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Defense Energy Resilience: Lessons from Ecology

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The Letort Papers
DEFENSE ENERGY RESILIENCE:
LESSONS FROM ECOLOGY

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Mr. David Kerner

August 2010

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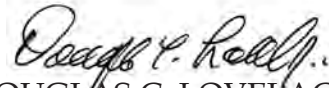
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FOREWORD

Energy security is a fundamental requirement for national security, and global energy competition threatens to make Department of Defense (DoD) missions increasingly vulnerable to the vagaries of energy supply. Dr. Scott Thomas and Mr. David Kerner argue that DoD's approach to energy security must accommodate a highly uncertain outlook for energy resource availability. The authors argue that while U.S. energy security needs are currently met, the shrinking gap between global supply and demand draws the world closer to a tipping point at which competition disrupts social and geopolitical normalizing forces, and conflict becomes likely. This analysis offers key insights into what a shifting energy security environment is and provides a novel theoretical framework for how the United States can best respond to it.

Dr. Thomas and Mr. Kerner opine that while DoD expresses concern for trends threatening energy security, Defense planners nevertheless continue to operate as if adequate energy supplies will continue to be available, and what limited energy-related planning is done addresses only the symptoms of a systemic over-reliance on very few energy resources. In order to tackle this cognitive disconnect, the authors argue that DoD would be best served by devising and implementing a sustainable, resilient energy strategy that addresses current projections and adapts to evolving conditions. The authors explain two resource management concepts, drawn from the field of ecological management, that provide perspective for managing energy security: resilience theory, which can benefit energy planning through the introduction of a systems

perspective; and the adaptive management approach, which emphasizes institutional learning and an investigational approach in refining energy programs and policy.

A handwritten signature in black ink, reading "Douglas C. Lovelace, Jr." in a cursive script.

DOUGLAS C. LOVELACE, JR.
Director
Strategic Studies Institute

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SUMMARY

National security relies heavily on the ready availability of energy resources in the types, quantities, and locations that the military demands. However, global energy competition is rendering those resources ever tighter, leaving the U.S. Department of Defense (DoD) missions increasingly vulnerable to even small supply perturbations. DoD's response has been to pursue a variety of energy security-related initiatives, including conservation measures and alternative energy resources. These measures, however, must counter the ever-increasing energy demands of more and longer military actions and of employing modern weapons and mobility platforms, whose fuel use increases with each new design iteration.

DoD's approach to energy security must accommodate a highly uncertain outlook for energy resource availability, one of contracting oil supplies, increasing demand by the developing world, and decreasing production due to an aging infrastructure and tight financing for new facilities. DoD still functions under the assumption that adequate energy supplies will continue to be available, either through technological innovation or through discovery of new resources. Several energy studies point to supply constrictions over the next 1 to 3 decades, against a backdrop of environmental pressures to reduce burning of hydrocarbon fuels. While U.S. energy needs are currently being met, the shrinking gap between global supply and demand draws the world closer to a tipping point at which human behavior is less predictable, competition overwhelms social and geopolitical normalizing forces, and conflict becomes likelier and more pronounced.

Given these concerns about future resources, DoD would be best served by devising and implementing a sustainable, resilient energy strategy that addresses current projections and adapts to evolving conditions. The U.S. Army has begun to address its energy security concerns, but has not yet formulated an enduring and flexible approach to shifting energy resources. Two concepts that have become increasingly important in modern ecological theory and conservation practice are *resilience of social-ecological systems* (SESs) and the *adaptive management* approach for managing these systems. Advances in ecosystem-based management of natural resources and sustainability science have yielded theory that is markedly different from theory arising from more narrowly focused perspectives, such as those driving conventional business and economic practices, agriculture, energy production and distribution, and security policy. Ecological resilience has been defined as the amount of disturbance that a social-ecological system can absorb without changing its structure, feedbacks, function, and overall identity. Adaptive management is exploratory policy development: the application of science to policy to produce reliable knowledge from unavoidable errors (i.e., through deliberate trial and error). These two concepts may provide a fresh perspective to inform energy security policy, with resilience providing a systems perspective on planning and adaptive management offering mechanisms for emphasizing institutional learning and an investigational approach in refining energy programs and policy.

DEFENSE ENERGY RESILIENCE: LESSONS FROM ECOLOGY

INTRODUCTION TO THE PROBLEM

The mission of the U.S. Department of Defense (DoD) is “to provide the military forces needed to deter war and protect the security of our country.”¹ It achieves this through the highly effective use of manpower and technological capabilities while being powered by vast quantities of energy resources. U.S. military capabilities have co-evolved with the quantity and type of readily available energy assets.

The energy source in greatest use today is oil, from which fuels are derived well suited to the propulsion of military weapons platforms and to distribution via air, road, rail, and sea. Three-quarters of DoD energy use comes from oil; the rest is predominantly electricity and natural gas used on military installations.²

Oil’s energy density, transportability, and other physical properties have enabled the development of ever-greater military mobility and lethality. Its seemingly endless supply has fostered, until recently, an attitude among military planners of nearly exclusive reliance on oil, and a belief that whatever quantities are needed will always be provided, bounded only by budgetary and logistical considerations. In fact, oil’s abundance has fostered the assumption that mission planning and technology development need not consider potential resource constraints. As a result, the U.S. military now systemically relies on the ready availability of an extremely narrow range of energy types in great quantities, of specific qualities, and in far-ranging locations.

With the necessary energy supplies, U.S. military might is unparalleled; without them, its capabilities

are severely curtailed. In this regard, the existing acute reliance on a single resource renders military missions – and, hence, national security – increasingly vulnerable to even small energy supply disruptions.

However, global energy competition is now making the availability of energy supplies ever tighter. DoD must accommodate to a highly uncertain outlook for energy availability, one of contracting oil supplies, increasing demand by China, India, and the developing world, and decreasing production due to an aging infrastructure and tight financing for new facilities.³

Yet DoD is only now beginning to question the assumption that either technological innovation or discovery of new resources will ensure continued availability of adequate energy supplies. That assumption has sufficed for the past 100 years, during which oil supplies usually met existing demands with minimal constraint. Several recent energy studies, however, point to supply constrictions over the next 1 to 3 decades, amplified by environmental pressures to reduce the burning of hydrocarbon fuels.⁴

The Defense Science Board has examined DoD's energy use and issued strong recommendations for near- and long-term initiatives to reduce oil dependence and improve overall energy efficiencies.⁵ The Office of the Secretary of Defense created an Energy Security Task Force that drafted a strategic plan providing a way forward for the DoD.⁶ In 2008, the Secretary of the Army established the Army Energy Security Task Force (AESTF), the recommendations of which led to the creation of an Army Senior Energy Council (SEC). The SEC, in turn, approved the Army Energy Security Implementation Strategy (AESIS), which lays out the Army's energy security vision, mission, and goals.⁷ Other services have made similar

efforts. The DoD has also begun to pursue a variety of energy security-related initiatives, including conservation measures for buildings and infrastructure; renewable energy facilities developed on DoD land; improvements in the energy efficiency of ships, field shelters, and fixed installations; and policy changes to ensure that energy use is fully considered during the acquisition process.⁸

These measures, however, must counter the ever-increasing energy demands of frequent, extended military actions, including employment of the most profligate of energy users – modern weapons and mobility platforms, whose power, agility, lethality, and fuel use increase with each new design. In addition, concern has been expressed about the prospect in future military actions of “outrunning” the logistics tail because weapons and mobility platforms consume resources faster and/or at greater range than the supply chain can accommodate.⁹ More profoundly, development of these systems is not based on well-founded, methodically established energy sustainability goals tied to overarching and fully articulated national security goals, nor do they include an adaptive approach for achieving them.¹⁰ DoD’s planning must consider first and foremost its principal objectives, then holistically explore the means by which it will achieve them. Treating energy as simply an oil supply challenge is ill advised, since intense reliance on that single resource is the ultimate problem.

As a more focused example, the Army’s energy strategy, as specified in its AESIS, lays out five broad energy security goals (ESGs): (1) reduced energy consumption; (2) increased energy efficiency across platforms and facilities; (3) increased use of renewable/alternative energy; (4) assured access to sufficient

energy supplies; and (5) reduced adverse impacts on the environment.¹¹ Within these five goals, metrics for the measurement of progress are being developed that address installation and tactical applications.¹² The Army clearly stipulates that any improvements in these areas “shall not lead to reductions in operational capability or the ability of the Army to carry out its primary missions.”¹³ While these goals are necessary for achieving lower energy demand, they are not, however, linked to energy resource projections nor to a clearly articulated definition of mission resilience in the face of energy uncertainties. Moreover, the AESIS does not direct Army components to address such key considerations, nor does it offer guidance on how to flexibly adapt to changing energy conditions.

While U.S. energy needs are currently being met, the shrinking gap between global supply of and demand for energy draws the world closer to an energy competition tipping point at which human behavior becomes less predictable, social and geopolitical normalizing forces are overwhelmed, and conflict becomes likelier and more pronounced. Moreover, energy resource uncertainty degrades DoD mission planning confidence.

For example, if a series of blockades, embargoes, labor strikes, and/or military attacks suddenly shut down the global oil supply network, reserve stores of petroleum and petroleum-based fuels would dwindle quickly—particularly during wartime operations—leaving the U.S. military unable to obtain suitable alternative fuels and rendering it virtually immobile.¹⁴ This situation would last as long as it took to restart and deliver supplies of current fuels, or to replace them with suitable alternatives, both of which could take months, if not years. In fact, not much of a per-

turbation is needed to cause havoc. Even a gradual reduction in oil-based fuel supply—perhaps over a period of months or a few years—would outpace any foreseeable program to develop suitable replacements, thus greatly reducing the mobility of our oil-dependent military and altering our national security stance. In this event, planning assumptions regarding national security and power projection would require hasty reconsideration.

The problem is not just that DoD uses so much energy; it is that DoD relies heavily on a very limited selection of energy resources and is thus extremely vulnerable to vagaries of supply. Moreover, defense planning proceeds as though oil supplies are limitless. Even within wargaming scenarios, imposed limits on oil supply that are designed to test the effect of scarcity on military function typically assume that those limits are merely temporary disruptions, rather than long-term or permanent shortfalls.¹⁵

The assumption of unlimited oil, available whenever and in whatever form it is needed, contributes to an energy myopia that has left DoD systemically calcified and inadequately prepared to employ other energy sources. If DoD does not improve its energy flexibility and routinize its use of alternate energy resources, even small fluctuations in the cost and availability of its current fuels may have a magnified and possibly overwhelming effect on mission capabilities. An incident such as the obstruction of even a single critical oil transport route would quickly create a man-made global shortage and force global powers to prioritize their use of this critical resource.¹⁶ As the world's largest consumer of oil—the United States has less than 5 percent of the world's population but consumes about one-quarter of the world's oil output¹⁷—

it would have to choose between its health, emergency services, agriculture, home heating, transportation, industrial, defense, and other sectors in allotting what oil it could obtain. Given this internal competition for the resource, the military may well face diminished supplies, causing reduced capabilities and a more vulnerable defense posture around the globe.

In summary, DoD's energy security is entering a period of increased unpredictability and complexity, one for which previous approaches to solutions are no longer adequate. DoD would be best served by an energy strategy featuring sustainability, resilience, and adaptability to evolving conditions, a strategy derived from the fields of ecology and natural resource management. We will explore the theory behind these concepts, and then ground the theory with (1) discussion of how it applies to managing military energy security, and (2) an action plan for achieving more resilience in energy security.

A New Theoretical Perspective.

Seeking a useful approach to increasing the resilience of our energy security policy, we look afield to examine lessons from nontraditional sources. Recent research regarding natural resource management and the provision of ecosystem services reveals how human and "natural" systems are interlinked.¹⁸ Ecosystems provide the myriad services upon which society depends for survival. Society influences ecosystems through conversion of land cover, harvesting of plants, animals, and minerals, management of freshwater hydrology, introduction of wastes, and numerous other ways. The term "social-ecological system" (SES) has been adopted to recognize this inter-connectedness

of complex and evolving systems of humans and nature.¹⁹ Tools to increase the resilience of SESs appear appropriate for application to energy security as well.

Two concepts that have become increasingly important in modern ecological theory are the resilience of SESs and the adaptive management approach for managing these systems. Advances in ecosystem-based management of natural resources and sustainability science have yielded theory that is markedly different from theory arising from more narrowly focused perspectives, such as those driving conventional business and economic practices, agriculture, energy production and distribution, and security policy.

Ecological resilience has been defined as the amount of disturbance that a social-ecological system can absorb without changing its structure, feedbacks, function, and overall identity.²⁰ Adaptive management (AM) is exploratory policy development: the application of science to policy to produce reliable knowledge from unavoidable errors.²¹ These two concepts may provide a fresh perspective to inform energy security policy, with resilience providing a systems perspective on planning and adaptive management offering mechanisms for emphasizing institutional learning and developing an investigational approach in refining energy programs and policy.

“Defense energy security” typically refers to ensuring adequate energy resources to meet demands. However, **true security relies more on a state of operational resilience that ensures mission sustainability in the face of uncertain and changing energy resource availability.** While inadequate energy resources can greatly impair military capabilities,²² this monograph does not presuppose, per se, a set date on which specific existing energy resources will peak or decline,

nor on when new energy resources are anticipated to be available. Instead, it examines the underpinnings of current DoD energy vulnerabilities to discern opportunities for increasing energy resilience.

All levels of national security, from the strategic to the tactical, are greatly challenged by energy uncertainty. Similarly, the concepts of resilience and adaptive management apply at all levels. We will examine resilience theory and explore the operational thresholds that define what a system can do and how well. An instructive example is the logistics supply chain. It is designed to deliver (and is entirely reliant on) a very limited range of energy resources. If fuel supplies become uncertain, run low, run out, or change in quality, or if the delivery system falters, then mission capabilities can quickly degrade, often simply by the introduction of uncertainty into the military planning equation. Questions arise: How long and how well will the supply chain function? How responsive and dependable will it be? How readily can logistics-specific equipment and specially trained logistics personnel be retooled and retrained to accommodate other fuel sources?

Resilience theory also suggests that we can ameliorate the effect of possible energy perturbations by providing alternate paths to sustain system (i.e., mission) functionality. This could mean incorporating the ability to use a variety of fuels, or to function without fuel-dependent equipment; adopting doctrinal, training, operational, planning, and other nonmateriel changes that promote mission flexibility; changing larger-scale mission plans that negate those energy demands altogether; and even changing higher-level national strategy that affects mission choices and their attendant energy needs.

To assess the resilience and cyclical vulnerabilities of systems driven by humans and resources, we will examine a framework called the adaptive cycle through which a system evolves, that is, taking shape, growing rapidly, optimizing for existing resources and conditions, and finally collapsing when outside forces overwhelm or no longer accommodate its form and functionality. We will discuss how this collapse can be avoided by taking deliberate steps to move backwards through the adaptive cycle phases. To continue with the aforementioned example, a logistics system comes into existence to satisfy the chosen military force structure (which itself was shaped to meet national goals within the bounds of physical and human resources), evolves, and eventually becomes “efficient” in a certain parameter (e.g., the harmonized use of a single fuel across multiple platforms). However, this efficiency renders it rigid in other ways (e.g., a dependency on that single fuel), and the system can fail if that requirement can no longer be met. A mitigative measure, however, could include loosening the bounds of allowable approaches (e.g., can we accomplish a function with different or even no fuel?), which is in essence moving the system into a prior phase of the adaptive cycle.

Ensuring resilience requires a flexible management strategy that lends itself to complex and evolving systems. Adaptive management engages scientific principles to formulate policies that can accommodate the inevitable surprises of a dynamic world. Given the ubiquitous role of energy resources, the impact of changes in those resources cannot be addressed by “snapshot” management approaches. Adaptive management requires managers to assess the status of critical systems, determine their dependencies and

vulnerabilities, hypothesize how changes can be addressed, develop metrics and targets to measure the effectiveness of steps taken, and modify those steps—repeatedly, if necessary—in the continued pursuit of optimal system performance. This approach recognizes that surprises are the rule in changing systems and strives to adapt management strategies accordingly.

RESILIENCE THEORY

Engineering resilience has been regarded as a measure of a system's resistance to disturbance and of the speed with which it returns to equilibrium.²³ While this definition is useful for describing closed systems, those systems that are characterized by uncertainty and unpredictability appear more tractable when examined from an ecological systems perspective. Ecological resilience has been defined as (1) the amount of disturbance that a system can absorb and still retain its basic structure, feedbacks, and function—its overall identity,²⁴ and alternatively (2) the *potential* of a system to remain in a particular configuration and to maintain its feedbacks and functions.²⁵

So far as the theoretical underpinnings are concerned, social-ecological systems exist in “regimes” that are bounded by thresholds which, when transgressed, lead to changes in system function and structure.²⁶ To illustrate, grasslands are often maintained free of trees by periodic fires. Grasses grow, building up fuel loads, and fires periodically reduce the fuel load. The fires typically return at a frequency too high for most trees and shrubs to accommodate, so the grasslands are maintained. Grasslands are often used for livestock grazing, and, at low stocking densities, the system persists as described above. However, at

higher stocking densities, grass (fuel) levels decline to the point where the fire regime cannot be supported. When the SES crosses a threshold or tipping point, woody vegetation starts invading the grasslands, and the system takes on a different character. Even without further grazing, the system may not return to grasslands.²⁷

Resilience has also been defined in a business context: “the capacity of an enterprise to survive, adapt, and grow in the face of turbulent change.”²⁸ But focusing analysis at the enterprise or program level yields fundamentally different strategies for success (or risk management) than focusing at the SES scale. Current best practice in business and government usually consists of optimizing the production and delivery of goods and services,²⁹ as DoD has done by developing transport and weapons platforms that make effective use of the most efficient mode of energy delivery – that of oil. Increasing efficiency in production and delivery often requires tight control of a system’s elements *in isolation* to create a steady “maximum sustainable yield.”

However, elements of SESs are connected to each other and are *shaped over time by extreme events* – floods, fires, famines, droughts, energy shortages, labor strikes, financial collapses, technological transformations – that are likely *more extreme* than the assumptions upon which the models guiding production and delivery programs are normally based. When these inevitable, low-frequency, high-impact events occur, they upset the carefully optimized system. Similarly, the unrealistic assumption that the supply of a particular energy resource is unlimited fosters the development of, and reliance upon, a system that will fail when the supply of that resource is seriously perturbed.

U.S. energy security policy assumes that hydrocarbon fuels are readily available, with market forces dictating that more will become available, albeit at a higher price, as demand rises. The assumption of unlimited resources serves conventional models that focus on maximizing economic productivity and growth, but those models do not accommodate the magnified vulnerabilities inherent in such a narrow resource dependency. US infrastructure now requires these fossil fuels – without which homes are not heated, fertilizers are not produced for farms, food is not brought to market, emergency services cannot be delivered, chemicals are not produced, medicines are not manufactured, coal is not delivered to power plants, power plants do not produce electricity, transportation of all types – including military – is curtailed, and literally thousands of other functions of a modern society are constrained or cease entirely.

A focus solely on efficiency models is likely to eliminate consideration of redundancies that provide “response diversity,” the different adaptation strategies or capacities inherent in different solutions to system challenges. Loss of this response diversity reduces resilience in a system.³⁰ The more reliant a system is on a single resource, operating strategy, or paradigmatic assumption, the less resilient it is and the more vulnerable it is to failure; DoD’s energy reliance model is a prime example.

By way of contrast, Martin Christopher and Helen Peck, using empirical research, developed an initial framework for a resilient supply chain. They show that supply chain resilience can be created through four key principles: (1) resilience can be built into a system in advance of a disruption (i.e., reengineering), (2) a high level of collaboration is required to iden-

tify and manage risks, (3) agility is essential to react quickly to unforeseen events, and (4) the culture of risk management is needed.³¹

Social-ecological systems can exist in more than one stable regime. If a system changes too much, it crosses an identity threshold and starts to operate in a different manner—the grassland becomes a shrubland.³² Moreover, it is difficult to predict these thresholds since our understanding of these systems is limited, as measurement and prediction are typically imprecise.³³ Ecosystem regime shifts are typically driven by infrequently or slowly changing variables. In our natural resource examples, these variables might include the frequency of wildfires or “50-year floods.”

Management can build or destroy resilience, depending on how the system reorganizes in response to management prescriptions.³⁴ “Efficiency myopia” may propel exploitation and profit (savings) over the short term, but eventually extreme events (or perhaps merely infrequently occurring phenomena—the slow variables) will threaten to breach a threshold separating a desirable, accommodating, stable regime from a different, perhaps undesirable one. For example, continuing to rely upon the least costly energy sources (even as supply is becoming less reliable) without systematic exploration of alternatives would leave an institution with few choices when the supply gradually (or suddenly) runs out. A shift to this new state may be socially, economically, and environmentally challenging: “Though efficiency, per se, is not the problem, when it is applied to only a narrow range of values and a particular set of interests it sets the system on a trajectory that, due to its complex nature, leads inevitably to unwanted outcomes.”³⁵

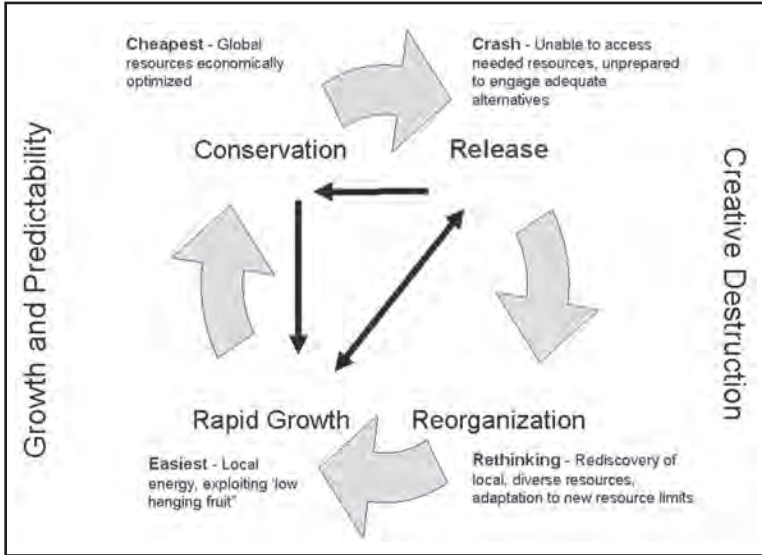
A management approach based on assumed stability and equilibrium seeks to maintain a predictable

world with maximized, consistent production as the goal.³⁶ However, this assumption is unrealistic over the long term. Nature is not static. A management approach based on the concept of resilience would emphasize the need to keep options open, monitor events at multiple scales, and emphasize heterogeneity. It would also presume insufficient knowledge of all possible future events, leading to an adaptive approach (discussed in the next section) as the best means to create a capacity for accommodating surprises.³⁷

The more heavily invested we are in efficiency, the more difficult and costly it is to reform towards resiliency. Why is this so? One answer is that systemic configuration to optimize one variable imposes structural constraints that by definition resist other forcing functions. For instance, logistics operations are optimized to deliver large quantities of one type of fuel, typically J-8, to forward operating bases. The vehicles, equipment, trained personnel, security requirements, and operational plans satisfy the need for a single fuel, but are inadequate for delivering a diverse range of energy and power resources. But, if we look beyond logistics management, then larger “adaptive cycles” come into play, influencing the potential for, and rate of, growth and change in the system.

What is an adaptive cycle? Ecologists have discovered that most systems operate within a four-phase cycle of (1) rapid growth, (2) conservation, (3) release, and (4) reorganization, as depicted in Figure 1. How the system behaves depends upon where it is within the adaptive cycle. For instance, early in the cycle resources may be plentiful, and people and other organisms exploit such abundance. Pioneers and innovators prosper. Over time the system organizes around increasing efficiency and conservation of resources and

capital. The advantage then shifts from opportunists to specialists who can overcome the effects of variability to increase efficiency.



Based on Walker and Salt, 2006.

Figure 1. The Adaptive Cycle.

Whereas the pioneers of the rapid growth phase are agile and operate at small scales, the specialists of the conservation phase succeed across larger scales based upon economies of scale, conservative strategies, cultivation of relationships, and system regulation (to the extent possible). At the beginnings of World War II and the Korean War, the U.S. Army and Marine Corps experienced the rapid growth phase and matured quickly by necessity. In contrast, the standing army of the last 4 decades is characterized by the bureaucratic systems and efficiencies of the conservation phase.

The third phase, release (of energy, resources, and accumulated capital), can occur very rapidly, even catastrophically. How does this happen? Regulatory controls evaporate, partnerships end, system feedback loops break down, and thresholds are crossed. Agents of release in SESs include fire, flood, drought, famine, disease, war, transformational technology, financial failure, market shocks, economic decline, *and loss of a resource base* (witness the failed African states).

The release phase is chaotic, but can manifest as “creative destruction” when released energy, capital, and talent become the fuel for reorganization, renewal, and rapid growth. In the reorganization phase the chaos of release gives way to thriving novelty, experimentation, and adaptation, setting the foundation for rapid growth. Opportunists may once again find fertile ground for possibilities, new strategies, and revolution.³⁸ One should note, however, that the cycle does not necessarily repeat. With the crossing of thresholds and release, an SES may reorganize differently, in ways that are inferior, less comfortable and unaccommodating.

Moreover, the adaptive cycle does not necessarily progress in order. Rapid growth or even reorganization may devolve unexpectedly into release without passing through a conservation phase. Or conservation may be perturbed slightly to invite limited rapid growth. Based on resilience theory, the rapid growth and reorganization phases present the greatest opportunity for adaptive change; the conservation and release phases present the greatest risk.

ADAPTIVE MANAGEMENT

Adaptive management has been defined as the “application of science to policy to produce reliable knowledge from unavoidable errors.”³⁹ An adaptive policy is designed from the outset to test clearly formulated hypotheses about the behavior of an ecosystem being changed by human use.⁴⁰ Several other definitions are listed in Table 1.

A mechanism for integrating scientific knowledge and experience for the purpose of understanding and managing natural systems (Holling, 1978).

The application of science to policy to produce reliable knowledge from unavoidable errors. An adaptive policy is one that is designed from the outset to test clearly formulated hypotheses about the behavior of an ecosystem being changed by human use. Adaptive management is an approach that embodies a simple imperative: policies are experiments; learn from them (Lee, 1993).

The process of implementing policy decisions as scientifically driven management experiments that test predictions and assumptions in management plans, and using the resulting information to improve the plans (Noss and Cooperrider, 1994).

Table 1. Definitions of Adaptive Management.

As can be inferred from Table 1, adaptive management is a structured process designed to improve understanding and management by helping managers and scientists learn from the implementation and consequences of natural resource policies.⁴¹ Adaptive management policies are really “questions masquerading as answers”; management actions become exploratory treatments, in an experimental sense, to answer those questions.⁴²

In co-evolving systems of man and nature, surprises are the rule rather than the exception. The ultimate goal of adaptive management is “resilience in the face of surprise.”⁴³ Within this context, a surprise is a qualitative disjunction between observations and expectations when an SES fails to behave according to form.⁴⁴

By integrating the concepts of resilience and adaptive management, an adaptive manager promotes the resilience of the system within a desired stable state by working (1) to shrink the frequency and amplitude of cycles in alternate, undesirable stable states;⁴⁵ and (2) to elevate, if possible, the thresholds dividing such stable states, effectively reducing the probability of a state change.⁴⁶

Researchers make the distinction between “passive” and “active” adaptive management.⁴⁷ Passive adaptive management may be as simple as a commitment to learn and adapt while a program matures. Active adaptive management is more in line with the scientific method, entailing development and testing of hypotheses about management outcomes in which policies are explicitly treated as experiments.⁴⁸ In active adaptive management, hypotheses are stated at the outset, and measuring procedures are designed in advance to test them.⁴⁹ Managers are unlikely to get things exactly right, but through programmatic learning, focused by the scientific method, they may come close enough to sustain energy security. For instance, military installation planners may provide a reasonably close estimate of energy requirements, and monitoring will reveal whether technological measures match energy consumption with energy availability. Planners may develop policies for shifting certain facilities or systems to an alternate energy source, moni-

toring may track program effectiveness, and a lessons-learned process may build institutional knowledge concerning this transition.

Adaptive management is a philosophy premised on the understanding that systems are dynamic rather than static. Static policies to manage (presumed) static systems have advantages for efficiency, as we have seen, and treatment of a system as static may appear analytically and politically tractable, **but real systems are not static**—they do not persist forever in the rapid growth or conservation phase, and they do not respond well *at a large scale* to tight engineering solutions. Tight control of a system without a focus on learning and adaptation makes massive collapse (release) more likely.⁵⁰

Regarding the pace of adaptive management, the models developed by Carpenter *et al.*⁵¹ suggest that management experiments should be frequent, lasting long enough to enable interpretation of how the system responds to the experiment. Then a different regime should be tried. Managers should track system response to each sequence of policies. Some policy experiments may appear expensive and inefficient if they are economically sub-optimal in the short term,⁵² yet they may build redundancy and resilience into the system.⁵³ Information gained from these experiments is used to adjust policies, with continual learning and adjustment becoming the norm.⁵⁴ Adaptive management is thus a mode of learning attractive to those with scientific or engineering training who are drawn to the trustworthiness of experimentation as a way to establish reliable knowledge concerning complex and subtle systems, including those driven far from their undisturbed equilibrium state. “The complexity suggests that even simple steps may yield surprising out-

comes—and science is an efficient way of recognizing and diagnosing surprise.”⁵⁵

Adaptive management involves learning while doing. Management actions cannot wait, as time and resources are invariably too limited to defer actions to address urgent problems. However, the urgent is not necessarily the important, and management policies should accordingly be chosen in light of the assumptions they test, so that the critical uncertainties are tested rigorously and early.⁵⁶ In the words of Lance Gunderson, “Learning is a long-term proposition that requires ballast against short-term politics and objectives.”⁵⁷ This is especially important for military institutions where personnel rotate frequently. Many programs appear to be initiated to demonstrate the leadership vision of a newly installed commander, promote near-term management flexibility, or limit encumbrance of personnel and funding, all at the expense of institutional learning and long-term resilience.⁵⁸ Developing a capacity for learning is problematic among many institutions. Learning by doing requires leaders to acknowledge that they can and do make mistakes, and without this recognition and acceptance, institutional learning cannot occur.⁵⁹ When policies appear to work, there is often little or no emphasis on learning why they work. When policies publicly fail, agencies deem learning a priority. Those agencies that succeed in developing an institutional learning capacity seem to achieve it by focusing on understanding, rather than efficiency, and by networking with those who practice learning.⁶⁰

How an organization handles information affects its learning capacity. Managers who focus on adaptive management are explicit concerning expectations; they measure relevant parameters, collect data, moni-

tor progress, analyze data following a set protocol, document their improved understanding of the situation, change plans as required, and, perhaps most importantly, institutionalize the new understanding.⁶¹

System monitoring serves as the mechanism regulating the feedback loop between management goals and strategy outcomes. Information provided by targeted research, inventory, and monitoring enables iterative refinement of both targets and strategies for achieving them.⁶² Table 2 lists key elements of adaptive management.⁶³

<ol style="list-style-type: none">1. Numerical targets/goals.2. Actions targeted to specific locations.3. Recognition that biological and physical properties are fundamentally important and are often characterized by slow feedback, which can conflict with institutional timelines.4. Integration of policies and initiatives so as not to miss cumulative impacts.5. Experiments using controls and replication, and analyzed using statistics.6. Monitoring.7. A process for analysis and synthesis of experimental results and learning. There must be a paper trail leading from data to output if learning is to take place.
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Table 2. Key Elements of Adaptive Management Framework.

Decisions should never be viewed as final; they must always be followed by more informed decisions as the knowledge base grows. Leaders must pursue the best data available to enable timely decisionmaking, recognizing that all decisions are open to subsequent revision as **learning takes place**.

BENEFITS AND RISKS OF ADAPTIVE MANAGEMENT

Table 3 lists several compelling practical reasons for military energy security managers to implement the adaptive management approach.

1. When a program is already performing large-scale interventions and extensive monitoring, it makes sense to capitalize upon this investment and follow a process focused on institutional learning in order to improve the quality of planning and management.⁶⁴
2. What an agency does not know can hurt it. To counteract loss of program flexibility and preserve options, an agency would be well served to obtain the best data and analysis available, understand trends, and take action before management flexibility is lost.⁶⁵
3. Early experimentation may lead to improved methods, saving time, money, manpower, or other resources,⁶⁶ and, importantly, may enable an agency to avoid costly catastrophes, management failures, and litigation.⁶⁷

Table 3. Benefits of Adaptive Management.

In addition to the benefits, however, adaptive management also poses some risks to a manager or organization (see Table 4).

1. Having “failures” clearly documented can be politically risky—even though such transparency and documentation are prerequisites to institutional learning.⁶⁸

2. Actors within DoD may be reluctant to undertake changes in energy policies due to the potential for temporary operational disruption and its associated perceived vulnerability in military posture.

3. The apparent cost of monitoring and experimentation appears high compared with traditional programs.⁶⁹ The actual cost may be much smaller when managers consider the hidden costs of traditional programs heavy with reactive problem solving.⁷⁰

4. Since experimentation is a form of study, it can be viewed by action-oriented leaders as a form of delay.⁷¹

5. There will be false alarms. Deciding which of the surprising findings to pursue (through policy changes or further data collection) and which to set aside is a matter of judgment.⁷²

6. The time scale for system response is typically long. Many organizations are impatient, mired in reactive problem solving.⁷³ Institutional inertia and crisis management can lead to collection of immense amounts of data without generating useful information, no real institutional learning, and merely a more expensive trial and error cycle than before.⁷⁴

7. In large systems, it may take large interventions in order to see any change above the “noise level” of natural fluctuations, but such interventions are perceived to be the most risky in terms of cost and potential failure.

Table 4. Risks of Adaptive Management.

DISCUSSION: ENHANCING ENERGY SECURITY BASED ON A RESILIENCE PERSPECTIVE

The fitness of strategies for exploiting opportunities or reducing risk depends upon the system's position within the adaptive cycle (see Figure 1). Relatively little energy and resources may be needed to adjust a program during the reorganization or rapid growth phases, but the entrenched nature of the U.S. military's current conservation phase (characterized by mature institutions and relationships) may cause transformative policies to appear prohibitively expensive. Conversely, the types of collaborative, political solutions possible during the conservation phase may not be possible during the immature rapid-growth phase. During the release phase, damage control may be all that is possible. How can we use this knowledge?

The current U.S. military energy security programs appear to operate firmly within the conservation phase of the adaptive cycle. Resources that may be brought to bear on the problem include amassed capital (both economic and intellectual), mature institutions, formidable research capacity, quality leadership, collaborative relationships, and impressive technology. Leaders and planners might examine how to use these resources in such a manner as to influence the position of energy security programs relative to key thresholds—to move away from or to raise these thresholds that bound the system. For example, raising a threshold might include increasing the number of days the military can persist in using oil reserves, decreasing the percentage of energy the military gets from any one fuel source, or increasing the number of different market sources available for oil or gas.⁷⁵

Resilience theory also reveals that systems, with their adaptive cycles and thresholds, operate at multiple scales in space and time. Systems tend to be organized hierarchically, with smaller-scale, quicker processes embedded in and constrained by larger-scale, slower processes. Management strategies and policies that focus on the small, fast-moving components can have significant, adverse consequences for the slower processes and, thus, for the long-run evolution of the whole system. Therefore, policy should incorporate analysis of how energy security at one scale relates to cycles at larger and smaller scales. What are the key linkages between system scales? For example, energy managers might examine energy demand for transportation fleets within a county or region versus the whole of DoD; one class of ship versus the whole Navy; energy supporting water treatment and distribution systems at a base versus the base's complete energy needs; or energy requirements over the next 10-15 years versus what is required over the next 100 years.

What are the slow variables that control energy security, and how might they be changing? Are there tipping points beyond which the system will behave differently? For example, how are procurement and provisioning processes impacted when oil becomes 30 percent less available? Forty percent? Fifty percent? How should the system be managed to avoid crossing a threshold into an undesirable state? Is it possible to design or modify governance structures so that key intervention points can be addressed at the appropriate scales and times? Or are such governance structures already in place? How should leaders define metrics and thresholds in order to motivate and focus policy development and action? Might research focus

upon building system resilience and adaptive capacity in order to better cope with shocks? For example, what should be done to increase the diversity of energy resources? How might operational and mission planning adjust to accommodate energy uncertainty?

Attempting to increase resilience can be a complex undertaking. Is it possible to perturb the conservation phase enough to reinvigorate the entrepreneurial qualities of rapid growth (as businesses do when they introduce a new product that makes their previous best-seller obsolete)? Increasing adaptability at one place or scale may induce a decrease in adaptability and resilience at other places and scales. For example, economic subsidies may prop up an industry or region, raising local capital and increasing local resilience. However, the localized stimulus may adversely affect the overall system at another location or at a larger scale; converting croplands to production of biofuels may promote energy security while degrading food security; so that the overall system may suffer compromised adaptability and resilience. Moreover, increasing a system's resilience to a particular class of disturbances may further entrench the system in its current pattern of operations, thus decreasing general resilience to unforeseen disturbances.

Some important determinants of a system's ability to transform include (1) incentives to change (rather than not to change), (2) cross-scale awareness and reactivity (networking within and between systems), (3) the willingness (and political capital) needed to treat policy as experiment (adaptive management), and (4) reserves and convertible assets (human, natural, and capital accumulation).⁷⁶ Preventing the crossing of a threshold, or changing the structure of a system to move away from a threshold, requires innovative

skills; agreement on what to do; and access to natural capital, financial resources, and infrastructure. If any or all of these are limited, crossing a threshold may be unavoidable.⁷⁷

What is likely to happen when managers approach implementation of resilience theory cautiously, half-stepping on a small scale as seems the politically natural course of events? The key to success would be to concentrate the experimental approach in a specific region or industry and treat other regions or industries as experimental “controls.” Committing to the experimental approach, even on a small scale, is likely to be more instructive than pursuing half measures everywhere. This experimental approach is the essence of adaptive management.

Adaptive managers explicitly address uncertainties through active probing, monitoring, learning, and response, making energy security policies exploratory and adaptive. Hypotheses (or assumptions) guide policies, and monitoring and experimentation test the hypotheses. Adaptive managers develop formal processes for institutional learning and share the lessons learned.

APPLICATION

As an exercise in applying resilience theory and adaptive management, the following planning questions and policy are suggested:

1. How should one address resource base uncertainty, including quantity, quality, type, location, and ease of recovery? Develop hypotheses or sets of assumptions regarding these resource attributes and probe uncertainties, extending institutional knowledge of system boundaries. Monitor the “slow vari-

ables” associated with these resources—the system drivers—and manage interrelationships between variables.

2. How much time will it take to develop and implement service-wide Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) changes? Each element can be expected to respond at a different rate and on different scales. Resilience theory suggests that managing across scales is important. The service-wide transition must be managed on multiple scales, examining how changes in one element influence other elements.

3. What is the potential for, and effect of, subsystem collapses during a systemic transition in energy source? Resilience theory suggests that regime shifts from a perceived “stable state” to an unstable state, and “release” may proceed in an uncontrolled fashion. However, the state of the science does not yet support reliable predictions.

4. What do adaptive managers focus on during technology transformation to accommodate new and more sustainable energy demands? Ensure that the transition is monitored so as to learn as much as possible.

5. How should one plan for the availability of non-energy material resources needed to build new energy systems? Exploit multiple materials and sources so as to avoid a monoculture mentality and to elevate response diversity.

6. Will DoD be able to recognize and adjust to evolving conditions? Whether DoD can recognize and act may depend upon application of adaptive management principles—developing hypotheses to describe the situation and monitor, model, and even experiment with policies and programs, re-examining

these on a regular basis and adjusting policies appropriately.

ACTION PLAN

Resilience theory and adaptive management have real-world utility for addressing the threats to national security posed by uncertain and shifting energy resources. While broad, systems-level scrutiny is needed to address any highly complex problem, these tools provide the analytical framework necessary to develop truly sustainable solutions. In the case of energy, this involves assessing system health through an examination of strengths and vulnerabilities; delineating corrective measures for greater resiliency; developing adaptive management strategies to achieve and sustain that resilience; and creating a policy framework that provides durable support to adaptive management approaches. Notional approaches to these stages are as follows:

Step 1. Explore and Define the System.

Determine current thresholds in energy vulnerabilities and the forces and trends that would result in going beyond them. Recognizing the thresholds for critical energy variables and the forces that could push those variables past tipping points provides a basis for adaptive management planning and highlights the metrics to which plans must be pegged. This knowledge would also inform meaningful estimates of the time frames within which mitigation and response measures must be accomplished, the sensitivities of the interdependent metrics, and the approximate correlation between variables. Thresholds are deter-

mined by predicting the likely response of DoD mission capabilities to a broad range of realistic energy scenarios, including:

- Perturbations in the short- and long-term supply of conventional fuels;
- Slow and rapid depletion scenarios;
- Use of stored energy reserves;
- Introduction of alternate energy capabilities over realistic time frames;
- Interplay of energy demands and priorities posed across different missions.

A detailed analysis of past energy supply disruptions and successful anticipation, recovery, and adaptation solutions would prove beneficial in determining the significant linkages between specific system capabilities and inherent energy supply vulnerabilities.

A study, such as a table-top exercise, that explores these responses would expose gaps in knowledge about current defense energy dependencies. This knowledge would greatly enhance resilience planning, highlighting the levels of change possible and necessary, thereby realistically informing development of long-term sustainability policies. Finally, it would expose weaknesses in current assumptions about energy availability and the supposed resilience of the status quo, promoting greater openness to new energy strategies.

The research community should be charged with two supporting tasks. The first is to structure and present in an accessible manner what has been learned from application of resilience theory and adaptive management of natural resources, relating this knowledge to energy security. The second is to investigate the processes and variables thought to be important, critically

scrutinizing historical and current assumptions about system behavior. The detailed construction of such a program is beyond the scope of this monograph, but it should include a high degree of collaboration within and between members of the defense logistics and operations communities, energy experts, and the scientific community.

Step 2. Define Corrective Measures for Greater Resiliency.

Develop new energy strategies that address military capabilities and requirements based on knowledge of the vulnerabilities (identified in the previous step) and anticipated future defense requirements. For example:

- Develop models and decision-support tools to support dynamic adaptive management (rather than static management and optimization based on a quest for increased efficiency). These models should examine lifecycle impacts at multiple scales.⁷⁸
- Develop response diversity—a portfolio of options for meeting energy requirements—to build resilience.⁷⁹
- Avoid “perverse subsidies” that serve as disincentives for desired change or serve to degrade system resilience at larger scales.
- Tighten feedbacks between actions and reactions.

Step 3. Develop and Implement an Adaptive Management Approach.

Develop an adaptive management approach for defense resilience. This might include:

- Develop goals and metrics.
- Measure and manage key slowly changing variables that drive energy security system dynamics.⁸⁰
- Make decisions based on knowledge of where the system is within the adaptive cycle.
- Develop techniques used to anticipate, mitigate, and overcome energy supply disruptions.
- Develop potential mid-course corrective measures and alternative strategies.

Step 4. Develop Policies to Support Resilience.

Establish federal and defense department policies that promote resilience. For example:

- Embed the goal of increasing resilience within energy policy elements and guidance, such as *Executive Orders 13423 and 13514*,⁸¹ recommendations of the Defense Science Board,⁸² the DoD Energy Security Strategic Plan (currently under development), and the Army Energy Security Implementation Strategy.⁸³
- Expand the adaptive management framework (from the national down to the local scales) to include “exploratory policy development.”
- Remove command and control “pathologies” that decrease flexibility.⁸⁴
- Build institutional capital (financial, organizational memory, response diversity, capacity to innovate) that supports increasing resilience.⁸⁵

CONCLUSIONS AND RECOMMENDATIONS

National security is heavily reliant on the ready availability of energy resources in the types, quantities, and locations our military demands. However, global energy competition is rendering DoD missions increasingly vulnerable to even small perturbations in supply.

DoD's approach to energy security must accommodate to a highly uncertain outlook for energy resource availability, one of contracting oil supplies, increasing demand by the developing world, and decreasing production due to an aging infrastructure and tight financing for new facilities. However, DoD continues to function under the assumption that adequate energy supplies will always be available despite several energy studies that point to supply constrictions over the next 1 to 3 decades.⁸⁶

While U.S. energy needs are currently being met, the shrinking gap between global supply and demand draws the world closer to a tipping point that will adversely affect energy security. Given these concerns, DoD would be well served by devising and implementing a sustainable, resilient energy strategy that addresses current projections but also adapts to evolving conditions.

The energy world is rife with incomplete knowledge about the extent of resources (i.e., in Saudi Arabia, oil resource projections are a state secret). Instead of focusing solely on resource outlooks, better prospects for policy planning may be found in a realistic characterization of the military vulnerability posed by relying on a singular energy resource, and the curative value of a more energy-resilient posture.

Advances in ecosystem-based management of natural resources and sustainability science have yielded theory applicable to energy resource planning, offering fresh perspectives to inform energy security policy. Resilience theory provides a systems perspective, while adaptive management offers mechanisms for emphasizing institutional learning and developing an investigational approach to refining energy programs and policy.

Some recommendations to guide energy security policy include:

1. Employing an adaptive management framework for exploratory policy development.
2. Using scenario-based studies to envision the plausible bounds of change and motivate and inform planning and policy development.⁸⁷
3. Developing response diversity to build resilience.⁸⁸
4. Conversely, avoiding command and control pathologies that decrease flexibility.⁸⁹
5. Making decisions based on knowledge of where the system being managed (at multiple scales) is within the adaptive cycle.
6. Measuring and managing key slowly changing variables that drive energy security system dynamics.⁹⁰
7. Building institutional capital (financial, organizational memory, response diversity, capacity to innovate) to increase resilience.⁹¹
8. Developing models and decision-support tools to support dynamic adaptive management (rather than static management and optimization based on a quest for increased efficiency). These models should examine lifecycle impacts at multiple scales.⁹²

9. Embedding the goal of increasing resilience within energy policy elements and guidance, such as *Executive Orders 13423 and 13514*,⁹³ recommendations of the Defense Science Board,⁹⁴ the DoD Energy Security Strategic Plan, and the Army Energy Security Implementation Strategy.⁹⁵

10. Avoiding “perverse subsidies” that serve as disincentives for desired change⁹⁶ or serve to degrade system resilience at larger scales.

11. Tightening feedback between actions and reactions.

12. Considering “answers” to be questions, since viewing issues as having been solved diminishes program resilience, reduces options, and constrains flexibility going forward.

Finally, further research is required to address measurement and implementation issues in order to convert these concepts and the recommendations above into a successful managerial tool to build energy security resilience.⁹⁷

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