Strategy Research Project

Reducing the Logistics Tail by Embracing Energy Efficiency

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Abstract

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Reducing the Logistics Tail by Embracing Energy Efficiency

> Operational Energy in the battle space is about improving combat effectiveness. It's about increasing our forces' endurance, being more lethal, and reducing the number of men and women risking their lives moving fuel.
>
> —General John R. Allen[1]

Energy is a critical requirement enabling military capabilities to have full effect on our adversaries. Energy is also a critical vulnerability as most of our systems and weapons platforms require some form of energy to operate. Recent wars and operations demonstrated our reliance on energy and the effects those large energy requirements have on our supply lines and logistics footprint. United States (U.S.) Code defines operational energy (OE) as "the energy required for training, moving, and sustaining military forces and weapons platforms for military operations. The term includes energy used by tactical power systems and generators and weapons platforms."[2] OE does not include nuclear power for naval vessels or energy required for space launch operations. While OE encompasses many types of energy, the majority of Department of Defense (DOD) energy consumption is petroleum-based liquid fuel.[3]

The DOD's heavy reliance on petroleum-based fuel has several strategic and operational challenges and risks. The primary strategic challenge is ensuring the free flow of oil through the global commons. Miscalculations when protecting the flow of oil through strategic chokepoints could lead to combat operations. Disruptions in the flow of oil result in increased prices throughout the world and disrupt all major economies; every recession in the last four decades was preceded by an increase in oil prices.[4] The long-term trend of increasing fuel costs result in a larger proportion of the DOD budget spent on fuel. Since the early 1990s, the cost of fuel grew faster than any other DOD budget category including health care and personnel.[5] This trend presents budgetary risks to readiness, force structure and modernization. The short-term volatility of fuel prices can lead to execution-year budget shortfalls that could force reduced training, flight hours, and Navy steaming days.[6] Operational challenges include: diverting combat power and other resources to protecting fuel shipments; the vulnerability of supply lines to enemy attack, weather, and natural disasters on ports and lines of communication; and limited operational reach due to large fuel requirements.[7] A robust OE effort to reduce DOD energy dependence is in our national interests to ensure economic prosperity and maintain peace.

In 2008, the Defense Science Board compared energy consumption between peacetime and wartime operations.[8] As expected, increased operations tempo (OPTEMPO) yielded increased consumption, but the varying increase among differing consumers pointed to areas of potential improvements. Table One shows that generators become the Army's largest fuel consumers during war at 34%, followed by ground vehicles at 31% (tactical and combat vehicle total) and then aircraft at 29%. The increases in demand strained supply lines from the strategic level to the last tactical mile in delivery. Leaders at every level, from Congress through the DOD and the Army, recognized the burden our energy consumption placed on our economy and the risk to operations and forces protecting long lines of communications. DOD and the Army released OE policies and strategies to mitigate risk and reduce our logistics footprint.

Table 1. Army Fuel Consumption as a Function of Operations Tempo[9]

Energy Consumers	Wartime Optempo, million gallons	Percent of Total	Peacetime Optempo, million gallons	Percent of Total
Non-Tactical	51	5%	51	18%
Combat Vehicles	162	15%	30	10%
Tactical Vehicles	173	16%	44	15%
Combat Aircraft	307	29%	140	48%
Generators	357	34%	26	9%
Total	**1,050**	**100%**	**291**	**100%**

These DOD and Army strategies highlight OE ends but propose little in terms of the ways to accomplish the ends. The strategies offer little discussion of risk, especially in light of emerging joint and Army operating concepts that will further complicate energy use. This project will review the policies, strategies and emerging concepts to discern the energy and logistics implications to determine if it is possible to reduce our logistics footprint while improving mobility and lethality in the future way the Army will fight. The project will explore and recommend energy-related contingency basing and mobility alternatives (ways) for deployed operations supporting the end of accomplishing the mission by making optimal use of available resources with the lowest possible logistics footprint.

Background

Since World War Two, the U.S. has struggled with operational energy challenges. The first few days of the Battle of Guadalcanal demonstrates how a lack of resources limited a commander's options and increased risk to troops. Within 48 hours of the initial Marine amphibious landings, Vice Admiral Fletcher, commander of Allied Expeditionary Forces, withdrew his aircraft carriers due to a fuel shortage, thus leaving the landing force without air cover for force protection and limiting further landing and ground operations.[10] On the Eastern Front, Allied logistics planners developed an innovative approach to overcome weather challenges and enemy attacks on tanker ships to supply up to one million gallons of fuel per day to the Allies following the Normandy invasion; Operation PLUTO, short for Pipe Line Under The Ocean, demonstrated outstanding cooperation between military, industry and engineering leaders to overcome operational energy challenges.[11] The long supply lines, limited resources and contested environments present in World War II will continue to offer OE challenges for future U.S. strategic leaders.

In the future, unlike today, safe passage within the global commons of energy resources supporting U.S. operations is not guaranteed. The Capstone Concept for Joint Operations, *Joint Force 2030,* envisions the "immediate fight is for control of the commons" and requires a logistics capability to support operations in highly contested environments.[12] The Joint Operational Access Concept (JOAC) describes how future joint forces will overcome emerging anti-access and area denial (A2/AD) threats with disaggregated basing and distributed operations resulting in increased logistical and protection burdens.[13] The JOAC identifies "the logistically intensive nature of force projection" and that sustainment capabilities are "a likely target for enemy attack."[14] The JOAC correctly identifies the risk that "the concept may be logistically unsupportable" and consequently calls for a decreased appetite of fossil fuels, however, it "offers no direct remedies other than improving efficiency" to mitigate the logistics burden.[15] Similarly, the supporting joint Army and Marine Corps Concept for Gaining and Maintaining Access identifies the need to reduce bulk liquid and energy consumption to "assist in counter area-denial strategies."[16] All of these future concepts agree that fuel demand reduction is required to enhance feasibility, but do not reduce the logistics burden associated with fuel consumption.

The Joint Concept for Logistics identifies a growing *logistics gap* (see Figure 1) resulting from the increased logistics demands and reduced supply due to globally integrated operations, the increased energy use of new technologies, A2/AD threats and losses from cyber attacks.[17] The concept makes two suggestions to bend the demand curve to reduce the logistics gap. First, conduct better operational planning that reduces logistics requirements.[18] This results in the potential for logistics, specifically fuel factors, to drive operations, thus limiting a commander's options. Second, acquire a lighter and leaner force with increased fuel efficiency and decreased demand.[19] The difficulty in reducing the escalating energy demands remains an unmitigated risk to executing globally integrated logistics and operations. Unless the logistics gap is closed, commanders will face limited options for force employment.

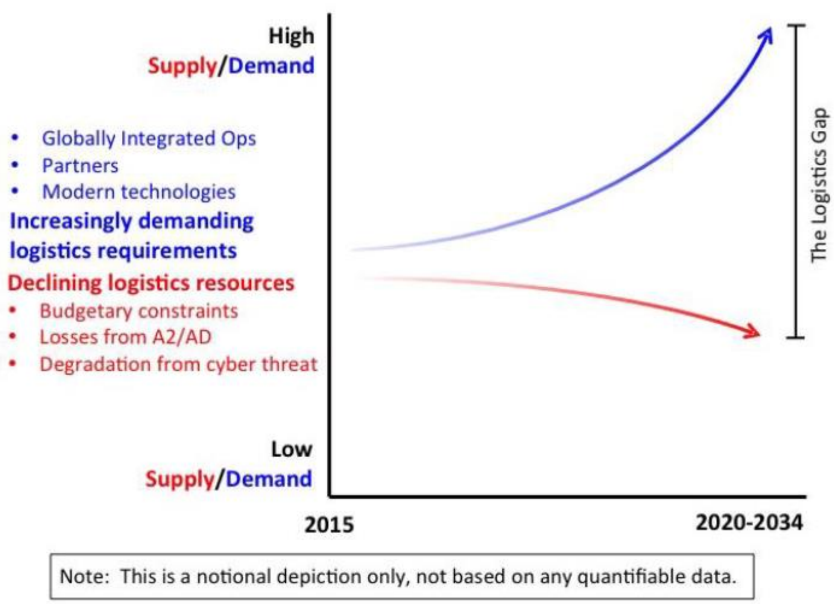

Figure 1. The Logistics Gap[20]

Historical OE challenges and future operating concepts indicate that OE will remain a strategic risk for the future. The benefit of economy of scale on the size of the logistics footprint is minimized by distributed operations in contested environments. Fuel efficiency improvements may reduce the size of each individual logistics footprint, but the number of footprints required will likely increase to support distributed, globally integrated operations.

Future joint concepts rely heavily on air and maritime assets to achieve cross-domain synergy and domain dominance in joint entry and operational access environments and call for greater joint and multi-national interoperability. Analysis of recent DOD energy consumption data provides insights for Army logistics implications in this future operating environment. To enable cross-domain synergy, future Army fuel units will likely need to fuel Air Force and Navy operations as they currently are the largest consumers of fuel at 57% and 26% respectively (see Figure 2 below). While OE efforts in the Air Force and Navy are outside the scope of this paper, the energy consumption of these services may not decrease without significant technological advances in air and sea mobility. The figure also shows the near equal energy use in Pacific Command (PACOM) and Central Command (CENTCOM) which highlights the energy demands created by these services operating over the vast distances of the PACOM theater despite the higher OPTEMPO in the CENTCOM theater.

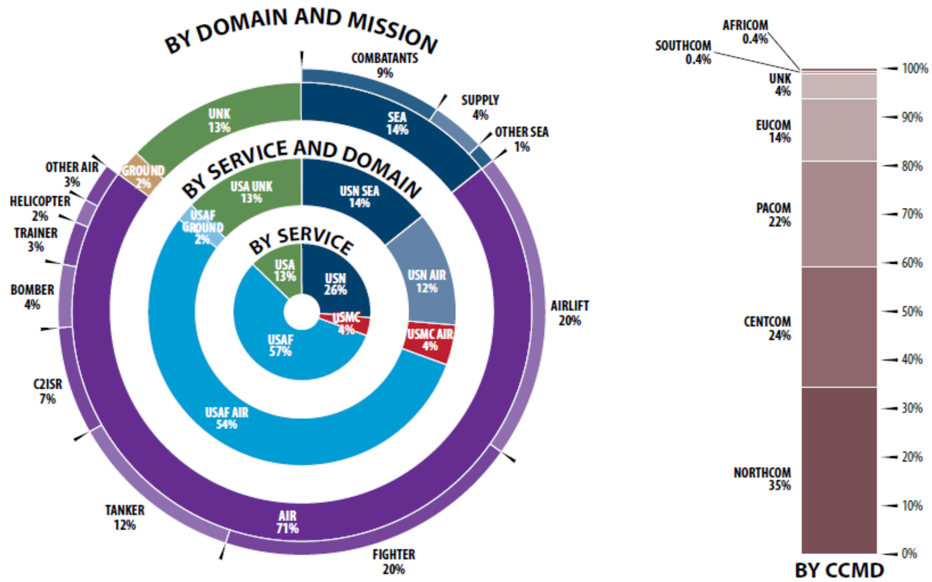

Figure 2. Department of Defense Energy Use Fiscal Year 2014[21]

Policy and Strategy

Recent DOD and service-level OE policies and strategies began around 2008-2011 due mandates in U.S. law designed to promote energy security and reduce costs at home and abroad. All of the strategies promote the idea of reducing logistics requirements while enhancing warfighting capabilities. These strategies question the unspoken assumption that operational energy will be abundantly available to support future operations by encouraging leaders at all levels, especially operational and strategic, to assess risk to operations, plans and acquisition programs from an OE perspective.

Department of Defense

The most current Department of Defense energy policy, published in 2014, is straightforward and lists three broad ends for energy planning, use and management; they are “to enhance military capability, improve energy security, and mitigate costs in its use and management of energy.”[22] The policy lists six specific directives toward accomplishing the ends: improve energy performance of systems, installations and military forces; diversify and expand energy supplies including renewable sources and alternative fuels; ensure energy analyses are including in requirements, acquisition, and planning, programming, budgeting, and execution processes; assess and manage energy-related risks; develop and acquire technologies that meet DOD energy needs and manage risks; and educate and train personnel on valuing energy as a resource.[23] The policy gives more specific guidance to the Service Secretaries, including guidance to "develop, acquire, and deploy weapons systems, platforms, and equipment…that improve energy performance and mission effectiveness."[24] While this directive nests well with the six directives and the three ends of the policy, implementation of the directive is not easy. Developing and acquiring new systems that improve energy performance *and* mission effectiveness, while a noble policy goal, does not reduce energy demands. Energy performance improves, but mission requirements create a need for more energy to power the new technologies. A simple example is a 1980s era Soldier using a map and compass in a squad with a single radio compared with the current requirement that every Soldier has a hand-held device that enables cross-pollenated situational awareness through data, voice and location sharing. Today's Soldier requires more energy in the form of batteries. Our vehicle platforms have similar increased power requirements (electric and fossil fuel related) due to new required capabilities. The overall energy consumption increases due to added capabilities, despite sub-system energy efficiency savings.

The DOD published its first operational energy strategy in 2011 as required by law.[25] This inaugural strategy focused actions in reducing demand for fuel, diversifying supplies and sources, and building energy security into future force planning decisions.[26] These initial goals derive from a common-sense approach to reducing risk posed by rising costs and global demand for fuel and the challenges associated with moving fuel to the user. While the principles of demand reduction, supply expansion and future planning remain important to improving operational energy management, the DOD updated the strategy in 2016 based on an evolving operational environment.[27]

Specifically, the challenges associated with the rebalance to the Asia-Pacific region, including the tyranny of distance stressing our power projection coupled with the growing regional A2/AD threat, will require more than just reducing energy demands and diversifying supply. Addressing these challenges may drive operational change and/or changes to logistics capacity.[28] Since implementing the 2011 strategy, the DOD gained a better understanding of energy implications across a wide array of operation plans (OPLANS), concepts of operation (CONOPS) and combat systems due to improved analytic capability.[29] These analyses identified the need to alter systems, "CONOPS, force structure and logistics capacity."[30] While the department always noted the tactical risk of moving fuel on the battlefield, they gained a new appreciation for strategic risk to our energy supplies and its effect on our warfighting capability and commander's options; the DOD began to envision fuel logistics limiting OPLAN execution. Consequently, the 2016 strategy pursues three objectives: increase future warfighting capability, identify and reduce logistics and operational risk, and enhance mission effectiveness of the current force.[31]

Increasing future capability retains the ideas from 2011 of demand reduction and future planning while proposing two goals. The first goal of institutionalizing energy supportability analyses (ESAs) in capability development looks to mandate use of ESAs to account for and mitigate logistics risks in all decisions.[32] The second goal supporting increased future capability involves leveraging innovations in energy efficiencies for major acquisition programs with priority “given to investments that support the rebalance to the Asia-Pacific region.”[33] These goals, once operationalized, should result in better decision-making for future acquisition investments while also incentivizing innovation in the private sector to reduce energy waste.

Identifying and reducing logistics and operational risk is the primary difference in the 2016 DOD OE strategy and will enable better resource prioritization. This objective includes three goals: to identify and mitigate energy related risks in deliberate planning, to improve energy supportability in CONOPs, and to diversify energy supplies to reduce risk.[34] Together these goals focus Joint Staff and Combatant Commander risk mitigation efforts to shape the current environment and set the logistical conditions necessary for future operations.

The objective of enhancing the mission effectiveness of the current force follows the 2011 goal of demand reduction through a strategy of increased efficiency. The two supporting goals of upgrading current equipment and improving energy behavior will continue the incremental change sought in the 2011 strategy.[35]

While the 2016 strategy will certainly yield better informed planning and acquisition decisions across the department and within the services, the assertion that these initiatives will reduce the logistics footprint is questionable. How each service implements the strategy for system acquisition and modification combined with combatant commander campaign and operational plans will determine if the logistics footprint will shrink or just disperse throughout the operating area.

United States Army

The current U.S. Army OE policy nests well with the DOD policy and strategy. It lists nine directives focused on increasing energy efficiency, integrating energy considerations into planning and acquisition activities, reducing consumption, increasing use of renewable and alternative energy sources, and establishing an energy informed culture.[36] The Army's Energy Security and Sustainability (ES^2) Strategy shares the Army's vision regarding OE that includes deployed forces making "optimal use of available resources *with the lowest possible logistics footprint.*"[37] The ES^2 strategy lists five goals to support the vision: inform decisions, optimize use, assure access, build resiliency, and drive innovation.[38] These goals are similar to the objectives found in the 2011 and 2016 DOD OE strategies; they focus on making energy informed decisions, improving efficiency through technology and innovation, diversifying supply, and improving energy adaptability. However, the ES2 strategy does not overtly discuss risk which may lead the reader to assume energy availability will remain unchallenged. This false conclusion has the potential to slow implementation by not developing the urgency required to spur changes.

The Army Equipment Modernization Strategy (AEMS) does articulate risk to Soldier's lives when protecting long supply lines and the risk to mission as commander's have less freedom due to energy dependence.[39] However, the AEMS only proposes increased efficiency as the mitigation strategy for OE challenges. Similarly, the Army Tactical Wheeled Vehicle Strategy (TWVS) lists the specific end of improved fuel economy of "by 10-15 percent or more from the FY10 baseline to reduce costs and limit personnel and asset risk during battlefield resupply."[40] The TWVS suggests the ways and means to achieve the efficiency is to "leverage industry-developed/government mandated fuel efficiency advancements."[41] These strategies imply that an innovative leap in mobility power technology is required to do anything more than incremental improvements.

The U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) is the ground system expert within the Army's Research, Development and Engineering Command and provides engineering and scientific expertise for manned and unmanned ground systems while serving "as the nation's laboratory for advanced military automotive technology."[42] Two of TARDEC's five listed means to help the Army achieve enduring value include "reducing manpower, logistics and similar burdens on the battlefield," and "improving operating efficiencies, such as reductions in space, weight, power, and cooling requirements and reducing fuel and energy consumption for ground systems."[43] The TARDEC's strategy to shape the future force includes a Power Density and Energy Efficiency line of effort focused on increasing power density and energy efficiency resulting in reduced vehicle size and weight, increased "range, endurance and operational tempo while reducing the number of logistics convoys on the battlefield."[44] According to TARDEC, the most effective ways to reduce ground vehicle energy consumption are to decrease rolling resistance, decrease weight and increase powertrain efficiency.[45] However, TARDEC is also exploring alternative fuels to increase vehicle adaptability.[46] Currently, TARDEC manages multiple fuel efficiency projects to inform future requirements processes. These projects seek to develop "new capabilities that are enabled by leap-ahead, innovative, modular, flexible, smart and adaptable technologies."[47] However, many of the leap-ahead technologies remain technology gaps for the foreseeable future, thus the Army will likely not see any reduction of the logistics footprint due to increased efficiencies of ground systems.

Recent historical data may cause one to view short term wins in OE efficiencies, however, the energy reductions are more attributed to reduced OPTEMPO than increased efficiency resulting from recent policy and strategy initiatives. Figure 3 shows OE demand between 2010 and 2015, with estimated use for 2016 and 2017. The data confirms that Air Force and Navy consumption dominate the department's use. Overall demand reductions based on recent increased efficiency gains are negligible; the primary reason for declining demand is reduced operations from pulling out of Iraq in 2011 and the end of the surge in Afghanistan. The effectiveness of recent policy and strategy efforts is yet to be determined. The durability of these initiatives is more important to maintain, since the U.S. has an episodic history with energy security, often undoing progress when military and oil crises end and energy prices stabilize.

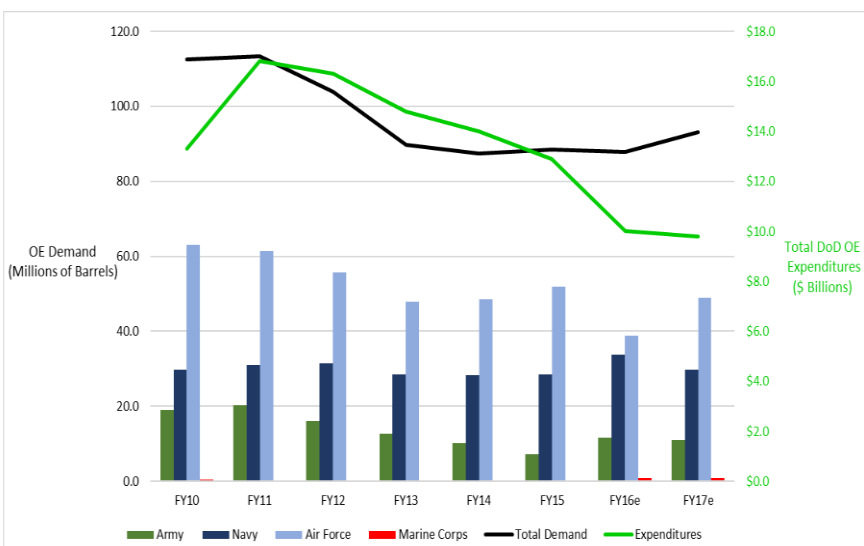

Figure 3. Department of Defense Operational Energy Demand by Service[48]

The Army has maintained reducing logistics support requirements as a long-time goal. In the late 1990s, the Army commissioned the National Research Council to make recommendations that "reduce logistics burdens…for an Army After Next (AAN) battle force in 2025."[49] The council determined that fuel and ammunition demands would overshadow all other logistics demands and identified the following energy reduction goals: "reducing fuel demand; increasing fuel energy density; improving energy systems and energy management; reducing the weight of vehicles…"[50] The study found that reducing vehicle weight was the most important factor to reduce fuel demand.[51] They posited four technological strategies to achieve weight reduction: autonomous vehicles; stronger and lighter materials; optimized subsystems and components; and better usage including - idling discipline, reduced towing, better route selection.[52]

The committee studied numerous options including a high-risk, more energy dense option of deploying a small nuclear reactor to provide the power necessary to create hydrogen fuel from water in a staging area; they determined that this alternative fuel strategy would ultimately increase the logistics footprint to overcome the many obstacles with this idea.[53] This suggestion to attempt a radical, high-risk nuclear solution to our energy dependence is worth continued exploration. They also studied hybrid vehicles but found no significant fuel economy improvements due to how military vehicles are operated.[54] This study shows that despite incremental improvements in fuel efficiency the Army continues to struggle to find ways to reduce the logistics footprint. The study occurred prior to the counter improvised explosive device (IED) efforts that increased vehicle weight with added armor resulting in decreased fuel efficiency (HMMWV versus MRAP). Updated studies using current and predicted threat streams and technologies are needed to refocus and adapt OE investment and innovation with the changing environment.

The RAND Corporation developed a new methodology to model and assess the impact of tactical fuel consumption on combat effectiveness.[55] They compared a current Armored Brigade Combat Team (ABCT), circa 2015, with a future ABCT using the five 2020 modernization program vehicles. Their model predicts a 12% fuel increase for a Bradley Fighting Vehicle equipped 2020 ABCT and a 36% fuel increase for a Ground Combat Vehicle equipped ABCT compared with current ABCT performing similar missions.[56] Overall, the RAND model demonstrates tactically what could happen strategically--"the vulnerability of the logistics forces will increase, thereby expanding the security requirement, which in turn raises the fuel demand."[57]

An increase fuel use at the tactical level, could ripple through higher echelons, into the air and maritime domains, and create larger logistics footprints at the operational and strategic levels. Despite efforts to reduce fuel consumption, future systems continue consuming more fuel to accomplish the same missions and combat effectiveness gains are minimized due to the increased vulnerability of logistics forces. As the Army modernizes the BCTs, including increasing the number of combat forces, they reduced the amount of bulk fuel distribution platforms within the BCTs. While the logistics demand increases, the logistics footprint shifted to rear in Combat Sustainment Support Battalions for economy of scale. This solution may be feasible on a linear battlefield, but it is not aligned with distributed operations in the Army Operating Concept. The Army needs to align organizational design with doctrine and emerging concepts. Recommend the Army and DOD use a similar methodology to determine energy requirements and implications for future operating concepts and doctrine.

Recent OE Initiatives

From 2010-2014, the U.S. Army Logistics Innovation Agency partnered with the U.S. Department of Energy's Pacific Northwest National Laboratory to determine how Smart and Green Energy (SAGE) commercial off-the-shelf technologies could reduce the fuel consumption of Forward Operating Bases (FOBs).[58] The SAGE project tested and modeled multiple technologies at Fort Devens, Massachusetts in the Base Camp Integration Laboratory to achieve a 49%-84% reduction in fuel consumption depending on FOB size (150 person, 600 person, or 5,000 person).[59] The SAGE study prioritized recommendations for increasing energy efficiency of FOBs beginning with replacing "spot generation systems with properly sized power generators that are integrated with smart microgrids."[60] Use of microgrid technology is a feasible solution for tactical units and is worth continued exploration. While feasible for reducing energy use on static, long-term FOBs, many of the SAGE recommendations are not feasible for integrating into Army warfighting doctrine or unit equipment requirements due to their non-expeditionary nature; it is not feasible to replace unit tents with insulated wooden shelters.

While the Army explored large-scale energy technologies, the U.S. Marine Corps developed a modular, small-scale replacement for spot generators called the Ground Renewable Expeditionary Energy Network System (GREENS). The GREENS system converts solar energy into a maximum of 1 kilowatt of usable power; networking the systems produces up to 5 kilowatts, which will run a Marine battalion command post and power artillery operations.[61] The system also stores excess energy in a battery array for use when solar power is not available.[62] A single, untrained soldier can deploy the lightweight system in about twenty minutes and it can be configured in tandem with a generator in a hybrid configuration.[63] The Army should field the GREENS systems to supplement unit power generation to reduce fuel requirements. The GREENS project serves as an example of energy saving innovations applied at the tactical-level; the Army needs to continue to develop similar fieldable capabilities using multiple types of renewable and alternative energy sources.

Figure 4. USMC Ground Renewable Expeditionary Energy System Alternatives[64]

Many energy alternatives and technologies exist today with many more constantly being developed that are suitable for the Army to meet its objectives of enhanced combat power with a reduced logistics burden. However, some alternatives may not be acceptable based on current law, DOD policy or from programmatic considerations. Other alternatives may not be feasible with current technology. Prior to discussing potential alternatives for power generation or mobility applications, the paper will briefly review laws, policy and establish a few working assumptions. The paper will then explore the concept of energy density and how it relates to potential alternative fuels. These considerations support establishment of requirements for alternatives to meet the end of reducing logistics while enhancing combat capability.

All potential alternatives must be acceptable according to current laws and policy amongst other considerations. Current U.S. law focuses on alternative fuel sources and requires that lifecycle greenhouse gas emissions are less than or equal to conventional petroleum based fuels.[65] DOD officials have stated that alternative fuels for operations must: “be drop-in, that is, requiring no modification to existing engines; be cost-competitive with conventional petroleum fuels; be available in sufficient quantities; be derived from a non-food crop feedstock.”[66] DOD Directive 4140.25 establishes that the “primary fuel support for land-based air and ground forces in all theaters (overseas and in the Continental U.S.) shall be accomplished using a single kerosene-based fuel.”[67]

The DOD developed this single fuel on the battlefield policy to simplify logistics required to fuel the services while gaining maximum efficiency; this remains a worthy policy for reducing logistics footprints due to multiple fuels. Two assumptions made by the Army’s Tactical Fuel and Energy Implementation Plan study remain valid for determining acceptability of any alternative energy solutions; they are “current legacy equipment, platforms, systems and fleets will not be replaced until the end of their planned lifecycle unless replacement is determined to be cost effective or driven by operational necessity; existing platforms and systems can be modified / re-tooled / retrofitted if necessary to achieve desired efficiencies.”[68]

The concept of energy density must be a primary consideration when exploring alternative fuels. Energy density is the amount of stored energy of a fuel per unit of volume or mass. Energy density is important to this study because less energy dense fuels reduce the power output or require more fuel for the same capability. Thus, solutions involving a switch to a less dense fuel will likely increase the logistics burden. Figure five shows the energy density of common fuel alternatives as a percentage of diesel energy density. Nuclear fuels are the only fuels with greater energy density than liquid petroleum. The figure shows that many of the alternative fuel technologies, such as hydrogen or electric (batteries), are significantly less dense than a diesel-based fuel. Without technological breakthrough, many of these alternatives are not acceptable for military applications as the loss of power and range from a similar sized storage tank would reduce the system capability. The logistics burden would increase using less dense fuels because the storage and distribution systems would grow due to the increased volume required. Despite these limitations, the Army should continue to invest in alternative fuels and technology for niche applications while allowing the U.S. Air Force and the Defense Logistics Agency-Energy (DLA-E) to continue to lead the search for a jet fuel alternative.[69]

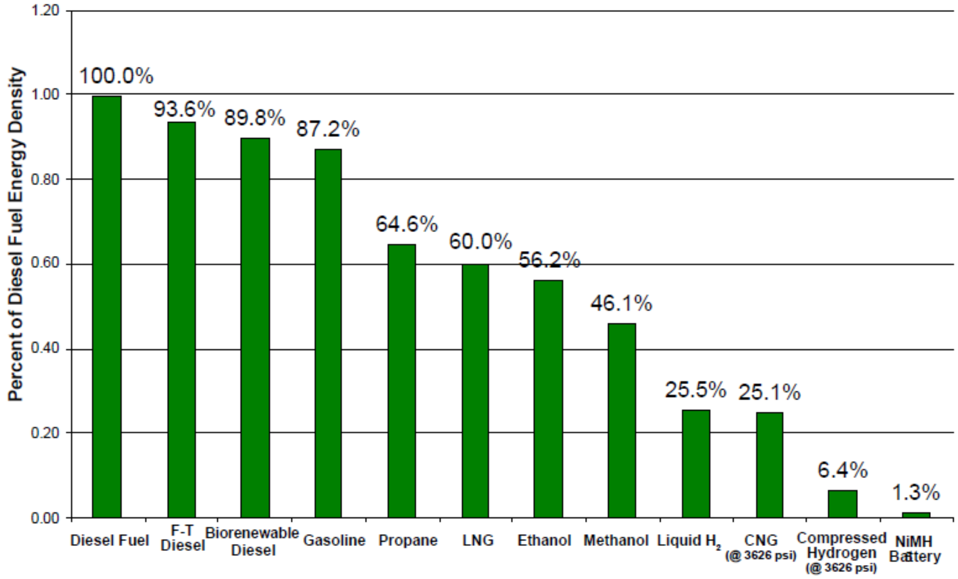

Figure 5. Energy Density of Fuels Normalized to Diesel Fuel[70]

In addition to the DOD policy requirements for alternative fuels, several other requirements are suggested for acceptable alternative solutions for U.S. Army energy requirements. Potential alternatives must be deployable, easy to use with minimal training, as safe as petroleum, functioning in all terrain and weather conditions, provide adequate energy per volume, are reliable, readily available, and not producing additional logistics burdens. Safety is a major concern since all fuel systems are vulnerable to enemy fire; they must not create a more hazardous situation for Soldiers and in-depth risk assessments must inform decisions. All of these suggested requirements support the end of reducing logistics footprint and enhancing combat capability.

The following sections of alternatives are divided into power generation and mobility applications based on the 2008 Defense Science Board study referenced in Table One. Since generators consume the largest proportion of wartime fuel for the Army, efforts to reduce fuel consumption in power generation equipment have the greatest potential impact on reducing the logistics footprint. Ground and air mobility applications both consume approximately 30% of fuel and also offer the possibility of reducing required logistics, especially when all efforts work synergistically.

Contingency Basing / Power Generation

Diesel generators provide the majority the power generation requirement at contingency bases and in expeditionary tactical field settings. Because the Army requires ~82% of the total DOD mobile generator requirement, the Army manages the program for all mobile generators.[71] Various sizes of generators provide power to a variety of mission types and are often wired in parallel for redundant back-up capability.[72] Most generators are sized to a unit based on peak load requirements. These factors often result in wasted excess capacity, wasted fuel, increased maintenance requirements and decreased equipment lifespan. This section will discuss current the Army alternatives of Advanced Medium Mobile Power Sources (AMMPS) and microgrids followed with a review of renewable and nuclear options for contingency bases and tactical applications.

The Army has three on-going generator programs; the Large Advanced Mobile Power Source providing 100-840kWs, the Small Tactical Electric Power generators providing <3kW, and the AMMPS providing between 5-60kW. The largest program is the AMMPS that replaces the 25-year old Tactical Quiet Generator (TQG) systems; this fielding began in 2012 and will be complete across the total force by 2028. Advanced Medium Mobile Power Sources deliver a “fleet weighted average of 21% improved fuel efficiency” over the TQGs.[73] This fuel savings alone justifies the fielding. Recommend the Army accelerate the fielding schedule to replace all legacy power generation systems. While spot generation efficiencies are helpful in reducing the logistics burden, several other technologies will enable further savings.

Microgrid technology is the most promising emerging technology to improve power generation fuel efficiency and reduce logistical burdens. A microgrid is "an integrated power delivery system consisting of interconnected loads and distributed generation sources which as an integrated system can operate in grid-connected or autonomous (islanded) modes."[74] Intelligent microgrids automatically manage and optimize supply to demand and offer reductions in fuel use, increased individual generator loading thus reducing the potential for "wet-stacking," and reductions in generator run time resulting in less greenhouse gases and spare part requirements.[75] Micro-grid technology works; in 2012, the Army installed 28 mini-grids at base camps throughout Afghanistan that saved 33 million gallons of fuel per year.[76] The Army's Communications-Electronics Research, Development and Engineering Center (CERDEC) is currently developing an Energy Informed Operations tactical microgrid that will allow plug and play interoperability with a variety of power sources.[77] While microgrids will not replace all spot-generation in the Army, the technology will enable fuel savings in areas with multiple power generation systems like command posts, base camps, and logistics areas. Developing and fielding a tactical microgrid system will further enhance the fuel savings from new generators while allowing for renewable power generation sources to plug-in and further enhance fuel savings.

Incorporating renewable energy sources into a tactical microgrid will further reduce fuel consumption and reduce the logistics footprint. However, not all renewable sources are suited solely for military applications, but may be useful for supplementing existing tactical power generation and reducing fuel sustainment of long-term oversea basing. Common renewable technologies include photovoltaic solar panels (PV), wind turbines, hydro turbines and biofuels; each have their own benefits but are limited based on environmental conditions, such as wind profiles, available sunlight, water sources. As discussed previously, the USMC GREENS technology exemplifies the type of tactical energy supplementation that will reduce consumption and contribute to logistics footprint reductions. The Army should field the GREENS technology across the force while CERDEC develops larger, new PV capabilities. Small wind turbine systems have potential to supplement in some tactical scenarios. The CERDEC developed the Renewable Energy for Distribute Under-supplied Command Environments (REDUCE) that harvests, stores and distributes solar and wind energy and produces up to 5kW of tactical power (see Figure 6).[78] The Army should field the REDUCE system to augment unit-level power generation and further reduce liquid petroleum consumption. Larger wind and solar systems are too big and heavy for expeditionary operations and should only be considered for permanent bases. Also, there are possible issues with wind turbine interference with radar operations that must be mitigated to reduce risk of use. Hydro turbines are not recommended due to the need for a flowing water source that is only found in limited scenarios. Biofuels are not recommended for power generation scenarios based upon the lower energy density and higher costs; however, biofuels that are “drop-in” replacements for JP-8/FS-24 should be identified for use when available. Overall solar and wind renewable sources provide the best alternatives for supplemental power generation. Continuing to develop and field GREENS, REDUCE and similar technologies will contribute to shrinking the logistics footprint while maintaining combat capability. Implementing large-scale renewable power generation at permanent bases will significantly decrease the strategic fuel requirement and is worth the investment.

Figure 6. Renewable Energy for Distribute Under-supplied Command Environments (REDUCE)[79]

Nuclear energy is the most energy dense source and could provide a power generation capability for large permanent bases that would eliminate the need for fossil fuel transportation. The Army had an active nuclear power program from the late 1950s through the late 1970s and developed eight small nuclear power plants; one plant was placed on a floating barge while another was designed to be air transportable. The plant at Fort Belvoir was the first nuclear plant to be connected to a power grid.[80] Several companies are currently developing new small modular reactors (SMR) that show promise for military applications. While the technology is not expeditionary in its current form, some future reactors may be man-sized.[81] Small nuclear power may be good for semi-permanent bases. Nuclear power could provide the high electrical power needed to create hydrogen for use in fuel cells; however, a military-operated, in-theater hydrogen production system would create a new, and possibly more robust, logistics burden.[82]

The political questions of deploying a mobile, modular nuclear power system into another country and its associated risks must be answered before further exploration. The only U.S. nuclear fatality happened at the Army nuclear plant in Idaho in January 1961.[83] This accident coupled with the Three Mile Island, Chernobyl and Fukushima nuclear disasters will make starting a nuclear power option in the Army very difficult from a public and political standpoint. Pursuing a nuclear power generation solution only for the purpose of reducing the logistics footprint is not an acceptable alternative considering the political and safety aspects. The DOD should encourage the Department of Energy to continue to fund private nuclear experiments in SMR development. The Army could then leverage this technology in a commercial off-the-shelf application should petroleum-based fuels become more scarce.

Mobility / Air and Ground Vehicles

Based on the data in Table One, Army mobility systems (tactical vehicles, combat vehicles, and aircraft) consume between 60% (wartime OPTEMPO) to 73% (peacetime OPTEMPO) of the total fuel consumption. During war, aircraft and vehicles use about the same percentage of fuel and during peace aircraft consume more. Army peacetime fuel consumption is similar to total U.S. petroleum use; in 2014, transportation systems consumed 69% of all petroleum in the U.S. (see Figure 7). However, cars and trucks consume about 86% of all transportation fuel while aircraft use about 7.8%.[84]

This U.S. data yields insight into areas of potential technological innovation--the government and industry are more inclined to explore energy technologies to reduce consumption, increase fuel efficiency and find alternative mobility solutions for cars and trucks than for aviation. The military has a long history of aviation innovation and will likely need to lead efforts toward finding new aviation fuels or mobility power technologies as it is not currently cost-effective for the commercial industry to change. The auto industry is motivated and regulated to increase fuel efficiency, thus the DOD and Army must maintain close ties to industry to leverage their new technologies.

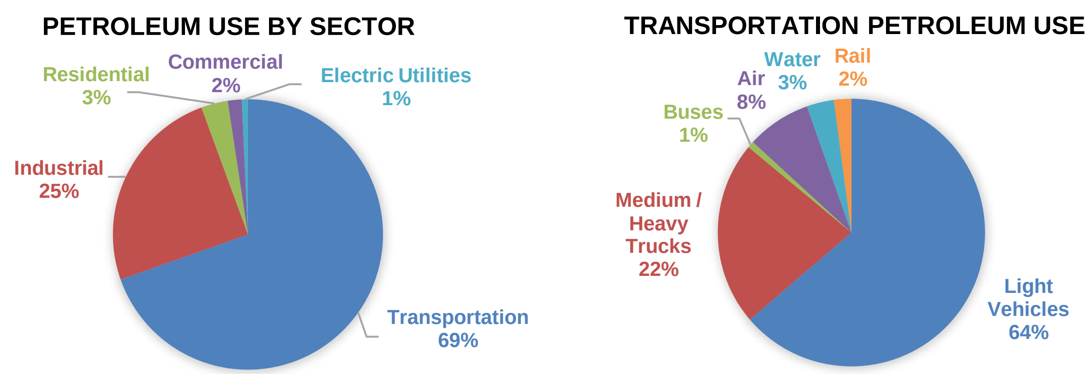

Figure 7. U.S. Petroleum Fuel Use in 2014[85]

This section will discuss Army efforts to reduce aircraft fuel consumption and then explore multiple ground mobility alternatives to meet the end of reducing logistics while increasing warfighter capability.

Both the aviation industry and military aviation communities take an incremental approach to improvements in overall aircraft design and fuel efficiency. The high-energy requirements for flight necessitates the use of highly energy dense jet fuel and drives incremental performance advances. The current fleet of helicopters in the U.S. military inventory are incremental enhancements to 1950s and 60s technology. Among commercial endeavors at Boeing, the new 737-Max only offers 8% better fuel efficiency through incremental advances in reducing airplane weight, improving aerodynamics and slight efficiencies in engine design.[86] The United State Air Force (USAF) is the largest consumer of aviation fuel in the DOD and they follow the industry pattern of seeking to reduce aircraft weight, improve aerodynamics and create more efficient engines. The largest USAF OE program in the 2016 budget is a research initiative called the Adaptive Engine Technology ($243.7M in FY 2016) that targets a 25% fuel efficiency gain.[87] As the USAF and DLA-E continue to identify "drop-in" alternative fuel replacements for jet propellant 8 (JP-8), the Army should test and certify these fuels for Army systems to fulfill some home station fuel requirements.[88] While this effort will not reduce the logistics burden, it diversifies supply to reduce our energy dependence and vulnerabilities while offering options to operational commanders. The Army should continue to follow USAF leadership in aviation mobility technology, but should encourage industry to find new energy solutions. Remotely piloted aircraft (RPAs) require less energy to attain lift and offer developmental opportunities for alternative energy aviation solutions. Boeing developed the Phantom Eye, "a liquid-hydrogen fueled, high-altitude and long endurance" RPA for persistent intelligence, surveillance and reconnaissance missions lasting 4-10 days.[89] Adapting alternative energy technology from RPAs to manned aircraft may enable future fuel savings for Army aviation that may contribute to a reduced logistics footprint.

Currently, the only major program for fuel savings in Army aviation is the Improved Turbine Engine Program (ITEP). The ITEP is a replacement engine to improve lift, increase range, and minimize fuel consumption for Black Hawk, Apache, and the future Joint Multi-Role helicopters. The ITEP provides a high-hot capability by extending the full mission operating envelope to 6,000 feet / 95 degree Fahrenheit conditions while offering a 25% reduction in specific fuel consumption.[90] Pending new leap-ahead technology to power air mobility, incremental fuel efficiency improvements remain the only feasible solution for reducing Army aviation's fuel consumption enough to impact the logistics footprint. As such, the Army should continue to upgrade all helicopter fleets to continuously improve fuel efficiency. Although aviation OE opportunities may be limited, innovators constantly develop new ground mobility energy alternatives.

Ground mobility systems consist of the standard propulsion technology components of "engines, transmissions, generators, air cleaners, cooling systems and energy storage."[91] While scientists and engineers continually seek to improve the efficiencies of all of these systems, increased power demands for communications, survivability and lethality systems often limit the overall increased fuel efficiency as propulsion systems are required to power all of the add-on technology. The TARDEC remains committed to improving efficiencies of all vehicle systems to reduce the logistics requirements of the future force. Listing all current ground mobility technologies is a futile effort as the list would be quickly outdated. However, certain technologies are worth pursuing for military applications with the end of increasing combat capability while reducing required logistics. With continued research and development, biofuel, electric, hybrid, and hydrogen engine technologies all offer potential military benefits. Partnering with the auto industry to share the burden of developing these technologies remains the most suitable and acceptable strategy for the Army.

Due to the rising costs of traditional petroleum-based fuels, biofuels have gained popularity throughout the world with many governments mandating and subsidizing use. Automakers offer many E85-capable vehicles due to the increasing prevalence of this biofuel blend. Biofuel use is expected to increase on all continents with many nations investing in biofuel refining plants.[92] Biofuels consist primarily of ethanol (mixed with gasoline) and biodiesel (mixed with diesel fuel) and are made with sugar, corn, grains, soybeans and sunflower seeds. Since 2007, the Army has experimented with biofuels to certify 50:50 blends with JP-8 for use in generators, ground vehicles and helicopters.[93] Blending biofuels and traditional fuels can mitigate the lower energy density of a strict biofuel, but these mixes still result in reduced capability for the vehicles. The resulting reduced range and increased fuel consumption will increase logistics requirements for units using biofuels. However, the DOD and Army should continue to integrate biofuels into operations to increase logistics flexibility by diversifying supply sources to limit A2/AD effects.

All-electric vehicle popularity is rising throughout the world due to the lower overall operating costs and increasing technology resulting in lighter weight, more powerful and longer life batteries. All-electric vehicle technology is not suitable for most military applications based on the requirements to recharge the batteries; recharging takes time and requires access to significant electricity. Both of these requirements limit the ability of military vehicles to remain on the move and will increase logistics requirements. All-electric vehicles are vulnerable to electro-magnetic pulse weapons. The Army should not adopt electric vehicles for major vehicle fleets, but may develop niche electric vehicles requiring limited range and quiet operations. The DOD could best employ electric vehicles in non-tactical roles at fixed bases with access to an electric grid; this would reduce strategic petroleum resupply requirements. Although all-electric vehicles have limited military applications, hybrid electric vehicles offer more options to reduce logistics while increasing vehicle capabilities.

Hybrid electric vehicles typically combine traditional internal combustion engines (ICE) with electric motors and batteries to achieve better fuel efficiencies while maintaining the benefits of typical ICE. The Army and defense industries frequently experiment with hybrid vehicles, although have yet to integrate any of the hybrid systems into vehicle modernization programs. In 2001, the U.S. Army National Automotive Center (NAC) selected Oshkosh to integrate their ProPulse hybrid-electric system into the HEMTT military truck.[94] Oshkosh unveiled the HEMTT A3 with ProPulse technology in 2002 and boasted of a 20% fuel economy improvement and "an on-board generator with enough output to power an entire airfield or hospital."[95] The ProPulse hybrid technology proved practical for heavy vehicle, off-road, military duty applications but was not purchased to upgrade any military systems. In 2007, TARDEC began testing a hybrid-drive system for all tracked combat vehicles in the Future Combat Systems (FCS) variants that produced the same horsepower with a 50% savings in volume and weight over the Bradley Fighting Vehicle engine.[96] Integrating hybrid drive solutions into tracked vehicles offers the greatest fuel savings benefits for ground combat systems with the largest potential savings of support force structure.

The Army also developed hybrid-electric systems for lighter weight wheeled vehicles. In 2011, TARDEC and Ricardo, a British company, unveiled the Fuel Efficient Ground Vehicle Demonstrator (FED Alpha) that incorporated a lightweight aluminum structure, improved drivelines, high efficiency starter/generator, and low rolling tires.[97] The FED Alpha used 70% less fuel than an up-armored HMMWV with all the same capabilities.[98] While the FED Alpha was not a hybrid-electric vehicle, its' success led to TARDEC collaborating with the College for Creative Studies in Detroit to develop the hybrid-electric FED Bravo.[99] FED Bravo used a “road-coupled parallel hybrid drive system,” and “has the capability to generate and export electric power” by plugging into microgrids.[100] FED Bravo doubled the fuel efficiency of the traditional HMMWV, uses regenerative braking technologies, and is capable of all-electric operation for distances up to five miles.[101] The TARDEC also developed the diesel-hybrid Clandestine Extended-Range Vehicle for special operations requirements.[102] Technology advanced rapidly in the decade plus since the AAN study recommended against hybrid-vehicles in 1999 and now provides considerable advantages toward reducing fuel requirements while maintaining combat capabilities.[103] Further technological innovations, including the new electric motor developed by Oak Ridge National Labs that produces 75% more power using iron-based magnets vice rare earth magnets, will make hybrid-electric vehicles even more profitable for military use in the future.[104] The Army should take advantage of the completed research and invest in upgrading vehicle systems with proven hybrid technology as this will maintain current capabilities and reduce support requirements.

Hydrogen fuel-cell vehicle technology is also rapidly advancing and could soon offer military benefits. Hydrogen fuel cell vehicles convert stored, highly compressed hydrogen gas into electricity using fuel cells. Liquid and compressed hydrogen gas both have lower energy densities than diesel fuel, thus require large storage tanks to maintain similar capabilities to petroleum-based vehicles. Hydrogen does have some military advantages, including, reduced thermal signatures and potable water production (as the by-product of hydrogen combustion). Combining hydrogen vehicles with other hybrid features, like regenerative braking and high-power motors, may make hydrogen more feasible for Army use. The TARDEC and General Motors recently revealed the ZH2, a hydrogen fuel-cell Chevy Colorado, that Soldiers at Fort Bragg, North Carolina, will test in tactical conditions.[105] Hydrogen fuel-cells will not likely reduce the logistics footprint due to the larger amounts of hydrogen required and would require a complete retrofit of logistics resupply capabilities. However, hydrogen fuel-cells may fill niche requirements for stealthy vehicles. The Army does use hydrogen fuel-cell non-tactical vehicles on some installations to reduce petroleum dependence; expanding this application may further relieve U.S. dependence on petroleum. Partnering with General Motors and other industry leaders to leverage their research funds is an acceptable strategy for developing new military mobility systems.

Leveraging interagency funds also offers additional cost savings to OE modernization research and development efforts. The Department of Energy (DoE) Vehicle Technologies Office launched their SuperTruck program in 2009 to encourage competition amongst tractor trailer manufacturers to optimize a variety of technologies to improve freight efficiency by 50%.[106] Class 8 / large trucks, also known as 18-wheelers, only make up 4% of vehicles in the U.S., but consume 20% of all transportation fuel; improving these trucks by 50% can save 300M barrels of fuel per year.[107] The Advanced Engine Technologies engine developed in the SuperTruck program reduces fuel use by 20%.[108] On 1 March 2016, DoE launched SuperTruck II, a $80M funding opportunity, to encourage industry to research, develop and demonstrate technologies that improve truck freight efficiency by more than 100% relative to best-in class technology from 2009.[109] Army vehicles have similar engine requirements as Class 8 commercial trucks and the Army should leverage the engine technology innovations funded by the SuperTruck program to incorporate into military systems, including the M1 Abrams tank.

The M1 tank engine is a 1500 horsepower turbine engine developed in the 1960s and 70s when diesel engines peaked around 900-1000 horsepower before getting exponentially heavier. Diesel engine technology now creates higher horsepower with lower weight than the turbine engines. Several diesel manufacturers proved this during the competition for a common engine that would replace M1 turbine engines and power the Crusader artillery system.[110] Current diesel engine advances meet the power requirements of our fuel-guzzling tanks while significantly reducing fuel consumption. Retrofitting tanks with new diesel power packs would reduce the lifecycle costs, energy requirements and logistics burdens associated with the turbine engines and increase the operational reach of our Armored Brigade Combat Teams.

Recommendations

The U.S. Army will likely not be able to shrink the overall logistics footprint for fueling operations without leap-ahead technology that changes how ground and air mobility is fueled. However, continuing to pursue current policy and strategy goals is an important aim for improving overall energy security and efficiency--every improvement helps and will trickle up to provide strategic flexibility and small footprint reductions. Reducing the future logistics gap involves bending both the demand and supply curves through doctrinal, training, organizational and material solutions. One must balance the risk inherent in the tension between greater logistics efficiencies from economy of scale and the need for logistics redundancy; becoming too efficient through consolidated logistics forces may limit effectiveness during distributed operations.

From a policy and strategy perspective, the Army can make several OE improvements. First, the Army should continue to work with our multi-national and inter-service partners on alternative fuel developments, so that we maintain and improve interoperability. Second, the Army must continue aggressive research, development, testing and evaluation (RDT&E) in leap-ahead power generation and mobility technology; leveraging industry and DoE funds to stretch RDT&E costs will enable spending on modernizing equipment. Third, the Army should consider setting a more aggressive energy efficiency improvement goal, in the range of 25-50% improvement over current baseline energy use, to drive the decisions to purchase modernization improvements for the force. Finally, the Army and DOD should evaluate employing high risk solutions for reducing energy demands; nuclear SMR technology might be useful in permanent basing situations.

In addition to the recommendations throughout the paper, several doctrinal, organizational, training and material recommendations can improve our OE posture in the near term. Combined, all of these recommendations will lead to greater flexibility and reduced energy demands that will lead to lower risk operations. They may not reduce the logistics force structure, but they will contribute to less frequent logistics operations.

Doctrinal. Add a joint requirement for tactical and operational Army logistics units to provide limited fuel to USAF and U.S. Navy operations; this will support cross-domain operational synergy and enhance interoperability.

Organizational. Transform petroleum supply units to create greater modularity to support distributed operations; this will increase logistics flexibility while reducing economy of scale by decentralizing petroleum supply and distribution operations. Consider adding fuel distribution force structure back into BCTs to enhance operational reach and limit dependency on higher support echelons.

Training. Formalize joint and multi-national interoperability training. Establish training for fuel specialists to test and transform local fuel into MILSPEC fuel for ground operations; this will support diversifying energy supplies. Train battalion-level and above Soldiers on microgrid set-up and use.

Material. Continue to pursue commercial off-the-shelf technologies that improve energy use, reduce demand and increase efficiency. Continue incremental strategy to improve efficiency in all petroleum-based equipment. Provide company-level units with simple fuel testing capability and fuel additive equipment to transform local fuels into military-compatible fuels. Accelerate the AMMPs fielding across total force. Field microgrid capability to battalion and above command posts, combat support and combat-service support units. Field USMC GREENS technology to company-sized units across the force. Field the REDUCE system to augment battalion-level unit power generation across the force. Replace all helicopter engines with the ITEP. Upgrade heavy vehicle fleets with the Oshkosh ProPulse or similar hybrid technology. Conduct cost-benefit analysis on replacing M1 turbine engines with efficient diesel engine technology.

Conclusion

Overall, DOD and Army policy and strategies are solid. The ends are suitable and the ways are acceptable; fuel efficiency efforts are essential to closing the logistics gap, increasing lethality and extending the operational reach of our forces, thus giving commanders more options to engage adversaries. The Army, specifically TARDEC and

CERDEC, developed feasible means to support the strategy; plenty of technological innovations exist, from hybrid vehicles to renewable energy generators, the question remains--will the Army get serious about the requirements to reduce fuel dependency and obligate funds to this effort. It is possible to reduce the logistics footprint while improving combat capability. However, the strategic tension between funding fuel-saving modernization and funding survivability and lethality improvements currently tends to be unilaterally biased toward the later. A crisis, similar to the IED crisis that led to survivability improvements, may be necessary to highlight the risks necessary to create the urgency required for change. Leaders must understand the paradox that we become more lethal and survivable when we become more fuel efficient; shrinking the tail through efficiency gains in the tooth enables greater spending on the tooth. A robust OE effort across the DOD is vital to supporting our national interests in the anticipated strategic environment of the future.

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