MORE CAPABLE WARFIGHTING THROUGH REDUCED FUEL BURDEN

The Defense Science Board Task Force
on
Improving Fuel Efficiency of Weapons Platforms

January 2001

OFFICE OF THE UNDER SECRETARY OF DEFENSE
FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
WASHINGTON, D.C. 20301-3140

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DEFENSE SCIENCE
BOARD

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY AND LOGISTICS)

SUBJECT: Final Report of the Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms

I am forwarding the final report of the Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms.

The Terms of Reference directed the Task Force to identify technologies that improve fuel efficiency of the full range of weapons platforms with an emphasis on those with the greatest potential to begin implementation within the next 10 years. The Task Force addressed operational, logistical, cost, and environmental impacts for a range of practical implementation scenarios. The Task Force estimated:

- the increase in operational performance resultant from increased fuel efficiency;
- the reduction in the logistics tail associated with efficiency in platform performance;
- the costs and benefits of each technology for a range of implementation scenarios;
- the corresponding decrease in Green House Gas emissions from the application of advanced technologies.

The Task Force determined that a broad range of problems exist which inhibit the incorporation of new technologies into weapons platforms. Incorporation of these technologies would enhance the performance of these platforms and offer significant returns on investment for the Department of Defense.

I endorse all of the Task Force's recommendations and recommend you forward the report to the Secretary of Defense.

William Schneider, Jr.
Chairman

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DEFENSE SCIENCE BOARD

January 31, 2001

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Report of the Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms

Attached is the final task force report. The task force was asked to identify technologies that improve fuel efficiency of the full range of weapons platforms (land, sea, and air) and assess their operational, logistics, cost and environmental impacts for a range or practical implementation scenarios.

The task force carefully examined DoD's research portfolio, and concluded there are many technologies with the potential to improve fuel efficiency applicable to all platforms at all levels of maturity. We concluded that the analytical tools necessary to quantify the warfighting, logistics and cost impacts of implementing the technologies were inadequate to the task. We also probed into a number of institutional barriers and implementation issues that bear upon the Department's decisions regarding fuel efficiency. Further, the task force found that these benefits, and the burden to warfighting capability of not focusing on efficiency, were not factored into decision-making.

The study resulted in five findings:

- Although significant warfighting, logistics and cost benefits occur when weapons systems are made more fuel-efficient, these benefits are not valued or emphasized in the DoD requirements and acquisition processes.

- The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision-making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices.

- The DoD resource allocation and accounting processes (PPBS, DoD Comptroller) do not reward fuel efficiency or penalize inefficiency.

- Operational and logistics wargaming of fuel requirements is not cross-linked to the Service requirements development or acquisition program processes.

- High payoff, fuel-efficient technologies are available now to improve warfighting effectiveness in current weapon systems through retrofit and in new systems acquisition.

The task force recommends the following series of actions that would result in the development the analytical tools necessary to quantify the warfighting, logistics and cost implications of implementing specific technologies in platforms, and implement their results into the requirements, acquisition and PPBS processes.

- Base investment decisions on the true cost of delivered fuel and on warfighting and environmental benefits.

- Strengthen linkage between warfighting capability and fuel logistics requirements through wargaming and new analytical tools.

- Provide leadership that incentivizes fuel efficiency throughout the DoD.

- Specifically target fuel efficiency improvements through investments in Science and Technology and systems designs.

- Explicitly include fuel efficiency in requirements and acquisition processes.

Developing analytical tools that link requirements to acquisition to logistics in a holistic way and using them as the basis for force structure decisions will move DoD toward a more agile, deployable and sustainable force structure that delivers maximum capability for the DoD budget.

On behalf of the task force members and staff who supported this study, I particularly want to express our sincere appreciation to all of those who made presentations and contributed to the report.

Richard Truly

VADM Richard H. Truly (USN, Ret.)
Co-Chair

Dedication

Alvin L. Alm
1937 - 2000

During the course of this Defense Science Board task force, our Co-Chairman was taken from us. Although ***Al Alm****, President of Chambers Associates, Inc. was not able to see or brief this final report, his leadership, thoughts and incisive analytical capabilities pervade it.*

> ***Al Alm*** *served under five Presidents of both parties in the White House, the Environmental Protection Agency, and the Department of Energy. Although he supplemented his government work with interludes in business and academia, he exemplified dedicated public service in support of sound environmental and energy policies and often described himself as a "government recidivist." He saw immense opportunity for our national defense in the work of this task force. His grand sense of humor, friendship and intellect are sorely missed and his loss is deeply felt.*

Task Force Membership

Co-Chairs

Mr. Alvin Alm	Chambers Associates, Inc.
VADM Richard Truly (USN, Ret)	National Renewable Energy Laboratory

Members

Gen Mike Carns (USAF, Ret)	Center for International Political Economy
Ms. Leslie Carothers	United Technologies Corporation
Dr. Robert Cooper	Atlantic Aerospace Electronics
Dr. Susan Coughlin	American Trucking Associations Foundation
Lt Gen Jerome Granrud (USA, Ret)	Spectrum Group
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Foreword

This report summarizes the work of the Defense Science Board task force on Improving the Fuel Efficiency of Weapons Platforms. The report consists of an Executive Summary; Introduction; major sections on National Security Fuel Use and Global Supply; Linking Fuel Efficiency to Military Capability, National Security and Environmental Security; Improving Platform Fuel Efficiency Through Technology; Findings and Recommendations; and appendices.

Appendix A: Task Force Terms of Reference.

Appendix B: Translating Energy Savings into Environmental Benefits presents an approach for quantifying the environmental benefits of improved efficiency.

Appendix C: Futures Overview was written by a member of the task force, Dr. Paul MacCready. It discusses revolutionary and radically fuel-saving changes in warfighting possible over the coming decades based on basic research.

Appendix D: Uncertain Fuel Consumption Data and DoD Greenhouse Gas Emissions illustrates the difficulty in obtaining comprehensive fuel data.

EXECUTIVE SUMMARY

The Under Secretary of Defense (Acquisition, Technology and Logistics), recognizing the crucial importance of weapons platform fuel usage to U.S. military capability, requested that the Defense Science Board form a task force on Improving Fuel Efficiency of Weapons Platforms. Asked to consider existing or emerging technologies that could significantly improve platform efficiency, the task force also examined institutional barriers that exist and must be overcome to understand and capture the full advantages of more efficient military systems.

Overview

The United States uses more petroleum each year than the next five largest consuming nations combined. Military fuel consumption for aircraft, ships, ground vehicles and facilities makes the DoD the single largest consumer of petroleum in America, perhaps in the world. However, DoD consumes a very small proportion of the total national or global fuel supply. The most important sources of the world's oil are increasingly concentrated in the Southwest Asia, and if recent decades are a guide for the future, America's military forces will be called upon again when the world fuel supply is threatened or interrupted.

Ten years after the Cold War, over 70 percent of the tonnage required to position today's U.S. Army into battle is fuel. Naval forces depend each day on millions of gallons of fuel to operate around the globe. The Air Force is the largest DoD consumer, and spends approximately 85 percent of its fuel budget to deliver, by airborne tankers, just 6 percent of its annual jet fuel usage.

Considering this large and costly fuel usage, it would seem logical for the DoD to instinctively strive for continuous improvement in the fuel efficiency of all its platforms and forces. Similarly, a high and visible DoD priority would be to improve fuel efficiency to enhance platform performance, reduce the size of the fuel logistics system, reduce the burden high fuel consumption places on agility, reduce operating costs, and dampen the budget impact from volatile oil prices.

To achieve these goals, future Science & Technology investments would focus more on fuel efficiency; cost-benefit decisions would be based on the true cost of fuel; and modern, near-real-time modeling tools concerning fuel efficiency choices would aid decision makers in the requirements determination, acquisition and wargaming communities. Strong incentives would then encourage operators to reduce consumption while still maintaining readiness; the requirements process would demand fuel efficiency in platforms; the acquisition system would produce more efficient platforms and systems; and senior civilian and military leadership would trumpet the huge advantages of efficiency to combat capability.

Unfortunately, none of these priorities, tools or incentives are in evidence today.

Task Force Findings

The task force reviewed approximately 100 current and future technology solutions and sought to understand DoD's fuel requirements and its end-to-end fuel delivery processes. The task force then turned its attention to understanding DoD's policy on energy efficiency and the processes for requiring and acquiring more efficient platforms and systems. The task force also investigated the environmental impacts of fossil fuel use, including global climate change. The task force made the following significant Findings during the course of its work.

Although significant warfighting, logistics and cost benefits occur when weapons systems are made more fuel-efficient, these benefits are not valued or emphasized in the DoD requirements and acquisition processes.

Military requirements documents understandably place the highest priority on performance. Focusing on this singular demand often carries a substantial provisioning and maintenance penalty. While recent DoD policy guidance has placed heavy emphasis on improved reliability, it has overlooked the substantial performance gains that can also be achieved through energy efficiencies. These include greater range, lighter weight systems, and reduced combat vulnerability.

When asked to describe the capability improvements that would result from better efficiency, laboratories largely focus on an individual platform, but are unable to address the broader question of how it affects the capability of the entire force. The ability to conduct these critical analyses is limited by lack of modern analytical models to quantify the efficiency benefits in terms of numbers of systems needed to execute a mission, deployment times, sustainability for a given logistics capability, or vulnerability of the logistics tail.

Energy and fuel efficiency would become a major variable in making final weapons system performance decisions if specified as a clear requirement (such as a key performance parameter) in all platforms.

The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices.

The Defense Energy Supply Center (DESC) acts as the market consolidator and wholesale agent for the DoD. For simplicity in dealing with its service customers, OSD establishes a "standard fuel price" annually. The standard price does not reflect the cost to the Services of delivering the fuel from the DESC supply point to the ultimate consumer, such as a tank, ship or aircraft. The cost of delivery is absorbed by each military service budget and is spread across many accounts, making the actual cost of delivering fuel uncomputed, unknown and not factored into important investment decisions.

The difference between the price and true cost reflects what the Services must pay to deliver the fuel. In FY99, the standard DESC fuel mix price (average price of the fuels sold) was $0.87 per gallon, in FY00 it was $0.62, in FY01 it is $1.01, and in FY 02 it will be $1.337. But the true cost of these fuels is much higher - $17.50 per gallon for USAF worldwide tanker-delivered fuel, and hundreds of dollars per gallon for Army forces deep into the battlespace. These costs are not used in economic analyses that form the basis for efficiency investment decisions, which result in sub-optimal allocation of resources.

A consequence of using the DESC price is that the logistical cost of delivering fuel to platforms is considered free, even though logistics accounts for about a third of DoD's budget and half of its personnel, and most of the tonnage delivered by the logistics effort is fuel. The Services maintain huge infrastructures to ensure fuel delivery. Large and small surface trucking organizations, naval fleet tankers and aerial refueling aircraft, along with substantial maintenance and logistics organizations contribute to significant overhead costs. Increases in fuel efficiency would correspondingly shrink this overhead burden, enabling savings through reductions in logistics requirements far in excess of the investment.

Were the true costs of fuel delivery and supporting infrastructure (including equipment, people, facilities and other overhead costs) known, understood and factored into the cost of fuel, there would be proper visibility to focus the requirements and acquisition processes on the true benefits of improving platform efficiency. This would create incentives to introduce fuel efficiency into those processes, thereby cutting battlefield fuel demand and reducing the fuel logistics structure needed to deploy and employ weapons systems.

Until policy guidance requires emphasis on weapons system fuel efficiency and the true cost of provisioning fuel to end users is gathered and understood, there is no incentive for leaders, managers or operators to depart from current practices.

The DoD resource allocation and accounting processes (PPBS, DoD Comptroller) do not reward fuel efficiency or penalize inefficiency.

In the business world, financial reporting reflects the priorities and policies of leadership to ensure that there is tight coupling between input and output. However, in DoD there is weak and inaccurate linkage between allocation of resources and mission outcome, despite some prior efforts to make such a linkage. Interest in fuel and energy efficiency is largely limited to meeting federal executive orders or legislative mandates. However, since federal mandates do not apply to military weapons systems, there is neither a policy focus nor resource incentives to seek operational fuel efficiencies.

Management attention, focus and interest in fuel efficiency will result from documented analyses that quantify the military services' operational, logistics, and environmental costs of fuel use, and savings from efficiency investments.

The Planning, Programming and Budgeting System (PPBS), DoD’s budget allocation system, contains no incentive to significantly improve platform fuel efficiency. A lack of analytical tools to quantify warfighting benefits understates the contribution to capability, and Mission Needs Statements (MNS) for platforms and systems do not explicitly require efficiency. The subsidized fuel pricing distorts the economic picture by understating economic benefits. The consequences of no efficiency requirement and a subsidized price are that investments to improve efficiency do not compete well (or at all) in the PPBS process. The result is increased costs and degraded warfighting capability.

Other disincentives include comptroller practices that penalize commanders who reduce energy costs by reducing their budgets. Funding to make platforms more efficient requires acquisition program or maintenance funding, but the beneficiaries of these investments are the operations and support accounts. In the business world this is called a “split incentive.” While the DoD has made progress in factoring support costs into acquisition decisions, the analysis used to determine the appropriate level of investment is hampered by the artificially low fuel price and the inability to quantify the contribution to operational capability beyond the single platform level.

Operational and logistics wargaming of fuel requirements is not cross-linked to the Service requirements development or acquisition program processes.

Operational and logistics wargaming focuses on mission execution, considering fuel as a fixed demand that is assumed to be satisfied. Requirements and acquisition modeling may examine fuel demand but are primarily focused on performance satisfaction, again with energy/fuel requirements considered a "given".

With little or no understanding of the end-to-end cost of the energy/fuel provisioning process, the operator and logistician are unaware of the potential positive impact of fuel efficiency on warfighting effectiveness. Conversely, the warfighters are unaware of the vulnerability of the fuel supply chain. The situation is further aggravated because the requirements-setting function and acquisition process lack modeling data to evaluate the potential gain in warfighting effectiveness available through more efficient fuel use.

In some areas, the DoD has recognized this issue. Models are becoming more realistic; for example, the Joint Warfare System (JWARS) model focuses on logistics, and may better quantify penalties for running out of fuel during battle. In addition, the recently completed Mobility Requirements Study (MRS-05) investigated supply requirements in detail, and those results are being tied directly to acquisition programs. While good first steps, the DoD still lacks assessment models that would illustrate the effect of more efficient platforms and identify, as a result, how many fewer platforms would be required to execute a particular mission.

Modern analytical models are not in place that could determine the logistics reductions enabled by platform efficiency options under consideration. Planners are not using such crucial tools to modify performance features of platforms and quantify the impact of those changes in terms of overall operational capability and logistics requirements. In addition, this analytical capability is a crucial enabler to attaining a force structure that can achieve the objectives of Joint Vision 2010 / 2020 and the Army Transformation.

High payoff, fuel-efficient technologies are available now to improve warfighting effectiveness in current weapon systems through retrofit and in new systems acquisition.

Existing and emerging technologies are available now, at all stages of maturity, that could materially improve weapons systems efficiencies and performance, but the current assessment models place insufficient weight and value on their efficiency merits.

The task force examined several Service studies that resulted in decisions not to implement a proposed efficiency for near term cost reasons. The analyses were overly near term cost-sensitive, thereby foregoing significant near and long term operational, performance, logistical, and reliability gains (B-52 re-engining; M1A1/2 auxiliary power unit; naval stern flap). For example, the B-52 study shows that re-engining significantly reduces tanker force structure requirements.

In almost every case, the research laboratories were not asked to focus directly on fuel-efficient technologies. When laboratories did determine the capability improvements that would result from implementing specific technologies, they were generally expressed for a single platform, such as a specific increase in range, payload or time over target. The collective warfighting benefit of an entire inventory of platforms with this enhanced capability in a force-on-force simulation was not available.

An analytical tool that could link the total force improvement in warfighting capability to specific efficiency/effectiveness benefits would result in materially different characterizations of these investment opportunities, and possibly in quite different investment decisions.

Task Force Recommendations

The task force recommends DoD take the following five actions that will improve military capability through reduced fuel burden:

1. Base investment decisions on the true cost of delivered fuel and on warfighting and environmental benefits.

To take full advantage of more capable and efficient weapons platforms, the DoD must take several actions to break the cycle of hidden costs caused by relying on the low DESC standard fuel price. Several policy changes in the requirement generation process, the Science & Technology investment program, the acquisition system, and wargaming and force structure planning are necessary.

One of the most important actions is to institute routine activity-based cost accounting to determine the true cost of providing fuel to end users. The task force recommends DoD use the true delivered cost of delivered fuel, rather than the artificially low "standard price," when evaluating proposed retrofits for legacy systems, conducting Assessments of Alternatives for new platforms, making Science and Technology investment decisions and determining total ownership costs.

In addition to economic considerations and important warfighting benefits, there are environmental benefits to improving efficiency, which may have additional operational as well as economic value to the DoD. The DoD should institute a standard practice of conducting assessments comparing the environmental performance of new systems with the systems they replace, with the objective of taking advantage of pollution credits or other available benefits.

2. Strengthen linkage between warfighting capability and fuel logistics requirements through wargaming and new analytical tools.

Wargaming and analysis play key and important roles in requirements setting, strategy development and combat commander training. It is essential that battlefield fuel demand be thoroughly integrated into gaming, and investments be made in readily available, easy-to-use, rapid analytical tools that can reveal opportunities to improve capability through improved fuel efficiency. These steps will begin to create and inculcate awareness of the operational benefits of improving the efficiency of platforms and systems.

The DoD conducts different types of wargames for different purposes. Tactical wargames are typically short duration, and should not assume perfect logistics. However, they should play logistics to a level of granularity adequate to identify the specific capability limitations or operational "work-logistics shortfalls impose on operational commanders. Logistics should be played and when it breaks, wargamers must account for it rather than continue to force movements as though logistics were available. This important issue should be incorporated into the ongoing Dynamic Commitment Wargame series.

Logistics-specific wargames, such as the Focused Logistics Wargame (FLOW), must not only focus on how well the logistics pipeline delivers the materials required by the warplans, but also address the impact of platform requirements on logistics burden.

3. Provide leadership that incentivizes fuel efficiency throughout the DoD.

For the DoD to take advantage of the large cost and performance benefits of significant improvements in weapons platform fuel efficiency, senior civilian and military leadership must set the tone and agenda within the Department. Leadership must begin promoting the message that efficiency at the tactical platform and system level is a clear strategic path to improve performance, reduce logistics burden and free resources for modernization and readiness. This needed emphasis by DoD leadership is not merely desirable; it is an essential ingredient to achieve the force improvements to execute joint doctrine.

It is essential that the requirements determination community, specifically the Joint Requirements Oversight Council (JROC) and the Services organizations that input to the JROC, recognize the importance of their decisions in creating the existing scale of logistics infrastructure. Having created it, they exclusively have the ability to shrink it by requiring efficient platforms and systems. This recognition of responsibility at all levels, the implementation of analytical tools and action on newly revealed opportunities are essential tasks of departmental leadership.

4. Specifically target fuel efficiency improvements through investments in Science and Technology and systems designs.

While DoD laboratories were able to describe a large number of technologies in their portfolios that could improve the efficiency of platforms and systems, a consistent message was that their customers, the operators, were not asking for efficiency. A notable and recent exception is the Army in its Transformation effort.

The Science and Technology community should specifically review its overall investment and make platform fuel efficiency a primary focus to identify, track and package technologies that improve efficiency. Highlighting the potential of a mix of technologies to improve the warfighting capability of fleets of specific platforms through higher efficiency gives operators greater flexibility in choosing retrofit and new system features that minimize support requirements and maximize overall operational capability.

It is essential that the DoD support fundamental science (Categories 6.1 and 6.2) investments that can lead to revolutionary improvements in the fuel efficiency of tomorrow's weapon platform systems.

5. Explicitly include fuel efficiency in requirements and acquisition processes.

Joint Vision 2010 / 2020 and the Army Transformation emphasize agility as an important operational capability to counter diverse and asymmetric post-Cold War threats. Efficiency is a strong component of agility. However, in order for U.S. forces to become more agile and efficient, these qualities must be translated into quantifiable and measurable performance criteria and inserted into the requirements determination processes. Capstone documents, Mission Needs Statements (MNS) and Operational Requirements Documents (ORDs) must directly address efficiency issues at platform and force levels.

The task force recommends that the DoD develop and apply an efficiency metric for platforms and systems, preferably as a key performance parameter (KPP) in the requirements and acquisition processes. This will drive the development of the necessary analytical tools to trade off efficiency investments against other competing needs, such as Analyses of Alternatives (AoA) studies that would treat efficiency as an independent variable. Constraining the logistics required to deploy and sustain forces will begin to create a necessary shift in force structure from "tail" to "tooth".

Summary

The magnitude of the DoD's fuel consumption indicates substantial changes must be made in the performance DoD requires of its future systems in order to achieve the goals of Joint Vision 2010 and 2020. To shift the focus more toward efficiency will require the highest levels of leadership to recognize the need to improve efficiency and issue strong and unambiguous policy.

Implementing these recommendations will help DoD realize the goals of Joint Visions 2010 and 2020 by more closely integrating the requirements determination process, acquisition, wargaming and logistics. A more rigorous analytical approach to force structure decisions will enable the DoD to lead the next revolutionary change in warfighting.

I. Introduction

The Under Secretary of Defense (Acquisition, Technology and Logistics) commissioned a Defense Science Board (DSB) task force to investigate technologies to Improve the fuel efficiency of weapons platforms. The task force Terms of Reference are at Appendix A.

Section II provides an overview of DoD fuel use and suggests a national, global and historical context for considering the importance of improving platform efficiency. The US consumes more oil than the next five highest consuming nations in the world combined. DoD is the single largest fuel user in the US, and probably the world. However, it is unlikely that the DoD would ultimately be unable to obtain from the world market the fuel needed to conduct operations. The biggest impact to DoD resulting from any supply fluctuations is likely to be financial. In trying to identify which specific investments yielded the greatest reduction in DoD fuel demand, the task force discovered that sources for fuel consumption data are dispersed throughout the Services and Defense Agencies. This made it difficult to collect data for meaningful analysis.

Section III examines how improving platform fuel efficiency contributes to DoD's core capabilities, as described in Joint Vision 2010 / 2020 and the Army Transformation. These documents underscore the need for agility and address the importance of balance between "tooth" and "tail". Since fuel constitutes a huge portion of DoD's logistics burden, this section explores how improving fuel efficiency affects deployability and sustainability of forces. The task force found numerous institutional barriers in linking improved efficiency to improved capability. These include DoD's use of highly subsidized fuel prices to conduct cost benefit calculations, and lack of rigorous analytical tools for modeling the warfighting capability of more fuel efficient forces. Improving fuel efficiency also addresses important emerging environmental issues, such as global climate change.

Section IV describes many of the technologies in DoD's research portfolio that could improve platform efficiency. They are available at all phases of maturity, from ready to retrofit into legacy platforms today to revolutionary technologies that offer greater capability with less logistics and support in future systems; and they apply to all categories of platforms: land, sea and air. Section IV also examines the processes used to make investment decisions to deploy technologies that improve fuel efficiency. Briefings from the Joint Staff, OSD, the Service staffs, program offices and Defense Agencies provided insights into how these decisions are made and their underlying analytical methodologies. Specific examples of technologies and retrofit opportunities are presented for each Service. These include re-engining the Air Force B-52H, installing auxiliary power units on Army tanks, and adding "stern flaps" or "bulbous bows" to the hulls of Naval vessels. Where possible, the task force compared the decision factors presented by the Services and program offices with a more comprehensive approach developed by the task force. This area of investigation revealed underlying structural reasons why the benefits of making weapons platforms more efficient are not recognized. For example, the analyses that quantify the operational and cost benefits of specific technologies applied to specific platforms were often not reflected in the analyses conducted by program offices to support investment decisions. As a result, the benefits are absent or undervalued at key decision points. This section also explores how revolutionary research activities have the potential to transform the nature of DoD's warfighting capabilities beyond the ten-year horizon specified in the terms of reference.

Section V presents the task force primary findings and recommendations. If the true warfighting benefits of more efficient platforms were quantified and factored into key decision points, DoD would move more directly to a force structure with the capabilities described in its joint vision documents. The institutional impediments to becoming more efficient are pervasive. They exist at every level of every function that determines requirements; funds research; acquires and retrofits systems; manages the PPBS process and conducts wargames. DoD must adopt a more rigorous analytical approach to quantifying the total capability, force structure and financial implications of improving the efficiency of platforms and systems. This requires a change in the way that systems requirements are established, adopting a more realistic view of fuel cost, and a decision by DoD's leadership to make fuel efficiency a priority in developing weapons platforms for the future.

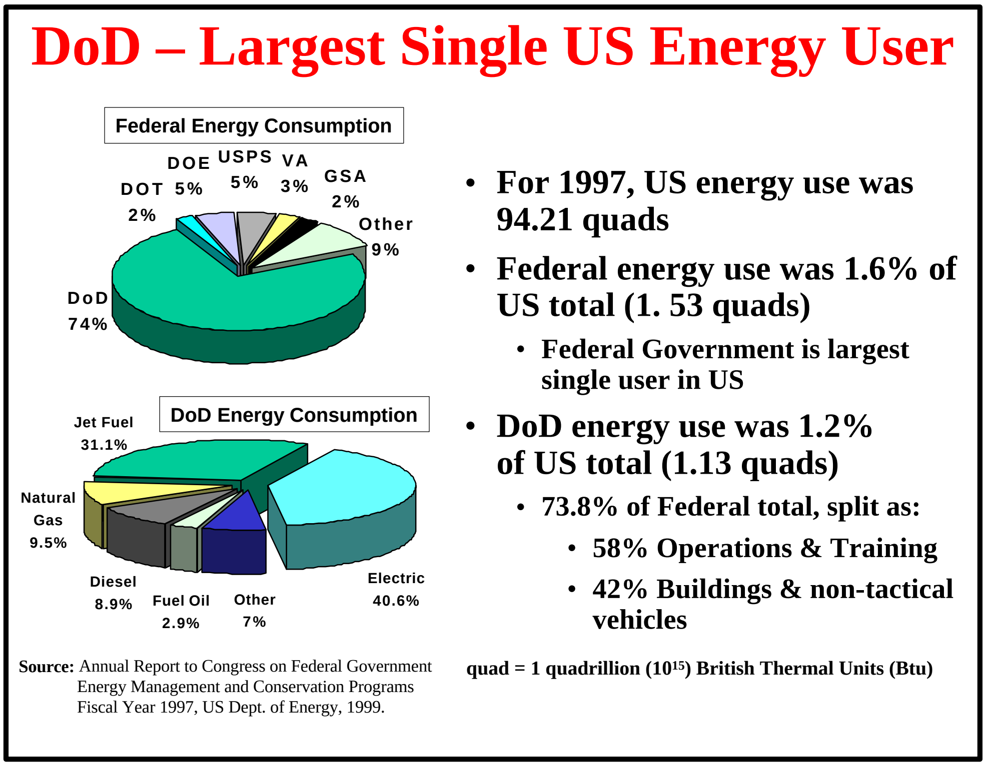
II. National Security Fuel Use and Global Supply

The Task Force made a concerted effort to understand both the energy consumption patterns for DoD elements within the context of U.S. and global patterns, and to recognize the potential future effect on national security issues that would be influenced by worldwide petroleum supply and demand trends.

II a. DoD Fuel Consumption Patterns

The scale and breadth of DoD operations are extremely complex and far-flung, as illustrated by the global military infrastructure DoD manages:

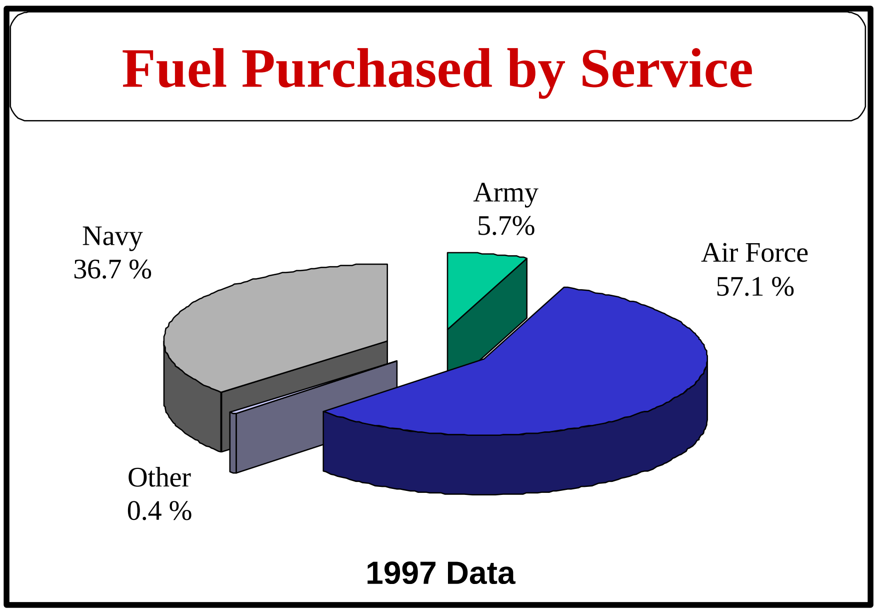
- 3 million military personnel and civilians
- 36 million acres of land
- More than 250 major installations; 40,000 additional properties; and 550 public utility systems
- More than 150,000 ground vehicles; 22,000 aircraft; and hundreds of ocean-going vessels



It is important to examine DoD fuel consumption patterns against this backdrop in order to evaluate weapons platform fuel efficiency opportunities.

Data for 1999, the most recently published, indicate that the U.S. government consumes approximately 1 percent of the nation's energy, with DoD consuming 80 percent of that total, as indicated in the chart above. Of DoD's total energy use, operations and training consume approximately 58 percent and facilities and non-tactical vehicles consumed 42 percent. Primarily because of downsizing and modernization, between 1990 and 1999, DoD reduced its total energy purchases from all sources by 36 percent.

The DoD purchases and consumes approximately 5 billion gallons of fuel per year. DoD must also comply with a variety of Executive Orders and legislation requiring improvements in energy efficiency. However, these efforts have focused exclusively on facilities and non-tactical, non-deploying support vehicles. The goals of these mandates have been to reduce facility energy consumption per square foot of building space and to promote the purchase of alternative fuel vehicles. As a result, energy consumption data for facilities and fleet vehicles is readily available. However, data on fuel consumption by weapons and support platforms are not readily available. Total consumption figures are available from DESC, but meaningful analysis is not possible using data at that level of aggregation.



As shown in the chart above, the Air Force is the largest purchaser of fuel, followed by the Navy; the Army is a much smaller fuel purchaser. The figure chart represents the fuel purchased by each Service from the Defense Energy Support Center. However, the data do not accurately represent the amount of fuel each Service actually consumed, or the demand they created. For example, the Air Force often provides in flight refueling to the Navy; and during deployments, the Air Force and Navy transport Army troops and equipment. Therefore, a significant change in Army platform fuel usage would directly drive a change in Air Force and Navy fuel consumption. As a result, the Army portion of fuel purchased understates the amount of demand it drives. This made it difficult for the task force to determine which platform efficiency measures would have the largest impact on battlefield fuel demand during wartime or expenditure for fuel during peacetime.

Over half of DoD's delivered energy consumption is jet fuel, with other forms of energy such as diesel, electricity and others collectively making up the remainder of the total. (These figures were provided by the DESC, which purchases fuels from the world market and sells them to the Services.) Since the single battlefield fuel is JP-8 (JP-5 is used by Navy carrier-based aircraft), some of the jet fuel shown is used to power tanks and other tactical vehicles, as well as support equipment deployed with combat units, such as power generators and field kitchens.

The task force contacted the Services to obtain consumption data, by platform, and during peacetime as well as recent operational situations, such as the Gulf War and Kosovo. The results were mixed. Some Services were able to provide good data, and others were not. Some Services maintain centralized records that are relatively easy to access, and others reported that their records resided at lower levels of command, closer to where the fuel was consumed. As a result, it was impossible to compile comprehensive fuel consumption patterns and discern how those patterns changed from peacetime to wartime situations. In the absence of complete data, it is not possible to determine the relative battlefield fuel burden represented by a single platform or system.

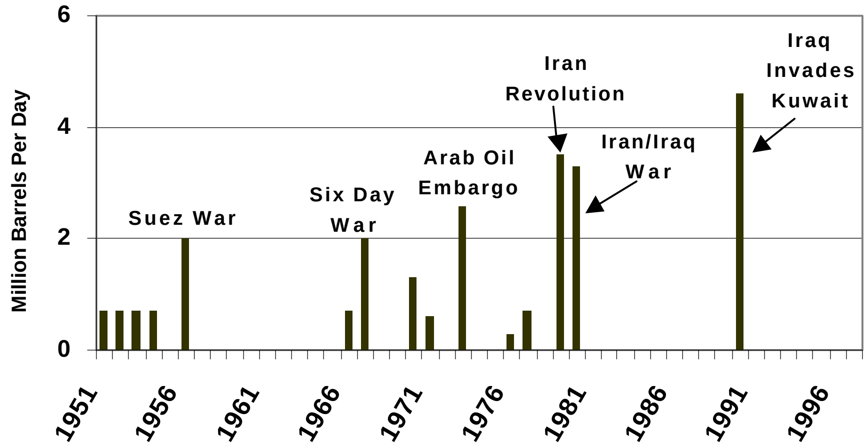
Despite the relatively large quantities of fuel consumed by the DoD, it is small compared to national or global consumption. Because of this, and as a result of the high priority of military operations, it is unlikely the DoD will experience any availability problems in the foreseeable future. However, global supply and consumption patterns will certainly have an impact on the price DoD must pay for that fuel. While this is of little consequence during a major theater war, it could have significant fiscal implications during peacetime and cause budgetary issues during small-scale contingencies because DoD cannot predict or budget for these costs. DoD 's options in these cases are simply to absorb the cost or request supplemental appropriations.

II b. Global Trends and Future Fuel Prices

Future oil prices cannot be predicted with any degree of certainty, but many experts predict continuing price escalation and volatility over the coming decades is likely. It has occurred throughout the past century, and there are no recent signs of stabilization.

Relatively small disruptions in supply can cause significant price fluctuations and economic escalation beyond the initial price spikes. Following the Arab oil embargo of 1973, the United States' gross national product declined, and unemployment doubled. The bars in the chart below indicate specific events that disrupted global oil supply. The length of each bar represents the number of barrels taken out of the world oil market daily as the result of each event. To put these numbers in perspective, the global economy uses approximately 75 million barrels of oil per day. Despite the relatively small amount of oil removed from the world market relative to total consumption and availability, there were economic repercussions for the U.S., particularly in the early to mid 70s and early 80s, when substantial oil price hikes drove deep recessions in the U.S. and world economies.

National Security Events Related to Major Disruptions in Fuel Supply

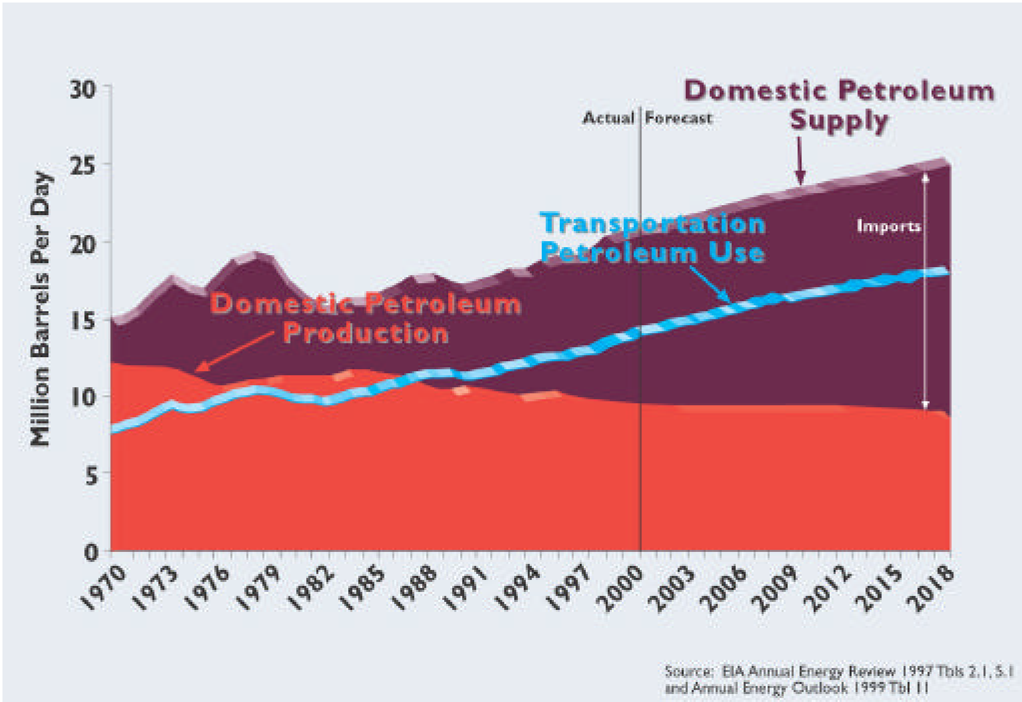


Source: http://www.eia.doe.gov/emeu/25opec/All_25th_Anniversary.xls
Barrels of oil per day removed from world markets as a result of conflicts.

While the Organization of Petroleum Exporting Countries (OPEC) controls a smaller portion of the global market than it once did (43 percent today compared to a high of 55 in the past), the US continues to grow more dependent on foreign sources, importing 55 percent of its domestic oil needs in 1999. Projections are that the US will grow increasingly dependent on foreign oil sources, despite the implementation of energy efficient technologies and the development of non-fossil fuel energy sources.

Other factors also indicate that over the long term, oil prices may increase beyond the rate of inflation. According to the Department of Energy's Energy Information Administration, it is likely that by 2010 the world will consume 90 million barrels per day, a 20% increase over today. The International Energy Agency (IEA) projects an even greater growth in demand due to population growth, urbanization, and industrialization, particularly in developing countries. The world's population is expected to increase from the current 6 billion by as much as a third in the next 20-30 years, with more than half of those additional people born in Asia and Latin America.

**Domestic Production with Transportation Use
(1970-2020)**



The coming peak of world oil production is also a concern. Until 1998, the IEA never projected a peak in world oil production. But in March 2000, for the G8 Energy Ministers' meeting, the IEA stated that a peak in world oil production is likely to occur between the years 2010 and 2020. A more detailed study supports this forecast by projecting the peak of oil production in 42 countries (Duncan & Youngquist, 1998). If these forecasts prove to be accurate, the world oil production peak will occur during the lives of most people now living and, more importantly to DoD, during the time that many legacy weapons platforms plus those currently in development will the basis for our national defense.

The issue is not whether DoD will be able to obtain the oil it needs to provide for our national defense, because it will. However, trends in global supply and consumption patterns, as recently experienced and depicted in the chart below, complicate the logistics challenge of providing fuel to DoD’s far-flung operations as well as affecting the price DoD must pay for fuel.

US Dependence on Foreign Oil

Have Oil		Use Oil	
Saudi Arabia	26%	US	25%
Iraq	10%	Japan	8%
Kuwait	10%	China	5%
Iran	9%	Russia	4%
Venezuela	6%	Germany	4%
Russia	5%	S. Korea	3%
Mexico	5%	Italy	3%
US	3%	France	3%
		England	3%

The US uses more than the next 5 highest consuming nations combined.

(Source: "Petroleum Primer" by Randy Udall, Director Community Office for Resource Efficiency, Aspen, CO, 2000)

II c. Impacts to DoD of Fuel Price Fluctuations

Most DoD fuel is purchased centrally through the DESC, a sub-command of the Defense Logistics Agency (DLA). The DESC buys fuel in bulk and charges its customers--mainly the Services--a stabilized rate for that fuel. The rates are set at the time of the budget, over one year in advance of when the Services purchase the fuel for consumption.

Impacts of Recent Oil Price Volatility

- Crude oil rose from $10 to $37 per barrel from Jan 99 to Sep 00
- Average U.S. gasoline price rose from $0.97 per gallon to $1.58
- Other Fuel Price Increases between Jan 99 and Sep 00
  - Jet Fuel: 179%
  - #2 Diesel: 156%
  - Home Heating Oil: 135%
  - Residential Propane: 37%
  - Residential Natural Gas: 69%
- Solomon Smith Barney estimated that these price increases will reduce economic growth by 1.5 percentage points and add a percentage point to the rate of inflation

The market price for fuel can fluctuate greatly between the time rates are set and the fuel is actually used. The Services buy fuel from DESC with operation and maintenance (O&M) funds. When the actual cost of fuel is less than the stabilized rate, the DESC receives more money than the fuel actually costs, and future rates are adjusted to reflect the change. This rate structure simplifies accounting by allowing for minor fluctuations in actual pricing.

The problem arises when the cost of fuel greatly exceeds the stabilized rate. The rates are adjusted to reflect the change, and the Services have insufficient O&M funds to fuel their vehicles and perform other functions that are paid from that budget. The Department must delay other efforts, normally maintenance and training activities, in order to pay utility bills, including those necessary to fuel its weapon systems. These delayed functions are lost opportunities.

Congress provides supplemental funds when the cost of fuel far outstrips the stabilized rates that the Services use in their budget estimates. For example, the FY 2000 Emergency Supplemental Act, among other things, appropriated $1.556 billion to cover the increased costs of fuel in FY 2000 and FY 2001. These supplemental funds reached the Department in the last quarter of the fiscal year. As a result, training scheduled in the first three quarters of the fiscal year was cancelled due to constrained O&M funds. This lost training cannot be made up with funds provided in the fourth quarter. While delayed maintenance can still be performed, it is more costly.

More realistic fuel cost projections, identifying the real cost of fuel to the operating forces (including the costs of air-to-air and at-sea refueling) and using that information to buy the optimum level of fuel efficiency can all help DoD maintain its training, weapons and facilities maintenance. This improves overall readiness.

III. Linking Fuel Efficiency to Military Capability, National Security and Environmental Security

This section addresses the contribution of fuel efficiency to DoD's core capabilities as described in Joint Vision 2010 / 2020, and the Army Transformation. These documents describe the nature of future threats and the capabilities US forces must posses to counter them. The post-Cold War threats are characterized by diversity and asymmetry. To counter them, US forces must become more agile and autonomous. Efficiency, or the achievement of maximum lethality for minimum logistics, is a strong indicator of agility. Better fuel efficiency improves warfighting capability, reduces deployment times and increases sustainability. However, the analytical tools available for quantifying the contribution of fuel efficiency to these outcomes are weak.

Improved warfighting capability can be directly linked to improved adherence to the following Principles of War.

- Surprise: Fuel efficiency increases platform stealth by diminishing the platform's heat signatures, exhaust, and/or wakes; and affords less chance of compromising movement by reducing the logistics tail and resupply communications.
- Mass: Fuel efficiency decreases the time required to assemble an overwhelming force.
- Efficiency: Fuel efficiency increases commander's flexibility in efficiently assembling an overwhelming force.
- Maneuver: Platforms will travel faster and farther with reduced weight and smaller logistics tails that improve platform agility, loiter and flexibility.
- Security: Fuel efficiency decreases platform vulnerability to attacks on supply lines, and reduces demand for strategic reserves.
- Simplicity: Fuel efficiency decreases the complexity and frequency of refueling operations and logistics planning, while reducing vulnerability to the "Fog of War".

The link to national security also includes the stimulus that a stronger DoD focus on fuel efficiency would exert on the commercial market through spin-off technologies and products, affecting both domestic and foreign markets. Efficiency makes U.S. companies more competitive in an increasing number of foreign markets where efficiency is more highly valued. Markets in an increasing number of allied nations place a higher value on efficiency than the US. These include Western and Central Europe, where positions on global climate change and the Kyoto Protocol differ sharply with those of the U.S. This foreign emphasis on greater efficiency also has the potential to decrease foreign military sales (FMS), an important component of modernization because increased production rates lower system unit cost.

An additional national security consideration is the degree to which an increasingly efficient US industrial base will offset future increases in US dependence on foreign oil. The undervaluation of fuel efficiency described throughout this report is a major reason that DoD underinvests in the development and deployment of technologies that increase the efficient use of fuel. One underlying barrier to accelerating the rate of efficiency improvements, both in the DoD and the economy in general, is the difficulty in quantifying the true benefit. The DoD-established standard price of fuel that simplifies accounting for the Services is also used as the basis for cost benefit analyses supporting investment decisions. This standard price substantially undervalues the benefits of increased efficiency, making investments in efficiency artificially non-competitive in the PPBS process.

Finally, the environmental impact of war is coming under increasing scrutiny. Following the Kosovo operation, a number of organizations conducted official and private investigations of the environmental fallout of the air campaign. Such debates serve to highlight environmental performance of military operations. An increasingly important global environmental issue that affects the military is global climate change. The United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol call upon its Parties to “anticipate, prevent, or minimize” damage from climate change before it happens, and this issue will have increasingly significant impacts over the long-term. The UNFCCC seeks to reduce the emission of greenhouse gases to the atmosphere, principally carbon dioxide. The consumption of fossil fuels is the largest source of human-induced carbon dioxide emissions to the atmosphere.

The DoD should continually monitor this debate, and compare the timeframe of its weapons systems development, deployment and retirement cycle to the pace and direction in which the climate change issue is evolving.

III a. Dramatic Improvements In Fuel Efficiency of Platforms and Systems Are Critical Enablers To Achieving the Objectives of Joint Vision 2010 and 2020

Joint Vision 2010 and 2020 explicitly recognize that improving platform and system level fuel efficiency improves agility, while concurrently reducing deployment times and support / logistics requirements. The excerpts in the chart below are examples from over a dozen specific statements that stress the importance of improving the efficiency of weapons platforms and systems to meet the new and diverse threats to our national security. These observations contained in Joint Vision 2010 and 2020 are completely consistent with the findings of the task force. Further, each of the approximately 100 technologies the task force reviewed that improved the fuel efficiency of platforms also improved military capability.

Dramatic improvements in fuel efficiency are critical to Joint Vision 2010/2020

- Joint Vision 2010 – on force structure balance

  "We must maintain a careful balance between equipping and sustaining our forces and between tooth and tail in our force structure…we will need to wring every ounce of capability from every available source…we should not expect a return to the larger active forces of the Cold War period."

- Joint Vision 2020 – on the need for less logistics

  "…reduce sustainment requirements and the vulnerability of logistics lines of communication, while appropriately sizing and potentially reducing the logistics footprint."

- Army Transformation
  - Responsive, Deployable, Agile, Versatile, Lethal, Survivable, Sustainable

Other passages within Joint Vision 2010 and 2020 describe future visions of military capability that require platforms that are more quickly deployable and more self-sufficient. Joint Vision 2010 and 2020 also note that the future force must be achieved mostly with the legacy systems still in the inventory. As a result, this task force concluded that the "rules" by which retrofits are justified on the basis of economics and capability must be changed to capture all of the benefits of improving efficiency, to include force structure changes enabled by making platforms and systems more efficient.

This task force studied how unconstrained fuel requirements present a burden to military forces and impair capability. The task force concluded "dramatic improvements in fuel efficiency of platforms and systems are critical enablers of Joint Vision 2010 / 2020 objectives."

The Army Transformation seeks dramatic improvements in agility, with an objective force capable of placing:

- a combat-capable brigade anywhere in the world in 96 hours
- a division on the ground in 120 hours
- five divisions on the ground in theater in 30 days

Fuel efficiency as both a limiter and enabler to this transformation is shown in figure below. Today, the Army's Science and Technology community is working hard to:

- Reduce combat vehicle weight while increasing lethality (a deployment issue),
- Increase deployability without sacrificing survivability (a weight issue), and
- Reduce in-theater logistics (a fuel issue).

Battlefield Fuel Logistics Burden

- **Fuel comprises 70% of Army tonnage shipped**
  - Armored division consumes approx. 600,000 gal/day
  - Air assault division requires approx. 300,000 gal/day
- **Future battlefield scenarios will likely impose severe fuel availability constraints**
  - Global geopolitical environment
  - Short lead time for deployment preparation
  - Fuel requirements pose a major obstacle to exercising deployment options
- **During Desert Shield, *if* the Abrams tanks had been 50% more fuel efficient**, and ***if*** we had chosen to take correspondingly less fuel and infrastructure, the **build up would have taken 20% less time time.** (Five months, rather than six).

The Army's challenge is to prepare the research and development plans by 2003 that will enable an Objective Force described above. These questions and issues should address fuel efficiency by explicitly:

- including efficiency in the requirements determination process,
- testing the operational value of efficiency in wargaming, and
- scoring efficiency in the acquisition process.

In its presentations to the task force, the Army recognized the constraint high battlefield fuel demand places on rapid deployment and sustainability, and expressed a very real concern over the consequences of high fuel demand on battlefield maneuverability. A number of briefers highlighted instances where battlefield maneuverability during Desert Storm was hampered by the need for large and frequent fuel deliveries to main battle tanks and armored personnel carriers.

The Army recognizes that fuel constitutes a significant portion of the logistics required to flow into the battle area. Reducing the battlefield-day fuel demand improves both force deployment and sustainment. The Army Research Laboratory (ARL) indicated that the Army goals for reduced battlefield fuel demand were linked to specific reductions in logistics tail by using a model known as the Force Analysis Simulation of Theater Administrative and Logistics Support (FASTALS), a part of the Total Army Analysis. This analytical tool was modified to allow estimation of the logistics assets and the time to move fuel. The ARL estimated that if the Abrams tank were 50% more fuel efficient, the Desert Storm buildup would have taken 20% less time. FASTALS could calculate the reduced battlefield fuel demand as well as quantify the logistics assets that would have been unnecessary to support Desert Storm as a result of the reduced need to provision fuel. The auxiliary power unit under consideration by the Army as a retrofit for the tank would reduce the Abram's battlefield fuel demand by as much as 50%. However, it is unclear how the reduced deployment time, the extended range or improved sustainability would have affected the outcome of the battle. While this is the real question that needs to be answered in order to determine the real benefit of more efficient platforms, the analytical tools necessary to predict the impact on warfighting capability do not appear to be well developed.

It appears that the statements in Joint Vision 2010 and 2020 and the Army Transformation have not yet translated into tangible changes in decision-making processes. This situation is not unique to the Army. For example, the requirements determination process for new systems (i.e., the JROC and Service inputs) does not explicitly include fuel efficiency, and decision rules that guide retrofit trade-offs do not place increased value on efficiency. However, it is important to point out that systems requirements do include elements that could be construed as weak proxies for efficiency. For example, a typical Mission Needs Statement (MNS) includes requirements for range and payload, which imply some level of fuel efficiency. In addition, MNS include a limit on the amount of logistics a platform can demand. For example, the Joint Strike Fighter (JSF) Joint Operational Requirements Document (JORD) specifies the number of C-17 equivalents of logistics support it can require. This is a high level aggregation of logistics support. However, in 1997, the threshold value for C-17 equivalents was 4 or less. Today, the threshold value is 8 or less -- a doubling of the acceptable logistics burden. Further, this logistics specification does not include fuel.

The task force was unable to identify any case where the logistics reductions or deployment and sustainment enhancements achievable from improvements in platform efficiency were quantitatively included as capability improvements and factored into trade-off decisions. While Joint Vision 2010 and 2020 and the Army Transformation statements clearly recognize the critical warfighting contribution of improved platform and system level efficiency, the requirements determination and acquisition decision processes do not quantitatively include it.

III b. The True Cost to Provision Fuel is Much Higher Than the DoD Standard Price

III b.1 Use of DoD Standard Pricing

Program offices that briefed the task force reported that they use the standard DoD fuel price in cost and benefit analyses conducted to support decisions on whether or not to invest in upgrades to platforms that improved their fuel efficiency. The task force determined, however, that the fuel delivered by the

Services often costs significantly more than the standard price. However, the true costs include hidden externalities absorbed by the Services. This is a major barrier to achieving the warfighting and budgetary benefits of more fuel efficient platforms.

The DESC is the organization within DLA responsible for procuring and delivering fuel. The task force was briefed twice by DESC and was very impressed by the efficiency and effectiveness with which DESC carries out its mission. Nevertheless, a clear conclusion emerged that the DESC standard fuel price, while an effective way to centrally manage bulk fuel purchases, has serious unintended consequences for DoD's ability to estimate realistically the economic benefits of increased fuel efficiency.

DESC delivery points are storage locations owned either by DESC or the Services, and are typically located on or near DoD installations. DESC also maintains some large tank farms from which it dispenses fuel. The price the Services pay for fuel is fixed annually by OSD and DESC. This price is supposed to cover both the acquisition cost of the fuel and DESC's operating costs. This is a convenient accounting practice that simplifies the Services' budgeting processes. For example, it allows all military units to budget easily for fuel, because each unit pays the same for fuel throughout the fiscal year, regardless of where it is located or under what circumstances the fuel must be delivered.

The True Cost to Provision Fuel is Much Higher Than The DoD Standard Price

- Standard price is paid by Services to cover Defense Energy Support Center (DESC) costs
  - $0.87 / Gallon in FY 99
  - $0.62 / Gallon in FY 00
  - $1.01 / Gallon in FY 01
  - 1.337 / Gallon in FY 02
- Simplifies accounting and standardizes cost-benefit analyses
- However, true cost includes shipping from DESC delivered point to end use weapons platform
  - True cost of fuel is unknown by requirements generators and is not used by decision makers
  - Using artificially low price undervalues efficiency investments
  - Using true cost in decision making reveals opportunities to reduce operating costs and improve warfighting capability

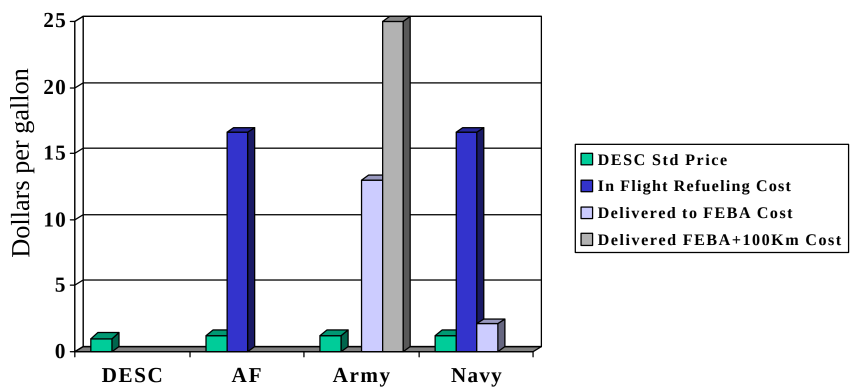
Any fluctuation in world oil price DESC must pay is absorbed by a revolving fund. This fund has a positive balance when the price DESC pays drops below the standard price, and a negative balance when prices rise. In FY99, the average standard fuel mix price (average of the fuels DESC sells) was $0.87 per gallon. In FY00 it was $0.62 per gallon, and in FY01 it is $1.01 per gallon. In FY02, it will be $1.337 per gallon.

However, this standard price represents only a fraction of the true cost of delivered fuel. From the point of DESC delivery to the point of use, the Services incur significant additional cost. These include the people, training, physical logistics assets, their delivery operating costs, such as tankers, oilers, trucks, tanker aircraft, and other hardware and infrastructure necessary to deliver fuel where and when it is needed.

The additional cost of owning and operating the logistics assets needed to move fuel from the DESC supply point to end use platforms is neither quantified nor factored into decision making processes. Further, these costs do not appear as budget or appropriation line items and are therefore invisible. The consequence of using artificially low fuel prices is that investments in fuel efficiency appear too expensive, when in fact they are cost-effective. As a result, these cost effective investments are not competitive in cost benefit analyses and program trade-off studies used to prioritize system acquisition decisions.

True Cost of Fuel Delivered to the Battlefield

Cost of delivered fuel is much higher than the DESC standard price.



Notes:
FEBA = Forward Edge of Battle Area
DESC Standard Price is price paid by Service to DESC - fixed annually, worldwide price
Cost of delivering fuel to Army battlefield varies from 10's to 100's $/gallon, depending on scenario
Real Numbers: DESC standard price, AF in-flight refueling, Army FEBA and FEBA + 100Km

III b.2 Examples of Potential Platform Fuel Costs Using Delivered Cost Instead of Standard Price

The Services assisted the task force by analyzing the true costs of delivered fuel for several situations, as shown in the figure below. These included:

- worldwide in-flight refueling by USAF tankers
- fuel to Army ground forces in battle areas, and
- fuel to Navy ships underway.

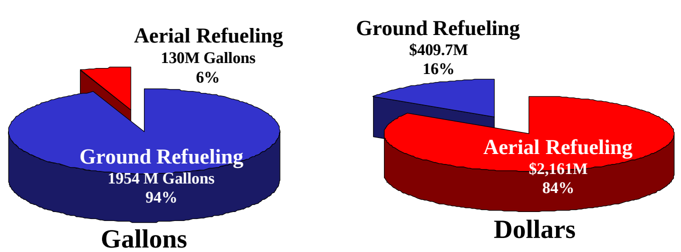
Since the cost of carrier-based in-flight refueling of naval aircraft was not available, and because Air Force aircraft also provide in-flight refueling, the cost is assumed to be the same as from Air Force aircraft in the figure below.

The largest element of the total fuel cost in DoD is the cost of delivery. The Services pay dearly to deliver fuel to where it is needed. In-flight refueling is the most expensive way to deliver fuel. However, delivering fuel to the Forward Edge of the Battle Area (FEBA) is also costly, and the further beyond the FEBA fuel is moved, the more costly it becomes.

To illustrate the difference between the visible standard price of fuel and the true cost of fuel, the task force asked the Air Force to calculate the total embedded cost of delivering fuel in-flight, shown in the chart below. The total cost of the tanker fleet (including crew, training, maintenance, infrastructure, and other logistics costs) was added to the cost to purchase the fuel and deliver it to the tanker aircraft on the ground. This calculation did not include tanker acquisition costs.

True Cost of Fuel
Delivered to USAF Aircraft

JP-8 PURCHASED 2,085,000,000 Gallons DESC PRICE - $1.8 B	+	JP-8 DELIVERY COST $2.57 B	=	TRUE COST $4.37B

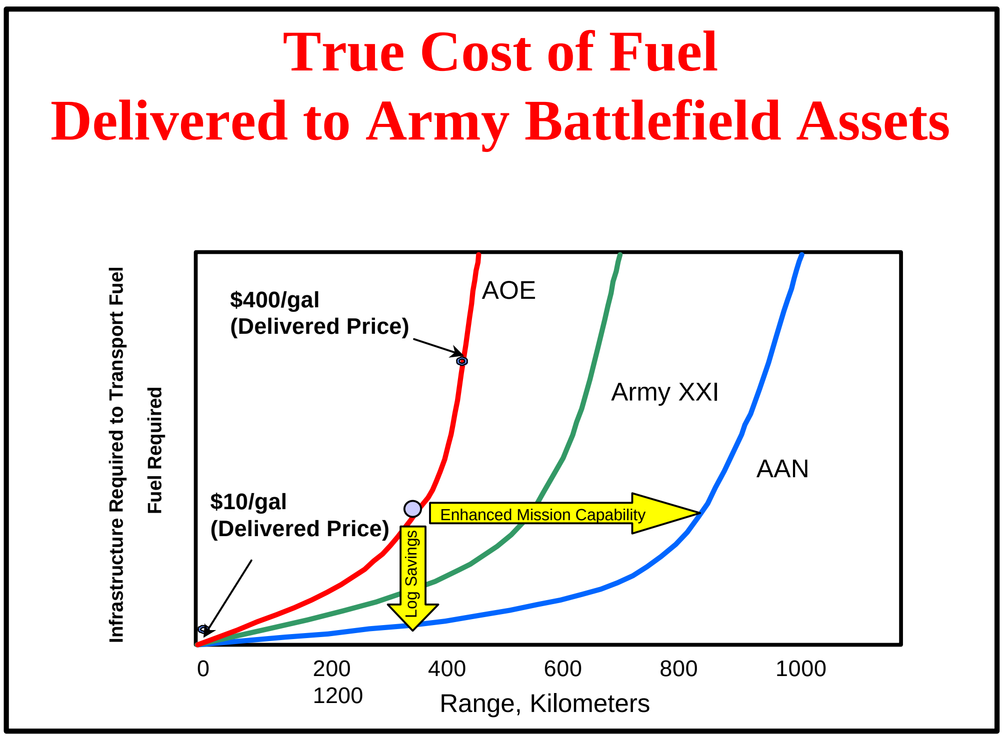


The Air Force spends 84% of its fuel delivery budget to deliver 6% of its fuel.

Air Force analysis of cost fuel delivered in-flight revealed approximately $16.60 per gallon
Includes total ownership costs of tanker fleet - crews, training, maintenance, etc…
Does not include initial procurement cost of tankers

The analysis revealed that it cost the Air Force over $2.5 billion to deliver 130 million gallons of fuel in FY99. The Air Force spent 84 percent of its fuel delivery budget to deliver 6 percent of its fuel in FY99. In terms of cost per gallon, this translates into a total embedded cost of a single gallon of fuel delivered by a tanker of about $17.50. By contrast, it costs about 20 cents per gallon to deliver fuel from the DESC supply point to an aircraft at a military installation. Including the true cost of delivering fuel in cost-benefit analyses, rather than the DESC standard price, would significantly change the life cycle cost impact of in-flight refueling requirements.

Although the tanker procurement costs were not included in this analysis, they should be included in cases where the choice involves buying new tanker assets versus re-engining receiver aircraft to gain greater fuel efficiency and thus reduce tanker requirements. In this case, improving the efficiency of receivers is the equivalent of acquiring additional tanker capacity, without incurring the operations and support costs associated with maintaining an expanded tanker fleet. This issue is discussed further in the analysis of re-engining the B-52 in Section IV. In short, re-engining not only achieves important operational advantages, but also eliminates the need for new tankers.



The ARL conducted a similar analysis, as shown in the chart above, as part of its work in support of Army Transformation. Like the Air Force, the true cost of delivered fuel to combat systems on the battlefield is dominated by handling and distribution. As a result, the cost is very scenario dependent. To gain some insight into the true cost of delivered fuel, the task force considered two scenarios: the first was based on using CH47D helicopter fuel delivery to armored forces beyond the FEBA and the second was using HEMTT (Heavy Expanded Mobility Tactical Truck) for delivery in similar conditions.

In the first scenario, a mobile force had penetrated or been inserted far beyond the FEBA, requiring aerial re-supply because of either isolation or extreme terrain conditions. The re-supply distance was 600 km. Assuming the range of the fully loaded delivery platform without refueling was 200 km (a generous estimate for a CH-47), three staging legs were needed to reach the mobile force 600 km out. At each staging area, a full fuel payload was required for each aircraft to continue through to the next staging area, and a partial payload for the support aircraft to return to the base light. Hence for this 3-stage re-supply mission, 8 logistical supply aircraft are required for each one that arrived at the force 600 km out and returned to base.

The cost per delivered gallon depended on the full operating cost of the re-supply platforms. The ATL calculated it costs about $7,500/hr to operate the CH-47D. On average, this 3-staged re-supply scenario demands about 10 flight-hours per aircraft (take-off, fly 200 km, land, refuel, take-off, fly 200 km, land). For a 1,500-gallon payload per aircraft (three 500-gallon fuel bladders), the delivered cost was $400/gallon. While the above scenario may seem extreme, battlefield necessity often drives exactly these kinds of extreme situations.

Under more normal conditions, the force could be re-supplied overland. The cost calculation would be based on the same approach and algorithm. If a HEMTT tanker fleet (5,000-gallon payload/vehicle) were employed over secondary roads and limited cross-country, each stage would be about 300 km and take about one day. To sustain this rate of supply over many days would require that the staging pipeline remain filled each way, so actually the 2-stage scenario would require committing 4.4 times the number of vehicles to the re-supply pipeline for each delivery per day. With HEMTT tanker acquisition cost at about $0.5M, the 20-year life cycle support cost assumed to be about the same, and the life consuming usage rate to be about 1,000 km/yr, the real total cost of operation is about $50/km. This works out to be about $66,000/delivered load, or about $10/gallon delivered overland at 600 km. At 1,000 miles (the likely real route distance to reach a force 600 km out), the cost of fuel delivered calculates to be about $30/gallon.

The above two analyses do not include the scenario-dependent cost of bringing fuel into theater, storage and handling at the in-theater depot level, and overall fuel handling infrastructure overhead. Delivery to port by large ocean going tanker (up to 1 million tons gross displacement) is quite cheap, well under $1 per gallon. Port-to-storage area handling could be anything from pennies/gallon if a pipeline infrastructure exists up to many dollars per gallon if one has to be built, or line haul/rail transport has to be hired and mobilized. The ARL calculated typical cost of $13 per gallon for those operations, which includes the direct and indirect costs, primarily personnel related to the Army's Petroleum, Oil and Lubricants (POL) infrastructure. A first order adjustment to the above scenario cost would be to add the $13 per gallon.

Taking all these factors into account, a reasonable estimate of the total cost of fuel when delivered to Army combat platforms over even modest distances is in the $10's/gallon range. Over large distances the total cost would range from at least $40-$50 per gallon for overland transport up to more than $400 per gallon for air delivery using platforms with today's capability.

True Cost of Delivered Fuel Naval Forces

- NAVSEA Analysis of Total Delivered Fuel Cost to Fleet
  - Not calculated annually since 1994
  - Added 30% to 90% to standard ship fuel price
  - Previously used to compare new construction ship design options (e.g. Nuclear vs Conventional Propulsion) but not used since CVX Analysis of Alternatives (AoA)
  - Never used to determine ROI/Payback Time for ship energy efficiency improvement initiatives (e.g. Stern Flaps)
- Generated Single Navy-wide Price
  - No local vs distant delivery comparison
  - No known counterpart study for Navy Aircraft fuel, but Navy aircraft are in-flight refueled by Air Force tankers
  - Cost to Air Force is about $17.50 per gallon

The Naval Sea Systems Command (NAVSEA) analysis of the total cost of fuel delivered to the fleet adds 30 to 90 per cent to the standard price of ship fuel by including the operating cost of fleet oilers and fuel depots, as indicated in the chart above. This analysis has not been done by NAVSEA since 1994. These fuel costs had been used to compare the operating costs of new construction ship design options, in particular, nuclear compared to conventional power. However, this delivered cost of fuel was not used in the CVS AOA. At the request of the task force, the Navy performed a study to provide updated delivered fuel cost. This study showed that in 1999 handling and delivery cost after receipt from DESC added 15 to 85 percent to the standard price of ship and fuel depending on the delivery scenario assumed. Scenarios studied were delivery to aircraft at an air station, delivery to ships in port, and delivery to ships at sea by oilers. No in-flight refueling cost was available, but Navy aircraft are in-flight refueled by Air Force tankers and therefore the cost is assumed to be the same as for the Air Force. While this delivered cost is much less than for the Air Force and Army scenarios, it would significantly increase the calculated benefits of fuel efficiency technologies in Navy weapons platforms.

III c. Improving DoD Energy Efficiency Addresses Important Environmental Security Issues

Maintaining our national security is DoD's paramount mission. That is why the task force has stressed in this report the evidence that improving the fuel efficiency of weapons platform has large and unrecognized potential to strengthen warfighting capability and free resources for other high priority military needs. There are, in addition, major environmental benefits from reducing DoD's fuel consumption and hence the environmental footprint of its worldwide operations. These, too, should be recognized in making decisions on investment in fuel efficiency technology.

An emerging issue that will take on increased importance over the coming years and decades is global climate change. In October 1992, the Congress of the United States ratified the United Nations Framework Convention on Global Climate Change (UNFCCC), which entered into force globally in March 1994 and calls for an international effort to reduce emissions of greenhouse gases. It requires the Parties, including the United States, to submit annual inventories of greenhouse gas emissions and to make non-binding commitments to reduce these emissions. The United States emits more greenhouse gases to the atmosphere than any other nation. With 4½ percent of world population, the U.S. emits approximately 25 percent of global man-made greenhouse gases and consumes approximately 25 percent of the world's energy.

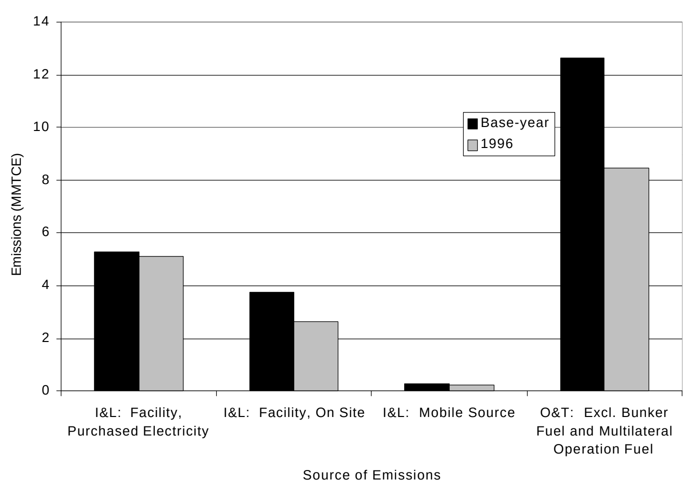
Nationally, greenhouse gas emissions have risen from 1,650 million metric tons of carbon in 1990, the base year under the UNFCCC, to 1,835 million metric tons of carbon in 1998, an increase of about 11 percent. Conversely, DoD's emissions have declined by about 20 percent since 1990. There are two primary reasons for this: 1990 was a high consumption year due to Desert Storm and DoD has subsequently downsized its force structure and consolidated a number of installations. Emissions of carbon dioxide produced by the burning of fossil fuels constitute over 80 percent of greenhouse gas emissions and are the largest single contributor to the risk of rapid climate change. Carbon dioxide released from the burning of fossil fuels represents 94 percent of Department of Defense greenhouse gas emissions.

This is important to DoD because proposals pending under the UNFCCC's Kyoto Protocol would make the measures binding, and provide incentives for reducing emissions below the required treaty levels. The United States signed the Kyoto Protocol in December 1997, but the Senate has not yet ratified it. DoD should continue to track and document its emissions and remain aware of the potential for accruing carbon credits by reducing those emissions.

Determining DoD’s greenhouse gas emissions is not an exact exercise because data are uncertain and must be collected from a wide range of sources. No single source collects or maintains a complete and accurate data set for all fuel types and end uses. The DESC provides some of the petroleum consumption data from the Defense Fuels Automated Management System (DFAMS), but each Service must provide much of the necessary data. Because specific provisions advocated by DoD were included in Decision 2 of the Third Conference of the Parties to the UNFCCC, emissions from fuels used in international transport (aviation and shipping bunker fuels) are not counted against national emissions inventories, but must be reported separately.

In this way Climate Treaty negotiators were able to achieve a compromise that did not subject bunker fuel emissions to proposed national emission reduction targets. This requires data beyond that maintained by DESC, and, in some cases, consumption estimates because DoD does not maintain comprehensive fuel consumption data necessary to determine emissions directly. For example, emissions from U.S. and non-U.S. bunker fuels were estimated for the Air Force and the Navy. The Army did not estimate any bunker fuel use. Bunker fuel emissions from embarked Marine Corps aircraft were included in the Navy bunker fuel estimates, and bunker fuels from other Marine Corps operations and training were assumed to be zero. Bunker fuel estimates from other DoD activities were assumed to be zero. A complete description of the methodology used to determine DoD’s emissions are contained in Appendix E. Because of the difficulty of obtaining accurate data, DoD should consider establishing a centralized energy and fuel data collection and analysis function.

DoD Greenhouse Gas Emissions From Energy Use



I&L is Installations and Logistics
O&T is Operations and Training

(MMTCE – Million Metric Tonnes Carbon Equivalent)

DoD emitted approximately 41 million metric tons of carbon in 1996, the most recent year for which DoD has calculated its greenhouse gas emissions. While this is a relatively small percentage of the 1,804 million tons of greenhouse gas emitted nationally in 1996, in some sectors the military makes a significant contribution. The chart below is from DoD's comments to the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998. It shows the DoD consumed about 21 percent of all aviation fuel used in the US in 1990, but because DoD use has declined and commercial aviation has grown, the DoD was only about 8 percent in 1998. While not as large as 1990, it is still significant.

Aviation Jet Fuel Consumption for International Transport (million gallons)									
Nationality	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
U.S. Carriers	1,982	1,970	2,069	2,078	2,155	2,256	2,329	2,482	2,363
Foreign Carriers	2,062	2,075	2,185	2,252	2,326	2,549	2,629	2,918	3,138
U.S. Military	862	855	700	677	608	581	540	496	502
Total	**4,096**	**4,900**	**4,954**	**5,007**	**5,089**	**5,386**	**5,498**	**5,896**	**6,003**

The DoD also makes a significant contribution to fuel used by the US in marine transport. In this sector, the DoD totals decline slightly, but commercial totals decline more sharply. The DoD makes about an 8 percent contribution in 1990, but that increases to 10 percent by 1998.

Marine Vessel Distillate and Residual Fuel Consumption for International Transport (million gallons)									
Fuel Type	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Residual Fuel Oil	5,137	5,354	4,474	3,566	3,503	3,495	3,583	3,842	3,973
Distillate Fuel &: Other	598	595	561	609	510	573	456	421	627
U.S. Military Navy Fuels	522	481	491	448	364	334	362	477	506
Total	**6,257**	**6,430**	**5,526**	**4,623**	**4,377**	**4,402**	**4,401**	**4,740**	**5,106**

It is noteworthy that the automobile manufacturing industry is looking more seriously than ever at changes in engine and platform technology that would yield significant fuel economy improvements. This has been motivated by public demand, the need to respond to the global warming threat and potential future governmental requirements. In areas where technology sponsored by DoD has set the pace, such as aircraft systems, development of advanced technologies could once again stimulate commercial spin-offs that would help make U.S. companies more competitive in foreign markets where efficiency is already highly valued. This is one way in which the U.S. military's leadership in technology can improve the environment while improving military capability and U.S. competitiveness.

This issue is becoming increasingly important. International scientific evidence adds credence to the rapid climate change concern each year. Further, the international will to take proactive steps to curb human emissions grows stronger. Generators of requirements for new weapons platforms should be mindful of the lifetimes of new systems relative to the evolutionary timescale of this environmental issue.

IV. Improving Platform Fuel Efficiency Through Technology

IV a. Introduction

The task force reviewed currently available and next generation technologies from each of the Services, and the decision-making processes that result in their implementation in platforms and systems. This section describes selected technologies that are mature enough to be suitable for retrofit on legacy platforms, and are appropriate to include in systems under development. It also addresses how program offices evaluate the applicability of the technologies for deployment into platforms and systems. The technology discussions address fuel efficiency improvements and other benefits, where available or calculable by the cognizant laboratory. The laboratory briefings revealed limitations in the evaluation of benefits of improved efficiency, and program office briefings revealed that logistics impacts of platform efficiency improvements did not typically factor into decision processes that result in technology deployment.

The task force received technology briefings from all the Services' research and development organizations, DARPA, the Department of Energy, the National Renewable Energy Laboratory, as well as industry and university researchers. The briefings described current and future major research and development programs that make more efficient use of fuel. The presentations revealed technologies that:

- are currently available to improve fuel efficiency of fielded systems through retrofit

- are in the Science and Technology program and can improve the efficiency of new systems in the acquisition process

- increase operational capability and reduce logistics / support requirements as well as improve efficiency

To understand how technology costs and benefits are factored into decisions that result in technology deployment, the task force followed the decision trail from the laboratory forward to decision points within program offices. However, the task force recognized that the acquisition process and program offices only respond to requirements, so the task force also received briefings from the Joint Staff, Service staffs, Defense Agencies and others responsible for establishing requirements, managing acquisition programs, managing and participating in the Planning, Programming and Budgeting System (PPBS) process, and managing the logistics system that provisions fuel. The task force asked these organizations to describe their roles, responsibilities and decision-making processes.

The task force selected examples from each Service to illustrate how benefits are determined and evaluated, pointing out how current decision processes operate and how more effective analytical approaches to determine benefits can produce different results and options for decision-makers. Strong similarities exist across the Services in their approach to valuing the financial benefits of efficiency, but differences are evident in their approach to determining operational capability.

Laboratories and program offices generally based their capability improvement assessments on individual platforms, rather than on overall impacts of complete fighting units such as brigades, wings or battle groups. For example, while laboratories were able to describe the increases in range that would be realized from a more efficient platform, an assessment of the warfighting capability impact of an entire force comprised of more efficient platforms was indeterminable. The closest any Service came to being able to describe increased warfighting capability was the Army, which determined how much faster a more efficient Abrams could be deployed to the Middle East. This points out the need for better analytical tools to evaluate the impact of more efficient platforms on warfighting scenarios, and to integrate results into requirements determination, research and development, and acquisition decisions.

Despite increasing emphasis on life cycle or total ownership cost considerations in acquisition programs, pressure to meet “fly-away” costs takes precedence. Features that increase “fly-away” cost and efficiency, but are not required to meet acquisition milestones are unlikely to be implemented. The result is to generate increased future “must pay bill” operations and support bills that exceed the value of the increase in “fly-away” cost.

These discussions provided a strong endorsement for considering the true burden of fuel demand in technology implementation decisions and revealed shortcomings in the information used as the basis for funding decisions.

IV b. Technologies for Achieving Energy Efficiency in Air Force Platforms

The Air Force is a leader in the Integrated High Performance Turbine Engine Technology (IHPTET) Program, its flagship program for improving the thrust-to-weight ratio and fuel efficiency of gas turbine engines. The other Services, NASA and industry are also strong partners. In addition to improving thrust-to-weight ratio and fuel efficiency, IHPTET improves reliability and reduces manufacturing costs. The task force received several briefings on the IHPTET and post-IHPTET (Versatile, Affordable, Advanced Turbine Engines, VAATE) activities and strongly supports these programs, which provide fuel efficiencies to all Services and improves U.S. industry competitiveness.

From a broader perspective, the Air Force has not established explicit Service-wide goals for reducing battlespace fuel demand. In its cost benefits analyses that describe the economic benefits of IHPTET, the Air Force, like the other Services, used DoD's standard fuel price as the basis for their calculations. And like the other Services, this ignores the resources within the logistics system required to deliver the fuel to the platforms. Operational benefits were described in terms of single platforms, which does not take into account overall capability impact. For example, it does not address the question of how many fewer efficient platforms would it take to execute a Defense Planning Guidance (DPG) mission than with current platforms.

The Air Force consumes approximately 2 billion gallons of fuel each year. The IHPTET program is projected to improve fuel efficiency by 20 to 40 percent, a significant amount. IHPTET is a multiyear, multiphase program. Its first goals were set for 1991, and were achieved. Engines incorporating the results of previous phases of IHPTET are commercially available today and suitable for retrofit into DoD legacy platforms. IHPTET is described in more detail in Section IV b.3 below.

The task force was briefed on the Air Force decision not to re-engine the B-52H aircraft. The engine options, and decision process and the ultimate decision are discussed in section IV b.2 below and provided here as a case study. The task force was also briefed on other older bomber, cargo and fighter platforms that would benefit from newer technology, commercially available engines. However, the task force selected the B-52 to analyze because data were available to examine the logistics force structure impacts of re-engining. Understanding these impacts reveal opportunities for the DoD to produce greater capability from available funding.

IV b.1 Retrofit Technologies for Legacy Air Force Platforms

In addition to IHPTET, the Air Force Research Laboratory (AFRL) provided an extensive overview of their Science and Technology portfolio and assessments of the warfighting benefits its technologies offer. These included near-term technologies with the potential to increase fuel efficiency. One of the technology areas AFRL presented was improved command, control and communications (C3) technology. It improves efficiency by minimizing flight delays, enabling more direct routing and allowing greater aircraft payload. To illustrate the payoff to the warfighter, AFRL applied them to two scenarios: an Air Mobility scenario and a Kosovo scenario.

AIR MOBILITY SCENARIO

Technologies to improve C3 are important because Air Mobility Command (AMC) consumed 61percent of the aviation fuel in Fiscal Year 1999. One of the ways for AMC to save fuel is to use these technologies to optimize routes, schedules and deployment plans, and to employ in-flight rescheduling. In-flight rescheduling and global rerouting can minimize inefficient routing due to weather and enable increased cargo loads.

According to AFRL calculations, applying integrated C3 technologies being developed and demonstrated today at AMC has the potential to reduce AMC's yearly fuel consumption by 7 percent. This represents $203M savings in FY99. Over 10 years, this would produce over $2 billion in cumulative savings. Some specific applications of C3 technologies are described below.

The Advanced Computer Flight Plan Program (ACFP), which provides wind optimized computer flight planing for Air Force aircraft, has the potential to produce 2.8 percent in fuel savings and reduce flight time by 2.3 percent. In initial FY1999 tests, ACFP saved $19M in fuel and 8,908 flying hours. In addition, it helped automate flight planning by generating flight plans 6 percent faster than when done manually. The resulting more accurate flight plans saved $4M in personnel costs.

Aircraft Communications Addressing and Reporting System (ACARS) has the potential to produce 2 to 3 percent in fuel savings, based on demonstrated savings by commercial airlines. In FY1999, ACARS saved $91M in fuel and 8,504 flying hours. Reduced "Diplomatic Clearance" diversions saved 950M gallons of fuel. In addition, ACARS reduced "Burn to Carry", "reduced Aircraft Operation Time" and increased "Payload/Mission Ratio".

The Worldwide Aeronautical Route Planner (WARP) is a technology that provides near real-time, fuel efficient flight plans for military aircraft using weather pattern data and existing military and commercial navigational aids and restrictions to optimize course routing. It has the potential to reduce fuel consumption by 1 to 2 percent.

The Information for Global Reach (IFGR) program is a set of integrated communication technologies that provide exchange of timely, accurate C3 information to support AMC operations worldwide. In-flight Management is a scheduling technology. According to AFRL, coupling these two programs with the flight dispatch process has the potential to save:

- 952 flight hours through increased short ton capacity (more aircraft load)
- $2.9 M by reducing turn-around time
- 8,504 flying hours
- $91.3M in fuel
- $48 M due to more accurate flight plans

AFRL stated that these technologies benefit the warfighter by providing:

- real-time event monitoring and retasking of AMC assets (e.g., location and status of aircraft)

- rapid push forward to target
- increased situational awareness via information fusion
- threat avoidance

KOSOVO SCENARIO

AFRL also analyzed the benefits of fuel efficient technologies in terms of the situation operational forces faced during the Kosovo conflict. Over 38,000 sorties were flown over Kosovo. Sorties began at the rate of 200 per day and went as high as 1000 per day. By June 1999, there were 731 US aircraft at 25 bases in Europe.

The Kosovo experience revealed a number of shortfalls and lessons learned.

Strike Forces:

- Lack of targets due to inability to see through weather and foliage
- Weather caused about 25 percent of sorties to be aborted (22 percent ground abort and 3 percent air abort)
- A significant number of flights did not meet objectives due to inability to find targets they were sent to hit
- Lack of precision targeting required for small smart weapons precluded optimum use

Airlift:

- Kosovo increased AMC's daily operations by only 10 to 20 percent
- Maximum on-Ground (MOG) is the maximum number of aircraft that can be on the ground simultaneously at an airfield, and was a primary limiting factor for the speed of the Kosovo airlift

Aerial Refueling Support:

- There were insufficient air bases in the area to support all aircraft, so air refueling was required by many aircraft to reach the target area
- Planners had to overcome numerous coordination and support issues, including providing tanker support for global attack sorties from the US by B-2 bombers
- Increased tanker support was needed to provide continuous refueling capability for at least 4 Combat Air Patrol stations

The C3 technologies identified in the Mobility Scenario would also help in the Kosovo Scenario. The Air Force has concluded, however, that the highest potential increase in fuel savings results from increasing the efficiency of the strike force, thus reducing the number of sorties required, and in turn reducing the aerial refueling support required.

Each of the problems identified above is discussed below with regard to the technologies AFRL is developing to address them.

WEATHER: About 25 percent of sorties were aborted due to weather. Of these, 3% were in-air aborts. The Joint Environment Exploitation Segment is a technology development program with the goal of informing military planning and operations personnel as to whether the atmosphere is affecting the performance of targeting acquisition and surveillance systems, and the target acquisition systems and weapons seekers. It has the potential to save 3 to 5 percent of fuel by turning the air-aborted missions into successful strikes of alternative targets, or keeping them on the ground until the weather improves

TARGETING: Many sorties did not achieve their goals because the targets could not be located and identified by the Intelligence, Surveillance & Reconnaissance (ISR) assets or the strike force over the target area. Current limitations include:

- inability to find and kill deeply hidden targets
- inability to find and kill targets hidden under trees
- inability to consistently discriminate between decoys and targets
- excessive time required to find, fix, track and identify moving targets

Consequently, the goals of AFRL research are to:

- deny sanctuary for mobile targets
- reduce the time to identify and kill high value mobile targets
- improve weapon lethality to hidden targets
- improve combat identification capability in difficult deployment conditions

.
AFRL has several programs addressing the target solution set within the Air Operations Center targeting cell. Examples are:

- The Moving Target Exploitation program is developing technology to track and identify moving targets using existing ISR platforms
- The Targets Under Trees program is focused on finding targets using newly developed foliage penetrating radar
- Programs to provide in-flight weapons updates to warfighter

In general terms, AFRL stated these technologies would:

- Improve knowledge of targets to reduce the number of sorties flown looking for "targets of opportunity"
- Optimize hitting the target the first time, reducing reallocation of the same targets to subsequent sorties and the total number of sorties required.
- Reduce operational timelines by fusing sensor/data/information for rapid targeting of time critical targets.

AFRL stated that while the main objective of these programs is to improve the efficiency and effectiveness of the strike force, increased fuel efficiency would be a by-product.

TRAFFIC MANAGEMENT: "Communications, Navigation, Surveillance/Air Traffic Management" (CNS/ATM) is a civil aviation plan that incorporates an evolving combination of ground and airborne technologies and improved flight procedures, managed by controllers and flight crews and made possible by digital communication, computer interpretation of flight instructions and satellite systems that precisely locate aircraft. Total fuel savings estimates by the civil aviation industry range from 6 to 17 percent, depending on region of the world. The military counterpart is Global Air Traffic Management (GATM), which is part of a more comprehensive upgrade known as Global Access, Navigation and Safety (GANS).

These programs enable military aircraft to use more efficient trans-oceanic traffic routes, and plan to add Global Positioning Systems (GPS) to all passenger-carrying aircraft by 2001, with further avionics improvements in other aircraft by 2005. This is in part a response to 1996 legislation that states "After Sep 30, 2000, funds may not be obligated to modify or procure any DoD aircraft, ship, armored vehicle or indirect fire weapon system that is not equipped with a GPS receiver." GATM includes upgrades to navigation, communications, surveillance and air traffic management systems, allowing reduced vertical separation of aircraft. For example, in 1997 the vertical separation over North Atlantic airspace decreased to 1000 feet. Aircraft not equipped with compliant equipment are prohibited from using this space. The Air Force estimated that compliant aircraft could deploy to the Gulf region in 42 days less than noncompliant aircraft.

IV b.2 B-52H Re-engining Study

The B-52H program office presented a re-engining analysis conducted a few years earlier to determine the cost and benefit of replacing the eight B-52H 1960s-era engines with four more current model engines. The Air Force considered four different engine options as shown in the chart below. In addition to better fuel efficiency, all engines also provide better reliability. Two of the options, the RB-211 and PW 2040, comply with international emission and noise standard and increase aircraft range.

The graphic below was prepared by AFRL to compare a B-52H flying from Minot to Iraq with existing engines to one with IHPTET engines. The IHPTET efficiency improvement assumed in this graphic is the same as the improvement provided by the RB-211 engine, 33 percent. However, the range increase estimates are different, with the IHPTET engine showing a 49 percent increase from 8,352 nm to 12,460 nm and the RB-211 showing 28 percent from 8,700 nm to 11,136 nm.

The cost and benefit analysis provided by the Air Force program office calculated the total lifetime ownership cost of the B-52H with the various options over its remaining 40-year life, which included operational fuel as well as the other factors shown in the chart below. The calculation assumed the price of fuel to be the DoD standard price in the year the calculation was made, in this case

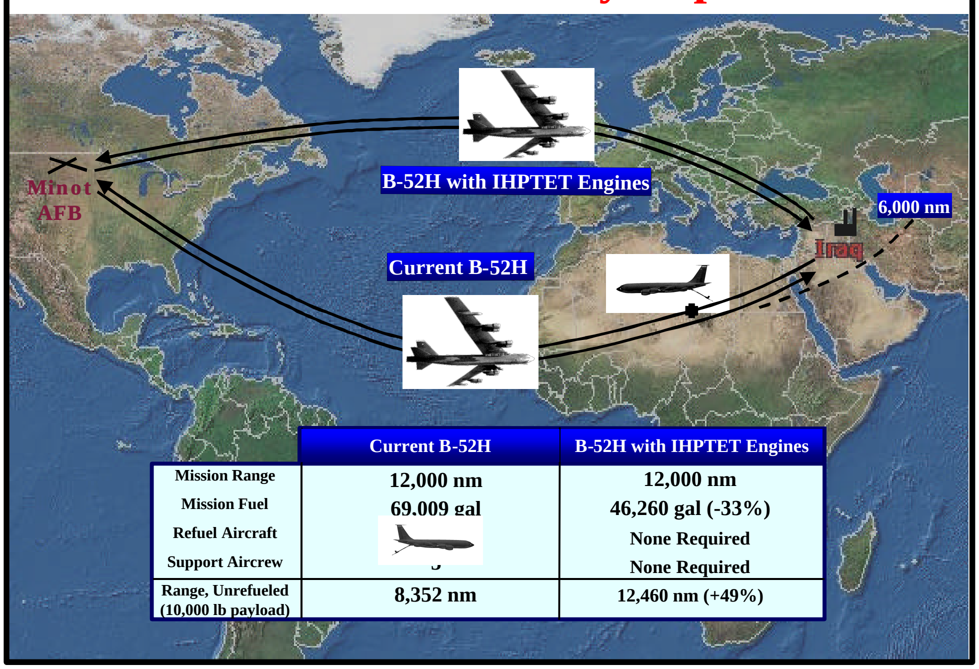
$0.927 per gallon for JP-8 in FY97, over the remaining 40-year lifetime. The program office concluded the only option of the three that reduced the total lifetime ownership cost was the TF-33 retrofit. The other more efficient options actually increased total ownership costs. The program office analysis estimated the total 40-year lifetime savings to be less than $400M.

B-52H – Engine Option Comparison

	Baseline	TF33 Upgrade	RB211	PW2040
Max. Range (nm)	8,700	-	+28%	+17%
Fuel Consumption (gallons/hr)	3,334	-2%	-33%	-27%
Reliability	-	+35%	+91%	+88%
Commonality	-	-	-	C-17(F117)
Meets ICAO Emissions	No	No	Yes*	Yes*
Meets Stage III Noise	No	No	Yes*	Yes*
Thrust Reverser	No	No	No	Yes

* Based on analytical projections - no airframe specific test data - applies to all subsequent assessment charts

Benefits of B-52H Efficiency Improvements



	Current B-52H	B-52H with IHPTET Engines
Mission Range	12,000 nm	12,000 nm
Mission Fuel	69,009 gal	46,260 gal (-33%)
Refuel Aircraft		None Required
Support Aircrew		None Required
Range, Unrefueled (10,000 lb payload)	8,352 nm	12,460 nm (+49%)

The task force re-ran the analysis, using the same assumptions and factors shown in the program office analysis below, but changed only the price of fuel. The results are shown in the chart below. These analyses assumed a conservative $1.50 per gallon for fuel averaged over the next 40 years, then apportioned 10 percent of the fuel consumed at the in-flight rate of $17.50 per gallon. At $1.50 per gallon and no recognition of the in-flight refueling costs, savings from the TF-33 modification grew modestly to just under $500M and the RB-211 about broke even. Yet apportioning 10 percent in-flight refueling pushed the TF-33 savings by about 50 percent to just under $1B, but increased the RB-211 savings by about a factor of 4 to about $1.7B

Air Force Program Office (ASC) 1997 Analysis

- Assumptions
  - Relevant Cost Factors Used by ASC Included
    - Operational Fuel
    - Contractor Logistics Support
    - Operations and Support Maintenance
    - Procurement
    - Non-Recurring (transaction) costs
  - Fuel cost fixed at 1997 DESC price through 2040
  - Results
    - TF-33 Upgrade reduces life cycle ownership cost by $396M
    - All other options increase life cycle ownership cost
- Conclusion – Re-engining B-52 not cost effective

The Air Force briefed that the initial savings estimate of about $400M was not sufficient to invest in the retrofit. However, given the other factors important to a decision such as this, it is unclear whether a savings of $1.7B would be considered sufficient to change the decision. This is particularly true because these savings include the cost of operating the tanker aircraft used to deliver fuel, and realizing the savings would require eliminating tanker aircraft from the inventory. Understanding the implications of a reduction in tanker force structure requires a deployment and employment model that calculates the change in logistics requirements that would result from more efficient B-52Hs. The task force found that the Institute for Defense Analyses (IDA) used such a model as the basis for a 1996 tanker requirements study. The B-52H refueling requirements that were used as inputs to the IDA study came from a 1994 RAND Corporation study. The study was conducted because in 1995 the AMC asked IDA to evaluate tanker requirements. The task force asked IDA to re-run its model assuming a 25 percent improvement in the efficiency of the B-52H fleet.

The results are summarized in the chart below. They showed that for the Single Integrated Operational Plan (SIOP) mission alone, making the B-52H 25 percent more efficient eliminated the need for 55 tanker platforms, or about 25 percent of the entire inventory. The results also showed that the tanker requirement impacts of making the F-16 C and B-52H more efficient based on other operational scenarios, such as Southwest Asia (SWA) and Northwest Asia (NWA), were not nearly as dramatic. The IDA study also estimated the cost savings that would result from tanker force reductions. Based on those cost reduction factors (which assume no infrastructure would be closed, such as maintenance and operational facilities), IDA estimated savings of $154M per year over the remaining 40 year life of the B-52H, for a total of over $6B. Closing redundant infrastructure would increase the savings, but the data were not available for quantifying the savings. The savings estimates also assume the excess tankers have no salvage value, treating acquisition funds spent to date as sunk costs. The Air Force Cost Analysis Improvement Group (CAIG) calculated the annual ownership cost of the existing tanker fleet to be about $2.15B. Based on this, the task force savings estimates may be conservative.

Alternative Economic Analysis B-52H Re-Engining Using Higher Fuel Price

Total 40 year estimated life savings produced by re-engining options

Life Cycle Cost Impact for B-52H Fleet			TF33 Upgrade	RB211	PW2040
Air Force Program Office (ASC) Analysis					
Assuming $0.87/gal	No In-Flight Refueling		**$386.90**	-$483.40	-$569.00
Analysis Assuming $1.50/gal Fuel Cost Ground Delivery and $17.50/gal In-Flight					
Assuming $1.50/gal	No In-Flight Refueling		$488.06	-$23.48	-$166.56
	10% In-Flight Refueling		$922.46	**$1,693.73**	$1,469.45

Results of economic analysis are very sensitive to cost of fuel assumptions.

Positive numbers indicate life cycle cost savings
Negative numbers indicate higher life cycle cost.

If making the B-52Hs more efficient offsets the need to procure additional tankers for other missions, the savings increase significantly. To quantify these savings, the task force estimated the cost of procuring "new" KC-10 tanker aircraft. The DC-10 (commercial version of the KC-10) production line is closed, so to estimate the cost, the task force asked Boeing for assistance. The cost of a used DC-10 airframe runs approximately $18M, and modifications would run $35M on the low side, but would increase depending on navigational aids and other possible options. For the purpose of this rough order of magnitude estimate, the task force assumed a "new" KC-10 would cost about $60M. Based on this figure, offsetting the need to procure 55 new tankers increases the total savings to about $9B. AMC is currently conducting a new internal study of tanker requirements. The savings generated by reduced tanker requirements could be reapplied to weapons platforms improving their fuel efficiency to bootstrap still further fuel savings and boosting their operational capability.

While this analysis is more comprehensive than that conducted by the program office, it is still not complete. The IDA study examined tanker requirements for the employment phase of the scenario only, and not deployment phase (the movement of aircraft from their home base to their operational location). Often this requires establishing an air bridge to provide in-flight refueling en route. Reductions in the number of tankers required for the deployment phase would be in addition to those cited below, and the financial savings correspondingly larger.

B-52H Re-Engining Impact on Tanker Force Structure

- **Single Major Regional Contingency--Employment**

Aircraft (Fleet)	Fuel Efficiency Improvement	Nominal Tanker Requirement Reduction (KC-135R equivalents)	
		NEA	SW A
F-16C	5%	1	2
	10%	1	4
	15%	1	6
B-52H	25%	0	2

Source: IDA Tanker Requirements Model

- **Single Integrated Operational Plan (Nuclear Exchange)**

Aircraft (Fleet)	Fuel Efficiency Improvement	Nom inal Tanker Requirement Reduction (KC-135R equivalents)
		SIOP
B-52H	25%	>55

Sources: *B-52H Re-Engining and Tanker Force Structure Requirements*, IDA D-1946, September 1996 and *Aerial Refueling Requirements for Bomber Operations,* Rand N-3471-AF, October 1994

Enables over 55 Tanker Platforms to be removed from the force structure.

Note: Tanker requirements for National Taskings, Combat Crew Training School, and Receiver Training expected to remain constant with potential aircraft fuel efficiency improvements

The chart below summarizes the different analytical approaches the task force reviewed and the different results. The chart also highlights a passage from Joint Vision 2010 that indicating that task force findings of weak analytical linkage between platforms and logistics directly address the concern over "tooth" to "tail" balance expressed at the highest levels of DoD leadership.

There are two ways to satisfy logistics requirements: to make platforms and systems more efficient so they require less logistics, or acquire more logistics assets. DoD should routinely compare the economic and operational implications of both approaches. Acquiring more logistics assets produce future year costs in terms of maintenance, personnel and other burdens of ownership. Making operational platforms more efficient eliminates these future year costs and makes DoD's forces more autonomous, invulnerable and agile.

Consequences of Re-Engining Decision

We must maintain a careful balance between equipping and sustaining our forces and between tooth and tail in our force structure.
Joint Vision 2010

- Operational costs for 55 KC-10s is approximately $154M per year, for a 40 year total of $6.1B.*
- If the Air Force decides there is a tanker shortage, savings increase by eliminating procurement costs
  - Procurement cost for a KC-10 is approximately $50M to $60M
  - Procuring 55 KC-10s would cost approximately $3.0B
  - Total avoidable lifetime ownership cost would be over $9B

Decision Enables $9B to Move From Tail to Tooth Over Remaining Life of B-52H Fleet

* Assuming no infrastructure is eliminated. Closing installations and maintenance facilities that support tankers would increase savings.

IV b.3 Emerging Technologies for New Air Force Platforms

The Air Force is investing 17 percent of its FY 2001 Science and Technology (S&T) portfolio toward developing superior air, weapon and space propulsion and power technologies. The flagship of this effort is the Integrated High Performance Turbine Engine Technology (IHPTET) program described in the introduction to this Section.

The IHPTET program is a three-phased national (DoD, NASA and industry) effort to double the 1987 state-of-the-art turbine engine thrust to weight ratio by 2005. The Air Force is the DoD lead and the program is highly leveraged, with industry contributing 50 percent of the total cost. IHPTET is not a single technology, but is a suite of technologies focused on all facets of gas turbine propulsion: turbofan/turbojet, turboprop/turboshaft, and expendable engines. Its goals are ambitious but rigorously established.

IHPTET targets the following discrete components of the turbine engine:

- Compression Systems
- Combustion Systems
- Turbine Systems
- Exhaust Systems

- Mechanical Systems
- Controls & Accessories

IHPTET Program Goals*

	PHASE I (1991)	PHASE II (1997)	PHASE III (2005)
TURBOFAN / TURBOJET			
Thrust / Weight Ratio	+30%	+60%	+100%
Combustion Initiation Temp	+100°F	+200°F	+400°F
Production Cost	---	-20%	-35%
Maintenance Cost	---	-20%	-35%
Fuel Burn**	-20%	-30%	-40%
TURBOSHAFT / TURBOPROP			
Specific Fuel Consumption	-20%	-30%	-40%
Power / Weight Ratio	+40%	+80%	+120%
Production Cost	---	-20%	-35%
Maintenance Cost	---	-20%	-35%
EXPENDABLE			
Specific Fuel Consumption (Strategic)	-20%	-30%	-40%
Thrust / Airflow Ratio (Tactical)	+35%	+70%	+100%
Production Cost	-30%	-45%	-60%

* Reference 1987 state of the art, at constant life
** For reference--not an official program goal

Examples of the specific technologies being developed and demonstrated under the IHPTET umbrella include:

- Turbine blades that use double wall, "supercooling" concept to operate at gas path conditions over 600°F higher than the baseline F-22 engine
- Advanced damping technologies and enhanced manufacturing methods (such as Laser Shock Peening) to increase high cycle fatigue resistance of critical engine hardware.
- Advanced intermetallic refractory alloys (Molybdenum or Niobium based) for turbine blades that can operate up to 900° higher than the baseline F-22 engine for greater thrust per pound of airflow, or double (to 4000 hours) turbine blade life.

As a joint program, the IHPTET and its successor the VAATE initiative, benefit platforms for other Services also. The chart below provides examples of the benefits to Air Force and Navy platforms, and shows other studies underway to determine applicability to other platforms.

IHPTET System Level Payoffs*

Air Superiority Supercruise Fighter
- **33% TOGW reduction (@ constant radius)**
- 38% reduced fuel burn (@ constant mission)

Tactical Fighter (Combat Air Patrol)
- **36% TOGW reduction (@ constant mission)**
- 44% reduced fuel burn (@ constant mission)

Global Strike Aircraft
- 25% TOGW reduction (@ constant radius)
- 14% increased radius (@ constant TOGW)

Supersonic ASTOVL Fighter
- **36% TOGW reduction (@ constant radius)**
- 42% reduced fuel burn (@ constant radius)

Close Air Support
- **62% TOGW reduction (@ constant mission)**
- 75% reduced fuel burn (@ constant mission)

Anti-Submarine Warfare - Fixed Wing
- +130% radius (@ constant time on station)
- +200% time on station (@ constant radius)

Anti-Submarine Warfare - Rotary Wing
- +430% radius (@constant payload and loiter)
- +80% payload (@ constant radius and loiter)

Advanced Cargo Aircraft
- +42% payload (@ constant range)
- +82% range (@ constant payload)

Supersonic Tactical 2.5M Sea-level
- +75% range (@ constant payload)

Other Payoff Studies Underway:
- F-22 & JSF growth versions
- UAVs of various classes
- Global reach transport, Rapid reaction fighter

* 13 examples highlighted in IHPTET TDA document (includes mission profiles and assumptions)

(TDA – Technology Development Approach)

The chart below shows other technologies AFRL is investigating that would also improve the efficiency of future platforms. They include more streamlined aerodynamic structures; materials that can change their shape to optimize performance; and electronic systems for more precise flight planning. Other pursuits include uninhabited vehicles to accomplish tasks currently requiring piloted aircraft; more electric aircraft to significantly reduce weight by eliminating hydraulics; new fuels; and smarter target sensors and munitions to reduce the number of sorties required for mission success.

Other Fuel Savings Technologies Under AFRL Development

- Materials
- Airborne Vehicles
  - Active Aeroelastic Wing
  - Close Formation Flight for Drag Reduction
  - JSF/Integrated Subsystems Technology
  - Continuous Mold Line
  - Flow Control
  - UAVs
- Propulsion
  - More Electric Aircraft
  - Fuel Technology
- Munitions - Small Smart Weapons

IV c. Technologies for Achieving Fuel Efficiency in Army Platforms

IV c.1 Army Transformation Goals for Fuel Efficiency Improvements

Land combat is executed directly by weapons systems to dominate an opposing force. To win, the land force of whatever size must be able to move to points of decision rapidly and reliably, employ overwhelming weapons effects for extended periods of combat, and sustain the capability of people to operate and survive during those periods. Fuel, ammunition, and water are the principal constituents of the logistics pipeline.

The Army has established aggressive battlefield fuel demand reduction goals at the highest leadership levels as part of the Army Transformation in order to achieve the agility necessary to respond to a post-Cold War threat. These goals are shown in the chart below. Army research organizations have responded with technologies at all levels of maturity that would improve the efficiency of legacy and future systems.

Reducing fuel demand reduces logistic force structure requirements. The Army owns and operates significant logistics infrastructure for the purpose of delivering fuel. Some Army fuel facts:

Army directly uses $200M of fuel per year or 300M gallons.
Army has 20,000 active POL* related soldiers @ 100,000 per annum and 40,000 reserve POL-related soldiers @ 30,000 per annum.

	$ 200,000,000	fuel
	$2,000,000,000	active
	$1,200,000,000	reserve
Total annual cost of Army fuel	$3,400,000,000	

Thus it costs the Army about 16 times as much to deliver fuel as to purchase it, yet only the purchase cost is visible to the designers and acquirers of Army platforms. The ratio would be even higher if it included the indirect Army use of fuel purchased, delivered and consumed by the Navy and Air Force to move and support Army assets.

To provide some perspective, the Army consumes only about 5.7 percent of DoD's total fuel. However, the Air Force and Navy transport the Army to battle areas around the world. The task force was unable to determine the quantity of fuel used by the Air Force and Navy to transport the Army. As a result, the task force was also unable to determine the impact that lighter, more agile Army systems would have on fuel consumption or logistics requirements of the other Services. But it is clear that other Services' support of Army operations would

* POL – Petroleum, Oil and Lubricants

amplify any direct fuel savings the Army achieved, partly because a major means of saving the Army's direct fuel use is to make its platforms lighter weight.

Army Transformation Goals to Improve Capability By Improving Energy Efficiency

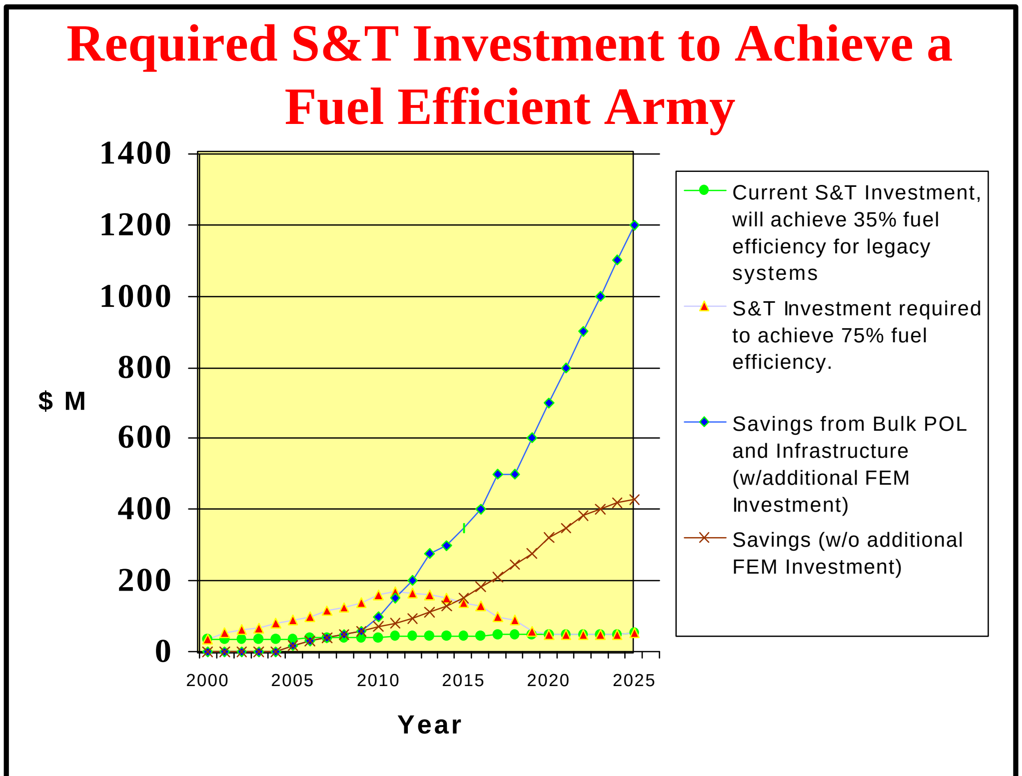
- Army Strategic Goal is to Reduce Real Fuel Costs by 30% by 2025
  - This will save over $1B per year in direct fuel and infrastructure costs
  - This enables force planners to allocate more resources to combat divisions
- Achievable Goals
  - 75% fuel efficiency improvement for future combat platforms and systems
  - 75% reduction in battlefield fuel consumption achievable for combat systems
  - 30-50% reduction in legacy combat platforms (air and ground)
  - 30-50% reduction for tactical support vehicles (National Automotive Center)
- Provides Battlefield Options
  - Expanded battlespace
  - Faster insertion and extraction
  - Reduced logistics tail (up to 20,000 POL support personnel)

Fuel efficiency is a critical capability enabler

The ARL calculates that fuel actually costs the Army about $13 per gallon, well to tank, in peacetime and at home. The monetary value of the reduced logistics requirements created by increased efficiency exceeds the value of the saved fuel. Becoming more efficient would enable some of the $3.4 billion in annual POL logistics resources to be diverted to other purposes, such as to acquire and support additional combat assets, modernize the force or enhance readiness.

The ARL also estimated the return on investment from technologies that reduce battlefield fuel demand. Their study compared the investment in Science and Technology needed to achieve a 75 percent reduction in battlefield fuel demand with the resulting savings the Army would realize from reduced bulk POL and infrastructure requirements. The chart below shows an estimated annual net savings of between $400M and $1.2 billion.

However, the task force found no examples where the returns were quantified in a way that presented decision makers with a clear comparison of the capability impacts of competing investment options.



(Source: Fuel Efficient Army After Next, January 14, 1999, Page 26)

The chart below is an illustrative example provided by OSD. There are many economic and capability benefits to operating vehicles with the features shown (i.e., 40 percent lighter, 20 percent less silhouette, and half the crew). However, unless they are quantified in terms of economic savings, decision makers have little basis for deciding where to invest to maximize return in terms of increased capability or reduced operating costs.

GROUND VEHICLES
Rationale For Investment

- Ground combat vehicles are the major component of Army Armored and Mechanized Infantry Divisions, as well as Marine Corps expeditionary forces. There are approximately 25,000 combat vehicles in the active force structure.
- Annual average procurement investment is $1.4B.
- **Vehicle Impacts**
  - 40 % lighter
  - 20% reduced silhouette
  - 50% smaller crews

  Operational Payoffs
  - increased exchange ratios
  - lower life cycle costs
  - deployable
- **Transition opportunities**
  - Future Scout & Cavalry System
  - Future Infantry Vehicle
  - Light Strike Vehicle
  - Abrams & Bradley upgrades
  - Crusader
  - Advanced Amphibious Assault Vehicle

Army Combat Vehicles

- Army Future Combat Vehicle (FCV)
  - Reduce support requirements by 90%; unrestricted transportability
  - Single Concept to be Chosen December 2005
- Future Scout and Calvary Systems
  - Fuel Efficiency Not a Specific Requirement
- Force XXI Systems
  - No Planned Upgrades Specifically Targeting Fuel Efficiency
  - Upgrades that are planned will have small fuel efficiency impacts, either positive or negative
- Fuel Efficient Army After Next (FEAAN) identified fuel economy improvements over baseline platforms for two cases:
  - Modified Existing Subsystems (Abrams 35%, Others 17%)
  - Completely new Subsystems (Abrams 61% - 81%, Others 32%)

Despite the Army's overarching need to improve efficiency, the use of efficiency goals in the Army requirements determination process appears to be weak. For example, the Future Combat Vehicle program includes a requirement to reduce support requirements by 90 percent, a component of which is fuel. However, as shown in the chart above, the future Scout and Calvary systems include no specific requirement to improve fuel efficiency. In addition, the current Force XXI systems include no planned upgrades that specifically target fuel efficiency. Currently planned upgrades to these systems have small impacts on efficiency, sometimes positively, but sometimes negatively. Because efficiency is not an explicit requirement and the indirect but tangible benefits are not explicitly factored into cost benefit analyses or acquisition systems engineering trade-off studies, technologies to make systems more efficient are not implemented as quickly as they could or should.

IV c.2 Top Ten Battlefield Users

Because Army combat power is a function of many different equipment systems working together as a system of systems, the task force examined the relative contribution of each deployed system that uses fuel. The list of "top ten battlefield fuel users" is based on a Southwest Asia combat scenario modeled by the Force Analysis Simulation of Theater Administrative and Logistics Support (FASTALS). The model was run by CASCOM (Combined Arms Support Command), and was written by the Center for Army Analyses in 1972 using the FORTRAN language. The results revealed that support, rather than combat systems, constitute a substantial portion of the total battlefield fuel demand. The task force is grateful to CASCOM for running FASTALS in support of this study.

Today's Top 10 Battlefield Fuel Users

SWA scenario using current Equipment Usage Profile data

Of the top 10 Army battlefield fuel users, only #5 and #10 are combat platforms

1. **TRUCK TRACTOR: LINE HAUL C/S 50000 GVWR 6X4 M915**
2. **HELICOPTER UTILITY: UH-60L**
3. **TRUCK TRACTOR: MTV W/E**
4. **TRUCK TRACTOR: HEAVY EQUIPMENT TRANSPORTER (HET)**
5. ***TANK COMBAT FULL TRACKED: 120MM GUN M1A2***
6. **HELICOPTER CARGO TRANSPORT: CH-47D**
7. **DECONTAMINATING APPARATUS: PWR DRVN LT WT**
8. **TRUCK UTILITY: CARGO/TROOP CARRIER 1-1/4 TON 4X4 W/E (HMMWV)**
9. **WATER HEATER: MOUNTED RATION**
10. ***HELICOPTER: ATTACK AH-64D***

List produced by CASCOM for TAA-2007 using FASTALS for SWA. For more details, see backup slides.
Blue: Supply transport vehicles; Green: field kitchen systems; Red: weapons platforms

While the task force did not receive briefings from centers responsible for developing support systems, these systems appear to offer significant opportunities for substantial reductions to overall fuel requirements. Based on Army briefings and other interviews, many Army support systems are based largely on 1970s era technology. They appear to be particularly inefficient and may offer more opportunities to reduce battlefield fuel demand very cost effectively. The Army should carefully evaluate all systems deployed to the battlefield - not just combat platforms - for opportunities to reduce fuel demand.

IV c.3 Retrofit Technologies for Legacy Army Systems

The Army Tank-Automotive and Armaments Command (TACOM) presented the results of Fuel Efficient Army After Next (FEAAN) studies that identified achievable fuel efficiency improvements over legacy baseline platforms for two cases. FEAAN estimated that by modifying existing vehicle subsystems, fuel efficiency improvements of 35 percent could be achieved for Abrams and 17 percent for other legacy systems. It also estimated that by retrofitting completely new subsystems, the fuel efficiency would improve by 61 to 81 percent for the Abrams and by 32 percent for other legacy systems. The briefing also pointed out that retrofitting the Abrams with newer engines would require an investment of at least $4 billion.

The engines currently in Abrams are based on late '60s technology, costly to maintain and very inefficient. A total of 12,163 of these engines were produced when production ended in 1992. M1A2/AI overhaul programs use overhauled engines. The Service Life Extension Program (SLEP) is implemented as part of overhauls and improves engine reliability and durability by incorporating a number of newer technologies, including digital electronic control units (DECU), boltless rotors and improved recuperators. These enhancements produce engines with a mean time-between-failure (MTBF) of 335-525 hours.

According to Abrams program office figures, the total ownership cost breakdown for the Abrams systems is:

Petroleum, Oil and Lubricants (POL)	Less than 1 percent
Class IX (Spare Parts)	17 percent
Modifications	1 percent
Depot Maintenance	4 percent
Ammunition	11 percent
Personnel	66 percent

POL, parts, modifications and depot maintenance are typically considered operations and support (O&S) costs. For the Abrams, this represents 23 percent of the total ownership cost, based on Army cost calculations. Maintaining the engine constitutes 64 percent of the O&S cost. The program office was directed to reduce O&S costs and, based on these figures, is focusing on the engine. The goal is to reduce logistics support costs by 20 percent by FY05.

A number of manufacturers produce engines that could replace the existing engines. These commercially available options offer:

- 4 to 5 times improvement in MTBF
- 15 to 20 percent improvement in vehicle mobility
- 35 percent reduction in fuel consumption
- 42 percent fewer parts

Re-engining is predicted to reduce ownership costs by about 40 percent over the remaining 30-year life compared to a 1995 baseline, after accounting for investment for engine replacement costs.

However, the Army's total ownership cost figures cited above are based on the standard price for fuel rather than the cost of delivering the fuel to the battlefield. No analyses were presented that estimated the POL logistics assets that could be eliminated or troops that could be redirected to combat functions if the benefits listed above were achieved. At the time the task force received the Abrams program office briefing (August 2000) the Army had not made a decision on re-engining the Abrams.

IV c.4 M1A1 / M1A2 Auxiliary Power Unit Case Study

Because the Abrams has no auxiliary energy source to power electronics and space conditioning systems, the main engine must run even when the tank is stationary in order to keep combat and air conditioning systems functioning. Current M1 engines at idle burn 12 gallons of fuel per hour to support a roughly five-kilowatt load, an efficiency on the order of one percent.[*] Additionally, at the time the M1 was fielded, the Army procured a significant number of tanker trucks because its fuel requirements were so much greater than the M-60 tank it replaced. The task force was unable to obtain estimates of the size of this POL logistics increase.

In addition to the re-engining option presented above, the Army has the option of installing an auxiliary power unit (APU). It is a small engine capable of producing enough power to operate auxiliary loads, avoiding the need to run the main engine. The program office presented its cost and benefit analysis for installing new engines and auxiliary power units, as shown in the chart below.

M1A1 / M1A2 Auxiliary Power Unit Retrofit – Program Office Analysis

	M1A1	M1A2
Potential POL Savings (GPH)	**12 - .5 = 11.5 Gal**	**12 - 4 = 8 Gal**
APU hrs	**98hrs**	**98hrs**
DESC Fuel Price	**$.97/gal (Diesel)***	**$1.02/gal (JP-8)***
Cost W/O APU	**$2,500/yr**	**$2,500/yr**
Cost W/APU	**$1,350/yr**	**$1,700/yr**
Savings	**$1,150/yr**	**$ 800/yr**

- Annual Fleet Average Cost for POL = $14M (FY99)
- Potential POL Savings = $6M/Year
- Cost of APU Retrofit = $276M
- Based on DESC standard price of fuel, payback occurs in 46 years
- (Program Management Office – Mr. John Fleck, 810-574-6850

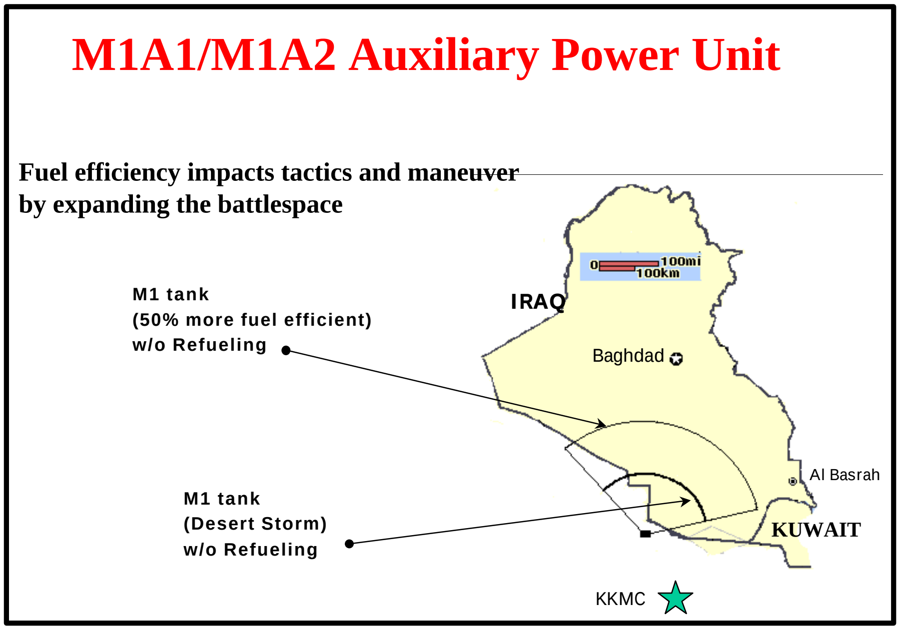
* Army Cost and Economic Analysis Center

The analysis used the DoD standard price of fuel to estimate the fuel component of the savings and concluded the investment paid for itself in 46 years. Alternative analyses using the true cost of fuel were unavailable, as were analyses to estimate the impact on logistics requirements. However, substituting the Army's peacetime estimate of $13/gallon delivered cost would reduce the 46-year payback to about 3.5 years, or roughly a 40% annual return on investment.

In addition to operating cost considerations, the ARL studied the operational benefits of extending the range of main battle tanks that would result from greater fuel efficiency. They concluded that an APU would have expanded

[*] This is a task force calculation based on an M1 burning 1.62MBTU/hr (heat equivalent of 12 gal/hr JP8 consumption) to power a standby load of 5 kwh/hr (17 kBTU/hr).

the battlespace in Desert Storm by 50 percent, as shown in the chart below. However, there was no assessment of the capability or economic benefit to a tank with 50 percent greater range, making it difficult to value to the operational benefit of re-engining or retrofitting the APU.



(Source: Army Research Laboratory)

The Army's FASTALS analytical model described above in section IVc.3 can determine battlefield fuel demand and can estimate the fuel demand generated during the time the tank is at idle compared to operating an APU. The model uses primary data elements for calculating fuel requirements; fuel consumption rates, equipment usage profiles, fuel weights, and equipment densities. Equipment usage is collected by scenario, by campaign and by posture or phase at company/team level. Phases of the campaign include buildup, denial, counter offensive, and exploitation. Postures include attack, delay, defend, reserve, and static. This very detailed model determines logistics requirements for various force structure and campaign scenarios. It also allows platform logistics requirements to be altered to determine overall logistics burden. Outputs are expressed in pounds of logistics support required per day of battle.

To determine fuel requirements, the model assumes fuel consumption rates to deployed systems under differing utilization rates. For example, it assumes the Abrams consumes fuel at a certain rate while idling, while traveling along unimproved terrain, and traveling along improved roads. Based on the mission profile, it determines total fuel required for mission execution. Installing an APU consumption rate at idle, with fuel consumption varying among APU options, thus allowing comparison of logistics impacts.

Force Structure Analysis

- Army has not determined the logistic force structure impacts of Abrams APU installation
- The Force Analysis Simulation of Theater Administrative and Logistics Systems (FASTALS) is capable of determining force structure impacts, but
  - The model is cumbersome to use and time consuming to run
  - Was written in 1972 using FORTRAN language
  - Platform utilization factors have been updated
  - Software has not been updated to improve ease of use, speed of use or flexibility

FASTALS is primarily used in the Total Army Analysis (TAA) to determine Doctrinal Support Force Requirements, which compete for funding in the Program Objective Memorandum (POM). While utilization rates for equipment included in the model have been updated, the software has not. As a result, it is costly and time consuming to run. However, the output is important to understanding the logistics implications of improving efficiency at the platform and system level. The Army should consider the updating the software to enable FASTALS to produce logistics impact assessments of competing platform modification options.

While FASTALS can quantify the logistics impact of an improvement in platform efficiency, it does not assess the operational capability impact. The task force was unable to identify force employment models that could be used to support the requirement process by assessing the capability impact of various platform options.

At the time the task force received the briefing by the Abrams program office, the Army had not made a decision on retrofitting an APU on the Abrams.

IV c.5 Emerging Technologies for New Army Platforms

The Army briefed the task force on many technologies in its portfolio that improve the fuel efficiency of Army systems. They are summarized below and estimates of their contribution to improved fuel efficiency are provided where available. One of these is IHPTET, described in more detail in Section IV b above, which applies to turbines used to power Army helicopters and tanks. It is one of 5 Defense Technology Objectives (DTOs) for improving the efficiency of air platforms. IHPTET applies to the OH-58D, AH-64, UH-60, CH47D and JTR helicopters. The IHPTET timeframe and goals for Army air vehicles are as shown in the chart below.

IHPTET Goals

Turboshaft / Turboprop	PHASE I (1991)	PHASE II (1997)	PHASE III (2003)
Specific Fuel Consumption	-20%	-30%	-40%
Power / Weight Ratio	+40%	+80%	+120%
Production Cost	---	-20%	-35%
Maintenance Cost	---	-20%	-35%

* Reference 1987 state of the art, at constant life

Most of the Army's Science and Technology thrust areas that contribute to fuel improved fuel efficiency apply to ground platforms and are as follows:

- Propulsion
  - o Advanced Ultra-Efficient Engines
  - o Hybrid Drives / Energy Storage Systems
  - o Alternative Energy Conversion
  - o Compatibility with Likely Alternative Fuels
- Materials and Structures
  - o Lightweight Composite Vehicles / Airframes
  - o Optimum application of Material Properties
  - o New Emerging Structural Materials
- Armor
  - o Lightweight Composite and Advanced Armors
  - o Active Protection
- Advanced Platform Concepts
  - o Ultra Efficient Propulsors (Wheels / Tracks / Suspensions / Rotors / Propellers)
  - o Configuration Efficiencies
  - o Unoccupied Aerial and Ground Vehicles (UAVs / UGVs)
- Usage and Tactics
  - o Information Based Mission Planning
  - o Optimum Routing and Dispatching

Hybrid electric drive is becoming increasingly feasible for a wider range of vehicle weight classes and duty cycles. During the 2000 model year, two automobile manufacturers offered commercially available hybrid electric passenger cars, with rated fuel economy ranging from 48 to 67 miles per gallon. The private sector, the Army and other federal agencies are working cooperatively to advance the application of hybrid technology, to include tactical and non-tactical Army vehicles.

In the areas of tactical support vehicles, the Army is pursuing Hybrid Electric Line Haul Trucks, which are the equivalent of Class 8 diesel commercial trucks, and is also researching fuel cells for vehicles, which still have significant technical hurdles to overcome before becoming viable. Some of the more significant technical challenges include making the system robust enough to withstand the shock and vibration experienced by vehicles, and transforming liquid fuel into hydrogen, the fuel used by the fuel cell. A number of companies are working on fuel cells for vehicles. The companies Plug Power, HBT and TRW have teamed to develop and demonstrate the first diesel/JP-8 fueled fuel cell powered Hybrid Electric High Mobility, Multipurpose Wheeled Vehicle (HMMWV).

DARPA and the Army jointly manage the Combat Hybrid Power Systems (CHPS) program, which features a flexible electric drive, regenerative braking and constant output motor. These technologies have the potential to improve vehicle fuel economy by 35 to 45 percent, while reducing system weight and volume by 25 to 35 percent. A major technical obstacle to fielding a combat system is improving battery storage density. The Army Transformation emphasis on reduced battlefield fuel demand provides an opportunity to assess the relative benefit and technical risk of a timely migration of hybrid technology into the Army vehicle fleet beginning with non-tactical vehicles, but moving aggressively to tactical platforms as technology permits.

Continuously variable transmissions (CVT) have the potential to improve fuel efficiency by 5 to 13 percent, improve traction, run more smoothly, reduce noise, and reduce vehicle weight. Some auto manufacturers have announced they are introducing CVT in their 2001 and 2002 model years.

New fuels may also provide energy increase of 5 to15 percent, while advances in engine oil lubricity may gain another 2 to 4 percent, and improved gear lubricants may contribute an additional 1 to 4 percent improvement.

The figures associated with specific technologies are additive. There is no single technology with the potential to produce revolutionary improvements in fuel efficiency, but by considering the logistics and support implications of incremental efficiency improvements the collective impact of multiple technologies becomes significant. This is especially true if hybrid-electric drive is added to an ultralight, low drag platform. One task force member, Dr. Amory Lovins, reported that this approach recently achieved 82% fuel savings, equivalent to 99 miles/gallon, in a civilian midsized sport-utility vehicle concept car, improving its acceleration, load-hauling, safety and other attributes. Analogous advances appear feasible for light military platforms, such as the scout vehicle.

The 21st Century Truck Program is an example of an opportunity to partner with other governmental agencies as well as industry in the development of technologies designed to produce breakthroughs for more fuel efficient vehicles for light, medium, and heavy duty trucks and buses. This program is led by the Department of Energy, with participation by the Departments of Defense and Transportation, as well the Environmental Protection Agency and 16 industrial partners. In January 2000, over 65 scientists and engineers from industry and government issued a roadmap to guide the research and development efforts encompassed in this partnership, which include both commercial and military vehicles.[*]

IV d. Technologies for Achieving Energy Efficiency in Navy Platforms

The Navy has had a program since 1977 to improve weapon platform fuel efficiency, focused primarily on legacy systems. The Navy staff estimates it has reduced the fuel consumption of the ship and aircraft fleet by 15 and 6 percent respectively. Deployment of the technologies and products has been primarily through no- and low-cost routes, such as the normal overhaul process or procedural changes. However, fuel efficiency has not been given a high priority in future system design. Fuel consumption enters design tradeoffs as one of many components of operating cost, and in most cases is one of the least important components because its benefits are so undervalued for reasons presented in Section III. As a result of this undervaluation and split incentives, new fuel saving technologies that promise increased performance and positive return on investment do not compete well for funding if the initial investment is high and the savings do not appear for several years.

IV d.1 Retrofit Technologies for Legacy Navy Platforms

A portion of the Navy's Development, Test and Evaluation (DT&E) program (Categories 6.4 and 6.5) is specifically dedicated to improving the fuel efficiency of ships, primarily legacy ships. This program began in the late 1970s, with funding peaking at about $35M in 1984. After fuel prices dropped in 1985 the program was funded at a more modest level, settling to around $8M per year through the 1990s.

The Navy briefed the task force on a wide range of technologies in its portfolio that improve the fuel efficiency of ships. The technologies are listed or summarized below, with estimates of their contribution to improved efficiency shown where available. These technology areas are as follows:

[*] This document can be found at: http://www.osti.gov/hvt/21stcenturytruck.pdf

SHIP SYSTEMS

Propulsion and Auxiliary Power Systems

- Existing Gas Turbine Improvements
  - Improved coatings
  - Revised exhaust ducting to reduce back pressure
  - Digital engine controls
  - Variable speed engine module cooling blower for the LM-2500 main propulsion engine
  - New 1st stage turbine ceramic blade track for the DDA 501-K17/34 turbo generator
  - On-line water wash systems
- Diesels
  - Low load operating condition engine management – state-of-art electronic fuel injection
- Boiler Plants
  - Improved plant operating diagnostics and procedures

These power plant improvements are estimated to improve fuel efficiency by 3 to 8 percent, as shown in the charts below.

Navy Diesel Engine Population and Efficiency Improvement Benefits

- Fleet Diesel power plants
  - 14% (345) medium speed engines (<1500 rpm)
  - 86% (2083) high speed engines (>1500 rpm)
- Annual fuel usage/cost for Diesel engines
  - 37M gal/yr (ships)
  - 25M gal/yr (not including ship emergency use boats)
- Diesel engines Consume 18% of total Fleet Fuel
- Electronic Fuel Injection - Up to 5% fuel use reduction (71K gal/yr) and 250K $/yr maintenance reduction.
- Low Load Operations Management - Up to 14% fuel use reduction (125K gal/yr.) and 305K $/yr maintenance reduction.

Hull Systems Hydrodynamic improvements

- Stern Flaps
    - Developed and being retrofitted to DD-963, CG-47, DDG-51 Flight I & II, and FFG-7
    - Designs being evaluated for LSD-41/49, LHA/LHD
    - Included in baseline design for DDG-51 new construction
- Bow Bulbs
    - In service on TAO-187, LSD-41/49, LHD
- Bow Fins
    - Being evaluated for TAO-187 (Similar hydrodynamic effect as bow bulb but less costly to retrofit)

These hydrodynamic improvements have been proven to improve fuel efficiency by 3 to 8 percent.

Legacy Boiler Plant Improvements
Replacing Pneumatic Controls With Electronics

- Intermediate Maintenance Costs go from $10K to zero
- Depot Maintenance Costs go from $60.4K to $10.4K
- Operator Level Maintenance Costs go from $35.0K to $3.2K
- Fuel Consumption Decreases
    - 15% for single boiler operations
    - 4% for two boiler operations
- Technician Training time decreases from 7 weeks to 2 weeks
- Calibration time per boiler decreases from 40 hours to 2 hours

Navy analysis of costs and benefits priced fuel at $1 per gallon

Hull Coatings/Cleaning

- Navy employs ablative, copper containing, anti-fouling hull coatings fleet wide, which reduce hull cleaning frequency and provide an approximate 6% fuel consumption reduction compared to previous systems.

- Self polishing, copper containing, coatings with cobiocides are being evaluated with a life of over ten years which are expected to eliminate biofilm formation and reduce drag further, producing an added 5% reduction in fuel consumption.

- Navy has developed and employs condition based cleaning procedures for propellers, rudders, struts and shafts and is completing development of a remotely operated hull maintenance vehicle to perform these tasks.

Auxiliary Systems

- State-of-the art centrifugal compressor designs are being developed for shipboard air conditioning plants that improve efficiency 3 to 6 percent.

- High efficiency motors and variable speed drives are specified for all new construction ships

Sensors, Controls and Procedures

- The Navy has instituted a program to provide legacy ships with improved sensors, controls, and crew training in energy efficient operating procedures.

Hotel Loads

- High efficiency fluorescent lighting fixtures have been used for all new ships since the late 1980s.

- Occupancy sensing lighting controls and central source, light pipe systems are being evaluated.

- Reverse osmosis fresh water production systems replaced distillation plants in the mid 1980s. However, these systems use more energy than the old systems, which used waste heat.

The task force had numerous discussions internally and with Navy staff about hotel loads, and concluded there are cost-effective opportunities to improve the efficiency of hotel functions. The Navy should apply "state of the art" building energy efficient design practices to shipboard hotel functions. This would reduce auxiliary loads, help enable additional combat system electrical loads and facilitate progress toward the Navy's goal of an all-electric ship.[*]

[*] One task force member, Dr. Amory Lovins, reports that a preliminary ONR-funded field assessment of a typical surface combatant, being completed as this report is being completed, found retrofittable hotel-load electric savings potential on the order of 20 to 50 percent, with significant further opportunities still to be assessed. Many of the savings opportunities were purely operational, requiring little or not investment. As much as about 30 percent of the Navy's non-aviation fuel appears to go to hotel loads.

While not a strictly a technology, the Naval Sea Systems Command's (Energy Conservation) ENCON program, summarized in the chart below, combines proven techniques for maximizing efficient ship's plant operation with economic incentives for commanders to reduce fuel consumption. Under this program, the fleet comptrollers are allowing commanders to share in the fuel cost savings. Commanders keep a portion of the reduction in fuel cost, and have wide discretion over how the funds are spent. One ship reduced its consumption by over a million dollars in a year and used its share of the proceeds to purchase a natural gas powered bus for transporting troops ashore during port calls.

NAVSEA Encon Program

- Incentivizes ship commanders to operate more efficiently by allowing them to keep some of the multiyear savings - Comptroller sponsored
- FY99 savings - $23M - less than half minimum estimated potential with full participation
- Most efficient power settings reduce consumption by up to about 65%
- No capital investment required, no new reporting requirements

AIRCRAFT SYSTEMS

- Propulsion Systems
    - New engine component technologies emerging from the IHPTET and other development programs are being retrofitted to existing Navy aircraft engine systems through a continuing program. For example, component improvements to the F/A-18 engine will improve efficiency by 5 percent.

- Sensors, Controls and Procedures
    - Navy and Marine corps pilots are provided with a family of flight planning systems ranging from PC-based pre-flight planning systems through carry on palm-based systems to cockpit-integrated systems. These systems evolve as the fleet aircraft mix changes and computing capability improves, and provide a measured 3 to 6 percent fuel use reductions.

IV d.2 Stern Flap Retrofit Study

The stern flap is one of a family of hull modifications that improves the hydrodynamics of ships. As with many of the technologies the task force reviewed, it offers incremental fuel efficiency improvements of a few percent. Stern flaps are extremely inexpensive and the ship does not have to be in dry dock for the retrofit. However, funding comes from maintenance budgets while benefits accrue to readiness accounts, a classic example of split incentives.

A stern flap is an appendage attached at the transom that redirects the wake energy in a way that reduces drag and improves top speed by varying amounts, depending on hull design. The cost of installing stern flaps varies depending on ship size and design, but tends to be in the range of a few hundred thousand dollars or less. The Navy is also constructing cofferdams for the purpose of installing stern flaps without having to place the ship in dry dock.

Stern Flap Implementation Decision

- Stern flap could be installed on 118 ships for an annual savings of over $20M in fuel, using the artificially low DESC standard price
- Stern flap has been installed on 12 ships for an annual savings of almost $2M
- Stern flap is scheduled to be installed on an additional 48 ships with an annual savings of $8M
- Navy should accelerate installing stern flaps on remaining 58 ships to realize remaining annual savings of $10M
- Payback typically occurs within two years, often within one year
- Ship Modernization Budget pays for stern flap installation, but Operations Budget benefits from the savings

As shown in the chart above, the cost of installation is extremely low compared to typical ship modifications, and the payback is very fast, even using the standard price of fuel for the cost benefit calculations. This is one of the easiest to implement, highest economic return and lowest first cost retrofits the task force found during this study. Moving out quickly with the implementation of stern flaps on all Navy hulls should be an easy decision.

IV d.3 Emerging Technologies for New Navy Platforms

The Navy is also developing a number of technologies that are appropriate for incorporation into new platform designs that have the potential to make future systems dramatically more efficient than current designs. They are summarized below, and estimates of their efficiency improvements are show where they are available. These technologies are:

SHIP SYSTEMS

Propulsion and Power Generation

- The Navy is developing integrated power systems for all future ship designs. The design and operating flexibility inherent in these systems will improve fuel efficiency by allowing prime movers to be operated at, or close to, peak efficiency most of the time.

- Advanced cycle gas turbines, such as the Navy-developed Intercooled, Recuperated Gas Turbine system (ICR), are around 30% more efficient compared to the 1950s and 1960s technology simple cycle marine gas turbines in current ships. The ICR is now in final stages of test and evaluation.

- Additionally, the application of IHPTET technology to the core of future advanced cycle marine gas turbines would further improve their efficiency. The Navy is a participant in the IHPTET program, and although the program currently focuses on aircraft propulsion systems, most of the technologies are directly applicable to marine gas turbines.

Navy Fuel Cell Program

- Increased Fuel Efficiency and Operational Range
- Distributed Power for Increased Survivability
- 96% Reduction in NO_x, CO and HC Emissions
- 30% Reduction in CO_2 Emissions
- $0.6M to $1M Savings per Ship
- Reduced Thermal and Visual Signatures

- Navy is pursuing the development of fuel cell systems for shipboard power generation, as shown in the chart above. These systems target a 30 to 50 percent improvement in fuel efficiency and reduced maintenance compared to current power plants. The more advanced molten carbonate and solid oxide systems provide higher efficiencies, especially if the high quality waste heat is captured. The Navy's challenge is to develop high energy density, marine environment compatible systems, and compact, efficient and reliable fuel reforming systems capable of handling marine diesel fuels.

Collectively, these have the potential to reduce fuel consumption 50 percent or more compared to current systems.

Hull and Propulsor Systems

- An optimized conventional ship hull form can improve fuel efficiency by 5 to 10 percent. The Navy is developing a Hull Design Data System (HDDS) to accelerate optimization of hull forms. This interactive database currently includes over 600 hull form drag data sets with more to be added. The Navy will make this available on a web site to both government and private sector ship designers.

- The interaction of the propulsor with the hull needs to be better understood to optimize efficiency of the total system.

- The efficiency advantage of contra-rotating propeller systems makes them a technology deserving of continued exploitation.

- Integrated ship power systems and electric drive make use of "podded propulsors."

- For advanced hull forms the Navy is investigating several boundary layer air and polymer injection concepts that hold the promise of large skin drag reductions.

Materials and Structures

- Programs focusing on advanced materials and structures for future ship applications promise 30 to 50 percent hull weight reduction and 25 to 35 percent topside structure weight reduction. These translate directly to increased payload and/or reduced fuel demand.

Technologies to Improve Efficiency of Sea Platforms and their Impact

- Propulsion
  - Intercooled Recuperated (ICR) Gas Turbine Engine Development
    - Reduce Propulsion Fuel Consumption by 20%-30%
  - The All Electric Ship - Reduces fuel consumption by 15-19%
  - Gas Turbine Improvements
  - Diesel Engine Energy Improvements
  - Legacy Boiler Plant Improvements
- Hull Performance
  - Hull Hydrodynamics Improvements
    - Saves 1000 ~ 5000 barrels / ship and $40,000 ~ $200,000 annually (1 to 2 yr payback)
  - Low Drag, High Performance Hulls
    - Non-toxic Fouling Release Hull Coatings
    - Vertical Motor Propulsor – eliminates propellers and cavitation
  - Hull Husbandry – keeps hull free of organisms and reduces drag
- Hotel Load Improvements – frees up energy for combat systems
- Air Conditioning Compressor Improvements
- Advanced Materials and Structures
  - 30% to 50% hull weight reduction
  - 25% to 35% topside structure weight reduction

AIRCRAFT SYSTEMS

Propulsion Systems, Airframe Design and Advanced Materials and Structures

- IHPTET: The Navy is a participant in the IHPTET program and has R&D programs similar to the Air Force in the airframe design, advanced materials and structures areas. Comments made in section IV b. (Air Force) of this report regarding the promise of these technologies also apply to the Navy.

- Control Systems: The Navy has demonstrated that linking the F/A-18 airframe and engine control systems optimizes performance of the total aircraft system, produced fuel efficiency improvements of 3% to 5%.

- Subsystems: Closed loop, variable output environmental control systems for pressurized aircraft (e.g. P-3) or tactical aircraft needing Chemical Biological Defense (CBD) systems are under development, allowing fuel savings attributed to aircraft environmental control system of 50%.

IV d.4 Fuel Efficiency Considerations in the New Ship Acquisition Process

DD-21

The task force received briefings on DD-21 acquisition process, which is unlike other acquisition programs. Two industry teams are currently competing for the procurement contact, and are allowed to develop independent total ship designs and life cycle support strategies with Navy-provided performance and life cycle cost requirements and targets. However, there are no specific fuel efficiency requirements or targets prescribed. Instead, the teams are competing to minimize "per underway steaming hour" operating and support cost threshold and target values, with fuel efficiency one of many components.

The Navy specified that a fuel price of $58.85/bbl ($1.40 per gallon) be used to calculate annual fuel costs. This was the Navy estimated delivered price in 1996. This represents the DESC standard price plus an estimated delivery cost, which includes a prorated cost of Navy operated oilers and fuel depots. This was the only program reviewed by the task force that used delivered fuel costs to estimate operating costs in the acquisition decision process. It was unclear whether Navy systems designers use appropriate whole-system design methodologies to capture the full value of potential fuel savings

DDG-51

This destroyer class has been in production through the 1990s and will be produced for several more years. The Navy briefed the task force on the design philosophy for the ship to determine what considerations were given to fuel efficiency. The Navy chose a gas turbine system (LM 2500) for main propulsion because it was a proven system already in operation in the DD 963 and CG 47 class ships. Reliability, known cost and the logistics benefits of commonality appear to have overridden other considerations.

During DDG-51 design, space was provided to include the Rankine Cycle Energy Recovery (RACER) system, a steam system under development at the time that recovered gas turbine exhaust heat to provide additional propulsive power. While it promised significant efficiency improvements, this program was cancelled because of major technical development problems.

At the time of the DDG-51 conceptual design, the Navy was experiencing serious maintenance problems with waste heat boilers (boilers that recover gas turbine heat for hotel load purposes) on other ship classes. This led to a recommendation to use all electric auxiliary systems in the DDG-51.

Originally, diesel generator sets were considered for auxiliary power generation, which would have been more efficient than gas turbines. However, because of serious maintenance problems with the FFG-7 class diesel generator set, the Navy selected the DDA 501-K17/K36 gas turbine system family, already being used in the DD-963 and CG-47 classes.

As the DDG-51 design has evolved, the only changes affecting fuel efficiency have been incremental ones, resulting from the legacy system ship energy efficiency program described earlier (improved hull coatings, lighting, HVAC (Heating, Ventilation and Air Conditioning), stern flaps, etc.). The Navy has not aggressively pursued improved efficiency in the remaining designs or in addressing the technical obstacles to implementing more efficient systems.

INTERCOOLED, RECUPERATED, GAS TURBINE ENGINE (ICR)

The ICR gas turbine engine is an advanced cycle system that includes a water-cooled intercooler between compressor stages and a recuperator to recover exhaust heat prior to the combustor. This engine is currently under development for surface ship main propulsion applications with a targeted efficiency improvement of 30 percent compared to current simple cycle systems.

ICR design studies began in 1984 and in 1987 and the Center for Naval Analysis completed a cost effectiveness study for the system. This analysis assumed that the all planned new construction ships beginning in 1993 would use the engine, with operation beginning in 1996. An efficiency improvement of 30% was assumed and a sensitivity analysis was conducted assuming different fuel inflation rates and discount factors. The initial fuel price used was $31.50/bbl ($0.75/gallon), the DESC standard price in 1987. The study showed that by assuming fuel prices increased at the general inflation rate, and using a discount factor of 6 percent, the program would break even in 28 years.

Notably, the report cited the significant military advantages provided by the system, including increased range and/or payload, reduced infrared signature, and the synergistic benefits inherent in a battle group comprising ships with this system. The report discussed the option of using the Navy estimated delivered price of $51.37/bbl ($1.22/gallon) rather than the standard price, but did not do so. The reason given was that even with a 30 percent improvement in fuel efficiency for a large part of the fleet and a reduced POL logistics requirement, the Navy would be unlikely to reduce fuel supply infrastructure.

In spite of the performance and economic benefits promised, an ICR development contract was not signed until 1992 and, because of a series of funding crises and delays, the program will not be completed until 2002. The UK and French Navies became partners in the development program and will perform the final test and evaluation work. However, there are no firm plans to use this engine in any future U S Navy ship. The first warship to use the engine will probably be of European design.

IV e. Investing in Research and Development to Revolutionize Warfighting

The terms of reference asked the task force to identify “technologies with the greatest potential to begin implementation within the next 10 years.” This report focuses principally on technologies and policies to enhance fuel efficiency in the short term (now and in the next few years). Such near term opportunities merit a closer look with a more complete analysis of warfighting and cost reduction benefits. However, the task force also devoted a two-day meeting at the Massachusetts Institute of Technology to bring together some notable visionaries who, in the opinion of the task force, are conducting research into technologies most likely to revolutionize the nature of warfare over the longer term. The task force chose specific technology areas (advanced power generation, biomimetics, robotics, advanced materials, etc) to investigate based on their ability to deliver capability in an inherently more efficient manner than is possible with today’s technology. These technologies have the potential to revolutionize the way energy is produced and used in warfighting.

The DoD is totally responsible for preparing platforms and systems for active engagement, including establishing performance requirements, planning, research and development, acquisition, logistics, operational support, and ultimate disposal at the end of its useful life. This encompasses legacy vehicles as well as developmental and new platforms. Part of any research and development portfolio should take advantage of science and engineering developments to provide enabling technologies for revolutionary improvements in fuel efficiency to more effectively enhance and extend warfighting capability.

A key step in determining longer-range research and development direction is establishing a complete set of desirable attributes for advanced systems. Even though performance of warfighters and their weapons is frequently dependent on fuel conversion efficiency for propulsion and targeting, there is rarely a direct connection made to improved energy efficiency on such systems. For example, revolutionary systems may be significantly smaller, lighter and smarter with substantial cost and energy savings and with a reduced logistical tail. The task force found it useful to think of the potential of specific technologies to benefit warfighting capability in these terms.

Because fuel use is inherent in virtually every aspect of military apparatus and operations, it is important to consider revolutionary rather than evolutionary strategies and to raise our vision toward larger goals.

The task force extends its special thanks to the following presenters for volunteering their time, and for their thoughtful insights on technologies to revolutionize energy usage for warfighting:

Space Technologies & Capabilities
Dr. Ivan Beckey

Power and Actuation for Future Robotic Systems
Dr. Ephrahim Garcia
DARPA

Battery Storage and Capacity Technologies
Dr. Ian Grant
Evonynx,. Inc

Thin Film Layered Batteries
Professor Donald Sadoway
Massachusetts Institute of Technology

The MIT Microengine Project
Professor Alan Epstein
Massachusetts Institute of Technology

Aerospace Transportation and Advanced Systems
Dr. Jim McMichael
Georgia Institute of Technology Research Institute

Advanced Ultralight Airframe Design
David Taggart
Hypercar, Inc.

Carbon Nanotube Technology for High Density Hydrogen Storage
Dr. Michael Heben
National Renewable Energy Laboratory

IV e.1 Opportunities for Revolutionary Long term Research and Development

Based on the outcome of the MIT workshop, the task force concluded there are a number of research opportunities that might produce revolutionary improvements:

- Autonomous and/or remotely controlled robotic devices, with or without human intervention, will play an increasing role in warfighting with the potential of substantial decreases in energy use.

- Focusing on smaller, lighter and smarter systems will lead to very significant energy and cost savings if this metric is properly integrated into DoD's research, development and acquisition goals. Energy performance objectives (fuel conversion efficiency, energy storage attributes, and emissions) should be added to Science & Technology and development work (6.1, 6.2, 6.3 programs).

- Lighter storage may not cost more. For example, a conceptual 95 percent carbon-fiber composite advanced tactical fighter aircraft was 1/3 lighter, yet 2/3 cheaper than its metal predecessor.

- Efficient energy supply and usage are crucial to the full range of warfighting uses to increase performance and warfighting capability, from the individual warrior, to a tank and to large scale combat systems such as ships and aircraft.

- Fundamental changes are needed in the way new platforms are developed and fielded in order to take advantage of revolutionary advances in biomimetics, genomics, nanotechnology, and information technology that are rapidly occurring outside the military.

A balanced portfolio of both basic and applied research and development has the potential to accelerate the integration of efficient component technologies into future generation weapons platforms. Several relevant examples are:

- The joint DARPA and Army Combat Hybrid Power Systems (CHPS) Program
- Shipboard Electric propulsion
- Uninhabited vehicles
- Information fusion, including sensors, controls, data base management and expert systems
- Advanced materials and design integration to achieve breakthrough performance from existing technologies.
- Smarter weapons
- Increasing role of autonomous, unmanned remote systems
- System survivability – includes active and passive armor, low signature, or redundancy and remote system expendability
- High energy density of propellants
- Increased electrification (generation, storage, and distribution

IV e.2 Conclusions and Observations on Pursuing Revolutionary Warfighting

By pursuing the research opportunities discussed above, very large reductions in fuel requirements may be possible in out year systems. The task force believes DoD should consider the following in evaluating its future technology needs:

- Energy performance must be part of the overall equation of selecting Science and Technology (6.1 and 6.2), research and development (6.3 and 6.4) and technology deployment (6.5 and beyond) investments.

- Rapidly evolving information, robotics and energy conversion technologies merit a higher priority for investment.

- Changes toward robotics and uninhabited vehicles will reduce demands on energy, and hence will act to cut energy consumption, and reduce associated local, regional and global pollution. Many vehicle system improvements offer revolutionary increases in performance and economy, or decreases in size.

- Information gathering will grow through new and improved sensors, sensor data delivery techniques, and communication systems. Management techniques for assimilating the data to produce clear, relevant and useful information for action is a severe challenge, and deserves high priority.

- Rapid change will be a consequence of advances by competitors, and of perceptive planners/researchers who produce unanticipated technological breakthroughs. It will be prudent for DoD to continue to strengthen its lead in scientific research and to serve as an incubator for developing breakthrough, revolutionary technologies.

- The spread of technological progress in the private marketplace heightens the risks of asymmetrical warfare. Homemade crude missiles are no longer impossible. At the speed of Moore's law (which is slower than current advances in photonics or wireless communications), a 20-year old platform can be 10,000 times less capable per dollar than current commercial consumer electronics products.

- Developing leadership capabilities and attitudes is especially important to DoD's ability to identify useful new technologies and translate them quickly into operational capabilities. DoD should be especially careful to seek out breakthrough technologies not developed within the DoD, but should be attuned to the direction technology development is moving in industry and by international competitors.

V. Findings and Recommendations

V a. Findings

Finding #1

Although significant warfighting, logistics and cost benefits occur when weapons systems are made more fuel-efficient, these benefits are not valued or emphasized in the DoD requirements and acquisition processes.

Military requirements documents understandably place the highest priority on performance. However, defining performance too narrowly imposes a substantial provisioning and maintenance penalty. There have been efforts to reduce support costs by improving certain platform features, but they too have focused narrowly. For example, recent DoD policy guidance placed heavy emphasis on improving reliability as a way to reduce support costs and logistics burden. However, substantial performance gains can also be achieved through improving the efficiency of platforms and systems in other ways. These opportunities are overlooked because the analyses used to identify cost drivers do not include important factors. Making a platform more fuel efficient also improves its combat capability by increasing range and payload, and reducing combat vulnerability. In terms of their broader contribution to warfighting capability, more efficient platforms are more deployable and sustainable. To optimize costs and capability, all these factors must be considered as integral to the whole combat system. Current approaches overlook opportunities to deliver more capability at less cost.

The Service laboratories that briefed the task force described the capability improvements that would result from better efficiency focused on an individual platform. The Air Force and Army quantified the increase in range possible for aircraft and tanks based on adoption of specific technologies. They also made calculations of how much less time it would take to deploy specific missions. However, the broader issue of how to quantify its impact on the capability of the entire force was ill defined. There is no way to know how many fewer F-16s would be required to accomplish a specific mission if they had greater payload or range because of a more efficient engine. This is an invisible, but real, force multiplier.

When considered as part of an end-to-end and interdependent force, making changes to a fleet of platforms can significantly impact requirements for other parts of the force structures. Achieving this higher level of analytical integration is fundamental to moving toward the goals of the future vision documents. These documents also all have efficiency as a central theme, by focusing on agility, deployability and sustainability. However, Operational Requirements Documents (ORDs), Mission Needs Statements (MNS) and Capstone Requirements Documents, do not explicitly require efficiency. As a result, there are no metrics that quantify platform or system efficiency generally, or fuel-efficiency specifically. This is one of the reasons the acquisition process lacks analytical tools to perform trades between efficiency and other options that improve capability.

The Services sometimes contended that range and payload act as a proxy for fuel efficiency. However, this is a very inexact metric and it does not include the significant benefit of reduced logistics and support requirements that would result. If ORDs contained specific efficiency criteria (particularly if the efficiency metric was a key performance parameter (KPP)), acquisition programs would develop tools to treat efficiency as an independent variable comparable to current procedures that trade off cost as an independent variable (CAIV)). Efficiency would become a major variable in making final weapons system performance decisions.

Finding #2

The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices.

DESC acts as DoD's energy market consolidator and wholesale agent. To simplify accounting, OSD establishes a "standard fuel price" annually. This price includes the cost for purchasing the fuel from the world market, plus DESC operating costs. The DESC price does not reflect the cost to the Services of moving the fuel from the DESC supply point to the ultimate consumer, such as a tank, ship or aircraft. These delivery costs are absorbed in each military service budget and are spread across many accounts, making the actual cost of delivered fuel uncomputed, unknown and not factored into important investment decisions.

The difference between the price and true cost reflect what the Services must pay to deliver the fuel. In FY99, the standard DESC fuel mix price (average price of the fuels sold) was $0.87 per gallon, in FY00 it was $0.62 per gallon, in FY01 it is $1.01 per gallon, and in FY 02 it will be $1.337. But the true cost of these fuels delivered to weapons platforms is much higher. To deliver a gallon of fuel through a tanker in-flight costs $17.50 per gallon. To deliver a gallon of fuel to the forward edge of a battle area (FEBA) costs about $15.00. To deliver a gallon of fuel far beyond the FEBA costs hundreds of dollars per gallon. These costs are not used in economic analyses used to make decisions about investing in efficiency. This produces a sub-optimal allocation of resources.

The Services maintain huge infrastructures to ensure fuel delivery. Large and small surface trucking organizations, naval fleet tankers and aerial refueling aircraft, along with substantial maintenance and logistics organizations contribute to considerable overhead costs. Increases in fuel efficiency would correspondingly shrink this overhead burden, enabling savings through reductions in logistics requirements far in excess of the investment. These savings accrue largely during peacetime, and represent opportunities to shift financial resources from logistics to operations, or from "tail to tooth", over time. However, realizing these savings requires a leadership willing to make the vertical cuts necessary to right-size the force structure.

If the true costs of fuel delivery and supporting infrastructure (including equipment, people, facilities and other overhead costs) were known, understood and factored into the cost of fuel, the requirements and acquisition processes would be more focused on the true benefits of improving platform efficiency. This would create incentives for DoD to integrate efficiency into those processes, thereby cutting battlefield fuel demand and reducing the fuel logistics structure.

Until policy guidance requires emphasis on weapons system fuel efficiency and the true cost of provisioning fuel to end users is gathered and understood, there is no incentive for leaders, managers or operators to depart from current practice. Clear policy guidance will enable the DoD to achieve the deployability, agility and sustainability required by joint doctrine.

Finding #3

The DoD resource allocation and accounting processes (PPBS, DoD Comptroller) do not reward fuel efficiency or penalize inefficiency.

In the business world, financial reporting reflects the priorities and policies of leadership to insure tight coupling between input and output. However, in DoD fuel efficiency investments there is weak and inaccurate linkage between allocation of resources and mission outcome, despite efforts to make such a linkage. Historically, interest in fuel and energy efficiency has largely been limited to meeting federal executive order or legislative mandates. Since federal mandates usually do not apply to military weapons systems, there is neither a policy focus nor resource incentives to seek operational fuel efficiencies. Management will focus on fuel efficiency when analyses quantify the operational, logistics, and environmental costs of unrestrained fuel use, and the economic savings from efficiency investments.

An incentive to significantly improve platform fuel efficiency is missing from the planning, programming and budgeting system (PPBS). Because of a lack of analytical tools to quantify warfighting benefits the contribution to capability is understated. A consequence is that Operational Requirements Documents do not explicitly require efficiency. The subsidized fuel pricing also distorts the economic picture by understating economic benefits. The consequence is that investments to improve efficiency do not compete well (or at all) in the PPBS.

Funding to make platforms more efficient often requires investment from an acquisition program or maintenance account to change hardware. However, it is the operations and support accounts that benefit from these investments. In the business world this is called a “split incentive.” While the DoD has made progress in factoring support costs into acquisition decisions, the analysis used to determine the appropriate level of investment is hampered by the artificially low fuel price and an inability to describe the contribution to warfighting capability in a meaningful way.

Other disincentives include comptroller practices that penalize commanders that reduce energy costs by reducing their budgets. Comptrollers should consider the benefit of incentivizing managers of operations and support accounts by sharing the savings from energy efficiency investments.

Finding #4

Operational and logistics wargaming of fuel requirements is not cross-linked to the Service requirements development or acquisition program processes.

Operational and logistics wargaming focuses on mission execution, considering fuel as a fixed demand to be satisfied. Modeling used to determine requirements and to make acquisition trade-offs may examine fuel demand but are mainly focused on performance satisfaction. Availability of POL logistics is considered a "given" and not a factor for consideration. With little understanding of the end-to-end cost and logistics assets dedicated to the energy/fuel provisioning process, the operator and logistician are unaware of the potential positive impact of fuel efficiency on warfighting effectiveness.

Wargaming provides commanders with the most important lessons to win in battle. The task force made many inquiries about how fuel efficiency is played in wargames, but only received examples of games that focused on exercising the logistics pipeline to ensure it met the logistics requirements generated by the operational forces. An example is the Focused Logistics Wargame (FLOW). While war plans generally address adequacy of logistics, wargames do not. Because they assume perfect logistics, commanders are not forced to develop battlefield work-arounds. This is because tactical wargames generally do not simulate conditions to a level of detail to reveal how battlefield fuel shortfalls could impact battlefield maneuverability or tactics.

With little to no understanding of the end-to-end cost of the energy/fuel provisioning process, nor the impact on military operations resulting from a fuel shortfall, the operator and logistician are unaware of the potential impact of fuel use on warfighting effectiveness. By including logistics to a high level of fidelity in tactical wargames, the requirements determination and acquisition processes could gain insight into how improving fuel efficiency could reduce logistics burden and improve battlefield sustainability. It could also help reveal and focus attention on the vulnerability of the logistics tail.

The concept behind DARPA's Advanced Logistics Program approaches in some respects the analytical linkages the task force recommends. It models an objective force and the logistics requirements of each of its component pieces as a function of time and mission. The output includes a description of the logistics force structure needed to support that force for that mission. However, it is not possible to conduct sensitivity analyses by changing the fuel demand of various elements of deployed systems and determining the resulting logistics impact, deployment and sustainment times, or increase in operational capability.

Collecting fuel data necessary for this type of analysis represents a significant challenge. This is because end-to-end fuel consumption data is not systematically collected or analyzed, nor is it resident in a central location. Some important data regarding fuel consumption was eventually collected to accomplish this study but in many cases the data requested was unobtainable.

For example, only FY97-99 fuel consumption data by platform or system was available from the Air Force. Platform-specific data for contingency operations, such as Desert Storm or Kosovo, were not available. While such data may exist somewhere, they were not readily obtainable for this study. Detailed fuel consumption for Navy ships was available, but not for naval aircraft. The Army explained that these data were maintained at the local level and not aggregated or kept centrally.

Each Service has developed its own policies and procedures to quantify the benefits of specific investments and prioritize its options. For this reason, each Service must develop its own methodology for holistically valuing investments that improve efficiency and integrating those into its decision-making processes. Without extensive analysis beyond the scope of this study, it is not possible to tell the Air Force precisely how many tanker equivalents it offsets by improving the fuel efficiency of its B-52H fleet, or what the total lifecycle ownership cost advantages would be of such a decision. However, these kinds of questions need to be answered to understand where to focus resources, including research to get the best returns.

Future vision statements recognize the importance of efficiency to capability. However, translating these concepts into more deployable and sustainable systems requires DoD to achieve a higher level of integration in its force structure modeling. The technology to build these more highly integrated models is available, but the DoD has not upgraded its analytical capability.

Finding #5

High payoff, fuel-efficient technologies are available now to improve warfighting effectiveness in current weapon systems through retrofit and in new systems acquisition.

Existing and emerging technologies are available now, at all stages of maturity, that could materially improve weapons systems efficiencies and performance, but the current assessment models place insufficient weight and value on their efficiency merits. Technologies that improve platform and system efficiency come to light when the S&T community is specifically asked to present them as opportunities to improve efficiency, but are not otherwise obvious. With few exceptions, technologies that improve efficiency are not developed for that purpose and are not presented in a way makes their contribution to efficiency improvements obvious.

In almost every case, the research laboratories had not been previously asked to focus directly on fuel-efficiency. When laboratories did present the capability improvements that would result from implementing specific technologies, they were generally expressed for a single platform, such as a specific increase in range, payload or time over target. The collective warfighting benefit of an inventory of platforms with this enhanced capability in a force-on-force simulation was not available.

Most of the technologies offer incremental improvements to specific air, seas or land platforms, and, no single technology offers substantial efficiency improvements across multiple platforms. This lack of a single obvious high impact technology obscures the collective impact of multiple technologies. Significant reductions in fuel demand and associated logistics can be achieved if decision processes are changed to include a more holistic view of the value of efficiency improvements.

The task force examined several Service studies that resulted in decisions not to implement a proposed efficiency for near term cost reasons. The analyses were overly near term cost-sensitive, thereby forgoing significant near and long term operational, performance, logistical, and reliability gains (B-52 re-engining; M1A1/2 auxiliary power unit; naval stern flap). For example, the B-52 study shows that re-engining significantly reduces tanker force structure requirements.

An analytical tool that could link the total improvement in warfighting capability to specific efficiency/effectiveness benefits would result in materially different characterizations of these investment opportunities, and possibly different investment decisions.

V b. Recommendations

Recommendation #1

Base investment decisions on the true cost of delivered fuel and on warfighting and environmental benefits.

The DoD must take several actions to break the cycle of hidden costs caused by relying on the low DESC standard fuel price in order to take full advantage of more capable and efficient weapons platforms. Several policy changes in the requirement generation process, the Science & Technology investment program, the acquisition system and in wargaming and force structure planning must be implemented to achieve these goals.

One of the most important actions is to broaden the use of activity-based cost accounting to routinely determine the true cost of providing fuel. The task force recommends DoD use the true delivered cost, rather than the artificially low "standard price," when evaluating proposed retrofits for legacy systems, conducting Assessments of Alternatives for new platforms, making Science and Technology investments and determining total ownership costs.

The task force recommends that the Department:

- Implement accounting mechanisms to reveal true cost of delivered fuel and identify decision points where it would be appropriate to use the full cost as the basis for economic analyses.

- Classify all assets used for fuel delivery as logistics costs, thereby enabling commanders to benefit by reducing POL logistics requirements.

- Direct that the total cost of delivered fuel be used in all cost-benefit calculations that support retrofit, acquisition, S&T investments, and other decisions where economic considerations are a factor.

- Increase the visibility of comprehensive energy consumption data by establishing an energy database to support meaningful future analyses of options for increasing operational capability and reducing POL logistics requirements.

- Use fuel data collected to establish energy efficiency metrics for use in all ORDs and Capstone documents based on savings, capability improvements, and other policy objectives.

In addition to economic considerations, there are environmental benefits to improving efficiency, which may have operational as well as economic value to the DoD. The DoD should institute a standard practice of conducting assessments comparing the environmental performance of new systems with the systems they replace, with the objective of taking advantage of pollution credits or other available benefits.

Recommendation #2

Strengthen linkage between warfighting capability and fuel logistics requirements through wargaming and new analytical tools.

Wargaming and analysis play key roles in requirements setting, strategy development and combat commander training. It is essential that battlefield fuel demand be thoroughly integrated into gaming, and investments be made in readily available, easy-to-use, rapid analytical tools that can reveal opportunities to improve capability through improved fuel efficiency. These are the first steps in creating awareness of the operational benefits of improving the efficiency of platforms and systems. As discussed in Section IIIa of the report, the analytical linkage between platform demands and the resulting logistics requirements is not well developed. While Section IIIb introduces the total cost of fuel by pricing the ownership of the logistics assets needed to deliver the fuel, it is only a surrogate for the logistics assets because the funds will only be saved if the logistics force structure is reduced.

The DoD conducts different types of wargames for different purposes. Tactical wargames are typically short duration, and typically assume perfect logistics. However, these wargames should include logistics to a level of granularity adequate to identify the specific capability limitations or operational “work-arounds” that shortfalls impose on operational commanders, and potential logistics vulnerabilities exploitable by adversaries. Logistics should be played and when it breaks, wargamers must account for it rather than continue to force movements as though logistics were available. This important issue should be incorporated into the ongoing Dynamic Commitment Wargame series. Logistics-specific wargames, such as the Focused Logistics Wargame (FLOW), must not only focus on how well the logistics pipeline delivers the materials required by the warplans, but also address the impact of platform requirements on logistics burden.

When fielded, DARPA's Advanced Logistics Program will enable sensitivity analyses to determine the logistics impact of reduced platform requirements, but does not address how they would enhance warfighting capability.

The task force recommends that the Department:

- Develop and implement tactical wargames that realistically incorporate fuel logistics and address the operational impacts of the current battlefield and battlespace fuel logistics burden.

- Develop analytical models to quantify the warfighting benefits improving platform and system efficiency would contribute to DPG requirements. These include:

    - deployment and sustainment improvements,

    - logistics reductions, including logistics platforms (e.g., tankers, oilers, fuel trucks, people, training, etc).

    - operational improvements, such as range, payload, time over target, increased optempo (operational tempo), and

    - the overall ability to execute the same mission using fewer platforms.

These sharper analytical tools should enable sensitivity analyses to determine the operational capability and logistics impacts that would result from changing fuel demand of specific platforms and systems. One example would be to update the Army's FASTALS modeling tool, enabling it to be quickly responsive to information needs of the requirements determination process or acquisition programs regarding the logistics implications of changes to platform performance features.

While this Task Force focused only on fuel, broadening the definition of platform efficiency might enable comparable improvements in capability, logistics and cost by reducing other logistics and support requirements. Analytically linking capability to other logistics and support requirements, such as people or parts, would result in a more holistic way of improving the efficiency with which platforms fulfill their missions. The analytical model described above could be expanded to encompass a sensitivity analysis of the impacts of making platform efficiency improvements in other areas.

Recommendation #3

Provide leadership that incentivizes fuel efficiency throughout the DoD.

For the DoD to take advantage of the large cost and performance benefits of significant improvements in weapons platform fuel efficiency, senior civilian and military leadership must set the tone and agenda within the Department. Leadership must begin promoting the message that efficiency at the tactical platform and system level is a clear strategic path to improve performance, reduce logistics burden and free resources for modernization and readiness.

It is essential that the requirements determination community, specifically the Joint Requirements Oversight Council (JROC) and the Services organizations that input to the JROC, recognize the importance of their decisions in creating the existing scale of logistics infrastructure. Having created the existing scale of the logistics infrastructure, they have the ability and an important obligation to reduce the demand on logistics infrastructure by requiring efficient platforms and systems. This recognition of responsibility at all levels, and willingness to implement analytical tools that can reveal where the opportunities exist and act on analytically indicated opportunities are necessary departmental leadership roles.

The task force recommends that the Department:

- Develop and implement incentives for operational users to find ways to become more efficient in training, exercise and combat operations, similar to NAVSEA's Encon Program in which operational commanders are permitted to keep a portion of the financial savings for local priorities rather than relinquishing the entire savings to the comptroller.

- Issue a policy memorandum recognizing efficiency at the platform level as an important element of becoming more agile, deployable, sustainable and reducing support costs.

Recommendation #4

Specifically target fuel efficiency improvements through investments in Science and Technology and systems designs.

While DoD laboratories were able to describe a large number of technologies in their portfolios that could improve the efficiency of platforms and systems, a consistent message was that their customers, the operators, were not asking for efficiency. A notable and recent exception is the Army in its Transformation effort. The Army's Transformation goals are strongly linked to improving efficiency, and Army Research Laboratory was able to describe how much faster the Desert Storm deployment would have been with a more efficient main battle tank. However, even the Army's analytical tools for determining overall logistics benefits are expensive to use, not linked to capability and indirectly linked to cost.

The Science & Technology community should specifically review its overall investment and make platform fuel efficiency a primary focus to identify, track and package technologies that improve efficiency and reduce operations and support costs. Highlighting the potential of a mix of technologies to improve the warfighting capability of fleets of specific platforms through higher efficiency gives operators greater flexibility in choosing retrofit and new system features that minimize support requirements and maximize overall operational capability. While the laboratories were able to describe how much more range, payload or speed a specific platform would achieve with implementation of a specific technology, they were not able to describe the overall impact on the force structure's ability to execute the DPG requirements.

In addition to pursuing more mature technologies that improve efficiency, it is essential that the DoD support fundamental science (6.1, 6.2) investments that can lead to revolutionary improvements in the efficiency of tomorrow's weapon platforms and systems.

The task force recommends that the Department:

- Increase S&T investments in technologies that offer greatest capability improvements as retrofits to legacy systems or as features in future platforms.

- Change retrofit decision rules to encompass total life cycle benefit of the investment, and include true cost of fuel and all benefits in the analyses.

- Charge laboratories and force structure planners to jointly evaluate operational benefits of specific technologies based on wargame and end-to-end capability analyses.

- Maintain a robust fundamental science investment to enable future revolutionary improvements in weapons platforms.

The Science and Technology community should also specifically identify, track and package technologies that improve platform efficiency, and determine their collective contribution to capability, logistics and cost improvements. This should be a standard way of evaluating the benefits of specific technologies. It would enable the laboratories and their customers to more effectively advocate investments in technologies that improve efficiency in the PPBS. Finally, only continued support for fundamental research today can pave tomorrow's way to revolutionary new fuel-efficient platforms.

Recommendation #5

Explicitly include fuel efficiency in requirements and acquisition processes.

Joint Vision 2010 / 2020 and the Army Transformation emphasize agility as an important operational capability to counter diverse and asymmetric post-Cold War threats. Efficiency is a strong component of agility. However, in order to produce more agile and efficient forces, these qualities must be translated into quantifiable and measurable performance criteria and inserted into the requirements determination processes. Capstone documents, Mission Needs Statements (MNS) and Operational Requirements Documents (ORDs) must directly address efficiency issues at platform and total force levels.

Program requirements currently either do not address efficiency directly, or only at a highly aggregated level, e.g., number of C-17 equivalents to deploy and sustain for a period of time. Because efficiency is not explicitly required, the acquisition process has not developed or applied the tools necessary to holistically consider the value of investments in efficiency improvements, or trade them off against other investments that improve capability.

The DoD should develop and apply an efficiency metric for platforms and systems, preferably as a key performance parameter (KPP), and apply it to all appropriate programs. This will drive the development of analytical tools to trade off efficiency investments against other competing needs. Studies such as Analyses of Alternatives (AoA) would then treat efficiency as an independent variable. Constraining the logistics required to deploy and sustain forces will begin to create a necessary shift in force structure from "tail" to "tooth".

The task force recommends that the Department:

- Incorporate efficiency into:
  - Requirements processes (Capstone, MNS, ORDs)
  - Acquisition processes as KPPs, which will in turn drive their use in Exit Criteria and AoAs
  - Multiyear planning, programming and budgeting (POM) decisions
  - Acquisition reform

- Require program offices to use true cost of delivered fuel to calculate platform total ownership costs

- Use results of wargames and capability analyses as the inputs to program office trade-off studies that quantify the logistics support requirements created by their design decisions.

Summary

The magnitude of the DoD's fuel consumption indicates substantial changes must be made in the performance that the DoD requires of its future systems in order to achieve the goals of Joint Vision 2010 and 2020. To shift the focus more toward efficiency will require the highest levels of leadership to recognize the need to improve efficiency and issue strong and unambiguous policy.

Implementing these recommendations will help the DoD realize the goals of Joint Visions 2010 and 2020 by more closely integrating the requirements determination process, acquisition, wargaming and logistics. A more rigorous analytical approach to force structure decisions will enable the DoD to lead the next revolutionary change in warfighting.

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

ACQUISITION AND
TECHNOLOGY

JUN 18 1999

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms

You are requested to form a Defense Science Board (DSB) Task Force to identify technologies that improve fuel efficiency of the full range of weapons platforms (land, sea, and air) and assess their operational, logistical, cost, and environmental impacts for a range of practical implementation scenarios.

You should specifically identify fuel-efficient technologies (broadly defined to include new or improved fuels, engines, Alternative Fueled Vehicles, and other advanced technologies) throughout the research, development, test and evaluation pipeline, with an emphasis on those with the greatest potential to begin implementation within the next 10 years.

Specifically, the Task Force should evaluate each technology in terms of the following:

1. OPERATIONS: Weapons Platforms which require less fuel to operate at performance levels necessary to accomplish their mission would be able to remain engaged for longer periods of time, carry additional payload, reach targets from greater distances, require less refueling, or a combination of the preceding depending on operational requirements. The Task Force should estimate the increase in operational performance.

2. LOGISTICS: Fossil fuels represent a significant proportion of the logistics burden needed to support forward air, ground and sea operations. Reducing the logistics tail acts as a force multiplier in a variety of ways. The Task Force should estimate the reduction in logistics tail associated with efficiency improvements in platform performance, and coordinate closely with the relevant logistics organizations to fully understand and quantify the range of benefits.

3. COSTS: Lower fuel consumption reduces the contribution of fuel to the costs of operations and logistics. The Task Force should address the costs and benefits of each technology area for the range of implementation scenarios. The methodology for evaluating cost, operational, logistics and other effects should be similar to the Cost and Operational Effectiveness Analysis (COEA) methodology used to evaluate other investments in weapons system performance improvements.

4. ENVIRONMENTAL: The accumulation of carbon dioxide and other greenhouse gases (GHG) in the atmosphere may result in rapid global warming. Carbon dioxide and

other pollutants are released from burning fossil fuels, and propulsion systems on weapons platforms burn large quantities of fossil fuels. Globally, the burning of fossil fuels is the largest anthropogenic source of carbon dioxide, which is responsible for over 85% of the total increase in GHG accumulation in the atmosphere. The Federal Government consumes approximately 2% of the nations' total energy, and the Department of Defense consumes approximately 75% of the Federal Government total. Jet fuel represents the largest portion of the DoD total. The Task Force should estimate the corresponding decrease in GHG emissions from the application of advanced technologies.

Illustrative of the types of programs the Task Force should evaluate is the Integrated High Performance Turbine Engine Technology (IHPTET) program. This is a joint DoD/industry initiative designed to produce a series of technologies that continuously improve the performance and efficiency of turbine engines. A second example is the advanced diesel technologies which increase fuel efficiency and reduce the logistics burden. Finally, the Navy's Stern Flap Design is an example which reduces fuel consumption from ships while underway by up to 20 percent. The Stern Flap is already scheduled for implementation on some conventionally powered ships. The Task Force should include all three efforts in their study.

The Task Force will provide advice, recommendations and supporting rationale that addresses research, development, test, evaluation, and acquisition funding of the technologies for OSD, the Military Departments, the Joint Staff, Unified and Specified Commands, Defense Agencies, and DoD Field Activities.

The Task Force should: (a) submit its final report by January 31, 2001, (b) include an assessment of the costs, benefits and risks for each technology and implementation scenario.

The Deputy Under Secretary of Defense (Environmental Security) and Deputy Under Secretary of Defense (Science and Technology) will co-sponsor this Task Force. VADM Richard H. Truly, USN (Ret) and Mr. Al Alm will serve as co -chairmen of the Task Force. Mr. Kevin Doxey will serve as the Executive Secretary and CDR Brian Hughes will serve as the Defense Science Board Secretariat representative.

The Task Force will be operated according to the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5104.5, "DoD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, United States Code, nor will it cause any member to be place in the position of acting as a procurement official.

J. S. Gansler

Appendix B

Translating Energy Savings into Environmental Benefits

This Defense Science Report documents that warfighting capability is increased by improving the energy efficiency of weapons platforms and systems. In addition to improved warfighting, more efficient platforms and systems also reduce the environmental footprint, or improve the environmental performance, of the DoD. This appendix describes information sources, simple tools, and consulting services that can be used to quantify the environmental benefits of energy efficiency improvements.

The Full Benefit/Cost Equation

Investment in energy efficiency has multiple benefits that are cumulative:

- +Warfighting Capability
  - Stealth (less heat, noise, and emissions signature)
  - Logistics (more tooth, less tail)
  - Deployment (faster, further)
- +Environmental Protection
  - Less carbon dioxide, sulfur, nitrogen oxide, and other pollutants
    - Reducing climate change, acid rain, smog, particulates, etc.
  - Improved human health
  - More productive agriculture and healthier natural ecosystems
  - Avoided costs of increased storms and sea level rise
- +Energy Independence
  - Less vulnerable energy supply, stable prices, investment security
- -Cost of Energy Investment
  - Offset by future energy savings
- =Net Benefit of Investment in Energy Efficiency/Warfighting Capability

Translating Energy Savings into Environmental Benefits

Fossil fuel combustion and electricity use can easily be translated into environmental impact. The environmental impact of air emissions caused by electricity generation can be compared to familiar air pollution sources such as automobile emissions.

> Calculations of total emissions resulting from direct fuel combustion in aircraft, ships, vehicles, and buildings depends primarily on the quality and quantity of fuel consumed.
>
> Calculations of emissions from electricity depend on how the electricity is produced. Wind and solar power have emissions only from the materials, manufacture, and disposal of the equipment while coal-fired powerplants have

emissions that also include coal mining, transport, combustion, and waste disposal. The emissions from electricity produced by public utilities depend on the combination of electricity generation in a particular location. Simple calculations typically use average regional pollution factors, but it is possible to further refine the calculation to reflect specific electricity sources. Emissions can be directly calculated from fuel consumption where electricity is locally generated for military use.

The United States Environmental Protection Agency is offering military organizations reference documents and consulting services to accurately translate fuel and electricity use into environmental indicators.

EPA emissions calculation reference documents can be downloaded from:
http://www.epa.gov/oms/ap42.htm
http://www.epa.gov/acidrain/egrid/egrid.html

EPA plans to provide a website that will automate environmental benefit calculations.

Military organizations can obtain EPA consulting services by contacting Mr. Caley Johnson or Dr. Stephen Andersen at:

U.S. Environmental Protection Agency
Climate Protection Partnerships Division
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Appendix C

Futures Overview

This paper is a summary of a presentation to the Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms given by Dr. Paul MacCready at a Future Warfighting Vision Meeting at the Massachusetts Institute of Technology on September 19, 2000.

Dr. Paul MacCready earned his B.S. in physics from Yale in 1947, a Ph.D. in physics from the California Institute of Technology in 1948 and a second Ph.D. in aeronautics at Caltech in 1952.

MacCready is renowned for his design of ultra-light flight vehicles. His human-powered Gossamer Condor won the £50,000 award offered by British industrialist Henry Kremer by flying a figure-eight course around two pylons one-half mile apart. The Gossamer Albatross won a £100,000 Kremer Award for its human-powered flight from England to France in 1979. The Condor is in the Smithsonian's National Air and Space Museum beside the Wright Flyer and Lindbergh's Spirit of St. Louis.

With GM support, his Sunraycer won the first solar car race across Australia. He later conceived and built GM's Impact battery-powered demonstrator car, predecessor to the production EV-1. In 1998, his giant solar-powered Pathfinder climbed to 80,200 feet.

In 1970 MacCready founded AeroVironment, Inc., a 100-person company working on problems of air quality, alternative energy sources and products related to atmospheric monitoring and energy efficiency. With NASA support, AeroVironment is building a new generation of lightweight solar-powered planes to ascend high into the stratosphere and remain there for months, possibly serving as high bandwidth communications stations. AeroVironment designs micro air vehicles and palm-size battery-powered crafts equipped with tiny video cameras that could provide real-time reconnaissance for soldiers in the field.

Dr. MacCready's many awards and honors include: "Engineer of the Century" Gold Medal, 1980; the 1982 Lindberg Award; the 1979 Collier Trophy. He is a Fellow of the American Institute of Aeronautics and Astronautics, is the American Meteorogical Society, and is International President of the International Human Powered Vehicle Association. His professional and personal interests fit the theme of causing rapid change in institutions, technologies and public understanding in order to improve the likelihood of a desirable and sustainable future world.

A 10 Year Perspective Encompasses Some Revolutions

The Task Force directive states:

"…identify fuel-efficient technologies (broadly defined to include new or improved fuels, engines, alternatively fueled vehicles and other advanced technologies) throughout the research, development, test and evaluation pipeline, with emphasis on those with the greatest potential to begin implementation within the next 10 years."

The emphasis on a 10-year horizon might be taken as limiting consideration here to ''practical" improvements of existing or planned systems. However, as information technology, science, and robotics play increasing roles, some of the relevant time constants move toward the fast changes of Silicon Valley and away from the relatively slower changes in technologies and habits associated with high-inertia fields such as aerospace, transportation and the military. Thus for some areas "10-years" both permits and demands consideration of breakthroughs, revolutionary approaches, and fast change.

The Task Force studied many desirable improvements in technology, operations and policy that would help military effectiveness (top priority) and simultaneously decrease fuel consumption and fuel's real costs. These were generally evolutionary/incremental technological changes. This "Futures Overview" finds the changing military mission dictates visionary priority on information technology and robotics devices/systems; that systems based on these technologies offer potentials for revolutionary advances; and that they generally have only small energy requirements and so all together will greatly decrease fuel consumption.

In summary, the 10-year timeframe will encompass some radical changes, especially growth in fields that use little fuel while improving military capabilities. This presentation is about the advisability and inevitability of change, and so focuses on that perspective. The reality of past and present devices, management, and wisdom is in no way downgraded.

Start With The Challenge

The total DoD responsibility encompasses planning, research and development, acquisition, basing, training, and the logistics support and engagement operation of Army, Navy, and Air Force (and Marines and National Guard). This includes legacy vehicles and procedures, as well as developmental and future systems.

There must be air superiority, quieting of enemy air power and of ground-based missile and intelligence-gathering sites, the capability for massive area destruction, and assessing and coping with deep underground enemy facilities. There will be very high priority on intelligence gathering and assimilation, including CW & BW monitoring, for finding and keeping tabs on potential terrorists as well as during major confrontations.

Also on the priority list are stealth devices and operations, precision offensive targeting and damage assessment, and strong emphasis on U.S. and allied troop and civilian security. Robotic devices, autonomous and/or remotely controlled, with or without humans in the loop, will play an increasing role – especially important considering the political effect of any appreciable number of publicized deaths to U.S. personnel. Devices must be simple enough for use by relatively untrained troops, and in many cases numerous and inexpensive enough to be expendable.

While this menu is much too large for digestion in a small document, nevertheless it helps raise our vision toward larger goals, and sets the stage for consideration of revolutionary rather than evolutionary strategies. To some extent the whole DoD mission need consideration, not just military effectiveness and the cost aspects of fuels (the Task Force assignment), because fuels are inherent in virtually every aspect of military apparatus and operations. Fuel use, or conservation/efficiency that minimizes or substitutes for fuel needs, or distributed sources that supply needs are as much a part of DoD's operations as is blood circulation to a human. A human's activities are not measured by blood, but are not possible without it.

Introduction to Change

The September 19-20, 2000 meeting at MIT was aimed at illuminating some potentials and examples within the many fields of revolutionary future technology, and thereby serve as a catalyst to stimulate an appreciation for change and to identify and explore a few potential "breakthroughs".

Huge, fast changes are afoot, changes because of new and upcoming technology, changes because of the different (and widely varying) types of future wars and security threats.

As terrorist threats and capabilities grow, as the U.S. takes more numerous and firmer roles in thwarting ethnic cleansing and other dictatorial offenses against humanity outside our borders, and as the response times for flexing military muscles get shorter, the gathering, distilling, and disseminating of information becomes hugely important. Robotic technologies also grow in priority – especially as the public's response to media coverage of the capture or death of U.S. personnel tends to inhibit the options for our military leaders.

Change is uncomfortable but inevitable. Others will be embracing it. Prudence dictates that the U.S. military maintains a continuing role in leading it.

Satchel Paige allegedly said: "Don't look back. Someone may be gaining on you."

Examples of What Causes Decisive Change

Outside Pressures. Small and large organizations, complacent because of success in dominating a field, are often displaced by lesser competitors featuring less inertia (resistance to change). Examples of some large organizations that responded appropriately to the wake-up call are:

- The complacent U.S. auto industry of the ‘80s opened the door to Japan (using Deming techniques that we disdained). The U.S. companies eventually reconstituted themselves and met the competition but permanently lost market share and cannot yet match Japan’s “quick to market” and “quality” talents.
- The U.S. pioneered/dominated initial microchip production. After Japan zoomed ahead, the U.S. groups were motivated to change and, with big investments, eventually recovered the lead.
- For the U.S. science/technology/education community, Sputnik is the classic example. An earlier case was German aviation in the 1930s. In each instance we were asleep at the wheel, but once awakened we moved ahead and won the race (especially through the application of large resources).

Unpredictable Happenings.

The transistor and microprocessor; the Internet; DNA; nanoengineering; superconductors; genetic engineering; GPS; etc., were envisioned by their developers but their actual impacts were only dimly seen. Each represented the start of a revolution.

Consciously –Generated Stimuli (with consequences beyond original intentions)

- The “man to the moon” program of the 1960s, and the commitment to cross the U.S. with tracks in the 1800s, represent prime examples.
- In the recent automotive field, the Zero Emission Vehicle mandate in California, and the resulting PNGV (Program for the Next Generation of Vehicles), have stimulated technological developments that will be paying significant dividends.
- For aviation in the 1930s, the Thompson Trophy, the Schneider Cup, and other prestigious prizes clearly advanced aviation. In crossing the Atlantic solo in 1927 to win the Ortig Prize, Charles Lindbergh became the catalyst for global enthusiasm for aviation.
- Even the 1959 Kremer Prize for human powered flight had a big effect on development. The “impractical” Gossamer Condor, with which we won the prize in 1977, spawned unexpected technologies. As one program led to another, eventually we created the GM IMPACT battery powered car that indirectly resulted in the California ZEV mandate. Another consequence is Helios, our solar powered stratospheric “eternal” flier, the goal of earlier Pathfinder and Centurion programs. Helios is aimed at having a major influence on future information technology by providing high altitude antennas for relaying broadband, multichannel communications.

Attitudes/Strategies Suggested by the Example

- Complacency or the acceptance of past habits can be unhealthy, inhibiting self-change – sometimes delaying treatment too long for recovery. An attitude of expecting and welcoming change, in spite of its discomfort, can be healthy.

- Even the best forecasters cannot always predict the winning technologies for industries or the military, especially because some of the technologies arise from unpredictable breakthroughs. However, when a potentially winning technology (or organizational principle) becomes known, there is great payoff in being faster than others in making use of it.

- Faster to market wins. Work on your own new technologies/concepts but, most importantly, quickly adapt/absorb from any/every source whatever is best. New evolutionary computational principles are starting to speed not only the engineering of new solutions but also to speed the reverse engineering of competitors' products and systems.

- Planning for (and expecting) change is more prudent than having to play catch-up – having the change forced on you by outside pressures of competition or circumstance.

Past/Present/Future Attitudes

This Task Force has regularly been impressed by the high quality of the presentation made to us over the past year by representatives of all DoD operational services and associated research groups.

The presentations covered the past, present, and near future, and illuminated the DoD systems' economic and procedural constraints and the legacies within which the future would evolve. However, while recognizing restraints and realities, the presenters often demonstrated a refreshing willingness to explore big future potentials: "leap" revolution instead of "incremental" evolution.

One significant example was that the "white scarf" syndrome seems to have evaporated considerably in just the last several years, with a corresponding acceptance of the fact that UAVs (Unoccupied Air Vehicles) can perform many missions better, and more safely for personnel, than can piloted machines. Tactical UAVs can maneuver at much higher G loads, have better range and speed because they need not carry humans and all the associated life support systems, can be stored in readiness mode for many years, need not consume fuel in continued pilot training, and can cost far less to procure and operate. Long duration surveillance vehicles need not be crew-limited. Numerous tiny surveillance vehicles and devices can be deployed economically and be cheap enough to be expendable. The UAV history has been characterized by many teething problems (but fortunately also some dramatic successes). As more resources are applied to the UAV area, the main challenges of performance, control, reliability, and simplicity/economy appear resolvable. Remotely piloted or autonomous vehicle systems for ground and water have similar challenges and benefits. Remotely or autonomously controlled vehicle robotics are obvious avenues toward benefits. Exoskeleton developments are proceeding – but always with the question of whether the human needs to be inside instead of safely remote.

Not only did the many DoD presenters at prior meetings of the Task Force have valid perspectives about future military needs and future technologies, it was noted that treatment of breakthrough technologies is appearing more regularly in the media, in personnel communications, and in formal reports for DoD.

Of the concepts embedded in the above, there is a strong flavor of priority for information gathering and the systems aspects of information processing; precision strikes instead of large or redundant ones; carefully keeping personnel out of harm's way as much as possible, and exploring/developing the technologies and policies to permit these capabilities. The fast digestion of huge masses of information is especially challenging.

Organizations that dominate the high technology field tend to be those that combine a long view with ability for fast action. The long view means devoting resources to basic research as well as applied. Public companies in the U.S. need to pay attention to quarterly financial results – short term results that are benefited by short-changing investments in long term potentials. (This is the "eating the seed corn" philosophy.) Government support, non-public ownership, and strong, respected leadership of public companies can better balance the short term and long term.

Overview of Main Energy Devices

- Some low-end possibilities: for human body pedaling (anaerobic, or 1 hour aerobic), steel spring, rubber band, energy delivered is in the range of 0.0001 to 0.003 kWhr/kg. Low energy/kg, but may be very convenient.

- Supercapacitor: delivers electrical output of 0.01 kWhr/kg (for 2x voltage change), offers high cycle life, high power/kg.

- Rechargeable battery: delivers electrical output of 0.04 – 0.15 kWhr/kg, at 1 hour charge-discharge rate, with about 0.85 out/in efficiency (higher for low rates, much lower for very high rates.) Primary (non-rechargeable) have more energy/kgCycle life and efficiency vary widely with type, rate, and depth of discharge. Non-rechargeable batteries have more energy/kg. 0.2 kWhr/kg is considered likely for commercial batteries in a few years. 0.5 kWhr/kg may not prove to be impossible.

- Fuel consuming energy generation: 2.1 kWhr (methanol) to 5.3 kWhr (diesel) of mechanical energy per kg of fuel consumed in air breathing internal or external combustion heat engines, assuming 30% efficiency and ignoring use of heat. 20

kWhr/kg of electrical energy per kg of hydrogen for fuel cell (assumes 50% efficiency). (If hydride or pressure tank or mixing chemicals comprise the energy storage system specific energy value drops to under 1.5 – 2.0 kWhr/kg of hydrogen storage system supply plus hydrogen). For all the energy systems assume about 1 kg weight of mechanism for every kW of power capability (mechanical power from electric source or shaft-turning heat engine).

- Way out: theoretical energies from $5.8{\cdot}10^5$ to $1.8{\cdot}10^8$ kWhr/kg for radioactive fuel, to $1.5{\cdot}10^9$ kWhkg for matter-antimatter interaction.

Hybrid systems offer great practicality: combine a low power, high energy fueled engine with a high power, low energy battery to get the best of both. (Note that a human has a hybrid energy/power system – anaerobic and aerobic energy/power sources to handle varying tasks.) Flywheels are omitted here because their demonstrated technology does not suggest they will prove better than the steadily improving alternatives. The energy/power system chosen depends strongly on the application. A battery suits a wristwatch or GPS. Combustion of a liquid fuel is appropriate for an 18- wheel truck carrying huge loads over mountains, or fighter or transport aircraft. In between these extremes are many options, the number increasing as vehicles/devices are made to require less power.

Some AeroVironment Experiences With Change

A 6-1/2 minute 1994 video was part of the September 19 MIT presentation. It is a theme piece titled “Doing More With Much Less” that shows some intriguing pioneering developments (by others as well as ourselves). Although the information technology and nanoengineering fields are in some ways more extreme examples of the theme, the examples depicted focused on vehicles whose function precludes microminiaturization. The air, land, and sea vehicles shown operate on small power. Some are human-powered, most are electric (photovoltaic energy and/or battery), one is an electric-human hybrid, while “unpowered” sailplanes are shown that efficiently exploit atmospheric motion from the sun’s heating of the earth. All have a special value – even the vehicles that would be deemed “impractical” compared to conventional ones powered by burning fossil fuel. The emphasis on efficiency forced their designers to generate new goals, attitudes, and insights – and the vehicles achieved capabilities even beyond the goals of their developers.

The two human-powered aircraft (Gossamer Condor and Albatross) achieved history-making flights needing an average of only ¼ - ½ horsepower. The Sunraycer solar powered car crossed Australia averaging about 40 mph using 1 kW (1.3 HP). The Solar Challenger was piloted 163 miles at 11,000 feet from Paris to England powered solely by sunlight (about 1-2 kW). (All 4 pioneering vehicles have been acquired by museums of the Smithsonian Institution.) A human powered water vehicle achieved 18 mph; one human powered land vehicle reached 68 mph, and a 2-person version averaged over 50 mph on a 40 mile demonstration. Our 100 foot Pathfinder solar-powered airplane was shown. In 1998 a 120 foot version climbed over 80,000 feet, and in 2001 our 247 foot span Helios is expected to reach 100,000 feet and then be fitted with a 110 kwhr, 10 kW regenerative fuel cell system to permit the plane to remain at 60,000 – 65,000 feet for over 6 months. Its role is both atmospheric research and serving as a communications relay for economical multichannel wideband communications. At the other end of the size spectrum a new 6" span, 2-3 oz, “Black Widow” surveillance aircraft has emerged as a cousin to the battery powered 9 lb, 9' Pointer surveillance drone (still in production) shown in the video. A 4 oz VTOL is in the works. The battery powered Impact car (0-60 mph in 8 seconds) became the production GM EV-1, and along the way was the catalyst for California’s Zero Emission Vehicle mandate that forced worldwide advanced vehicle development.

One point of the video, and the developments that followed from vehicles depicted therein, is putting priority on revolution rather than evolution. Amazing breakthroughs can become achievable when creativity is unleashed to win prizes, to produce symbols, to explore the impossible, or to leap past the accepted. There may be many evolutionary/incremental improvements incorporated into the revolutionary devices, but the underlying attitude of dramatic change is what counts. To deal substantively with global environment, or global education, or U.S. security, the stakes are too high and the time too short for incremental/evolutionary strategies to be sufficient. Similarly, the handling of the new security threats of terrorists, warfare of mass destruction, and uncontrollable dictatorships, puts a premium on supporting revolutionary technologies in the military.

<u>Petroleum Perspectives</u>

- Fossil fuels as energy sources offer great benefits: high energy and power using well established heat engine technology and emerging FC technology.
    - inexpensive, easily transported
    - widely available, from many sources

- Associated with the positives are negatives such as
    - growing U.S. dependence on unreliable and even antagonistic foreign suppliers
    - questionable global resources in 25-50 years
    - contribution to global climate change and to local pollution

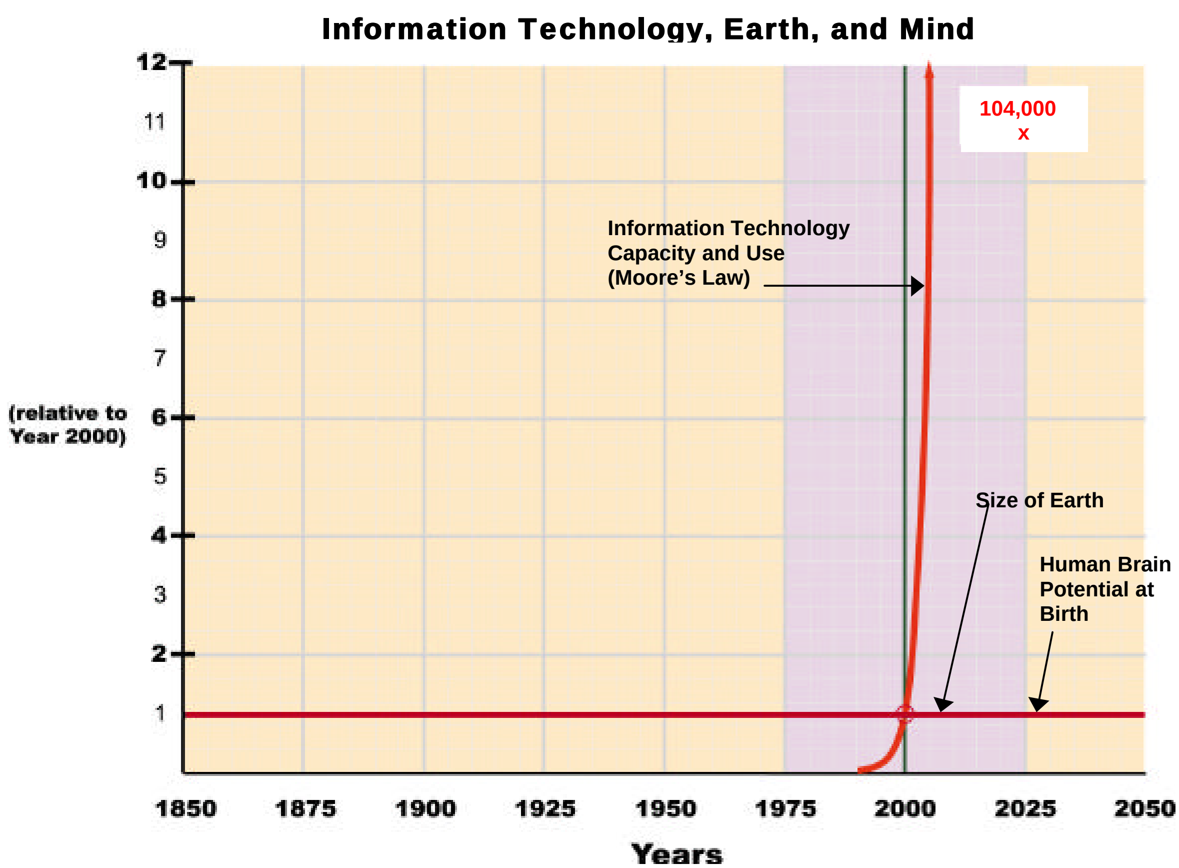
- U.S. citizens generally feel the short-term positives outweigh the long-term negatives.

- The amount of oil now used by the U.S. military is a small (~1.4%) part of the U.S. total, and tiny (under 0.5%) of the global total. Because DOD’s consumption of oil represent the highest priority of all uses, there will be no fundamental limits to DOD’s fuel supply for many, many decades.

- The U.S. public's addiction to low cost fuel, and thus increasing consumption, involves growing potential for stresses in international relations and thus relates to DOD's mission. The policy and technology issues to cause a substantial lessening of the global or U.S. consumption are not a DOD responsibility. However, many new technologies that improve military effectiveness are associated with decreasing consumption of fuels. The technologies will have value outside the military for generally decreasing energy use. Widely applied they can decrease international stresses and so decrease the responsibilities DOD must handle.

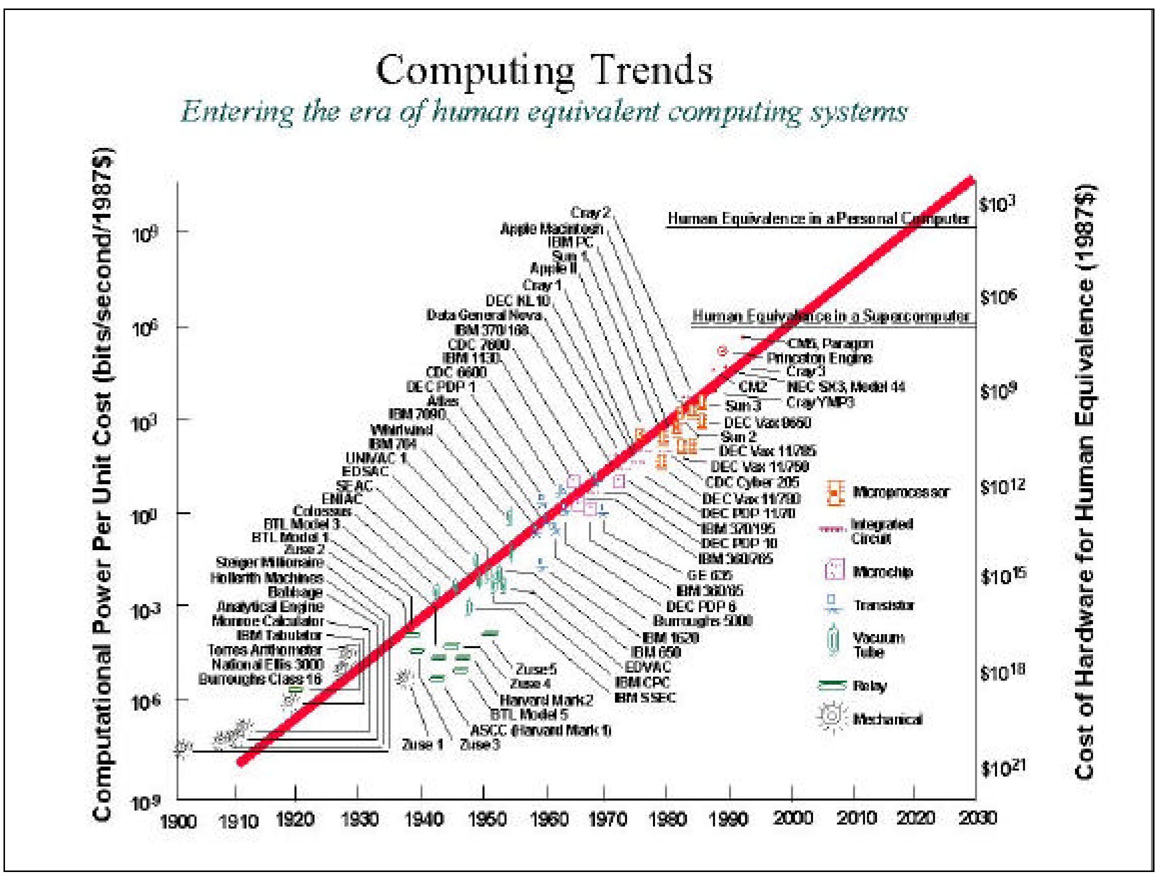
A Bigger Picture – Both Exciting and Disturbing

We individuals, focusing on our short-term tasks, participate in growth/change and have little occasion to perceive the bigger future of the ensemble of changes on a global scale. The fields of information technology, computers, micro- and nano-engineering of actuators and sensors, biomorphic devices, and neuroscience are growing more explosively than energy, agriculture, or transportation (although the latter make some use of the former). The graph below provides a perspective on humans vs information technology.



Moore's empirical "law", showing a doubling of bit storage density every 18 months, has turned out to be a qualitative guide to the growth rate of many other aspects of information technology and computers. At 2025 it indicates a 104,000-fold increase over today. Most likely the exponential growth will be flattening in 15 years (still a 1000-fold increase). As computers do more and more of what humans have been doing, the future relative roles of humans and computers get very confused – and deserving of intense study. (It is sobering to realize that recently a computer program taught itself, with no human input beyond the game's rules, to play checkers and quickly reached the master's level.) In the meantime, the military importance grows for information gathering and processing/utilizing, robotic and autonomous vehicles and devices (some very tiny), and sensors. The development time for many of these technologies is getting shorter, and the resources required are getting less – and so the opportunities for talented competitors increases. The danger of terrorists grows. CW and BW agents can wipe out cities or countries, bioengineered bacteria/viruses can be developed to affect millions before any cure or medication can be concocted. A few Stinger missiles could put an instant halt to commercial aviation. There is no perfect defense. Certainly widespread sensors and information gathering are vital, and then the extrapolation of useful intelligence from the data.

When price-performance is considered in the context of Moore's Law, the chart below shows a "human-equivalent" computer (one capable of 10^{13} to 10^{14} bits per second) at the approximate cost of a personal computer (about $10,000) available around 2015. At this point, your desktop will be capable of performing certain human cognitive capabilities. Beyond that, each additional 18-month time interval results in a computer performing at twice the speed of the human brain. This, of course, relates to pure computing power, and does not recognize that the human brain has additionally evolved sophisticated algorithms.



The combination of wide-band web-centric communications, wall-sized immerse displays, sensory interface technologies, and enormous computing power will allow the development of applications that will profoundly affects methods of work and the conduct of warfare. For example, worldwide collaborative planning with hundreds of simultaneous sites interacting as if all were present together. In addition, fast-forward mission planning and contingency analysis will be routinely used to explore options and novel concepts well beyond human capability. It will also be possible to automate many target recognition tasks currently done by trained analysts, but in real time provided significant advances in algorithms also occur. [1]

Some Personal Conclusions and Recommendations

- A U.S. challenge is for DOD to stimulate/support its own breakthroughs in order to be best prepared for future realities. It already is doing a rather good job, with reasonable compromises for allocating resources to the large legacy systems that maintain our present military might, basic research with long time payoff possibilities, and the many topics in between. The perspectives that emerge from thinking about the changing nature of future threats to the U.S. military and to all U.S. citizens, and the rapidly evolving technologies of **information technology** and **robotics** and **energy**, suggests that the resource allocation be modified toward a higher priority in these areas of rapid change and military significance.

- These changes toward robotics and uninhabited vehicles (that put our troops in less danger) will place but small demands on energy, and hence will act to cut energy consumption (and associated local and global pollution). The changes will place new demands on convenient energy to operate distributed small devices. Many vehicle system improvements can offer revolutionary increases in performance and simultaneously better economy.

- Information gathering will grow through new/improved sensors, sensor delivery techniques, and communication systems. Assimilating the data to produce clear, useful information for action is a severe challenge, and deserves high priority attention.

- Computational procedures for design, analysis, and operational simulation are rapidly improving. Examples of tools are computational fluid dynamics, finite element analysis, evolutionary computation, and multidisciplinary design optimization with genetic algorithms, used to program or speed system developments far beyond the capabilities of human designers. Maintaining leadership in these areas is important. Using simulations for testing/evaluating products and field operations saves time and dollars.

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[1] Section on price-performance is an excerpted and paraphrased from Dr. William Howard, Defense Science Board Summer Study “???TITLE???”,. (DATE). Dr. Howard serves as chair of the U.S. Department of Defense's Advisory Group on Electron Devices and is a member of the Defense Science Board, and served on the Army Research Laboratory's Technical Review Board

- More accurate microengineered inertial navigational systems can be especially helpful for some small flight vehicles, to lessen the dependence on vulnerable radio navigation aids.

- There are high potentials for energy conservation. Remember that vehicle or device efficiency is our best fuel. Efficient vehicles that require much less energy represent breakthrough possibilities. Techniques for generating that energy more efficiency offer mostly only incremental improvements – desirable but of lower priority.

- There is a likelihood that rechargeable batteries for electric vehicles will in a few years be achieving the 0.2 kWhr/kg goal (including high power, long life, and reasonable economy) of the Advanced Battery Consortium. In the long run, 0.5 kWh/kg may be reached, a value that can make significant changes in surface transportation policy.

- Personnel training to deal with the changing nature of technology puts a premium on developing training methodology and motivating people to remain with the Service. The development of creativity and thinking skills, rather neglected in typical high-inertia U.S. schooling, can be handled surprisingly effectively and quickly to yield high dividends for DOD.

- Rapid change will be a consequence of advances by competitors, by perceptive planners/researchers who develop new approaches, and by unanticipated technological breakthroughs. It will be prudent for DOD to continue and strengthen its lead in scientific and breakthrough/revolutionary technological development.

- Especially important is the development of attitudes and capabilities to move useful new technologies quickly (whether generated by ourselves or competitors) into operational capabilities. It's the "fastest to market" concept that beats competition.

- Accept, stimulate, and reward a culture of change in DOD. Huge change is inevitable, and will be most valuable to us if we are the source. Understanding change is embedded in many parts of DOD. A permanent, separate advisory office chartered to continue exploring all aspects of change, policy as well as technology, might prove useful for coordinating fast change and for keeping change highly visible and accepted.

(N45) to fulfill DoD's requirement to report greenhouse gas emissions for the base year of 1990 and 1996. This section describes the methodology used to estimate DoD's greenhouse gas emissions and addresses the uncertainty of those estimates due to lack of adequate fuel consumption data. Other sections of the report discuss greenhouse gas emissions from sources other than energy. However, energy represents about 94 percent of DoD's total greenhouse gas emissions. The entire report is available from the Office of the Deputy Under Secretary of Defense (Environmental Security).

2. Energy

Greenhouse gas (GHG) emissions are produced during all phases of energy production, transmission, and distribution. The only energy activity considered in the Department of Defense (DoD) GHG Inventory is fossil fuel combustion. Both direct combustion of fossil fuels, and upstream combustion of fossil fuels used to generate electricity, steam, and hot water purchased by DoD (hereafter referred to as "purchased electricity") are included. Preliminary calculations have shown that emissions from other energy activities (e.g., fugitive emissions from natural gas transmission and distribution) are relatively insignificant for DoD. Emissions are estimated for both mobile and stationary sources. Mobile sources cover all tactical and non-tactical vehicles used by the Services and Defense Logistics Agency (DLA) including aircraft, ships, ground support vehicles, and U.S. General Services Administration (GSA)-leased vehicles. Stationary sources include direct fossil fuel combustion for heating, hot water, cogeneration, and electricity production, as well as upstream fossil fuel combustion used to generate purchased electricity that is consumed at DoD-owned facilities.

Fossil fuel combustion is, by far, the largest anthropogenic source of carbon dioxide (CO_2) emissions in the United States. Carbon dioxide results from the oxidation of carbon in fuels during combustion. The amount of CO_2 released per unit of fuel combusted depends on the carbon content and combustion efficiency of the fuel. On a per unit of energy basis, coal has the highest carbon content, followed by oil and then natural gas. There is little variation in the combustion efficiency of fossil fuels burned in conventional technologies, generally ranging from 99 to 99.5 percent. The GHG impact of fossil fuel combustion is not limited to CO_2 emissions. During combustion, sulfur dioxide (SO_2), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOCs), and to a lesser extent methane (CH_4) and nitrous oxide (N_2O), are also emitted. In addition to fuel type, emissions of non-CO_2 gases depend on the combustion technologies, the use of pollution control technologies (e.g., catalytic converters), and ambient environmental conditions. The DoD GHG Inventory and consequently the methods outlined in this manual cover only direct GHGs,[1] which is consistent with national GHG inventory reporting requirements; therefore, only CO_2, CH_4, and N_2O emissions are estimated.

This chapter is organized as follows:

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[1] Direct GHGs are gases that absorb outgoing heat energy from the Earth, and thereby directly influence the Earth's radiative balance. The direct GHGs include CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6. Other gases may affect the Earth's radiative balance in an indirect way, for example, by reacting with other gases in the atmosphere to alter the atmospheric lifetimes and/or concentrations of direct GHGs.

Section 2.1: Carbon Dioxide Emissions from Direct Fossil Fuel Combustion
Section 2.2: Methane and Nitrous Oxide Emissions from Direct Fossil Fuel Combustion
Section 2.3: GHG Emissions from Purchased Electricity

2.1 Carbon Dioxide Emissions from Direct Fossil Fuel Combustion

This section discusses the methodology, data sources, and uncertainties associated with estimating CO_2 emissions from direct fossil fuel combustion.

2.1.1 Methodology

The amount of CO_2 emitted from fossil fuel combustion is directly related to the amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel carbon that is oxidized. The methodology used to estimate CO_2 emissions from fossil fuel combustion for the DoD GHG Inventory is consistent with the approach recommended by the IPCC for national GHG inventories (IPCC/UNEP/OECD/IEA, 1997) and used by the United States to develop the *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1996* (U.S. EPA, 1998c). The DoD methodology is characterized by the following five steps:

1. *Determine fuel consumption by fuel type, country, and defense category; and determine bunker and multilateral fuels.* Estimates of DoD fuel consumption for 1990 and 1996 by primary fuel type (e.g., coal, oil, gas), secondary fuel category (e.g., motor gasoline, distillate fuel, etc.), and by country were collected for each of the Services and the DLA, for two defense categories – Operations & Training and Installations & Logistics. Data were collected from a number of different sources including the Services, the Defense Energy Support Center (DESC), the DoD Energy Resources Management Progress Report, and the Construction Engineering Research Laboratory (CERL) (see Section 2.1.2). Fuel consumption data were comprised of data from facilities, aircraft, ships, ground-support vehicles and equipment, and automobiles. Fuel consumption data include fuel consumed in GSA-leased vehicles. Fuels consumed that were bunker fuels and fuels used in multilateral operations pursuant to the UN Charter were estimated by each Service.[2] Petroleum data were reported in

[2] Under the UNFCCC, GHG emissions from bunker fuels and from multilateral operations pursuant to the UN Charter are not to be included in emission totals in national GHG inventories, but are to be reported separately. Bunker fuels are defined as fuels sold to ships or aircraft engaged in international transport. The DoD interprets this definition to include fuel sold to military aircraft and ships for use in all military operations and training activities that involve flying or cruising in international airspace or waters, i.e., outside the territorial sea of any country or the airspace over the territorial sea, including those that begin and end within the same country in support of operations in international waters or airspace, and to activities that involve direct flying or cruising between two countries. The DoD interprets the term "multilateral operations" to mean operations involving more than one country, and may include providing combat forces, logistics and other support, or any combination of these. The DoD interprets the phrase "pursuant to the UN Charter" to mean multilateral operations that are consistent with the UN Charter, including not only multilateral operations expressly authorized by the UN Security Council, but also multilateral operations not expressly authorized but consistent with the UN Charter.

gallons, coal data were reported in short tons[3] (ston), and natural gas data were reported in million Btu[4] (MBtu) or cubic feet (ft^3).

2. *Determine energy contents of fuels.* Gross calorific values,[5] or high heating values, were used to convert quantity of fuel consumed to energy content of fuel consumed. The heat contents are listed in Table 2-1 and Table 2-2 in units of MBtu/ston, MBtu/ft^3, and MBtu/barrel[6] for coal, natural gas, and petroleum, respectively.

- Petroleum consumption (other than aviation gasoline and jet fuel) was converted from gallons to barrels. Petroleum consumption in barrels was then converted to units of MBtu using heat contents listed in Table 2-1.[7]
- When coal consumption was reported in ston, and natural gas consumption was reported in ft^3, the data were multiplied by the country-specific heat contents presented in Table 2-2.
- The heat contents of aviation gasoline and jet fuel were calculated using an alternate method. Fuel consumption was multiplied by the density of the fuel (kg/gallon), and then by the heat content in units of trillion Btu (TBtu)/kg (Table 2-3).

3. *Determine the carbon contents of fuels.* All energy contents were first converted to QBtu.[8] The carbon content coefficients, presented in Table 2-1 in million metric tons of carbon equivalent (MMTCE)/QBtu, represent the amount of carbon per unit of energy contained in the fuel. Total fuel carbon was obtained by multiplying the energy content of fuel consumed by the carbon content. This equals the maximum amount of carbon that could potentially be released to the atmosphere through combustion.

4. *Determine the fraction of carbon that oxidizes during combustion.* Because combustion processes are not 100 percent efficient, some of the carbon contained in fuels is not emitted to the atmosphere. Rather, it remains behind as soot or other by-products of inefficient combustion. The estimated fraction of carbon oxidized during the combustion process ranges from 99 percent for petroleum and coal to 99.5 percent for natural gas. Table 2-1 presents the fraction of fuel carbon that is oxidized for each fuel type.

5. *Calculate carbon equivalent emissions.*

$$CE = \sum_{f} \sum_{r} FC_{f,r} \times EC_{f,r} \times CC_{f,r} \times FO_{f}$$

where **CE** is the emissions of CO_2 expressed in carbon equivalents (MMTCE)

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[3] A unit of weight equal to 2,000 pounds.
[4] British Thermal Unit (Btu). This is the quantity of heat needed to raise the temperature of 1 pound of water by 1° F at or near 39.2° F. One Btu = 1.0551×10^3 joules.
[5] All fossil fuel combustion emission estimates in the DoD GHG Inventory, as in the U.S. GHG Inventory (U.S. EPA 1998c), are based on higher heating values (HHV) rather than lower heating values to be consistent with international convention (IPCC/UNEP/OECD/IEA, 1997).
[6] 1 barrel = 42 gallons.
[7] US heat contents were used for petroleum consumed in all countries because calorific values for refined oil products (i.e., secondary petroleum fuels) do not vary significantly by country (IPCC/UNEP/OECD/IEA, 1997).
[8] 1 QBtu = 10^9 MBtu = 10^3 TBtu.

$FC_{f,r}$ is the fuel consumption of fuel type f in region r (ston, ft^3, or gallon)
$EC_{f,r}$ is the energy content of fuel type f in region r (MBtu/ston, MBtu/ft^3, or MBtu/gallon)
$CC_{f,r}$ is the carbon content of fuel type f in region r (MMTCE/MBtu)
FO_f is the fraction of the fuel type f that is oxidized

Table 2-1: Key Assumptions for Estimating Carbon Dioxide Emissions

Fuel Type	Heat Content (MBtu/barrel)	Carbon Content Coefficient (MMTCE/QBtu)	Fraction Oxidized
Coal	[a]	25.92[b]	0.99
Natural Gas	[a]	14.47	0.995
Petroleum			
Fuel Oil, Distillate	5.825	19.95	0.99
Fuel Oil, Residual	6.287	21.49	0.99
Fuel Oil, Mixed	5.825	19.95	0.99
Fuel Oil, Reclaimed	5.825	19.95	0.99
Diesel	5.825	19.95	0.99
Motor gasoline	5.253	[c]	0.99
E-85 [d]	5.253	[c]	0.99
LPG/propane	3.490	16.99[b]	0.99
Aviation Gasoline	[e]	18.87	0.99
Jet Fuel			
JA 1, IA 1	[e]	19.95	0.99
JAA, IAA	[e]	19.95	0.99
JP 4 , IP 4	[e]	19.95	0.99
JP 5	[e]	19.33	0.99
JP 8 , IP 8, JB 8	[e]	19.33	0.99

Sources: Heat contents and carbon coefficients from EIA, 1998. Combustion efficiency for coal from Bechtel, 1993 and for petroleum and natural gas from IPCC/UNEP/OECD/IEA, 1997.

[a] These coefficients vary by country (see Table 2-2).

[b] Although these coefficients can vary annually due to fluctuations in fuel quality, they were the same for both 1990 and 1996.

[c] This coefficient varies annually due to fluctuations in fuel quality, with values of 19.41 and 19.36 MMTCE/QBtu in 1990 and 1996, respectively.

[d] E-85 is comprised of 85 percent ethanol and 15 percent gasoline. Only CO_2, N_2O, and CH_4 emissions from the gasoline portion are accounted for in the DoD GHG Inventory.

[e] Presented in Table 2-3.

Table 2-2: Heat Contents for Coal and Natural Gas by Country

Country/Territory	Coal (MBtu/ston)		Natural Gas (MBtu/ft³)	
	1990	1996	1990	1996
Belgium	17.23	15.18	0.001065	0.001065
Germany	10.20[a]	11.05	0.000893	0.000894
Italy	9.77	8.35	0.001038	0.001023
Japan	21.09	19.81	0.001101	0.001101
Netherlands	17.23[b]	15.18[b]	0.000894	0.000894
South Korea	16.20	22.89	0.001047	0.001152
United Kingdom	22.69	21.65	0.001094	0.001053
United States	21.82	21.28	0.001031	0.001027
Virgin Islands[c]	21.82	21.28	0.001031	0.001027

Source: EIA, 1998

[a] 1991 value.

[b] Values for Belgium because Netherlands data unavailable.

[c] Values for United States used due to unavailable data.

Table 2-3: Densities and Heat Contents of Aviation Gasoline and Jet Fuels

Fuel Type	Density (kg/gallon)	Heat Content (TBtu/kg)
Aviation Gasoline	2.72	4.49E-08
Jet Fuel		
JA 1, IA 1	3.04	4.50E-08
JAA, IAA	3.08	4.50E-08
JP 4 , IP 4	2.90	4.50E-08
JP 5 [c]	3.08	4.50E-08
JP 8 , IP 8, JB 8	3.04	4.50E-08

Source: U.S. EPA, 2000

2.1.2 Data Sources

Activity Data

Energy data were taken from a number of different sources because no one data source had a complete and accurate data set for all fuel types. The following data sources were used to estimate fuel consumption in 1990 and 1996:

- Inventory Data Collected from Services: Fuel consumption data by secondary fuel type, country, and defense category (i.e., Installations & Logistics and Operations & Training) were provided by each of the Services and DLA for FY1990 and FY1996. In addition, each Service provided data for bunker fuels and fuels consumed in multilateral operations pursuant to the UN Charter, by country.
- Defense Energy Support Center (DESC): Petroleum consumption data from the Defense Fuels Automated Management System (DFAMS) were provided by the DESC (1999b). Data were available for 1995-1998, by Service, activity (installation/ship), country (location to which fuel was delivered), product (fuel grade), quantity, unit (e.g., gallons, tonnes), and cost (DLA charge to the activity). In addition, petroleum procurement data reported by fuel type were taken from the *Defense Energy Support Center Fact Book, Fiscal Year 1998* (DESC, 1999a).
- DoD FY 1996 Energy Resources Management Progress Report: Petroleum consumption data by Service and by fuel type was reported by DoD in the DoD *FY 1996 Energy Resources Management Progress Report* (DoD, 1997) for use in the DOE *Annual Report to Congress on Federal Government Energy Management and Conservation Programs*.
- Construction Engineering Research Laboratory (CERL): Energy consumption data for the Army Corps of Engineers (ACOE) for 1990 and 1996 were obtained from the Defense Utility Energy Reporting System (DUERS) and provided by CERL (1999).

The methods used to estimate energy consumption by the Services were based on the completeness of each data source, the level of detail in each data source (e.g., availability of country-level data), and the need to use a consistent data source for a given fuel type to avoid double-counting or under-counting.

For Installations & Logistics, all fuel consumption data for 1990 and 1996 were provided by the Services. Based on comparison of this data and data from the *FY 1996 Energy Resources Management Progress Report* (DoD, 1997), the Services' data for distillate and residual fuel oil appeared to also include LPG/propane consumption for facilities. Therefore, the proportions of fuel oil and LPG/propane consumption reported in DoD (1997) were applied to total consumption of these fuels reported by the Services. Global totals were allocated to individual countries based on the data provided by the Services. Total ACOE energy consumption data for 1990 and 1996 were provided by CERL (1999).

For Operations & Training, a mix of data sources was used. For 1996 aviation gasoline, jet fuel, and distillate fuel oil, data were taken from DFAMS. Because DFAMS data were not available before 1995, 1990 aviation gasoline, jet fuel, and distillate fuel oil consumption data by Service, and by U.S. and non-U.S. regions, were back-calculated from 1995 DFAMS data using DESC procurement data (in barrels) (DESC, 1999a). For the Air Force and Navy, total non-U.S. distillate fuel oil consumption in 1990 was re-derived by subtracting the back-calculated U.S. distillate consumption from each Service's estimate of global distillate consumption. This was done to ensure that total mobility fuel consumption data equaled the Services' estimates. To allocate total non-U.S. fuel consumption to individual countries, the country percentages from the 1990 data collected by the Services were applied. For other fuel oil, diesel, and motor gasoline use, the data collected by the Services were used.

Emissions from U.S. and non-U.S. bunker fuels were estimated for the Air Force and the Navy. The Army did not estimate any bunker fuel use. Bunker fuel emissions from embarked Marine Corps aircraft were included in the Navy bunker fuel estimates. Bunker fuels from other Marine Corps operations and training were assumed to be zero. Bunker fuel estimates from other DoD activities were assumed to be zero.

Military aviation bunkers include fuels used in international operations, operations conducted from naval vessels at sea, and operations conducted from installations principally over international water in direct support of military operations at sea. For the Air Force, the weighted average percent of aviation fuel that is bunker fuel was calculated based on flying hours by major command. The Air Force bunker fuel percentage was determined to be 13.2 percent. This percentage was multiplied by total annual Air Force aviation fuel delivered to U.S. activities to estimate U.S. bunker fuels, and by total annual Air Force aviation fuel delivered to other countries to estimate non-U.S. bunker fuels. The Navy aviation bunker fuel percentage of total fuel was calculated using flying hour data from Chief of Naval Operations Flying Hour Projection System Budget Analysis Report for 1998, and estimates of bunker fuel percent of flights provided by the fleet. The Navy aviation bunker fuel percentage, determined to be 40.4 percent, was multiplied by total annual Navy aviation fuel delivered to U.S. activities, yielding total Navy aviation bunker fuel consumed. The same percent was applied to non-U.S. aviation fuel consumption to estimate non-U.S. bunker fuels.

For marine bunkers, fuels consumed while ships are underway are assumed to be bunker fuels. The Navy reported that 87 percent of vessel operations are underway, while the remaining 13 percent of operations occur in port. Therefore, the Navy maritime bunker fuel percentage was determined to be 87 percent.

Each of the Services provided an estimate of the percent of annual fuel consumed by fuel type in multilateral operations pursuant to the UN Charter. The Air Force estimates were based on estimated fuels in reserve and in stand-alone storage tanks at each operating location. The Army estimates for 1990 were based on fuel consumption data for Operation Desert Shield, taken from the 1993 Rand Report entitled *Assessment of DoD Fuel Standardization Policies*. Fuel consumption for Operation Just Cause could not be determined because no historical fuel consumption records exist. Just Cause is believed to represent a small portion of fuel consumption because it was a short duration operation by light forces.

The Army provided an estimate of the percent of fuel consumed by fuel type and by country for 1996. The Marine Corps developed estimates for 1990; however, data were not available for 1996. The Navy accounted for fuel consumed by two carrier battle groups active in multilateral operations in the Persian Gulf in 1990. Fuel consumption from one carrier battle group in 1996 was estimated. However, all fuel consumption from Navy multilateral operations were reported as bunker fuel.

Emission/Conversion Factors

Heat contents, carbon contents, and densities of fuels were obtained from the Energy Information Administration (EIA) of the U.S. Department of Energy (EIA, 1998) and from the U.S. EPA (U.S. EPA, 2000). Combustion efficiency rates for petroleum and natural gas were obtained from IPCC (IPCC/UNEP/OECD/IEA, 1997); combustion efficiency rates for coal were taken from Bechtel (1993).

2.1.3 Uncertainty

There are four potential sources of uncertainty in the estimates of CO_2 from fossil fuel combustion: the fuel consumption data, heat contents, carbon contents, and combustion efficiencies. The largest source of uncertainty is in the fuel consumption data. These data were collected from four different sources, which for some fuel types, reported inconsistent consumption statistics. The other three sources of uncertainty are minor because variability among fuel types and regions has already been taken into account. Despite the limitations in the activity data, the CO_2 estimates from fossil fuel combustion are among the most reliable estimates in the DoD GHG Inventory because all relevant variables have been taken into account.[9] Uncertainty in the emission estimates can be reduced by improving the reliability of the underlying fuel consumption data, especially by collecting the data from a common source using a common method.

2.2 Methane and Nitrous Oxide Emissions from Direct Fossil Fuel Combustion

Fossil fuel combustion emits GHGs other than CO_2. Emissions of these other GHGs, namely CH_4 and N_2O, depend upon fuel characteristics, technology type, usage of pollution control equipment, and ambient environmental conditions. Methane and N_2O emissions also vary with the size and vintage of the combustion technology as well as maintenance and operational practices. This section presents the methodology, data sources, and uncertainties associated with estimating CH_4 and N_2O emissions from direct fossil fuel combustion.

2.2.1 Methodology

Methane emissions are, in part, a function of the CH_4 content of the fuel and post-combustion controls of hydrocarbon emissions (e.g., catalytic converters). Nitrous oxide emissions are closely related to air-fuel mixes and combustion temperatures, as well as the characteristics of any pollution control equipment that is in use. Fuel consumption data were collected by each Service by fuel type, country, and defense category (i.e., Operations & Training and Installations & Logistics), not by end-use technology. Because the Services and DLA did not provide fuel consumption by end-use, fuels were allocated to broad end-use categories based on fuel type. These end-use categories include air transport, marine

[9] Because CO_2 is not removed or destroyed by pollution control systems, emissions are a direct stoichiometric function of fuel carbon input.

transport, tactical ground-support vehicles, non-tactical vehicles, and stationary sources. Methane and N_2O emissions were estimated by multiplying fuel-specific emission factors for each end-use category by the amount of fossil fuel consumed. This "top-down" methodology is characterized by four steps, described below.

1. *Determine fuel consumption by fuel type, country, defense category, and end-use; and determine bunker and multilateral fuels*. Estimates of DoD fuel consumption for 1990 and 1996 by primary fuel type (e.g., coal, oil, gas), and secondary fuel category (e.g., motor gasoline, distillate fuel, etc.) by country were collected for each of the Services and the DLA for two defense categories – Operations & Training and Installations & Logistics. Data were collected from a number of different sources including the Services, the DFAMS, CERL, and the DoD Energy Resources Management Progress Report (see Section 2.1.2). Fuel consumption includes fuel consumed by GSA-leased vehicles, to the extent possible. The DoD was not able to provide fuel consumption by end-use (e.g., passenger cars with catalytic converters). As discussed above, fuels were allocated to broad end-use categories based on fuel type. It was assumed that all diesel, motor gasoline, E-85, and CNG consumed in Installations & Logistics were consumed in non-tactical vehicles. Coal, natural gas, fuel oil and LPG/propane consumed in the Installations & Logistics defense category were assumed to be consumed in stationary sources. For Operations & Training, all distillate and residual fuel oil were assumed to be used for marine transport, and all motor gasoline and diesel were assumed to be consumed in tactical ground-support vehicles. Aviation gasoline and jet fuel were allocated to aviation transport. The percentages of fuels consumed that were bunker fuels and fuels used in multilateral operations pursuant to the UN Charter were estimated by each Service. Petroleum data were reported in gallons, coal data were reported in ston, and natural gas data were reported in MBtu or ft^3.

2. *Calculate CH_4 and N_2O emissions for stationary sources*. The Installations & Logistics data set included fuel consumed in stationary sources and in non-tactical vehicles, so the first part of this step was to subtract vehicle use. For stationary sources, fuel consumption for each fuel type was multiplied by CH_4 and N_2O emission factors to obtain emission estimates (full molecular weight basis). Emission factors were taken from the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA, 1997). Table 2-4 provides emission factors used for each fuel type, in grams per GJ (g/GJ).

$$E_{GHG} = \sum_f FC_f \times EF_f$$

where **E_{GHG}** are CH_4 and N_2O emissions expressed in full molecular weight units (g CH_4, g N_2O)
FC_f is the fuel combustion in stationary sources of fuel type f (GJ)
EF_f is the average estimated emission factor for the fuel type f (g CH_4/GJ, g N_2O/GJ)

Table 2-4: Stationary Sources: CH_4 and N_2O Emission Factors by Fuel Type (g/GJ)[10]

Fuel/End-Use Sector	CH_4	N_2O
Coal		
Commercial/Institutional	10	1.4
Petroleum		
Residential/Commercial/Institutional	10	0.6
Natural Gas		
Residential/Commercial/Institutional	5	0.1

Source: IPCC/UNEP/OECD/IEA, 1997

3. *Calculate CH_4 and N_2O emissions from non-tactical mobile sources.* Fuel consumed in non-tactical vehicles was disaggregated from the Installations & Logistics data set as discussed in Step 2. Emission factors for mobile sources from the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA, 1997) and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996* (U.S. EPA, 1998c) are shown in Table 2-5, Table 2-6, and Table 2-7 for each fuel type and vehicle type. Tables 2-5 and 2-6 illustrate the variability of emission factors available by vehicle type and control technology. For this study, maximum N_2O and CH_4 emission factors for gas and diesel vehicles were used, thereby providing an upper bound emission estimate for these sources (Table 2-7). Emissions of CH_4 and N_2O, full molecular weight basis, from mobile source combustion were calculated by multiplying fuel consumption by emission factors.

$$E_{GHG} = \sum_f FC_f \times EF_f$$

where **E_{GHG}** is CH_4 and N_2O emissions expressed in full molecular weight units (g CH_4, g N_2O)
FC_f is the fuel combustion for the fuel type f (MJ)
EF_f is the emission factor for the fuel type f (g CH_4/MJ, g N_2O/MJ)

Table 2-5: Non-Tactical Mobile Sources: IPCC CH_4 Emission factors by Fuel Type and Vehicle Type (g/MJ)

	Gas			Diesel		
Control Technology	Light Duty Vehicles	Light Duty Trucks	Heavy Duty Vehicles	Light Duty Vehicles	Light Duty Trucks	Heavy Duty Vehicles
Low-Emission Vehicle	0.009	0.007	-	-	-	-
3-Way Catalyst	0.009	0.007	0.005	-	-	-
Early 3-Way Catalyst	0.011	0.014	-	-	-	-
Oxidation Catalyst	0.014	0.015	-	-	-	-
Non-Catalyst Control	0.017	0.018	0.009	-	-	-
Advanced	-	-	-	0.001	0.002	0.003
Moderate	-	-	-	0.002	0.002	0.004
Uncontrolled	0.020	0.018	0.016	0.003	0.002	0.004

Source: IPCC/UNEP/OECD/IEA, 1997
- = Not Applicable

[10] GJ (Gigajoule) = 10^9 joules. One joule = 9.486×10^{-4} Btu.

Table 2-6: Non-Tactical Mobile Sources: IPCC N_2O Emission Factors by Fuel Type and Vehicle Type (g/MJ)

	Gas			Diesel		
Control Technology	Light Duty Vehicles	Light Duty Trucks	Heavy Duty Vehicles	Light Duty Vehicles	Light Duty Trucks	Heavy Duty Vehicles
Low-Emission Vehicle	0.010	0.010	-	-	-	-
3-Way Catalyst	0.043	0.043	0.043	-	-	-
Early 3-Way Catalyst	0.041	0.041	-	-	-	-
Oxidation Catalyst	0.014	0.014	-	-	-	-
Non-Catalyst Control	0.003	0.003	0.041	-	-	-
Advanced	-	-	-	0.002	0.005	0.002
Moderate	-	-	-	0.003	0.014	0.002
Uncontrolled	0.003	0.003	0.003	0.003	0.005	0.002

Source: IPCC/UNEP/OECD/IEA, 1997
- = Not Applicable

4. *Calculate CH_4 and N_2O emissions from tactical mobile sources.* The fuel consumption statistics reported in the Operations & Training data set were disaggregated by vehicle type (i.e., aircraft, ships, ground support vehicles) based on fuel type. Assumptions about vehicle type were made on a Service-specific basis as needed. Emission factors were obtained as described in Step 3, and are listed in Table 2-7. Emissions were calculated as follows:

$$E_{GHG} = \sum_{v} \sum_{f} FC_{f,v} \times EF_{f,v}$$

where **E_{GHG}** is CH_4 and N_2O emissions (g CH_4, g N_2O)
$FC_{f,v}$ is the fuel combustion for the fuel type f vehicle type v (GJ)
$EF_{f,v}$ is the emission factor for the fuel type f and vehicle type v (g/GJ)

5. *Convert to carbon equivalent emissions.* Using the 100-year global warming potentials (GWPs)[11] of IPCC (Table 1-1), emissions of CH_4 and N_2O were converted to carbon equivalent emissions. The following formula was used:

$$CE = \sum_{GHG=CH4}^{N2O} E_{GHG} \times GWP_{GHG} \times CF \times CF2$$

where **CE** is emissions of CH_4 and N_2O expressed in carbon equivalents (MMTCE)
E_{GHG} are the CH_4 and N_2O emissions in full molecular weights from mobile and stationary sources (g CH_4, g N_2O)
GWP_{GHG} is the 100-year GWP of the GHG, which is 21 for CH_4 and 310 for N_2O

[11] The GWP metric has been developed to allow scientists and policy makers to express emissions of GHGs on an equivalent basis that reflects their relative contributions to possible future warming. The GWP of a GHG is the cumulative radiative forcing (i.e., cumulative effect on the Earth's energy balance) between the present and some chosen later time horizon that is caused by a unit mass of gas emitted now, expressed relative to CO_2. While any time horizon can be selected, the 100-year GWPs are required for use in national GHG inventories and are used in this report.

CF is the factor used to convert CO_2 equivalent emissions to carbon equivalent emissions, i.e., the mass ratio of carbon to carbon dioxide, or 12/44
CF2 is the factor used to convert from grams to million metric tons (10^{-12} MMT/g).

Table 2-7: Mobile Sources: CH_4 and N_2O Emission Factors Used in DoD Inventory, by Vehicle and Fuel Type (g/GJ)

Vehicle Type/Fuel Type	CH_4	N_2O
Non-tactical Mobile Sources		
Diesel	4	14
Motor Gasoline	18	43
E-85	18	43
CNG	5	0.1
Aircraft		
Jet Fuel[a]	2	2
Aviation Gasoline[b]	60	0.9
Ocean Going Ships		
Distillate Fuel Oil	7	2
Residual Fuel Oil	7	2

Source: U.S. EPA, 1998c; IPCC/UNEP/OECD/IEA, 1997
[a]Emissions for Jet and Turboprop Aircraft
[b]Gasoline (Piston) Aircraft

2.2.2 Data Sources

Activity Data

The energy data used to estimate CH_4 and N_2O emissions from fossil fuel combustion are the same as those used to estimate CO_2 emissions (Section 2.1.2). Energy data were taken from a number of different sources because no one data source had a complete and accurate data set for all fuel types. The final approach to estimate energy consumption by the Services was based on the completeness of each data source, the level of detail in each data source (e.g., availability of country-level data), and the need to use a consistent data source for a given fuel type to avoid double-counting, or under-counting.

Emission/Conversion Factors

Stationary source emission factors were taken from the IPCC (IPCC/UNEP/OECD/IEA, 1997). For stationary sources, CH_4 and N_2O emission factors depend on the end-use – residential, commercial, institutional, and utility. For coal, the residential, commercial/institutional and utility emission factors are different. The commercial/institutional emission factor was determined to be the most appropriate and was applied. For natural gas and petroleum, the residential and commercial/institutional emission factors are the same, were determined to be appropriate, and were applied.

Mobile source emission factors are taken from IPCC/UNEP/OECD/IEA (1997) and U.S. EPA (1998c). For non-tactical mobile sources, a range of emission factors by vehicle type and control technology was investigated. The maximum emission factors for vehicles were used. For tactical mobile sources, emission factors were chosen based on fuel type and vehicle type.

2.2.3 Uncertainty

Estimates of CH_4 and N_2O emissions are considerably less certain than estimates of CO_2 emissions because of large uncertainties associated with the emission factors that were used. However, the CH_4 and N_2O emissions are almost two orders of magnitude less than the CO_2 emissions, so their contribution to overall uncertainty is relatively small. Methane and N_2O emissions are a function of not only the amount of fuel and fuel type, but also the combustion and control technology. Because the combustion and control technology were not provided by the Services with the fuel consumption data, broad end-use assumptions were made based on fuel type. Emission estimates, therefore, were derived from fuel consumption, by type and broad end-use category, and aggregate emission factors that are representative of fuel types and end-use categories. However, emission factors within each fuel type can vary by an order of magnitude, depending on the specific combustion technology and type of emission control. Methane and N_2O emission estimates can be improved considerably by collecting fuel consumption data by end-use technology and control technology.

Appendix E
GLOSSARY

ACARS	Aircraft Communications Addressing and Reporting System
ACFP	Advanced Computer Flight Plan Program
AFRL	Air Force Research Laboratory
AMC	Air Mobility Command
AoA	Analysis of Alternatives
APU	Auxiliary Power Unit
ARL	Army Research Laboratory
ASC	Air Force Program Office
BTu	British Thermal Units
C3 Technology	Command, Control, and Communications Technology
CAIG	Air Force Cost Analysis Improvement Group
CAIV	Cost as an Independent Variable
CASCOM	Combined Arms Support Command
CBD	Chemical Biological Defense
CERL	Construction Engineering Research Laboratory
CHPS	Combat Hybrid Power Systems
CNS/ATM	Communications, Navigation, Surveillance/Air Traffic Management
CVT	Continuously Variable Transmissions
DARPA	Defense Advanced Research Projects Agency
DECU	Digital Electronic Control Units
DESC	Defense Energy Supply Center
DFAMS	Defense Fuels Automated Management System
DLA	Defense Logistics Agency
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DPG	Defense Planning Guidance
DSB	Defense Science Board
DT&E	Development, Test and Evaluation
DTOs	Defense Technology Objectives
ENCON	Energy Conservation Program

FASTALS	Force Analysis Simulation of Theatre Administrative and Logistics Support
FCV	Army Future Combat Vehicle
FEAAN	Fuel Efficient Army After Next
FEBA	Forward Edge of Battle Area
FLOW	Focused Logistics Wargame
FMS	Foreign Military Sales
G8	Global 8
GANS	Global Access, Navigation and Safety
GATM	Global Air Traffic Management
GHG	Greenhouse Gas Emissions
GPS	Global Positioning Systems
GSA	General Services Administration
HDDS	Hull Design Data System
HEMTT	Heavy Expanded Mobility Tactical Truck
HET	Heavy Equipment Transporter
HMMWV	Hybrid Electric High Mobility, Multipurpose Wheeled Vehicle
HVAC	Heating, Ventilation and Air Conditioning
ICR	Intercooled, Recuperated Gas Turbine system
I&L	Installations and Logistics
ICAO	International Civil Aviation Organization
IDA	Institute for Defense Analyses
IEA	International Energy Agency
IFGR	Information for Global Reach
IHPTET	Integrated High Performance Turbine Engine Technology
ISR	Intelligence, Surveillance and Reconnaissance
JORD	Joint Operational Requirements Document
JROC	Joint Requirements Oversight Council
JSF	Joint Strike Fighter
JWARS	Joint Warfare System
KPP	Key Performance Parameter
MIT	Massachusetts Institute of Technology
MMTCE	Million Metric Tonnes Carbon Equivalent
MNS	Mission Needs Statements
MOG	Maximum on-Ground
MRS-05	Mobility Requirements Study
MTBF	Mean Time-Between-Failure

NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NWA	Northwest Asia
O&M	Operation and Maintenance
O&S	Operations and Support
O&T	Operations and Training
OPEC	Organization of Petroleum Exporting Countries
ORDS	Operational Requirements Documents
OSD	Office of the Secretary of Defense
POL	Petroleum, Oil and Lubricants
POM	Program Objective Memorandum
PPBS	Planning, Programming and Budgeting System
R&D	Research and Development
RACER	Rankine Cycle Energy Recovery
ROI	Return on Investment
S&T	Science and Technology
SLEP	Service Life Extension Program
SIOP	Single Integrated Operational Plan
SWA	Southwest Asia
TAA	Total Army Analysis
TACOM	Army Tank-Automotive and Armaments Command
TDA	Technology Development Approach
TOGW	Takeoff Gross Weight
UAVs	Unoccupied Aerial Vehicles
UGVs	Unoccupied Ground Vehicles
UNFCC	United Nations Frameword Convention on Climate Change
U.S.	United States
USAF	United States Air Force
USN	United States Navy
VA	Veterans Administration
VAATE	Versatile, Affordable, Advanced Turbine Engines
WARP	Worldwide Aeronautical Route Planner