Program Research

STRATEGIC ART AND ENERGY: AN ALTERNATE ENDS-WAYS-MEANS VIEW

BY

COLONEL JOHN B. WISSLER
United States Air Force

DISTRIBUTION STATEMENT A:
Approved for Public Release.

USAWC CLASS OF 2007

U.S. Army War College, Carlisle Barracks, PA 17013-

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 JUN 2007	**Program Research Project**	**00-00-2006 to 00-00-2007**

4. TITLE AND SUBTITLE
Strategic Art and Energy An Alternative Ends-Ways-Means View

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
John Wissler

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army War College,Carlisle Barracks,Carlisle,PA,17013-5050

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

14. ABSTRACT
See attached.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**30**	

USAWC PROGRAM RESEARCH PAPER

STRATEGIC ART AND ENERGY: AN ALTERNATE ENDS-WAYS-MEANS VIEW

by

Colonel John B. Wissler
United States Air Force

Topic approved by
Colonel Patrick Cassidy

This PRP is submitted in partial fulfillment of the requirements of the Master of Strategic Studies Degree. The U.S. Army War College is accredited by the Commission on Higher Education of the Middle States Association of Colleges and Schools, 3624 Market Street, Philadelphia, PA 19104, (215) 662-5606. The Commission on Higher Education is an institutional accrediting agency recognized by the U.S. Secretary of Education and the Council for Higher Education Accreditation.

U.S. Army War College
CARLISLE BARRACKS, PENNSYLVANIA 17013

ABSTRACT

AUTHOR: Colonel John B. Wissler

TITLE: Strategic Art and Energy: an Alternate Ends-Ways-Means View

FORMAT: DDE Research Project

DATE: 9 May 2007 WORD COUNT: 5,439 PAGES: 26

CLASSIFICATION: Unclassified

With Hurricane Katrina, Americans tasted of a future defined by constrained energy supplies and a likely worldwide oil production peak sometime in the next 30 years. This paper will consider how energy should be viewed in a strategic context and takes the position that a truly strategic view must focus not only on energy supplies, but also on how and why the military uses that energy, particularly with regard to the systems it acquires. After briefly discussing the importance of energy to the United States and military operations, the paper then proposes an alternate Ends-Ways-Means approach that focuses on a three-pole construct comprised of effectiveness, efficiency, and energy. In this construct, one must take a systems perspective when it comes to analyzing and addressing military energy use. Because operational success is generally based on effectiveness, a balanced approach is needed in the quest to reduce energy consumption. This balance can be addressed in a variety of ways and this paper first develops a theoretical foundation, and then offers way of applying this theory, for example by lowering weight and applying the techniques of thermoeconomics to military problems. The paper breaks up energy use into warfighting and non-warfighting domains and expresses that the Effectiveness-Efficiency-Energy balance will be different in each domain.

STRATEGIC ART AND ENERGY: AN ALTERNATE ENDS-WAYS-MEANS VIEW

In 2005, Hurricanes Katrina and Rita severely affected the United States' petroleum refining capacity, causing gas prices to spike as high as $5 per gallon. In an instant, Americans got a taste of a new future defined by constrained energy supplies; the reality is that global energy demand is increasing at rates faster than global supply increases.[1] China, India, and other countries are rapidly increasing their consumption just as production from known oil fields is nearing a peak (known as Hubbert's Peak) which has been predicted since the 1950s with varying degrees of accuracy.[2] Furthermore, the rate at which new fields are being discovered, and the amounts of oil associated with those discoveries, are declining. While there is uncertainty as to when world oil production will begin to decline, it will likely occur in the next 30 years. The effects will be felt before then due to continually increasing worldwide demand.

Given the above, one should consider how energy should be viewed in a strategic military context. This paper contends that a strategic view must focus not only on the continued availability of energy supplies, but also on how and why the military uses energy. Taking this approach can then influence what the Department of Defense acquires in the way of weapon systems and how it uses those systems.

Background

To a large extent, energy dictates this country's foreign policy interests. It is a critical need for the United States even as other countries complain that the United States has 5% of the world's population but accounts for 22% of global energy use.[3] In short, energy is absolutely critical to the nation's prosperity. Because of its outstanding properties with respect to storage, energy density, and ease of use, the United States' meets many of its needs with petroleum. Tertzakian shows a strong, almost linear relationship between the United States' Gross Domestic Product and oil consumption and how this relationship underwent a sharp change after the 1979 oil shock; even after the shock, the relationship was still linear.[4] Fairness aside, the fact is undeniable, and the nation's well-being is tied directly to the availability and use of cheap, ubiquitous energy sources for transportation, food, defense, industry, and health.

Because energy is a vital national interest, the United States is compelled to remain engaged in places that have large oil reserves and/or the infrastructure needed to extract, transport, and process those reserves. For this the United States pays a high price economically, militarily, and politically.

As one of the instruments of national policy, the military operates where there are abundant oil reserves, e.g., the Middle East. As worldwide petroleum demand and availability diverge, it is likely the nation will take an even greater interest in regions that contain oil reserves. Unfortunately, these regions are often places of unrest, instability, and oppression located in remote parts of the world. If the nation is to be able to employ the military instrument of power to serve national needs with respect to securing energy resources, DoD must be capable of fielding forces that can quickly project thousands of miles, remain there for extended periods of time, operate with impunity, and dominate the battlespace.

Operating a predominantly petroleum-fueled force at such distances is expensive. Although it represents less than 2% of the nation's overall oil consumption, DoD is the single largest institutional user in the United States with an annual fuel bill of over five billion dollars. Within DoD, aviation is the largest user, accounting for over 70% of the DoD total.[5] Much of this cost is mobility-related (e.g., airlift and air refueling), as opposed to combat forces-related. Although DoD pays market rates for fuel, the real costs are considerably higher; in fact, some estimates are that it costs 10 to 100 times the market rate to actually get the fuel where it is needed, especially if it is to a remote location. The cost includes the fuel's price, as well as the transportation and infrastructure costs associated with actually getting it to the point of use. A 2001 Defense Science Board study noted that the cost of fuel delivered by Air Force tankers world-wide was $17.50 per gallon, not the approximately $1.00 per gallon that DoD paid for the fuel at that time. The fuel cost for forward deployed Army units was even higher, in the range of hundreds of dollars per gallon.[6] Thus, increases in fuel prices have a huge impact on the cost of operating at the extended distances characteristic of today's expeditionary forces.

Ends-Ways-Means

Given that energy is of prime strategic importance to the United States and is absolutely key to its prosperity and defense, it is prudent to consider how energy should be viewed with regard to strategic art. The Army War College defines strategic art as the "skillful formulation, coordination, and application of ends, ways, and means to promote and defend the nation's interests."[7] Thinking about ends, ways, and means in an energy context leads to one possible construct, shown in Figure 1, in which "Ends" represent what needs to be achieved (i.e., effectiveness at a mission or task), "Ways" describe how that end is achieved (i.e., efficiency in the use of resources), and "Means" represent what is actually used to achieve those ends (i.e., the energy that must be expended). Situated in the middle between these three poles is the system that DoD must develop, field, and use. This system can be the actual weapon or platform the acquisition system produces, or the interdependent commands and units that actually employ those weapons and platforms according to Combatant Commander direction.

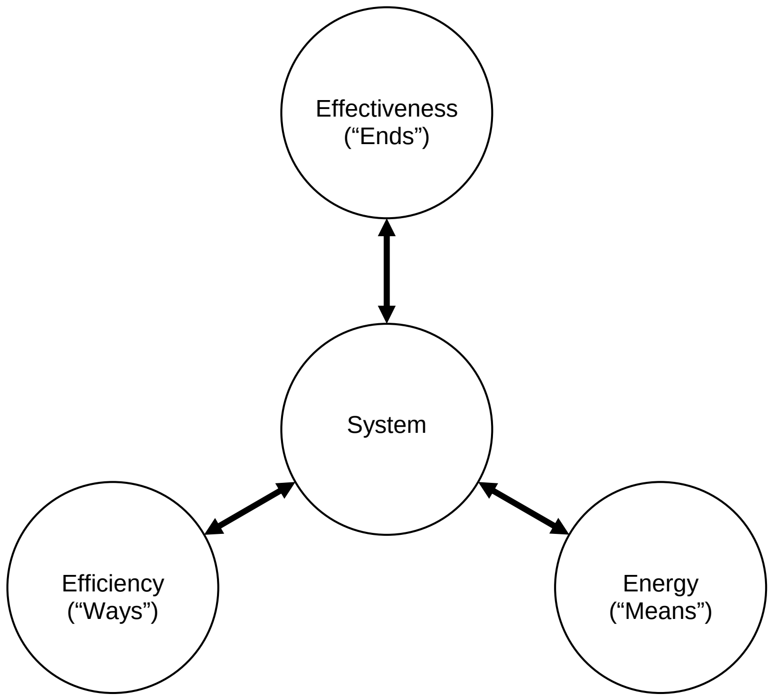

Figure 1-Three-Pole End-Ways-Means Concept in an Energy Context

For the acquisition, planning, and operational communities, this three-pole construct illustrates there are inherent tensions that need to be considered when developing weapon systems or planning and executing military operations. One cannot focus exclusively on one aspect of the problem (e.g., reducing energy expenditures, increasing efficiency, or improving effectiveness) to the exclusion of the other two aspects; a balanced approach is required.   For example, the drive for efficiency must not be done blindly. If one were designing an aircraft for maximum efficiency, one might end up with something like Dr Paul MacCready's Gossamer Albatross (see Figure 2), arguably one of the most efficient aircraft ever built because it flew across the English Channel using power generated by only one person. For ground vehicles, it would be hard to beat a bicycle, one of the most efficient means of transportation ever devised. However, the military utility of these highly efficient systems appears rather limited.

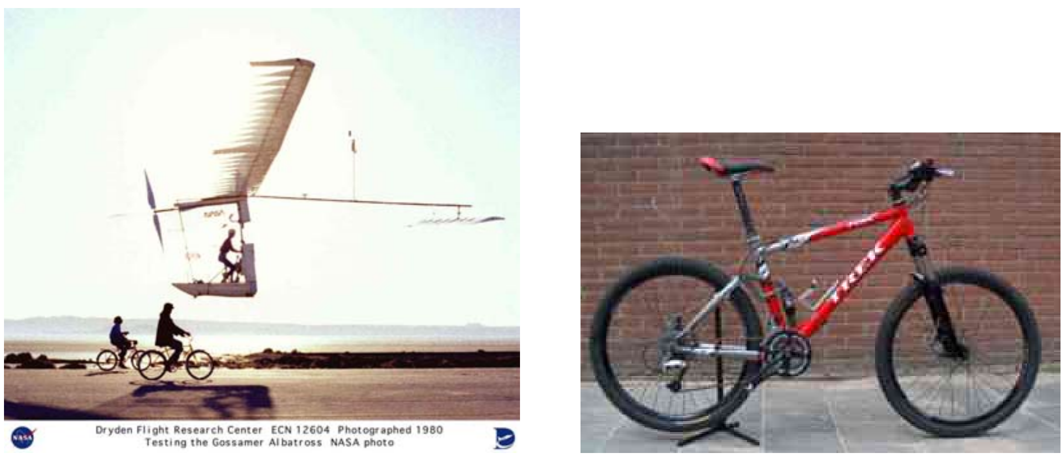

Figure 2-Gossamer Albatross and Bicycle, two of the most energy efficient machines ever built[8]

Warfare is an endeavor of absolutes, and the absolute requirement is mission effectiveness. Most combat systems, including those shown in Figure 3, dominate not because they are efficient users of energy, but because they are profligate users of energy. Using massive amounts of energy gives them the speed, maneuverability, and power to prevail. Having the most efficient fighter aircraft or ground vehicle may allow them to get to the fight, but that is for naught if their opponents outclass them.

Nonetheless, operating efficiently also enables systems to be affordable, particularly in times of increasing energy costs. Therefore, as the operational and acquisition communities begin to address the issue of increased energy costs, they will no doubt confront the tensions between energy input, efficiency, and effectiveness (Figure 1).

Figure 3-SR-71 and M-1A2 Tank, two of the least energy efficient, but most effective systems ever made.[9]

When the DoD acquires new weapon systems, it uses requirements that are usually reflected as Key Performance Parameters (KPPs). Because KPPs capture the most important characteristics desired by the user, they usually involve measures related to effectiveness (e.g., range, speed, protection, and payload) or sustainability (i.e., amount or level of maintenance required). It may be that some measure of energy efficiency, in addition to measures of effectiveness, will have to be included as a KPP on future weapon systems. In these cases, the tension between energy input, effectiveness, and efficiency will be acute.

If efficiency-related KPPs are in order, how does one define such a KPP? The thermodynamic definition of efficiency is the amount of useful work out of a system divided by the amount of energy that goes into a system.[10] However, the devil is in the details: exactly what is the energy into a system and the useful work out? For that matter, exactly what is the system in the first place? If we are dealing with a weapon system, is it the platform, the weapons carried on and fired by the platform, or the support systems, such as refueling vehicles, that must support the weapon? What if the system does not carry a weapon per se, but its effectiveness is measured in other ways?

To provide a framework for addressing these questions, it is useful to "go back to basics" and examine the meanings of energy, efficiency, and their constituent parts such as mass and velocity from the broad strategic viewpoint, without getting mired in details, many of which are the subject of debate not only in DoD, but also in the country.

Back to Basics

The subject of energy and how to use it efficiently while maintaining required effectiveness is a complicated question that has direct bearing on combat performance and the desired weapon system characteristics. Thinking in physical terms, because much of what armed forces do is physical, one can consider mass, velocity, and energy. Its energy (i.e., kinetic energy, KE) is proportional to its mass, m, and the square of its velocity, V. In mathematical terms this is expressed as:

$$KE = \frac{1}{2} m V^2 \qquad (1)$$

This means that big heavy objects going very fast have a large amount of (kinetic) energy and will require large amounts of energy to get them moving and usually to keep them moving. All else being equal, a heavy tank will require much more energy to move than a light armored vehicle. A large aircraft will use much more energy than a lighter, smaller one traveling at the same speed. A fast aircraft will require more energy than a slow one of the same size.

It is possible to plot Equation (1) as mass versus velocity squared showing lines of constant (kinetic) energy; Figure 4 displays the basics of the construct. Two curved lines are shown, each representing constant energy levels. The vertical axis represents mass and the horizontal axis represents velocity squared. Thus, as shown by the straight arrow, as one moves "outward," away from the origin, energy level increases.

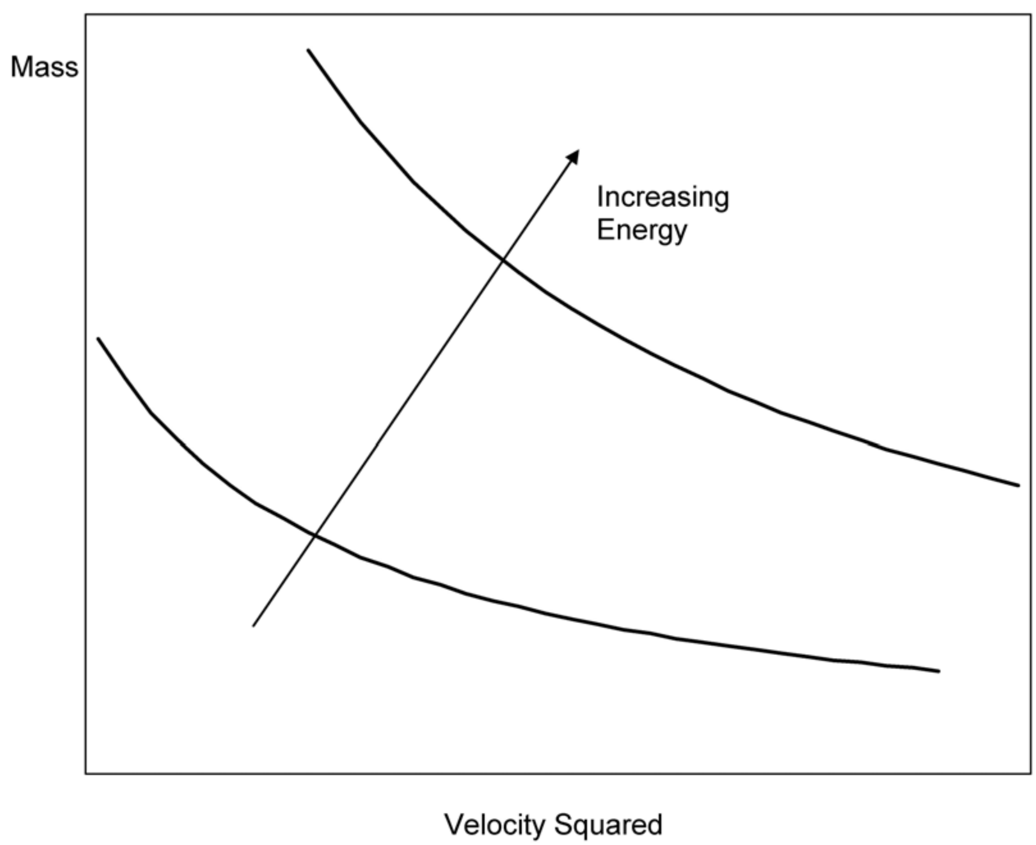

Figure 4: Plot of Equation (1)

Using this notion of lines of constant energy, one can consider a system of a certain mass moving at a given velocity. Nominally, such a system could be described by the energy line E_2 in Figure 5.   If one wanted to reduce this system's energy requirements and move from E_2 to a lower E_1, there are two basic choices: either reduce the system's mass or reduce its speed.

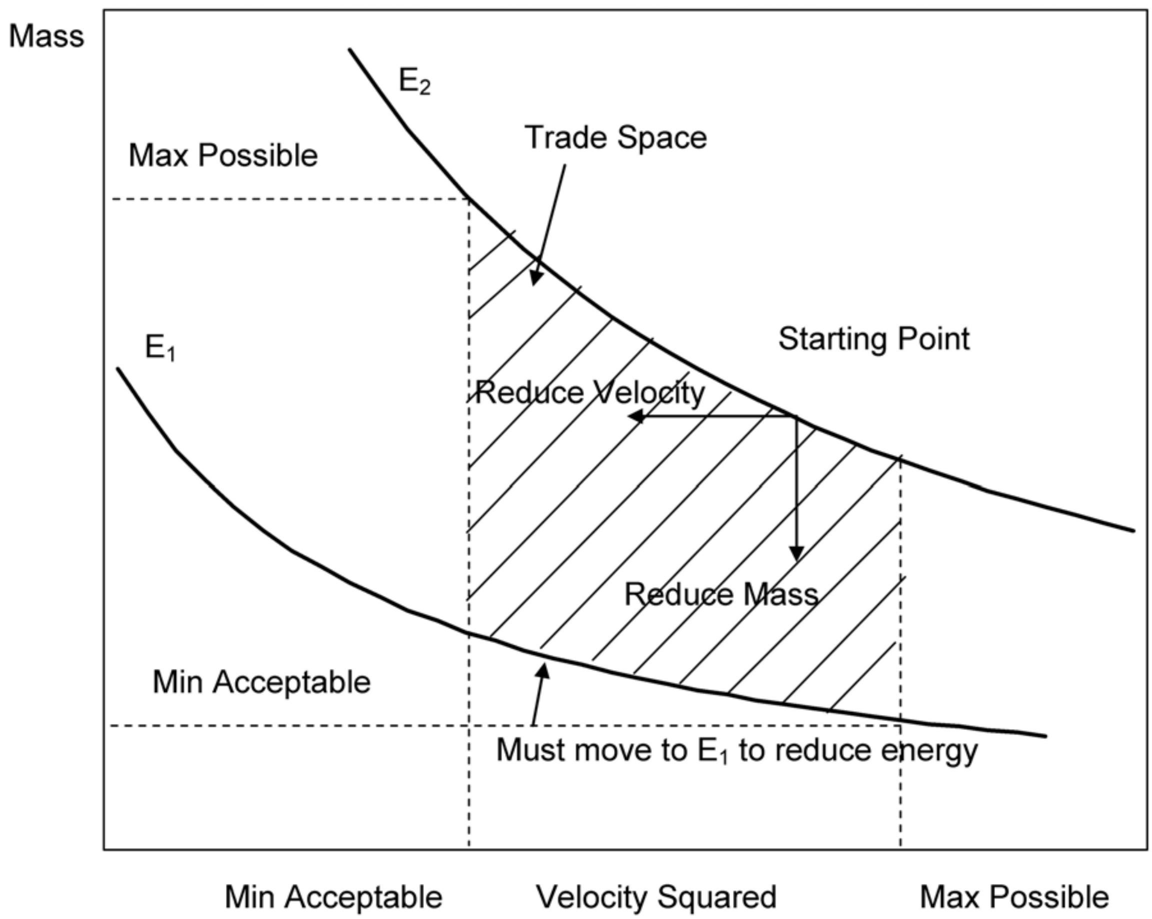

Figure 5: The Trade Space Defined by Equation (1)

In a sense, Figure 5 defines a trade space for different energy levels and allows one to consider the question "what's more important, mass, i.e., moving something substantial, or velocity, i.e., getting there quickly?" Mass is important because it is related to several variables of direct interest. It can indicate the level of protection; for example, heavy objects, perhaps made of hardened steel, generally have greater protection and survivability in the face of fires than light objects made of aluminum. In that sense, perhaps there is a minimum acceptable mass based on a requirement for protection and a maximum acceptable mass based on the need to have another system carry the system in question. Mass is also directly related to fuel capacity; larger, heavier systems might carry more fuel, thereby allowing them to range farther with greater persistence than systems that are lighter. Finally, if the goal is to transport something, heavier systems can usually have a greater payload than lighter systems.

Velocity (or velocity squared as displayed in Figures 4 and 5) is related to other characteristics of interest to the warfighter. It can indicate a weapon system's agility, because fast systems are generally able to move from one location to another more rapidly. Related to agility are such characteristics as responsiveness and coverage. Fast systems can be employed more quickly than slow systems against threats or to take advantage of opportunities. Thus, high velocity systems can allow their users to seize the initiative, to engage or disengage at will, thereby dictating the ebb and flow of combat.

Another way to consider energy is to focus on the Figure 1 construct and examine the trades between energy, effectiveness, and efficiency. Energy is related to the effort required to accomplish a task or mission, effectiveness is related to the reason that task is done, and efficiency is related to the endeavor’s “cost versus benefit.” Recalling the definition of efficiency, one can think of the relationship between the useful energy output of a system (E_{out}, or what was called useful work earlier), the energy input (E_{in}), and the efficiency (η) as displayed in Equation (2):

$$E_{out} = \eta E_{in} \quad (2)$$

The general form of Equation (2) leads one to the argument that the relationship between effort (analogous to E_{in}), effectiveness (analogous to E_{out}), and efficiency η is an inverse relationship as shown in Figure 6. From this, it follows that achieving more at the same efficiency requires more effort or energy while achieving more at the same level of effort or energy requires greater efficiency. Additionally, the relationships show that as one tries to achieve greater efficiency one faces diminishing returns or even hits a barrier; at some point, large efficiency increases get harder to achieve in terms of significant reductions in energy required.

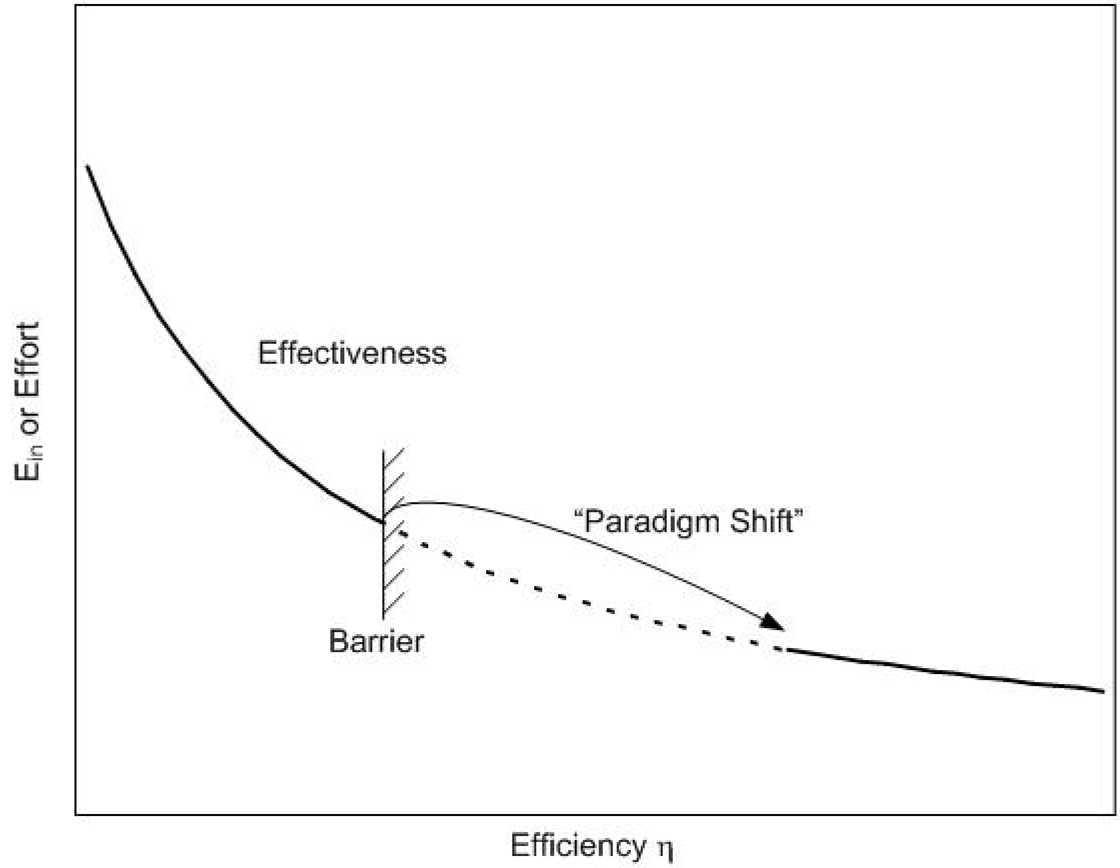

Figure 6-Plot of Equation (2)

In the larger picture, to achieve greater effectiveness with reduced energy input or effort, one must consider a paradigm shift that enables dramatic increases in systems effectiveness, driven by synergies that are unrealizable before the paradigm shift. However, the mathematics are inexorable; even with paradigm shifts, at some point it is difficult to realize large decreases in energy input even with large efficiency increases. At this point, one must consider the costs of achieving such efficiency increases versus the benefits of reducing the energy required. This leads one to the subject of system optimization using critical parameters (i.e., KPPs).

When optimizing systems and energy flows associated with those systems, it is important to consider not only the amounts of energy and how it is being used (sometimes referred to as a "1st Law Analysis"), but also the quality of the energy being used (sometimes referred to as a "2nd Law Analysis"). Much of today's debate centers on the amount of energy and the need to reduce it and increase efficiency, but the quality of the energy is equally important. For example, wind has immense amounts of energy as it flows over the earth, but it is very diffuse and disorganized, and is therefore difficult to concentrate and use. The concept of *exergy* speaks directly to this need for assessing the quality of the energy being used.

Exergy is the part of an energy stream that can be converted into other forms of energy, and is therefore highly usable.[11] Thermal energy has low exergy (i.e., the potential to convert energy into useful work), making it a poor candidate for energy conversion; an example of thermal energy is combustion, which is inherently inefficient.[12]

Tsataronis and Valero show that it is important to preserve exergy in an energy system. Analyzing an electrical power plant, they show the largest source of waste is not in rejecting the waste, but in the boiler's use of thermal energy for converting liquid water into steam.[13] This admittedly civil-oriented example points to the need for *thermoeconomic* analysis that systematically looks at all parts of a system.[14] While thermoeconomic analysis uses exergy as its main metric for analysis, ultimately the goal is to use energy efficiently while still meeting customer requirements. There is no reason why these techniques could not be applied to military systems.

Applying the Concepts in a Strategic Sense

When considering any system and its energy flows, it is important to define that system carefully and clearly. Weapons are complex machines, composed of a myriad of parts. In fact, most weapon systems are actually systems of systems; for true battlefield synergy and effectiveness each system must operate with other systems. For example, combat aircraft achieve maximum effectiveness only when they operate with air control aircraft and tankers in the air and with forces on the ground. Therefore, as discussed above, one must be careful about blindly increasing efficiency or reducing energy consumption of the components without first considering the system of systems in question and what its overall purpose is in the larger battle or operation.

Taking the above into account, and recognizing that weapon systems use energy to achieve an effect or accomplish a mission, one should begin by defining that mission or effect, and then seek an optimal solution in terms of energy expenditure.[15] In this manner, one can achieve the best Ends-Ways-Means alignment between effect, efficiency, and energy required.

Moorhouse and others have taken steps to adapt and apply thermoeconomic analysis techniques (to include using exergy as a key parameter) formerly applied to power plant design to aircraft design. Moorhouse, in particular, describes an approach that optimizes both reconnaissance and transport aircraft designs as a function of their exergy, thereby resulting in aircraft designs that are the most efficient.[16] Indeed, taking into account effects-based operations, one could conceive using a thermoeconomics-based methodology that seeks to minimize the amount of energy needed to achieve a mission effect. As one does this, one must be careful to first define the system, assess the performance requirements placed on that system (i.e., the effectiveness desired), develop a means of relating those requirements to the energy flows (using exergy as a variable), and then optimize for maximum efficiency or minimum energy required to achieve the effect desired.[17]

Another aspect of such analysis is that it allows one to consider harvesting waste streams of energy to power subsystems such as environmental controls. To some extent military systems already do this; examples are using the engine exhaust for heating the crew compartment and cooking food. However, every added feature has a cost and one must analyze whether that added feature is worth the cost. Typically, this cost is expressed in terms of procurement or acquisition cost, but the energy cost must also be considered.[18] In some cases, it may be better to let the waste stream happen because the cost to capitalize on and control it is too high.

When designing systems from an energy perspective, a key player that emerges from the overall analysis is weight. Based on the above discussion, unless one looks hard at reducing system weight, it is difficult to make huge improvements in energy use. Lovins' "super car" concept is based on drastic weight reduction.[19] Equation (1) above shows this; mass is just as important as speed squared (note that speed, because it is squared, has a greater influence on overall energy requirements).

In the case of automotive systems, only a tiny fraction of the energy used by the fuel system actually goes toward achieving the purpose for which the energy is intended (i.e., move the wheels, thereby propelling the payload forward). Ross shows that in the average American car, the purpose of which is to move people, only about 15 percent of the energy going into the tank as gasoline actually moves the car.[20] He shows that fuel consumption is driven by two main factors: the load the vehicle and its subsystems place on the power train and the efficiency of the power train itself.

In some cases, both efficiency and effectiveness may be possible. In these cases, one can conceive of designing the power train to handle not the peak load, as is typical, but for the average or cruise load, and including augmenter systems to provide peak power for acceleration. Indeed, this is what the hybrid automobiles do; they use a small gas engine for cruise speeds and augment it with an electric motor for acceleration.

Despite their different approaches, one common thread through Moorhouse, Ross, and Lovins is the centrality of weight to the overall issue of energy used, especially given that all three deal with systems that move. Because the cruising speed load is fairly small, major fuel savings can be achieved by making the vehicle lighter.[21] Assume for the moment that the military requirement is such that need for high velocity outweighs the need for protection, which classically implies mass (hence the debate between advocates of heavy armor and light armor). But, suppose one could get the same level of protection at reduced mass? What might be the interplay between effectiveness and efficiency? This might enable Figure 6's "paradigm shift." By reducing mass, one reduces the amount of energy required to move the system. If mass is reduced enough, then the amount of energy required drops to where drastically different types of motive power can be used. For example, if the system is lightened enough without sacrificing protection, then it needs smaller engines or perhaps a completely different engine type, thus allowing a trade of gas turbine engines for fuel cell-powered electric motors. The reducted energy required then ripples through the entire force, because if smaller amounts of energy are required, then less fuel must be transported.

Therefore, moving toward lighter systems is a viable option, perhaps via synthetic materials such as carbon-fiber that offer the potential for drastic weight reductions and the possible energy savings that accompany such weight reductions. Indeed, the Army's push towards lighter mechanized systems such as Future Combat System offers the potential for greatly reduced fuel consumption with mission-adequate mobility and protection. However, moving to such advanced materials presents other issues such as manufacturability and affordability. Although the automobile companies are working at using advanced materials in design and construction of new cars, it may prove difficult to reproduce these advances in economically viable quantities.[22]

The comparatively smaller DoD production runs may allow the use of advanced materials to enable drastic weight reductions in the name of high energy efficiency and effectiveness. Capitalizing on reduced weight, the Army and Navy are pushing toward electrically-driven vehicles. Direct electric drive promises to be more efficient while at the same time more effective. All-electric vehicles, possibly equipped with electrically-powered directed energy weapon systems and protection, can offer improved combat capability and flexibility over today's systems.[23]

Addressing the three-pole energy-efficiency-effectiveness issue in weapon system development is a complicated problem that potentially can be very expensive. The sheer number of variables also defies analytical approaches except in the most basic cases. However, by taking full advantage of modeling and simulation (M&S), developers can “wargame” energy cost and availability and its effect on military operations. DoD can develop new energy-related metrics and KPPs and assess their impacts on combat performance, much as the Army has used M&S to assess the impact of switching from its legacy heavy force to the lighter, more mobile Future Combat System. This would allow DoD to incorporate thermoeconomic analysis techniques that involve economic and thermodynamic considerations, to include using exergy as a key parameter of interest.[24]

One could argue that without officially-endorsed requirements, embarking on these efforts wastes time and money, and resources could be better spent on addressing “real,” more near-term, problems. However, although it may be outside the user community’s horizons, energy will be more constrained in the future. Therefore, as mentioned above, the time to assess impacts of the coming changes in the energy universe is now, with or without identified user community requirements. Results of such investigations can then inform the development of real requirements when the user is ready to begin defining them.

Operations and Maintenance Considerations

In the warfighting arena, the balance between efficiency and effectiveness must tilt towards effectiveness. An efficiency-based solution that may work on a stateside garrison base may not be optimal for an overseas or expeditionary base, particularly one is in a combat zone. Systems that must work in combat must be effective, with efficiency as a secondary consideration; effectiveness, based on mission requirements, must be the ultimate goal.

Today's systems will be in service for 30 years or more. Those in the acquisition pipeline now may be in operation even longer. Figure 7 shows a simple graphic of Hubbert's Peak; overlaid on it are the acquisition timelines for three of DoD's most expensive weapon systems. It is clear that "the horse has already left the barn" on these systems as they are already mostly designed and are in test or early production. Advanced lightweighting or power system technologies may not be viable options for these systems. Therefore, given the massive investment already made in these systems, any DoD energy strategy must accommodate them, or risk marginalizing that investment and further delaying desperately needed combat capability.

In these cases, it may be necessary to assure access to current types of fuels or their substitutes, perhaps via Fischer-Tropsch processing of biomass or coal. One might conceive of DoD fuel plants operated as government-owned, contractor-operated facilities, wherein DoD essentially supplies itself with its own fuel, much as it supplies itself with its own ammunition from Army Ammunition Plants or runs its own depots for refurbishing aircraft and tanks. However, such an approach would likely be extremely expensive, and a far better approach might be to build and subsidize a domestic capacity that would normally be used for civilian use, but could be tapped for critical military needs.

In other cases, simulators may reduce the need to consume fuel on training missions. For example, unmanned systems could offer ways to achieve mission effectiveness without the need to train operators *in situ*. Many unmanned systems such as the Global Hawk are not even directly controlled by the operator, who instead works through an interface by assigning tasks to the system, which then executes that task. For other unmanned systems, the operator uses synthetic vision as a way of interfacing with the system. In either case, the operator cannot tell if the system he or she is operating is real or simulated. Thus, for training, one need not actually operate the system. As DoD continues to capitalize on the coming revolution in unmanned ground, sea, and air systems, the requirement to operate those systems for training, thus consuming fuel, will decrease.

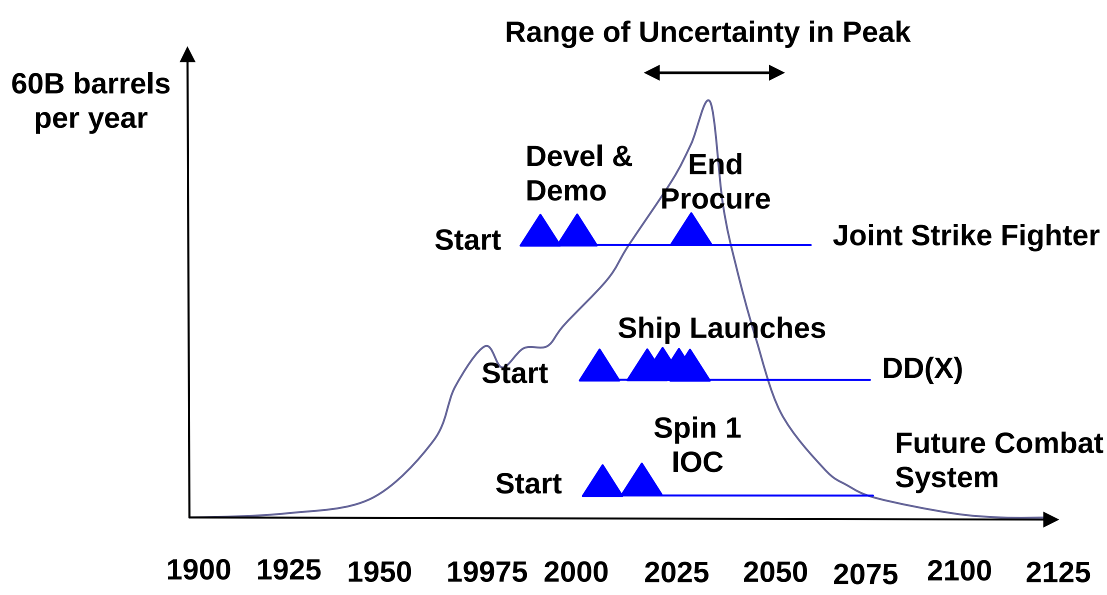

Figure 7-Hubbert's Peak overlaid with typical life cycle milestones from current acquisition programs.[25]

Even for manned systems, simulators are being used to achieve unprecedented levels of training fidelity. The Air Force is using them to greatly reduce training hours on its aircraft and has progressed to the point where simulators from widely separated bases can be netted together in a distributed mission training system.[26] In fact, while these measures save fuel, they also permit training that can only be achieved at great cost and effort because of the difficulty in bringing together the necessary assets in one location. However, not all training can be done in simulators which are most likely best suited for training on large, complex weapon systems that are netted together. For operations that require face-to-face interaction, judgment, and skill in difficult environmental conditions, such as counterinsurgency or special operations, simulators may be less useful. Fortunately, many of those operations and their accompanying training are much less fuel intensive than large force-on-force engagements.

The use of M&S has already been discussed as part of systems development to assess the impact of energy on KPP development. However, M&S, when combined with Effects-Based Operations (EBO) planning, can also be used to examine the role energy-based approaches can play in planning operations, while at the same time focusing on the effect one desires with the operation being planned. EBO "focuses on improving our ability to affect an adversary's behavior and/or capabilities through the integrated application of select instruments of national power," to include providing for "enhanced economy of force. "[27] The fact that EBO is an effects and systems-oriented approach makes it especially amenable to incorporating energy as a parameter in mission-planning. In this case, taking a cue from thermoeconomics, one would look for mission options that minimize the expenditure of energy while still achieving the desired effect, thereby achieving true economy of force and correctly aligning ends, ways, and means in a systemic fashion. For example, it may be that a single missile strike at the key node that embodies a critical vulnerability is the most energy efficient, better than any other course of action such as mounting a massive air strike or sending in a special operations team.[28] The point here is to use such approaches to *optimize* operations planning using energy as a key criterion, much as Moorhouse proposes using energy as a key criterion in systems design.

The consideration of effectiveness, energy, and efficiency for nonwarfighting systems, such as one might find on bases in the continental United States, offers a completely different set of options for systems designers. In these situations, efficiency can take a larger role. For example, DoD bases generally purchase electricity for all uses, using organic sources in emergencies for only critical needs (e.g., medical or air traffic control), DoD has begun making changes in this arena; for example, the Air Force is using "green" energy sources such as wind power to provide electricity to western bases.[29] As energy costs increase, DoD installation managers can increase the efficiency of new buildings and incorporate distributed energy production such as solar panels on roofs. One possibility might be for DoD to have its own version of the California Solar Initiative, which commits California to having photovoltaic systems incorporated on one million roofs over the next 10 years. This will result in enough renewable electricity to offset California's need for five new conventional power stations.[30] Finally, DoD can retrofit older buildings with energy efficiency measures.

In the transportation arena, most installations have a fleet of gasoline or diesel-powered vehicles, many of which travel only a few miles a day and never leave the base. One way to address energy efficiency and petroleum dependence is to convert these fleets over to alternative energy sources like flex-fuel and electricity, thus reducing energy requirements without sacrificing effectiveness. This is already beginning to happen; many bases now use what are essentially heavy-duty golf carts for applications that required a gas-powered pickup truck only a few years ago.

In both the infrastructure and transportation arenas, there is an opportunity for synergy between the civil/commercial and the military sectors of the US economy. As Hornitschek points out, DoD has often been a catalyst for change in American society.[31] In this case, as it saves taxpayer funds for higher priority activities, DoD can be a proving ground for the commercial marketplace as well as a market all by itself. Then, as the market develops, DoD can capitalize on the economies-of-scale to meet its needs for energy efficient non-warfighting systems. Such approaches would have to be backed up by policy changes that force DoD to account for the true cost of energy, and not hide much of the cost, as it conducts planning, programming, and budgeting.[32]

Conclusion

Reducing dependence on foreign sources of oil can have positive strategic and economic impacts. It would diminish the strategic importance of the entire Middle East, by making the United States less dependent on that troubled part of the world. It would also reduce friction points with countries such as China, with whom the United States will face increasing competition for energy sources. Finally, it would reduce the likelihood that the countries that control those sources will be able to dictate events and conditions to the United States. Energy is clearly a long-term DoD issue and will have a major impact on where DoD fights, when it fights, and with what it fights.

However, the issue is not simply about reducing energy use and increasing efficiency. Because of the high stakes that accompany military operations (to include life and death), one must also focus on effectiveness. This creates a tension between efficiency on one hand and effectiveness on the other, creating the need for approaches that seek an optimum solution appropriate for the mission at hand. It is necessary to balance the ends sought, the ways one achieves those ends, and the means used. In tomorrow's energy-constrained world, this can only be done by taking a systems level perspective that seeks to achieve a true strategic balance between effectiveness, efficiency, and energy.

Endnotes

[1] Adam E. Sieminski, "World Energy Futures," in Energy and Security: Toward a New Foreign Policy Strategy, ed Jan H. Kalicki and David L. Goldwyn (Baltimore, MD: The Johns Hopkins University Press, 2005), 21-22, 24, 48. See also, "Introduction," 2-3.

[2] Guy Caruso, "When Will World Oil Production Peak," presentation to the 10th Annual Asia Oil and Gas Conference, Kuala Lumpur, Malaysia, 13 June 2005

[3] Energy data from U.S. Energy Information Agency, http://www.eia.doe.gov/pub/international/iealf/tablee1.xls, 13 July 2006, accessed on 22 April 2007; population data from U.S. Energy Information Agency, http://www.eia.doe.gov/pub/international/iealf/tableb1.xls, 6 Oct 2006, accessed on 22 April 2007.

[4] Peter Tertzakian, A Thousand Barrels a Second: The Coming Oil Break Point and the Challenges Facing an Energy Dependent World (New York: McGraw-Hill, 2006), 105.

[5] Michael Hornitschek, "War Without Oil: A Catalyst for True Transformation" (Maxwell AFB, AL: Air War College, February, 2006), p. 20.

[6] "More Capable Warfighting Through Reduced Fuel Burden," Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms (Washington, DC: Defense Science Board, January 2001), ES-3, 16-18.

[7] Stephen A. Shambach, ed., Strategic Leadership Primer, 2nd Edition (Carlisle Barracks, PA: U.S. Army War College, 2004), 6.

[8] Mountain bike picture from Wikipedia, www.wikipedia.com, accessed on 25 February 2007. Gossamer Albatross picture from NASA Dryden Flight Research Center photograph gallery, www.dfrc.nasa.gov, accessed on 25 February 2007.

[9] M1A2 picture from www.globalsecurity.org, accessed on 25 February 2007. SR-71 picture from NASA Dryden Flight Research Center photograph gallery, www.dfrc.nasa.gov, accessed on 25 February 2007.

[10] H.C. Van Ness, Understanding Thermodynamics (New York, NY: Dover Publications, Inc, 1969), 35-36.

[11] George Tsatsaronis and Antonio Valero, "Thermodynamics Meets Economics," Mechanical Engineering (August 1989): 84.

[12] Marc Ross, "Fuel Efficiency and the Physics of Automobiles," Contemporary Physics, 38, no. 6 (1997): 363.

[13] Tsatsaronis and Valero, 85.

[14] Tsatsaronis and Valero, 86.

[15] David J. Moorhouse, "Proposed System-Level Multidisciplinary Analysis Technique Based on Exergy Methods," Journal of Aircraft, 40, no. 1 (January-February 2003): 11-12

[16] Ibid., 11-12.

[17] David M. Paulus , Jr, and Richard A. Gagglioli, "Rational Objective Functions for Vehicles," Journal of Aircraft, 40, no. 1 (January-February 2003): 27.

[18] Moorhouse, 14.

[19] Frank Field, "A practical road to lightweight cars," Technology Review, 100, no. 1, (January 1997): 29.

[20] Ross, 388.

[21] Ibid., 382-383.

[22] Field, 35-36.

[23] Geoff S. Fein, "Army and Marines Weigh Pros, Cons of Hybrid-Electric Vehilcles," National Defense Magazine (September 2003).

[24] Tsatsaronis and Valero, 84.

[25] JSF information from "Air Force Proposes Initial Joint Strike Fighter Locations," US Federal News Service, Arlington, VA, October 4, 2006, with additional information from Douglas Barrie, "Lightning Strike," Aviation Week and Space Technology, Vol 165 Issue 20, New York, NY, (20 November 2006), 44; FCS information from "Future Combat Systems Restructuring: A Balancing Act," US Federal News Service, Arlington, VA, 8 February 2007; DD(X) information available from http://peoships.crane.navy.mil/DDG1000/images/scheduleIV.jpg, accessed on 22 April 2007.

[26] "Synthetic Training Enables U.S., Coalition Forces To Play in Virtual Missions," C4I News (13 April 2006): 1.

[27] Commander's Handbook for an Effects-Based Approach to Joint Operations (Suffolk, VA, Joint Warfighting Center, 24 February 2006), I-1.

[28] Ibid*.,* II-2 to II-12.

[29] Environmental Protection Agency, Green Power Partnership Website, available from http://www.epa.gov/greenpower/partners/partners/usairforce.htm, accessed on 19 May 2006.

[30] Richard Chapo, "Governor Schwarzenegger Turns California to Solar Roof Systems," available from http://ezinearticles.com/?Governor-Schwarzenegger-Turns-California-to-Solar-Roof-Systems&id=130953, accessed on 10 June 2006.

[31] Hornitschek, 5, 73.

[32] Kip P. Nygren, Darrell D. Massie, and Paul J. Kern, "Army Energy Strategy for the End of Cheap Oil," National Defense Industrial Association paper available from www.ndia.org, accessed on 26 March 2007, pp. 5-6.