

Fire for Effect: Calling for a More Potent Energy System

**A Monograph
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AY 07-08

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

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|--|---------------------------|---|-----------------------------------|---|--|
| 1. REPORT DATE (DD-MM-YYYY) 18-04-2008 | | 2. REPORT TYPE AMSP Monograph | | 3. DATES COVERED (From - To) July 2007 – May 2008 | |
| 4. TITLE AND SUBTITLE Fire for Effect: Calling for a More Potent Energy System | | | | 5a. CONTRACT NUMBER | |
| | | | | 5b. GRANT NUMBER | |
| | | | | 5c. PROGRAM ELEMENT NUMBER | |
| 6. AUTHOR(S) Major Jonathan E. Jeckell | | | | 5d. PROJECT NUMBER | |
| | | | | 5e. TASK NUMBER | |
| | | | | 5f. WORK UNIT NUMBER | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Advanced Military Studies Program 250 Gibbon Avenue Fort Leavenworth, KS 66027-2134 | | | | 8. PERFORMING ORG REPORT NUMBER | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army Command and General Staff College 1 Reynolds Avenue Fort Leavenworth, KS 66027 | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) USACGSC | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | |
| 12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution is Unlimited | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | |
| 14. ABSTRACT The United States and its allies depend heavily on energy for their way of life and key capabilities in warfare. The current energy system has served us well for nearly 100 years, but is now shifting out of our favor and is creating strategic liabilities and tactical vulnerabilities. Our leaders are becoming increasingly concerned about these issues, but most of the attention is focused on alternative sources for the civilian economy. Some of these alternatives may not be suitable for expeditionary military forces deployed in distant theaters of war. This inquiry employed a confluence of technical and logistical analysis with an assessment of the strategic and political environment. This study not only examines what is technically and physically possible, but examines the way the energy is used, where it comes from, how the military distributes it, and how that impacts the range of desirable choices. These conditions create an opportunity for the military to fundamentally change the way it uses energy and make comprehensive changes to the way we sustain deployed forces. Rather than merely introducing an adequate substitute for oil, or using less of it, we should transcend our current energy system and unshackle our forces from the lethargic, vulnerable logistics infrastructure. Renewable power generation systems could immediately alleviate the largest single fuel burden for deployed ground forces, particularly remote outposts. Meanwhile mobile, tactical nuclear power generation could provide for all other ground energy needs, such as electrically powered or hybrid ground vehicles. This would eliminate bulk fuel requirements for ground systems, while water recycling and use of local resources would alleviate bulk liquid distribution requirements. This would reduce or eliminate our reliance on predictable lines of communication associated with delivering fuel to the last muddy mile, facilitate greater resilience, operational flexibility, agility, innovation and greater focus on strategic objectives. <u>It would also save countless lives.</u> | | | | | |
| 15. SUBJECT TERMS Energy, Renewable Energy, Sustainability, Fuel, Security, International Relations, Revolution in Military Affairs (RMA), Grand Strategy, Distribution, Expeditionary Joint Logistics, Operational Art, Tactical Power Generation | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON Stefan J. Banach, Colonel, US Army |
| a. REPORT (U) | b. ABSTRACT (U) | c. THIS PAGE (U) | | | 19b. PHONE NUMBER (include area code) 913-758-3302 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

SCHOOL OF ADVANCED MILITARY STUDIES

MONOGRAPH APPROVAL

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Title of Monograph: Fire for Effect: Calling for a More Potent Energy System

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Abstract

Fire For Effect: Calling for a More Potent Energy System by MAJ Jonathan E. Jeckell, US Army, 78 pages.

The United States and its allies depend heavily on energy for their way of life and key capabilities in warfare. The current energy system has served us well for nearly 100 years, but is now shifting out of our favor and is creating strategic liabilities and tactical vulnerabilities. Our leaders are becoming increasingly concerned about these issues, but most of the attention is focused on alternative sources for the civilian economy. Some of these alternatives may not be suitable for expeditionary military forces deployed in distant theaters of war.

This inquiry employed a confluence of technical and logistical analysis with an assessment of the strategic and political environment. This study not only examines what is technically and physically possible, but examines the way the energy is used, where it comes from, how the military distributes it, and how that impacts the range of desirable choices.

These conditions create an opportunity for the military to fundamentally change the way it uses energy and make comprehensive changes to the way we sustain deployed forces. Rather than merely introducing an adequate substitute for oil, or using less of it, we should transcend our current energy system and unshackle our forces from the lethargic, vulnerable logistics infrastructure. Renewable power generation systems could immediately alleviate the largest single fuel burden for deployed ground forces, particularly remote outposts. Meanwhile mobile, tactical nuclear power generation could provide for all other ground energy needs, such as electrically powered or hybrid ground vehicles. This would eliminate bulk fuel requirements for ground systems, while water recycling and use of local resources would alleviate bulk liquid distribution requirements. This would reduce or eliminate our reliance on predictable lines of communication associated with delivering fuel to the last muddy mile, facilitate greater resilience, operational flexibility, agility, innovation and greater focus on strategic objectives. It would also save countless lives.

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Introduction

The United States depends heavily on energy for many of our key advantages that provide for our prosperity and security. The hardest systems to change are ones perceived to be successful. The current energy system has served us well for well over 100 years, but is now shifting out of our favor, particularly when it comes to petroleum-based energy. Many of our leaders are becoming increasingly alarmed about our ability to access to this energy or the consequences, conflicts with our other priorities or costs of accessing them. While the nation examines alternatives sources of energy, some of these alternatives may not be suitable for deployed military forces.

This presents an opportunity for the military to examine the entire logistics infrastructure and the associated costs and risks. It should not use less fuel or merely replace oil, but transcend the current energy system. This is particularly true for ground forces. While they only consume about 15% of U.S. military energy, they impose the greatest indirect costs and risks associated with distributing fuel to the last muddy mile. Unshackling ground maneuver forces from ground lines of communication and large logistics bases and infrastructure would facilitate enormous operational flexibility, agility and innovation. It could also save countless lives on future battlefields and lead to greater focus on strategic objectives rather than housekeeping overhead.

Background and Purpose

The US and its allies have an opportunity to break out of a system that was once a major source of our advantages and fueled our prosperity, but is rapidly becoming a liability and a strategic vulnerability. However, the greater the perception that a system is successful, the harder it is to reform when conditions change.¹ The energy system that once served America and our

¹ Up to 2/3 of the History block in the Army Command and General Staff College curriculum dealt with the inter-war period and military revolutions, particularly Williamson Murray and Allan R.

allies well is now gradually shifting out of our favor. The uncertainty over fuel prices and availability could be problematic or lead to a catastrophic crisis in the near future. Concern about petroleum costs, security, availability, and environmental damage is building momentum to adopt alternative energy sources. American and allied military forces are overly optimized on a single energy source with increasing dependence on outside sources, which makes it vulnerable to any shock to the system.² Weapon systems procurement cycles now frequently require decades before fielding new equipment.³ Failure to reform, or at least diversify soon could result in sudden deprivation of key advantages during a crisis.

Millet's *Military Innovations in the Interwar Period*. (New York, NY: Cambridge University Press 1996), and MacGregor Knox and Williamson Murray's *The Dynamics of Military Revolution, 1300-2050*. (New York, NY: Cambridge University Press 2001). A recurring theme was the need for professional self-awareness and critical examination of perceived success to discern the real factors contributing to the result. Another recurring theme was the resistance to change due to perceived success, resulting catastrophic failure and dramatic reform. Huge volumes have been written about the logistical success, whatever the effort, in Operation Desert Storm, such as LTG Pagonis's *Moving Mountains: Lessons in Leadership and Logistics from the Gulf War* (Boston: Harvard Business Press, 1992), or US TRANSCOM's *So Many, So Much, So Far, So Fast: United States Army Transportation Command and Strategic Deployment for Operation Desert Shield/Desert Storm* (Joint History Staff of the Joint Chiefs of Staff, 1996). Several of these volumes led to real progress in logistics, but also emphasized the success through monumental effort to make the current system work. The CGSC history block also examined the relationships between changes in society and changes in warfare. Williamson Murray and Allan Millet's, *Military Innovation in the Interwar Period* (New York: Cambridge University Press 1996) and Knox and Murray in *The Dynamics of Military Revolution, 1300-2050* (New York: Cambridge University Press, 2001) examined military innovation and the impediments to change, including the perception of success. They posit that France's perception that it's "methodical battle" led to their victory in World War I stifled critical examination of the real dynamics of the battlefield and impeded reforms that might have precluded the disaster in World War II. Machiavelli once said "There is no more delicate matter to take in hand, nor more dangerous to conduct, nor more doubtful in its success, than to be a leader in the introduction of changes. For he who innovates will have for enemies all those who are well off under the old order of things, and only lukewarm supporters in those who might be better off under the new." (*The Prince*, Chapter 6, 1513)

² Dr. Anne-Marie Grisogono from the Australian Defense Science and Technology Organization gave a presentation to the School of Advanced Military Studies (SAMS, Ft. Leavenworth, KS) and noted how systems of monocultures are often more efficient and can optimize to their environment, but are much more vulnerable to shocks to the system and face catastrophic failure. Diverse and hybrid systems sometimes perform less efficiently, but offer resiliency and adapt rapidly to changes.

³ USAF Lt. Col Michael Hornitschek cites several examples of increasing life spans and design cycles for new weapons systems on page 3 of his Air War College thesis, *War Without Oil: A Catalyst for True Transformation* (Maxwell AFB, 17 February 2006).

Geopolitical conditions present an opportunity for the US military to fundamentally change the way it uses energy, but it must be cognizant of the strategic implications and range of acceptable choices. To understand energy, one must develop a systemic understanding of acceptable sources, how it is distributed, and how the user employs it. While government and industry leaders are beginning to take action to address the problem, most of the studies proposed focus on plans suitable for the civilian economy.⁴ This inquiry will briefly delve into the strategic, economic and political reasons driving this movement, which will inform the criteria for acceptable successors or supplements to the current system. It will highlight concepts with a linkage to strategy, not merely prescribe a single technical solution because the world energy market is a complex adaptive system. Portions of the system are opaque, the various elements are controlled by intelligent agents with decision making capability and their own separate interests, and have an imperfect understanding of the remainder of the system, if they even understand their own part. Solving this problem will involve a greater level of understanding of the dynamics of this complex system, not merely the technical specifications and thermodynamics.

Various perspectives shape energy choices, including sustainability, security, moral values, cost, and environmental impact. The US military must explore these options and ensure that strategic, operational and tactical requirements are satisfied for alternative sources to maintain or improve efficacy on the battlefield. This is not simply a technical, supply, or acquisition issue—one must also examine the system and anticipate second and third order effects on the strategic level, as well as impacts on readiness and capabilities at the tactical level. Moreover, leaders at all levels must understand and consider the relationship of energy in the way we plan for and execute logistics and the contemporary operating environment. It will also

⁴ Some of the studies cited here, such as USAF Lt. Col Hornitschek's "War Without Oil," and the studies conducted by the DoD Assured Fuels Initiative are good exceptions.

facilitate a better understanding of the energy system in relation to other environmental variables in the operating environment.⁵

Military innovation results from complex interactions with greater society, they do not happen in isolation and purely at the whim of military acquisition planners and strategic leaders.⁶ While military requirements may not drive the fuels selected for the civilian market, the consequences for employing a civilian fuel without consideration of tactical needs could be severe. The military alone spends \$10.6 billion on fuel a year and has billions more invested in infrastructure and equipment designed to use a particular kind of fuel.⁷ The military comprises about 1.5% of the US oil demand, which makes DoD the single largest consumer in the United States with some leverage in developing alternatives.⁸ Developing a substitute fuel directly

⁵ Systems of Systems Analysis (SOSA) is one tool employed by military planners, which examines the Political, Military, Economic, Social, Infrastructure, and Information (PMESII) systems at various levels to understand the operating environment. Leaders in Iraq and Afghanistan and not just the Army Corps of Engineers or other experts, have been deeply involved with planning and executing infrastructure projects. (MG Chiarelli and MAJ Patrick R. Michaelis, "Winning the Peace Requirement for Full Spectrum Operations." *Military Review* (July/August 2005).

⁶ Martin Van Creveld examined military logistics over time and highlighted its co-evolution with broader society in his book *Supplying War: Logistics from Wallenstein to Patton* (Cambridge: Cambridge University Press 1977). Clifford Rogers also examined the interactions between social, political, economic and technological changes in relation to changes in how the military fights and organizes in *The Military Revolution Debate: Readings in Military Transformation of Early Modern Europe* (Boulder, CO: Westview Press, 1995).

⁷ Defense Energy Support Center (DESC) *FY2005 Fact Book, 28th Edition* ([Online] available from <http://www.desc.dla.mil/DCM/Files/Fact05Revised.pdf>; Internet; Accessed 28 April 2008) pages 14 and 18. Page 11 of the Defense Science Board *Report of the Defense Science Board Task Force on DoD Energy Strategy* (Washington DC, February 2008) says this is now \$13.6 billion for 110 million barrels of fuel.

⁸ "The Role of Fischer-Tropsch Fuels in the US Military," a 30 August 2006 briefing by William E. Harrison III for the OSD Assured Fuels Initiative, slides 6 and 7 cites statistics aggregated from the DESC 2004 Fact Book, the 2005 DOE Annual Energy Review and fuel usage for other major fuel consumers demonstrating the Department of Defense is indeed the largest fuel consumer, with American Airlines tying the US Air Force at 3.2 billion gallons. Other large fuel users are the other major airlines and air cargo carriers. Lt. Col. Michael J. Hornitschek posits in his 17 February 2006 *War Without Oil: A Catalyst for True Change* that as the single biggest fuel consumer in the US and possibly the world, that the DoD possesses the market clout and ability to work with cutting edge technologies to catalyze transformation in the civilian energy sector (pages 1, 49, 56, 67, and C-3). He asserts that the large, monolithic DoD market and budget could act as a catalyst to transform energy usage in the civilian economy by developing and smoothing out high risk technologies. Examples he used were aircraft and jet engines, both of which debuted in the military and spread to the civilian economy after the technology

compatible with oil may not solve the constraints of an emergency unless it can produce sufficient quantities to completely offset imports for the entire economy. Contractors producing the replacement fuel would sell it for market price and would make it subject to same price volatility of imported oil in a crisis.⁹ Moreover, the complex nature of the energy system and the recursive aspects of its economics work against an actor as they move away from it. Reducing consumption or exploiting today's affordable alternatives can lead to reduced demand and reduced prices, leading to the selected solution becoming less attractive as it succeeds.

Finding an acceptable source is only part of the problem. Erstwhile acceptable civilian sources of energy may not be feasible to deploy and distribute on the battlefield. The military employs energy in more diverse and demanding environments and circumstances than mainstream civilian users, and therefore have unique requirements. Civilian infrastructure is static, and even the transportation system relies on fixed facilities, roads, bridges, and fueling stations. The military often operates in harsh, austere environments and must deploy an expeditionary, mobile infrastructure to be able to function. This is amply demonstrated by the aerial insertion of 1st Infantry Division's Task Force 1-63 Armor in support of 173d Airborne Brigade into Northern Iraq in 2003. This inquiry will re-examine that scenario, and substitute several other concepts for our current fuel distribution system to investigate the feasibility of alternate fuels and the potential for similar operational concepts with different logistics models.

matured, became more reliable, and became more affordable. Motor vehicles, nuclear power, and numerous medical breakthroughs were catalyzed by the military and adopted for civilian use. Finding number 3, page 4 of the January 2001 Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms *More Capable Warfighting Through Reduced Fuel Burden* (Washington, DC) was not so sanguine. It said that DoD's market share was not enough to drive the market, but demurred that DoD does have a role in testing, certification, and demonstration of fuel technologies.

⁹ Hornitschek, *War Without Oil*, pg 50-54 The military would presumably not own the alternate fuel source in this case, and would have to purchase the fuel in competition with the market. Unless the substitute fuel makes up a very large percent of the fuel market, it will not command prices, but will follow the dominant component driving the price of the commodity. Even if the contractors can produce the fuel at the current price of \$35 a barrel, they cannot be compelled to sell it for less than the market value of equivalent fuel as driven by petroleum prices.

The current logistics system was designed for linear battles with large rear areas for enormous logistics bases, and secure lines of communication for thin-skinned logistics vehicles to operate out of contact with the enemy. Fuel is normally the single largest commodity on the battlefield with mechanized or aviation-equipped forces. Fuel management receives enormous attention in combat because it is the biggest impediment constraining operations and most frequently causes forces to culminate prematurely, with numerous documented cases in recent history.¹⁰ It also receives special attention because of the specialized nature of tankers, which other platforms cannot supplement during shortfalls, as with most other commodities.¹¹

The US military should not merely substitute one fuel for another, it should re-examine the entire system to identify ways to leverage new capabilities with a new energy system. If future wars are more like Iraq and Afghanistan than like World War I, then reforming the

¹⁰ MAJ Bernard Moxley's School of Advanced Military Studies monograph, *Class III(Bulk) Distribution Successes: What Can Be Learned?* (US Army Command and General Staff College, Ft. Leavenworth, KS 2005) examines organizational and other changes between Operation Desert Storm and Operation Iraqi Freedom that led to greater reliability of fuel distribution to combat forces. MAJ Moxley recounts the frustration over fuel constraints in Desert Storm, which led to changes and intensive management of fuel distribution in Operation Iraqi Freedom to the detriment of other commodities. He cited LTG Pagonis's book *Moving Mountains: Lessons in Leadership and Logistics from the Gulf War* in which LTG Pagonis asserted that units ran short of fuel during that war. CPT Jason Miseli's article "The View From My Windshield: Just-In-Time-Logistics Just Isn't Working" (Sep-Oct 2003 *Armor Magazine*) sums up the perceptions of many Operation Iraqi Freedom veterans that if fuel distribution was considered successful, it probably came at the expense of other supplies. Logisticians normally focus their efforts on "35MM," or Class III Bulk (fuel), V (ammunition), Maintenance and Medical. Although that mnemonic does not include water, it also presents major management and asset challenges to logisticians. However, fuel has normally gotten the lion's share of emphasis. COIN environments, such as Iraq and Afghanistan also tend to consume more, less bulky small arms munitions, plus the increased use of precision guided munitions (PGMs) are projected to reduce ammunition requirements in the whole spectrum of operations as they seem to have done with aerial munitions.

¹¹ ISO shipping containers, the beds of regular trucks, flat beds, and so forth can move most other commodities. Specialized tankers are required to move fuel to contain the liquid cargo. Moreover, these tankers cannot be used interchangeably for other bulk liquid cargo, such as water, and must be certified regularly to verify they are capable of hauling fuel without contaminating it. At the lower tactical level, some units employ a recently fielded fuel container which can be hauled with an ordinary Palletized Load System (PLS) type truck, but one still requires a number of these the tanks, which are only good for this one activity, and that activity cannot proceed without them in the right place and time.

logistics system is critical to reforming the force to fight these wars.¹² The purpose of this study is to explore the possibility of leveraging this opportunity to make a comprehensive change to the logistics system rather than merely introduce a substitute. Can alternative energy sources and greater efficiency reduce military reliance on sea, air, and ground lines of communication (LOCs) and large, static Forward Operating Bases (FOBs) while maintaining combat efficacy? This study will examine employment of various alternate forms of energy and efficient practices to evaluate them against military requirements and situations. A disruptive innovation in military energy sources could present opportunities to improve other logistical functions along the way, because fuel comprises the single greatest transportation challenge for military forces.¹³

¹² Australian Brigadier Michael Krause asserts that US nuclear deterrence and peerless conventional superiority in makes it unlikely an enemy will play to American strengths and confront us directly, but will employ asymmetric means in *Square Pegs Round Holes: Current Approaches To Future Warfare And The Need To Adapt* (Working Paper No. 132, Land Warfare Studies Centre Working Papers, Australian Army, June 2007). GEN Sir Rupert Smith advised changes in the way we view and approach warfare in his talk at the Carnegie Council on 24 January 2007 (“The Utility of Force: The Art of War in the Modern World,” *Carnegie Council Podcast*, [Online] available from <http://www.cceia.org/resources/video/data/000025>; Internet; accessed 5 May 2008). GEN Sir Smith said traditional state based industrial warfare is becoming less likely, as wars among the people and confrontations become more prevalent. LTC John Nagl and Paul Yingling claim in a 13 February 2008 Council for Foreign Relations podcast entitled “Restructuring the US Military” (*CFR.org* podcast, MP3 file. [Online] available from <http://www.cfr.org/content/publications/media/podcast/2008/MilitaryRestructur020908.mp3> Internet; Accessed 14 February 2008) that adversaries are learning lessons from the wars in Iraq and Afghanistan and future conflicts will be more like them than conventional fights of the past. GEN James Mattis and Frank Hoffman’s November 2005 article in *Proceedings*, “The Future of Warfare: The Rise of Hybrid Wars,” and Lester Grau and Timothy Thomas’s discussion of the Russian experience at Grozny in “Soft Log and Concrete Canyons” (Foreign Military Studies Office, Fort Leavenworth, 1999) are also enlightening.

¹³ Clayton Christian defined two types of innovation in his book *The Innovator’s Dilemma: The Revolutionary Book That Will Change the Way You Do Business* (Boston: Harvard Business School Press, 1997). Sustaining innovation involves improving existing products and services that cater to core customers of an organization. Disruptive innovation initially do not appeal to the core customers and often initially have lower performance. However, sustaining innovations sometimes over-satisfy the needs of some customers and disruptive innovations may meet have other traits that new customers find appealing, like low cost, convenience, or other abilities that solve more than the initial problem that appeals to new markets. Dr. Christianson used minicomputers and personal computers versus mainframes, and hydraulic backhoes versus cable operated steam shovels as two of his examples.

Hypothesis and Criteria

Can the US military change its energy system to reduce its dependence on lines of communication while maintaining or improving efficacy on the battlefield? To answer this, we must examine acceptable sources, delivery, and how users employ energy. Rather than merely substituting one fuel for another, changing the energy system may have synergistic effects on other aspects of logistics and warfighting functions that will enhance combat effectiveness, security, and operational flexibility. The military requires energy sources capable of projecting into expeditionary theaters of operation, performing in the full range of operating environments, and reasonable costs to facilitate repetitive training. This inquiry will focus on the ability of an energy source to reduce or eliminate the need for deliveries to deployed forces.

Limitations

Engineers and scientists are making enormous efforts to develop new energy technologies, and political decisions are rapidly changing the landscape of this topic by making choices that affect the range of acceptable choices. Corporate laboratories are developing trade secrets that are not publicly available, nor is the inside information on ongoing political decisions or intentions. This study will only examine options feasible in the near future and will refrain from deep future “blue-sky” technology.¹⁴ It will also refrain from classified sources, which may narrow the research, but will promote wider availability of the results for implementation.

Experts still hotly debate many of the energy and environmental issues discussed here, such as climate change and Hubbert’s Peak (also known as Peak Oil theory), which predicts the

¹⁴ Examples of “blue-sky” technology include orbital solar power stations beaming energy down using microwaves, as found in *Army Logistician* January-February 2007 article “Energy on Demand,” by Dr. Keith Aliberti and Thomas L. Bruen. Another example involves on-board nuclear power plants for individual vehicles. Both of these are featured in Asher H. Sharoni and Lawrence D. Bacon’s January-February 1998 *Armor Magazine* article, “The Future Combat System (FCS): A Satellite-fueled, Solar-powered Tank?”

eventual failure to increase oil production followed by a decline.¹⁵ These assumptions and perceptions are included regardless of controversy or consensus because they shape the political discourse and outcome.

Moreover, the world energy system is a complex adaptive system, which impedes understanding this problem and precludes easy solutions. This dynamic system is comprised of intelligent actors with their own interests, perspectives, and perceptions of the status and relationships of the system, and the nature and dynamics of those relationships are subject to change spontaneously or in response to other actions in the system.¹⁶ Major portions of the system are opaque, especially because of the high stakes for people and even nations involved. For example, Saudi Arabia's real petroleum reserves are a closely held secret.¹⁷ True to this topic, professionals studying a complex adaptive system can and will disagree about how the system works and how to employ it. This system has a plethora of dimensions mingling the opinions of experts from a gamut of professions, including economics, technical, political and ecological, each with their own perspective and priorities. Portions of the system are completely outside the control of any actor within the system, such as weather, geology, and accidents, which further hinders understanding and control of the system. While energy seems like a purely technical issue, many aspects of this topic preclude technical, easy, or static conclusions.

¹⁵ Dr. Marion Hubbert expressed the concept of peak oil in his presentation *Nuclear Energy and Fossil Fuels* at a meeting of the American Petroleum Institute on 7-9 March 1956. [Online] available from <http://www.hubbertpeak.com/Hubbert/1956/1956.pdf>; Internet; Accessed 30 April 2008.

¹⁶ Dr. Robert Axelrod, and Dr. Michael D. Cohen's *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (New York, NY: Basic Books, 2000) discuss complex adaptive systems. BG Shimon Naveh Ph.D. employed the concept in developing the concept of Systemic Operational Design for military leaders to frame, understand and attempt to solve the correct problem. Dr. Anne-Marie Grisogono from the Australian Defense Science and Technology Organization focuses on adaptation to complex environments especially within military contexts.

¹⁷ Defense Science Board, *Report of the Defense Science Board Task Force on DoD Energy Strategy*, 2008, page 11

Organization

The first section of this inquiry explores the importance of energy to national power and why particular sources matter to deduce the relative importance of petroleum compared to other energy sources and its strategic liabilities. It will examine the prevailing schools of thought shaping, influencing and constraining energy choices, particularly for military forces and other organizations beholden to taxpayers. Next the inquiry will shift to the tactical vulnerabilities intrinsic in the current expeditionary fuel delivery and distribution system. It will examine a selection of replacement fuels and options for their suitability in military operations.¹⁸ This will explore ways that the US military can reduce its reliance on sea, air, and especially ground lines of communication (LOC) while maintaining combat efficacy. Finally, it will close with findings and recommendations.

Choosing Acceptable Sources

Why Energy Is Important

Energy is fundamental to the quality of our lives. Nowadays, we are totally dependent on an abundant and uninterrupted supply of energy for living and working. It is a key ingredient in all sectors of modern economies....Many things have changed the shape of the world we know and live in today. But underlying them all is an abundant and relatively cheap supply of energy. This fact underpins all of our economic activities as well as our leisure pursuits.

The European Commission Energy Research Division¹⁹

¹⁸ The air deployment of Task Force 1-63 Armor in support of 173d Airborne Brigade in Operation Iraqi Freedom will serve as a model for the type of operations this system should make more feasible. MAJ Brian Maddox's *Armor Magazine* Sep-Oct 2003 article, "Checkmate on the Northern Front: The Deployment of Task Force 1-63 Armor in Support of Operation Iraqi Freedom" discussed this operation. This task force conducted an aerial insertion of the 1st Infantry Division's Immediate Ready Force (IRC) consisting of a Medium Ready Company (MRC) and a Heavy Ready Company (HRC) into Northern Iraq in support of 173d Airborne Brigade. COL Fontenot and LTCs Degen and Tohn, *On Point: The United States Army in Operation Iraqi Freedom*, a 2004 Combat Studies Institute Press book, pages 79, 224, 229, and 231 provides the official Army history of the event.

¹⁹ The European Commission Energy Research Division, [Online] http://ec.europa.eu/research/energy/gp/gp_imp/article_1081_en.htm; Internet; Accessed 28 April 2008

The American way of life, our economy and our key advantages in war are predicated upon the intensive use of energy. The economy is an instrument of national power in its own right, and is a critical element in the United States' ability to shape the global system.²⁰ The military instrument of national power is constrained by the economic means and the political will. Economic power can be virtually unlimited, unthreatening in nature, and attract others willingly into our system.²¹ Therefore, the implications of energy resources are vital in themselves, not just in warfare. They are integral to national power and intrinsic in the American strategy of securing against war through economic cooperation and wealth creation through virtuous trade.²² The theory of this system posits that trade interdependence imposes an unbearable opportunity cost for pariahs or those who wage war on others in the system. So, large portions of US grand strategy tradition run counter to the notion of "energy independence."

²⁰ Joint Publication 1.0, *Joint Warfare of the Armed Forces of the United States*, 14 November 2000 defines the elements of national power with the DIME (Diplomatic, Information, Military and Economic) model. Kem, *Strategic Concepts*, pg 2 (CGSC book C202RC) on the US military of the elements of national power. John Mills, "All Elements of National Power': Re-Organizing the Interagency Structure and Process for Victory in the Long War," *Strategic Insights*, Volume 5, Issue 6 also discusses the DIME. See also the 2006 *National Security Strategy* pg 13 reference to Political, Security and Economic tracks of integrated activity in Iraq and Afghanistan.

²¹ The Center for Strategic and International Studies (CSIS) *Smart Power* project ([Online] <http://www.csis.org/smartpower/>; Internet: Accessed 30 April 2008)) discusses using so-called "hard power," of the DIME intelligently in concert with so-called "soft power." Soft power includes less tangible, attractive forms of power, as outlined by Joseph Nye in the 20 August 2007 Carnegie Council podcast *Soft Power: the Means to Success in World Politics*. [Online] available from http://media.cceia.org/carnegie/audio/20040413_JosephNye.mp3; Internet; Accessed 30 April 2008.

²² The 2006 *National Security Strategy*, Section VI explicitly links trade and economic cooperation with stability and promotion of democracy. Walter McDougal's *Promised Land, Crusader State: The American Encounter with the World Since 1776* (New York: Mariner Books 1997); Walter Russell Mead's *Special Providence: American Foreign Policy and How It Changed the World* (New York: Routledge, 2002) and *God and Gold: Britain, American and the Making of the Modern World* (New York: Borzai Books Published by Alfred A. Knopf, 2007); and Thomas Friedman's, *The Lexus and the Olive Tree: Understanding Globalization*. (New York: Anchor, 2000) and *The World is Flat: A Brief History of the Twenty-First Century. Release 2.0* (New York: Farrar, Straus and Giroux, 2006), highlight the importance of trade, which leads to relationships, which leads to the rule of law, which leads to democracy and stability. John Gaddis has a more skeptical take on this on page 78 of *Surprise, Security and the American Experience* (Cambridge, Massachusetts Harvard University Press: 2004).

Sustainable military superiority requires a strong, prosperous economy with reliable, continuous, inexpensive access to energy. In the classical Realism school of international relations, a strong economy drives technical innovation, business practices, and the ability to sustain a nation in a protracted struggle with long-term qualitative and quantitative advantages over rivals. More directly, the material wealth of the nation provides tools and manpower for the military.

Energy directly predicates nearly all of our advantages in warfare at the tactical level as well. In a long struggle with economic constraints or energy shortages, the military may face restrictions on training that would be deleterious to readiness. Affordable energy facilitates frequent, tough, realistic training with our equipment, which produces confident and competent warriors who are instinctively familiar with their equipment and tactics. It also refines and drives doctrine, technological development as lessons are learned off the battlefield. For example, US Air Force combat pilots normally fly about 200 hours a year to maintain proficiency, and the average Army brigade combat team annually conducts a rotation through one of the combat training centers.²³ Very few nations in the world can afford the opportunity to train this intensively because they are unwilling or unable to bear the fuel and maintenance costs;

²³ A 27 February 2008 *Air Force Link* article “Pilot reaches 1,000 combat hours flown” quotes USAF Lt. Col. Andy Uribe as saying US Air Force fighter pilots ordinarily get 200 flight hours per year, or 350 in times of combat. [Online] available from <http://www.af.mil/news/story.asp?id=123087914>; Internet; Accessed 1 March 2008. In comparison, GlobalSecurity.org cited a Defense Intelligence Agency report that Chinese and Indian fighter pilots—both relatively well equipped militaries compared to many, each get around 100 flight hours per year. “People’s Republic of China: People’s Liberation Army Air Force.” May 1991 via Globalsecurity.org [Online] available from <http://www.globalsecurity.org/military/library/report/1991/plaaf-ch21.htm>; Internet; Accessed 25 April 2008. Furthermore, a DefenseTech.org article on the combined US-India fighter exercise, COPE 2005 suggested the Indian fighter pilots’ flight hours were much higher than their neighbors. (Christian Lowe, “India 1, USAF 0,” Defensetech.org, 24 June 2004 [Online] available from <http://www.defensetech.org/archives/000976.html>); Internet; Accessed 15 April 2008. While part of this is due to maintenance costs, fuel costs make up a very large part of it. Page 5 of Representative Steve Israeli’s *Next Generation Energy Security Plan* says that an F-16 fighter can consume 23 gallons of fuel a minute, illustrating the energy intensity of US military equipment. [Online] available from <http://israel.house.gov/uploads/nextgen.pdf>; Internet; Accessed 30 April 2008.

ultimately they must learn their lessons on the battlefield. Simulations were introduced to supplement energy intensive, realistic training, but cannot replace it.

Moreover, weapons system development cycles often require over twenty years to complete, such as the F-22 fighter, the Future Combat System, V-22 Osprey, Littoral Combat Ship and next generation destroyers. The US military faces the risk losing our conventional superiority if the world energy situation changes in that timeframe.²⁴

Deploying, employing, and sustaining forces around the globe demands massive amounts of energy. The American way of war emphasizes rapid deployment, intensive use of airpower for air supremacy and shaping the battlefield. Ground combat employs dominant maneuver of mechanized or airmobile units in order to minimize our casualties. In counter-insurgency operations, the US military employs heavily armored vehicles and air mobility to protect our service members and gain every possible advantage against asymmetric threats. Our special operations forces rely on a variety of energy intensive platforms to insert, extract, sustain, and support them with fires. The US military almost takes air and sea dominance, not mere superiority, for granted as a prerequisite in US doctrine. This emphasis on air power in all forms of warfare underscores the criticality of energy. The fuel consumption statistics support this view. The US Air Force alone consumes 57% of military fuel, and aircraft across the entire Department of Defense consume 73% of the \$10.6 billion spent on fuel in 2005.²⁵

Regardless of the intensity of the conflict or the forces employed, the US military and most of our key allies rely on intensive energy consumption. Despite criticism and claims that the US needs more troops on the ground in Iraq and Afghanistan, the coalition seems to be

²⁴ Hornitschek, *War Without Oil: A Catalyst for True Transformation*, pg. 3

²⁵ The data came from the Defense Energy Support Center (DESC) *FY2005 Factbook*, 28th Edition; the analysis concept from Lt. Col Hornitschek's *War Without Oil: A Catalyst for True Transformation*, pg. 20. Page 11 of the 2008 *Report of the Defense Science Board Task Force on DoD Energy Strategy* says this is now \$13.6 billion for 110 million barrels of fuel.

substituting firepower and mobility for mass in accordance with our doctrine.²⁶ This concept would not even be conceivable without the vast advantages the US military enjoys due to our energy intensive form of warfare. USAF Lt. Col. Michael Hornitschek examined the consequences for the US military operating in a various fuel-constrained environments; he noted that at best US forces would fight without key enablers, and at worst would face a level playing field with much higher risk and casualties.²⁷ The most obvious consequence predicted was loss of ubiquitous and plentiful airpower and the accompanying inter- and intra-theater airlift, C4I, air interdiction, close air support, and a multitude of other key advantages. A plethora of other more subtle, but equally important problems would plague such an expeditionary force. Lt. Col. Hornitschek also noted that the risk to omnipresent contractors and the civilian logistics infrastructure is under appreciated, and would cause even further erosion of capabilities and advantages.²⁸

Of course, the entire civilian economy that supports our whole system would also be in peril. A disruption to the flow of energy would have extremely serious consequences for all elements of national power. Some of these disruptions have nothing to do with rivalry or malice, such as weather, supply constraints or accidents. So-called “strategic stockpiles” provide a buffer for emergencies and short-term operations, but the US military must be capable of protracted operations in any contingency. While the economy is the root of American power, it is far more resilient and adaptable than the US military to sudden changes to the energy system.

²⁶The 28 January 2004 *PBS Frontline* episode, “The Invasion of Iraq: The Interviews,” with James Fallows, discussed GEN Shinseki’s assertion that over 400,000 troops were required in Iraq. (Transcript- [Online] available from <http://www.pbs.org/wgbh/pages/frontline/shows/invasion/interviews/fallows.html>; Internet; Accessed 25 April 2008.) Despite discussion since 2003, the US has not decided to deploy anywhere near that many troops to Iraq. Either leaders believe the current strategy of substituting local forces and our superior mobility and firepower will work, or we are unwilling or unable to deploy that number with our current political will, or a combination of these factors.

²⁷ Hornitschek, *War Without Oil: A Catalyst for True Transformation*, pp 21-22

²⁸ Hornitschek, *War Without Oil: A Catalyst for True Transformation*, pp 17-18

The Impetus to Change the System

Keeping America competitive requires affordable energy. And here we have a serious problem: America is addicted to oil, which is often imported from unstable parts of the world. The best way to break this addiction is through technology....new technologies will help us reach another great goal: to replace more than 75 percent of our oil imports from the Middle East by 2025.

President George W. Bush, 2006 State of the Union Address²⁹

Oil is often called the lifeblood of our economy-the indispensable commodity that keeps commerce humming and America on the move. But, in today's world, our dependency on foreign oil and the way we use hydrocarbons is a major strategic vulnerability, a serious threat to our security, our economy and the well being of our planet.

Senator John McCain³⁰

Of course, many Americans have gotten this point, and it's true that the call for energy independence is now coming from an amazingly diverse coalition of interests. From farmers and businesses, military leaders and CIA officials, scientists and Evangelical Christians, auto executives and unions, and politicians of almost every political persuasion, people are realizing that an oil future is not a secure future for this country.

Senator Barack Obama³¹

What could be more dysfunctional than borrowing money from China to fund defense budgets that pay Persian Gulf states for oil to power our military to defend us from China and Persian Gulf instability?

Representative Steve Israel³²

Concerns are arising over energy. Perceptions are forming that this vital system that predicated our key capabilities is shifting out of our favor. Every 2008 Presidential candidate has

²⁹ President George W. Bush, the *2006 State of the Union Address*

³⁰ Senator John McCain's 23 April 2007 speech at the Center for Strategic and International Studies on the CSIS *Decision 2008* podcast. [Online] available at http://media.csis.org/podcast/070423_mccain.mp3; Internet; Accessed 30 April 2008.

³¹ Senator Barack Obama gave a speech at Chicago, Illinois on 3 April 2006 entitled *Energy Independence and the Safety of Our Planet*. Transcript-[Online] available from http://obama.senate.gov/speech/060403-energy_independ/; Internet; Accessed 10 April 2008.

an energy plan, as do many congressmen, think tanks, and experts in a wide variety of fields.³³

The emphasis of these energy plans varies and includes the following prevalent themes:

sustainability, security, morality, ecology, and economic cost, as depicted by the first five lenses in Figure 1. These themes are not comprehensive, exclusive or monolithic, and coalitions form among subscribers of these disparate schools when their interests coincide, but they are also frequently in disagreement and competition, as different lenses have different characteristics.

Each group struggles with internal conflicts as well, as parties within take different perspectives on the same priority, as different portions of a lens refracts light differently. Coherent patterns at the correct focal length of a properly shaped lens produces a clear image, and combinations of lenses, in a telescope for example, make clear images of objects when the various lenses are properly focused together. Likewise, the more the system coincides with the interests of these five constituencies, the more likely it will be adopted, especially when it comes to government funding. The spectra and clarity of our petroleum based fuel system are shifting out of favor for the US as depicted by the expanding breach between production and consumption, representing strategic liabilities.

³² Representative Steve Israeli's 29 August 2006 draft of the *Next Generation Energy Security Initiative*, page 12

³³ Christine Parthemore wrote "Balancing The Energy Debates" for the Center for a New American Security on 4 February 2008. [Online] available from <http://www.cnas.org/en/art/?379>; Internet; Accessed 30 April 2008. A sample of these plans includes Representative Steve Israeli's, *Next Generation Energy Security Initiative*, the products available from the Securing America's Future Energy organization, and the Center for a New American Security *Solarium II* project. [Online] available from <http://www.cnas.org/solarium2/>; Internet; Accessed 30 April 2008. Senator John McCain's and Governor Mike Huckabee's *Decision 2008* Center for Strategic and International Studies podcast interviews spent extensive time discussing their proposals for energy. Numerous feature articles in *Scientific American* focus on energy, including an entire special issue dedicated to the topic in September 2006 entitled "Energy's Future Beyond Carbon."

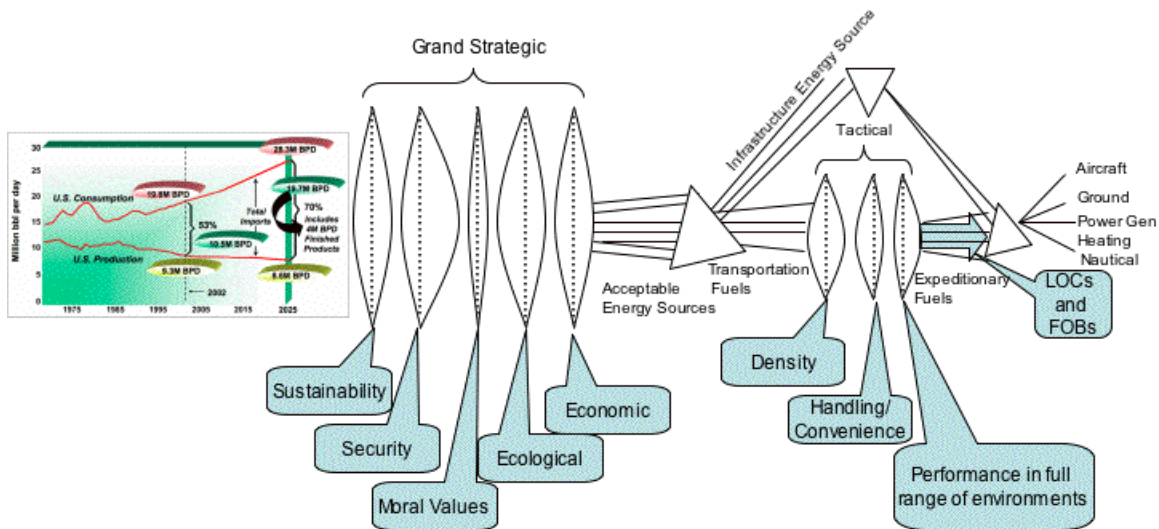


Figure 1: Examining energy through an expeditionary lens.³⁴

The prism differentiates the different ways we use energy, such as transportation fuels, electrical power, heating, etc. from the available acceptable choices. The second set of lenses depicts desirable characteristics for transportation fuels, which currently provides the vast majority of US military energy. The military logistics system must ship these fuels to forward deployed locations, usually by ship and then by tanker truck to the user. For ground combat forces, these trucks must run the gauntlet of enemy fire and efforts to disrupt coordinated delivery to combat forces. Not only are these fuels used for vehicles and aircraft, but also for heating and power generation as well.

Comprehending the whole system systemically reveals the strategic liabilities and the tactical vulnerabilities of the current system. It also aids in envisioning systems that coherently align strategic aims and perceptions of the major constituencies with tactically favorable systems. Failure to satisfactorily articulate changes to a replacement energy system to these major constituencies will result in resistance, and failure to address the unique tactical requirements of deployed military forces will result in increased risk.

³⁴ Consumption gap graph courtesy of John Winslow, US Department of Energy, from Energy Information Agency (AEO 2004) Reference Case Scenario

Sustainability—finding renewable alternatives

This theme focuses on sustainable resources because of concerns about resource exhaustion. People in this camp emphasize efficient practices and renewable energy supplies, such as wind and solar, although other fuel sources with longer projected availability, such as coal will satisfy others in the interim.³⁵ There is also considerable debate and disagreement in this theme about the sustainability of and potential yield of bio-fuels, such as ethanol and biodiesel.³⁶

³⁵ The BP 2007 *Statistical Review of World Energy* ([Online] http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2007/STAGING/local_assets/downloads/pdf/coal_section_2007.pdf; Internet: Accessed 30 April 2008 page 32) estimates the US has 27% of the world's proven reserves, or 234 years worth of coal at current consumption rates. Ben Kenney in episode 71 of the Watt podcast calculated this would actually only be about 51 years worth factoring in the rate of increased consumption. [Online] available from <http://www.podtrac.com/pts/redirect.mp3?http://media.libsyn.com/media/thewattpodcast/tWP71-2008-02-08.mp3>; Internet: Accessed 30 April 2008.

³⁶ One of the controversies over biofuels involves its sustainability. The measure of the amount of energy put into making the fuel versus the amount the fuel yields is known as the energy balance. Examples of energy inputs are fertilizers and pesticides made with natural gas or coal, petroleum fuels for tending and transporting the crop, and natural gas for the distillation process. Most agree that the carbon and energy balance for biodiesel is quite good, and that cellulosic ethanol (made from switchgrass, corn stalks, willow, or other woody plant parts) probably is as well. Corn ethanol has been the center of a furious debate over its energy and carbon benefits. The University of Minnesota conducted the most definitive study on biofuels "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," which was presented in the 2 June 2006 *Proceedings of the National Academy of Sciences*. It holds that corn based ethanol gives a 25% energy gain, while biodiesel will give a 93% energy gain. The study also held that ethanol could only displace 12% of current gasoline used in the US even if 100% of the corn is used. Switchgrass and other cellulosic sources would do three times better but still cannot totally displace current gasoline consumption. Biodiesel promises far greater potential for petroleum displacement due to the ability to make it using algae grown in bracken water or unused land, as suggested in the National Renewable Energy Lab's report "A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae." (Golden, CO: National Renewable Energy Laboratory, U.S. Department of Energy, July 1998. [Online] available from <http://www.nrel.gov/docs/legosti/fy98/24190.pdf>; Internet: Accessed 30 April 2008.) According to this study, 2% of the land area in the US, including non-arable land, could meet all transportation fuel needs. This study suggested raising a specific species of algae on an area flooded with bracken water in the desert Southwest known as the Salton Sea. Other sustainability examples with ethanol includes a 28 February 2008 article by *The Economist* entitled "Ethanol and Water Don't Mix: New reasons to be suspicious of ethanol," which mainly cited water usage as an issue. The 28 February 2008 episode of *Inside Renewable Energy* podcast entitled "Conflicting research on renewables," ([Online] available from <http://www.renewableenergyworld.com/rea/news/podcast?id=51686>; Internet: Accessed 30 April 2008.) and an 18 January 2008 *International Herald Tribune* article by Elisabeth Rosenthal entitled "States roll back subsidies for bio-fuels" cited other concerns. Some experts are linking biofuel production to increased food prices. The *Stratfor Daily Podcast* for 15 April 08 "Agriculture: France Canvases More

Petroleum presents their most pressing concern because it is the only energy source that realistically has a near term supply concern.³⁷ Petroleum is a finite, non-renewable resource, which will one day run out.³⁸ Before that happens, according to Hubbert's Peak, or Peak Oil theory, discovery of new oil fields and production will cease to increase and gradually begin to decline.³⁹ The US has long been blessed with an abundance of natural resources, and had sufficient domestic sources of energy until around World War II, when only about one eighth of our wartime fuel came from foreign wells.⁴⁰ However, US interest in foreign sources of

Subsidies" ([Online] available from http://www.stratfor.com/audio/download/114745/20080415Stratfor_Daily_Podcast-EDITED.mp3; Internet; Accessed 30 April 2008) quoted UN Special Rapporteur for the Right to Food Jean Ziegler's comment on the German radio station Bayerischer Rundfunk that producing biofuels is a crime against humanity because of its effect on food prices. Others such as Austin Bay, have suggested a more complex relationship, and that higher fuel prices are also driving food prices because of the expense of growing crops, as well as the rising demand from growing middle class affluence in India and China.

³⁷ Lt. Col. Hornitschek includes a table of expert predictions for peak oil on page 8, Figure 3-36, of *War Without Oil* taken from an EIA presentation by Guy Caruso "When Will Oil Peak?" Meanwhile the 2007 BP *Statistical Review of World Energy* estimates of 234 years of coal remain in US (27% of world proven reserves). Web searches for "Peak Oil" will yield thousands of websites, blogs and books dedicated to the subject, but very little such discussion about any other energy source. Numerous oil experts, such as the CEO of Total, one of the biggest oil companies, discussed predicted output shortfalls with *Financial Times* correspondent Ed Crooks in the 31 October 2007 article "Total chief warns on output."

³⁸ Naturally occurring petroleum results from organic material buried within certain rock formations exposed to high heat and pressure over geologic timeframes (30-150 million years). High oil prices have made unconventional methods of oil recovery, including extraction from tar sands and oil shale feasible. This is one of the major sources of oil for Canada, which is currently the largest foreign oil source for the US according to the US Department of Energy's Energy Information Agency (EIA). Information about the Alberta tar sands can be found [Online] <http://www.energy.gov.ab.ca/OurBusiness/oilsands.asp>; Internet; Accessed 30 April 2008, or at the Argonne National Laboratory site *Tar Sands Basics* [Online] available at <http://ostseis.anl.gov/guide/tarsands/index.cfm>; Internet; Accessed 30 April 2008. Companies in the US are exploring this process with abundant American oil shale and tar sands as well. These resources may give a temporary reprieve, but even with these vastly expanded sources will inevitably deplete as well, and most of this camp would recommend focusing on truly sustainable sources.

³⁹ Hubbert, *Nuclear Energy and Fossil Fuels*. Dr. Hubbert developed the theory of peak oil, where production ceases to increase and gradually begins to decline.

⁴⁰ The secondary source for this was Lovins, *Winning the Oil Endgame*, page 84, which cited D.S. Painter's entry "Oil" in the 2002 *Encyclopedia of American Foreign Policy* and M. Claire's 2004 *Blood and Oil: The Dangers and Consequences of America's Growing Oil Dependency* (New York: Metropolitan)

petroleum began earlier, in the early 1920s due to growing concern about the eventual depletion of domestic resources and concerns about a European monopoly elsewhere.⁴¹

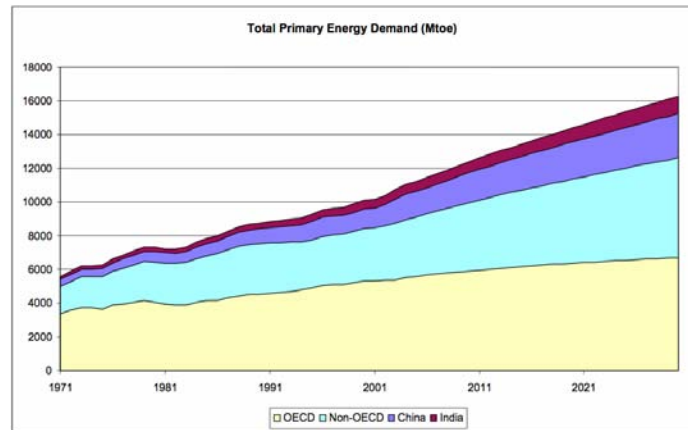


Figure 2: World energy demand will escalate substantially, particularly in non-OECD countries, especially China and India. (from bottom to top the layers are OECD, non-OECD, China and India).⁴²

Even without actual peak or depletion of energy sources, scarcity concerns arise from a 50% projected increase in demand in the next 25 years, especially from skyrocketing demand in the developing world that is rapidly outpacing production.⁴³ 70% of that growth came from

⁴¹ Bernard Lewis discussed the beginning of the relationship between Standard Oil Company and the Saudi Royal family on pages 126-127 of *The Crisis of Islam: Holy War and Unholy Terror* (New York: Modern Library, 2003). Steve LeVine's 1 November 2007 University of Chicago *World Behind the Headlines* podcast interview on his book *The Oil and the Glory The Pursuit of Empire and Fortune on the Caspian Sea* also discusses early American involvement in the development of the Baku oil fields in Azerbaijan. [Online] available from http://feeds.feedburner.com/~r/WorldBeyondTheHeadlinesFromTheCenterForInternationalStudiesAtTheUniversityOfChicago/~5/244757056/wbh_levine_128k.mp3; Internet; Accessed 30 April 2008. During World War II and the Cold War the US lost access to these oil fields due to Soviet influence. The US and other Western nations are competing there again, but Russian views that this is their sphere of influence causes tension.

⁴² Chart from slide 18 of the briefing given in Beijing in 2006 entitled "China and India's Energy Development in Global Perspective" by Yo Osumi, head of the Asia-Pacific and Latin American division of the International Energy Agency. [Online] available from http://www.iea.org/textbase/speech/2006/yo_apec.pdf; Internet' Accessed 29 April 2008.

⁴³ Peter J. Robertson, Vice Chairman of Chevron, was interviewed by Lee Hudson Teslik, Assistant Editor for the Council on Foreign Relations on 7 December 2007 in the CFR.org podcast entitled *Prospects for Future Oil Production*. [Online] available from

China and India alone, as depicted in Figure 2.⁴⁴ Oil companies are struggling against a number of bottlenecks to increase production, including looting, terrorism, and demands for larger shares from national oil companies.⁴⁵ This aspect of sustainability dovetails with the next theme on security issues.

Energy Security or Energy Independence

Even if oil supplies do not begin to dwindle anytime soon, there are serious perceptions of increasing problems obtaining reliable, open, and fair access to energy. Energy security for the United States really means access to oil because domestically available resources largely meet the electrical power generation and most other energy needs.⁴⁶ The electrical grid for most of the US is diversified, powered by domestically available sources, and would be relatively unaffected by

<http://www.cfr.org/publication/14901/robertson.html>; Internet; Accessed 14 February 2008. Robertson referred to estimates by the National Petroleum Council and called the ability to meet this demand “a real stretch,” citing above the surface geo-political risks and flat or declining production in existing wells over the next 30 years.

⁴⁴ Fatih Birol, Chief Economist at the International Energy Agency, in “World Energy Outlook 2007: China and India Insights,” Council on Foreign Relations, *Inside CFR Events* podcast, 27 November 2007 [Online] available from http://www.cfr.org/publication/14888/world_energy_outlook_2007_rush_transcript_federal_news_service.html; Internet; Accessed 20 April 2008.

⁴⁵ Birol, *World Energy Outlook*; Former Ambassador David Manning, “Energy: A Burning Issue for Foreign Policy,” 13 March 2006 podcast of address to the Freeman Spogli Institute of International Relations, Stanford University [Online] available from http://fsi.stanford.edu/events/energy_a_burning_issue_for_foreign_policy/; Internet; Accessed 30 April 2008; and Robertson, *Oil Production Prospects*, Council for Foreign Relations podcast.

⁴⁶ The US Energy Information Agency *Global Energy Decisions* states that overall US electrical production is based on 49.9% coal, 19.9% nuclear, 18.6% natural gas, 6.4% hydro, 2.7% renewables, and only 3.0% oil. [Online] available from <http://www.eia.doe.gov/>; Internet; Accessed 25 April 2008. A few areas of the US rely on petroleum for their electricity. Hawaii gets 78.4% of its electricity from oil according to the EIA, which is largely responsible for their high electricity rates. Hawaii has the most expensive electricity at 25.21¢ per kilowatt hour, versus the national average of 8.91¢ per kilowatt hour according to a Nebraska government site on energy, [Online] <http://www.neo.ne.gov/statshtml/115.htm>; Internet; Accessed 30 April 2008. In contrast, some of our allies heavily rely on oil for electrical generation. Italy generates about 47% of its electricity from oil and 35% from natural gas, making it the fourth largest oil consumer in the EU. These statistics come from the EIA *Country Analysis Briefs*. Note that Italy has steadily decreased its use of petroleum to produce electricity and can import it from neighboring countries to reduce that dependence. For example, see the 30 November 2007 *International Herald Tribune* article “Nuclear-free Italy increases access to atomic energy in deal with EDF.”

disruptions in petroleum supplies. In contrast, the US has experienced the consequences of supply disruptions several times.⁴⁷ While foreign oil producers, especially the Organization of Petroleum Exporting Countries (OPEC) make easy targets for pundits for these supply disruptions, the oil market is globally interconnected and deals with a fungible commodity.⁴⁸ Additionally, not all energy security concerns result from the intentions of the producers or supply constraints. Weather, such as Hurricane's Katrina and Rita in 2005, accidents, the pipeline fire in Minnesota in 2007, and terrorism can seriously disrupt the flow of oil.⁴⁹

⁴⁷ The US experienced numerous serious oil disruptions, including the 1973 embargo employed by OPEC countries and weather disruptions caused by Hurricanes Katrina and Rita in 2005.

⁴⁸ Fungibility means that a commodity is interchangeable and independent of the source. Moreover, even if one intentionally purchases oil from a specific country, they make other sources more attractive to others in balance by reducing demand. Therefore, one cannot reduce dependence on a particular region or supplier, nor can one effectively marginalize a region by refusing to buy their oil. Amory Lovins has a great discussion about the implications of the fungible nature of oil and its implications on page 14 of *Winning the Oil End Game*

⁴⁹ G. Luft and A. Korin's December 2003 article "Terror's Next Target" in the *Journal of International Security Affairs* notes that al Qaeda calls our oil supply the "umbilical cord of the Crusader community" and have repeatedly attacked a processing plant which solely handles 2/3 of their production. A map by Securing America's Future Energy (SAFE), *Instability in the Global Oil Market* map (see Appendix A), shows 80% of the oil from the Middle East flows through three key chokepoints. [Online] available from http://www.secureenergy.org/downloads/oil_map.pdf; Internet; Accessed 30 April 2008. A 29 November 2007 article in *International Herald Tribune*, *Bloomberg News* and *The Associated Press*, "Oil prices spike as fire shut down pipeline to U.S." demonstrates the frailty of the petroleum delivery system and reveals the lack of a buffer in the system. This single incident shut down the affected pipeline and four others, halting the flow of 14% of imports and caused oil prices to shoot up by 5%. Hurricanes Katrina and Rita not only disrupted supplies, but shut down refineries which were already running at over 90% capacity and damaged others. David Manning called energy security "the West's Achilles Heel" in his speech *Energy: A Burning Issue for Foreign Policy* to the Freeman Spogli Institute for International Studies at Stanford University.

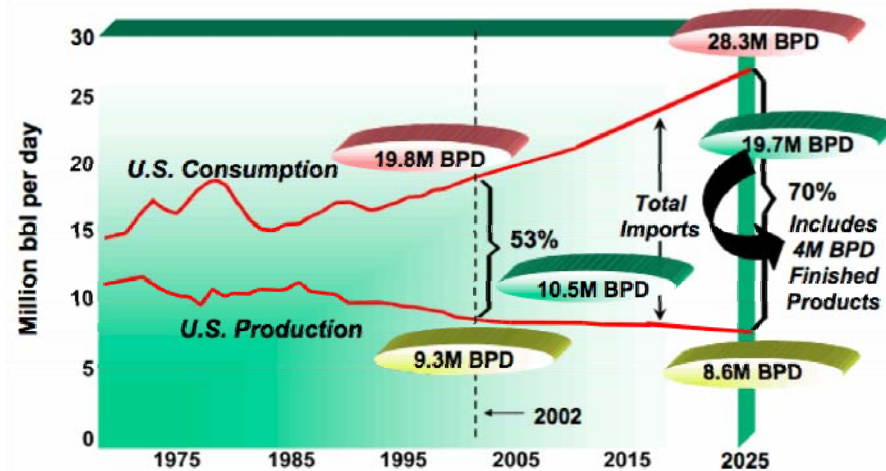


Figure 3: The increasing gap between US supply and demand is shaped like a crescendo and is filled by soaring levels of imports.⁵⁰

American reliance on oil imports has steadily increased to 53% of our oil and is projected to import 70% by 2025, as portrayed in Figure 3. The United States consumes 26% of the world’s oil output, with only 4% of the population, 8.9% of the oil production, and 2% of the known oil reserves.⁵¹ The US would exhaust all known reserves within four to five years if it tried to satisfy all of its demands domestically.⁵² Petroleum powers 96% of our transportation, and transportation accounts for the majority of our petroleum consumption, while the military almost exclusively relies on petroleum for its deployed energy needs.⁵³ This highlights the

⁵⁰ Consumption gap graph courtesy of John Winslow, US Department of Energy, from Energy Information Agency (AEO 2004) Reference Case Scenario. The 2002 estimate cited 68% imports by 2025.

⁵¹ Lovins, *Winning the Oil End Game*, page 12 with source data from the EIA. Senator John McCain made similar remarks in his Center for Strategic and International Studies speech, *Decision 2008*, saying we use 25% of the oil and have 3% of the known reserves.

⁵² Philip J. Deutch, in the November/December 2005 *Foreign Policy* article, “Think Again: Energy Independence,” page 20. This covers all known reserves, including the Alaskan National Wildlife Reserve and other areas currently declared off limits for production

⁵³ The US Department of Energy, Energy Information Agency analysis of energy use in 2004 reveals transportation as the single biggest user of petroleum at 68%. Slide 7 of a presentation by William E. Harrison III entitled “The Role of Fischer-Tropsch Fuels for the US Military,” 30 August 2006 as part of the OSD Assured Fuels Initiative shows that petroleum comprised 84% of USAF total energy use. [Online] available from <http://www.purdue.edu/dp/energy/pdf/Harrison08-30-06.pdf>; Internet; Accessed 29 April

national security importance of petroleum due to the near exclusive reliance of the transportation infrastructure and military on it. Of course, oil disruptions would also directly affect transportation of raw materials, goods, and services within the economy, as well as military operations.

Concerns are arising over increasing geo-political concentration of oil resources in areas of the world with political uncertainties, volatile relations, or governments that do not share our values.⁵⁴ Foreign governments directly or indirectly through their state owned oil companies own 94% of known reserves, and their real reserve information is considered a state secret.⁵⁵ The portion of oil produced in areas of the world labeled “Not Free” by FreedomHouse, or with serious social, political or stability issues are increasing.⁵⁶ Fatih Birol, chief economist at the International Energy Agency referred to this as the “eve of a new world energy order,” as worldwide demand skyrockets, but only about six countries can increase supplies. Nearly all of the output growth will come from Saudi Arabia, Iran, Iraq, Kuwait, UAE and Russia.⁵⁷ Richard N. Haas, President of the Council on Foreign Relations listed the empowerment of energy producers by our oil imports as the biggest single factor hastening the end of American influence

2008. Installation and infrastructure electrical power and heating composed the remaining 16%. Deployed Army and Marine Corps forces derive all of their heating and electrical power from petroleum, in addition to mobility. The Navy relies on petroleum less because of its nuclear powered submarines and aircraft carriers, except the USS *Kitty Hawk*. However, even the nuclear powered carriers rely on deliveries of petroleum-based fuel for their aircraft every three to five days.

⁵⁴ Manning, “Energy: A Burning Issue for Foreign Policy,” podcast of address to the Freeman Spogli Institute of International Relations, Stanford University

⁵⁵ Defense Science Board, *Report of the Defense Science Board Task Force on DoD Energy Strategy*, 2008, page 11.

⁵⁶ Manning, *Energy: A Burning Issue for Foreign Policy*

⁵⁷ Birol, *World Energy Outlook*. David Manning echoed these concerns in *Energy: A Burning Issue for Foreign Policy*

in the world.⁵⁸ This will give these players a considerable amount of leverage on the world oil market, and hence the world economy.

David Manning, former British Ambassador to the United States, and later the European Union, said that Henry Kissinger coined the term “oil weapon.” This concept described the Oil Producing and Exporting Countries’ (OPEC) use of oil and oil wealth for coercion during the 1973 Oil Crisis, when they declared an embargo against the United States.⁵⁹ Likewise, Europe is becoming increasingly alarmed at Russia’s insidious increases in control over oil and natural gas supplies and pipelines, and their perceived willingness to use it and the resulting wealth to coerce others.⁶⁰ Venezuela and other oil producing countries with national oil companies are retaining an increasingly share of production and threaten nationalization of assets.⁶¹

⁵⁸ Richard N. Haas, May/June issue of *Foreign Affairs*, “The Age of Nonpolarity: What Will Follow U.S. Dominance,” on the *Inside CFR Events* podcast, 15 April 2008. [Online] available from <http://www.cfr.org/publication/15784/podcast.html>; Internet; Accessed 30 April 2008.

⁵⁹ Manning, *Energy: A Burning Issue for Foreign Policy*

⁶⁰ The EU receives about 25% of their total oil and natural gas supplies from Russia. Their supplies were cut off when Russia cut off Ukraine in 2006 during a payment dispute. This increased awareness in the EU of their reliance on Russia for their energy and led to attempts to offset this reliance with renewable energy and pipeline deals with other suppliers. German Minister of State Gernot Erler spoke at the Carnegie Council on 5 February 2007 on European energy security and the role of Russia. [Online] available from <http://www.cceia.org/resources/transcripts/5416.html>; Internet; Accessed 30 April 2008. He stated that 40% of Russia’s budget comes from oil and gas revenues, and that Putin wanted to use those revenues to modernize Russia’s industrial base. He also stated that Russia longed for its former influence over the CIS and its world power status, and that they are indeed using their oil and gas leverage to coerce their neighbors, such as Ukraine, Georgia and Belarus. He also gave statistics showing that Germany is more reliant on Russia than Europe overall, and that they were going to use their rotation in the EU Presidency to try to influence Russia into greater economic and political interdependence with Europe by insisting they honor their contracts, etc. However, both the Europeans and the US has been consistently outflanked by Russia in making pipeline deals, and they continue to employ their energy supplies to coerce their former satellites. See the *International Herald Tribune* articles “Russia signs deal to bring natural gas pipeline through Bulgaria,” “Putin’s trip is next step in Gazprom’s march West,” “Russia signs Central Asian pipeline deal,” “Russia and West compete for Central Asian gas—and Russia is winning,” and “Ukraine accuses Russia of applying political pressure in gas dispute.” *The Economist* had several podcasts, including its 16 November 2006 *Europe.view* entitled “The Sorrows of Belarus,” about how Russia drastically increased Belarus’s gas supplies after they leaned Westward politically, as they did with Ukraine after the “Orange Revolution.” Other *Economist* podcasts with more information include “The fog of the ‘new cold war,’” and 10 April 2008’s *Certain Ideas of Europe* “Pipelines and pipedreams,” which interviewed Alexandros Peteresen, Program Director of the Caspian Europe Center in Brussels. Feigenbaum et al, authors of the book *Pipeline Politics in the Caspian Sea*, conducted a 13 February 2007 interview on the Council for Foreign Relations podcast *Inside CFR Events* that discussed the intense competition with Russia over control over gas and oil resources and pipelines out of the region, and their

Russia and others are also using oil money against us in a more indirect way, through funding their weapons development, such as the new Topol-M Intercontinental Ballistic Missile, Su-30 fighter aircraft, and numerous other weapons projects. These projects have coincided with resurgence in aggressive military actions as well.⁶² Moreover, Russia is the second largest arms exporter in the world, normally selling to nations Western countries won't sell to, and who potentially will use them to fight against the US or our allies.⁶³ While some may argue that Russia may do business with whomever they chose, regardless of international sanctions, American money for oil is flowing into Russia or the countries buying these weapons from Russia. Likewise, some have stated that we are funding both sides on the war on terrorism by purchasing oil from nations ambivalent or supportive of the terrorist causes.⁶⁴

The oil weapon also suggests why the West and China are reluctant to act too hastily or harshly against Iran and their alleged nuclear weapons program. Not only can Iran withhold their 5% contribution to the oil market, which alone would devastate world economies, but could

harm to good governance in the region. [Online] available from http://www.cfr.org/publication/14804/pursuit_of_black_gold.html; Internet; Accessed 10 February 2008).

⁶¹ Page 9 of the Closing Keynote Address of the University of Chicago International and Area Studies *Petroleum: Prospects and Politics* symposium by Venezeulan Ambassador Bernardo Alvarez Herrera. ([Online] <http://chicagosociety.uchicago.edu/petroleum/proceedings.html>; Internet; Accessed 30 April 2008); Robertson (vice chairman of Chevron), *Prospects for Future Oil Production*, cited increasing shares of oil production going to states and state owned oil companies as part of the problem for oil companies trying to meet increasing production targets. Fatih Birol's *World Energy Outlook 2007*, and David Manning's *Energy: A Burning Issue for Foreign Policy* (19:50) also discussed the role of state owned companies in constraining production available to the world market.

⁶² For example, Russia resumed bomber incursions into others' airspace, ("RAF intercepts eight Russian bombers as Putin provokes West", 7 September 2007, Michael Evans and Tony Halpin, *The Times*). "Russia Could 'Point Warheads' at Ukraine" in the 13 February 2008 article in *Der Spiegel* demonstrates the response to their attempt to join NATO. Other issues include the revision of school textbooks blaming the West for provoking the Cold War, repudiating the Conventional Forces in Europe treaty limiting conventional forces on the Russian border, and threatened non-renewal of treaties on nuclear weapons.

⁶³ This includes Russian sales of the state of the art S-300 air defense system to Iran and Syria, according to the 26 December 2007 *International Herald Tribune* article by the Associated Press entitled "Russia to supply Iran with new air defense system, defense minister says."

easily disrupt all of the oil coming through the Straits of Hormuz as well, bottling up 20% of the world's oil output in the Persian Gulf.⁶⁵ Potential attacks such as this on worldwide critical choke points on the sea lines of communication are a major source of concern. 80% of the oil from the Middle East flows through three key chokepoints—the Straits of Hormuz, the Suez Canal, and the Bab al Mandeb, and 95% of Asia's oil flows through the Straits of Malacca.⁶⁶ Asymmetric actors employing simple anti-ship mines, missiles, pirates, speedboats, or diesel electric submarines could easily disrupt oil flow at these points. The Persian Gulf has seen some disruption of this kind in the past, with the 1980's tanker war during the Iran-Iraq war, and recently with a run-in between Iranian speedboats and US Navy warships. Likewise, the nations surrounding the Straits of Malacca are struggling to quell piracy in that area.⁶⁷ A mere credible threat of this kind could cause severe disruptions because of shipping insurance costs and restrictions.

⁶⁴ Page 3 of Representative Steve Israeli's *New Generation Energy Security Initiative*, David Manning's speech at Stanford University *Energy, A Burning Issue in Foreign Policy* and page 11 of the 2008 Defense Science Board Energy Task Force all use variations of this sentence.

⁶⁵ A map produced by the organization Securing America's Future Energy (SAFE) produced a map illustrating global energy vulnerabilities (See Appendix A), particularly key chokepoints. The EIA provided the oil export figures in their section entitled *International Energy Data and Analysis for Iran*.

⁶⁶ See the Middle Eastern portion of the SAFE map in Appendix A.

⁶⁷ The Globalsecurity.org history of Operation *Earnest Will* ([Online] available from http://www.globalsecurity.org/military/ops/earnest_will.htm; Internet; Accessed; 30 April 2008)) recounts the difficulties of neutral nations' oil tankers operating in the Persian Gulf during the 1980's Iran-Iraq war. *Earnest Will* was the US response, escorting and reflagging tankers as US tankers to continue the flow of oil. The USS *Stark* was struck and damaged during an incident during the so-called "tanker war." US Navy warships and Iranian speedboats created an incident reported by the 7 January 2008 *International Herald Tribune* article "Iranian boats provoked U.S. Navy ships, Pentagon says." Older anti-ship missiles proved devastating against the Royal Navy during the Falkland Islands war. Even non-state actors, such as Hezbollah employed C802 anti-ship missiles in their 2006 war with Israel according to the 19 July 2006 *New York Times* article "Arming of Hezbollah Reveals U.S. and Israeli Blind Spots" by Mark Mazzetti and Thom Shanker. Prior wargames highlighted the potential for swarms of speedboats to saturate warship defenses with missiles, whereas normal ships would be completely vulnerable to these attacks. Moreover, a 20 July BBC article "Anti-piracy drive in Malacca Straits" and the proliferation of piracy off the Somali coast highlight the vulnerability of ships to much simpler asymmetric threats. A 21 April 2008 article by Martin Fackler in the *International Herald Tribune* entitled "Oil market rattled by attack on Japanese tanker" attacked by pirates off the coast of Somalia and Yemen and the subsequent effects on the oil market.

Unilateral concern for energy security runs counter to some of our other prevalent foreign policy traditions. One such tradition holds that free trade is not only good for our prosperity, but fosters stability and democracy.⁶⁸ President Bush stated in the 2006 State of the Union Address “America rejects the false comfort of isolationism” and reiterated the commitment to liberty worldwide.⁶⁹ Demand for oil in the developing world is skyrocketing and placing enormous strain on production capacity.⁷⁰ Perceptions of resource scarcity could lead nations to turn to autarky, rejection of our system for closed economic cartels, potentially trigger wars over resources that may escalate and inevitably drag the US in. Furthermore, concerns over open access to resources could lead to regional and global arms races as nations build fleets ostensibly to protect their tankers. A group with trivial resources could disrupt 95% of the oil going through this key chokepoint to China, Japan, and Taiwan. Fears of just such an event are allegedly driving the Chinese, Japanese, and other Asian powers to develop blue-water navies, which could be perceived as a threat by others and drive a regional arms race.⁷¹ As each builds assets to

⁶⁸ 2006 National Security Strategy, Section VI. Walter Mead also discussed this in *Special Providence: American Foreign Policy and How it Changed the World*, and in *God and Gold: Britain, America, and the Making of the Modern World*.

⁶⁹ Bush, 2006 State of the Union Address

⁷⁰ Manning, *Burning Issue for Foreign Policy*; Birol, *World Energy Outlook*; and Robertson, *Prospects for Future Oil Production*

⁷¹ Mead, “God and Gold: Britain, America, and the Making of the Modern World,” CFR *Inside CFR Events* Podcast. [Online] available from http://www.cfr.org/publication/14439/god_and_gold.html; Internet; Accessed 15 February 2008. Mead used this exact scenario but with Japan building ships for tanker escort which could instead be perceived by neighboring states as an a threat to their security, driving them to expand their fleets to counter them and triggering arms races. He also suggested another alternative could be cooperative security or acceptance of US hegemony to ensure the security of their LOCs. ADM Keating talked about China building a blue water fleet in a CSIS podcast, who claim their blue water naval assets including aircraft carriers and submarines are ostensibly for protecting their transit rights and are having the same effect on other Asian nations and the US. ADM Keating cited a PRC statement that said they only wanted to protect what is rightfully theirs, as 50% of their imported oil transits the Straits of Malacca. (ADM Timothy J. Keating, “A PACOM Perspective on Asia and the Pacific,” *Center for Strategic and International Studies* podcast, 25 July 2007 [Online] available from http://media.csis.org/podcast/070725_keating.mp3; Internet; Accessed 30 April 2008. An *International Herald Tribune* article entitled “U.S. military officials wary of China’s expanding fleet of submarines” by David Langué, written 7 February 2008, illustrate the US concern. An incident involving a Chinese *Song* class submarine exacerbated these fears of the Chinese naval build up when it surfaced within torpedo range of the USS *Kitty Hawk* in late 2006.

protect their access to resources, their neighbors see them building additional warships as well and build more to counter them.

Therefore, any energy plan must take into account not just our allies, but our competitors as well in order to maintain and further attract them into the global trading system.⁷² The globalized and interconnected economy has increased international cooperation and prosperity and with diminishing the likelihood of war.⁷³ The fate of our competitors matters to Americans because problems in other nations' economies affect our interconnected and globalized economy and financial institutions. Moreover, portions of our oil imports are hidden energy imports in the form of manufactured products that we depend upon.⁷⁴

⁷² Mead, "God and Gold: Britain, America, and the Making of the Modern World," CFR *Inside CFR Events* Podcast. CNAS's *Solarium II* also suggests this and among other things recommends a collective bargaining organization for consumer nations to mirror OPEC's production organization

⁷³ This is also referred to in economics as an opportunity cost—that losing the benefits of participation outweighs the gains one could make by breaking out from it. Thomas Freidman writes about this at length in *The Lexus and the Olive Tree* and *The World is Flat*, as does Walter Mead in numerous parts of *Special Providence* and *God and Gold*. Bernard Lewis gives us an example of what disillusionment, rejection or withdrawal from this system can inflict on society in Chapter VII: *A Failure of Modernity in Crisis of Islam*. Thomas Barnett has an interesting analysis of this in *The Pentagon's New Map: War and Peace in the Twenty-First Century* (New York: Putnam Adult, 2004), where he posits that the world is split between a "Functioning Core," which has embraced globalization and is increasingly prosperous and free, and the "Non-integrated Gap" of nations which have not, are poor, and largely comprised of dictatorships or weak states. *The Economist* has several articles on the effects of NAFTA on the economies and peoples of the member states in North America. "NAFTA: America, the unreliable ally," (6 March 2008) "Canada and the United States: A Fence in the North Too," (28 February 2008) and "NAFTA: An unfortunate lack of clarity" are about concerns about harmful political hyperbole about NAFTA that *the Economist* claims fails to match reality. *International Herald Tribune* also carried a 6 March 2008 OP-ED entitled "Stop blaming NAFTA" by Robert Pastor along the same lines. Economic ties are also part of the concept of Joseph Nye's "Soft Power," (listen to his 20 August 2007 podcast interview with the Carnegie Council on the book, "Soft Power: The Means to Success in World Politics," *Carnegie Council podcast*, [Online] available from http://media.cceia.org/carnegie/audio/20040413_JosephNye.mp3; Internet; Accessed 30 April 2008) or "Smart Power" (in concert with traditional hard power) as labeled by the Center for Strategic and International Studies (see the CSIS Smart Power project [Online] available from <http://www.csis.org/smartpower/>; Intenet; Accessed 30 April 2008.

⁷⁴ The moderator or another member of the panel for the Council on Foreign Relations 9 October 2007 *Inside CFR Events* podcast for Mead's *God and Gold: Britain, America and the Making of the Modern World* mentioned this during the discussion.

Moral Values

This group perceives a tension between our need natural resources and our ability to promote democracy and good governance worldwide. They contend our need for oil compromises our values and leads us to treat authoritarian regimes that do not share our values with deference, which drives cynicism about our motives and perceptions of exploitation around the world.⁷⁵ Democracy promotion is one of our key foreign policy tenets, yet the world gets 71.2% and the US gets 57.2% of its oil from nations listed as less than “Free” by FreedomHouse, an organization which measures signs of democratic progress.⁷⁶ Figure 4 shows the 2006 relative petroleum exports from the top 14 exporters superimposed on the 2006 map of world freedom published by FreedomHouse. This clearly illustrates a correlation between petroleum exports and authoritarian governments. Notable exceptions include Norway and Canada, which developed strong democratic institutions prior to the discovery of oil. Conversely, insistence on democratic reform has eroded our ability to compete for resources with nations without such qualms.⁷⁷

⁷⁵ CDR Thomas Kraemer, “Addicted to Oil: Strategic Implications of American Oil Policy,” Strategic Studies Institute, May 2006.

⁷⁶ Democracy promotion is listed in the National Security Strategy and in the 2006 *State of the Union* address. World oil production data from WorldOil.com ([Online] available from http://www.worldoil.com/INFOCENTER/STATISTICS_DETAIL.asp?Statfile=_worldoilproduction; Internet; Accessed 30 April 2008), US import data from the Energy Information Agency of the US Department of Energy. Freedom ratings from FreedomHouse.org ([Online] available from <http://www.freedomhouse.org>; Internet; Accessed 30 April 2008). Canada is by far the largest supplier to the United States, at around 2,400 thousand barrels a day, for about 20% of US imported oil. FreedomHouse rates Canada as FREE at 1 out of 7 for civil liberties and political rights. Mexico is our fourth largest supplier, at around 1,300-1,700 barrels per day, or 15% of our imported oil Mexico’s FreedomHouse rating is FREE, with a 2 out of 7 for political rights and a 3 out of 7 for civil liberties. Those two countries together provide the US 35% of its imported oil. With 57% of US oil coming from nations FreedomHouse rated less than FREE, and two suppliers accounting for much of the difference, it highlights the extent of tyranny among the oil producing states.

⁷⁷ Feigenbaum et al, *Pipeline Politics in the Caspian Sea*, cited US companies are losing contracts to Russia in Central Asia due to conflicts between our values of democracy promotion with our need for resources. One example of a democracy promoting activity is the creation of the Millennium Challenge Corporation, which ties foreign aid to performance and democratization. In contrast, the 13 March 2008 *Economist* article “China’s Quest for Resources: No Strings: Why Developing Countries Like Doing Business With China” cites China’s lack of conditions on doing business. *International Herald Tribune* ran an article on 20 December 2007 entitled “Russia and West compete for Central Asia gas-and Russia is winning” by Andrew Kramer and a subsequent article by C.J. Chivers on 3 February 2008 entitled “U.S.

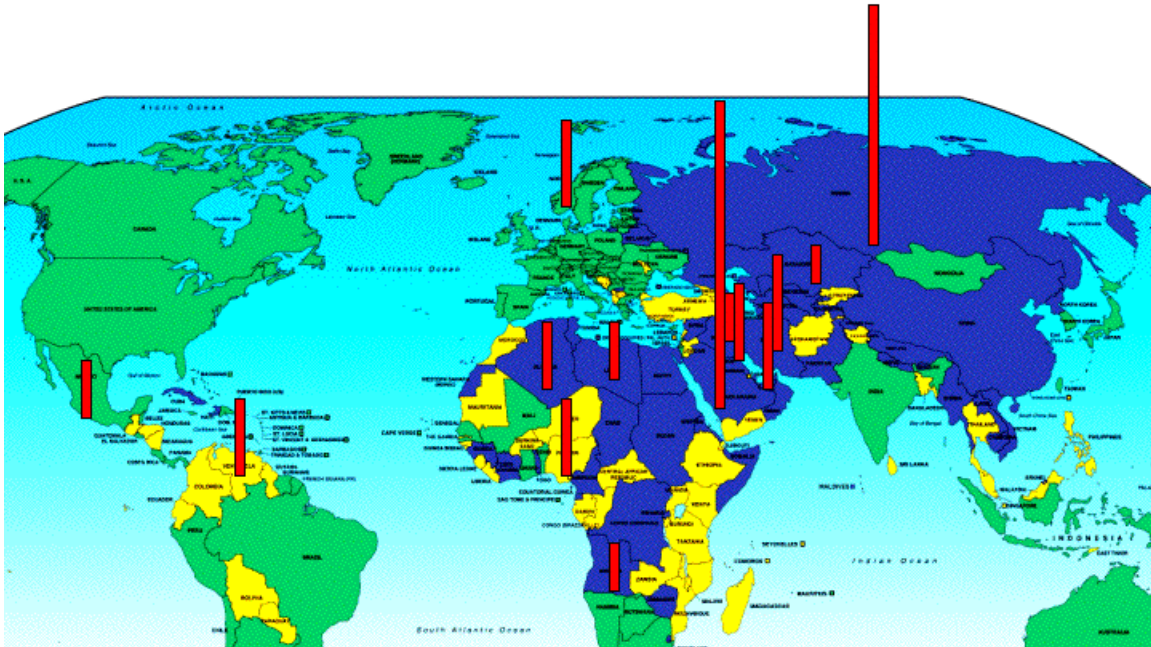


Figure 4: Top world oil exports compared to freedom ratings.⁷⁸

The Paradox of Plenty, also known the Resource Curse theory posits that concentrated forms of wealth, such as petroleum, facilitate the existence of authoritarian regimes and insulate them from public sentiment at home and abroad.⁷⁹ For example, Russia is spending much of

policy shifts in Central Asia” discuss the reduced ambition of democracy promotion efforts. France also suffered setbacks. A 25 February 2008 *International Herald Tribune* article by Timothy W. Ryback and Elazar Barkan entitled “Turkey and Armenia: A \$12 billion history lesson” covers Gaz de France’s exclusion from a Turkish pipeline deal because of their stance on the Armenian Genocide.

⁷⁸ The map from FreedomHouse.org illustrates their 2006 ratings of world freedom. Green indicates FREE, yellow indicates PARTLY-FREE, and Purple depicts NOT-FREE. The red bars overlaid on the map indicate the 2006 exports for the top 14 oil exporters, with a strong correlation to NOT-FREE ratings.

⁷⁹ Auty, *Sustaining Development in Mineral Economies: The Resource Curse Thesis*; Jeffrey Sachs, *Natural resource abundance and economic growth*; Bernard Lewis, *Crisis of Islam* page 131 discusses the Rentier State, where rather than taxation leading to representation—along with demands for accountability, transparency, and competent government, a state that derives its revenues from natural resource profits inverts the relationship—no taxation leads to no representation, and instead leads to corruption, authoritarian rule, and the tendency to spend on “white elephant” projects. Thomas Friedman takes this logic a step further with “The First Law of Petro-politics” in the May/June 2006 issue of *Foreign Affairs* by drawing a direct correlation between oil wealth and authoritarian regimes. The 21 December 2007 Council on Foreign Relations podcast “The World Next Year” with Michael Moran and Daniel Franklin (Executive Editors at CFR and *The Economist* respectively), elaborated on this by discussing how states with strong democratic institutions and civil society, such as Norway and Canada, can absorb oil wealth without this effect, whereas countries such as Russia lack structures capable of resisting the

their oil income on weapons programs rather than developing other economic sectors or even maintaining the petroleum infrastructure fueling its rise in prosperity.⁸⁰ Others have cited capricious, unwise or self-aggrandizing white elephant projects made possible by oil money, such as the giant statues built by the former leader of Turkmenistan.⁸¹ Oil has also fueled instability and conflict in many other places, particularly over perceptions of unfair allocation of the profits, such as in Iraq, Iran and Nigeria.⁸²

Ecological

The Nixon administration created the Environmental Protection Agency (EPA), and one of its key directives was reduction of the detrimental environmental impact of our society, especially from our use of energy and our industries. Some members of this theme self-identify as “Greens,” environmentalists, or conservationists, and continually seek to reduce the human

aforementioned temptations. [Online] available at <http://www.cfr.org/content/publications/media/podcast/2007/WorldNextYear20071221.mp3>; Internet; Accessed 30 April 2008. Moreover, a study conducted for the DoD by LMI concluded that “dependence on foreign supplies of fuel limits its flexibility in dealing with certain producer nations.” (cited in Kristine Blackwell’s *The Department of Defense: Reducing Its Reliance on Fossil-Based Aviation Fuel—Issues for Congress*. (Washington, D.C.: Congressional Research Service 15 June 2007))

⁸⁰ This was the focus of the 23 November 2006 *Economist* Europe.view podcast, “Paying the Piper,” which highlighted Gazprom’s failure to re-invest in infrastructure and the long term implications for their production. [Online] available from <http://www.economist.com/media/audio/europeview231106.mp3>; Internet; Accessed 30 April 2008. For more on Russia’s revisionist history, see the *Economist* articles “Lights, Camera, Different Ending” (14 February 2008) and “America’s Russia Problem” (19 December 2007).

⁸¹ Tom Parfitt’s 21 December 2006 *Guardian* article, “‘Father of all Turkmen’ dies aged 66” covers the aftermath of the death of Saparmurat Niyazov, a.k.a. “Turkmenbashi.” He ruled Turkmenistan capriciously through the benefit of oil and gas revenues, which he used in numerous quirky and bizarre projects.

⁸² In *States, Ideologies and Social Revolution: A Comparative Analysis of Iran, Nicaragua and the Philippines*, (Cambridge: Cambridge University Press, 2000) Misagh Parsa cites inequities from oil wealth and the repression of the middle class as one of the major contributing factors to the rise of unrest against the Shah of Iran. Disagreements over sharing of oil revenues are also driving sectarian violence in Iraq. Nigeria’s oil wealth is concentrated on the coast, but people there perceived a disproportionate share of that wealth being given to tribes in the North, aside from endemic government corruption. The report of the Iraq Study Group in 2006 cited disagreements over distribution of oil wealth plague reconciliation and political stability within Iraq, as did GEN Petraeus (Commander of Multi-National Forces, Iraq) and Ambassador Ryan Crocker during their 2008 testimony before Congress.

impact on the environment, with emphasis on clean sources of energy. Concerns about climate change increasingly focus on carbon-free sources of energy.⁸³ This concern is no longer as controversial as it once was and has captured a much larger share of the mainstream, including defense and foreign policy professionals. The UK Ministry of Defense listed climate change as the number one threat to their national security.⁸⁴ The European Union mandated carbon emissions objectives for their member states. Most of the mainstream national security think tanks have produced reports warning of national security implications of climate change, including a panel of former senior US military leaders. These officers outlined their concerns about the strategic implications of climate change and the consequences for the US military.⁸⁵

⁸³ The US Office of the Secretary of Defense Assured Fuels Initiative advocates using the Fischer-Tropsch process to make synthetic fuel from coal. Dr. Theodore Barna's briefing at the *OSD Assured Fuels Initiative* briefing at the 2006 Aerospace in the News Executive Symposium, and the 30 August 2006 briefing "The Role of Fischer-Tropsch Fuels for the US Military" by William Harrison III have more details. However, the process is controversial because of enormous landscape damage from mining the sands, from water use and pollution in the extraction process, and because of the enormous amount of greenhouse gas emissions released from this process. *The Economist* article, "Please buy our dirty oil," 13 March 2008 discussed some of these issues. The 20 June 2007 *Washington Post* article by Sholnn Freeman entitled "Coal-to-Liquid Provision Stalls" cites carbon emissions as a key reason why congress declined to support building coal-to-liquid plants, nor mandate production quotas for synthetic fuel in the 2007 energy bill. The process also uses large amounts of natural gas, which together with vast expansion in natural gas electrical generation and home heating have spiked natural gas prices.

⁸⁴ Trip notes from School of Advanced Military Studies (SAMS) Fellows COL Hawkins and Schäfer (Oberst, German Army equivalent of a US Army Colonel) to SAMS Seminar 1, 5 November 2007 David Manning also noted in his discussion *Energy: A Burning Issue in Foreign Policy* that climate change was PM Blair's number one priority at the G8 summit. Dr. Olafur Ragnar Grimsson, H.E, President of Iceland state in "Climate Change and New Security Issues" at the Carnegie Council on 2 April 2008 that British Prime Minister Gordon Brown assembled a special task force to deal with the threats of terrorism and climate change. [Online] available at <http://www.cceia.org/resources/audio/data/000189>; Internet; Accessed 30 April 2008.

⁸⁵ Two examples include a Joshua Busby's *Climate Change and National Security: An Agenda for Action* (New York: Council on Foreign Relations, CSR No. 32, November 2007) with an accompanying 14 February 2008 panel interview on the Council for Foreign Relations (CFR) podcast ([Online] available from <http://www.cfr.org/content/publications/media/2008/2-14-08-Climate.mp3>; Internet; Accessed 30 April 2008), and the November 2007 Center for a New American Security (CNAS) and the Center for Strategic and International Studies (CSIS) joint project *Age of Consequences: The Foreign Policy Implications of Climate Change*. [Online] available from <http://www.cnas.org/en/cms/?1278>; Internet; Accessed 30 April 2008. Sheri Goodman's *National Security and the Threat of Climate Change* by CNA Corporation, featured Generals Gordon R. Sullivan, Paul J. Kern, Charles F. "Chuck" Wald, Anthony C. "Tony" Zinni, Admirals Frank "Skip" Bowman, T. Joseph Lopez, Donald L. "Don" Pilling, Joseph W. Prueher, LTG Lawrence P. Farrel Jr., and Vice Admirals Paul G. Gaffney II, and Richard H. Truly as the

The US Supreme Court ruled in 2007 that the EPA could regulate carbon emissions as a pollutant, and all three 2008 Presidential candidates favor mandatory emissions caps.⁸⁶

There are major divisions within this theme about priorities and what best constitutes protection of the environment. One example is the division over nuclear power, which has gained favor because it is carbon free, but has many traditional enemies in the traditional “Green” camp.⁸⁷ Another division is over the use of biofuels, which some tout as more environmentally friendly than petroleum fuels, but others contend do more harm to the environment through deforestation, use of petroleum based fertilizers, etc.⁸⁸

military advisory board for the 2007 study. [Online] available from <http://SecurityAndClimate.cna.org>; Internet; Accessed 30 April 2008.

⁸⁶ The 18 April 2008 *International Tribune* article “Bush shifts policy on greenhouse emissions” by Sheryl Gay Stolberg and Brian Knowlton states that Senators John McCain, Hillary Clinton and Barack Obama all favor mandatory limits on greenhouse gas emissions. Another article on 3 April 2007 entitled “Environmentalists hail Supreme Court ruling on carbon” by Linda Greenhouse covers the US Supreme Court decision ruling that the EPA can regulate greenhouse gas emissions under the Clean Air Act.

⁸⁷ Patrick Moore, one of the co-founders of Greenpeace is now an avid nuclear advocate, but the remainder of Greenpeace and other organizations such as the Union of Concerned Scientists are staunchly anti-nuclear. Gwyneth Cravens is a former nuclear protester in her youth that upon further reflection and research became an advocate of nuclear power and wrote the book *Power to Save the World: The Truth About Nuclear Energy*. (See the interviews by Rod Adams on *Atomic Show* episodes 73-1 and 73-2 on 27 and 31 October 2007 respectively [Online] available at , <http://atomic.thepodcastnetwork.com/2007/10/30/the-atomic-show-073-1-gwyneth-cravens-and-rip-anderson-author-and-tour-guide-for-power-to-save-the-world/>; Internet; Accessed 12 February 2008. The main disagreement over nuclear power within the “Green” camp is over the perceived dilemma of nuclear waste storage versus greenhouse gas production.

⁸⁸ Carbon balance and ecological concerns are another controversy with biofuels, which are often touted as more environmentally friendly than petroleum. Aside from water use issues discussed in the sustainability section, this group worries about pesticides, fertilizers, and aggressive land use employed in growing biofuels. Another arising concern involves biofuels’ carbon balance. The most touted environmental benefit of biofuels. Biofuels are made with biomass that take carbon dioxide out of the atmosphere. However, the amount of carbon based energy used to grow and produce the biomass, and distil and distribute the biofuel affects the carbon balance. If more carbon is released from fossil fuel consumption than is absorbed in the life cycle of the plant, then the fuel does not have a beneficial carbon balance. The University of Minnesota biofuels study (“Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels,” 2 June 2006, *National Academy of Sciences*) claimed corn ethanol produced 12% less net carbon emissions, while biodiesel made from soybeans produced 41% less. Other energy sources produce different perspectives within this group as well. Although most assert that wind turbines are overall good for the environment, some groups fight them on the grounds that they kill birds or harm their view.

Cost

To this group, the economics and convenience of an energy source are paramount.⁸⁹ They primarily worry about price fluctuations and long term cost increases. Skyrocketing demand in the developing world greatly exacerbate price concerns. This is not limited to petroleum, because natural gas prices have spiked because of enormous increases in gas fired power plants, home heating and extraction of unconventional oil resources, such as the Alberta tar sands. This group frets about economic trends, such as the rise in oil prices over \$100 and the \$27.1 billion a month contribution of oil imports to the trade deficit.⁹⁰ Cost is also of particular concern to the US military, because although fuel costs are about 3% of the budget, every \$10 increase in a barrel of oil increases the Air Force's fuel costs by \$600 million.⁹¹ Conversely, this group also highlights the opportunities for economic stimulation and job creation from use of domestic commodities or facilities.⁹²

The effort to improve efficiency and investments in alternative fuels in the 1970s partially led to reduction in demand and intentional price decreases to keep oil competitive, which

⁸⁹ An example of convenience in this sense includes the ability to easily find a filling station for your type of vehicle. Several types of alternative fueled vehicle sales suffered because their owners had to put a lot of effort into finding specialized refueling stations.

⁹⁰ *Associated Press, International Herald Tribune* "High oil prices help widen U.S. trade deficit." 11 March 2008. See also the 13 March 2008 *Economist* article "A Few Good Machines," which states that the US trade deficit would have shrunk had it not been for oil imports. Richard N. Haas, the President of the Council on Foreign Relations highlighted the reliance on oil imports empowering energy producers as the biggest factor hastening the end of the unipolar world that favors the US and our allies. (15 April 2008 *Inside CFR Events* podcast of his May/June *Foreign Affairs* article "The Age of Nonpolarity: What Will Follow U.S. Dominance.")

⁹¹ Blackwell, CRS Report for Congress, *The Department of Defense: Reducing Its Reliance on Fossil-Based Aviation Fuel—Issues for Congress* 15 June 2007, pg 3.

⁹² Antonio José Ferreira Simões claims that up to six jobs are created for each biofuel job in the *International Herald Tribune* article "Biofuels will help fight hunger." They also published a story on 26 March 2008 by Steven Greenhouse entitled "'Green collars' becoming a force in U.S. economy," highlights the employment potential of the renewable energy industry. AUS Consultants and SJH Company published a study in 2002 which can be found at the American Coalition for Ethanol which states that each ethanol plant brings 700 jobs to the surrounding community, as well as about \$110 million a year to the local economy.

undermined further investment in efficiency and alternatives. This aspect of the energy camps introduces complexity and another tension in the system, because investments in efficiency and alternative sources also drive down the cost of the original source, making it more competitive again. Perversely, this school can undermine itself in the long term, as past efficiency efforts have led to greater consumption as people could afford to use more energy once it was available again.⁹³

Expeditionary Challenges

The primary purpose of an army-to be ready to fight effectively at all times-seemed to have been forgotten.... The unwillingness of the army to forgo certain creature comforts, its timidity about getting off the scanty roads, its reluctance to move without radio and telephone contact, and its lack of imagination in dealing with a foe whom they soon outmatched in firepower and dominated in the air and on the surrounding seas...

GEN Matthew B. Ridgeway's assessment of the U.S. Army in the Korean War⁹⁴

Satisfying the civilian transportation market's criteria for a suitable substitute fuel or energy system will be much easier than meeting military requirements. The civilian transportation system has a mature, static infrastructure of fueling stations and even the possibility of running electrical power lines near highways if required. Arguably, the civilian

⁹³ Jevon's Paradox, named for 19th Century British economist William Stanley Jevons, describes this phenomenon. He first expressed this phenomenon of demand elasticity in a book entitled *The Coal Question* about soaring English consumption of coal after improved, more efficient models of steam engines designed by James Watt superseded the original models designed by Thomas Newcomen. This increased efficiency afforded a wider range of industries access to a cost effective power source, and a net national surge in coal use. Likewise, *the Economist* observed in the article "CAFÉ Society" that while US automobile powertrains have steadily improved in efficiency, the average fuel economy has plummeted since the 1970s oil crisis due to increased weight and luxuries. Looking at this in other commodities, Detrich Dörner used vignettes in *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations* (New York: Basic Books, 1997) to test subjects on their ability to grapple with complex problems, including one involving food and birth rates in a fictitious African country. Some of the well-meaning participants massively increased their food output in an unsustainable manner, which led to a population explosion and subsequent collapse. Paradoxically, increased efficiency could well lead to increased, rather than decreased net consumption.

⁹⁴ GEN Matthew B. Ridgeway, *The Korean War* (New York: Da Capo Press, 1967), page 88.

transportation sector is also more resilient and ready to adapt than the military because social changes could make many trips unnecessary, albeit with initial inconvenience and disruption. Civilian equipment often has a shorter replacement cycle than the majority of military systems. Electric cars could handle short trips, such as commuting and shopping as battery technologies mature. Biodiesel or cellulosic ethanol could ease this transition or possibly displace gasoline for long trips while battery-powered vehicles handle the short trips.⁹⁵ Biodiesel or electricity could perform long haul operations with supporting road or rail-side power lines. The most difficult transportation problem to solve would be aircraft, due to the narrow range of technically feasible fuels.⁹⁶ However rail and ships could offset this and resume the dominance they enjoyed before the era of air travel.

Meanwhile, military energy systems must deploy an off-road mobile expeditionary energy system into an austere environment filled with hostile actors trying to disrupt and destroy it. Consequently, these systems must be robust, resilient, portable, take up a relatively small footprint, and emit a low signature, while the systems they support are energy intensive by nature. This energy system must be able to perform in the full range of operational environments where it could potentially deploy and work with the whole suite of tools it needs. Ideally, a change in this energy system would leverage existing investments in equipment and infrastructure or at least

⁹⁵ The Toyota Prius and other hybrids have proven themselves on the road since 1997, and some users have modified them into Plug-in Hybrid Electric Vehicles (PHEV) to provide a greater share of their mobility from cleaner, cheaper, more efficient grid power. General Motors and others experimented with electrically powered cars, such as the EV1. Currently at least three manufacturers will release electrically powered cars to the commercial market, including the General Motor's Volt, Aptera, and the Tesla Roadster, as well as a factory-built PHEV version of the Prius. The National Renewable Energy Lab's report "A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae" suggests 2% of the land area in the US, including non-arable land, could meet all transportation fuel needs. This study suggested raising a specific species of algae on an area flooded with brackish water in the desert Southwest known as the Salton Sea.

⁹⁶ David Daggett of Boeing Corporation, Robert Hendricks from NASA, Rainer Walther from MTU Aero Engines and Edwin Corporan from the Air Force Research Labs wrote the 2007 article "Alternate Fuels for use in Commercial Aircraft," discussing the parameters and difficulties involved in finding sustainable and feasible alternatives to jet fuel.

allow for a gradual transition through normal equipment attrition. It must be reasonably safe and convenient to handle to facilitate distribution and use on the battlefield. It must also be reasonably affordable to allow for repetitive realistic training.

The system must have a good energy density to allow for mission payloads, rather than fuel tanks to dominate carrying capacity. The greater the energy density, the lower the requirement for support vehicles and their commensurate support infrastructure to distribute the fuel. Energy density measures the amount of energy contained in a fuel per unit mass or unit volume. While biodiesel or synthetic fuel made from coal would be practically indistinguishable in this manner, ethanol would increase the number of tankers and storage containers required by 60% and reduce vehicle range by 40% because of its lower energy density.⁹⁷ This would exacerbate the fuel “pyramid effect” inherent in the legacy distribution system.

⁹⁷ Dave Daggett of Boeing illustrates a notional ethanol powered airliner with 25% larger wings, 50% larger engines, and 35% greater takeoff weight and 15% greater total energy consumption to perform the same mission as a biodiesel, Jet-A or synthetic fueled equivalent on slide 17 of “The Role of Fischer-Tropsch Fuels in the US Military” by William Harrison III.

Legacy System – The Irony of the Lethargic Energy Infrastructure

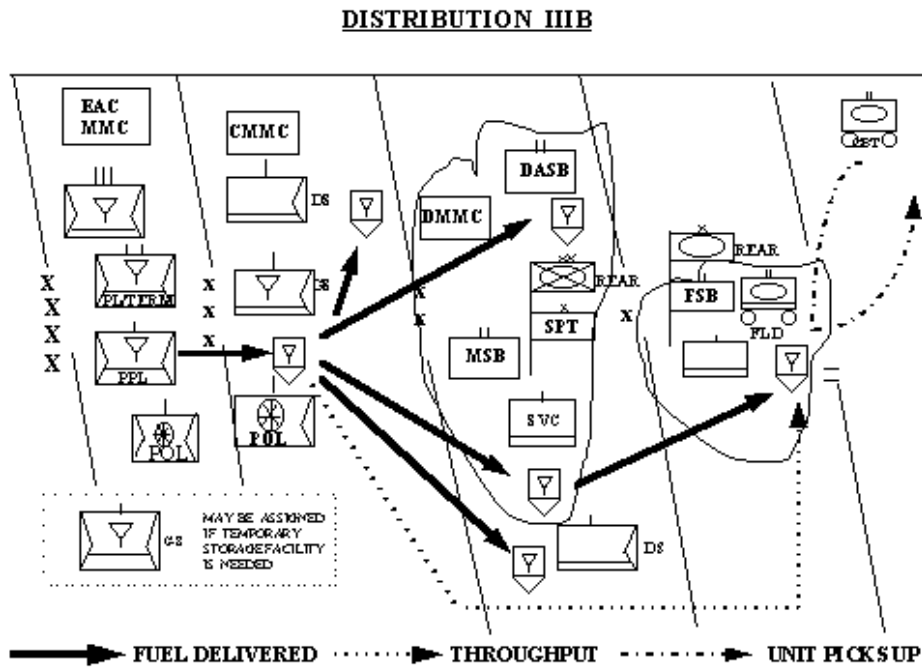


Figure 5: Fuel distribution on the linear battlefield.⁹⁸

Military fuel tankers carry the fuel required by the users in the echelon ahead of them, as seen in Figure 5. Delivering a fuel with low energy density in the legacy system requires more tankers, cascading from the vehicles delivering to the end user and all the way back to support the consumption of the additional tankers and infrastructure. Travel time and the commensurate crew fatigue dictates an echelon of tankers or at least a secure location to bed down every 150-300 kilometers, similar to a highway rest stop. These locations are often used to trans-load the fuel and the tankers return to their base to load fuel for the next day's shipment.

They often form logistics bases at this distance for this purpose, also known as forward operating bases, or FOBs, which appear at about every 150 kilometers of tactical depth. These

⁹⁸ Class IIIB (bulk fuel) distribution on a notional linear battlefield from Figure 6-1 *Student Text 63-1: Division and Corps Logistics* U.S. Army Command and General Staff College, Fort Leavenworth, KS: 1 July 1997.

must also have a commensurate complete set of fuel tankers capable of carrying the entire fuel needs of the units and the support infrastructure for the soldiers and tankers in front of it, which in the case of Figure 5 would be an additional layer of General Support (GS) tankers. These bases require force protection and other life support functions to operate. This force protection and life support requirement consumes combat power, prevents its employment elsewhere on the battlefield, and further adds to fuel and other logistical requirements to support. These logistics bases usually maintain an emergency buffer of fuel on hand to hedge against any sort of delivery problems for a predetermined number of days. This storage normally consists of fabric “blivets.” Groups of these blivets are pejoratively referred to as “bag farms,” which cover a large expanse of terrain, and are vulnerable to artillery and mortar fire and render the infrastructure immobile. The increased size also expands the size of the perimeter, which increases requirements for force protection. This led one observer in Vietnam to remark that logistics was “the tail that wagged the dog.”⁹⁹

On the other hand, many commanders assert that these FOBs also provide a secure place for soldiers to sleep, get good food, and enjoy recreation. They further posit that this helps alleviate the stress of battle, increase morale and focus in combat, and helps maintain higher re-enlistment rates of experienced and valuable combat veterans.¹⁰⁰ However, reducing or eliminating the logistics burden on the FOBs would reduce their required size, make them less of a lucrative target, make them far more mobile, and facilitate placing them in more advantageous positions. See Figures 6-8 for major forward operating base sites in Iraq, and particularly Figures

⁹⁹ LTG John H. Hay, Jr. in *Vietnam Studies: Tactical and Material Innovations*, (Washington, DC: Department Of The Army, 1974), page 151, referring to the enormous logistics effort to support combat operations leading to siphoning combat power to protect logistics assets.

¹⁰⁰ The American Academy of Sleep Medicine released a study entitled “Sleep Deprivation Affects Moral Judgment” on 2 March 2007 which suggests better sleep results in better leadership decisions and a more patient, wise, and effective counter-insurgency force. [Online] available at <http://www.sciencedaily.com/releases/2007/03/070301081831.htm>; Internet; Accessed 5 March 2008.

7 and 8 to contrast the locations of logistically driven forward operating bases with security driven joint combat outposts.

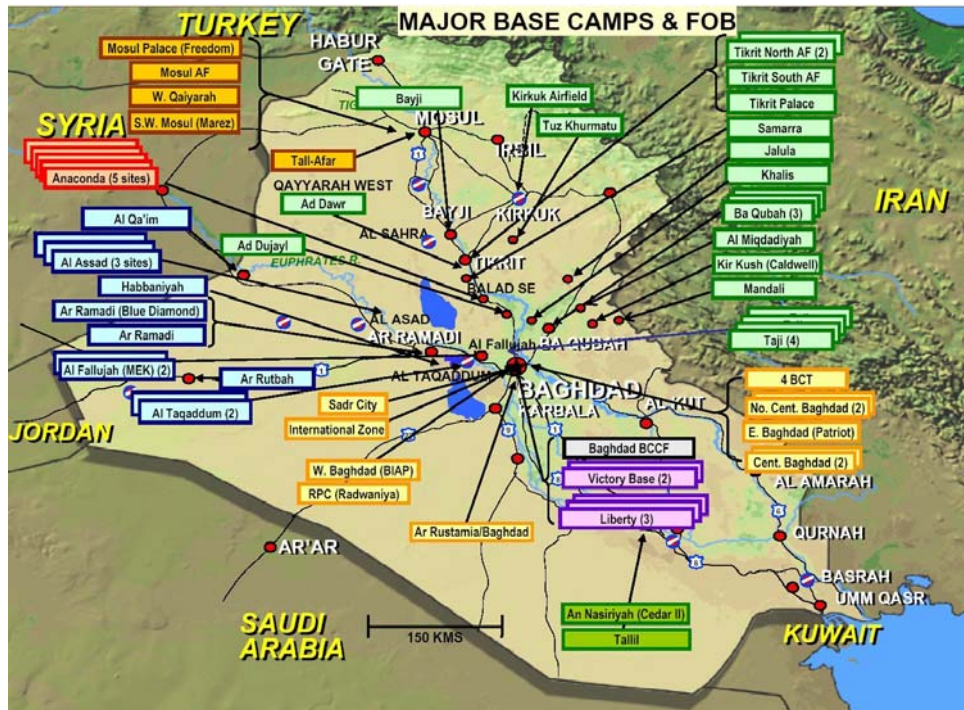


Figure 6: The major camps and forward operating bases in Iraq, 21 April 2005.¹⁰¹

¹⁰¹ Forward operating base and camp locations for Multinational Forces, Iraq, available via Globalsecurity.org [Online] available from <http://www.globalsecurity.org/military/facility/iraq-maps.htm>; Internet; Accessed 30 April 2008.

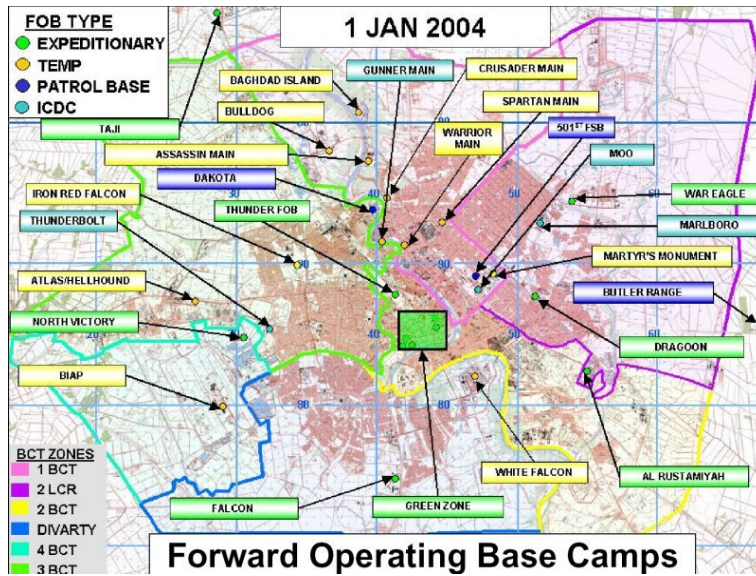


Figure 7: Forward Operating Bases within Baghdad alone.

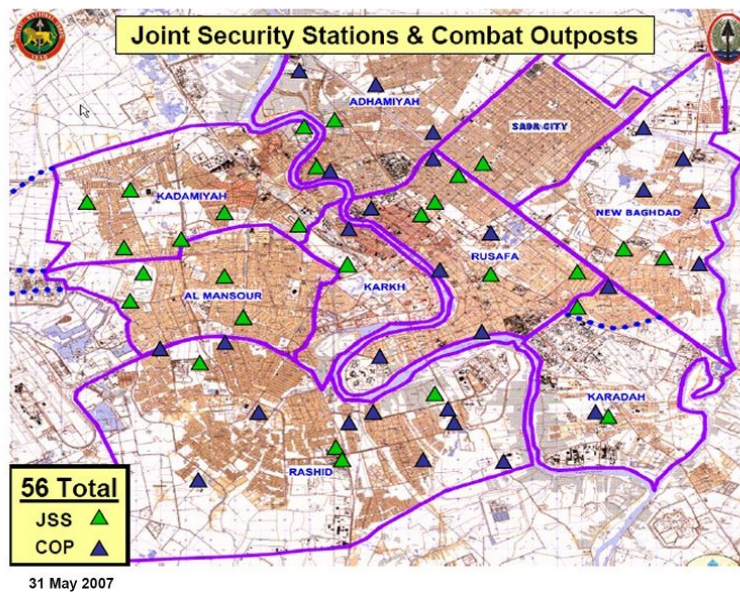


Figure 8: Joint Security Stations and Combat Outposts for contrast with Forward Operating Bases. Tactical value drives the location of these installations, versus logistical limitations that drive FOB locations.¹⁰²

¹⁰² 31 May 2007 Joint Security Station and Combat Outpost slide from Multi-National Corps Iraq via Globalsecurity.org.

Operational and Tactical Imperatives – Getting Fuel through the Fire

Domestically produced synthetic fuel does not contribute to DoD’s most critical fuel problem – delivering fuel to deployed forces.

Defense Science Board on DoD Energy Strategy¹⁰³

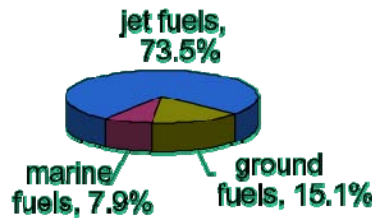


Figure 9: DoD fuel consumption by use.

Although ground systems only consume about 15 percent of all military fuel, increasing system efficiency and reducing external fuel demand for land systems could potentially have the highest indirect payoff. These forces are at the very end of the delivery chain with the most effort

¹⁰³ *Report of the Defense Science Board Task Force on DoD Energy Strategy “More Fight-Less Fuel”* Defense Science Board Task Force, 2008 Section 4.2, page 50

placed in delivering fuel to widespread locations.¹⁰⁴ For example, 54.2% of the Air Force fuel share provides for transport aircraft, many of which deliver Army forces and supplies.¹⁰⁵ Historically one of the biggest costs of supporting ground forces was capturing a suitable port to rapidly offload cargo from ships.¹⁰⁶ Getting fuel to deployed forces remains a challenge.

¹⁰⁴ The map of Insecurities in the World Oil market by SAFE (Securing America's Future Energy) in Appendix A illustrates a few of the key choke points. Tanker ships in wartime face risks from submarines, aircraft and other ships, especially since they must generally conform to well-known shipping lanes to efficiently and quickly move their cargo to their destination. The battles of the Atlantic in World Wars I and II devastated allied shipping and nearly succeeded in choking off Britain's war effort. Diesel-electric submarines continued to advance since World War II and present a threat against even the US Navy. A Chinese *Song* class submarine surfaced within torpedo range of the USS *Kitty Hawk*. *International Herald Tribune* article entitled "U.S. military officials wary of China's expanding fleet of submarines" by David Langue, written 7 February 2008 discusses the incident, which took place in late 2006. Additionally, several nations are fielding even quieter Air Independent Propulsion (AIP) fuel cell powered submarines. The Nuclear Threat Initiative (NTI) published an analysis of the proliferation of diesel-electric and AIP submarines in the article "Global Submarine Proliferation: Emerging Trends and Problems" by Dr. James Clay Moeltz in March 2006. [Online] available from http://www.nti.org/e_research/e3_74.html; Internet; Accessed 30 April 2008. Additionally, Robert Kaplan wrote in "The new balance of power" at the Foreign Policy Research Institute on 14 April 2008 that China will not try to compete on even terms with the US Navy. [Online] available from <http://www.cnas.org/en/art/?451>; Internet; Accessed 24 April 2008. They will focus on employment of an asymmetric strategy focusing on missiles capable of striking ships at sea, quiet diesel-electric submarines, and anti-satellite technology.

¹⁰⁵ The information and chart in Figure 9 came from Slide 5 of William E. Harrison III's briefing "The Role of Fischer-Tropsch Fuels for the US Military", 30 August 2006. The proportion of Air Force fuel consumed by tanker aircraft came from slide 6. The 2008 Defense Science Board *Report of the Defense Science Board Task Force on DoD Energy Strategy* Finding #6 said, "Moving fuel to deployed forces has proven to be a high risk operation."

¹⁰⁶ This was a major German assumption in World War II that the allies avoided through the construction of the Mulberry Harbor, an artificial, portable harbor built, hauled into position and emplaced to support the Allied forces following the successful landing at Normandy until they could seize a port, such as Antwerp intact. This harbor system was a monument to ingenuity, comprising of large floating concrete blocks which were sunk in place to attenuate wave height, a floating landing platform, and a ribbon float bridge to shore. The Allies deployed two of these systems; one at Omaha beach, the other at Arromanches in the British sector. This system gave the Allies the logistics support ashore to save the landing force from counter-attack, and to encircle and capture a port in the most effective, not necessarily the quickest (and bloodiest) way. The modern antecedent of the Mulberry Harbor is JLOTS (Joint Logistics Over the Shore). This requirement also highlights the importance of Pusan to the Allies in the Korean War, and of seizing Um Qasr in Operation Iraqi Freedom, among other examples.

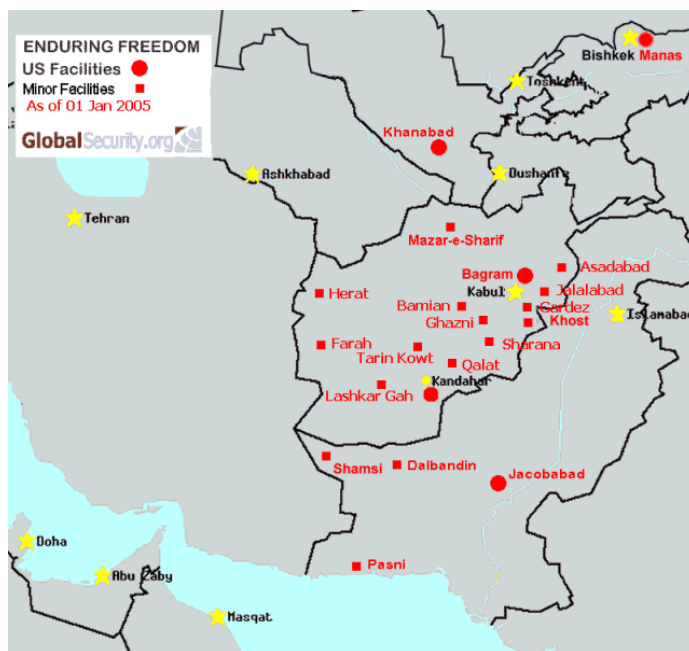


Figure 10: US facilities in Afghanistan and Pakistan.¹⁰⁷

During the early phases of Operation Enduring Freedom, US ground forces had no means of moving fuel into Afghanistan. Figure 10 shows the major US facilities, and illustrates difficulty in supplying them. Afghanistan is a land-locked country, requiring aerial delivery or permission to transit on the ground through adjacent countries. C-17 cargo aircraft landed at airfields, drained their center tanks into awaiting fuel trucks, took off using fuel in their wing tanks, and were refueled in the air. They then landed again and repeated the process to meet the fuel requirements on the ground.¹⁰⁸ Even years later, after the Defense Logistics Agency

¹⁰⁷ Facility map from GlobalSecurity.org. [Online] available from <http://www.globalsecurity.org/military/facility/afghanistan.htm>; Internet; Accessed 30 April 2008. Currently, 75% of all supplies and 40% of vehicular fuel supplies travel over land through Pakistan. Recent concerns over stability in Pakistan forced logisticians in Afghanistan to consider alternates, all of which involve airlift. The 15 November 2007 *International Herald Tribune* article “Pentagon making plans in case Pakistan unrest disrupts Afghan war supplies.” Note also that US access to Uzbekistan was closed in 2005 after the US protested when Uzbek government troops fired on protesters. This is another dimension of the conflict in the current system between the moral dimension and practical needs.

¹⁰⁸ Pages 35 and 36 of *The United States Army in Afghanistan: Operation Enduring Freedom* (Dr. Richard W. Stewart, US Army Center for Military History October 2001-March 2002) discussed having to resort to “wet wing” operations--draining fuel from aircraft to deliver fuel--during Operation Enduring Freedom.

established contracts for fuel from Pakistan, units in Afghanistan were still having severe problems with fuel deliveries and ran dangerously low and constrained operations at least three times in 2004-2005.¹⁰⁹ Fuel delivery problems continually plague forces in Iraq.

Moreover, once the fuel reaches the area of operations, these deliveries go through hostile territory, over easily predictable land routes on a rhythmic, pulse-like predictable schedule. Currently the highest costs accrue from delivery by predictable ground lines of communication. The current distribution system adds hidden costs to tactical fuel, including delivery.¹¹⁰ The vehicles, infrastructure and personnel required to deliver fuel comprise a substantial portion of these costs. This fuel distribution system also entails intangible risks and costs of dead and wounded soldiers, their Veterans benefits and medical bills, damaged and destroyed vehicles, contractor support expenses to augment fuel delivery, the costs of building, maintaining and securing forward operating bases and roads.¹¹¹ It also includes intangible costs to mission accomplishment, such as undermining counter-insurgency efforts by disrupting local traffic, through accidents, etc. Figure 6-10 also depict the wide dispersion of the facilities that require replenishment, which is exacerbated in Afghanistan by its rugged terrain. Lt. Col. Ian Hope, the 2006 commander of the Canadian Task Force Orion in Kandahar Afghanistan said:

It is quite possible [this lack of transport helicopters] has cost limbs, if not more, because we have had to sustain [resupply troops in remote areas using vehicles] on the ground. That has produced a risk that would be reduced if we could take helicopter flights. It does not take a military tactician to know this. We have mitigated the risks. Losses have been reduced, but not yet to zero.

¹⁰⁹ *Operational Leadership Experiences in the Global War on Terror*, "Interview with MAJ Joseph Rawlings," Combat Studies Institute, Fort Leavenworth, KS, May 2006, pp 8-9

¹¹⁰ Both the 2001 and 2008 Defense Science Board reports on energy cited the vulnerabilities and costs of delivering fuel in their findings and recommendations, and asserted that DoD does not fully appreciate these risks, costs and externalities, nor their impact on effectiveness.

¹¹¹ David M. Herszenhorn wrote a 19 March 2008 article in the *International Herald Tribune* entitled "\$600 billion? \$5 trillion? Costs of the Iraq war are hotly disputed." The article discusses the assertion by Nobel Prize-winning economist Joseph Stiglitz that the war in Iraq's long-term costs are between \$3 trillion and \$5 trillion. The Congressional Budget Office set it more like \$1 trillion to \$2 trillion.

While Canada's senior logistician in Kandahar, Lt. Col. John Conrad added: "The convoys are now in harm's way almost daily because supplies have to follow the infantry and we have had to send those supplies by land..."¹¹² While the availability of helicopters for other coalition partners have eased casualties by avoiding ground lines of communication, aerial re-supply is not always feasible, especially with the quantities involved supporting mechanized forces.

The current fuel system was designed for large-scale, echeloned linear battle with large, secure rear areas in well-developed theaters. Although our enemies have always planned to disrupt our tactical energy system, these threats would only manifest during an actual outbreak of hostilities and did not materialize within the career span of most soldiers. The threat was generally localized in the zone where the enemy wished to penetrate, and was otherwise supposedly within the ability of logistics units to mitigate.¹¹³

The pervasive use of improvised explosive devices in Iraq and Afghanistan demonstrates the vulnerability of our ground lines of communication (LOCs), and future adversaries will likely learn from this and will exploit it.¹¹⁴ Aspects of Iraq and Afghanistan are likely models for future

¹¹² Both quotes come from the 8 April 2008 *Defense Industry Daily* article "On The Verge: Canada's \$4.7B Program for Medium-Heavy Transport Helicopters."

¹¹³ Doctrine emphasized dispersion and mobility to mitigate artillery fire and logistics units were expected to fight off "level 2" threats comprising of a squad sized enemy unit or smaller. Convoy commanders drilled also their drivers for reaction to artillery, ambush, and enemy aircraft. Lawrence Martin describes Soviet Operational Maneuver Groups (OMG) on page 90 of *NATO and the Defense of the West* (New York, NY: Holt, Rinehart and Winston 1985), as does Shimon Naveh in *In Pursuit of Military Excellence: The Evolution of Operational Theory* (Portland, OR: Frank Cass Publishers 1997) on 167, 173 and 194. Naveh's description of these units emphasizes their role in creating operational shock (*udar*) in an enemy system, particularly by disrupting logistics, C², etc. This involved *Spetsnaz* attacks and artillery interdiction into rear areas, as well as echeloning forces to create a breach for follow-on forces to penetrate deeply. Saddam Fedayeen during Operation Iraqi Freedom and now any of a number of insurgent groups are continuously and pervasively in "the rear area." Irregular warfare in Vietnam emphasized direct fire ambushes that led to greater armament on convoys, some known as "gun trucks," as well as convoy escorts of armed and armored vehicles for protection. These counter-ambush tactics led to Iraqi insurgents changing to the IED, and the subsequent counter-IED effort. For more on the evolution of "gun trucks" and convoy security, see the Combat Studies Institute publication *Circle the Wagons: The History of US Army Convoy Security* by Richard E. Killblane (Global War on Terrorism Occasional Paper 13, Combat Studies Institute, Fort Leavenworth, KS 2005)

¹¹⁴ 56% of the US casualties in Iraq for 2008 have been caused by Improvised Explosive Devices according to an Associated Press article entitled "U.S. military statistics in Iraq war." Additionally,

wars as adversaries will reasonably conclude that it is more advantageous to them to employ asymmetric attacks and irregular warfare than directly confront US combat forces.¹¹⁵ David Kilcullen, a counter-insurgency expert advising GEN Petraeus in Iraq stated that Exhaustion is a key insurgent strategy, where they force the counter-insurgent to expend vast resources and manpower performing tasks that do not further their strategic objective and spread out their forces over the battlefield.¹¹⁶ LOCs are impossible to completely defend against asymmetric threats, despite route clearing efforts. Route clearance becomes a hyperbolic effort and can only asymptotically approach complete security. This may reduce attacks, but does not necessarily further strategic objectives and may detract from the strategic aim. All it takes is one IED along the thousands of miles of road to chip away at logistics assets and morale and potentially disrupt operations in concert with other attacks, even if the attacks fail. Roads channel logistics patrols along predictable routes, allowing insurgents to place a weapon anywhere along a given route.

analysis of the casualties listed in the Office of the Secretary of Defense site for DoD Personnel and Procurement statistics, ([Online] <http://siadapp.dmdc.osd.mil/personnel/CASUALTY/castop.htm>; Internet; Accessed 30 April 2008) and inferring military occupational specialty by the name of the unit, logisticians suffered grossly disproportionate casualties in Operations Iraqi Freedom and Enduring Freedom in comparison to past US 20th Century wars. These problems surfaced prior to the full development of the insurgency. US forces used deep penetrations into enemy territory during Operation Desert Storm and in Operation Iraqi Freedom, which exposed units in the rear to more risk than the doctrinal construct they were designed for. The 507th Maintenance Company got lost early in the war and drove into enemy held territory, resulting in a number of dead, wounded and several soldiers taken prisoner by the Iraqis. The 2nd Brigade of the 3d Infantry Division and their armored raids into Baghdad required fuel and ammunition re-supply, and the column bringing these supplies took heavy fire from all directions. Enough of their un-armored fuel and ammunition trucks survived the trip and re-supplied the brigade to facilitate success, but many vehicles and supplies were lost and would not have been sustainable. (See *Thunder Run*, pages 204-260, or *On Point* pages 362-372).

¹¹⁵ Nagl and Yingling “Restructuring the US Military,” *Inside CFR Events* podcast; and Krause, *Square Pegs and Round Holes*

¹¹⁶ David Kilcullen, *Counter-Insurgency in Iraq 2007: From Theory to Practice*. [Online] available from <http://www.mcwl.usmc.mil/Counterinsurgency%20in%20Iraq%20theory%20and%20practice2007.ppt>; Internet; Accessed 30 April 2008. T.E. Lawrence neutralized the far more powerful and advanced Turkish Army regulars with a ragtag guerilla band by threatening their land lines of communications. LTC T.E. Lawrence, expounds upon this in “Evolution of a Revolt,” *Combat Studies* reprint of the 1920 article in the *UK Army Quarterly and Defense Journal*.

Fuelers and other line haul assets at progressively higher echelons carry increasing capacities but also lose their cross-country mobility, tying them to roads.

The purpose of a combat patrol is to perform a task with a purpose aligned with the strategy for winning. Logistics patrols are not about achieving the strategic objective, they are about sustaining and enabling the force that does. In doing so they present vulnerabilities and targets for insurgents and may instead contribute to the problem. Leaders carefully plan combat patrols specifically to create or shape opportunities to win tactical victories that align with the strategic objective and take all the time they need to do it. These are literally about the journey, not the destination. Combat forces in non-linear battles seize the initiative on the offense, and move capriciously and unpredictably.

Logistics patrols in contrast are the opposite. They are a means to an end and the soldiers on these patrols must avoid enemy contact and deliver their supplies to the destination intact. They normally cannot digress and are not equipped to divert to exploit opportunities and have much less patience with “distractors.” They need to get it over with as fast as possible, deliver the supplies, prepare for the next delivery, and are less apt to carefully observe an area for threats and opportunities to further the strategic objective. Logistics patrols by nature take place with a pulse-like rhythm, which make them predictable and even more vulnerable. They are continuously on the defensive and the enemy has the initiative. LTC Marian Vlasak noted that insurgent forces employ lean operations which lead to resilient lines of communication that are hard to interdict, whereas heavy use of logistics and the resulting heavy use of vulnerable supply convoys siphoned off combat power to protect them.¹¹⁷ The maps of the forward operating bases

¹¹⁷ LTC Marian Vlasak, “The Paradox of Logistics in Insurgencies and Counterinsurgencies, or Why a ‘Little Bit’ Goes a Long Way and a ‘Whole Lot’ is Never Enough,” January/February 2007 *Military Review*. LTC Vlasak notes that insurgencies derive much of their support from the population and sparingly and selectively employed the resources carried in on lines of communication, making those LOCs, such as the Ho Chi Minh trail very difficult to interdict. Conversely, counter-insurgents tend to use a lot of resources at all places and all the time to locate the insurgent. Using large amounts of supplies leads to supply convoys on roads, which present themselves as targets for insurgents to attack, which saps

in Iraq and Afghanistan in Figures 6, 7, 8, and 10 illustrate the problem supplying dispersed forces. This also highlights the need combat forces in counter-insurgency warfare to spread out over a wide area which exposes logistics forces in a way they were not designed to fight.

Logistics vehicles, especially fuel trucks, cannot effectively benefit from all the advances in protection available to other types of patrols, and use of armored vehicles for other types of patrols increases their vulnerability. Security vehicles and weapons are nearly useless after fuel trucks are already damaged. Armoring fuel trucks reduces their payload, which increases their fuel consumption and requires more fuel trucks to deliver more fuel with a net increased risk. The use of fuel-thirsty heavy armored vehicles to protect soldiers doing other missions, such as the pervasive use of the MRAP (Mine-resistant ambush protected) vehicles, and other heavily armored trucks may reduce the risk for forces that use them, but they correspondingly increase the net risk by increasing fuel requirements.¹¹⁸ The three aspects of armored warfare of mobility, firepower, and protection over time have led to ever increasing amounts of armor protection on tanks pitted against ever increasingly large guns or anti-tank mines. Engineers preserved mobility with ever more powerful, energy intensive drive trains as greater amounts of armor were applied to counter more powerful enemy guns. Technological breakthroughs on each of these aspects

combat forces from searching for insurgents to protect their own supplies. Perversely, this is also a way the counterinsurgent inadvertently supplies the insurgent. Meanwhile, Mr. Lester Grau and Timothy Thomas's article "'Soft Log' and Concrete Canyons: Russian Urban Combat Logistics in Grozny" (Fort Leavenworth: Foreign Military Studies Office, 1999) revealed that Russian logistics convoys were forced to stop outside the cities and trans-load their cargo into armored combat vehicles for final delivery.

¹¹⁸ Roxana Tiron's 24 July 2007 article "Firm guards niche in armored vehicles" in *The Hill* said that 72% of the lifecycle costs of the MRAP classes of vehicles goes into maintaining and sustaining the vehicles. On capital costs in vehicle purchases worth \$4 billion, over \$10 billion will be spent on fuel and maintenance. The fuel consumption is 5-10 miles per gallon, depending on which of the three categories examined. Retired General Jack Keane criticized their poor off-road performance as well as their support requirements. Senator Lindsey Graham also worried about the lifecycle costs, but added that such costs were preferable to military families losing a soldier. While the MRAP class vehicles' innovative blast deflecting design and usage of materials have demonstrably saved lives in combat, they may increase risk elsewhere. The fuel costs they are citing only count the fuel itself, and not the delivered costs, the costs of the associated infrastructure, or the risks to soldiers delivering the extra fuel. Nor does this account for the added tactical risks associated with greater reliance on roads, which canalize vehicles and puts them into the situation to be attacked more frequently in the first place.

aside, it has usually been cheaper and quicker to field new anti-tank weapons than to upgrade a tank force against the new weapon.¹¹⁹ Carefully constructed and placed IEDs have even damaged or destroyed a few magnificently armored 70-ton M1 tanks. Armor protection has saved US soldiers from IED attacks, but insurgents are constructing larger and more deadly IEDs as a result to counter it, while the new vehicles also indirectly increase risk for their own fuel delivery. Moreover, weight increases and reduced cross-country mobility further restricts vehicles to roads, making them predictable, easy targets, and putting them at greater risk of encountering ambushes and IEDs in the first place.

Locally procuring fuel averts the need to deliver it, but presents potentially severe risks to military forces by putting them at the mercy of the supplier.¹²⁰ Hiring contractors to deliver fuel in place of military logistics units shifts the risk and political costs to an external player. This arguably saves money over the long run, and yields short-term tactical gains, but can generate long-term strategic risks, especially in a counter-insurgency environment. The long-term risk is atrophy and failure to reform the military infrastructure to cope with the real problems faced on the battlefield. Conduct of contractors on the battlefield comprises the short-term risk. Bad contractor behavior can undermine the reputation of and good will toward counter-insurgent forces.

Unmanned vehicles could reduce the risk of delivering fuel. The Defense Advanced Research Projects Agency (DARPA) sponsored several “Grand Challenge” competitions to test autonomous robot vehicles in a variety of terrain types in part for this purpose.¹²¹ Although the

¹¹⁹ Kenneth Macksey, *Tank Versus Tank: The Illustrated Story of Armored Battlefield Conflict in the Twentieth Century* (London: Grub Street, 1999), pages 94 and 106 discuss historical examples of how fielding bigger or more powerful guns is cheaper and easier than fielding tanks with sufficient armor to protect against it, especially without sacrificing mobility and mechanical reliability.

¹²⁰ *Operational Leadership Experiences in the Global War on Terror*, “Interview with MAJ Joseph Rawlings,” Combat Studies Institute, Fort Leavenworth, KS, May 2006, pp 8-9

¹²¹ DARPA (Defense Advanced Research Projects Agency) Website, [Online] available from <http://www.darpa.mil/grandchallenge/index.asp>; Internet; Accessed 28 April 2008. The first DARPA

aces went well and numerous contestants satisfied the requirements of the race, these systems are still years away from deployment on a battlefield. Even then, while they could significantly reduce human casualties, destruction of these systems by IEDs by employing them in the legacy system would still be very costly and disruptive, and therefore would not solve the root problem by itself. However, replacing manned missions with unmanned aerial and ground vehicles (UAVs and UGVs) where feasible saves considerable amounts of fuel.¹²²

Another way to mitigate the risk of ground lines of communications is aerial insertion. 173d and 11D (TF 1-63) airlifted in to Northern Iraq during the opening of Operation Iraqi Freedom. These units and the Air Force expended a monumental effort to put a handful of armored vehicles in northern Iraq, and a subsequent effort to sustain them solely by air.¹²³ Fuel delivery this way is extremely risky and expensive, although it avoids predictable and easily interdicted land routes. Moreover, if delivery requirements for other commodities are sufficiently small, parachute delivery can further abate risk, particularly newly developed precision airdrop technologies.¹²⁴ However, this is not feasible with current fuel characteristics and quantities.

Grand Challenge event was held in the Mojave desert and involved traversing a course revealed to the teams at the last minute by global positioning system waypoints. The robots had to analyze the terrain and determine the best way to reach these waypoints without human intervention. The second event was held at the former George Air Force Base in Victorville California. The robots not only had to follow the prescribed route, but also had to obey all traffic regulations. Six contestants successfully finished the course.

¹²² Page 48 of the 2008 *Report of the Defense Science Board* highlights the thriftiness and utility of unmanned vehicles on the battlefield.

¹²³ Fontenot, *On Point*, page 230 said that placing the 173d Airborne Brigade into Northern Iraq posed an insurmountable challenge to the Iraqis. However, adding TF 1-63 also posed an *almost* insurmountable challenge to US Army and Air Force logisticians to sustain it, particularly the 10,000 gallon per day fuel requirement.

¹²⁴ JPADS (Joint Precision Air Drop System) employs global positioning system guidance to steer parachutes. These systems range in a variety of sizes and users can program them to land in specific coordinates en route to the drop zone. US Army Natick Soldier Systems website [Online] available from http://www.natick.army.mil/soldier/media/fact/airdrop/JPADS_ACTD.htm; Internet; Accessed 28 April 2008.

Efficiency and Combat Power

Moving fuel to deployed forces has proven to be a high risk operation. Reducing operational fuel demand is the single best means to reduce that risk, but DoD is not currently equipped to make informed decisions on the most effective way to do so.

The Defense Science Board 2008, Finding Number 6¹²⁵

The fuel pyramid effect highlights the role of efficiency in the ability to deploy and sustain of a force. Although the military values efficacy over efficiency, efficiency also directly affects the quantity of fuel and the amount of support infrastructure required.¹²⁶ This drives the amount of lift and time required to deploy into a theater of operations and constrains the proportion of combat power in the mix of equipment. Combat operations in Operation Desert

¹²⁵ Finding Number 6 of the 2008 *Report of the Defense Science Board Task Force on DoD Energy Strategy*.

¹²⁶ Finding number 1 of the 2001 Defense Science Board Task Force on *Energy More Capable Warfighting Through Reduced Fuel Burden* stated "Although significant warfighting, logistics and cost benefits occur when weapons systems are more fuel-efficient, these benefits are not valued or emphasized in the DOD requirements and acquisition processes. When buying new weapons, DOD placed performance as its highest priority and seemed to overlook how fuel efficiency could result in improved performance. Furthermore, when developing new systems the department did not seem to take into account how the fuel use of a particular system could have far-reaching effects on the total force (e.g., a system's logistical requirements may create a vulnerable delivery chain)." The design of the M1 tank held performance in a mobile defense against a Soviet invasion in Western Europe paramount, with little regard for efficiency. Lawrence Martin's *NATO and the Defense of the West: An Analysis of America's Fire Line of Defense*, page 39-40 recounts various NATO defensive strategies, and yields insight into the design rationale of the M1. As NATO strategy evolved, it became more determined to blunt a Soviet invasion at the border and resist penetration into Germany as much as possible. Strategy evolved from the "Fallback" plan, in which most of West Germany acted as a delaying zone and its Western border as the main defensive line, to "Tripwire" to "Active Defense" until finally the "FOFA" (Follow-on Force Attack) placed the defensive belt on the Eastern border with disruption zones within East Germany. The M1 is an extremely mobile and effective tank, but its 70-ton weight makes it very difficult to deploy by air, and its fuel consumption requires an enormous supporting logistics infrastructure to follow it on the battlefield. For example, the C5 Galaxy, the largest, most powerful cargo aircraft in the US inventory, can only airlift one M1 tank at a time. Similar problems emerged again with the deployment of Task Force Hawk to Albania for intervention in Kosovo, in part due to the enormous infrastructure to support the deploying units. (See Fontenot, *On Point*, pages 14 and 20) The deployment of Task Force 1-63 in support of 173d Airborne Brigade in Northern Iraq during Operation Iraqi Freedom also highlights this point. They inserted the Immediate Ready Force (IRF), consisting of an heavy ready company (HRC) of 5 M1 tanks and 5 Bradley fighting vehicles, and a medium ready company (MRC), consisting of 12 M113 Armored Personnel Carriers plus support on 27 C-17 flights. (*On Point*, pages 79, 224 and 229) See MAJ Brian Maddox's September/October 2003 *Armor Magazine* article, "Checkmate on the Northern Front: The Deployment of Task Force 1-63 Armor in Support of Operation Iraqi Freedom."

Storm could have started 20% earlier, from six months to five had the M1 tank been 50% more efficient and required correspondingly less fuel assets.¹²⁷ Fuel comprises 70% of the tonnage shipped for Army unit, yet the top ten list of Army fuel consumption includes only two combat vehicles; the M1 is fifth, and the Apache helicopter is tenth. Support platforms make up the remainder of the list, and units that are echelons above Corps consume 55% of the fuel.¹²⁸ The capacity of each echelon of the fuel pyramid must more than double the capacity of the tankers ahead of it for every 150-300 kilometers to cover their own and the end user consumption at each level.¹²⁹ Even assuming fuel costs of one dollar per gallon, the delivered cost of fuel on the battlefield ranged from about \$30 a gallon up to \$400 a gallon.¹³⁰ Moreover, the majority of fuel assets resides in the Army Reserve, and take months to mobilize and deploy.¹³¹

¹²⁷ Page 13 of the 2001 Defense Science Board publication *More Capable Warfighting Through Reduced Fuel Burden*.

¹²⁸ The list of platforms is provided by the 2001 report of the Defense Science Board, page 43. Percentage by unit from Sandra Erwin, "The Army's Next Battle, Fuel, Transportation Costs," *National Defense*, April 2002

¹²⁹ Fuel tankers at the end-user level can often carry enough fuel for two or three days of projected consumption and have some limited off-road capability. Units to the rear of these employ larger capacity tankers, many of which at the Corps level are restricted to improved roads. They may also offset this issue by making more frequent deliveries. Pipelines are used in more secure rear areas, such as within Kuwait and in operations in Western Europe, where US doctrine relied on secure rear areas. See *Student Text 63-1: Division and Corps Logistics*, US Army Command and General Staff College, chapter 6 for more details. Insurgencies in environments such as Iraq and Afghanistan make this an unwise practice because they regularly attack unguarded infrastructure.

¹³⁰ The 2001 Defense Science Board Task Force study *More Capable Warfighting Through Reduced Fuel Burden* derived these estimates on page 19. The higher estimate is for deliveries in combat beyond 400 kilometers, which often involves transportation of fuel using helicopters, which cost thousands of dollars per hour to operate and themselves consume enormous quantities of fuel. *Defense Industry Daily* wrote in a 6 April 2008 report entitled "USA's H-53 Engine Upgrade Program" that one flight hour of a CH-53 helicopter consumes 44 man-hours of maintenance, and altogether costs \$20,000.

¹³¹ Mobilizing these forces is a politically sensitive issue, especially during election cycles. Task Force Ironhorse, led by the 4th Infantry Division, deployed for Operation Iraqi Freedom before its Reserve and National Guard assets were mobilized. The Task Force originally planned to land in and transit across Turkey to attack Iraq from the North. (Fontenot, *On Point*, pages 41, 52, and 68) LTC Bryan Imiola, the Division Support Operations Officer created a plan to build "Task Force Log" to mitigate against the lack of logistics infrastructure and the bulk of the fuel assets required to shuttle fuel forward to combat units. Task Force Log was an amalgam of all the fuel tankers and supply vehicles from the entire division, and this unit was slated to be among the first to deploy. 1-10 Cavalry Squadron and the 1st Brigade Combat Team were the lead elements, and kept their organic fuel assets. All other combat units would get their logistics assets back once they arrived and once the reserve component fuel assets arrived.

Throughout the Cold War we refined and optimized the system for sustaining a massive force in a mobile defense, but within a well-developed theater. At the end of the Cold War we began to emphasize expeditionary capabilities and began to focus on deployments into austere environments, especially after Desert Storm. Despite virtually unlimited supplies of fuel support from Saudi Arabia, fuel constraints delayed the start of the war and forced units to prematurely culminate.¹³² The robust, mobile fuel infrastructure can only expand so far and so quickly, in part because the fuel trucks must travel twice the distance that combat vehicles cover in the same amount of time, and each echelon can only travel a finite distance each day.

The primary means to increase efficiency is to reduce vehicle weight, which would also have the added benefit of speeding deployment of equipment and make aerial insertion more feasible. Weight drives fuel usage for ground vehicles, and armor constitutes 20% of the weight of a typical combat vehicle.¹³³ But this reveals the tension between mobility and efficiency on one hand and armor protection on the other. Ultimately, better efficiency and mobility indirectly contribute to protection by avoiding canalization and large amounts of vulnerable sustainment assets. The biggest advancements in protection have come from superior use of materials rather than mass. Better materials and improved shaping, such as the sloping armor or the “v-hull” concept of the MRAP family can provide better protection for the same weight of armor protection. The “slat armor” on Strykers improve the protection considerably against shaped charge warheads while adding far less weight than equivalent conventional armor. Active

¹³² Chapters 18 and 19 of GEN Norman Schwarzkopf’s book *It Doesn’t Take a Hero: The Autobiography of General H. Norman Schwarzkopf* (New York: Bantam Books, 1993) said that the Saudi government provided vast quantities of fuel, but the biggest concern facing his logisticians was distribution, particularly the ability of the 5,000 gallon fuel tankers to travel in the sand. The 2001 Defense Science Board report on *More Effective Warfighting Through Increased Efficiency*, page 13; and MAJ Brian Moxley, *Class III (Bulk) Distribution Successes: What Can Be Learned?* page 3 quoted LTG Pagonis and several other leaders that despite robust resources provided by the Saudi government in Operation Desert Storm, the US Army distribution system could not distribute it fast enough during combat operations, leading some units to completely deplete their fuel and forcing them to culminate.

defense systems, such as the Israeli Trophy Active Protection System (APS) can vastly improve crew protection by intercepting warheads before they reach the hull.

User conservation such as careful mission planning, fuel usage tracking and reduction of time spent idling could yield immediate efficiency gains.¹³⁴ However, leaders must be very careful when encouraging efficient user behavior. Leaders must understand the role of energy and efficiency in the context of the overall environment, such as the increased logistical demands and commensurate risks and act appropriately to conserve. However, using budgetary tools to enforce or encourage conservation may be inappropriate because different units in different environments with different missions will consume energy differently. Energy conservation is often directly at odds with the military imperative to aggressively outmaneuver the enemy to gain the advantage. Moreover, budgetary rewards or punishments may result in adverse effects on morale and safety from miserly conservation measures designed to compensate for a high operational tempo.¹³⁵

¹³³ JASON Program Office, MITRE Corporation, *Reducing DoD Fossil-Fuel Dependence*, 2006 page 42-43

¹³⁴ JASON, *Reducing DoD Fossil-Fuel Dependence*, page 43

¹³⁵ JASON, *Reducing DoD Fossil-Fuel Dependence*, page 43; Hornitschek, *War Without Oil* page 45, Amory Lovins *Winning the Oil End Game*, page 90 and the 2001 Defense Science Board Task Force *More Capable Warfighting Through Reduced Fuel Burden*, page ES-7 suggested employing budget incentives to encourage efficiency at the user level. Commanders who saved energy could employ the money saved as discretionary funds. However, commanders could wind up in the dilemma of cutting air conditioning or employing dismounted patrols to avoid the stigma of going over budget. They also highlighted the need for externalities involved with fuel delivery and fuel efficiency as key performance parameters in the acquisition process.

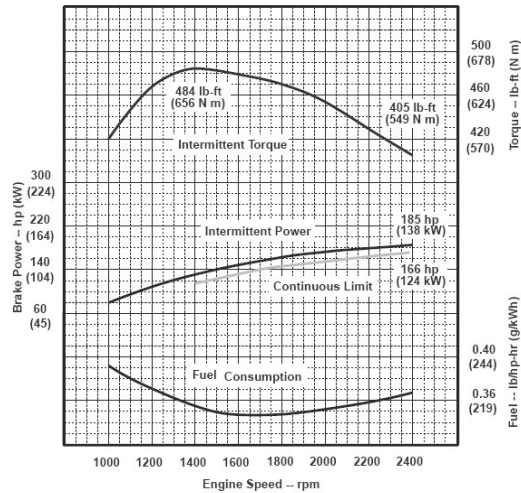


Figure 11: This notional diesel engine power and torque curve illustrates the variable efficiency engines produce power over a range of speeds.¹³⁶

Civilian vehicles increasingly employ hybrid drive trains to increase their efficiency. Military platforms may not glean all the benefits of a hybrid drive train that a civilian car does, but hybrid or electric drive trains would offer many compelling advantages.¹³⁷ Electric drives are

¹³⁶ Internal combustion engines, including diesel engines, have an ideal range of crankshaft revolutions per minute at which they operate most efficiently. This illustration came from Frontier Power Products “Making Sense of Diesel Engine Specifications” by Larrie York [Online] available from <http://www.frontierpower.com/library/makingsense.htm>; Internet; Accessed 28 April 2008. The website provides a more extensive explanation of this concept and how to read the power curves of diesel engine specifications. Many engines, particularly ones for automotive applications, and especially gasoline engines produce much more pronounced torque curves. Mechanical transmissions convert torque to match engine rpm to desired driving speed, but do so in discrete steps that cover a wide swath of the engine’s power band. Semi-truck tractors frequently have 10 to 12 gears in their transmissions to keep the engine employed within the optimal range on the torque curve as they pull their load. An October 1997 *Scientific American* article by Victor Wouk entitled “Hybrid Electric Vehicles” (pages 44-48) defined two different basic types of hybrid drive train and also highlighted this phenomenon. A parallel hybrid like the Toyota Prius uses the engine and conventional transmission to propel the car with electric motors assisting or providing the power at low speeds, and hence run the engine over a range of speeds. Series hybrids, such as diesel electric locomotives and submarines run the engine at a constant speed at the optimal point where they provide power most efficiently.

¹³⁷ Page 32 of the JASON report *Reducing DoD Fossil-Fuel Dependence* posits that the usage patterns of military vehicles do not take advantage of the regenerative braking offered by hybrid drive trains, which mainly confers their fuel efficiency advantages over mechanical drive trains. Regenerative braking employs generators to recover vehicle motion back into electricity, which is stored to provide power again later. This system yields its greatest savings over mechanical transmissions in stop-and-go traffic, as encountered in city driving, whereas mechanical transmissions perform just as efficiently in

very efficient even without the benefit of regenerative braking partly due to less friction from fewer moving parts and partly because the engine can run at a constant speed at the peak of its power curve. Series hybrids run the engine only when required to charge the battery pack, and then runs it at its optimal power output and efficiency. Military vehicles normally spend about 50-80% of their time idling to remain ready to move when needed, serve the “hotel load” powering the communications, navigation and fire control systems, and to providing heat for the crew.¹³⁸ This would eliminate idling because they would produce electrical power on demand for these systems and be intrinsically prepared to move when required. Moreover, reducing idling further adds to the mechanical reliability advantage over conventional power trains, because extended idling causes engine damage. This subsequently facilitates the use of smaller, lighter

highway settings. The report implied that the majority of military vehicles drive in highway-like steady state operations, but does not cite evidence for this perception. For example, most combat vehicles dash from one covered position to another, or in stop-and-go patterns in urban combat, which is much more prevalent in the contemporary operating environment than it had been in the past. The report also alleged that military vehicles do not drive enough miles in a year to generate a return on investment, citing a 2,000 kilometer per year utilization on HMMWVs (High Mobility Multipurpose Wheeled Vehicles). However, a 1 February 2007 Armed Forces Information Service article entitled “Army’s Equipment ‘Reset’ Program Ahead of 2006 Pace” by Gerry J. Gilmore quoted BG Charles Anderson, director of force development in his testimony before the Readiness and Air and Land Forces subcommittees of Congress. Congress authorized \$17.1 billion for the repair of Army and Marine Corps combat equipment. Anderson said “Tanks today are running at five times the program’s rate; trucks, five to six times their program usage, and they are running, as you well know, with heavy armor; helicopters, five to six times their program usage.” HMMWVs may have driven an average of 2,000 kilometers a year in peace-time, but this suggests that they drive substantially more in wartime.

¹³⁸ Pages 37 and 40 of the JASON report *Reducing DoD Fossil-Fuel Dependence* asserted that military ground vehicles typically spend 50-80% of their time idling. They cited another study on page 41 by Charles Raffe of TARDEC claiming the M1 tank idled 83% of the time during REFORGER exercises. The main reason they cited was powering the “hotel load” to power the electronics for communications, fire control, navigation, etc. Current batteries on board military vehicles cannot power these devices for long without occasionally starting the engine to recharge the batteries. 4th Infantry Division suffered a rash of alternator failures in their vehicles during exercises involving FBCB2 (Force XXI Battle Command, Brigade and Below, a computer based command and control system) and began installation of higher rated alternators in the Spring of 2000. CW3 Bill Johnson and CW5 Alexander LeMay, among others, attributed these alternator failures to repeatedly draining batteries while monitoring FBCB2 with the engine off, and the sudden high load the subjected to the alternator when restarting the vehicle. Army Materiel Command’s Tank and Automotive Command discounted this hypothesis. Soldiers also idle engines to maintain combat readiness in case the engine will not start when they receive the order to move, and to run the heater.

engines.¹³⁹ Electrical drives also reduce the number of moving parts and hence increase the reliability of the vehicle. Support units could carry fewer repair parts, the same parts could be used across a wide variety of vehicles, and would need fewer mechanics to repair vehicles.

An all electric configuration would be very quiet, emit a low infrared signature and no exhaust odor, provide a reliable source of electrical power for other electronics, and would be 85-90% efficient overall. Electric motors produce high torque at low speeds, which would aid smooth low speed maneuvers and climbing steep grades. Disadvantages of an all-electric system would include the time required to charge batteries, the short range, initial expense, and low energy density of current batteries.¹⁴⁰ The electric drive's intrinsic efficiency considerably offsets the lower energy density of batteries or other electrical storage media. Hot swapping multiple sets of batteries would obviate the concern about the time required to charge batteries. Electric drives also allow much greater flexibility in designing the vehicle layout.¹⁴¹ They could

¹³⁹ This configuration is sometimes called a series hybrid, where the engine powers a battery pack when needed, and the battery powers the wheels. The Toyota Prius is a parallel hybrid, where the engine can drive a normal drive train assisted during acceleration by electric motors. The series hybrid runs the engine only to recharge the batteries and does so at the peak portion of the engine's power band. Diesel locomotives and submarines are examples of series hybrids. (see footnote 136) Ordinary vehicles and parallel hybrids run the engine at a variety of speeds, and engines work most efficiently at a particular speed. Engines also lose efficiency when they increase or decrease their speed, and increase undesired emissions. For example, many diesel engines use turbochargers to increase efficiency, but the turbocharger "lags," or takes time to spool up to push the extra air needed by the engine when it speeds up significantly.

¹⁴⁰ Pages 36 and 37 of the JASON report *Reducing DoD Fossil-Fuel Dependence* discusses some advantages and disadvantages of electric (including all-electric, such as battery powered) drive trains. This efficiency rating includes charging losses as well as the efficiency that the vehicle itself turns stored energy into motion. The JASON report cited the need for a power source to charge the batteries as an example of a disadvantage for this type of platform. Battery costs are dropping, as exemplified by replacement cost for a Toyota Prius battery pack. Originally they were \$10,000 and have come down to \$3,000. They have also proven their reliability over long periods in the civilian transportation setting as well. Moreover, recycling at the end of their life cycle saves substantially on expensive materials, which can be almost completely recovered. John O'Dell, "Prius Keeps Car Dealers -- but Not Repairmen - Busy" *Los Angeles Times* 2 June 2005.

¹⁴¹ The General Motors Hy-Wire prototype demonstrated that electric or fuel cell powered cars can allow far more design flexibility with their "skateboard chassis." All power train components reside in the flat chassis, upon which the body is built without the need for a hump in the middle for the transmission or drive shaft. The engineers can focus on the function of the vehicle without constraints of drive-shaft positioning, etc. *Time Magazine* "2002 Best Inventions: Hy-Wire Car" [Online] available from

also provide unique risk reduction for military vehicles by providing multiple redundant pathways to apply power to drive the vehicle. Furthermore, electrically powered combat vehicles can virtually eliminate mobility kills by distributing power through multiple drive wheels. A conventional combat vehicle is immobilized if its transmission is destroyed, the track blown off, or the drive wheel damaged. An electrically driven vehicle could limp out of the kill zone to a safe repair area. Additionally, replacement motors would be substantially easier and more efficient to carry than bulky replacement transmissions. Electrical or hybrid drives also divorce the vehicle from a specific power source, allowing potential flexibility for future upgrades. Tight integration between engines and drive trains on conventional vehicles make upgrades expensive and difficult when more advanced versions emerge. The designs of the Joint Light Tactical Vehicle (JLTV) and Future Combat Systems employ hybrid electric drives with modular power plant options. For example, they can begin with conventional diesel engines and later substitute fuel cells or batteries as technology evolves.¹⁴²

Leveraging Better Energy Capabilities

We need to reform the entire logistics structure to adapt to conditions on the modern battlefield, not just substitute one fuel for another. Improving efficiency is the most important step in reducing logistics demands, as previously discussed. However, improved efficiency could actually lead to increased energy demands and logistics burden by facilitating greater range and

http://www.time.com/time/2002/inventions/tra_hywire.html; Internet; Accessed 2 April 2008. See also Joan Ogden's "High Hopes for Hydrogen." *Scientific American* (September 2006) 94-101.

¹⁴² A 15 August 2007 press release from BAE systems entitled "BAE Systems Unveils Hybrid Electric Drive System for Future Combat Systems" discusses the Future Combat System hybrid drive train and highlights the plan to initially use diesels with the ability to power them with fuel cells later. A 4 March 2008 Defensetalk.com article covering MG Charles Cartwright's session at the Association of the United States Army Land Warfare Symposium entitled "Hybrid-Electric Future Combat Systems to Roll on Line" also highlights this and other features. Moreover, Oshkosh Trucks offers a hybrid electric version of its ubiquitous HEMTT (Heavy Expanded Mobility Tactical Truck) series [Online] available from <http://www.oshkoshdefense.com/defense/products~a3~home.cfm>; Internet; Accessed 30 April 2008.

operations that are more energy intensive.¹⁴³ Depending on the same sources or direct substitutes propagate the same vulnerabilities, competition during a crisis, and delivery problems. Efficiency alone cannot solve military logistics requirements, nor can alternative fuels or distribution methods.

Electrically propelled ground combat vehicles powered by locally produced energy sources could solve this problem, although they appear to be a classic disruptive innovation. Clayton Christian warned that disruptive innovations usually do not appeal to the core users of a current technology, and may initially perform less well than the established technology, and hence may lack support of the core users and stakeholders. However, the current technology overshoots the needs of some users, or they find features desirable in the disruptive technology, such as cost, size, or convenience.¹⁴⁴ The market for the disruptive technology grows as the capabilities increase, and the disruptive technology usually has an asymmetric motivation to improve and move up market to erode market share from sustaining technologies.¹⁴⁵ Likewise, an electrically powered tank may not initially match the performance of an M1, but it would appeal to users needing armor protection where fuel is difficult to deliver. A system built around

¹⁴³ See the discussion on Jevin's Paradox in the section on the Cost theme of energy selection. Jevin's Paradox holds that more efficient use of energy or resources can foster greater consumption. Lower cost affords greater consumption or use of a resource for new purposes. Maneuver warfare favors intense, agile movement on the battlefield, so efficiency gains would logically translate into greater speed and operational reach, not necessarily lower energy consumption.

¹⁴⁴ Clayton Christianson, *The Innovator's Dilemma: The Revolutionary Book That Will Change the Way You Do Business* (Boston: Harvard Business School Press, 1997), page xvi.

¹⁴⁵ Sustaining technologies advance and improve an established technology. Dr. Christianson differentiates between a technological breakthrough and a disruptive innovation in *The Innovator's Dilemma*. Disruptive innovations may not involve advances in technology, just their application. Dr. Christianson used numerous case studies, including the shift from mainframes to minicomputers and eventually to the PC and noted that only one company out of dozens made the transition due to focusing on core customers who demanded more powerful mainframes. He also cited the rise of hydraulic driven construction equipment and the fall of cable operated steam shovels. Hydraulics initially had limited power and core customers of power shovels valued bucket size. Hydraulic backhoes found a market with housing contractors, who could fit them between buildings, and the hydraulic capacity improved over time and eroded market share from the cable-operated shovels.

electrically powered vehicles could drastically reduce dependence on LOCs, and the users and manufacturers would be motivated to continually improve the performance over time.

The low power density and shorter range of batteries or hydrogen for fuel cell powered vehicles would indeed be a disadvantage if these were shipped along the same lines as we currently ship fuel. The real advantage of such systems would come from producing the energy locally, near the point of consumption, obviating the need to transport it far. Although this study emphasized transportation fuels, power generation emerged as the largest single land user of fuel in wartime, consuming about 357 million gallons, or 34% of the Army's fuel per year.¹⁴⁶ Replacing them with deployable renewable energy systems that do not require outside fuel re-supply would cut theater fuel requirements by about 257 tanker trucks a day.¹⁴⁷ This figure only counts the last leg of the fuel delivery, and does not factor in reductions in delivery requirements at each higher delivery echelon with commensurate reductions in risk, infrastructure, and consumption at each stage. These systems would reduce maintenance costs compared to conventional diesel generators, which have a plethora of moving parts, which sit inactive for long periods of time and then must endure constant use during deployments. Additionally, operators must carefully match the load with diesel generators to prevent engine damage. The US military should employ portable renewable energy systems such as the Mobile Power Station (MPS) made by Skybuilt Power to provide power generation wherever tactically possible.¹⁴⁸ This system folds into a standard ISO shipping container that standard military equipment can haul, such as the

¹⁴⁶ The 2008 *Report of the Defense Science Board Task Force on DoD Energy Strategy*, page 44 states that aviation assets consumes 50% of the fuel in peacetime, but since the beginning of Operation Iraqi Freedom, power generation dominates fuel requirements, mostly for cooling. They recommended better insulation and passive cooling technologies. They also recommended expanded use of renewable energy systems.

¹⁴⁷ Generator fuel consumption rates are from page 44 of the 2008 *Report of the Defense Science Board Task Force on DoD Energy Strategy*. Military tanker trucks delivering fuel to units usually have a 5,000-gallon capacity, but only fill them up to a maximum of about 3,800 gallons when traveling cross-country, or up to 4,200 gallons on improved roads due to expansion and sloshing during movement.

Palletized Loading System (PLS). These carry fold out wind turbines and solar arrays with battery packs inside to attenuate lulls.¹⁴⁹ Units in Iraq and Afghanistan already employ these systems and favorably reported about their performance.¹⁵⁰ Wind turbines come in a variety of sizes, including man-portable versions much smaller than the aforementioned containerized version. Combat outposts and other small remote installations should employ small wind turbines and solar panels to recharge batteries, power radios, and other critical equipment.¹⁵¹

¹⁴⁸ Wind turbines and solar cells may not be tactically suitable in all environments, as they may increase RADAR signature and would be impossible to camouflage against aerial observation.

¹⁴⁹ These systems actually come with any combination of wind, solar, micro-hydro, battery back-up, and diesel generation capabilities desired by the customer. Skybuilt Power manufactures them in the form of any standard ISO container, including 10', 20' and 40' and provide from 500 watts to 1,500 kilowatts. Some models also provide climate controlled living, working, or equipment space. Skybuilt also provides suitcase-sized packages for man-portable applications, as well as a small trailer.

¹⁵⁰ The 2008 *Report of the Defense Science Board Task Force on DoD Energy Strategy*, page 45, recounted Marine MG Richard Zilmer's (then Commander, Multi-National Forces-West in Iraq) request renewable energy systems specifically to reduce fuel delivery risks to isolated units. The financial return on investment transpired much sooner than anticipated compared to diesel generators, even without counting the avoided costs associated with the fuel deliveries and commensurate risks and casualties.

¹⁵¹ US soldiers often carry 13 kilograms of batteries on a 24-hour mission according to Dr. Max Donelan, assistant professor of kinesiology at Simon Fraser University in an interview on CBC Radio's *Quirks and Quarks* entitled "Energy Brace" on 9 February 2008. [Online] available from <http://www.cbc.ca/quirks/archives/07-08/feb09.html>; Internet; Accessed 28 April 2008. Page 44 of the Defense Science Board 2008 Energy Task Force report stated that dismounted soldiers' battery loads are often 15-20% of their total load. This highlights the logistical strain of delivering batteries or fuel for generators to recharge batteries at the lower echelons in modern infantry combat. Dr. Donelan also noted that some of the units he studied took extra batteries in lieu of food due to their importance on the battlefield. A sample of devices carried by US soldiers include night vision goggles, global positioning systems, radios (small squad radios and larger man-pack radios for contacting higher echelons, calling for fire support, etc.), and sighting devices for weapons. Dr. Donelan designed a knee brace, which generates five watts of electricity, enough to charge ten cell phones, when the user walks. If it works, Dr. Donelan's device could provide electrical power when units are in motion, whereas solar and wind generation could provide power at outposts and other positions.

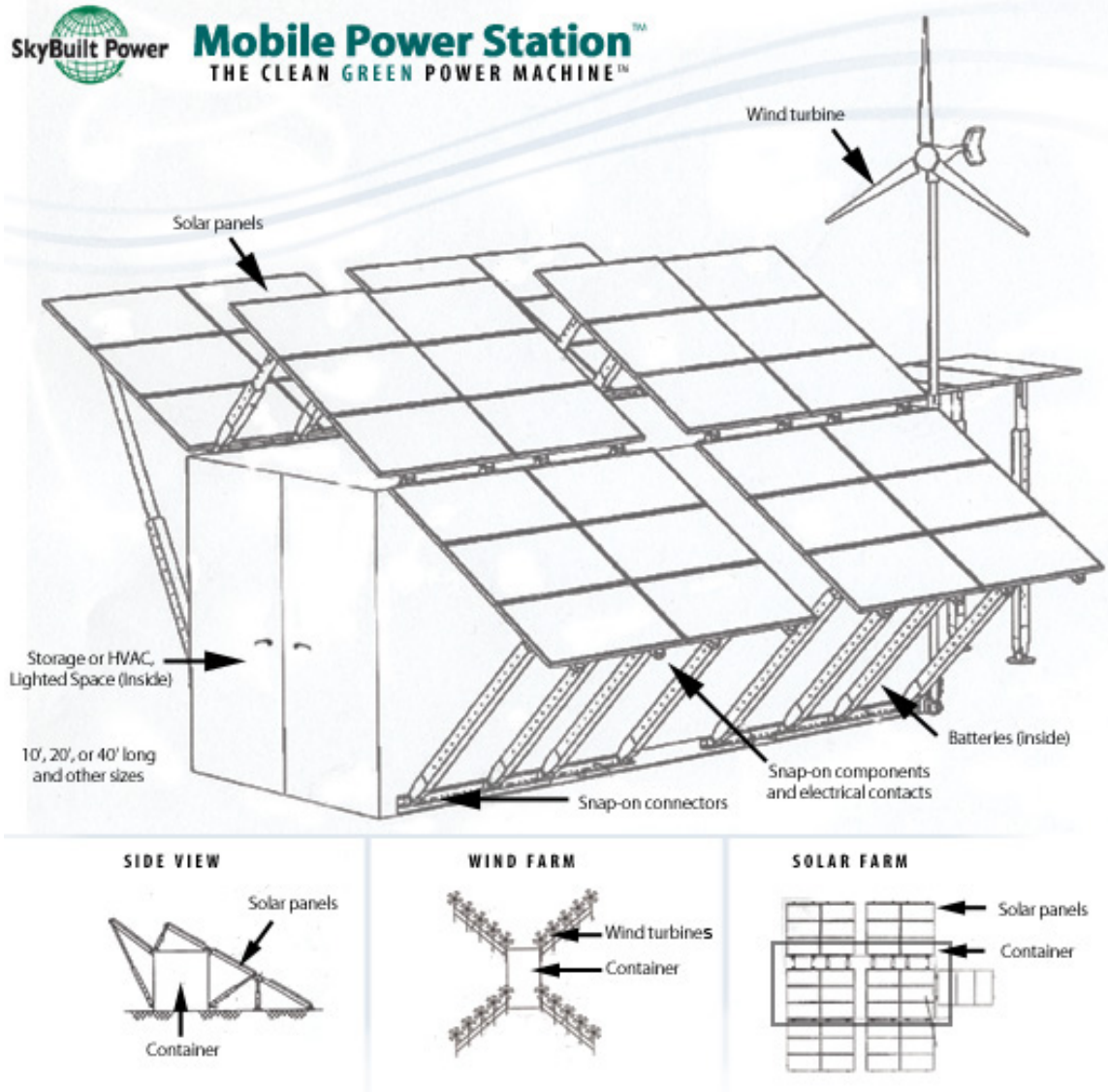


Figure 12: The Skybuilt Power Mobile Power Station fits into a standard ISO shipping container for transport using standard equipment. Solar panels, wind turbines and other optional equipment quickly fold out to produce power at remote locations, and can provide climate controlled living and working space as well.¹⁵²

Hydrogen fuel cell powered vehicles would have the added benefit of alleviating yet another major logistics burden—water delivery. Hydrogen fuel cells emit pure water as their

¹⁵² Skybuilt Power website, <http://www.skybuilt.com/schematic.htm>

only byproduct. Hydrogen has serious drawbacks. For starters, it is not a natural resource and must be made using another energy source, like electricity. The main obstacle derives from storage and transportation because it is very diffuse. Although hydrogen fuel cells are expensive, chiefly due to the use of platinum as a catalyst, this up front cost could be mostly recouped by recycling the materials from worn out fuel cells. Hydrogen could be produced through hydrolysis of local water, but would still require an energy source to split the water. Without a breakthrough in hydrogen storage, military vehicles could carry the hydrogen as a cryogenic liquid, but this would be more dangerous and bulky to carry than conventional kerosene fuel. Producing the hydrogen locally and avoiding higher echelon ground lines of communication would be the only justification for this approach. However, a gallium-aluminum alloy devised by Dr. Jerry Woodall could produce the hydrogen on board the vehicle as needed. Dr. Woodall discovered that a gallium facilitates complete reaction of aluminum with water, which releases hydrogen as it strips the oxygen away from the water.¹⁵³ Soldiers could drink the pure water from the fuel cells and

¹⁵³ Dr. Jerry Woodall, National Medal of Technology laureate and distinguished professor of electrical engineering at Purdue University, gave the 12 April 2007 keynote address entitled “The Science And Technology of Aluminum-Gallium Alloys As A Material For Energy Storage, Transport and Splitting Water.” He discovered that adding gallium to an aluminum alloy facilitates complete oxidation of aluminum, which releases hydrogen in the following reaction: $2Al + 3H_2O \rightarrow 3H_2 + Al_2O_3 + \text{heat}$. Aluminum oxidizes in water, but the resulting aluminum oxide, or alumina, forms a hard scale that protects underlying aluminum from further corrosion, unlike Iron-oxide (rust) which continually erodes away, revealing underlying iron for further corrosion. Recycling the gallium and alumina back into aluminum again preserves the aluminum and gallium, and is done through the technique $Al^{+3} + 3e^- \rightarrow Al$ at a rate of about 9 kilowatt-hours per pound, which is about 50% efficient. This technique allows hydrogen to be “transported” in the form of aluminum and water at about the one third the energy density as gasoline. 2.7 pounds of aluminum releases the energy equivalent of about 1 pound of gasoline. However, fuel cells are often at least 20% more efficient than engines burning petroleum at their peak efficiency, and do not waste fuel idling 50-80% of the time as military engines do. Page 802-811 of *Thermodynamics, 5th Edition* by Kenneth Wark, Jr. (Purdue University, McGraw Hill, 1966) explains the maximum temperature produced by combustion in relation to the surrounding environment limits the efficiency of heat engines (known as Carnot efficiency), such as diesels and gas turbines. Carnot efficiency does not limit fuel cells and batteries because they are isothermal and do not operate on heat engine principles, so they can potentially be much more efficient. Additionally, the water used with the aluminum would be recycled as much as possible, increasing the delivered energy density, and reducing the fuel and water transportation requirements. Aluminum powder is also the fuel employed in the space shuttle solid rocket boosters, providing 83% of liftoff thrust and providing further demonstration of the power available from aluminum. (NASA, “Shuttle Solid Rocket Booster Facts,” [Online] available from <http://shuttlepayloads.jsc.nasa.gov/flying/facts/srb.htm>; Internet; Accessed 2 April 2008) The JASON

use local or waste-water, such as urine, to mix with the aluminum to produce the hydrogen. This water recycling would be a huge benefit not only in water purification in theater, but also water distribution. The net delivered energy density, combined with the inherent efficiency of fuel cells would be on par with a diesel powered hybrid drive train.¹⁵⁴ The aluminum pellets would be much safer and convenient to transport and deliver than petroleum based fuels. Although aluminum can burn, it is much harder to ignite than JP-8. An aluminum fire would remain concentrated rather than spread, like fire of a spilled liquid fuel. Aluminum's solid form would obviate the need for specialized distribution platforms and facilitate easy, flexible transportation on any distribution platform interchangeably with other commodities.

report, pages 38 and 39 had a more skeptical take on fuel cells, but most of their concerns involved fuel cells that reform a hydrocarbon, which involves impurities that poison the cell, high temperatures and long start times to produce power. Some of their other concerns involved the cost of the catalyst, which could be recouped through recycling, and the durability of the cell. Room temperature hydrogen gas from produced on board by aluminum would reduce thermal stresses rather than cryogenic or high-pressure hydrogen gas.

¹⁵⁴ Assuming a diesel-hybrid would only run when needed, and run at the peak point on its power curve for maximum efficiency, diesel engines are about 40% efficient. The hydrogen produced per unit mass for this process is about one third of the equivalent mass of gasoline, or slightly less for JP-8. However, fuel cells are commonly about 50% energy efficient, making them at worst 17% efficient for a given delivered fuel mass compared to the peak of 40% achieved by conventional engines and fuels. Nevertheless, conventional engines rarely run at their peak efficiency band, and their efficiency varies widely below their optimal performance and normal automotive gasoline engines used in automobiles achieve 12-15% efficient use of the energy in gasoline. Military engines also currently spend 50-80% of their time idling at 0% efficiency. Therefore, since fuel cells and batteries only produce power as required, they can likely yield a net parity or reduction in delivered fuel mass despite the lower energy density of their fuel. See the sample power curve on Figure 11. The concept of well-to-wheel efficiency compares the "mileage" of electric vehicles, to conventionally powered vehicles. This compares the energy expended extracting the energy source, refining it, delivering it to the vehicle, and finally, the efficiency of the vehicle itself in converting the energy into motion. *The Watt* podcast, episode 46 makes several comparisons between standard vehicles and electric vehicles, demonstrating the total energy advantage of electric vehicles. [Online] available from http://www.podtrac.com/pts/redirect.mp3?http://media.libsyn.com/media/thewattpodcast/tWW46-2006-02-19_48kbps.mp3; Internet; Accessed 2 May 2008. In this case, the inherent efficiency of the electric drive generally overcomes the penalties imposed by lower energy density.

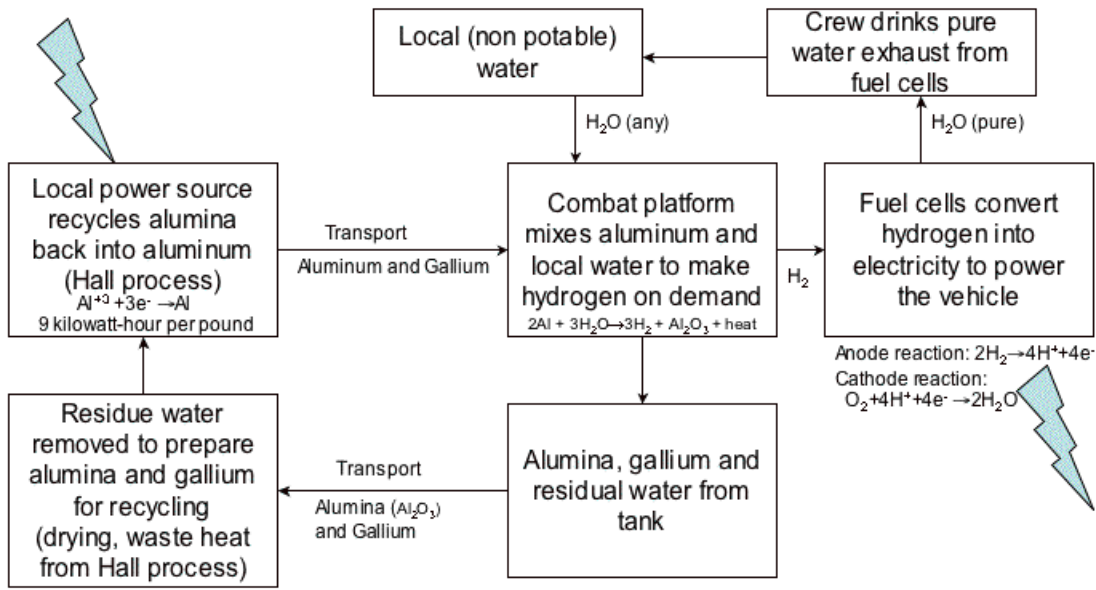


Figure 13: Process of “transporting” hydrogen via aluminum.¹⁵⁵

While solar and wind generation is feasible for power generation, they cannot serve the total energy demands of a deployed force due to the substantial sprawl of equipment and area required to completely power a brigade sized force. Small gas-cooled nuclear power plants such as a pebble bed modular reactor (PBMR) could do a better job as a very compact and powerful source of electrical power, especially when a unit requires a small footprint and low signature to avoid detection, as in high intensity combat.¹⁵⁶ One pound of uranium contains as much energy

¹⁵⁵ Based on slide 23 of Dr. Jerry Woodall’s presentation “The Science and Technology of Aluminum-Gallium Alloys.” All aluminum and gallium are recycled, as is much of the water. “Al” is aluminum, “H” is hydrogen, “O” is oxygen, and “Ga” is gallium.

¹⁵⁶ The most powerful current wind turbine with a blade diameter about the size of the wingspan of a 747 produces 4 megawatts in ideal wind conditions. A typical solar array the size of a residential roof produces about 7,000 watts from direct, summer daylight. Rod Adams, a former Navy nuclear submarine engineer advocates using nitrogen as the working gas in a closed cycle Pebble Bed Modular Reactor (PBMR).. The September/October 2001 *Army Logistician* article “Nuclear Power: An Option for the Army’s Future” by Robert Pfeffer and William Macon Jr. advocates the Army’s employment of nuclear power and further discusses pebble bed modular reactors. PBMRs contain a sub-critical core of uranium oxide in billiard-ball sized spheres coated with layers of three different types of ceramics capable of retaining the fission products in conditions beyond 1600°C. (See page 104-105 of the 2003 MIT Interdisciplinary study *The Future of Nuclear Power* for more on PBMRs. See also the 2003 article “Advanced Fuel Cycle Initiative: Closing the nuclear fuel cycle” by Vin LoPresti of Los Alamos National Laboratory [Online] available from

as 30 tanker trucks of fuel, and the reactor in a US nuclear submarine is about the size of an average office desk.¹⁵⁷ The U.S. Navy has a long and distinguished history of employing nuclear power safely and effectively. The Army has had successful nuclear power projects itself, notably the portable reactor employed at Camp Century in Greenland and powering the Panama Canal with a reactor aboard the MH-1A *Sturgis*.¹⁵⁸ The National Academy study *Reducing the*

<http://www.lanl.gov/orgs/nmt/nmtdo/AQarchive/03springsummer/AFCL.html>; Internet; Accessed 10 April 2008 or the website <http://www.pbmr.co.za/> for more information on PBMR technology.) The graphite automatically moderates the nuclear reaction and contains all fission products inside the sphere. A container holds these spheres like a gumball machine, with new balls added in the top, and spent fuel pellets dropping out the bottom. Gas circulating in the container cools the spheres and harvests the heat to power a gas turbine. The reaction automatically abates if it gets too hot, and the reaction stops if the pellets are not within close proximity of others because each pellet is sub-critical—they cannot sustain a chain reaction alone. These reactors ordinarily use helium gas cooling because of its superior thermodynamic properties, but Mr. Adams advocates nitrogen to facilitate the use of off-the-shelf gas turbines, since helium would require special bearings, etc. (See Rodney Adams, “Nuclear Power for Remote Areas.” *Atomic Insights* [Online] available from <http://www.atomicengines.com/distributed.html>; Internet; Accessed 25 April 2008.) Even with helium, these reactors are much simpler, robust and cheaper to build than equivalent light water reactors. Mr. Adam’s contends such reactors could produce 1 megawatt of power for \$1 million without the need for refueling, as with diesel generators, the sprawl associated with solar or wind turbines, or the complexity and expertise required with most commercial reactors. They would also be safe in a tactical environment because the reaction inherently self-moderates and much more resistant to damage than current fuel delivery systems. The cooling gas is an ordinary gas, regular nitrogen in the case of Mr. Adam’s proposal, and the fuel pellets contain the fission products. Any leak would merely release hot air and the reactor would stop if the temperature climbed too high. The pellets will cease to react if the enemy struck the reactor and scattered the pellets. The pellet’s hard coating would contain the fissile materials and fission products within the pellets because they are nearly as hard as diamond. They would remain thermally and radiologically hot for some time, preventing terrorists from seizing the pellets, but personnel with protective gear or robots could recover and reuse them. Nuclear terrorism experts, such as Michael Levi in *On Nuclear Terrorism* and William Langewische in *Atomic Bazaar: The Rise of the Nuclear Poor* assert that plutonium from spent reactor fuel would be more trouble than it is worth to terrorists trying to build nuclear weapons. Terrorists seeking nuclear material would much prefer highly enriched uranium, not plutonium or the reactor fuel used here, which is not sufficiently enriched for bomb making (up to 20% enriched vs. over 95% needed to be considered weapons grade). Moreover, the last time an Army Brigade was in danger of being overrun was at the Chosin Reservoir in Korea, as chronicled by Roy Edgar Appleman in *East of Chosin: Entrapment and Breakout in Korea, 1950*. Therefore only a peer competitor could conceivably overrun a reactor, and they could gain weapons grade materials much easier in other ways. Such a reactor would be safer for everyone around than the energy equivalent quantity of petroleum-based fuel.

¹⁵⁷ Rod Adams, *The Atomic Show* podcast Episode 71

¹⁵⁸ The Army employed a number of static nuclear reactors to power installations, but also had portable reactors in Sundance, Wyoming; Camp Century, Greenland; McMurdo Sound, Antarctica and the reactor aboard the USS *Sturgis*, formerly a World War II Liberty Ship named the USS *Kiwi*. The *Sturgis* offset the need for hydroelectric power to the Panama Canal and hence saved water to facilitate 2,500 more ships per year to transit the locks. The other reactors powered remote stations with an uninterrupted supply of power. See the 1996 *Atomic Insights* Volume 2, Issue 5 “MH-1A: First Nuclear Power Barge,” by Rod Adams [Online] available from <http://www.atomicinsights.com/aug96/MH-1A.html>; Internet;

Logistics Burden posits that a reactor producing hydrogen from local water sources would surpass the equivalent mass of delivered petroleum in two to nineteen days depending on other factors.¹⁵⁹ Hydrogen storage and distribution presented the biggest obstacle to tactical nuclear power according to this National Academy study. Nuclear power would be an ideal source for recycling aluminum for vehicular hydrogen production because it would provide intense and consistent energy production in a small, deployable package. 336 megawatts worth of reactors could indefinitely sustain a fuel cell powered equivalent of a current heavy brigade combat team in high intensity combat operations, although in practice substantially less power would be required.¹⁶⁰

Accessed 30 April 2008. The US Energy Information Agency's site on unique reactors at [Online] http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/superla.html; Internet; Accessed 15 April 2008 has more on the MH-1A. The July 2000 article in *Engineer* magazine entitled "U.S. Army Prime Power: A Tradition of Innovation and Excellence" by Andrew Potter discusses the history of Army nuclear plant operators and units.

¹⁵⁹ *Reducing the Logistics Burden for the Army After Next: Doing More with Less*, (Washington D.C: National Academy Press, 1999) page 52-55, figure 4-1 examined a nuclear-electric-hydrogen fuel cycle with fuel cell powered vehicles, and found the only really troublesome portion was hydrogen storage and distribution to the tactical users.

¹⁶⁰ The Logistics Estimate Worksheet (US Army logistics estimate tool developed by the Army Logistics Management College) projects that a Heavy Brigade Combat Team (HBCT) in offensive operations consumes about 109,000 gallons of fuel a day. This fuel contains about 133 mega joules of energy per gallon and costs about \$3.19 according to the Energy Information Agency. Consuming that fuel in 24 hours of offensive operations translates into about 168 megawatts released by the JP-8, for about \$348,000 in direct fuel costs. The most efficient diesel engines currently convert at best 40% of that energy into motion at the peak of their power band. A nuclear reactor moving the equivalent energy to a combat platform would require 336 megawatts of energy because the Hall process to recycle aluminum is 50% efficient according to Dr. Woodall's "The Science and Technology of Aluminum-Gallium Alloys." The remainder of the energy delivery chain is far more efficient. Fuel cells are at least 50% efficient, and electrical drive trains about 90%, so hypothetical fuel cell powered vehicles would require less energy in the first place. Of course, no unit would perpetually remain in high intensity combat operations for more than a few days without stopping for other reasons, such as crew rest. Logistics units would also stock additional aluminum in preparation for surge operations such as this. The real power requirements for such a BCT would be substantially smaller, especially with more efficient platforms such as the Future Combat System or a fuel cell powered Stryker. Additionally, the power would come from multiple dispersed reactors to prevent the enemy from targeting them and to ease distribution to the tactical platforms using the fuel. The commercial sector commonly builds nuclear plants five times this size at about 1,500 megawatts, so even a single conventional reactor for this power range would be feasible to build. Nuclear reactors would not only eliminate upper echelon delivery requirements and risk, but would be an assured source of power precisely when and where it is needed, and free from market volatility of purchasing commercial energy products.

Such a system could provide assured energy to the end user without the need for an elaborate and fragile theater distribution system with the commensurate monumental efforts to secure long ground lines of communication. Besides the lives saved by obviating the need for security and logistics patrols not directly related to the strategy, the power available could make other protection innovations practical, such as the Mobile Tactical High Energy Laser (MTHEL).¹⁶¹ This system is similar to the Navy Phalanx Close In Weapons System (CIWS), which originally provided point-protection for ships from cruise missiles.¹⁶² Recently coalition forces employed this system to protect critical land areas from mortar, rocket, and artillery attack. The Phalanx uses a high-speed 20-millimeter cannon to shoot down incoming projectiles, whereas the MTHEL uses a high-powered laser. MTHEL proved capable of hitting the targets successfully, but power generation and heat dissipation issues plagued its mobility on the battlefield.¹⁶³ Nuclear power could provide the portable power to make this system feasible and drastically reduce the risk of indirect fire. No enemy has come close to overrunning an Army brigade since the Korean War, but enemy indirect fire continues to present serious risk.¹⁶⁴

¹⁶¹ Page 190-191 of the 2005 United States Army Weapons Systems book discusses the MTHEL program and its milestones.

¹⁶² The 22 January 2008 Defense Industry Daily story “Phalanx CIWS: The Last Defense, On Ship and Ashore” discusses the Phalanx CIWS, and its evolution to include land-based protection against mortars, rockets and artillery. Other names for this system include C-RAM or Centurion.

¹⁶³ MTHEL is also referred to as Skyguard or Nautilus. The current design resides in three tractor trailers and costs \$3,000 per shot, largely due to the energy required to power it. The Mobile Tactical High Energy Laser system has proven it can interdict incoming artillery shells, but requires enormous quantities of power, which makes it currently impractical to move around the battlefield. Large bases in Iraq and Afghanistan employ Phalanx Close In Weapons Systems (CIWS) to protect against low-level attacks of this kind, but can be overwhelmed by large barrages. Unexploded outgoing 20mm rounds from this system can also harm the surrounding population and generate resentment and animosity.

¹⁶⁴ The last time a US Army brigade was seriously threatened in combat was 1950 during the Korean War, as chronicled by numerous works, including *East of Chosin: Entrapment and Breakout in Korea, 1950* by Roy Edgar Appleman. However, rocket fire destroyed the tactical operations center of the 2nd Brigade Combat Team of the 3^d Infantry Division on 7 April 2003 during Operation Iraqi Freedom, resulting in serious disruption to the command, control and sustainment of the brigade during a critical moment in a combat operation. See *Thunder Run*, pages 158-176 by David Zucchini, or pages 355-360 in *On Point* for details on the missile strike and the struggle to mitigate the disruption to the ongoing combat operations. US Army doctrine currently mitigates the risk of enemy artillery fire against valuable logistics

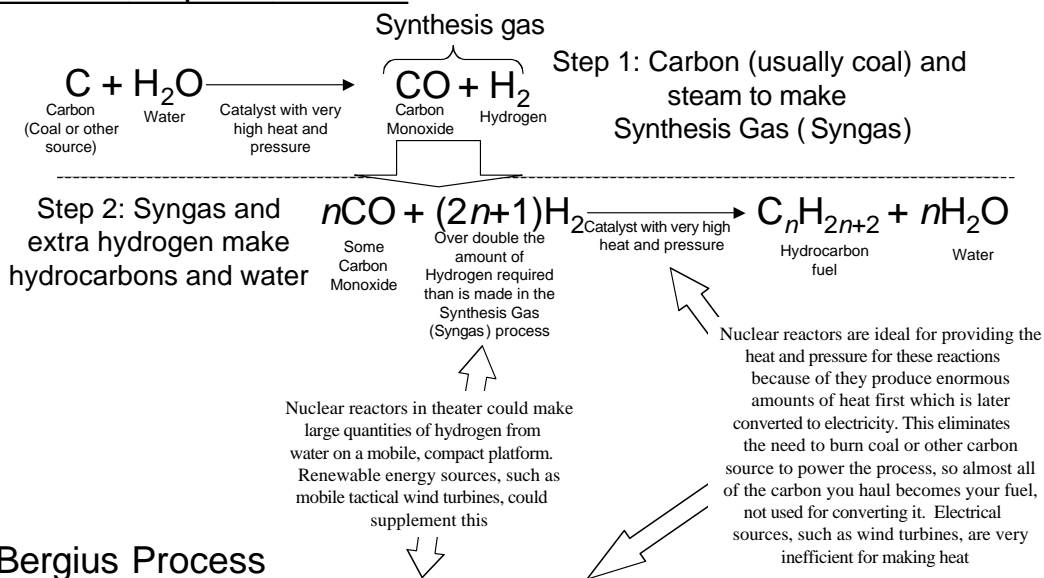
Helicopters may or may not be able to use the gallium-aluminum process, and cryogenic liquid hydrogen may not be tactically suitable for them because of helicopter's greater risk from ground fire than other aircraft. Even though liquid hydrogen is more bulky than JP-8, it is lighter, which could make it suitable for helicopters. However, battlefield helicopters require armor protection against ground fire, which would result in greater armor weight to cover the additional volume required for fuel storage. Helicopters are also more prone to fires and explosions from crashes and hard landings, whereas pilots of other combat aircraft can eject, dump fuel or employ other emergency options not available to helicopters. Helicopters ordinarily consume the majority of the Army's fuel in peacetime, around 50%, but their share in now is 30%, or about 307 million gallons.¹⁶⁵ Forward deployed devices employing the Bergius process or thermal depolymerization could at least partially offset their fuel requirements. The Bergius process uses

and command centers by emphasizing frequent moves to prevent enemy gunners from locating them. Forward observers can locate and call for fire much faster than any current tactical operations center can tear down and displace, especially with ubiquitous cell phone use making every civilian a possible artillery observer.

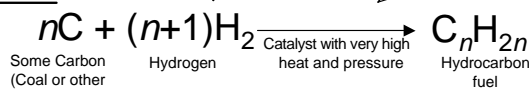
¹⁶⁵ 2008 *Report of the Defense Science Board Task Force on DoD Energy Strategy*, page 44

heat and a catalyst to form synthetic fuel from a carbon source and hydrogen.¹⁶⁶ Thermal

Fischer-Tropsch Process



Bergius Process



C is Carbon
H or H₂ is Hydrogen
n is any number
H₂O is water

Compiled from: Ebbing, Darrell D., *General Chemistry, 2nd Edition*, Wayne State University, 1987, Houghton Mifflin
The Future of Coal, Massachusetts Institute of Technology Interdisciplinary Study, page 154
and Fischer-Tropsch archive, <http://www.fischer-tropsch.org>

Figure 14: Comparison of the Fischer-Tropsch and Bergius coal-to-liquids processes.¹⁶⁷

¹⁶⁶ This process is similar to the Fischer-Tropsch process employed by Germany in World War II and the South African company SASOL. The US also experimented with the process in 1947 to offset the need for imported oil, but oil at the time was more economical. The OSD Assured Fuels project is re-examining the process to assure access to fuel and catalyze civilian production, which is currently economical at \$35 a barrel, whereas petroleum is over \$100. (Harrison, "The Role of Fischer-Tropsch Fuel; s in the US Military" and Barna, "OSD Assured Fuels Initiative") These processes are also known as coal-to-liquids (CTL) or coal liquefaction. The Fischer-Tropsch process coal and steam at high heat and temperature in the presence of a catalyst to make methane and carbon dioxide. The process continues to employ heat and pressure to form the methane into hydrocarbon chains. The Bergius process differs by using hydrogen, rather than water to react with the carbon source, so the process itself does not produce carbon dioxide and all of the carbon source feeds the process rather than siphoning off to produce energy. However, the hydrogen and heat for the Bergius process must be produced by some energy source, and in this case it could be a forward deployed nuclear plant, solar thermal, wind turbines, etc. producing it from local water. This would avoid the enormous carbon dioxide production problems endemic to the Fischer-Tropsch process. The 20 June 2007 *Washington Post* article by Sholnn Freeman entitled "Coal-to-Liquid Provision Stalls" cites carbon emissions as a key reason why congress declined to support building coal-to-liquid plants, nor mandate production quotas for synthetic fuel in the 2007 energy bill. The Bergius process's lower carbon dioxide production compared to the Fischer-Tropsch process would make it more palatable to the political leadership and would preserve more of the feedstock as fuel, reducing input requirements. See Figure 14 for diagrams of the Bergius and Fischer-Tropsch processes.

depolymerization uses heat and a catalyst to break down existing long-chain hydrocarbons, such as rubber, to produce synthetic fuel.¹⁶⁸ The synthetic fuel from each possesses superior qualities over conventional JP-8.¹⁶⁹ They could employ local biomass, sewage, or waste products, such as used tires as source material, and simultaneously ease the waste disposal burden. If such a system used nuclear reactors to provide the heat and convert local water into hydrogen, each ton of local carbon would produce approximately five tons of fuel.¹⁷⁰

¹⁶⁷ Process diagram compiled from *General Chemistry, 2nd Edition*, (Wayne State University: Houghton Mifflin, 1987) by Darrel D. Ebbing; the Massachusetts Institute of Technology interdisciplinary study *The Future of Coal*, page 154; and the Fischer-Tropsch archive at <http://www.fischer-tropsch.org>.

¹⁶⁸ Thermal depolymerization uses heat and pressure to break down complex, long chain hydrocarbons, and organic materials, such as fats, rubber, plastic, etc. Changing World Technologies has several pilot plants built in the US convert rubber and plastic in garbage into synthetic fuel, while another in Carthage, Missouri jointly operated with ConAgra converts waste from a turkey packing plant into 400 barrels of fuel a day for about 25% less than the price of conventional diesel as of 2003. See the 1 February 2005 *Fortune* magazine article, "A Turkey in Your Tank: Could poultry scraps be the next big source of fuel oil?" by Ellyn Spragins. *Discover Magazine's* Brad Lemley also wrote about Changing World Technology's Carthage plant in the 2 May 2006 article "Anything into Oil." The biggest drawbacks to the system are the vagaries of the inputs (they actually have to pay for the turkey waste) and the need to tune the process for different types of inputs to optimize production. A deployable version of this was built and tested, but consumes much of its own fuel to power the process. Powering it with one of the other sources discussed here would preserve the product produced from the waste for powering aircraft, leveraging the electrical generation potential of these systems into a useable form by helicopters. Deployed plants would have substantial quantities of source material from used tires, track pads, band track, food waste, sewage, etc. which currently must be backhauled and properly disposed.

¹⁶⁹ Harrison, "The Role of Fischer-Tropsch Fuels for the US Military," slides 24-28 outline the superior qualities of synthetic fuel over conventional JP-8. While the Fischer-Tropsch process creates about double the carbon emissions of conventional petroleum due to the coal burned to power the process, the fuel itself employs ideal hydrocarbon chain shapes for good combustion properties, and the process removes all contaminants, such as sulfur.

¹⁷⁰ Slide 13 of Dr. Theodore Barna's *OSD Assured Fuels Initiative* briefing at the 2006 Aerospace in the News Executive Symposium states that the Fischer Tropsch process converts one ton of coal into about 71.4 gallons of fuel. Page 8 of the of the Fischer-Tropsch Archive of Bergius's work [Online] available from http://www.fischer-tropsch.org/Bureau_of_mines/info_circ/ic_6075/ic_6075.pdf; Internet; Accessed 8 March 2008 shows that initial experiments with the Bergius process conducted in 1928 yielded about 124 gallons of fuel for half the carbon emissions. Calculating the densities of coal, kerosene, and yield data from the early Bergius process paper, using local power to power the process and water for hydrogen would require 1/5 of the volume of transportation compared to conventional fuel, which could be further reduced through use of local carbon sources.

Integration with Other Logistics Functions

Computer controlled fabrication devices could reduce requirements for class IX repair parts. These fabrication devices can produce increasingly complex items at ever decreasing prices and required expertise. These use a variety of methods to use raw materials to make complex objects. Some work like three-dimensional ink-jet printers, which form a mold out of plastic to cast metal, while others work directly with powdered metal. Some produce circuit boards. These systems could potentially fabricate many repair parts on the battlefield.¹⁷¹ Additionally, electric drive trains should be more reliable and simpler to maintain, as well as providing the ability to limp out of a kill zone without succumbing to a mobility kill. Employing common repair parts across multiple platforms, as with the Future Combat System, reduces the variety of repair parts units must carry on the battlefield. Using the same electric motors and other components across multiple vehicle fleets will further reduce stockage requirements and improve mobility.

The Army has fielded numerous precision-guided munitions (PGMs), such as the Guided Multiple Launch Rocket System (GLMRS), the Excalibur guided 155-millimeter artillery shell, and even guided mortar rounds. These will greatly reduce large caliber ammunition burdens on the battlefield, and consequently on ground re-supply, as they reduced ammunition requirements for aircraft. PGMs greatly enhanced the effectiveness of munitions, producing the same effect with much less ordnance. This reduction in ammunition requirements further diminishes the reliance on re-supply and makes aerial delivery even more feasible.

¹⁷¹ A 26 February 2007 article from Cornell University by Bill Steel entitled “Low-cost, home-built 3-D printer could launch a revolution, say Cornell engineers” ([Online] available from <http://www.news.cornell.edu/stories/Feb07/fabber.ws.html>; Internet; Accessed 10 May 2008) interviewed Hod Lipson, professor of mechanical and aerospace engineering about the Fab@Home project. Many universities have used these machines for years and the project aims to reduce the cost to about \$2,300 to reduce costs of computer controlled fabrication devices to empower ordinary people to perform rapid prototyping or small scale manufacturing in their homes.

The Joint Precision Air Drop System (JPADS) makes better use of aerial re-supply by guiding parachutes carrying supplies exactly where required without risking cargo aircraft to ground fire. This greatly improves the reliability and flexibility of heavy airlift by vastly improving delivery precision, and the delivering aircraft can remain at an altitude immune to ground fire. Heavy aircraft can deliver mass loads anywhere on the battlefield with this system so ground and air forces are not tied to airfields capable of handling the delivery aircraft. Nor does this put low flying and expensive rotary wing assets at risk. Some cargo aircraft can land at austere landing strips, but are far more susceptible to accidents and damage, such as sand ingestion in engines. Moreover, even airfields capable of landing a particular aircraft often can only handle a certain number of them on the ground at a time as they unload and orchestrate take-offs and landings. JPADS could feasibly provide delivery for nearly everything except bulk liquids.

Recommendations and Conclusion

Findings

The US military can eliminate dependence on ground lines of communication for deployed ground vehicles and substantially reduce deliveries for aviation assets by improving efficiency and employing renewable energy systems and tactical nuclear power to exploit local water and waste sources for fuel and drinking water. With vulnerable battlefield bulk liquid distribution eliminated, air delivery could provide nearly everything else. The remaining commodities, such as ammunition, do not lend to the pyramid effect exhibited to fuel. A single, simple platform can distribute all the remaining commodities, which are generally much safer to handle and resistant to enemy fire than fuel.¹⁷² The Army already has many of the pieces in place

¹⁷²Even ammunition is arguable safer to handle than fuel. Fuses and other volatile components are generally small and could be armored to shape any blast away from the driver, while other explosives and

or in progress to make the system proposed here a reality. Fuel delivery and distribution remains the biggest obstacle.

Ground forces could immediately eliminate its single biggest fuel requirement by fielding renewable energy power systems rather than diesel powered generators. These generators consume 357 million gallons, or 34% of its deployed ground fuel requirements, the equivalent of 257 5,000-gallon fuel tanker loads of fuel a day at the last delivery leg. These systems are movable by standard distribution platforms, are just as mobile as standard diesel generators, and possibly more mobile when also considering if living and work space requirements they can provide. They are also potentially far more mechanically reliable than equivalent diesel generators. These systems are essential for the distributed energy needs of a deployed force dispersed over a wide area. Moreover, these systems could drastically improve the sustainment of combat outposts and other remote installations, particularly in alleviating battery requirements for ubiquitous electronic devices.

The Future Combat System, Joint Light Tactical Vehicle and other vehicles employ modular hybrid electric drives, which can supplant the diesel power plant with fuel cells or batteries as their technology matures. Improved fuel efficiency itself, particularly eliminating vehicle idling will drastically reduce fuel requirements.¹⁷³ Fuel cells, batteries, or other energy carriers in conjunction with local power production could eliminate fuel delivery requirements to ground forces. The biggest gap in that technology is not the fuel cells themselves, although they

propellants burn rather than explode if their special detonation requirements are not met. For example, C4 requires an electrical charge. Fuel tankers also have mechanical pumps that require maintenance that complicates fuel distribution.

¹⁷³ Although some vehicles spend a portion of the time spent idling to power sensors, communications and other electronics, this “hotel load” usually constitutes a tiny fraction of the power produced at a vehicle’s minimum idle speed, wasting the remaining power produced by the engine. Even then the engine operates at its least efficient portion of its power band (see Figure 11).

are currently expensive and have shortcomings.¹⁷⁴ On site portable energy production and hydrogen storage to supply the fuel cells comprise that gap. Small, tactically designed portable nuclear power plants and pervasive use of solar, wind, and other renewable energy sources would eliminate the need for fuel re-supply to ground maneuver units in the field. These reactors should be built in the form of standard ISO shipping containers to ease battlefield mobility. They should be employed at the Brigade Combat Team level, or compromise between centralization to capitalize on economy of scale and decentralization to distribute them widely for greater responsiveness to supported units and resilience against enemy targeting. Together with Dr. Woodall's method of using aluminum to produce hydrogen on board vehicles from local water would yield similar delivery requirements to each tactical vehicle similar to the current fuel system with no delivery requirements from higher echelon units. Additionally, this system would alleviate water purification and delivery, facilitate a single battlefield distribution platform, and the aluminum fuel would be much safer to carry than petroleum fuels. Tactical nuclear power would also break down the biggest barrier to defending against enemy artillery and rocket fire.

Recommendations

Distributed renewable power systems and portable gas-cooled nuclear reactors could empower the US military to escape dependence on secure lines of communication and grant far more creative, flexible use of operational maneuver. Moreover, these systems would liberate the US military from budget volatility of fuel expenses from unanticipated changes to operational tempo or fuel costs and would reliably provide continuous, uninterrupted supplies of fuel so the military can perform its mission under any circumstances. This system would also reduce the

¹⁷⁴ The JASON report, pages 38-39 cited cost and durability for hydrogen fuel cells. Cost is primarily derived from the use of platinum as a catalyst, which could be recouped through recycling materials from older fuel cells. Using room temperature hydrogen from the aluminum production method rather than cryogenic hydrogen would improve durability.

logistical footprint required to sustain deployed forces, facilitating more rapid deployments with a much higher proportion devoted to combat missions. This would further reduce costs in casualties and equipment because maneuver forces move capriciously and unpredictably in contrast to predictable, road-bound and soft skinned logistics vehicles.

The military should exploit the modular nature of the electrical power trains on its upcoming generations of equipment to use the most advantageous power plant for the operating environment, while continually improving fuel cell and battery powered versions. Conventional diesel engine powered versions may initially perform better under classic, linear battlefield environments and can provide a useful transition while fuel cell and battery powered systems mature and improve. However, the electric drive trains will immediately scale across the full spectrum of operations and operational environments more readily and effectively than conventional drive trains can adapt to non-linear and austere environments. Mobile nuclear power generation at the brigade level or below will allow them to operate in even the most austere environment without reliance on ground resupply. Conversely, they could employ local grid-supplied electricity in more permissive environments if it was more economical and congruent with the mission. This could further reduce the investment required in the most expensive portions of the system, and reserve them for less permissive or more austere operating environments. It may also catalyze electric vehicle technology in synergy with the developing civilian market. Units should be created to experiment, train and develop tactics for employing them, as disruptive innovations often offer unanticipated new capabilities for which they were not originally intended. The performance and risks of the entire system should be examined and compared to get a true appreciation of the costs and performance of these systems and to prepare for long term, sustainable operations as petroleum availability wanes. Lighter, more efficient combat vehicles with reduced logistical infrastructure and with organic power production capability could deploy much more quickly to more austere environments and facilitate much more resilient, versatile and flexible application of combat power.

APPENDIX A-Energy Security

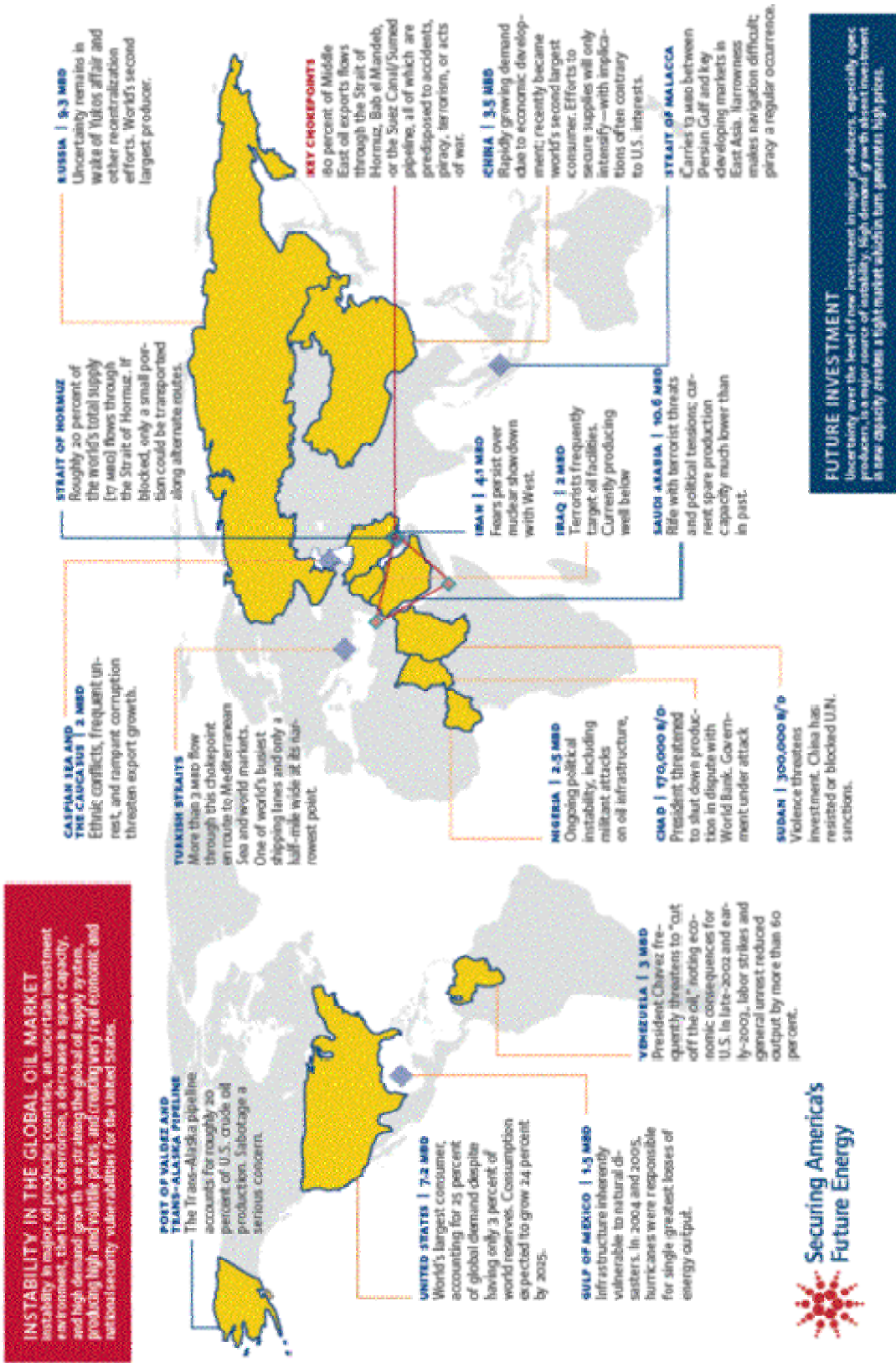


Figure 15: This map emphasizes the vulnerability of key oil production and transfer sites, political instability, and key transportation chokepoints around the globe.¹⁷⁵

APPENDIX B-Joint Inter-theater Fuel Delivery

The submarine is not an honest weapon. It suggests the foot pad, the garrote, and the treacherous knife dug in an opponent's back when he is off guard.

Sir Archibald Hurd, 1902¹⁷⁶

Even if a suitable direct substitute military fuel is created and can meet all of the previously discussed criterion, it must still run the gauntlet in a future conflict and be safely delivered to theater of operations. Aircraft will deploy some of this fuel, but this is much more costly than bulk transport by ship. Ships deploying support materiel to a war have historically faced interdiction by enemy forces.

For example, German U-boats wreaked havoc on supplies intended for Britain, causing severe problems for their war effort. Although the US has not faced a determined attempt to interdict its sea lines of communication since World War II, this should not result in complacency, as Allied Navies in the Interwar period lapsed in their anti-submarine warfare skills. Naval warfare experts are increasingly concerned about the proliferation of high quality quiet diesel-electric submarines. They are also concerned about a new development using fuel cells, known as Air Independent Propulsion (AIP), which enjoys significant advantages over

¹⁷⁵ *Instability in the Global Oil Market* map from SAFE (Securing America's Future Energy).

¹⁷⁶ Page 227 of *Military Innovation in the Interwar Period*, in a segment written by Holger Herwig. This section details the innovation in the German submarine corps in the interwar period, and the loss of the British and American Navy's anti-submarine warfare institutional knowledge from World War I. Similarly today many countries are deploying asymmetric naval weapons capable of interdicting sea lines of communication.

diesel-electric submarines. AIP uses fuel cells to power the submarine while submerged, which gives greater endurance and quieter running than conventional diesel-electric subs.¹⁷⁷

Moreover, mines are a very inexpensive and effective way to impede shipping, and Hezbollah's use of sophisticated anti-ship missiles indicates that even terrorist groups can acquire this type of capability. US Navy warships transiting the Straits of Hormuz also recently had an encounter with Iranian speedboats.¹⁷⁸ Enemy groups could use any of these to interdict unprotected support ships much easier than confronting warships directly. The naval tanker fleet is very small and would be very difficult to protect as they shuttle fuel to fleets at sea. Escort ships traditionally concentrate on protecting carrier task forces, and that is unlikely to change since a Chinese submarine surfaced within torpedo range of the USS *Kitty Hawk* in 2006.¹⁷⁹

¹⁷⁷ Several nations are fielding even quieter Air Independent Propulsion (AIP) fuel cell powered submarines. The Nuclear Threat Initiative (NTI) published an analysis of the proliferation of diesel-electric and AIP submarines in the article "Global Submarine Proliferation: Emerging Trends and Problems" by Dr. James Clay Moeltz in March 2006. [Online] available from http://www.nti.org/e_research/e3_74.html; Internet; Accessed 30 April 2008. Additionally, Robert Kaplan wrote in "The new balance of power" at the Foreign Policy Research Institute on 14 April 2008 that China will not try to compete on even terms with the US Navy. [Online] available from <http://www.cnas.org/en/art/2451>; Internet; Accessed 24 April 2008. They will focus on employment of an asymmetric strategy focusing on missiles capable of striking ships at sea, quiet diesel-electric submarines, and anti-satellite technology.

¹⁷⁸ US Navy warships and Iranian speedboats created an incident reported by the 7 January 2008 *International Herald Tribune* article "Iranian boats provoked U.S. Navy ships, Pentagon says." Older anti-ship missiles proved devastating against the Royal Navy during the Falkland Islands war. Even non-state actors, such as Hezbollah employed C802 anti-ship missiles in their 2006 war with Israel according to the 19 July 2006 *New York Times* article "Arming of Hezbollah Reveals U.S. and Israeli Blind Spots" by Mark Mazzetti and Thom Shanker. Prior wargames highlighted the potential for swarms of speedboats to saturate warship defenses with missiles, whereas normal ships would be completely vulnerable to these attacks.

¹⁷⁹ An *International Herald Tribune* article entitled "U.S. military officials wary of China's expanding fleet of submarines" by David Languet, written 7 February 2008, recalls when a Chinese *Song* class submarine surfaced within torpedo range of the USS *Kitty Hawk* in late 2006.

Air Uses

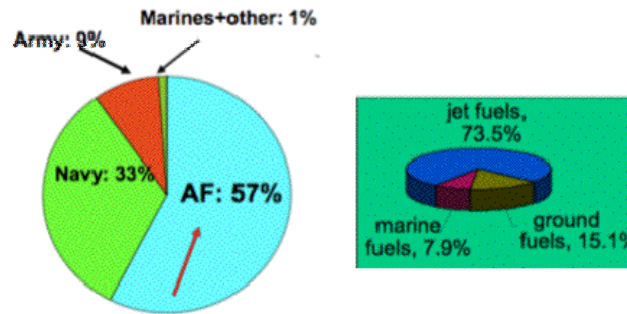


Figure 16: US military energy use by service and by platform type.¹⁸⁰

Aircraft consume 73% and the Air Force alone consumes 57% of DoD's fuel. Air mobility assets, such as tankers and cargo aircraft consume 54.2% of the aircraft fuel, much of which goes to moving Army equipment and supplies.¹⁸¹ Reducing ground deployment and support requirements will partially reduce this, but improving aircraft efficiency and flight operations are the most obvious and direct way to reduce fuel costs and usage. The Air Force is already initiating a number of programs to do this, such as modernizing engines to more efficient models on older aircraft, installing "winglets," as well as improved management of flights to get the most out of them.¹⁸² They are also considering the delivered cost of fuel to aircraft as a key performance parameter when making acquisition decisions.

¹⁸⁰ Harrison, Air Force Research Lab "The Role of Fischer Tropsch Fuels for the US Military, slides, 5 and 6, primary source from the DESC Factbook.

¹⁸¹ Harrison, Air Force Research Lab "The Role of Fischer Tropsch Fuels for the US Military, slide 6, primary source from the DESC Factbook.

¹⁸² Blackwell, *Department of Defense: Reducing Its Reliance on Fossil-Based Aviation Fuels* 23-28. Examples of better flight management involve more direct flights, less fuel dumping before landing, fewer aircraft rotations, etc.

Aircraft constrain the range of acceptable substitutes much more than other systems.¹⁸³

While hydrogen is a superior jet fuel, the Air Force currently favors fuels compatible with current jet fuels due to energy density and compatibility with current infrastructure.¹⁸⁴ Some feasible alternatives for aircraft include liquid hydrogen, synthetic fuels and bio-jet fuel. The Air Force conducted extensive testing with synthetic fuels as part of the OSD Assured Fuels Initiative, but Congress declined to support it in the 2007 Energy Bill.¹⁸⁵ Biomass generated fuels may garner greater support, as could using the Bergius process due to lower carbon emissions. The Air Force generally faces less risk delivering fuel to aircraft because airbases normally must be relatively secure locations. However, transporting fuel to forward locations where aircraft are deployed could pose great risks in future conflicts. The Air Force could reduce operational risk by making the synthetic fuel production capability they are exploring forward deployable. Assured sources of fuel do them little good if they cannot get the fuel to where they need it.¹⁸⁶ Making synthetic

¹⁸³ Blackwell, *Department of Defense: Reducing Its Reliance on Fossil-Based Aviation Fuels*; Harrison “The Role of Fischer-Tropsch Fuels for the US Military,” slides 24-28. David Daggett of Boeing Corporation, Robert Hendricks from NASA, Rainer Walther from MTU Aero Engines and Edwin Corporan from the Air Force Research Labs wrote the 2007 article “Alternate Fuels for use in Commercial Aircraft,” discussing the parameters and difficulties involved in finding sustainable and feasible alternatives to jet fuel.

¹⁸⁴ Project Sutan tested hydrogen powered jet aircraft. National Aeronautics and Space Administration. “Liquid Hydrogen as a Propulsion Fuel, 1945-1959.” [Online] available from <http://www.hq.nasa.gov/office/pao/History/SP-4404/contents.htm>; Internet; Accessed 30 April 2008, Chapter 8. NASA and the US Air Force has also tested liquid hydrogen in both conventional turbofan engines as well as scramjet (supersonic combustion ramjets capable of propelling craft to hypersonic speeds) engines. The August 2006 edition of *Scientific American Magazine* featured an article entitled “Power for a Space Plane” by Dr. Thomas A. Jackson, the Deputy for Science at the Aerospace Propulsion Division of the US Air Force Research Laboratory’s Propulsion Directorate. Page 59 featured numerous illustrations and graphs comparing the virtues of JP-7 kerosene and hydrogen as a fuel for various jet engine types, and he discussed the advantages and disadvantages of each on pages 62-63. The main virtues of JP-7 over hydrogen included an established global infrastructure for handling and distribution, and energy density to free up internal volume for other applications. See Figure 18 for a comparison of a hydrogen powered cargo aircraft with a conventional petroleum powered. aircraft.

¹⁸⁵ Harrison, “The Role of Fischer-Tropsch Fuels in the US Military” discussed some of the testing and results. The 20 June 2007 *Washington Post* article by Sholnn Freeman entitled “Coal-to-Liquid Provision Stalls” cites carbon emissions as a key reason why congress declined to support building coal-to-liquid plants, nor mandate production quotas for synthetic fuel in the 2007 energy bill.

¹⁸⁶ Defense Science Board Task Force on DoD Energy Strategy 2008, pg 51

fuels using local energy and water sources to produce hydrogen and they employed the Bergius process rather than the Fischer-Tropsch process, they could make the same amount of fuel for one-fifth the transportation requirements. Using local carbon sources, such as biomass or waste products instead of moving coal, could further reduce this.¹⁸⁷

Aerial fuel delivery comprises another, more tactical risk. The KC-135s that comprise the majority of this fleet are over fifty years old and the replacement tanker is stalled in congress.¹⁸⁸ Meanwhile, other nations are designing air weapons and tactics referred to as HVT (High Value Target) busting, specifically tailored to attack AWACS, tanker and other specialized support aircraft while avoiding confrontations with fighters in order to negate our advantages.¹⁸⁹ Newer tankers with newer countermeasures may or may not improve survivability against these new tactics, but this development highlights the need to reduce the demand for fuel that puts these

¹⁸⁷ Initial experiments conducted by Friederich Bergius in 1928 yielded about 124 gallons of fuel for every short ton of coal consumed according to page 8 of the Fischer-Tropsch Archive, [Online] available from http://www.fischer-tropsch.org/Bureau_of_mines/info_circ/ic_6075/ic_6075.pdf; Internet; Accessed 30 April 2008. Calculating the densities of coal, kerosene, and yield data from the early Bergius process paper, moving coal and using local water for hydrogen would require 1/5 of the volume of transportation depending on the granularity and quality of the coal. The total yield from the Fischer Tropsch process converts one ton of coal into about 71.4 gallons of fuel according to slide 13 of Dr. Theodore Barna's *OSD Assured Fuels Initiative* briefing at the 2006 Aerospace in the News Executive Symposium. The Bergius process is very similar to the Fischer Tropsch process currently employed in Air Force experiments with identical outputs. The Bergius process converts all of the coal or carbon source into fuel, but does require a source of power to make hydrogen and the heat required to power the process. The Fischer Tropsch process partially combusts the coal to do this. A small nuclear reactor could provide the heat and make hydrogen from local non-potable water and save 50% of ongoing lift over using the Fischer-Tropsch process, or 80% over transporting petroleum fuel to theater. The National Research Council study *Reducing the Logistics Burden for the Army After Next* analyzed the benefits of converting portable nuclear power into usable forms of energy for military vehicles. Page 54 illustrates the comparison between the energy equivalent quantity of diesel fuel and a nuclear reactor. The reactor offered lift advantages over the diesel after 2.2 to 19 days depending on other parameters. Thermal depolymerization could consume waste items, such as used tires and convert them into usable fuel.

¹⁸⁸ The KC-135 fleet entered service between 1956 and 1965. *Defense Industry Daily* had numerous articles on the KC-135 and the EADS/Northrop KC-30 and Boeing KC-767 programs to replace it, including "The USAF's KC-X Aerial Tanker RFP" and "KC-X: Rating the Contenders." The KC-30 won the bid, but Boeing protested the selection.

¹⁸⁹ Kopp and Goon, *Strategic Needs and Force Structure Analysis*, page 2. Other writings at Air Power Australia, and in *Defense Industry Daily* note new Russian designed weapons and techniques designed to negate key Western air power systems by striking key combat multipliers (high value targets, HVTs), such as fuel tankers, Airborne Warning and Control Systems (AWACS, also known as AEW&C, Airborne Early Warning and Control), etc.

aircraft at risk. These tankers not only service combat aircraft, but cargo aircraft servicing ground forces, and occasionally delivering fuel to ground forces. During the early phases of Operation Enduring Freedom, US ground forces had no means of moving fuel into Afghanistan. C-17 cargo aircraft landed at airfields, drained their center tanks into awaiting fuel trucks, took off using fuel in their wing tanks, and were refueled in the air. They then landed again and repeated the process to meet the fuel requirements on the ground.¹⁹⁰ This further reinforces the need for self-sustaining and renewable energy resources for ground forces to reduce this risk.

Naval Uses

GEN Tommy Franks noted in his book that the USS *Cole* had just arrived in the Central Command area of responsibility and had to immediately refuel after the transit from the US East Coast.¹⁹¹ Suicide boats attacked the *Cole* after it entered the Aden harbor in Yemen and connected to an offshore fuel dolphin. While US warships often visit such ports for other reasons, such as a demonstration of resolve or friendship, Congress questioned GEN Franks about the necessity of purchasing fuel at risky ports after the incident.

¹⁹⁰ Pages 35 and 36 of *The United States Army in Afghanistan: Operation Enduring Freedom* (Dr. Richard W. Stewart, US Army Center for Military History October 2001-March 2002) discussed having to resort to “wet wing” operations--draining fuel from aircraft to deliver fuel--during Operation Enduring Freedom.

¹⁹¹ GEN Tommy Franks, *American Soldier: General Tommy Franks*. (New York, NY: Harper Collins, 2004), page 224. The USS *Cole* had to refuel immediately upon arrival in theater because of fuel consumption from transit because US Navy ships must arrive on station with at least 51% of their fuel capacity to be considered operationally ready.

Concept of Operations

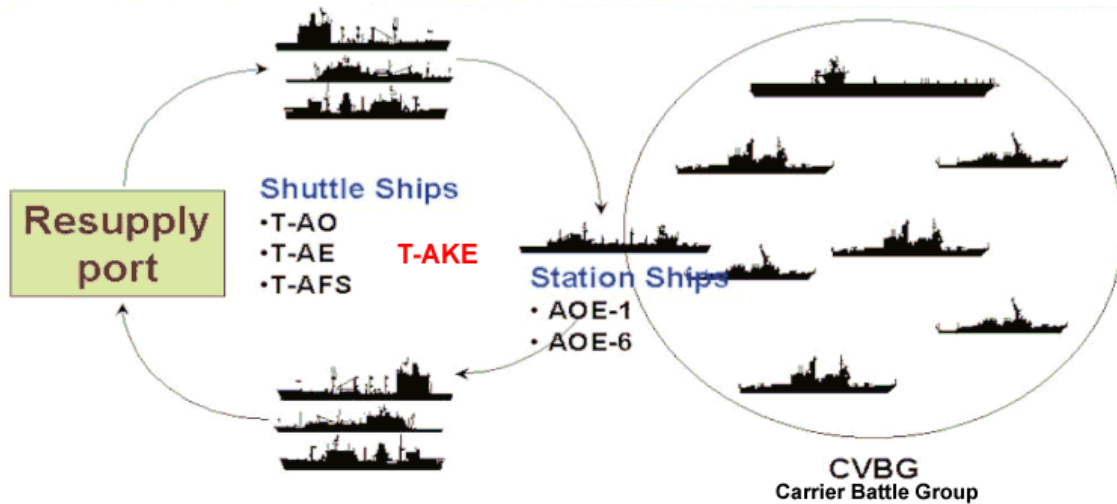


Figure 17: Naval supply concept of operations, illustrating the role of different types of supply ships in keeping warships ready for action.¹⁹²

Meanwhile, the Navy has a very small number of tenders to re-supply ships at sea. This underway replenishment (UNREP, or sometimes VERTREP-vertical replenishment by use of helicopters) forces both ships participating to hold a steady course. This makes them more vulnerable to enemy attacks, from torpedoes or cruise missiles for example. Ships often practice an emergency breakaway procedure to get clear of the ships involved in the UNREP in case such an incident occurs.

Very few foes will likely have comparable technology or a sufficiently large fleet to challenge the US Navy directly. Encounters with asymmetric threats, such as suicide boats,

¹⁹² From 10 March 2008 *Defense Industry Daily* article on the T-AKE class supply ship “US Navy on the T-AKE As It Beefs Up Supply Ship Capacity (updated).” The 2001 Defense Science Board Publication *More Effective Warfighting Through Reduced Fuel Burden* cited that 70% of fuel for US Navy warships was delivered at sea. Additionally, Robert Kaplan wrote in “The new balance of power” at the Foreign Policy Research Institute on 14 April 2008 that the Navy that China will not try to compete on

submarines, anti-ship missiles, mines, or other techniques are more likely. Targeting fueling tenders would be a far more effective use of resources than directly attacking warships.¹⁹³ Escort vessels appear to be hard pressed to protect battlegroups and may not be available to escort tenders, particularly the shuttle ships depicted in Figure 18.¹⁹⁴ Even if they did so, it would further drain resources from combat availability.

In contrast, nuclear powered ships and submarines have virtually unlimited range. This includes all US submarines and all but one aircraft carrier, which will be replaced with a nuclear carrier. However, carriers must refuel every three to five days to supply their aircraft, whereas the only limiting factor for submarines is food. Some Naval officers informally interviewed for this study cited some reasons why some US Navy warship designs use gas turbines rather than nuclear power.¹⁹⁵ The first reason was to cut up-front costs, because the gas-turbine power plants were cheaper to purchase than the reactor cores, although the reactors come with their lifetime

even terms with the US Navy. They will focus on employment of an asymmetric strategy focusing on missiles capable of striking ships at sea, quiet diesel-electric submarines, and anti-satellite technology.

¹⁹³ Page 16 of the 2 April 2007 CRS Report for Congress, *Navy Nuclear-Powered Surface Ships: Background, Issues, and Options for Congress*, by Ronald O'Rourke states that the Navy recognizes that oilers are a high value target and says they would be escorted and protected accordingly. However (combine with footnote below)

¹⁹⁴ A Chinese *Song* class submarine surfaced within torpedo range of the USS *Kitty Hawk*. *International Herald Tribune* article entitled "U.S. military officials wary of China's expanding fleet of submarines" by David Languer, written 7 February 2008 discusses the incident, which took place in late 2006. Additionally, several nations are fielding even quieter Air Independent Propulsion (AIP) fuel cell powered submarines. The Nuclear Threat Initiative (NTI) published an analysis of the proliferation of diesel-electric and AIP submarines in the article "Global Submarine Proliferation: Emerging Trends and Problems" by Dr. James Clay Moeltz in March 2006. [Online] available from http://www.nti.org/e_research/e3_74.html; Internet; Accessed 30 April 2008. Moreover, the proliferation of sophisticated anti-ship missile

¹⁹⁵ USS *Kitty Hawk* (CV-67) is the last non-nuclear carrier, and is scheduled to retire at the end of its current tour by the *Nimitz* class nuclear powered *George H. W. Bush* (CVN-77). All US Navy submarines are nuclear powered, as are all carriers except the USS *Kitty Hawk*. The *Virginia* class cruisers were nuclear powered, but were replaced by the gas turbine powered *Ticonderoga* class. Destroyers, frigates, and other smaller craft have always been coal or petroleum fueled. ADM "Skip" Bowman noted in a discussion at the Nuclear Energy Institute that there are about as many working US Navy nuclear reactors as there are in the US civilian economy, 103. The US Navy has an outstanding reputation of safely and effectively operating nuclear reactors in a tactical environment.

supply of fuel built in.¹⁹⁶ Petroleum based fuels were also much less expensive when today's generation of destroyers and cruisers were designed and built. Space considerations were also an issue, not just for the reactor itself, but also the berthing for the additional personnel to operate the system. Secondly, the training for the operators costs more and requires more competent personnel than gas turbine operators. Third, some line officers resent having to submit to a subject matter expert in engineering when he wants to do something with the ship, and older nuclear technology was less responsive than gas turbines.¹⁹⁷ Normal naval reactors require expertise to adjust the fuel and control rods inside a containment vessel to maintain the desired reaction rate to heat water to drive a steam turbine. This requires a team of highly trained and intelligent engineering staff to continually tend to the reactor. The reactor and its affiliated control, steam and power generation equipment can be miniaturized, but the additional personnel take up space on board as well.¹⁹⁸

Nuclear power also provides compelling advantages to the Navy as well. Nuclear power increases mobility and range, and even reduces the infrared signature of vessels as well.¹⁹⁹ Fuel is by far the largest commodity naval supply ships must deliver to the fleet, especially since many ships can produce their own water supplies through desalination. CODS (Carrier On Board

¹⁹⁶ The CRS study *Navy Nuclear-Powered Surface Ships*, page 2 stated that lifecycle costs for medium and larger ships are lower for nuclear ships, and could be lower for even smaller ships if oil reaches the \$200 a barrel range.

¹⁹⁷ Some of this is attributable to latent resentment of the policies and influence of the late Admiral Hyman Rickover, who was the father of the nuclear Navy and was renowned for his assertive leadership style and technical prowess. Rod Adams interviewed the author of the book *The Rickover Effect: The Inside Story of How Adm. Hyman Rickover Built the Nuclear Navy* in Atomic Show episode 14. Rickover's style, insistence of tightly controlling all things nuclear, and the closed nature of his elite, selected nuclear acolytes within the Navy caused a backlash among other Navy officers and their relationships with their engineers. With regard to response time, this refers to the ability to change power levels quickly. Older nuclear technology required more time to build up steam than for a gas turbine to spool up to produce more power.

¹⁹⁸ Rod Adams, a former US Navy nuclear engineering officer stated in Episode 71 of *The Atomic Show* that the reactor itself on a nuclear submarine is about the size of a small office desk. The CRS study, *Navy Nuclear-Powered Surface Ships*, page 5, states that for larger ships, such as aircraft carriers, nuclear plants save considerable space on these ships by obviating the need for fuel storage.

Delivery) could feasibly fly much of the remainder aboard. Therefore, fuel delivery to the fleet drives most of the external costs for the operation of naval vessels and drives operational risk because of the asymmetric threats to the tankers. The US Congress recently mandated the use of nuclear power on all new vessel designs of cruiser or larger, which will greatly reduce US Navy vulnerabilities on their sea lines of communication.²⁰⁰ However, the study they primarily relied upon for this decision only examined direct fuel costs to make this recommendation. The author of the study acknowledged operational effectiveness benefits, and mentioned the risks and costs of oilers, but did not factor them into the fiscal analysis.²⁰¹ Factoring in the cost of delivering the fuel, maintenance and operation of the oiler fleet, and the attendant operational risks may well make current nuclear power options more attractive for a wider range of US Navy vessels.

Since all carriers and many of the larger ships will be nuclear powered, the US Navy should explore powering their aircraft and Unmanned Underwater Vehicles (UUVs) with hydrogen rather than petroleum based jet fuel. The reactors on these ships provide tremendous amounts of energy for around 20 years without refueling. The nuclear reactor in the ship could produce the hydrogen from seawater on demand and compress it into a cryogenic liquid.²⁰² This would obviate the need for any fuel deliveries to the ship at all. While the hydrogen takes up greater volume than petroleum jet fuels, it is lower mass for the same amount of energy. Moreover, NASA and the US Air Force tested hydrogen on jet engines and noted its superior

¹⁹⁹ CRS study, *Navy Nuclear-Powered Surface Ships*, page 16

²⁰⁰ A 17 December 2007 article by Greg Grant in *Government Executive* entitled “Lawmakers call for future Navy cruisers to be nuclear powered” cites a Congressional call for future cruisers to employ nuclear power.

²⁰¹ CRS study, *Navy Nuclear-Powered Surface Ships*, page 16. The prices used to compare the lifecycle costs of nuclear vessels against conventionally powered vessels used acquisition prices, not the delivered cost. Considering the factors, infrastructure and risk commensurate with delivery of fuel to warships, nuclear power may compare even more favorably.

²⁰² Nuclear submarines currently produce their oxygen for the crew using this method, except they jettison the hydrogen. Adams, *Atomic Show*, episode 37.

performance.²⁰³ Hypersonic aircraft projects would also benefit from such hydrogen fuel production, since cryogenic hydrogen is an ideal fuel for scramjets.²⁰⁴ While the low density of hydrogen is a problem for storage and transportation in other contexts, producing the hydrogen on demand and immediately consuming it would obviate storage concerns. The aircraft would be fueled prior to takeoff and consume the hydrogen on the mission. Nearly all other deliveries could be conducted via aircraft if required because of the vastly lower volume delivered. Improved fuel safety would alleviate damage control concerns compared with the storage of thousands of gallons of kerosene aboard ship, which can potentially lead to disasters like the USS *Forrestal* incident.²⁰⁵ A weapons malfunction on the flight deck led to a fire, which cooked off ammunition and aircraft on deck, and eventually ignited the aviation fuel storage below, nearly leading to the loss of the entire ship. With hydrogen, only the small amount ready for loading and on board aircraft could pose a hazard. Moreover, hydrogen is lighter than atmospheric air, and

²⁰³ Project Sustain tested hydrogen powered jet aircraft. National Aeronautics and Space Administration. "Liquid Hydrogen as a Propulsion Fuel, 1945-1959." [Online] available from <http://www.hq.nasa.gov/office/pao/History/SP-4404/contents.htm>; Internet; Accessed 30 April 2008, Chapter 8. NASA and the US Air Force has also tested liquid hydrogen in both conventional turbofan engines as well as scramjet (supersonic combustion ramjets capable of propelling craft to hypersonic speeds) engines. The August 2006 edition of *Scientific American Magazine* featured an article entitled "Power for a Space Plane" by Dr. Thomas A. Jackson, the Deputy for Science at the Aerospace Propulsion Division of the US Air Force Research Laboratory's Propulsion Directorate. Page 59 featured numerous illustrations and graphs comparing the virtues of JP-7 kerosene and hydrogen as a fuel for various jet engine types, and he discussed the advantages and disadvantages of each on pages 62-63. The main virtues of JP-7 over hydrogen included an established global infrastructure for handling and distribution, and energy density to free up internal volume for other applications.

²⁰⁴ Hydrogen would be an ideal fuel for Unmanned Underwater Vehicles (UUVs) because they could employ fuel cells. Several nations are fielding quiet Air Independent Propulsion (AIP) fuel cell powered submarines. The Nuclear Threat Initiative (NTI) published an analysis of the proliferation of diesel-electric and AIP submarines in the article "Global Submarine Proliferation: Emerging Trends and Problems" by Dr. James Clay Moeltz in March 2006. Hydrogen would also facilitate the employment of hypersonic scramjet powered vehicles.

²⁰⁵ The 18 May 2007 National Geographic documentary *Seconds from Disaster* and other several other documentaries recount the July 1967 catastrophic fire aboard the USS *Forrestal* in the Gulf of Tonkin. A weapons mishap sparked a fuel fire, and subsequent explosions of ordnance killed the ship's qualified fire crews. The remainder of the crew desperately fought to extinguish the fire before it ignited the stored aviation fuel, and ammunition, as well as the ship's own petroleum fuel. The fire killed over 134 sailors and injured 161 more, and substantial numbers of aircraft were severely damaged, destroyed, or jettisoned overboard to save the ship.

rises when released. Kerosene settles onto a surface and spreads. If a hydrogen fire did occur, it would expand upward and away from people, rather than spreading horizontally over surfaces and into crevices in the ship.

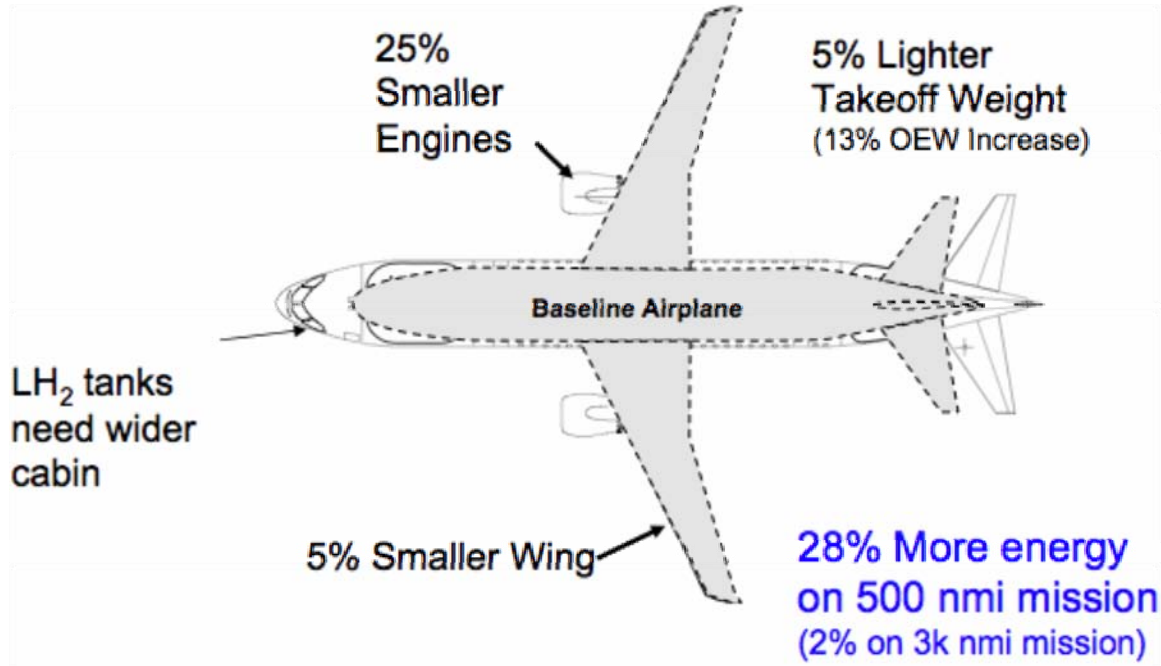


Figure 18: Comparison of an aircraft powered by kerosene with one powered by hydrogen. The lower energy density of hydrogen, along with the inability to put pressurized fuel storage tanks in the wings, demands higher fuel carrying capacity to maintain the same performance. This effect may be less prevalent in larger aircraft, which already have larger body volumes, and in fighter aircraft, which have very thin wings to facilitate supersonic flight, and hence store little fuel in them anyway.²⁰⁶

The Navy could also explore a simpler, cheaper reactor design for their smaller ships, such as destroyers and the Littoral Combat Ship (LCS). One such reactor design, known as the Pebble Bed Modular Reactor (PBMR), operates like a gumball machine, with a sub-critical

²⁰⁶ Comparison by Dave Daggett of Boeing and found in the Air Force Research Lab briefing “The Role of Fischer Tropsh Fuels for the US Military” by William Harrison, slide 15.

sphere of nuclear fuel inside billiard ball sized Tristructural Isotropic (TRISO) “pellets.”²⁰⁷

These pellets settle to the bottom as they are used up, and eventually drop out the bottom, while fresh pellets are loaded in the top. This reactor design self-moderates; the design intrinsically curbs the rate of the reaction if the temperature gets too high. The design is usually gas operated rather than steam operated, making them potentially simpler to operate and maintain. A closed cycle gas turbine like this could take a small footprint, such as the space allocated for similar gas turbines and their fuel, and require less maintenance than conventional nuclear plants.²⁰⁸ A former US Navy officer proposed using nitrogen as the working gas for such a design because standard un-modified gas turbines could be used to further reduce costs.²⁰⁹ An all-nuclear Navy would have virtually unlimited range and operational flexibility, and avoid the operational risks associated with dependence on refueling, as well as the attendant costs of the fuel, and the tanker fleet.

²⁰⁷ These pellets consist of a sub-critical core of uranium oxide with four layers of three isotropic materials, each containing different carbon compounds. Some primarily moderate the nuclear reaction, while others are extremely hard to contain fission products in conditions beyond 1600°C. These pellets do not react unless they are in close proximity to other pellets because they are sub-critical—too little material is present to sustain a fission reaction. The PBMR is simpler and safer to run because the shape and composition of the pellets self-regulate the fission reaction. If the reactor gets too hot, the reaction slows down by itself. See the 2003 MIT Interdisciplinary Study *The Future of Nuclear Power*, pages 104-105 or article “Advanced Fuel Cycle Initiative: Closing the nuclear fuel cycle” by Vin Lo Presti of Los Alamos National Laboratory [Online] available from <http://www.lanl.gov/orgs/nmt/nmtdo/AQarchive/03springsummer/AFCL.html>; Internet; Accessed 30 April 2008.

²⁰⁸ PBMRs would potentially require less maintenance compared to conventional nuclear plants due to using a stable gas as a coolant rather than water, which can cause corrosion in the steam system. PBMRs contain a sub-critical core of uranium oxide in billiard-ball sized spheres coated with layers of three different types of ceramics capable of retaining the fission products in conditions beyond 1600°C. Ibid. 205.

²⁰⁹ Rod Adams currently hosts a podcast called *The Atomic Show*. He advocates greater use of nuclear power. He proposes using a PBMR style reactor using nitrogen in a closed cycle as the working fluid. Most gas cooled reactor designs call for Helium because of its superior thermodynamic properties. However, helium is getting harder to obtain and requires special seals in the turbine and other design considerations that would make it more expensive to use. See Rodney Adams, “Nuclear Power for Remote Areas”

APPENDIX C- Energy Development in Irregular Warfare

Renewable energy would also be very valuable in infrastructure development in humanitarian aid and especially counter-insurgency operations. Restoring the critical services, such as electrical power is a crucial component of a successful counter-insurgency campaign.²¹⁰ The acronym SWEAT-MS describes the essential services to evaluate, including sewage, water, electricity, academics, trash, medical and security. Counter-insurgency forces work through the supported government to restore these services to give them greater legitimacy with the people. Electrical power is a pre-requisite for most, if not all of these to function. For example, many medical supplies require refrigeration, as do food supplies. Lighting facilitates school work beyond normal daylight hours, and also assists with security. Electricity pumps and purifies water, as well as disposal and processing of sewage. Insurgents attack the grid and centralized power stations, and other portions of the infrastructure to undermine the government for failing to provide these things.²¹¹ Power lines, like roads, are very hard to secure over long distances; insurgents easily interdict them. Commanders should conduct an assessment and weight the benefits of getting people reliable electrical power versus the leverage the central government can gain by integrating them into a centralized grid. Distributed electrical production such as wind turbines, solar panels, micro-hydro, and generators run off gas from anaerobic digesters processing sewage into fuel can provide continuous electrical power that would be far more difficult for insurgents to disrupt, and the local population will defend it.²¹² Electricity in remote

²¹⁰ Major General Peter W. Chiarelli and MAJ Patrick R. Michaelis wrote the article “Winning the Peace Requirement for Full Spectrum Operations” in the July/August 2005 issue of *Military Review* highlighting the importance of concurrent infrastructure restoration in conjunction with improving security in counter-insurgency operations.

²¹¹ The 10 February 2006 edition of NPR *Science Friday* “Engineering Iraq” featured engineers deployed to Iraq tasked with rebuilding the power grid. They detailed the hardships and absurdities of trying to rebuild major infrastructure projects more easily and quickly destroyed by insurgents than they could build. They also highlighted the penchant for large Western style centralized power production.

²¹² A Bergey Windpower published a case study about a wind power project in the Parwan district of Afghanistan. Empower Associates, UNICEF, the New Zealand government, and the Afghan Ministry of

portions of Iraq and Afghanistan costs 36¢ per kilowatt-hour in Iraq and Afghanistan because generators produce it fueled by diesel trucked in from Iran through mountains.²¹³ If the locals consider the systems their property after building and operating it and they themselves will defend it from insurgent forces, or force insurgents to directly confront the people they are trying to win over.²¹⁴ The people could stitch these pockets of distributed energy production together gradually in an ever-expanding grid to improve the reliability and interdependence with their neighbors as the security situation improves. Distributed energy systems would compliment the so-called “ink-blot” strategy of counter-insurgency by securing pockets of the population and expanding those pockets. The power distribution grids of the pockets would connect when pockets converge to provide greater reliability and stability.

Rural Reconstruction and Development conducted this project, which used a small wind turbine to drive an ozone water purifier. *Bergey Windpower Case Study* “Parwan District, Afghanistan: Ozone Based Water Treatment System” [Online] available from <http://www.bergey.com/Examples/Afghanistan.html>; Internet; Accessed 5 April 2008. Marine Corps MG Zilmer ordered 183 renewable energy systems to provide electrical power at many forward locations in the Anbar province to reduce fuel delivery risks. Page 58 of the 2008 Defense Science Board study suggests they successfully provided remote power. While these systems had a higher acquisition cost, the lifecycle costs were lower even without counting the cost of fuel deliveries.

²¹³ In contrast, the US electricity rate average is 8.91¢ per kilowatt-hour according to a Nebraska state energy site [Online] available from <http://www.neo.ne.gov/statshtml/115.htm>; Internet; Accessed 30 April 2008 Former US ambassador to Afghanistan Ronald Neumann talked to the Center for Strategic and International Studies on 31 May 2007. (“Statesmen’s Forum: Ronald Neumann, former U.S. ambassador to Afghanistan.” *Center for Strategic and International Studies* podcast. 31 May 2007 [Online] available from http://media.csis.org/podcast/070531_neumann.mp3; Internet; Accessed 30 April 2008) He highlighted the importance of electricity and considered it crucial for Afghanistan’s development. This price is probably quite a bargain given the circumstances, since Iran heavily subsidizes its fuels, so Iranians can buy it very cheaply. The 3 September 2007 *Economist* article “A Fuel Pinch” states that Iran’s refineries produce 44 million liters of gasoline a day, while Iranians buy 75 million liters a day, resulting in gasoline imports of over \$5 billion a year. The government imports the fuel at 50¢ a liter, and recently raised the price it charges its citizens from 9¢ to 12¢ a liter. Enterprising Iranians are buying up cheap fuel and selling it for a profit in neighboring countries. This black market business increases demand and strains the ability of Iranian refineries to keep up, resulting in Iran actually importing this huge quantity of refined petroleum products from abroad.

²¹⁴ In the book *Three Cups of Tea: One Man’s Mission to Fight Terrorism and Build Nations...One School at a Time*. (New York, NY: Viking Penguin 2006), Greg Mortenson describes his organization’s method of supporting local villagers build schools in their communities in Pakistan. The Central Asia Institute has been building these schools in Pakistan and Afghanistan since the 1993. The villagers built the schools, and therefore had a stake in defending and maintaining them.

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