer, an interactive system installed on ships that can run coordinated training scenarios at the ship or task-force level.[64] The Army is also developing Embedded Live-Virtual-Constructive (L-V-C) Multi-mode Training

---

[62] See Note 2.

[63] DoD Federal Energy Management Program, "U.S. Department of Defense Navy Shipboard Energy Conservation Team—'Outstanding Performance'," Washington, DC, 2002, http://www.eere.energy.gov/femp/newsevents/fempfocus_article.cfm/news_id=7241.

[64] George Dunn, "Battle Force Tactical Trainer Operator Course Reaches Fleet," Navy Center for Surface Combat Systems Public Affairs, October 15, 2004, http://www.news.navy.mil/search/display.asp?story_id=15553.

for its Future Combat System.[65] Although the main purpose of these systems is to provide a realistic training environment for sailors and soldiers, virtual training has the added benefit of reduced fuel expenditures for training operations.

Aircraft flight simulators can reduce the requirement for airborne training time. The Air Force Air Mobility Command has invented $1.4 billion in new and upgraded flight simulators, with an expected reduction in aircraft flight hours by more than 270,000 over 6.5 years.[66]

Low-Power Computing

The introduction of new computer processing capabilities into DoD applications has led to a significant growth in demand for onboard computer power in many portable systems. These increasing power requirements are of particular concern for soldier-portable systems, which often rely on primary or secondary batteries as their main power source. The Board on Army Science and Technology at the National Academy of Sciences identified the projected growth in computing power requirements as a concern in a 2004 study on meeting the power needs of future land warrior systems.[67] According to the study, the Army has generally developed computing requirements to meet combat effectiveness, without giving sufficient consideration to power consumption. As a result, electronic suites for land warrior systems currently in development are projected to require 20 watts average and 60 watts at peak power. This suite, coupled with sufficient batteries for a 72-hour mission, would increase a soldier’s load by 30 pounds. In addition to soldier systems, increasing computer power requirements are also a concern for satellites, UAVs, and other applications where the weight of the power supply may significantly impact platform performance.

In addition to improvements in supply-side power production technologies, the study recommended incorporating energy efficient or “low-power” computing technologies to reduce soldier system weight and power by a factor of ten. System-on-Chip (SoC) technologies can reduce power consumption by placing all system components—central processor, memory, and peripheral electronics—on a single integrated circuit. The commercial sector has employed SoC designs widely in the production of many portable electronic devices, including cell phones, WLAN and Bluetooth components.[68] The study also recommends the use of low-power interconnect technology, such as wireless networking, in place of standard USB and Ethernet connections.

---

[65] Future Combat System Program Manager, *FCS Whitepaper*, April 11, 2006, http://www.army.mil/fcs/whitepaper/FCSWhitepaper(11_Apr_06).pdf.

[66] Air Mobility Command Public Affairs, “AMC Reduces Costs Through Fuel Efficiency,” *Air Force Link*, http://www.af.mil/news/story.asp?id=123031427.

[67] Committee of Soldier Power/Energy Systems, National Research Council, *Meeting the Energy Needs of Future Warriors*, September 2004, http://books.nap.edu/catalog/11065.html.

[68] “SoC: System on Chip,” http://www.networkdictionary.com/hardware/soc.php.

Within DoD, the DARPA program for Power Aware Computing and Communication is developing new technologies for computer power management under the concept of just-in-time power, which seeks to improve energy efficiency across many aspects of computer systems via lower power computing algorithms, efficient compilers, and improved power management both at the system and mission levels.[69] Using a "novel integrated software/hardware technology suite incorporating innovative individual power reduction technologies," the program goals include achieving power reductions of a factor of 100 to 1,000 times in future imbedded computer systems. In 2002, DARPA contributed $2 million toward IBM's Low Power Computing Center, a research facility founded to develop more efficient and reliable high-end computer systems. BAE Systems was expected to develop prototype military applications from the resulting research. [70]

CROSS-CUTTING TECHNOLOGIES

Local Electricity Generation: Solar, Wind, and Hybrids

Photovoltaic systems make use of the abundant energy available from the sun, which is converted directly into electricity or stored (in capacitors or batteries). By harnessing energy without emitting carbon dioxide, these technologies reduce the impact on the environment. For military operations, their total reliance on liquid hydrocarbon fuel to generate electricity reduces dependence on foreign fossil fuel and lessens fuel logistics requirements because electricity is harnessed directly in the field. Electricity generation uses only a small fraction of the overall fuel allotment in the military, so—even if solar cells are used to provide all field electrical requirements—their contribution to decreasing fossil fuel use will be small.

DOE research in applications for photovoltaics includes pumping water, providing lighting, activating switches, charging batteries, supplying power to the utility grid, and others. Many of these applications have potential use for military purposes, especially where electricity is required, fuel is scarce, or fuel logistics are complex. DoD has a number of solar energy projects in the demonstration phase. The Navy currently has two of the largest federal U.S. photovoltaic projects. The ECIP will fund four new projects in FY07.

Because solar energy can be converted directly to electricity, this technology will likely have the greatest impact for DoD in small, isolated applications as a cross-cutting power technology—one that provides local power and reduces fuel supply demand. Solar panels could greatly contribute to supporting operations in desert regions of the world (Iraq, Afghanistan, Kuwait, etc.) and to economizing the operation of diesel-powered generators. Solar energy offers silent energy

---

[69] "DARPA Power Aware Computing and Communication (PAC/C) Program," http://www.darpa.mil/ipto/Programs/pacc/challenges.htm.

[70] Stacy Cowely, "IBM, DARPA Team on Low-Power Computing," *Computer World*, http://computerworld.com/action/article.do?command=printArticleBasic&articleId=73289.

production, which could substantially reduce the noise signature of our contingency operation locations and may increase the well-being of soldiers, who are also affected by noise.

Communications from the battlefield also confirm an interest in the use of solar energy in-theater. In July 2006, Maj. Gen. Richard Zilmer, the highest-ranking Marine Corps officer in Iraq's Anbar Province, characterized the development of solar and wind power capabilities as a "joint urgent operational need." General Zilmer cited reductions in often dangerous fuel transportation activities as the main motivation for this request: "By reducing the need for [petroleum-based fuels] at our outlying bases, we can decrease the frequency of logistics convoys on the road, thereby reducing the danger to our Marines, soldiers, and sailors."[71] The request calls for 183 renewable energy systems to be used on bases and outposts.

General Zilmer's request is believed to be the first formal request for use of alternative energies from a frontline commander, and the first that acknowledges the security advantages of alternative energy sources. In response, the Army plans to mobilize its Rapid Equipping Force to develop and test renewable energy systems in Iraq and Afghanistan in 2007, and it has released a BAA soliciting concepts for power generation that will reduce the amount of fuel shipped to bases and posts in-theater.

An alternative approach for military operations, especially in remote locations, is the use of hybrid power systems, which combine several electricity storage and production elements to meet the electric energy demands of a remote facility without relying on continuous liquid fuel logistics support. Other sources of energy, such as windmills, can be added to the system to meet the needs of tenants. Flexible combinations of solar and wind systems could be a "silent watch" alternative to the noisy generator for remote military operations. The combination lessens the risk to military operations by increasing the flexibility of the energy source.

Solar technology faces two primary challenges: the cost of the solar cells and efficiency. Highly efficient solar cells (more than 20 percent efficient) are available, but the cost of producing the silicon wafers can be prohibitive. Low-efficiency solar cells (of a couple of percent) are cheap, but a larger surface area is needed to achieve the amount of power needed to run a system. DARPA has funded a consortium, led by the University of Delaware, to develop very-high-efficiency solar cells.[72] The consortium is developing and demonstrating 50 percent efficient solar modules for charging tactical electronic devices.[73] This effort could have significant implications for operations by providing a solution for reducing the large logistics burden of battery management.

---

[71] Rati Bishnoi, "Renewable Energy Systems Wanted in Iraq," *InsideDefense.com NewsStand*, August 11, 2006.

[72] Press Release, "Defense Department Funds $53 Million Solar Program. Renewable Energy Access," http://www.renewableenergyaccess.com/rea/news/story?id=38812.

[73] See Note 42.

Photovoltaic systems could potentially see substantially reduced costs in the future as a result of thin-film technologies. Thin-film modules, which are material layers 1 µm thick, have reduced costs associated with energy, materials, handling, and capital. Thin-film technologies are not yet sufficiently developed to consider implementation in the next 10 years, but the modules hold significant potential for use in uniforms, tents, and other materials.

Other solar options, such as space solar, hold long-term possibilities, but the technology to beam the energy from a remote solar space station is many decades off.

Waste-to-Energy Conversion

Converting waste generated on the battlefield is a new opportunity to provide electricity to operational forces. DARPA is working on the Mobile Integrated Sustainable Energy Recovery program and teaming with the Natick Soldier Center's waste-to-energy program to develop a high-efficiency conversion system for use by field kitchens not only to eliminate their waste stream, but to become completely self-sufficient in the energy required to provide soldiers with three sanitary hot meals.

In its simplest form, waste-to-energy technology already exists. Many municipalities generate some of their electricity through combustion of trash. The goal for DoD is to use trash to generate energy in a clean, efficient manner. PyroGenesis has installed and operated its Plasma Resource Recovery System in both a Navy ship and a Carnival cruise ship.[74]

A more difficult challenge for DARPA and DoD is to develop the capability to reliably produce a liquid fuel (or alternatively, a gaseous fuel for bifuel generators) from waste. Most likely to emerge in the very far term, this fuel could greatly benefit DoD in contingency environments. Changing World Technologies has demonstrated that turkey offal, instead of being land fill, could be converted into an oil product suitable for fuel applications using a thermal conversion process. The Director, Defense Research and Engineering, is assessing this approach for installation applications.

Numerous companies have been reevaluating traditional pyrolysis methods that thermally crack waste biomass, producing three products: heat, gaseous fuel, and liquid oxygenated fuel. The heat is used to sustain the process, the gaseous fuel is sent to a generator to produce electricity, and the liquid oxygenated fuel can be deoxygenated and reformed using standard petroleum refinery processes to produce high-energy-density liquid fuel. The economic assessment of this latter technology indicates that the cost feasibility is reasonable compared with other alternative fuel approaches.

---

[74] "Innovative Plasma Waste Treatment on Carnival Cruise Ship," *The Naval Architect*, May 2004.

Fuel Cells

Fuel cell technology offers promise to DoD as a method for increasing the efficiency of fuel use and providing silent operations. Fuel cells combine hydrogen and oxygen (or some other combination of fuel and oxidant containing these two elements) in an electrochemical reaction, producing power in the form of electricity with water and heat as byproducts. Today’s fuel cells commonly use hydrogen, methanol, or butane as a fuel to generate electricity. Because fuel cells produce power electrochemically, they are not subject to the efficiency constraints of the internal combustion process and generally are more efficient (25 to 50 percent) than internal combustion engines. However, the cost of producing and delivering the hydrogen fuel must be factored in for an understanding of the true economics of the process.

The primary challenge preventing near-term insertion of fuel cell technology into operations is the need to reform JP-8 fuel to generate the hydrogen necessary to run the fuel cell. Adding reformers to fuel cells increases weight and volume, adds an additional thermal signature, and decreases overall system efficiency. A key challenge is the requirement to strip the sulfur from the gas stream: JP-8 is a sulfur-rich fuel, and sulfur poisons fuel cells. Sulfur removal adds another level of complexity to any potential operational use of present fuel cells.

Forklifts offer an excellent demonstration opportunity for fuel cell technologies that could eventually apply to other vehicles. Fuel-cell-powered forklifts offer higher productivity because they can be refueled quickly, as opposed to the lengthy recharging times of very heavy lead-acid batteries currently in use. Another major benefit is that the performance of the forklift will not be affected until the battery runs out completely.[75] The Defense Logistics Agency (DLA) is preparing a BAA for demonstration projects incorporating fuel cell forklift and associated hydrogen infrastructure at several of its sites.

Small fuel-cell-powered batteries in the 20-watt range may be viable in the medium term, reducing the burden of batteries on soldiers. Use of fuel cells by special operations that have access to butane in parts of the world in which they operate could save a great deal of weight. Also, fuel-cell-powered UAVs have great potential for longer distance and stealth operations if lightweight fuel cell systems can be developed.

Fuel cells also have the potential to improve the efficiency of shipboard power generation and to reduce ships’ thermal signatures through distributed power generation. The Office of Naval Research (ONR) funded several demonstration projects of megawatt-range, JP-8 reforming fuel cells for use as a ship service fuel cell. Shipboard fuel cell systems are intended to work in conjunction with gas turbine systems as part of a distributed power generation These included a 500 kW

---

[75] Steve Medwin, “Application of Fuel Cells to Fork Lift Trucks,” *Industrial Vehicle Magazine*, October 2005.

fuel processor to produce hydrogen directly for use in a low-temperature polymer electrolyte fuel cell (the most common fuel cell technology on the commercial market) and a 625 kW high-temperature molten carbonate fuel cell system.[76] ONR successfully demonstrated both systems in 2004 and awarded a contract to FuelCell Energy, Inc., in 2006 for follow-on development work.[77]

Generators

Generators require an external fuel supply and can produce power (generally AC electricity) continuously as long as fuel is provided. Generators are limited by the availability of fuel, as well as the inability to reduce weight and size for smaller applications. Even the smallest gasoline and diesel generators are too heavy for soldiers to carry in a tactical environment; they require a vehicle or platform for transport and fuel storage.

Internal combustion (IC) generators powered by gasoline or diesel fuel are still used for larger applications that demand continuous power, including mobile generators, industrial use, and shipboard service power. Generators are also used to recharge secondary batteries, so the two technologies are inherently linked for battlefield use. IC generator technology is fairly mature, particularly in the 1–5 kW range offered by commercial generators from Honda and Mechron. However, incremental improvements can help increase efficiency (currently less than 20 percent for most commercial generators) and reduce footprint and acoustic signature.[78]

The Army's Program Manager for Mobile Electric Power (PM-MEP), which oversees the development and standardization of DoD mobile generator technology, developed the first generations of military standard generators in the 0.5–750 kW starting in the late 1960s. These legacy generators are still used for the majority of the Army's power needs, and many generators in the field have been in operation for more than 25 years. In the late 1980s, PM-MEP introduced a second generation of generators, the Tactical Quiet Generator Sets, which are single-fuel (diesel/JP-8) compliant and feature lower acoustic and thermal signatures, improved reliability, and lower operating costs over the previous generation. These generator sets have been in operation since the early 1990s, and cover the 0.5–920 kW range. However, these new generators have only gradually replaced the approximately 90,000 first-generation generators that the Army procured in the 1960s through the 1980s. PM-MEP has also jointly developed auxiliary power units in the 5–10 kW range for mobile shelters and armored vehicles.[79] These units can be instrumental in improving operational fuel efficiency by enabling

---

[76] Donald Hoffman, Edward House, and Anthony Nickens, "U.S. Navy Shipboard Fuel Cell Program" (ONR briefing for American Society of Naval Engineers, July 2003).

[77] "Fuel Cell Energy Receives $2.5 Million Contract from the Office of Naval Research," *Fuel Cell Today,* August 16, 2006.

[78] See Note 67.

[79] "Auxiliary Power Units," http://www.pm-mep.army.mil/technicaldata/apu.htm.

tanks and armored vehicles to avoid operating on their main engines simply to provide power for communications, crew comfort, and portable electronics equipment.[80]

The largest gap in generator technology is for smaller power applications below the 1 kW range, for which IC generators cannot be easily scaled down. The smallest standard generator set is the 2 kW Military Tactical Generator, which was developed by the Canadian armed forces and adopted by the U.S. Army in 1996.[81] Despite its low power rating, the generator still weighs approximately 150 pounds, making it impractical for use by individual soldiers to recharge batteries or operate portable electronics. Alternative technologies, such as fuel cells, sterling engines, or micro turbines show promise in meeting power requirements in this range and bridging the gap between batteries and conventional generators.[82] DARPA has also conducted a research program on highly efficient, small-scale generators that run on tactical fuels. The Steam Engine Electric Generator program is developing a 2 kW generator with target efficiencies of more than 1 percent and power densities of 60 W/kg, which would make it considerably lighter and more efficient than current designs. As noted above, use of hybrid-electric tactical vehicles, with the ability to provide off-board power, may also be useful in supporting small power applications.

Batteries

Batteries store energy electrochemically and release it over time in the form of DC voltage, providing current to electric devices until the battery charge is expended. Batteries are limited by the amount of energy that can be stored for a given size and weight (the energy density) and the amount of peak power available (the power density). They are typically used for low-power, soldier-portable applications and small unmanned vehicles. Batteries are not inherently an energy efficiency technology or alternative energy technology, because they must still be charged by some fuel source, but they are often categorized as such because they can be used to store electricity generated from other alternative fuel sources such as wind turbines and solar cells. Batteries are also integral to hybrid electric vehicle systems, which increase fuel efficiency by using batteries to store energy that is recaptured from the braking process via regenerative braking systems. Thus, improvements in battery technology are important to DoD energy conservation and alternative fuel efforts.

One of the most urgent DoD needs is for storage batteries to provide power for propulsion, communications, sensors, and computers to portable warfighter applications and unmanned vehicles. According to a 2004 study by the Army Science and Technology Board, electronic suites for land warrior systems currently in

---

[80] “PM-MEP History,” http://www.pm-mep.army.mil/orginfo/backgnd.htm.

[81] “2kW Military Tactical Generator (MTG),” http://www.pm-mep.army.mil/technicaldata/2kw.htm.

[82] See Note 67.

development are projected to require 20 watts average and 60 watts at peak power. This suite, coupled with sufficient batteries for a 72-hour mission, would increase a soldier's load by 30 pounds.[83] In addition to the weight requirements for the individual soldier or system platform, the demand for batteries also places a large strain on the DoD logistics network due to the quantity and variety of batteries required. The lack of battery standardization among military applications requires DLA to stock more than 4,000 different power-related items. Although demand-side reductions in power consumption can help reduce power requirements of these systems over the long term, better battery and power-generation technologies are important to reduce the weight and logistical burden of existing systems.

Battery technologies are generally grouped into three categories:

- *Primary batteries*—one-time use or disposable batteries that cannot be recharged.
- *Secondary batteries*—rechargeable batteries that may be recharged multiple times by a reverse electrical current to allow for reuse.
- *Reserve batteries*—batteries designed for a single use but that require high reliability and a long shelf life for applications. These are typically employed in single-use applications such as missiles, guided munitions, torpedoes, and emergency devices.

DLA recently completed a DoD Power Sources Technology Roadmap Workshop, the first step in the creation of a strategic plan to address military power requirements.[84] One common issue identified for all three battery types is the difficulty of maintaining a consistent industrial base for producing military batteries due to the unpredictability in demand and the proliferation of battery specifications for different applications. Standardization of batteries for many applications would address this issue and allow DoD to better influence the commercial market, rather than remain a niche player. The workshop report also outlined technical trends and issues associated with each type of battery technology.

PRIMARY BATTERIES

Primary batteries are used extensively in current DoD operations because of their high power density and high reliability. However, they must be continuously restocked, and soldiers must carry enough batteries to ensure power throughout the possible duration of the mission (even if the probable duration is much shorter). Due to the environmental impact of battery materials, disposable batteries may also have to be retained during operations for proper disposal. Legacy battery systems include alkaline (commonly used in the consumer sector), mercury oxide,

---

[83] See Note 67.

[84] *DoD Technology Roadmap for Power Sources: Part A, Workshop Data*, November 24, 2006.

carbon zinc, and lithium sulfur. Current state-of-practice technologies include lithium sulfate ($LiSO_2$) and lithium magnesium oxide ($LiMnO_2$), as well as zinc air. These technologies offer improved power densities, shelf lives, and temperature ranges than previous chemistries, but a 2006 DLA study concluded that no single chemistry meets all requirements and recommended continued research into improving primary battery performance. DLA also recommends the development and employment of better state-of-charge sensors in primary batteries, to help warfighters avoid replacing batteries before their useful charge is depleted. DLA estimates that 30 percent of all batteries are returned to depots with 80 percent charge remaining.

SECONDARY BATTERIES

Secondary batteries are available in place of primary batteries for many applications—from portable power to submarine propulsion—but are often limited by lower energy and power densities than primary batteries of equivalent power ratings. DoD uses secondary batteries in place of primary batteries in many training operations that are short enough not to require recharging. However, primary batteries are used in combat operations because they provide a longer charge life and are less expensive to stock (although they can be reused if they are not destroyed or disposed of during the mission).

Secondary battery chemistries include lead acid (used in car batteries), nickel-cadmium, nickel-iron, nickel-zinc, and nickel metal hydride. The most promising secondary battery technologies are currently in the lithium family, including metal, air, oxide, and solid state chemistries. Lithium oxide batteries are used in most portable electronic applications such as cell phones, cameras, and notebook computers. Lithium batteries offer higher energy densities and lower self-discharge than other chemistries, but suffer from safety issues such as the risk of fire and explosion. DLA has concluded that like primary batteries, no secondary battery chemistry meets all current requirements and recommended improvements in battery chemistry and power management.

Despite the shortfalls of secondary batteries, the Army's Program Executive Office for the Future Combat System anticipates shifting from primary to secondary batteries for most operations in the next 5 years due to industrial base surge and cost considerations. The most likely continued users of primary batteries will be the highly mobile Marines and Special Operations forces, who are often unable to count on access to electricity for recharging secondary batteries during their missions.[85]

---

[85] Assertion made by PEO FCS during the development of *DoD Technology Roadmap for Power Sources*.

RESERVE BATTERIES

Reserve batteries are generally classified as either thermal batteries, lithium ambient batteries, or silver-based batteries, with lithium based (either thermal or ambient) being the most common. In most cases, one element of the battery (such as the electrolyte) is kept separate from the other components to prevent discharge and provide an extended shelf-life. According to DLA, the military services are developing improved technologies, but the limited market for these batteries in both the military and commercial sectors has hampered innovation.

Appendix F

Energy Technology Assessment Workshop

On January 24, 2007, LMI hosted an energy technology assessment workshop. During this session, subject matter experts (SMEs) in the energy field assessed the energy technologies we had identified based on their potential applicability and utility to DoD platforms and future operations. The intent of this session was to develop sufficient information to narrow the range of alternatives to a set of options appropriate for quantitative analysis to support a focused investment strategy. As part of their contribution, five SMEs attending the workshop ranked the technologies based on whether DoD should pursue fielding of the technology as a high, medium, or low priority for investment. The results of this exercise, displayed in Table F-1, indicate that demand-reduction technologies should be given priority over supply-side technologies. Of the supply-side technologies, solar, improvements to batteries, waste-to-energy conversion, and fuel cells were given the highest priority.

Table F-1. LMI Workshop Energy Investment Rankings
(From January 24, 2007, Energy Technology Assessment Workshop)

Technology	Count	Priority Score (L*1, M*2, H*3)					No Response	Mean Score
	High		Medium		Low			
Bulk energy for direct or indirect liquid fuel replacement								
Solar	3	9	0	0	1	1	1	2.5
Hydrogen	2	6	1	2	1	1	1	2.3
Synthetic fuels	2	6	1	2	2	2	0	2.0
Bio-based fuels	2	6	1	2	2	2	0	2.0
Geothermal	0	0	3	6	1	1	1	1.8
Ocean wave	1	3	1	2	3	3	0	1.6
Nuclear	1	3	0	0	3	3	1	1.5
MEAN bulk energy for direct or indirect liquid fuel replacement								1.9
Local energy supply -- fuel distribution avoidance								
Solar	3	9	2	4	0	0	0	2.6
Improved batteries	4	12	0	0	1	1	0	2.6
Waste-to-energy	2	6	2	4	0	0	1	2.5
Fuel cells	3	9	0	0	1	1	1	2.5
Nuclear	1	3	0	0	2	2	2	1.7
In-theater syn or bio fuel production	0	0	1	2	2	2	2	1.3
MEAN local energy supply -- fuel distribution avoidance								2.2
Demand reduction -- fuel distribution avoidance								
Unmanned vehicles	5	15	0	0	0	0	0	3.0
Lightweight metals and composites	5	15	0	0	0	0	0	3.0
Virtual training/simulators	5	15	0	0	0	0	0	3.0
More efficient design: Aerodynamic design	4	12	0	0	0	0	1	3.0
Engine development	3	9	1	2	0	0	1	2.8
Improved IT/IM	2	6	1	2	0	0	2	2.7
More efficient design: Blended wing aircraft	3	9	0	0	1	1	1	2.5
Hybrid technologies	3	9	1	2	1	1	0	2.4
More-electric architecture (MOE)	0	0	2	4	1	1	2	1.7
MEAN demand reduction -- fuel distribution avoidance								2.7
					STDEV	0.5	MEAN	2.3

Appendix G
Energy Savings Estimates for Mobility Operations

In this report, we suggest that DoD establish the goal of adopting, for its mobility operations, the energy efficiency requirements for federal facilities outlined in Executive Order (EO) 13423 ("Strengthening Federal Environmental, Energy, and Transportation Management," enacted January 24, 2007). EO 13423 requires federal agencies to achieve a 3 percent reduction per year through FY15, or a 30 percent total reduction by the end of FY15, in their federal facility energy usage based on an FY03 baseline. EO 13423 provides a useful marker by which to approximate similar reductions in energy consumption in the deployed setting. This appendix provides a rough estimate of the savings that may result from its implementation for DoD mobility operations.

DATA SOURCES

For our analysis, we used data on current DoD mobility energy usage from *Department of Defense Annual Energy Management Report, Fiscal Year 2006* (AEM report).[1] This report is available for FY99 through FY06, and we used its data on fuel usage for non-fleet/tactical vehicles and other equipment to generate figures for mobility fuel usage. The data in the AEM report, reported by DESC, includes consumption and cost figures for six types of energy: auto gas, diesel, LPG/propane, aviation gas, jet fuel, and Navy special. An additional fuel type, "other," was reported but was not used in our analysis because it is reported in different units (Btus rather than gallons) and does not constitute a significant proportion of total usage.

For our price projections, we used data derived from EIA's *Annual Energy Outlook 2007*.[2] The EIA used historical world oil prices from 1980 to 2005 to forecast the price of oil through 2030 in three scenarios: reference case, high-price scenario, and low-price scenario. Figure G-1 displays the EIA's forecasts (in FY05 dollars per barrel). Because DoD uses a variety of fuels processed from oil, the price it pays generally is greater than the crude oil prices cited by the EIA. To factor in this difference, we adjusted the units of EIA figures from barrels to gallons[3] to make them comparable with the figures in the AEM report and compared

---

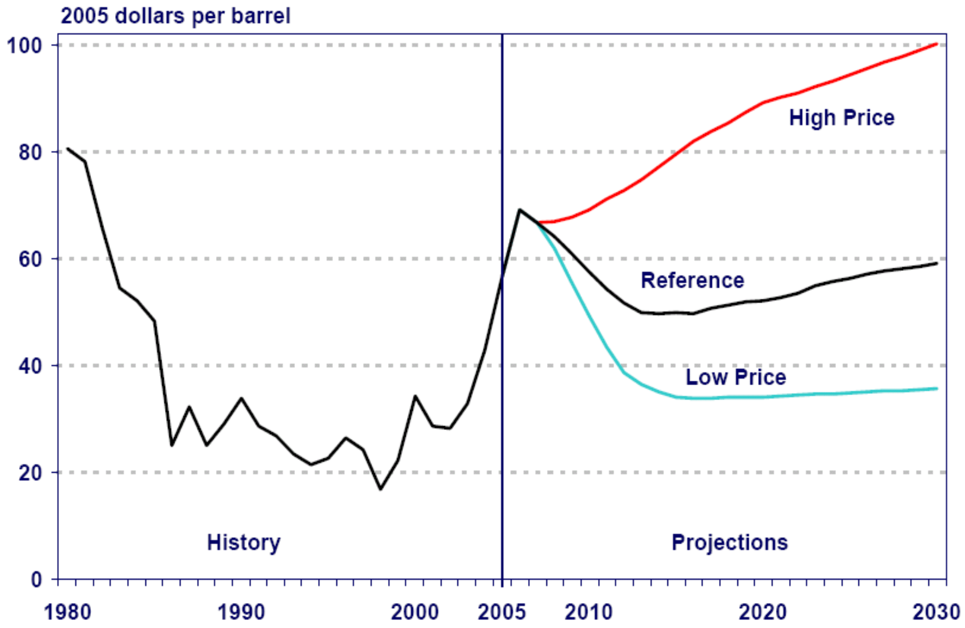
[1] USD(AT&L), *Department of Defense Annual Energy Management Report, Fiscal Year 2006*, http://www.acq.osd.mil/ie/irm/Energy/energymgmt_report/main.htm, January 2007.

[2] Energy Information Agency, *Annual Energy Outlook 2007*, DOE/EIA-0383(2007), February 2007. Available at http://www.eia.doe.gov/oiaf/aeo/index.html.

[3] A barrel (bbl) is the equivalent to 159 liters, or 42 gallons, U.S. Census Bureau.

the unit price DoD paid for mobility fuels from FY99 to FY06 with the unit price of world oil for these years reported by EIA. We found that, on average, the unit price for mobility fuel was 24 percent greater than that of oil. We adjusted the EIA forecasts to account for this price difference.

Figure G-1. Forecast of World Oil Prices in Three Cases, 1980–2030



Source: Energy Information Agency, *Annual Energy Outlook 2007*, DOE/EIA-0383(2007), February 2007.

CONSTRAINTS AND ASSUMPTIONS

Key constraints are as follows:

- These estimates do not consider any multiplier effects, which occur when a technology reduces end-user fuel consumption savings beyond just the fuel acquisition costs due to a decrease in the demand placed on the entire logistics tail. Multiplier effects are not considered because the magnitude of the effect depends on the nature of the changes implemented. Multiplier effects may be calculated more accurately once a set of changes are selected for implementation.

- The nature of the data may limit the precision of our projections. DoD guidance for the FY06 AEM report addresses the data limitations as follows:

> DESC will provide all input in this area except for LPG/Propane used in mobile platforms, however, each Component should provide the narrative input required to articulate consumption, trends, etc. DESC mobility fuels data will be based on issues of fuels to Service/Defense Agencies. Once fuel enters a mobile platform it will be assumed to be consumed. Costs of fuel consumed will be based on actual price paid for fuel by DESC. Fuel costs will not be based on DESC standard price. It is not necessary to provide AFV input in this section. AFV reporting is covered through a separate report.

- Data in the AEM report are reported in fiscal years, while EIA data are reported in calendar years. This misalignment may slightly affect the accuracy of our estimates.

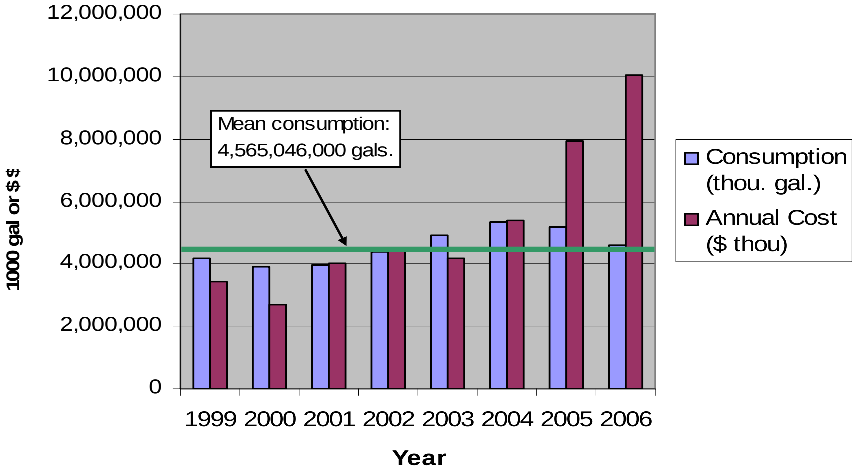
Key assumptions are as follows:

- The AEM report and EIA's *Annual Energy Outlook 2007* are the most accurate sources of information on mobility fuel usage and future energy prices readily available to us.
- Baseline mobility fuel consumption will remain constant at the mean of FY99–FY06 consumption levels.
- Energy-efficiency requirements for federal facilities outlined in the Executive Order 13423 can be applied to mobility operations.
- Following successful implementation of the EO's energy efficiency requirements, mobility energy consumption will remain at FY15 levels in subsequent years.

SUMMARY OF HISTORICAL DATA

Figure G-2 displays the annual data for both DoD mobility fuel consumption and cost reported in the AEM report for FY99–FY06. The data indicate that the cost of mobility fuels has grown steeply since FY03, while consumption has shown only a small deviation from the mean (denoted by the green line). This indicates that the unit cost of DoD mobility fuels has risen in recent years.

Figure G-2. Annual Consumption and Cost, DoD Mobility Fuel

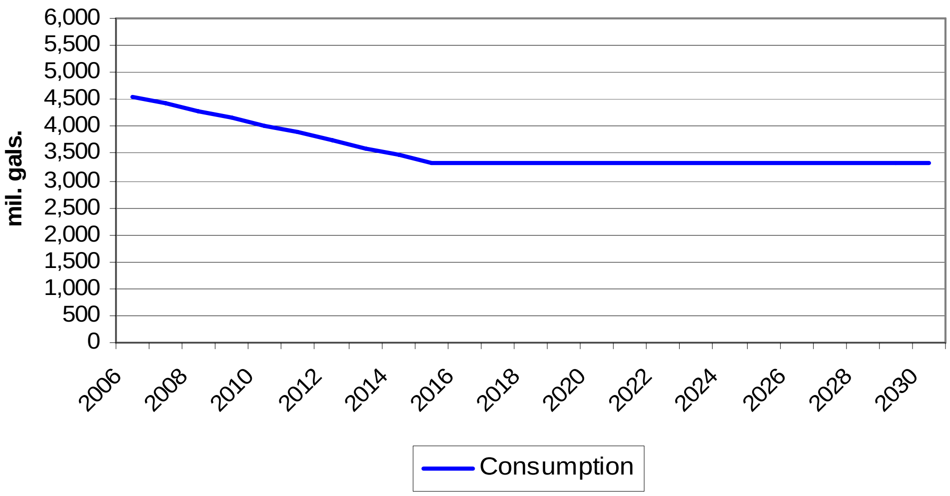


Source: *DoD Annual Energy Management Report, FY 1999–2006*.

ESTIMATED CONSUMPTION AND COST SAVINGS

Using the mean FY99–FY06 consumption levels as the baseline, we estimated future energy consumption and cost scenarios for mobility fuel. We projected a 3 percent reduction in energy consumption per year through the end of FY15. For the years beyond FY15, we assumed that consumption levels would remain at FY15 levels. DoD mobility fuel consumption under this scenario is displayed in Figure G-3.

Figure G-3. Mobility Fuel Consumption if Executive Order 13423 Adopted



By applying this consumption pattern to the price estimates derived from the EIA data, we projected the cost savings to DoD from implementing EO 13423 for mobility operations under the three scenarios (reference case, high price, and low price). Figure G-4 displays the forecasted annual savings to DoD, and Figure G-5 displays the cumulative savings through 2030. Estimated cumulative savings through 2030 range from $26 billion to $73 billion, with the reference case savings estimated at $43 billion.

Figure G-4. Annual Cost Savings (2006–2030) in FY05 Dollars

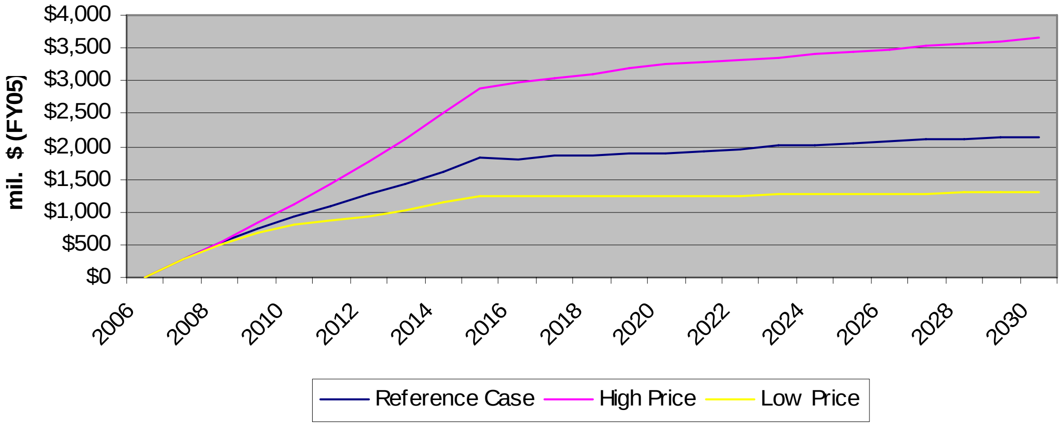
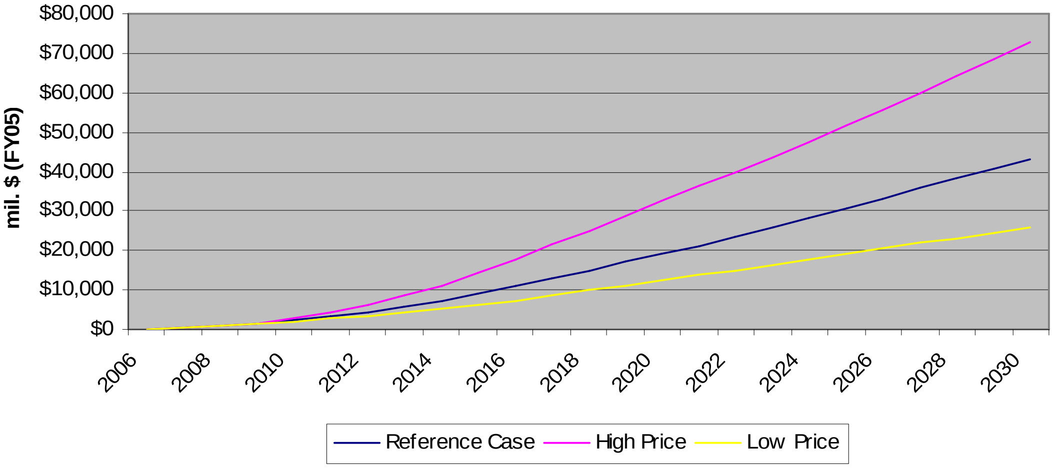


Figure G-5. Cumulative Cost Savings (2006–2030) in FY05 Dollars



CONCLUSION

Implementation of EO 13423 for mobility operations has the potential for significant cost savings. Although in the tens of billions of dollars, these estimates trend low because they do not account for the multiplier effect of technologies implemented and processes reconfigured. While investment would be required to achieve some of these savings—those not due to organizational, process, or operational changes—this investment would be compensated for by the multiplier effect. Once DoD identifies specific new operational concepts and capabilities for consideration, it will be possible to estimate multiplier effects and develop a more accurate estimate of the cost savings.

Appendix H

Abbreviations

ACSIM	Assistant Chief of Staff for Installation Management
AFEPPM	Air Force Energy Program Procedural Memorandum
AT&L	Acquisition, Technology and Logistics
ATM	air traffic management
BAA	broad agency announcement
BWB	blended-wing body
COA	course of action
DARPA	Defense Advanced Research Projects Agency
DASD	Deputy Assistant Secretary of Defense
DEPC	DoD Energy Policy Council
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
DoD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities
DUSD	Deputy Under Secretary of Defense
ECIP	Energy Conservation Investment Program
EIA	Energy Information Agency
EPA	Environmental Protection Agency
ESPC	Energy Saving Performance Contract
FAA	Federal Aviation Administration
FT	Fischer-Tropsch
I&E	Installations and Environment
IC	internal combustion
IEA	International Energy Agency
IM	information management
IPT	Integrated Project Team

IT	information technology
JASON	JASON Defense Advisory Group
JCIDS	Joint Capability Integration and Development System
JROC	Joint Requirements Oversight Council
KPP	key performance parameter
MEA	more-electric architecture
MEP	Mobile Electric Power
MSFD	Multi-Service Force Deployment
NDS	National Defense Strategy
NMS	National Military Strategy
NRAC	Naval Research Advisory Committee
NREL	National Renewable Energy Laboratory
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
OTEC	ocean thermal energy conversion
OWEC	Ocean Wave Energy Company
PA&E	Office of Program Analysis and Evaluation
PBMR	Pebble Bed Modular Reactor
PM	program manager
POC	point of contact
POM	Program Objective Memorandum
PPBE	planning, programming, budgeting, and execution
QDR	Quadrennial Defense Review
R&D	research and development
RFI	request for information
S&T	science and technology
SME	subject matter expert
SoC	System on Chip
SOCOM	Special Operations Command
UAV	unmanned aerial vehicle
UESC	Utility Energy Service Contract
USD	Under Secretary of Defense