

ENERGY OPTIMIZATION ON THE BATTLEFIELD: HOW INTEGRATING ENERGY
EFFICIENT TECHNOLOGIES AT THE TACTICAL LEVEL CAN REDUCE FUEL
CONSUMPTION AND LESSEN THE BURDEN OF FUEL LOGISTICS

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ABSTRACT

ENERGY OPTIMIZATION ON THE BATTLEFIELD: HOW INTEGRATING ENERGY EFFICIENT TECHNOLOGIES AT THE TACTICAL LEVEL CAN REDUCE FUEL CONSUMPTION AND LESSEN THE BURDEN OF FUEL LOGISTICS, by Major Mark C. Minella, 102 pages.

The Department of Defense organization is one of the largest consumers of fuel in the world. The military's dependence on fuel is an important factor on the tempo of operations and operational reach. Throughout the last 13 years of conflict, the military identified many significant operational and tactical challenges involving fuel logistics required to support and sustain large-scale ground and air operations. The military's dependence on fuel is so important to operations it assumes significant risk when fuel convoys are attacked, and more importantly risks the lives of the Soldiers and Marines who execute these missions. Through the implementation of an energy optimization strategy, which is the focus of this thesis, the U.S. Army and U.S. Marines can reduce battlefield fuel consumption up to 25 percent. These savings equate to millions of gallons of fuel saved. More importantly, a reduction in the frequency of fuel convoys will save lives. Energy optimization will enable the U.S. Army and U.S. Marine forces to divert resources to other missions that would otherwise be needed to sustain fuel convoys. These savings extend operational reach of ground forces in remote and austere environments, which can operate longer with less fuel sustainment.

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ACRONYMS

AMMPS	Advanced Medium Mobile Power Systems
CFL	Conventional Fluorescent Light
COP	Combat Outpost
DOD	Department of Defense
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, Policy
ECU	Environmental Control Units
FOB	Forward Operating Base
GPH	Gallons Per Hour
HEMTT	Heavy Expanded Mobility Tactical Truck
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IECU	Improved Environmental Control Units
IED	Improvised Explosive Devices
JP-8	Jet Propellant Eight
KW	Kilowatt
LED	Light-Emitting Diode
MPG	Miles Per Gallon
MPH	Miles Per Hour
MRAP	Mine Resistant Ambush Protection
MTVR	Medium Tactical Vehicle Replacement vehicles
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
TQG	Tactical Quiet Generators

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CHAPTER 1

INTRODUCTION

Reducing the military's dependence on fuel for power generation could reduce the number of road bound convoys . . . Without this solution personnel loss rates are likely to continue at their current rate. Continued casualty accumulation exhibits potential to jeopardize mission success.

—LtGen Richard Zilmer, USMC, quoted in
The Marine Corps Expeditionary Energy Office,
USMC Expeditionary Energy Strategy and Implementation Plan

Background

Since the beginning of warfare the amount of territory which could be conquered by great military leaders of the past all had one common competing problem, logistics. Military professionals define logistics as the art and science of planning and carrying out the movement and maintenance of forces.¹ Logistics provides resources for combat power, positions those resources on the battlefield, and sustains them throughout the execution of operations.² How well a force can sustain itself during military operations determines its operational reach, flexibility, and agility on the battlefield, which determines victory or defeat. There are many examples throughout history where military forces missed out or failed to exploit opportunities because of their inability to logistically sustain gains resulting from success in battles or engagements.³ This still holds true today. Advancing offensive ground operations are tethered to sustainment. If logistics cannot provide the critical resources needed, specifically fuel, operations halt thus losing the initiative. When we examine the military's dependency on fuel the facts indicate alarming figures in both cost and resources needed to sustain ground operations. The military's appetite for fuel is at its highest consumption rate in the history of the

United States. If this trend continues, there may be dire consequences to face if our military does not reduce its dependency on fossil fuels. Figure 1 represents fuel consumption by the military, gallons per soldier per day from the civil war to present.

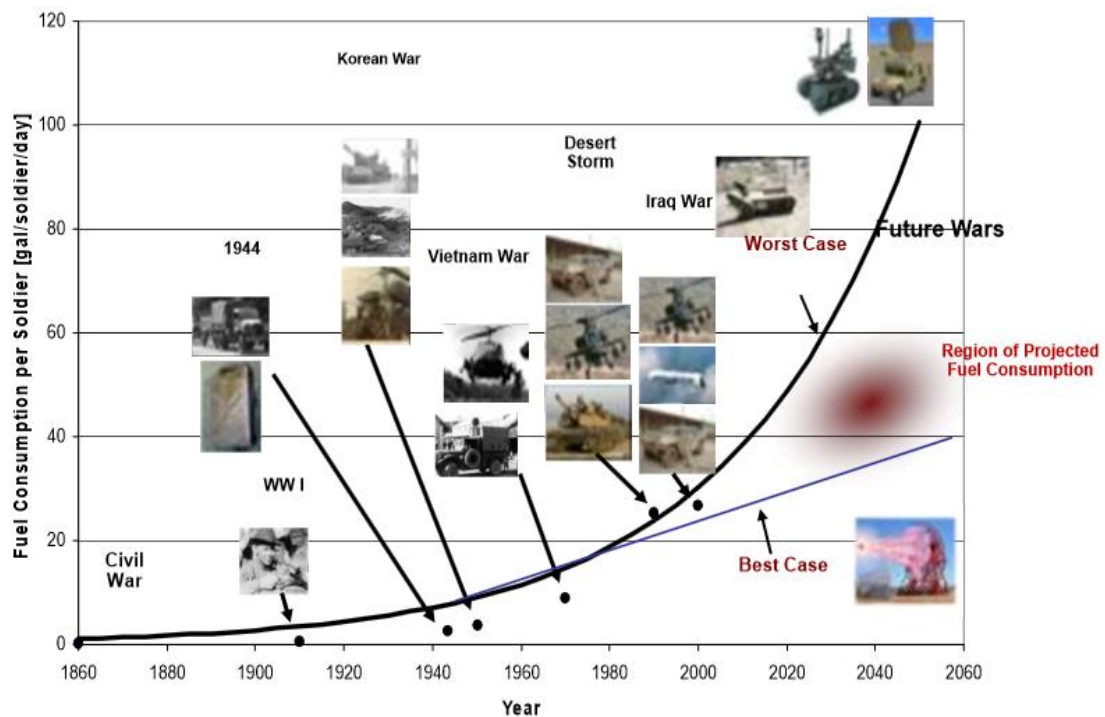


Figure 1. Fuel Consumption per Soldier, Civil War to Present

Source: Scott Schramm, "U.S. Army Hybrid Propulsion System R&D Overview" (Presented at ATA Technology and Maintenance Council 2011 Fall Meeting, Hybrid Powertrain Task Force Session, September 19, 2011, Raleigh, NC, Defense Technical Information Center), <http://www.dtic.mil/dtic/tr/fulltext/u2/a549388.pdf> (accessed January 27, 2014), 6.

The military's dependency on fuel is its Achilles' heel when conducting operations. The Department of Defense (DOD) is the nation's largest consumer of fuel. If the DOD were a country, it would rank in the top third of energy users in the world.⁴ The

energy consumption rates per soldier in Iraq and Afghanistan are four times greater than the rate during World War II.⁵ The logistics mission in Iraq and Afghanistan largely consists of transporting fuel required to execute and sustain operations.⁶ The coordination of moving fuel in theater is heavily resourced to supply hundreds of locations within the two countries. The equipment resources dedicated to fuel convoys such as air escorts, security vehicles, route clearance vehicles that detect Improvised Explosive Devices (IED), the Quick Response Force and recovery vehicle teams on standby are all committed to the fuel mission. However, aside from significant equipment resources needed for one fuel mission the most prized resources are the men and women who risk life and limb supporting the fuel missions. In a Marine Corps study conducted in the year 2011, one Marine was killed or wounded for every 50 fuel and water truck convoys in Afghanistan, and an IED disrupted one in 17 of the convoys.⁷ In Iraq and Afghanistan, the Marine Corps transports fuel and water onshore to over 300 sites which is over 70 percent of its supplies required to sustain forces.⁸ For example, generators on bases for Marines and their equipment burn 60 percent of fuel delivered.⁹ An infantry company (125-150 Marines) today uses more fuel than an infantry battalion (900-1,000 Marines) did in 2001 before operations started in Iraq and Afghanistan.¹⁰ The U.S. Army is no better off, as the Army provides a significantly larger logistics footprint to sustain theater wide operations. Similarly, the majority of Army fuel convoys experienced a number of personnel killed or wounded delivering fuel and supplies in both Iraq and Afghanistan.¹¹ One in eight Soldiers were killed or wounded in Iraq from 2003-2007 protecting fuel convoys that amounts to over 3,000 casualties in a four-year period.¹² The amount of resources, equipment, and personnel which contribute to supporting the fuel mission is

extraordinary. If the military was not dependent on fuel, many of the resources used for fuel missions could be diverted to other missions.

The author's own experience provides first hand witness that conducting convoy operations in both Iraq and Afghanistan are complex and dangerous missions. The next few paragraphs will illustrate the differences between operations in each country. Being responsible for planning or conducting over 100 convoys in Iraq and Afghanistan the experiences of conducting convoys in Iraq differed greatly from Afghanistan in terms of terrain, enemy tactics, and size of the convoys conducted. In Iraq, while assigned as a motor transport platoon commander supporting I Marine Expeditionary Forces in Al Anbar Province from August 2005-March 2006 the author's platoon conducted over 60 Combat Logistics Patrols (CLP) and traveled over 16,000 miles. Based in Al Taqaddum, Iraq, unit missions routinely supported U.S. Marines operating in the cities of Fallujah, Ramadi, and Al Assad. The platoon escorted U.S. line haul contractors, Kellogg Brown Root and Third Country Nationals delivering large amounts of fuel, water and up armored vehicles. The longest missions conducted in Iraq by this platoon and the company lasted no longer than two days. The motor transport company was the final leg for distributing supplies to U.S. Marine units that came via large U.S. Army and Kellogg Brown Root convoys from Kuwait or Jordan. The road infrastructure in Iraq consisted of paved single lane roads that enabled CLPs to travel rather quickly; however, the paved roads still did not deter insurgents from setting up IED positions on the roads.

Throughout the eight-month deployment the platoon encountered four hard hit IED attacks in which the vehicles were rendered inoperable and needed to be recovered. The platoon found over 25 undetonated roadside IEDs and encountered multiple ambushes

with small arms fire. The four other platoons in the company experienced a similar amount of enemy activity. The experience of conducting convoys in Afghanistan proved very different from Iraq. In Afghanistan, I was the company commander for a motor transport company in general support of II Marine Expeditionary Force operating in Regional Command Southwest, Helmand Province from March-October 2011. Over the course of an eight-month deployment, the company went from transporting 60,000 gallons of fuel every 18 days to transporting close to 200,000 gallons every 14 days. The company served as the final leg for distributing fuel to the outlying Forward Operating Bases (FOB) in northern Helmand Province. By the time the fuel reached us for the final leg to its final destination, it had traveled hundreds of miles from the ports of Karachi in Pakistan or thousands of miles if moved on the Northern Distribution Network from the Baltic Sea to the fuel farm on Camp Leatherneck. In Afghanistan, the enemy threat along the convoy routes was higher than Iraq. We were limited to one route in open desert on hard packed dirt, which often meant the enemy placed IEDs in the road that were hard to detect. The IEDs were also hidden in the ground along the shoulder of the roads and at chokepoints the convoy needed to traverse through.

The following paragraphs are a recount of the authors own experiences of conducting one of 18 fuel resupply missions in Afghanistan from Camp Leatherneck to FOB Edinburgh during February 2011 through October 2011 supporting Operation Enduring Freedom (OEF) 11-1. As company commander, I would routinely go on convoys to observe my lieutenants as convoy commanders and the Marines conducting CLPs. It was 0430 July 23, 2011 as the first signs of daybreak started to illuminate the desert sky over the Chalap Dalan Mountains in Helmond Province 65 miles north of

Camp Leatherneck. I just finished my shift manning the .50 caliber machine gun in the turret of our Mine Resistant Ambush Protection (MRAP) vehicle. We provided over watch for our sector of the convoy during the night security halt. The morning of July 23, we started our third day of travel having had only about seven hours sleep in two days. Even during night security halts, no one really slept because Marines would rotate being on watch every three hours. The vehicles also had to be turned on every few hours disturbing anyone trying to sleep to charge the vehicle batteries running the command and control systems. At daybreak, the Marines and our escorted Afghan local nationals slowly started to wake and were preparing to start moving by 0530 hours en-route to FOB Edinburgh that was approximately 100 miles away. FOB Edinburgh supported a helicopter squadron, a maintenance detachment and one infantry company. This FOB also had a medical care unit supporting operations in northern Helmond that routinely conducted air Medical Evacuation from the area. During the Edinburgh mission we would also stop at FOBs Now Zad, Musa Qula and Combat Outpost (COP) Shakvani to fill the camp fuel bladders for the U.S. forces stationed there (see figure 2 map of Helmond Province). The typical round trip mission resupplying all FOBs and COPs lasted 10-12 days. The time would vary depending on enemy attacks and break downs of the large 10,000-gallon Afghan tanker trucks, which were in constant need of repair. Sometimes we needed to stay at FOB Edinburgh for an extra one to two days waiting for aerial delivery of repair parts. As the early dawn light turned the sky from dark to light blue you could hear Marines and the Afghan nationals start to prepare themselves and their vehicles. Slowly the quite was replaced by the rumble of 110 vehicles starting their engines preparing for another day of travel. Of the 200,000 gallons of fuel we started

with only about 185,000 gallons would make it due to enemy attacks. An average convoy would lose two tanker trucks to IED attacks. Additional fuel was lost due to small arms fire aimed at the 10,000-gallon tanker trucks that would cause them to leak fuel heavily. This was just one of 18 fuel missions the company conducted over an eight-month deployment. Each fuel mission required more than 70 percent of the company resources to include personnel, crew served weapons and vehicles. The commitment to fuel convoys limited our ability to support other resupply missions the battalion was tasked with.

In Afghanistan, due to limited safe routes and the availability of route clearing platoons, many units submitted ground movement requests to join our convoy to FOB Edinburgh resulting in convoys exceeding 100 vehicles. Vehicles maintained 75-100 meters dispersion during convoys. These large convoys' were over 10 kilometers long. During the night while positioned in a night security halt the vehicles closed in and maintained a dispersion of 10 meters between vehicles in two columns of 55 vehicles each.

The road infrastructure in Afghanistan was very poor. We could not travel on the only two paved roads in our area of operation, Highway 1 built by the Soviet Union and Route Red built by U.S. and host nation contractors. If allowed to use the paved Main Supply Routes the drive time to FOB Edinburgh is less than a day. Due to multiple enemy IED attacks and ambushes along Route Red, which traveled through the Sangin valley, an enemy hold out, we needed to find an alternate route and the only feasible option was traveling through the desert. To reach FOB Edinburgh traveling in the open desert from Camp Leatherneck took an average of three to four days one way with

minimal enemy attacks and breakdowns. The 110-vehicle convoy traveled in the open desert crossing multiple wadies, chokepoints, streams, soft desert sand, through small compounds and the vast poppy fields of southern Afghanistan in 100 plus degree heat. On average, we would reach top speeds of 20 Miles per Hour (MPH) on the open hard packed terrain but most of the time our rate of travel was 10 MPH. We were fortunate to have the route-clearing platoon with us as they would often find or mistakenly detonate multiple IEDs as the convoy slowly approached chokepoints and crossed wadies. The fuel mission always guaranteed enemy attacks. The whole point to traveling in the open desert was to avoid the enemy but this seemed to only attract more attacks. We would routinely have Intelligence Surveillance Reconnaissance coverage and air support on station throughout the day scouting our planned route looking for signs of emplaced IEDs. On this particular mission during our movement back to Camp Leatherneck, in a 30-hour period the convoy moved less than two kilometers due to four enemy IED attacks consecutively. After each one was cleared less than a half mile down the road the lead elements hit another and then another. Each time we hit an IED it took about three to four hours to clear the ground up to the vehicle searching for secondary IEDs, recover it, conduct the post blast analysis and if needed call in a Medical Evacuation. This stop and go consumed a lot of fuel from all the vehicles. During the short security halts (less than two hours) and sometimes long halts both for maintenance issues or waiting for IED sites to be cleared all military vehicles never turned their engines off and ran on idol for hours upon hours to power radios and air conditioning units. This alone consumed hundreds if not thousands of gallons of fuel per mission due to the need to keep vehicles running at all times in the event a vehicle came under attack and the driver needed to quickly

navigate out of a kill zone. This also created maintenance issues including diesel soot buildup in the vehicles exhaust systems. Since it took three to four days to reach FOB Edinburgh each fuel mission required an M970, 5,000-gallon military fuel truck to fill up the military vehicles on the convoy each day while they were en route, exhausting more resources from the company

The conduct of the Marines during the fuel missions was extraordinary. The training and experience they brought saved countless hours of travel time. During this particular mission which lasted 11 days, the convoy successfully off loaded fuel and cargo while reporting nine IED attacks, one small arms ambush and one flipped fuel tanker truck. Once back at Camp Leatherneck it was only a three-day break before the next fuel mission would be outbound for FOB Edinburgh and the unit would face similar attacks along the one route of travel through the desert.

The company delivered a total of 2.1 million gallons of Jet Propellant eight (JP-8) fuel over the eight-month deployment. The harsh reality was many other combat support units in Afghanistan either Army or Marine which supported a fuel mission had similar experiences. To deliver on average 200,000 gallons of fuel every two weeks took many hours of preparation, coordination, equipment, and resources to support one of many fuel operations handled by II Marine Expeditionary Force during OEF 11-1. Every fuel mission the company conducted resulted in multiple IED attacks, sometimes as many as 15 attacks during a single mission. This resulted in two to three destroyed coalition vehicles and one to two Medical Evacuations primarily due to Soldiers and Marines getting concussions from IED blasts. By the end of the deployment, over 20 percent of the 225 Marines and Sailors of General Support Motor Transportation Company

sustained an IED hit and were medically evacuated during missions for concussion symptoms. On average we would also lose about 10-15 percent of all fuel transported due to enemy attacks on fuel trucks from rockets, IEDs and small arms fire. The fuel mission experience made me realize first-hand how important our mission was to sustaining combat operations in Helmond Province. No matter the cost in money, equipment, and even lives, for a military operation to be successful fuel is an operational necessity to ground forces and Marines and Soldiers will always be part of the equation in making sure ground forces have access to it.

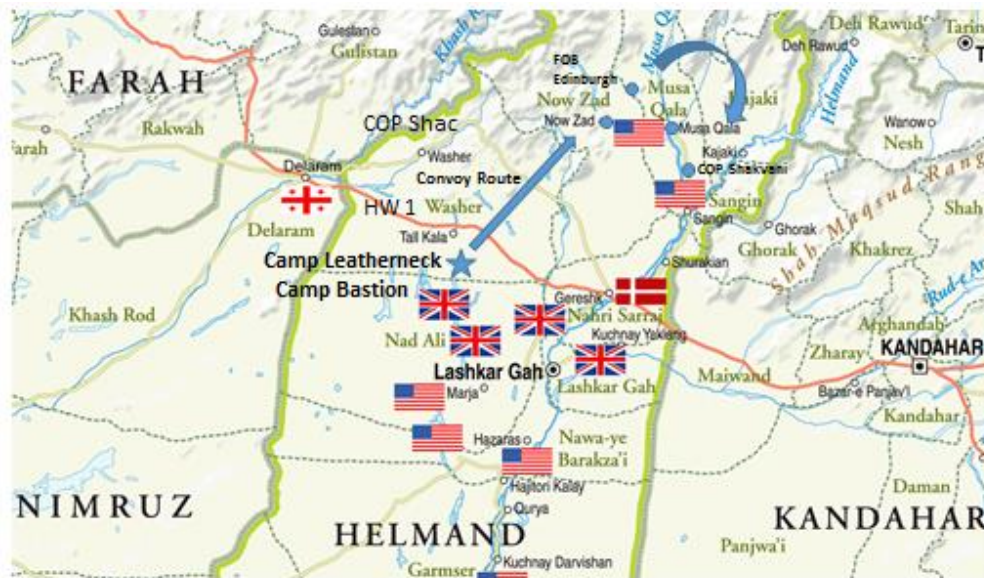


Figure 2. Map of Coalition Bases in Helmond Province

Source: Institute for the Study of War, “Afghanistan,” <http://www.understandingwar.org/afghanistan> (accessed January 25, 2014).

Problem Statement

It is a fundamental of operational level planning that military operations drives logistics. However, operations must take into account the logistics support needed to sustain operations. Logistics often places constraints on many different planning factors. Other than weather, logistics is one of the only other major factors that can contribute to stalling or halting operations. Throughout the last 13 years of conflict, the DOD and supporting organizations have logistically supported two major conflicts, in two different countries, Iraq from 2003-2011 and Afghanistan from 2001-present. Supporting both conflicts identified many significant operational and strategic level logistics challenges. One such challenge in supporting ground and air operations is the demand for fuel to sustain operations. The amount of fuel delivered into both countries reached into billions of gallons. The billions of dollars in damaged equipment from enemy attacks on fuel convoys is stunning as well as the large amount of resources needed to conduct fuel resupply missions. However, nothing can compare to the number of Soldiers, Marines and civilians who lost their lives or were injured supporting the fuel mission either by driving fuel tankers or providing security escorts for fuel convoys.¹³ In fiscal year 2009, the Army consumed over 620 million gallons of fuel for Operation Iraqi Freedom (OIF) and OEF. Reducing that amount by 20 percent, or 124 million gallons, would have the effect of reducing the number of fuel trucks by over 37,500 and decreasing required fuel convoys by over 2,500.¹⁴ Fuel consumption in the U.S. Marine Corps has similar statistics to the U.S. Army with equivalent effects if reductions of 20 percent is summed across all U.S. Marine Corps platforms. A 20 percent reduction in fuel guarantees a significant increase in money saved from the DODs budget. Many studies and reports

published over the past few years identified that DOD was spending between 400-700 dollars per gallon of fuel depending on the delivery method, air, ground, sea, and the resources needed to deliver fuel in Iraq and Afghanistan.¹⁵ These figures are the result of the fully burdened cost of fuel and each service reports different fully burden cost of fuel numbers ranging from nine to 45 dollars per gallon. This takes into consideration all the resources in personnel, equipment to transport and distribute fuel in a theater of operation such as Iraq and Afghanistan.¹⁶

The DOD is one of the largest consumers of fuel in the world.¹⁷ The military's dependence on fuel is an important factor on the operational reach, flexibility, and tempo U.S. operations. Our dependence on fuel is a critical issue for the conduct of military operations. It creates significant operational and strategic risks when fuel sources are lost or compromised to include the means of transporting fuel along roads, air, and sea.¹⁸ It can mean the success or failure of a mission at the operational and strategic level. As long as we rely on combustion engines to power tactical tracked and wheeled vehicles and rely on a power source such as tactical generators to produce electricity for command and control systems our dependence of a fuel will be a big factor in operational level planning specifically during wartime. Table 1 depicts the breakdown of fuel consumption of Army equipment in peacetime and wartime. As depicted in table 1, ground tactical vehicles and generators are the largest consumers of fossil fuels excluding combat aircraft during peacetime.

Table 1. Army Fuel Consumption in Peacetime and Wartime, 2008 (millions of gallons per year)

Equipment Category	Army Peacetime Consumption		Army Wartime Consumption	
	Gallons Consumed (millions)	Percent of Total Consumption	Gallons Consumed (millions)	Percent of Total Consumption
Combat Vehicles	30	10.31%	162	15.43%
Combat Aircraft	140	48.11%	307	29.23%
Tactical Vehicles	44	15.12%	173	16.48%
Generators	26	8.93%	357	34.00%
Non-Tactical	51	17.53%	51	4.86%
Total	291	100%	1050	100%

Source: James Meyer and Robert Talley, “U.S. Army 5-5 Study, Tactical Fuel and Energy Implementation Plan” (Chester, VA, Expeditionary Logistics Inc., September 24, 2010), Defense Technical Information Center, <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA529051> (accessed February 13, 2014), 13.

The U.S. government and the DOD are aware of the military’s profound dependence on fossil fuels and non-renewable energy resources and have outlined mitigating proposals in the 2010 *National Military Strategy*,¹⁹ 2010 *Quadrennial Defense Review*,²⁰ and 2010 *Operational Energy Strategy*.²¹ The policy presented in these documents is the driving force to effect change in the military from the top down. All the military services need to implement their own fuel efficiency measures to reduce dependency on fossil fuel and energy consumption at all levels of warfighting.²² These fuel efficiency measures will be addressed by both material and non-material solutions addressing Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy (DOTMLPF-P) in the force management process to drive change.²³ As the size of our forces decrease in the coming years the military must be able to adapt to be less dependent on fuel and non-renewable energy resources if the military

ground forces are to operate more expeditionary. Doing so will produce a modern, agile, leaner, and highly efficient fighting force.²⁴ Through this reduction of operational energy needs, the DOD can increase operational reach, battlefield flexibility, and agility while reducing the logistics sustainment needed to support tactical and operational level operations.

Primary Research Question

What must the DOD do to be prepared logistically for future warfare at the tactical level recognizing that current ground equipment systems have a massive dependency on non-renewable energy resources?

Subsidiary Questions

1. If implementing fuel reducing measures in the three areas of diesel hybrid electric engines, drop in biofuels and solar technology for tactical generators will data show a significant decrease in fuel consumption greater than twenty percent?
2. How effective will ground units be in conducting expeditionary operations with current tactical equipment platforms that are heavily dependent on fuel resources?
3. How will incorporating energy efficient technologies to ground units impact logistics sustainment?
4. What are the risks of investing in platforms which are less dependent on fuel?

Definitions

The following definitions will assist the reader in understanding concepts identified in this study. Word definitions came from a variety of military and private industry sources.

Alternative Fuels: Alternative fuels are the first of three types of non-petroleum liquid fuels. They are those transportation and mobility fuels that are not derived from traditional liquid petroleum including renewable and synthetic fuels.²⁵

Combat Out Post: A reinforced observation post capable of conducting limited combat operations.²⁶

Combat Vehicle: Vehicles considered front-line vehicles such as tracked vehicles, strikers, and light reconnaissance vehicles.

Drop in Biofuels: Fuels substantially similar to gasoline, diesel, and jet fuels. These fuels can be made from a variety of biomass feed stocks including crop residues, woody biomass, dedicated energy crops, and algae. The goal for drop-in fuels is to meet existing diesel, gasoline, and jet fuel quality specifications and be ready to "drop-in" to existing infrastructure.²⁷

Electric Generator: A device that converts mechanical energy to electrical energy.

Energy Optimization: Maximizing the use of limited resources in the most intelligent and efficient way possible to achieve the greatest and functional output.²⁸

Environmental Control Unit: A portable cooling and heating system for portable shelters and critical electronics. They come in multiple sizes and require an electric power source to function.

Forward Operating Base: An airfield used to support tactical operations without establishing full support facilities. In certain situations, this base will support units for an extended period. Support by a main operating base will be required to provide support for a forward operating base.²⁹

Fully Burdened Cost of Fuel: The commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel arrives from the commercial supplier to the point of use.³⁰

Hybrid Vehicle Technology: A hybrid vehicle that uses two or more distinct power sources to move a vehicle. The combination of an internal combustion engine that provides power to a generator that operates to store power in batteries to power one or more electric motors at the wheels of the vehicle.

Improvised Explosive Device: A weapon that is fabricated or emplaced in an unconventional manner incorporating destructive, lethal, noxious, pyrotechnic, or incendiary chemicals designed to kill, destroy, incapacitate, harass, deny mobility, or distract.³¹

JP-8: Jet Propellant 8 is a jet fuel, specified and used widely by the U.S. military. The primary ingredient of JP-8 is kerosene, and the composition of these fuels is the same as kerosene, with the exceptions that they are made under more stringent conditions and contain various additives.³²

Logistics: Planning and executing the movement and support of forces. It includes those aspects of military operations that deal with: a. design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposition of materiel; b. movement, evacuation, and hospitalization of personnel; c. acquisition or construction, maintenance, operation, and disposition of facilities; and d. acquisition or furnishing of services.³³

Operational Energy: Operational energy is 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.³⁴

Renewable Fuels: Federal legislation identifies renewable fuels as those transportation and mobility fuels derived from biomass or its decay products. These fuels can be used with stand-alone fuel or blended with petroleum.³⁵

Tactical Wheeled Vehicle: Vehicles considered support type vehicles such as logistics vehicles to move cargo, fuel, personnel, heavy equipment, HMMWVs, HEMTT, LVS, MTRVs, MRAPs, and M-ATVs.

Scope

The scope of operational energy is a complex subject especially because it spans all three levels of war: strategic, operational, and tactical. Operational energy's impact on logistics sustainment is also expansive as logistics also spans all three levels of war. Their interconnected relationship must be discussed in tandem as components of tactical, operational and strategic level logistics are inherently tied to operational energy. Operational energy is the energy required for training, moving, and sustaining military forces and weapons platforms for military operations.³⁶ At the tactical level to include transportation, maintenance, health services, and services. Operational level logistics plan, arrival and assembly of forces, intra-theater lift, theater distribution, sustainment, engineering, reconstitution and redeployment. Strategic level includes procurement, mobilization, war reserves, materiel readiness, deployment and support, force regeneration, mobilization, and facilities.³⁷

The scope of this study will focus on ground tactical equipment used by the U.S. Marine Corps and U.S. Army. Specifically it will focus on the fuel consumption of

tactical wheeled vehicles and generators to power tactical command and control centers, camp services and environmental control units. The study will also focus on developing an energy optimization strategy to reduce fuel consumption at the tactical level using commercial off the shelf technology. The time frame of this study will cover the last 13 years of sustained operations starting from the invasion of Afghanistan in October 2001, through the invasion of Iraq in March 2003 until the present.

Limitations

Due to the limits of technology in this field, many equipment systems and fuel blends are still in the experimental and testing stage. Biofuels on the market cover a wide range of products; however, many do not show a significant increase in engine efficiency. Studies do show biofuels produce fewer emissions than conventional fuel because they burn cleaner but engine emissions are not a focus of this study. Natural gas is abundant and cheaper but the properties of natural gas require a 50 percent increase in fuel usage in most equipment. Until the cost per gallon of biofuels or alternative fuels is lower than crude oil they will not be part of the study. No significant real world applications demonstrate the use of diesel hybrid electric engines with a military application. Research indicates testing is limited to laboratory and controlled testing environments. Significant field testing data with solar power equipment is available but long-term data and longevity of equipment systems is not available. Furthermore, no data is available on how improvements in operational energy technology will impact logistics sustainment, maintenance and battlefield distribution of repair parts for this new technology. No research is available on the implications of establishing new specialty Military

Occupation Specialty fields needed to sustain the equipment once it is fielded to the operating forces will pose challenges.

Delimitations

For the purpose of the research, the author will focus on operational energy systems of the U.S. Army and U.S. Marines that support fuel reduction for ground tactical equipment. Ground combat vehicles or front line vehicles such as tanks, assault amphibious vehicles, light armored reconnaissance vehicles and the Bradley Fighting vehicle are all large fuel consumers but account for a small percentage of the overall ground vehicle fuel consumption percentage and will not be part of this study.³⁸ Energy reduction on permanent military installations, bases, facilities, and the DOD's non-tactical vehicle fleet will not be part of the research conducted as they do not qualify under operational energy definition and are not under the expeditionary construct of military operations. Approximately 75 percent of the energy the DOD consumed in 2009 is operational energy, while fixed installations accounted for the other 25 percent, largely for facilities and non-tactical vehicles.³⁹ Because, unless biofuels or fuel blends do not show increases in the efficiency of engines in vehicles and generators they will not be included in the study. Studies show engines will burn cleaner with fewer emissions but if consumption rates for generators and vehicles do not decrease the total quantity of fuel transported by ground troops will remain status quo. Even though, operational fuel usage by the U.S. Air Force and U.S. Navy accounts for approximately 70 percent of the DOD fuel consumption rates they will not be part of the study.⁴⁰ Additionally, the U.S. Air Force accounts for approximately 64 percent of total aviation fuel costs within the DOD and ten percent of all aviation fuel used in the United States.⁴¹ Organizational cultural

challenges associated with introducing a new concept to a large base of personnel trying to change a mindset will not be a focus area of this research, however, discussing non-materiel solutions of influencing doctrine, training and policy will be.

Assumptions

The current DOD budget reduction will not impact the scope of research and implementation of energy saving equipment at the tactical level. The author uncovered many documents, journals, periodicals and articles dating back to the year 2000 which detain the military's dependency on fuel. Extensive research conducted also identifies the ends, ways, and means of the DODs fuel problem. DOD budget constraints will not impact the research and design of new and viable solutions to increase efficiency of engines for tactical wheeled vehicles and Environmental Control Units (ECUs). If fuel prices stabilize and the dependency of the United States on foreign oil decreases, this will not deter the DOD from researching with energy efficient technology and renewable biofuel technologies. The end state is a military that is less dependent on fuel and can operate longer and further without the large tether of fuel resupplies.

¹U.S. Marine Corps, Marine Corps Doctrinal Publication 4, *Logistics* (Washington, DC: Headquarters, U.S. Marine Corps, February 1997), 3.

²*Ibid.*, 4.

³*Ibid.*, 8.

⁴Sohbet Karbuz, "US military energy consumption-facts and figures," Resilience, Post Carbon Institute, May 21, 2007, <http://www.resilience.org/stories/2007-05-21/us-military-energy-consumption-facts-and-figures> (accessed September 15, 2013).

⁵Scott Buchanan, "Energy and Force Transformation," *Joint Forces Quarterly* 5, no. 42 (3rd Quarter April 2007): 51, http://www.army.mil/professionalWriting/volumes/volume5/april_2007/4_07_4pf.html (accessed November 10, 2013).

⁶Ibid.

⁷Justin Gerdes, “Marines Push to Front Lines in Renewable Energy Innovation,” Yale Environment 360, June 27, 2013, http://e360.yale.edu/feature/marines_push_to_front_lines_in_renewable_energy_innovation/2667/ (accessed November 10, 2013).

⁸Ibid.

⁹The Marine Corps Expeditionary Energy Office, *United States Marine Corps Expeditionary Energy Strategy and Implementation Plan* (Washington, DC: Headquarters, U.S. Marine Corps, 2010), 71.

¹⁰Gerdes.

¹¹David S. Eady, Steven B. Siegel, R. Steven Bell, and Scott H. Dicke, “Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys,” Army Environmental Policy Institute, September 2009, www.aepi.army.mil (accessed November 12, 2013).

¹²Ibid.

¹³Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy* (Washington, DC: Government Printing Office, 2010), 5.

¹⁴James Meyer and Robert Talley, “U.S. Army 5-5 Study, Tactical Fuel and Energy Implementation Plan ” (Chester, VA, Expeditionary Logistics Inc., September 24, 2010), Defense Technical Information Center, <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA529051> (accessed February 13, 2014), 13.

¹⁵Roxana Tiron, “\$400 per gallon gas to drive debate over cost of war in Afghanistan,” October 16, 2009, The Hill, <http://thehill.com/homenews/administration/63407-400gallon-gas-another-cost-of-war-in-afghanistan-#ixzz301lGw8SX> (accessed April 1, 2014).

¹⁶Moshe Schwartz, Katherine Blakeley, and Ronald O’Rourke, Congressional Research Service Report for Congress R42558, *Department of Defense Energy Initiatives: Background and Issues for Congress* (Washington, DC: Library of Congress, December 10, 2012), <http://www.fas.org/sgp/crs/natsec/R42558.pdf>. (accessed April 1, 2014), 6.

¹⁷E. O. Bustnes, K. E. Datta, N. J. Glasgow, J. G. Koomey, and A. B. Lovins, *Winning the Oil Endgame: Innovations for Profits, Jobs, and Security* (Snowmass, CO: Rocky Mountain Institute, 2005), 88.

¹⁸Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy*, 3.

¹⁹U.S. President, *U.S. National Security Strategy* (Washington, DC: Government Printing Office, 2010), 30.

²⁰Department of Defense, *Quadrennial Defense Review* (Washington, DC: Government Printing Office, 2010), 87.

²¹Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy*, 1.

²²Department of Defense, *Quadrennial Defense Review*, 87.

²³Headquarters, Department of the Army, Army Regulation 5-22, *The Army Force Modernization Proponent System* (Washington, DC: Government Printing Office, March 25, 2011), Official Department of the Army Publications and Forms, http://armypubs.army.mil/epubs/pdf/r5_22.pdf (accessed April 30, 2014), 2.

²⁴The Marine Corps Expeditionary Energy Office, *Expeditionary Energy Strategy and Implementation Plan*, 3.

²⁵Department of Defense, Section 334 Congressional Study, *Opportunities for DOD Use of Alternative and Renewable Fuels: FY10 NDAA* (Washington, DC: Government Printing Office, July 2011), 3.

²⁶Headquarters, Department of the Army, Army Doctrine Reference Publication 1-02, *Terms and Military Symbols* (Washington, DC: Government Printing Office, 2013), 1-12.

²⁷Alternative Fuels Data Center, “Drop-In Biofuels,” U.S. Department of Energy, http://www.afdc.energy.gov/fuels/emerging_dropin_biofuels.html (accessed February 8, 2014).

²⁸Anthony Pollman, “Energy Optimization: A Combat Multiplier,” *Marine Corps Gazette* 97, no. 11 (November 2013): 70, <https://www.mca-marines.org/gazette/2013/11/energy-optimization> (accessed November 12, 2013).

²⁹*Ibid.*, 109.

³⁰*Duncan Hunter National Defense Authorization Act for Fiscal Year 2009*, Public Law-110-417, U.S. Statutes at Large (October 14, 2008): 122 Stat. 4356, 110th Congress, http://www.dod.mil/dodgc/olc/docs/2009NDAA_PL110-417.pdf (accessed April 1 2014), 67, sect. 332, para g.

³¹Joint Chiefs of Staff, Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms* (Washington, DC: Government Printing Office, November 8, 2010, as amended through March 15, 2014), 128.

³²Department of Defense, *Opportunities for DOD Use of Alternative and Renewable Fuels*, 3.

³³U.S. Marine Corps, Marine Corps Doctrinal Publication 4, 3.

³⁴Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy*, 3.

³⁵*Ibid.*

³⁶*Ibid.*

³⁷U.S. Marine Corps, Marine Corps Doctrinal Publication 4, 52.

³⁸Naval Research Advisory Committee Future Fuels Study Panel, “Breaking the Tether of Fuel,” The Official Homepage of the United States Army, April 2007, http://www.army.mil/professionalWriting/volumes/volume5/april_2007/4_07_3.html (accessed November 10, 2013).

³⁹Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy*, 3.

⁴⁰Secretary of the Air Force for Installations, Environment and Logistics, *Air Force Energy Plan*, 2010, U.S. Air Force, <http://www.safie.hq.af.mil/shared/media/document/AFD-091208-027.pdf> (accessed October 20, 2013). 4.

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CHAPTER 2

REVIEW OF LITERATURE

Introduction

The scope of literature on operational energy's link to logistics sustainment is expansive. Both academia and the DOD have published numerous data and consumption factors on the subject. The research and development community publishes multiple articles on the latest technology designed to reduce fuel consumption at the tactical level as well as on operating bases and military installations. Scholars in engineering, biofuels and subject matter experts in energy continue to publish articles on innovative measures to promote reliable, cost-effective solutions. Several publications and articles that address the DOD's commitment to foster the implementation of operational energy and reduced logistical footprint support were examined. Many strategic level documents outline the DOD's energy reduction plan through 2025 and further provide explanations why the DOD must reduce its dependency on fossil fuels. Furthermore, service level documents and publications are available which outline each of the four services' own operation energy implementation and strategy plans for the near and long term.

Literature Review

The link from strategic to tactical is critical because the acquisition of energy efficient equipment is conducted at the strategic level within the DOD.¹ Fuel moving into a theater of operation has strategic and operational impacts if compromised. Since early 2000 extensive research conducted on determining the fuel consumption of ground forces have yielded staggering results.² This is evident when comparing two Marine battalions'

table of organization one in 2001 and the other in 2010. In 2001, a Marine infantry battalion table of organization listed 64 High Mobility Multipurpose Wheeled Vehicle (HMMWV).³ The average infantry battalion in Afghanistan in 2010 had 173 MRAPs, the new smaller MRAP-All Terrain Vehicles (M-ATV) and Medium Tactical Vehicle Replacement vehicles (MTVR).⁴ These vehicles are also about 75 percent heavier than the HMMWV gross weight and are 30 percent less fuel-efficient.⁵ Primarily tactical wheeled vehicles use more fuel is because they are much heavier due to armor plating, bulletproof windows, communication equipment, and larger air conditioner condensers that outfit all of the later model tactical vehicles.⁶ The fact that the United States conducted stability operations for a decade also contributed to the deep dependency on fuel to run basecamp generators either at large bases, smaller FOBs or Patrol Bases.⁷ The generators by themselves are relatively efficient but must always operate at maximum power even when fulfilling minimum requirements for electrical power.⁸ Additionally, ECUs which are powered by generators provide climate control in shelters that are poorly insulated and thermally inefficient.⁹

At the national strategic level, the guidance for reducing the DOD's dependency on fuel comes from the 2010 *National Strategic Strategy*.¹⁰ This document discusses the administration's position on energy dependency of the United States and the way ahead. It states as long as we are dependent on fossil fuels, we need to ensure the security and free flow of global energy resources by improving energy efficiency, increase use of renewable and nuclear power, reduce the dependence of vehicles on oil, and diversify energy sources and suppliers.¹¹ The United States will continue to invest in research, next-generation technology, and modernize the way we distribute electricity.¹² The

National Security Strategy overarching guidance paved the way for the DOD to initiate programs and policies that address the energy problem of the military.¹³

In the 2010 *Quadrennial Defense Review*, the DOD's guiding document outlines a way ahead for meeting the DOD's energy needs. It stated energy efficiency can serve as a force multiplier, because it increases the range and endurance of forces in the field and can reduce the number of combat forces diverted to protect energy supply lines, which are vulnerable to both asymmetric and conventional attacks and disruptions.¹⁴ The DOD must incorporate operational energy considerations into force planning, requirements development, and acquisition processes.¹⁵ The military departments have and will continue to invest in non-carbon power sources such as solar, wind, geothermal, and biomass energy at domestic installations and in vehicles powered by alternative fuels, including hybrid power, electricity, hydrogen, and compressed natural gas.¹⁶ Solving military challenges through innovations such as more efficient generators, better batteries, lighter materials, and tactically deployed energy sources has the potential to yield spin-off technologies that benefit the civilian community as well.¹⁷

DOD Operational Energy Strategy is a document that was nested with the *Quadrennial Defense Review* and was produced in 2010. This document provides more quantitative data and further outlines the DOD's way ahead in regards to adopting operating energy into the operating forces. Moving large volumes of fuel for military operations entails logistical and tactical risks and challenges which can also be costly. In 2010, U.S. armed forces consumed more than five billion gallons of fuel in military operations costing \$13.2 billion dollars, a 225 percent increase over the cost in 1997.¹⁸ Moreover, given the volatility of oil markets, it is difficult to anticipate and budget for

fuel costs. To better illustrate how fuel prices increase the military's budget a \$1.00 increase per gallon of fuel will cost the U.S. Navy an additional \$31,000,000 million dollars from their budget.¹⁹ The number one factor driving fuel consumption in the DOD is the nature of today's defense mission. Challenges to future U.S. national security are increasingly global and complex, requiring a broad range of military operations and capabilities and a large and steady supply of energy. Improving the range, endurance, and reliability of ground, air, and naval assets by lightening the logistics load and reducing the vulnerability of fuel supply lines will have significant impact in expeditionary and stability operations.²⁰ Decreasing the logistics load will refocus combat forces and capabilities from supply lines and fuel logistics to operational missions.²¹ Furthermore, the DOD needs to improve its ability to measure operational energy consumption, reduce demand, and increase the efficiency of energy use to enhance combat effectiveness. Numerous studies by the DOD identify a need to diversify its energy sources and protect access to energy supplies to have an assured supply of energy for military missions. Reliance on a single energy source—petroleum—has economic and strategic drawbacks to national defense.²² The military generally relies on petroleum-based fuels, which power equipment, expeditionary bases, tactical vehicles, aircraft, some naval vessels, and other platforms.²³

In order to put into action the guidance from the *Operational Energy Strategy* the DOD created the 2010 *Operational Energy Strategy and Implementation Plan*. This plan describes what is required from each of the services to reduce dependency on non-renewable resources. It identifies seven target goals to reach in reducing the military dependency of fossil fuels and increased use of renewable technologies through the year

2025.²⁴ The DOD will reduce the overall demand for operational energy and improve the efficiency of military energy use in order to enhance combat effectiveness and reduce risks and costs for military mission.²⁵ Figure 3 provides a breakdown of service level goals in energy reduction by year 2020-2025.

Military Departments' Goals and Metrics for Improving the Energy Efficiency of the Force	
Army	• 16 Net Zero Energy, Waste, and/or Water installations by 2020. • 25 Net Zero installations at home and/or abroad by 2030.
Navy	• Increase efficiency and reduce fuel consumption afloat by 15 percent by 2020.
Air Force	• Increase aviation energy efficiency by 10 percent by 2020.
Marine Corps	• Increase energy efficiency on the battlefield by 50 percent by 2025. • As a result, reduce fuel consumed per Marine per day by 50 percent by 2025.

Figure 3. DOD Services Goals in Energy Reduction

Source: Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy: Implementation Plan* (Washington, DC: Government Printing Office, 2010), 12.

Operational energy spans across all the services and for the purposes of the study, the author will refer primarily to the U.S. Marine Corps and U.S. Army as these have the preponderance of ground equipment, which is the focus of the study. As previously mentioned the U.S. Air Force and U.S. Navy are the largest consumers of fuel in the DOD due to high fuel consumption rates for aircraft and naval vessels.²⁶

The *United States Marine Corps Expeditionary Energy Strategy and Implementation Plan* provides information on the Marine Corps way ahead for reducing fuel consumption and further explains the importance of reducing fuel demand which reduces the sustainment to support expeditionary operations. Ideally, for a force to be expeditionary in nature the logistics tail ought not to determine operational reach, which it often does.

Researching Defense Logistics Agency-Energy provided significant consumption data for each of the services.²⁷ Defense Logistics Agency-Energy also catalogues historical information on fuel transportation amounts and consumption rates of the military. By the end of 2010, Defense Logistics Agency-Energy was transporting over 40 million gallons of fuel per month into Afghanistan alone.²⁸ Defense Logistics Agency-Energy. The agency also evaluates the impact of alternative fuel technologies on handling and distribution, and develops and approves new alternative fuel specifications for biofuels.²⁹

Studies from the Defense Science Board Task Force in 2001 and 2008 highlight the largest consumer of fuel on the battlefield among military vehicles are the support vehicles (tactical vehicles) which consume over 50 percent of the fuel for ground vehicle systems as shown in figure 4.³⁰

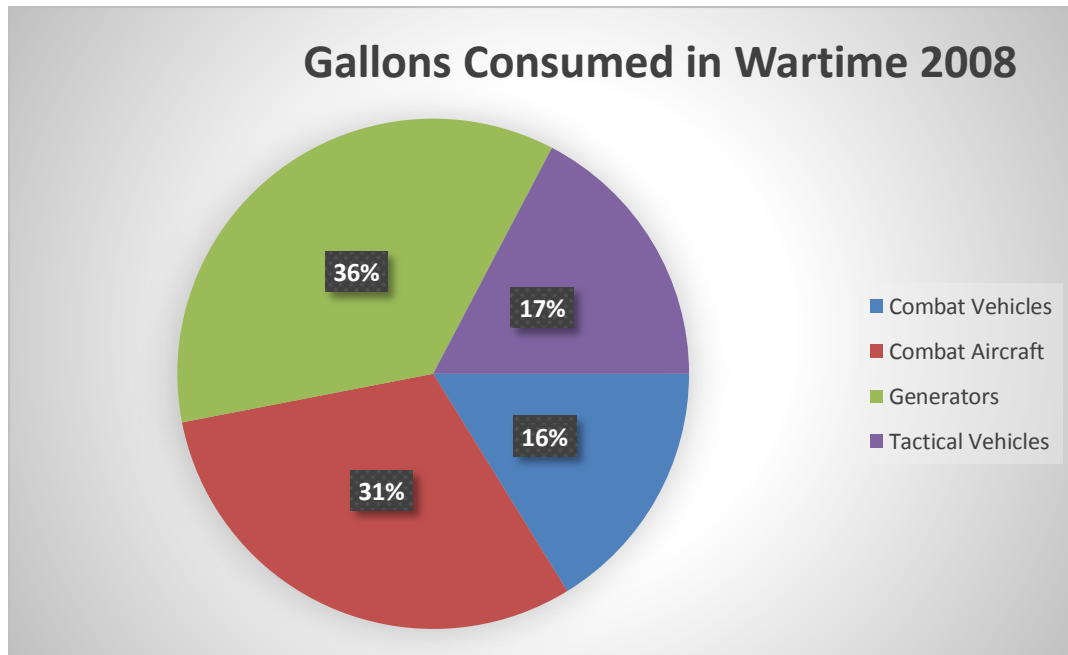


Figure 4. U.S. Army Largest Consumers of Fuel in Wartime, 2008

Source: Created by author using information from James Meyer and Robert Talley, “U.S. Army 5-5 Study, Tactical Fuel and Energy Implementation Plan” (Chester, VA, Expeditionary Logistics Inc., September 24, 2010), Defense Technical Information Center, <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA529051> (accessed February 13, 2014), 13.

The support vehicles include Heavy Equipment Transporter, MTVRs, Logistics Vehicle Systems, HMMWVs, MRAP, and MRAP-All Terrain Vehicle.³¹ The 2001 study identified the top 10 battlefield vehicles which consume the most fuel and eight of the 10 were support vehicles while the M1A1 and Apache Helicopter ranked fifth and tenth.³² Many independent articles and journals have produced findings suggesting the implementation of hybrid electric vehicle technology is the most logical solution for the short term. Hybrid technology combines a fuel-efficient internal combustion engine, with electric motors to power the vehicle. In the case of military vehicles, a diesel engine

provides power to a generator that stores power in batteries to power one or more electric motors at the wheels of the vehicle.³³ The generator will provide power to batteries for on board communication and temperature control systems eliminating the vehicle from running on idle for numerous hours consuming fuel and wearing on engine parts.³⁴ A lot of research and development is conducted in this field, particularly in the commercial automotive industry, which is a good jump off point for defense contractors willing to take the technology already out in the market and redesign it for a military application. As the DOD continues to shift in transforming its tactical wheeled vehicle fleet into a more fuel-efficient one, hybrid technology is the first in line to help ease the military's dependency on fuel. Some benefits of hybrid technology is the electric motors which become the primary source of power, meaning the vehicles can operate on battery alone, providing a more stealth like capability when engine noise could give away a position.³⁵ Electric hybrids are also a source of electricity. Instead of towing generators that provide electricity for expedient field command posts, the rechargeable batteries in hybrid vehicles can generate that power and recharge the batteries from an onboard generator. Lastly, initial acceleration in hybrids is faster than standard vehicles for short bursts of speed, which may aid if the driver needs to quickly exit a kill zone from an IED or ambush.³⁶ As this technology becomes more advanced and cheaper to produce, increased benefits will ensue. This produces big cost savings when mass producing the technology or installing a retrofit conversion on existing vehicle systems.

Currently, diesel electric hybrids technology show a 20 percent increase in fuel-efficiency when compared to conventional diesel-powered vehicles. Diesel electric hybrids are lighter which adds to increased fuel efficiency in vehicles such as the Army's

new Ground Combat Vehicle³⁷ and Heavy Expanded Mobility Tactical Truck (HEMTT).³⁸ The lighter vehicles do not compromise the integrity of the armor, found on heavier older model medium and heavy wheeled vehicles. A lot of fuel-efficient technology came on line during the past few years however; the DOD was slow to integrate the technology into existing systems due to current contracts in place as well as the lengthy process of the defense acquisition management system. The DOD conducts yearly reviews with the office Assistant Secretary of Defense for Operational Energy Plans and Programs identifying progress or failures with new programs in energy efficient technologies to keep the military services on track to meet 2025 service energy goals. Many new systems also go through rigorous testing for military applicability. In the case of hybrid electric vehicles, the technology was on the market for over 10 years demonstrating its fuel saving benefits. The limiting factor was that power storage on the older models was not suitable to power command and control systems for an extended period on batteries alone.³⁹ The current technology in power generation and storage is in the range of 10-15 kilowatt (KW) which can power a company sized command and control center for up to three days.⁴⁰

Another alternative to fuel reduction at the operational and tactical level is the use of alternative fuels such as biofuels. Biofuels are produced from living organisms or from metabolic by-products (organic or food waste products). In order for biofuel's to be considered, the fuel must contain over 80 percent renewable materials.⁴¹ Biofuel technology was under development for the past few decades and was slowly becoming marketable and affordable. Biofuels are inherently more expensive to produce than fossil fuels however, due to improvements in refining techniques; biofuels have become more

affordable to the open market and are an attractive alternative for military use. Due to high and volatile oil and gas prices over the past few years, biofuel prices have dropped to a level that is competitive with that of conventional fuels making them available for the military to experiment with as an alternative to fossil fuels. A type of biofuel that gained popularity with the DOD is the use of drop-in biofuels. Biofuels classified as drop-in fuels are chemically structured to mimic fuel designed with the same properties as JP-8, the predominate fuel used by the services.⁴² Due to their properties and dropping price per gallon, biofuels have become the new medium in supplementing fossil fuels in the DOD. Therefore, alternative biofuels must have a drop-in capability for use on tactical equipment systems and platforms, which means they are able to be integrated into existing systems without spending money to retrofit equipment or cause operational drawbacks to the equipment.⁴³ This is important, because existing systems are replaced on a generational scale. Most military equipment once designed and fielded to the force will remain in service for 25-50 years, excluding upgrades. Renewable fuels used in these systems must conform to existing fuel specifications, standards, and performance requirements. Prior to use in tactical systems, renewable fuels must be qualified, and weapon platforms certified, to ensure the fuel does not compromise mission performance and safety.⁴⁴ Because of this criterion, the DOD has not perused investing in natural gas as an alternative fuel for its tactical fleet of equipment even though it is cheaper and more plentiful. The density of the fuel determines platform range distances. Natural gas has a low energy density requiring a modification of vehicles to support the properties of natural gas. Because of its low density, more fuel is required, resulting in larger storage capacity to travel the same distance as conventional fuel or biofuels.⁴⁵

Drop in biofuels fuels are also significant because of how fuel logistics supports the battlefield. Currently, to simplify fuel distribution the military uses a single battlefield fuel JP-8, for all tracked and wheeled vehicles to include rotary winged aircraft. The use of drop-in biofuels reduces fuel logistics of supplying multiple types of fuel.⁴⁶

Considering all the facts for drop in biofuels, the one significant limitation uncovered is biofuels do not drastically improve engine efficiency. Tactical equipment platforms burn rate will be the same with drop in fuels when compared to conventional fuels or blended fuels thus having no significant impact on the requirement to resupply fuel via tactical convoys. The one positive outcome is a marginal reduction in engine emissions.⁴⁷ At the strategic level, biofuels and alternative fuels have significant implications in reducing the military's dependency of fossil fuels and saving hundreds of millions of dollars if biofuels remain cheaper than conventional fuels. The U.S. Navy is currently experimenting with replacing conventional fuels by 50 percent, meaning on some naval platforms a 50-to-50 mix of biofuel to JP-8 will be utilized.⁴⁸ By the year 2020, the Navy plans to supply 50 percent of its fuel needs with non-fossil-fuel sources that amounts to eight million barrels of biofuels a year.⁴⁹ However, according to a 2011 DOD study drop-in renewable fuels will cost more than petroleum. The estimated price premium for drop in biofuel will be between \$1.43 and \$5.24 per gallon in 2015.⁵⁰ Given the services' goals of biofuel usage, mid-range estimates suggest that DOD's drop-in renewable fuel use would represent an additional annual fuel cost of \$865 million by the year 2015 and \$2.2 billion by 2020, which represents a 10-15 percent increase over conventional petroleum fuels.⁵¹

In identifying the largest fuel consumers on the battlefield the average person may quickly point to combat vehicles such as the M1A2 Abrams tank, Striker vehicle, and the U.S. Marine Corps Amphibious Assault Vehicle or attack helicopters. The fact is most fuel consumption comes from running base generators powering command and control systems and life support equipment. Due to austere environments in which the Army and Marine Corps operate in they infrequently rely on host nation power grids to support base functions. Base camps are reliant on diesel generators for power. Independent and government studies indicate generators account for most of the fuel consumed on the battlefield with 50 to 90 percent of generated power going to ECUs. The issue of poor fuel efficiency in generators is also due to the fact they will run at optimum peak power even when they are under a minimal load to generate power. Although the generators are large consumers of fuel they often provide power to inefficient equipment and systems resulting in wasted power and fuel. Generators power inefficient ECUs that are constantly running due to poor thermostat controls. The ECUs then supply temperature controlled air to poorly insulated tents used for billeting or work and cool the air from inefficient lighting systems that produce excess heat.⁵²

Beyond increasing the efficiency of generators, ECUs, tents and lighting systems that will significantly reduce the amount of fuel required on the battlefield, solar power data clearly demonstrates a potential for reducing fuel consumption. Solar power is particularly attractive for military use at small combat outposts in very remote areas. Solar output on most current systems the military uses in the field is about 300 watts. This is far short of the power output of fossil fuel generators. However, if generators are used in conjunction with solar this will reduce fuel consumption. In 2010, the Marine

Corps fielded systems with solar technology to ground forces operating at out laying FOBs and COPs. The two systems currently fielded are Solar Portable Alternative Communications Energy System and Ground Renewable Expeditionary Energy System see figure 5. The Ground Renewable Expeditionary Energy System can provide continuous power to command and control systems and Solar Portable Alternative Communications Energy System has lightened the load for radio batteries for ground combat troops.⁵³ The Solar Portable Alternative Communications Energy System is a solar mat that recharges radio batteries saving the Marine from carrying extra batteries into the field or having to be resupplied during long patrols. Solar power is clean and renewable technology that saves fuel and is reliable.

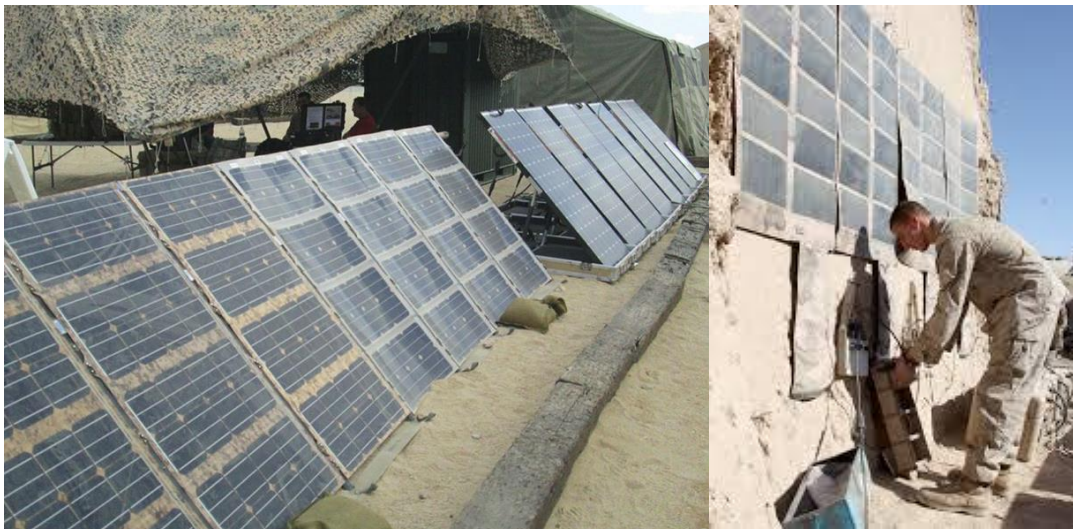


Figure 5. (L) Ground Renewable Expeditionary Energy System in Operation
(R) Solar Portable Alternative Communications Energy System
Being Set Up to Charge Portable Radio Batteries

Source: The Official Website of the United States Marine Corps, “Marine Corps Expeditionary Energy Office, Headquarters Marine Corps,” <http://www.hqmc.marines.mil/e2o/Fleet.aspx> (accessed May 11, 2014).

Summary

The research conducted during the literature review uncovered on many doctrinal references, studies, and recent lessons learned on implementing energy efficient systems that are shown to reduce fuel consumption on the battlefield. Many sourced documents from both U.S. government and military as well as independent research agencies verified and confirmed current equipment systems in use are extremely dependent on fuel and in many cases have been operating at well below performance standards. The literature review established a linkage between five ground systems that all contribute to excessive fuel consumption on the battlefield. Tactical wheeled vehicles, generators, environmental control units, portable ground shelters and shelter lighting systems all contribute to excess fuel demand at the tactical level. The systems mentioned in this chapter provide significant relative information that describes not one particular equipment system that contributes to the large dependency on fuel but rather a combination of ground systems. In the case of generators, being the largest consumer of fuel chapter 4 will analyze the systems that draw power from generators and discuss the inefficiency of ECUs, field tents and lighting systems have on increased power production in generators.

¹Department of Defense, *Quadrennial Defense Review*, 87-88.

²The Marine Corps Expeditionary Energy Office, *United States Marine Corps Expeditionary Energy Strategy and Implementation Plan*, 8.

³Ibid.

⁴Ibid.

⁵Ibid.

- ⁶Bustnes et al., 85-86.
- ⁷Pollman, 69-73.
- ⁸Ibid.
- ⁹Ibid.
- ¹⁰U.S. President, *U. S. National Security Strategy*, 30.
- ¹¹Ibid.
- ¹²Ibid.
- ¹³Ibid.
- ¹⁴Department of Defense, *Quadrennial Defense Review*, 87-88.
- ¹⁵Ibid.
- ¹⁶Ibid.
- ¹⁷Ibid.
- ¹⁸Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy*, 4.
- ¹⁹Erik Slavin, "The Great Green Fleet," *Stars and Stripes*, May 23, 2012, <http://www.stripes.com/news/navy/navy-looks-to-gamers-for-ideas-to-end-oil-dependence-1.178054?localLinksEnabled=false> (accessed November 9, 2013).
- ²⁰Assistant Secretary of Defense for Operational Energy, Plans and Programs, *Operational Energy Strategy*.
- ²¹Ibid.
- ²²Ibid.
- ²³Ibid.
- ²⁴Ibid., 12.
- ²⁵Ibid.
- ²⁶Secretary of the Air Force for Installations, Environment and Logistics, *Air Force Energy Plan*, 4.

²⁷Defense Logistics Agency Energy, *2011 Commander's Guidance*, <http://www.desc.dla.mil/DCM/Files/2011%20DLA%20Energy%20Commanders%20Guide.pdf> (accessed November 12, 2013), 10.

²⁸*Ibid.*

²⁹*Ibid.*

³⁰Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on DOD Energy Strategy: "More Fight-Less Fuel,"* February 4, 2008, <http://www.acq.osd.mil/dsb/reports/ADA477619.pdf> (accessed November 5, 2013).

³¹*Ibid.*

³²*Ibid.*

³³Scott Schramm, "U.S. Army Hybrid Propulsion System R&D Overview" (Presented at ATA Technology and Maintenance Council 2011 Fall Meeting, Hybrid Powertrain Task Force Session, September 19, 2011, Raleigh, NC, Defense Technical Information Center), <http://www.dtic.mil/dtic/tr/fulltext/u2/a549388.pdf> (accessed January 27, 2014), 14.

³⁴*Ibid.*

³⁵Steven Komarow, "Military hybrid vehicles could boost safety, mobility," *USA Today*, February 13, 2006, http://usatoday30.usatoday.com/news/world/iraq/2006-02-13-humvee_x.htm (accessed January 15, 2013).

³⁶*Ibid.*

³⁷Susan Defritas, "Army Hybrid Ground Combat Vehicle Ready to Roll," *Earth Techling*, March 4, 2012, <http://www.earthtechling.com/2012/03/us-armys-big-green-tank-ready-to-roll/> (accessed January 25, 2014).

³⁸Oshkosh Defense, "Heavy Expanded Mobility Tactical Truck, HEMTT A4, M977A4 Cargo Truck," Oshkosh Corporation, 2010, <http://oshkoshdefense.com/variants/m977a4-cargo-truck/#lit>, (accessed March 1, 2014).

³⁹Timothy Raney, "Onboard Vehicle Power: Talking Points on Emerging Requirements," 2007 Joint Service Power Expo, Materiel Systems Directorate, U.S. Army Combined Arms Support Command, Fort Lee, VA, April 25, 2007, Defense Technical Information Center, http://www.dtic.mil/ndia/2007power/NDIARegency/Wed/Session11presJOINTPOWEREXPOBRIEF_RANEY5APRIL2007.pdf (accessed February 4, 2014).

⁴⁰*Ibid.*

⁴¹AE Biofuels, “Biofuels,” Alternative Energy, <http://www.alternative-energy-news.info/technology/biofuels> (accessed January 29, 2014).

⁴²Department of Defense, *Opportunities for DOD use of Alternative and Renewable fuels: FY10 NDAA*, 8-18.

⁴³Andrew Holland and Nick Cunningham, “Department of Defense’s Biofuels Program,” American Security Project, January 2013, <http://americansecurityproject.org/featured-items/2013/dods-biofuels-program>, (accessed January 29 2014), 2.

⁴⁴Department of Defense, *Opportunities for DOD use of Alternative and Renewable fuels: FY10 NDAA*, iv.

⁴⁵Seth Robins, “Despite fracking boom, U.S. military still looks to biofuel over natural gas,” *Stars and Stripes*, August 12, 2013, <http://www.stripes.com/news/despite-fracking-boom-us-military-still-looks-to-biofuel-over-natural-gas-1.234403> (accessed January 31, 2014).

⁴⁶Department of Defense, *Opportunities for DOD use of Alternative and Renewable fuels: FY10 NDAA*, iv.

⁴⁷Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on DOD Energy Strategy: “More Fight-Less Fuel,”* 51.

⁴⁸*Ibid.*, 4-12.

⁴⁹*Ibid.*

⁵⁰*Ibid.*, 8-15.

⁵¹*Ibid.*

⁵²Meyer and Talley, 14-15.

⁵³The Official Website of the United States Marine Corps, “Marine Corps Expeditionary Energy Office,” <http://www.hqmc.marines.mil/e2o/Fleet.aspx> (accessed May 11, 2014).

CHAPTER 3

METHODOLOGY

My logisticians are a humorless lot . . . they know if my campaign fails, they are the first ones I will slay.

—Alexander the Great, in Defense Acquisition University, “Quotable Logistics Quotes”

Introduction

This chapter describes the research methodology used to answer the primary and secondary research questions. The research will identify what substitutes for fossil fuel energy the DOD can implement to reduce the demand for fuel by U.S. Army and U.S. Marine Corps ground forces. Second, the research will identify ground equipment systems that can modify commercial off the shelf technology to increase engine fuel efficiency for tactical vehicles and generators. Furthermore, finding viable solutions to these questions will mitigate the logistics burden of supporting the DODs ground fuel supply.

Methodology

Solutions to the military’s dependency on fossil fuels are not a one size fits all. The first step toward long-term petroleum independence is reducing consumption.¹ This may look like a relatively simple problem but with current equipment systems in place it is much too expensive to replace all systems that operate on fossil fuels with more efficient systems. This would require billions of dollars and is counterproductive to finding ways to save money. The process will be slow as older systems approach the end of their life cycle. In time, they will be replaced with newer efficient platforms. However,

with the current state of technology there are many possible ways to achieve reducing fuel consumption now. It is important to understand there is not one specific technology alone that will solve the problem. The fuel problem can be addressed with a combination of technologies through energy optimization on the battlefield. As discussed in the literature review, many new technologies and strategies are coming online and will be available to reduce battlefield fuel consumption. The technologies discussed, such as diesel electric hybrid technology, renewable and alternative fuels such as drop in biofuels, right sizing base generators using more efficient ECUs, interior lighting and better insulated field shelters will all contribute to reducing consumption and save the military thousands of gallons of fuel. The implementation of these ideas and new technologies will reflect changes in the DOTMLPF-P construct. Specifically addressing non-material changes in the application doctrine, organization, training, leadership and policy. These non-material solutions will help in developing an organizational culture of Soldiers and Marines acknowledging the need to reduce fuel consumption and to accept the new technology. An example is energy conservation training, increasing energy awareness at the individual and command level. Also establishing energy efficient processes identified in command standard operating procedures.² These small changes will have lasting effects in the military's ability to adapt to the future and increase readiness.

The author has investigated operational energy concepts and implementation in fuel reduction from the strategic level narrowing in scope to the operational and tactical level. The author's current research includes an extensive investigation of national strategic level documents, internet-based military and non-military sources. Information

obtained from the Combined Arms Research Library, Fort Leavenworth, Kansas provided collections of publications, reports, journals, briefings, and professional military studies pertaining to this subject. The levels of source materials ranged from very broad topics of military fuel dependency to transportation methods dating back to the Civil War. As current research directed the author to narrow down specific ground equipment used in Iraq and Afghanistan the research identified the major consumers of fuel. Tactical wheeled vehicles used by supporting units (non-front line vehicles) and base generators, account for close to half of all fuel consumed by ground forces.³ Ironically, the vehicles used to transport fuel and support fuel convoys with security and route clearing vehicles make up the preponderance of the vehicles that consume the most fuel.⁴

To answer the research questions from chapter one, this study will carry out two research methods in analyzing data. The first is to conduct a comparative analysis of JP-8 blended fuels and biofuels to check for an increase in efficiency. A threshold of 20 percent increase in efficiency is the target for blended and biofuels. Second, conduct a qualitative analysis study on hybrid diesel-electric technology, and solar power technology that show positive results in fuel reduction for tactical wheeled vehicles and generators. In the case of generators, the study will analyze the use of micro grids at FOBs to reduce the number of small inefficient generators by combining and loading generators correctly, which make them operate more efficiently as well as analyzing how solar power will reduce the load on generators. Lastly, the study will analyze the effects of ECUs and field shelters will have in reducing fuel consumption from power sources such as generators. The data captured will illustrate the quantity of fuel saved by using the new technology. This data will then determine the reduction in the number of fuel

tankers needed to deliver the fuel and how the data translates to reducing the number of vehicles and personnel needed to support fuel and resupply convoys.

The military will always need fuel and need a robust supply system to logistically support both ground and air platforms. As we transition into an uncertain future with no knowledge of where U.S. ground forces might be committed, the military has an opportunity to fix the problems learned during the last decade of war.

Summary

This chapter discusses the qualitative research methodology to be used during the study to determine if energy optimization on the battlefield is a viable solution to reducing fuel demands by supporting ground forces. Government and military studies conducted show the systems in use supporting ground units are inefficient due to a variety of reasons identified over the past several years. The systems which are part of the government and military studies focus on the fuel consumption rates of tactical wheeled vehicles and tactical generators which contribute to more than half of all fuel consumed. Additionally, the studies identify secondary consumers of power such as ECUs, field tents and lighting systems that force generators to run longer and consume more fuel.

¹Meyer and Talley, 13-14.

²Ibid., 5.

³Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on DOD Energy Strategy: "More Fight-Less Fuel,"* 44-47.

⁴Ibid.

CHAPTER 4

FINDINGS AND ANALYSIS

Introduction

This chapter will analyze the benefits of creating an energy optimization strategy by evaluating current fuel consumption rates of tactical ground equipment and comparing it to new energy efficient systems to illustrate a change in expenditure. This analysis will show that reducing fuel consumption will decrease fuel logistics on the battlefield. Over the past 13 years, supply requirements placed a significant burden on logistics convoys and the personnel who organize and conduct them in often austere and dangerous environments. The goal of the analysis is to identify what can be done now with current technology and practices by developing an energy optimization strategy. More important, this strategy considers solutions involving any combination of doctrine, organization, training, materiel, leadership and education, personnel, facilities and policy (DOTMLPF-P) in the force management process to implement change in the military.¹ Energy optimization can fill gaps in current capabilities of logistics sustainment for ground forces. Other capability gaps solved using DOTMLPF-P will also need consideration in influencing possible non-material solutions to drive change in doctrine, training, leadership, education, and policy. Change to systems integration onto the battlefield is beneficial but changes to organizational cultural behaviors to accompany material and non-material changes are critical. Through implementation of this strategy in both a material and non-material sense, the military can decrease fuel consumption, increase operational reach and flexibility, and reallocate military resources to other operations vice supporting fuel convoys.

The findings examine if reducing fuel usage in tactical wheeled vehicles (non-front line vehicles) and generators can produce significant results in lowering the number of road bound fuel convoys that will equate to lives saved. The quantitative analysis conducted by the author show introducing energy efficient technologies and practices did in fact produce results in lowering fuel consumption for both tactical wheeled vehicles and generators. Integration of diesel hybrid electric power in two different models of logistics vehicles used by the Army and Marine Corps accomplish a fuel savings of 13-27 gallons per tank. Introducing a combination of energy efficient technologies and practices reduced generator fuel consumption by 390 gallons per day. These results confirm in excess of a 20 percent reduction in fuel consumption that thereby lowers convoy traffic and saves lives.

The military's dependence on bulk fuel has numerous negative tactical implications. It has the potential to slow or stall operations and make forces more vulnerable to enemy attacks. In order to reduce the volume of tactical fuel requirements, improvements in ground equipment efficiency must be made specifically for primary consumers such as tactical wheeled vehicles and generators. Improvements in efficiency are also necessary for ECUs, field tents and tent lights that are secondary consumers of fuel. Increasing the efficiency in tactical wheeled vehicles through the use of hybrid power and replacing older less efficient generators and secondary consumers will not only reduce fuel consumption, it will also reduce the number and frequency of fuel convoys.²

This study will cover five focus areas of ground equipment in developing an energy optimization strategy:

1. Tactical wheeled vehicles
2. Generators
3. ECUs
4. Field tents
5. Tent lighting systems

For tactical wheeled vehicles, the study will analyze the use of hybrid diesel electric engines and the impact this system will have in reducing fuel demand for vehicles. The next area of interest will be on base generators and analyzing the benefits of switching to more fuel efficient models. The analysis of generators will also show how incorporating micro-grid technology and solar technology can further aid the reduction of the amount of fuel required for base power generation. The third area will analyze the impact of older inefficient ECUs to the newer efficient IECU model. The fourth area will analyze current field tent design using poorly insulated materials and the effects on power generation and fuel requirements. Lastly, the fifth area will discuss replacing existing light bulbs with LEDs to further contribute to power generation efficiency.

Background of Equipment Systems

Tactical ground combat equipment was responsible for over 50 percent of the fuel expended during combat operations in Iraq and Afghanistan.³ The research from the review of literature in chapter 2, identifies specific ground equipment that most contributes to the large consumption of fuel by ground forces. Tactical wheeled vehicles and generators are the primary users that contribute to the high frequency of fuel convoys.⁴ Each of these equipment systems add to the DOD's high consumption rates for a number of reasons and will be discussed in this chapter.

Tactical Wheeled Vehicles

Ground vehicles consume roughly one-third of all fuel during combat operations. Aviation and generators make up the other two-thirds.⁵ One of the reasons for the high consumption figures is the fact that tactical wheeled vehicles are now heavier and bigger. Extra plate armor and ballistic proof windows were added to protect the occupants from enemy attacks. Due to the extra armor, the body of the vehicle sits on a larger frame with a heavier suspension and a more powerful engine and transmission. The vehicles also have upgraded electronic equipment for climate control, communications, and IED defeat mechanisms. All of these systems increase demand on vehicle power systems, which decreases fuel efficiency. As enemy tactics changed over the years with an increase in IED attacks, the demand for greater protection for the vehicles occupants increased. The added protection came in adding armor plating to the vehicles. Pre-OIF tactical wheeled vehicles did not have the armor plating to protect vehicle passengers from roadside IEDs because at the time it was not a major threat to U.S. ground forces. As OIF and OEF continued over the years, IEDs became a growing concern. Armor plating kits added approximately seven to eleven thousand pounds of extra weight degrading the fuel efficiency of the tactical wheeled vehicles in the Army and Marine Corps ground vehicle fleet.⁶ The vehicles not designed for the extra weight are primarily older versions of the HMMWV, MTRV, Logistics Vehicle Systems, and HEMTT. The added weight increased fuel usage on these vehicles, whose fuel efficiency was already poor. Many vehicles received upgraded suspension retrofit kits to increase fuel efficiency slightly and prevent additional wear on the tires. As an example of the degraded fuel economy, a pre OIF HMMWV variant, the M998, weighed 5,200 pounds had a range of 350 miles on a 25-

gallon tank and averaged 14 miles per gallon (MPG).⁷ Throughout the years as the threat of IEDs grew, new variants of the HMMWV were fielded with better armor. In 2007, a M1151 A1 HMMWV variant weighed 13,500 pounds, had a range of 250 miles on a 25-gallon tank, and achieved 10 MPG.⁸ Some HMMWV variants went through a series of upgrades to provide better protection and receive more powerful engines to compensate for the added weight of the vehicle. The MTVR also went through similar upgrades in armor over the years. The MRAP is better suited than the HMMWV to survive IED strikes and thousands of these vehicles were fielded during 2007-2010 replacing the HMMWV in Iraq and Afghanistan. They are very effective due to their larger size, increased ground clearance, and V-shaped hull to deflect IED blasts away from the vehicle occupants. The fuel utilization of an MRAP averages four to six MPG.⁹ The MRAP-All Terrain Vehicle, the next generation MRAP is smaller and lighter with the V-shaped hull and can sustain IED blasts better than HMMWVs but gets approximately the same gas mileage as the MRAP. Ground tactical vehicles were all fitted with IED defeat systems requiring more electrical power. Tactical vehicles are also designed with upgraded communications and tracking systems to increase situational awareness on the battlefield. With all of these electronic systems, the need for internal power increases drawing more from batteries forcing the alternator to work harder and longer. This makes the engine operate at higher revolutions per minute especially at idle and consuming additional fuel. Under these circumstances of significant power draw from the batteries, the vehicles should run at all times, either in drive mode or in constant idle. If a vehicle stops for an extended period, as in a security halt, the vehicle must remain running to avoid draining the batteries. If the vehicle's engine is off for a long time with all the

vehicle systems running, the batteries will not have enough battery power to start the engine. The driver will then have to dismount and set up a slave cable from the vehicle to another to receive a jump-start.

The number of tactical wheeled vehicles both the Army and Marine Corps have on their tables of equipment is in the hundreds of thousands. In November 2010, the Army reported owning over 260,000 tactical wheeled vehicles.¹⁰ If each of these vehicle's fuel efficiency improved by 10 percent, the fuel reduction numbers across the force will save millions of gallons of fuel per year. It is highly unlikely that the tactical wheeled vehicles in the Army and Marines can receive a system upgrade to decrease fuel consumption in the near future. However, two tactical wheeled vehicles, the Army's HEMTT and the Marine Corps MTVR, considered the workhorse of each service are now available from Oshkosh Defense with hybrid diesel electric power.¹¹ The new generation of propulsion hybrid diesel power shows a 20 percent increase in fuel efficiency.¹² If these savings are summed for all the MTVRs and HEMTTs in the U.S. Army and U.S. Marine Corps fleets the amount of fuel and cost savings is substantial. As of September 2012, MTVRs number around 9,000¹³ vehicles in five different variants supporting the Marine Corps fleet with 800¹⁴ MTVRs operating in Afghanistan. The Army's HEMTTs number around 13,000¹⁵ in 11 variants with 1,700 operating in Afghanistan.¹⁶

Generators

Generators rank as the number one fuel consumer by sheer numbers when compared to combat vehicles, combat aircraft, and tactical vehicles.¹⁷ Our recent history shows that as a COP or FOB infrastructure builds over time the demand for power increases. As the infrastructure grows so does the desire to create a comfortable

environment. To achieve this more generated electrical power is required. In a mature theater there are large numbers of generators on bases to provide power for a number of different life support functions to include, command and control centers, billeting, medical and dining facilities. Generators supply all the power needs to support base functions and fueling them becomes a priority. Even a company-sized command and control center in a remote location that uses one small generator has to resupply it with fuel to maintain operations. During offensive operations towed generators power mobile command and control centers and medical facilities. During combat operations, ground vehicles are the number one consumer of fuel. When forces transition from mobile offensive operations to conducting operations out of fixed bases as experienced during OIF and OEF, generators become the top fuel consumer. In many cases when conducting expeditionary military operations, the ability to connect to the existing power grid of a host nation may not be feasible. Even if it is feasible, the host nation may not have the ability to provide constant power without the fear of intermittent blackouts that can halt operations. Generators provide a reliable source of power to keep command and control systems operating as well as systems for medical, dining, and billeting facilities. The quantity of generators used in both OIF and OEF to support FOBs number into the thousands and each consuming 0.33-5.0 gallons per hour.¹⁸ During peak troop numbers on the ground in the United States Central Command Area of Responsibility generators supported over 300 FOBs in Iraq and 400 in Afghanistan.¹⁹ As bases and outlying FOBs and COPs started to grow, so did their power demands. Generators as stand-alone units are efficient if used with connecting matched loads. The generators in theater, once installed, typically operated at optimum power 24 hours a day. At least once a day a fuel

truck refilled every generator with either JP-8 or Mobility Gasoline. Routine maintenance prolonged the generator life, but once it became unrepairable, a new or refurbished generator replaced the damaged one and the cycle continued. Generators in most instances are independent of each other and support individual groupings of loads that often demand far less than the peak generator capacity.²⁰ Generators sized to support peak demand results in excess power generation during off peak periods. In situations where generators are independent of each other the excess capacity doubles or triples depending on how many underpowered independent generators are in use at one location, refer to figure 6.

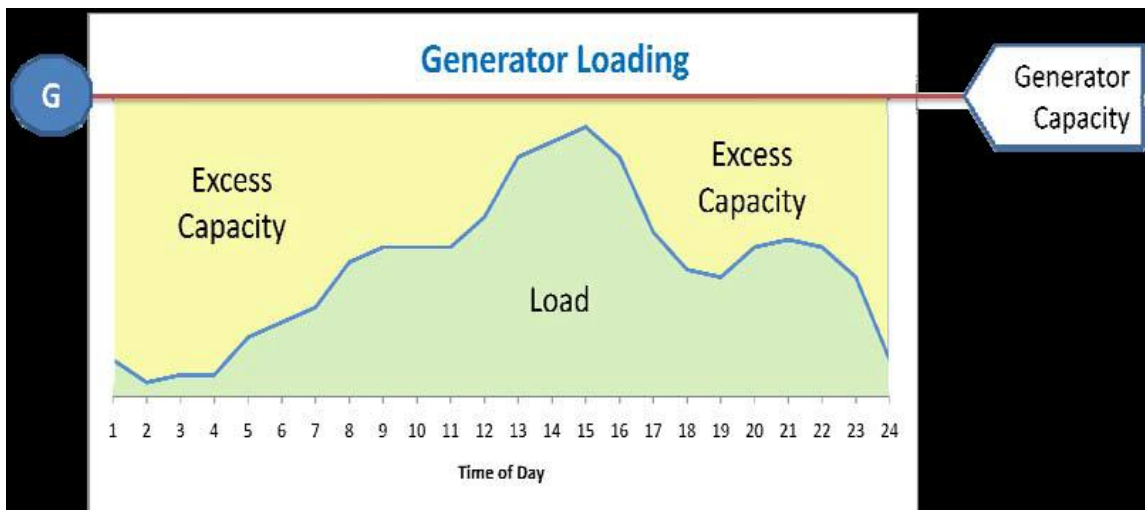


Figure 6. Generator Sized to Support Peak Periods Operates at Full Capacity

Source: James Meyer and Robert Talley, "U.S. Army 5-5 Study, Tactical Fuel and Energy Implementation Plan" (Chester, VA, Expeditionary Logistics Inc., September 24, 2010), Defense Technical Information Center, <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA529051> (accessed February 13, 2014), F-A-6.

Generators must operate at peak demand regardless of time duration and needed power. This ensures adequate supplied power is available when demand suddenly increases which prevents a surge in power preventing outages. An example is when a command and control center experiences a spike in activity and many systems that were dormant all suddenly are turned on.²¹ Because generators must operate at peak this presents the following problems; poor fuel efficiency, increased generator maintenance, and decreased generator lifespan due to constant runtime for only limited energy demand.²² There were even cases where three or more generators are used at one location and all are under-utilized, resulting in wasted power output and fuel. This practice was commonplace on many bases in Afghanistan and research teams identified a way to solve this problem with the development of micro-grid systems.²³ Micro-grids are common in commercial applications. They have the potential to save thousands of gallons of fuel by using an integrated energy system that monitors when to turn generators on and off depending on the required power generation. For example, a one-megawatt micro-grid can replace 22 generator sets with just four larger generators simplifying maintenance as well as cutting fuel consumption.²⁴ Both the Army and Marine Corps are testing and implementing micro-grid technology in Afghanistan as an additional way to cut down on fuel waste. To further aid in micro-grids, the Advanced Medium Mobile Power Systems (AMMPS) that are 20 percent more fuel-efficient and 85 percent less dependent on maintenance will replace the older generation Tactical Quiet Generators (TQG).²⁵ The micro-grids are also being adapted for solar technology integration as shown in figure 7. Another benefit of solar power generation is the system can be set up in remote locations

to power systems eliminating the need for generators and resulting in reduced logistics and extended operational reach.



Figure 7. Micro-grid with Solar Power Integration

Source: Martin LaMonica, “Hybrid Generator Would Cut Military Base Fuel Costs in Half,” IEEE Spectrum, February 3, 2014, <http://spectrum.ieee.org/energywise/aerospace/military/hybrid-generator-would-cut-military-base-fuel-costs-in-half> (accessed February 16, 2014).

Environmental Control Units

In Iraq and Afghanistan, typical loads on generators come from command and control systems and ECUs to cool or heat field tents or hardened structures. However, the system that is responsible for drawing the largest amount of power is the ECU.²⁶ There were thousands of ECUs used in Iraq and Afghanistan supporting close to 700 bases.

These systems not only provide climate control for work spaces and billeting they also

keep sensitive computer systems clean from dust and from overheating. Three reasons why ECUs have contributed to excess power draw on generators is they do not have efficient temperature controls and the field shelters they supply with air have minimal insulating properties in the fabric.²⁷ Also, inefficient lighting due to radiant heat from the lights which warms the air and adds to ECUs operating longer causing generators to consume more fuel.²⁸ There are many different models of ECUs used in theater. The newest model fielded is the Improved Environmental Control Units (IECU). The IECU runs with minimal noise pollution and is 20-25 percent more power efficient.²⁹ This efficiency contributes to reduced generator run time and thus a reduction in fuel consumption. These are significant savings when replacing 500 ECUs on an installation with IECUs. The overall savings in fuel will be substantial based on reduced fuel consumption in generators due to the more efficient IECUs.

Field Tents

Field tents are employed in just about every application on the battlefield and support all types of units operating in different environments. The tents design characteristics are lightweight, portable, easy to assemble and disassemble, rugged, waterproof, and tolerant of ultra violet light. The material used for field tents is light yet durable. Making the material heavier or thicker to increase energy rating compromises the purpose they were designed for which is to be lightweight and mobile. Thousands of field tents erected in both Iraq and Afghanistan over the years are exposed to extreme temperatures ranging from 120 degrees to below 32 degrees depending on geographic area and elevation. The extremely hot temperatures require ECUs to provide an almost constant flow of temperature controlled air to keep the inside of the tent habitable and

protect sensitive electronic equipment from overheating. As many of the bases continued to grow and improve many hardened structures replaced tents to provide a comfortable working and living environment for Soldiers and Marines thus making the tents unnecessary. However, on many smaller COPs and FOBs field tents remain the primary living and working quarters. With such a large number of tents spread throughout the battlefield, studies identified they added to increased fuel consumption by generators. The design and material of the tents cause them to absorb a lot of the sun's ultra violet energy. The temperature-controlled air provided by ECUs cannot keep the inside cool for long periods. In addition, entry and exit points cannot seal properly resulting in cooled or heated air being lost and ECUs running constantly. The inefficiency of the poorly insulated materials has caused both the Army and Marine Corps to experiment with new shelters that are lighter and more energy efficient. Many new materials for shelter construction have advanced materials and special aluminized coatings. Some of these materials can be applied to pre-existing shelter fabrics to reflect the sun's light away from the shelter reducing the load on the generator and ECU.³⁰ Another method used to increase tent efficiency is installing radiant barrier blankets. This barrier creates an additional thermal barrier inside the tent, increasing the shelter's insulation factor that has proven to control inside tent temperatures as illustrated in figure 8.³¹ Additionally, photovoltaic liners that cover existing tents much like solar shades are being tested which convert the sun's energy into electricity to provide power to the tent as shown in figure 9.



Figure 8. Radiant Barrier Blanket

Source: HDG Global, Base X-Press Shelters,” <http://www.hdtglobal.com/products/shelters/base-xpress/> (accessed May 13, 2014).



Figure 9. Shelters Set Up in Southwest Asia Tested by the Army and Air Force as Part of the Advanced, Energy-Efficient Shelter Systems

Source: Alexandra Foran, “NSRDEC Deploys Energy-Efficient Tents for Testing,” The Official Homepage of the United States Army, October 29, 2013, <http://www.army.mil/article/114066> (accessed February 8, 2014).

Lighting Systems

The lighting installed in field tents and hardened structures consists of Conventional Florescent Lights (CFL) and incandescent bulbs. Incandescent bulbs use four to six times more electricity than CFLs and Light-Emitting Diode (LED) and wastes 90 percent of its energy in the form of heat.³² CFLs which are standard in field tents are more efficient than incandescent bulbs but still lose efficiency in producing heat and use more electricity than newer LEDs. Studies show that replacing CFLs with LEDs has a small but significant savings in electricity and lasts three times longer which equates to an additional 25,000hours of light.³³ This can generate substantial cost savings when summed over the thousands of light fixtures used on bases and FOBs. Changing to LEDs in tents and installing motion sensors could help in turning the lights off when no occupants are inside which further adds to energy savings. Comparing a one for one swap of CFLs to LEDs the energy efficiency is relativity small at only a four percent increase of efficiency.³⁴ However, when that number translates to the thousands of CFLs that are used the savings in total energy adds up rather quickly.

Analyzing the Data

To understand how energy optimization on the battlefield will save fuel, reduce convoys, extend operational reach, and put less Soldiers and Marines in danger, this part of the study will analyze the findings of increased efficiency of tactical equipment systems. The increased efficiency of incorporating new and existing technology and practices does show a reduction in fuel consumption. It is important to understand how these systems and practices reduce overall fuel utilization on the battlefield that translates in a reduction of fuel convoys thus saving lives.

Tactical Wheeled Vehicles

This study will analyze two models of logistics vehicles used by the Army and Marine Corps. The Army's HEMTT and the Marine Corps MTVR. By comparing the fuel saving benefits of upgrading to diesel hybrid electric technology, currently available, the reader can comprehend the fuel saving benefits if the entire tactical wheeled vehicle fleet for both the Army and Marine Corps adopted full use this technology. The current specifications for the MTVR in terms of fuel efficiency are 3.8 miles per gallon (MPG) on a 78-gallon tank and 300-mile range.³⁵ This standard MTVR variant vehicle employed in Iraq and Afghanistan is fitted with armor kits making the already 30,000-pound vehicle heavier. The standard HEMTT's fuel usage is about 2.6 MPG, has a range of 300-400 miles on a 155-gallon tank, and weighs 41,000 pounds.³⁶

The Army and Marine Corps fielded thousands of these vehicles. They are combat worthy vehicles that have proven their worth time and again over the past 13 years. Because of poor fuel mileage, they contribute to the overwhelming fuel problem the DOD is facing with its ground tactical wheeled vehicle fleet. Introducing diesel hybrid electric engines into these two models showed an increase in fuel efficiency of 20-25 percent depending on terrain, environment, and payload.³⁷ The increase of 20 percent in fuel efficiency for the MTVR propulsion variant is equal to an increase from 3.8 to 4.6 MPG and a fuel savings of 13 gallons per tank. An increase of 20 percent fuel efficiency for the HEMTT A3 equals to an increase from 2.6 to 3.15 MPG and a fuel savings of 27 gallons per tank. These numbers may seem small but if distributed throughout the entire 800 MTVR fleet and 1,700 HEMTT fleet in Afghanistan the fuel savings per tank totals 56,300 gallons of fuel saved.

Table 2. Efficiency Comparison of Diesel Turbo Engines and Diesel Hybrid Electric Engines

	CONSUMPTION OF CURRENT SYSTEMS	20% INCREASE IN EFFICIENCY WITH HYBRID TECHNOLOGY	TANK SIZE	FUEL SAVED PER TANK	QUANTITY IN AFG	TOTAL FUEL IN GALLONS SAVED PER TANK
MTVR	3.8 MPG/ RANGE 300 MILES	4.6 MPG/ RANGE 360 MILES	78GAL	13 GAL	800	10,400 GAL
HEMTT	2.6 MPG/ RANGE 400 MILES	3.15 MPG/ RANGE 488 MILES	155GAL	27 GAL	1700	45,900 GAL
						56,300 GAL

Source: Created by author.

Generators

Generators are the largest consumer of fuel on the battlefield, numbering in the thousands in Afghanistan and varying in size, weight, and kilowatt production. Generator fuel consumption is measured in gallons per hour (GPH) where generators typically have a fuel capacity to run eight to 12 hours at peak. Due to the large variation in generator size and capacity, for purposes of the analysis this study will rely on research conducted in comparing TQG and the new efficient AMMPS generators that increase fuel savings by 20 percent.³⁸ This study will also analyze the integration of micro-grids and solar technology to determine further reductions in fuel consumption. The AMMPs generators also offer reliability of 750 hours without preventive maintenance versus the 500-600 hours of the TQGs before regularly scheduled maintenance is required.³⁹ In 2012, the Army fielded 1,600 AMMPS to Afghanistan ranging from 3-60 KWs.⁴⁰ Depending on the power output the AMMPS generators saved from 2.88 to 6.24 gallons per 24-hour period. The 1,600 AMMPs generators that will replace the TQG have a potential fuel savings of 9,705 gallons if distributed evenly among 3-KW, 5-KW, 15-KW, 30-KW, and

60-KW generators sets of 320 of each. This also equals 1.51 GPH for any mix of TQG and 1.23 GPH for any mix of AMMPs when comparing the two.

Table 3. Generator Fuel Efficiency Comparison of TQGs and AMMPS

	CONSUMPTION OF CURRENT SYSTEMS PER 24 HR	RUN TIME PER 9 GAL TANK	MAINT PERFORMED	INCREASE HOURS OF RUN TIME	FUEL SAVED PER 24 HR	QUANTITY BASELINE	TOTAL FUEL IN GALLONS SAVED PER 24 HR
TQG	1.51 GAL PER HR 36.24 GAL PER DAY	6 HR	Every 550 HR 23 DAYS 16 PER YR				
AMMPS	1.23 GAL PER HR 30 GAL PER DAY	7.3 HR	Every 750 HR 31.25 DAYS 11 PER YR	4.2 HRS	6.2 GAL	1600	9,920 GAL

Source: Created by author.

In right sizing generators for specific power requirements studies identified establishing a micro-grid can save a considerable amount of fuel. For the purposes of this study, the example used is to right size five 60-KW TQG each with a 43-gallon fuel capacity, a burn rate of 5.37 GPH and run time of eight hours each before needing refueling.⁴¹ This totals 129 gallons per day per generator. All five 60-KW generators use 654 gallons of fuel per day. Micro-grids maximize generator efficiency by turning them on or off depending on the power needed at the time. A common practice is using multiple generators at one location, all underutilized by 40-50 percent. This underutilization will still consume the same amount of fuel if the generators operated at maximum capacity. The generators run at full capacity regardless of the load.⁴² If two 60-KW generators come off line and the remaining three are connected to a micro-grid the savings is 258 gallons per day. With the thousands of generators in Afghanistan taking 25

percent of them offline by establishing micro-grids will constitute substantial savings in fuel without loss of power production.

Table 4. Micro-grid Fuel Saving Benefits

	POWER SOURCE	CONSUMPTION GAL PER HOUR	CAPACITY	CONSUMPTION OF CURRENT SYSTEMS	FUEL SAVINGS TAKING 2 GEN OFF LINE	FUEL SAVED PER DAY	TAKE 400 OFFLINE
MICRO-GRID	5 x 60KW TQG	4.8 GAL EACH	43 GAL TANK 8 HR RUN TIME	129 GAL PER DAY EACH GEN	40 PERCENT OF FUEL SAVED	2 GEN OFFLINE = 258 GAL	51,600 GAL SAVED

Source: Created by author.

The use of solar power is making significant gains in helping cut the consumption of fuel for power generation. Currently, in a deployed combat environment, solar power can contribute from 3-28 KW of power. Though this number may not be very significant, it still aids in reducing the load on generators and have proven effective at outlying COPS and FOBs who rely on air dropped fuel resupply. These COPS and FOBs have reported a fuel savings of 20 gallons a day using 3-5 KWs of solar power.⁴³ Solar can also tie into micro-grids contributing to the power demand of its users. When comparing a 3-KW generator and a 30-KW generator with comparable solar panels of each size the following calculated savings in fuel demonstrate the benefits of solar technology. A 3-KW generator has a 4-gallon capacity and uses .33 gallons per hour lasting 12 hours which equates to eight gallons a day saved by using solar power.⁴⁴ If replacing a 30-KW generator with a 30-KW solar power system the savings in fuel are as follows. A 30-KW generator has a 23-gallon capacity and uses 2.70 gallons per hour lasting 8.5 hours.⁴⁵ This

equals a consumption rate of 69 gallons per day. All of which is saved using solar panels. The number of generators that solar technology can replace on bases, FOBs and COPs will determine the reduction of fuel consumed. Every generator that solar power replaces is 100 percent fuel savings. Integrating solar technology has significant benefits in reducing overall fuel consumption on the battlefield and reducing convoys.

Table 5. Fuel Saving Benefits of Implementing Solar Technology as a Power Source

POWER SOURCE	CONSUMPTION PER HOUR	CAPACITY	RANGE	CONSUMPTION PER DAY	FUEL SAVED PER DAY	REPLACING 25 3KW & 30KW TQG W/ SOLAR
1 X 3KW TQG	0.33 GPH	4 GAL TANK	12 HR RUN TIME	8 GAL PER 24HR		
3 KW SOLAR			24 HR RUN TIME		8 GAL	200 GAL SAVED PER DAY
1 X 30 KW TQG	2.7 GPH	23 GAL TANK	8.5 HR RUN TIME	69 GAL PER 24HR		
28 KW SOLAR			24 HR RUN TIME		69 GAL	1725 GAL SAVED PER DAY

Source: Created by author.

ECUs

The newest ECUs currently fielded in Afghanistan, cut energy demand from 20-25 percent.⁴⁶ The new IECU are thermostat controlled through an internal computer that reads room temperature and monitors when to turn the unit on and off much like commercial and home systems. This reduces fuel consumption in generators. The IECUs are also capable of providing temperature controlled air to two 12-person field tents with

greater efficiency than the older ECU version that only provide temperature controlled air to one 12-person field tent.⁴⁷ If a 30-KW generator is powering an IECU rated at 20 percent increased power efficiency, this saves 14 gallons of fuel in a 24-hour period. Additionally, since one IECU can replace two ECUs the true fuel savings is 83 gallons in a 24-hour period. For the purposes of this study, the analysis will only compare the fuel savings if conducting a one for one, ECU to IECU change out.

Table 6. ECU and IECU Fuel Efficiency Comparison

	POWER SOURCE	CONSUMPTION RANGE	CAPACITY/ CONSUMPTION	SAVINGS PER DAY	SAVINGS BY REPLACING 500 ECUS W/ IECUS
ECU	1 X 30KW TQG 23 GAL TANK	2.7 GPH 8 HR RUN TIME PER TANK	69 GAL PER DAY		
IECU	1 X 30KW TQG 23 GAL TANK	13 HR RUN TIME PER TANK	55 GAL PER DAY	20% = 13.8 GAL	6,900 GAL SAVED

Source: Created by author.

Field Tents

Poorly insulated and designed field tents are a major factor in excessive running time of ECUs and increase excess power load and fuel waste by generators. Insulated tents and solar shades which cover the entire outside of the tent structure produced a reduction in energy as well. The solar shades block the sun's direct rays and lower inside air temperatures reducing run time for ECUs. In addition to solar shades, photovoltaic coverings also cover the outside of the structure and can draw up to 3-KW watts of power to for electronic components inside of the tents.⁴⁸ In the absence of the solar shades or photovoltaic coverings new tent designs come with a lightweight coating that reflects the

sun's energy. This reflective insulating layer doubles shelter efficiency.⁴⁹ The methods used to insulate field tents to make them more energy efficient will greatly reduce ECU run times thus cutting down on generator fuel utilization. Increasing the efficiency of tents with better materials and integrating solar shades or photovoltaic coverings reduces original energy consumption rates by up to 50 percent.

Table 7. Efficiency of Uninsulated Field Tents Vice Insulated

	POWER SOURCE	CONSUMPTION RATE	CAPACITY/ CONSUMPTION	SAVINGS PER DAY	REPLACE 500 UNINSULATED TENTS W/ INSULATED TENTS
FIELD TENTS	1 X 30KW TQG/ POWERING 1 ECU	2.7 GPH 8.5 HR RUN TIME	23 GAL TANK 69 GAL PER DAY	50% REDUCTION W/INSULATED TENTS = 35 GAL SAVED	17,500 GAL SAVED PER DAY

Source: Created by author.

Lighting Systems

The lighting in the tents may seem minimal but many lighting systems that use incandescent light bulbs and CFLs radiate heat using more energy. LEDs do not emit heat and need use less energy to run than CFLs and incandescent. Increased heat in a tent requires an ECU to run longer or turn on more frequently consuming more fuel. LEDs save .8 percent⁵⁰ more energy than CFLs that equals approximately one-half gallon of fuel saved per day. If this saving is distributed to 2,500 30-KW generators this saves 1,380 gallons of fuel per day.

Table 8. Benefits of Using LEDs Vice CFLs

	POWER SOURCE	CONSUMPTION RATE	CAPACITY/ CONSUMPTION	PERCENTAGE OF SAVINGS	SAVINGS PER DAY	REPLACING 2500 CFL BULBS W/LEDS
LIGHTS	1 X 30KW TQG	2.7 GPH 8.5 HR RUN TIME	23 GAL TANK = 69 GAL PER DAY	.8% PER DAY USING LEDs	.552 GAL	1,380 GAL SAVED PER DAY

Source: Created by author.

Summary

The analysis in this chapter identified that increasing fuel and performance efficiency in tactical wheeled vehicles, generators, ECUs, field tents, and tent lighting all contribute to a significant reduction in the use of fuel. As identified in chapter 2, a reduction in energy demand is accomplished through a combination of technologies. This analysis identifies and confirms it is not a one size fits all situations. Each system on the battlefield that is reliant on fossil fuels adds to the growing concern over military dependence on fuel. When each system is looked at individually the cost of fuel savings is small. However, when they are grouped by together in mass either by the same type of system or as identified in this study by different groupings of equipment, the little savings per individual piece of equipment combines to substantial savings in fuel. Through initiating an energy optimization strategy, deployed commands will realize the benefits quickly. Each of the systems identified contributes to an increased percentage in fuel efficiency when compared to current systems and practices. The new systems fielded to both the Army and Marine Corps will reduce fuel consumption on deployed bases from 20-25 percent. These savings have a significant impact on reducing the number of fuel

convoys, the focus of this thesis. A summary of all the systems discussed is listed in table 9.

Table 9. Benefits of Applying an Energy Optimization Strategy to a Large Fixed Base

OLD SYSTEM	CONSUMPTION OF OLDER SYSTEMS	NEW SYSTEM	PERCENT INCREASE IN EFFICIENCY & CONSUMPTION	FUEL SAVED	QUANTITY REPLACED	TOTALS
MTVR ANY VARIANT	AVG 3.8 MPG/ RANGE 300	MTVR HYBRID	20% INCREASE 4.6 MPG/RANGE 360	13 GAL PER TANK	800	10,400 GAL
HEMTT ANY VARIANT	AVG 2.6 MPG/ RANGE 400	HEMTT A3	20% INCREASE 3.15 MPG/RANGE 488	27 GAL PER TANK	1700	45,900 GAL
TQG AVG 3-60KW	1.51 GAL PER HR 36.24 GAL PER DAY	AMMPS AVG 3-60KW	20% INCREASE 30 GAL PER DAY	6.2 GAL PER DAY	1600	9,920 GAL
TQG 60 KW	129 GAL PER DAY	MICRO-GRID	40% INCREASE TAKING 2 OF 5 GENERATORS OFFLINE	258 GAL PER DAY	ESTABLISH 400 MICRO-GRIDS	51,600 GAL
ECU	69 GAL PER DAY	IECU	20% INCREASE 55 GAL PER DAY	13.8 GAL PER DAY	500	6,900 GAL
FIELD TENTS	69 GAL PER DAY	INSULATED TENTS	50% FUEL SAVINGS	35 GAL PER DAY	500	17,500 GAL
LIGHTS CLF	69 GAL PER DAY	LIGHTS LED	.8% FUEL SAVINGS ½ GAL PER DAY	.552 GAL PER DAY	2500	1,380 GAL
TQG 3 KW TQG 30 KW	8 GAL PER DAY 69 GAL PER DAY	SOLAR	100% FUEL SAVINGS	78 GAL PER DAY	25 3 KW 25 30 KW	1,925 GAL
						145,525 GAL SAVED

Source: Created by author.

If 145,525 gallons of saved fuel is applied as a base line for approximate amount of fuel that can be saved per day from all the systems listed and is spread out over 30 days the total fuel saved is 4,365,750 gallons. This amount of fuel savings equals 874 each, 5,000-gallon tanker trucks that do not need to be on the road. This reduces convoy traffic by 18 convoys, each consisting of 35 5,000-gallon tanker trucks and 15 support vehicles totaling a 50-vehicle convoy and over 140 supporting personnel.

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²¹Pollman, 70.

²²*Ibid.*

²³*Ibid.*

²⁴Claire Heininger Schwerin, Army deploys micro-grids in Afghanistan for smart battlefield power,” The Official Homepage of the United States Army, June 28, 2011, <http://www.army.mil/article/60709/> (accessed February 15, 2014).

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²⁶*Ibid.*, 14.

²⁷Pollman, 71.

²⁸Earth Easy, “Energy Efficient Lighting,” http://eartheasy.com/live_energyeff_lighting.htm (accessed February 19, 2014).

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Introduction

The purpose of this study is to determine if introducing energy efficient ground equipment onto the battlefield contributes to a reduction in fuel consumption to reduce the burden of fuel resupply. The research of currently available technologies confirms this. This chapter discusses the findings in chapter four and applies them to answering the primary and secondary research questions proposed in chapter one. It will also discuss the approaches for implementing these concepts using DOTMLPF-P solutions and provide recommendations to drive change in military culture to accepting these new technologies and practices.

Tactical wheeled vehicles and generators were two major contributors to the massive fuel consumption rates responsible for excess fuel convoys in both Iraq and Afghanistan. In order for the U.S. Army and the U.S. Marine Corps to achieve the goal of extending operational reach and longevity on the battlefield they must implement changes in fuel expenditure rates. The U.S. Army and U.S. Marine Corps can achieve this goal through energy optimization of existing and new technologies to reduce fuel demand. Integrating existing and new technologies will improve logistics sustainment on the battlefield by reducing unnecessary convoys, preserving resources, and saving lives.

In chapter 4 a comparative analysis conducted between tactical wheeled vehicles and generators to show how a small percentage of fuel reducing measures can add up to significant savings when applying an energy optimization strategy. The study compared the tactical vehicles HEMTT and MTVR current diesel turbo engines with the new diesel

hybrid systems for each model. The increased efficiency of the diesel hybrid engine rendered up to 25 percent fuel savings. Generators, also part of the study, are a primary fuel consumers for producing electricity on bases and during combat operations and are the largest fuel consumer during combat operations.¹ The analysis compared older TQGs with the new AMMPS generators that are 20 percent more efficient. The increase in efficiency showed considerable fuel saving when applied to a large number of generators. The analysis also included the benefits of establishing of micro-grids and the use of solar technology. Micro-grid technology regulates peak generator production that helps lower fuel waste. Solar technology is completely independent of fossil fuel and can supplement power production to further reduce fuel usage. Secondary consumers of generator power also analyzed are ECUs, field tents and tent lighting systems. The secondary consumers all contribute to increased power load on generators. New commercial off the shelf technology is now available for ECUs, field tents and tent lighting systems to reduce fuel utilization up to 20 percent.

The following example in table 10, illustrates how one Marine Infantry Battalion of 1,200 personnel in a deployed environment can save fuel using the methods discussed to develop an energy optimization strategy to reduce fuel consumption.

Table 10. Applied Energy Optimization Strategy
for One Marine Infantry Battalion

OLD SYSTEM	CONSUMPTION OF OLDER SYSTEMS	NEW SYSTEM	PERCENT INCREASE IN EFFICIENCY & CONSUMPTION	FUEL SAVED	QUANTITY REPLACED	TOTALS
MTVR ANY VARIANT	AVG 3.8 MPG/ RANGE 300	MTVR HYBRID	20% INCREASE 4.6 MPG/RANGE 360	13 GAL PER TANK	45	585 GAL
HEMTT ANY VARIANT	AVG 2.6 MPG/ RANGE 400	HEMTT A3	20% INCREASE 3.15 MPG/RANGE 488	27 GAL PER TANK	15	405 GAL
TQG AVG 3-60KW	1.51 GAL PER HR 36.24 GAL PER DAY	AMMPS AVG 3-60KW	20% INCREASE 30 GAL PER DAY	6.2 GAL PER DAY	35	217 GAL
TQG 60 KW	129 GAL PER DAY	AMMPS MICRO-GRID	40% INCREASE ESTABLISH 5 MICRO-GRIDS	258 GAL PER DAY 2 GEN OFFLINE	(10) 60 KW OFFLINE	1290 GAL
ECU	69 GAL PER DAY	IECU	20% INCREASE 55 GAL PER DAY	13.8 GAL PER DAY	40	552 GAL
FIELD TENTS	69 GAL PER DAY	INSULATED TENTS	50% FUEL SAVINGS	35 GAL PER DAY	60	2,100 GAL
LIGHTS CLF	69 GAL PER DAY	LIGHTS LED	.8% FUEL SAVINGS ½ GAL PER DAY	.552 GAL PER DAY	320	177 GAL
TQG 3 KW TQG 30 KW	8 GAL PER DAY 69 GAL PER DAY	SOLAR	100% FUEL SAVINGS	78 GAL PER DAY	(10) 3 KW TQG (15) 30 KW TQG	1,115 GAL
						6,441 GAL SAVED

Source: Created by author.

The analysis concludes with modest reductions in fuel consumption through establishing an energy optimization strategy one Marine Infantry Battalion with 1,200 personnel can save up to 6,000 gallons of fuel per day. In one month, this battalion saves 180,000 gallons of fuel, which equates to one 50-vehicle convoy with 140 support personnel that does not need to be on the road. In the long term this produces significant savings in unit fuel consumption, reduces fuel resupply convoys and road time exposure for military personnel subject to enemy attacks. This also translates into reallocating military resources in personnel and equipment for use on other missions.

Conclusion

The military's dependence on fuel during combat operations is shared equally by all the services. The U.S. Air Force and U.S. Navy are the largest consumers of fuel with aviation fuel topping the list.² The U.S. Army and U.S. Marine Corps are the largest fuel consumers of ground equipment.³ This study identified tactical wheeled vehicles and generators as the principle fuel consumers of ground equipment systems during combat operations.⁴ One reason for this is the nature of the Operational Environment in Iraq and Afghanistan. When Iraq and Afghanistan transitioned from symmetric to a-symmetric warfare, stability and counterinsurgency operations increased. These types of operations are widely dispersed at many different locations. As COPs and FOBs became established at these locations, the demand for transporting fuel increased. This pattern of widely dispersed operations was determined to primarily be why the military has grown to become exorbitantly dependent on fuel and reinforces why additional fuel resupply convoys are needed to support dispersed operations. In supporting dispersed operations effectively, an energy optimization strategy and implementation plan is the first step to release the military from the tether of fuel.

The Army and Marines are totally dependent on their ground vehicle fleet. On average, tactical wheeled vehicles fuel consumption is between three and 10 MPG depending on weight and terrain. Vehicle range is also an important factor because regardless of fuel rates, military vehicles will still need to travel up to 250-300 miles per tank of fuel. What this equates to is vehicles that get three MPG will be equipped with fuel tanks with a capacity of 80-90 gallons to ensure it can travel 250-300 miles. This reduces the concern to design vehicles that are more fuel-efficient because the vehicle

can still travel up to 250-300 miles on a single tank meeting mission requirements. Excluding MRAPS and MATVs, most of the current tactical wheeled vehicle fleet built during the late 1990s and early 2000s had lower fuel efficiency standards because JP-8 fuel was much cheaper than fuel is today. This is important in understanding that a portion of today's fuel problems is a result of the older vehicle systems design. The vehicles designed with fuel efficiency standards of the 1990s with low cost fuel in mind, were fighting a conventional adversary along a linear front.

Due to the force management budgeting and acquisition process vehicles are generational. All equipment must remain serviceable and operate for decades, undergoing system modifications and upgrades when the technology is available and affordable. The HEMTTs and MTVRs of the 1990s and early 2000s are still in service because it is too expensive to replace them all with upgraded systems. As capability gaps in the fuel efficiency of tactical wheeled vehicles addresses a material solution, using a system modifications results in the new logistics vehicle models fielded with diesel hybrid designs as in the HEMTT A3 model and MTVR. Now that the technology in hybrid diesel electric engines is available and provide a 25 percent improvement in fuel efficiency over standard diesel turbo engines, as older vehicles become too expensive to repair they will be phased out and replaced with hybrid technology.

Over the past decade, the military experienced an increase in base operations requiring a daily supply of thousands of gallons of fuel for basic life support needs. In 2010, Camp Leatherneck, Afghanistan reported using 15,000 gallons of fuel daily to power over 200 generators.⁵ The military is reliant on generators because of the inability to tie into an existing power grid specifically during mobile offensive operations. Even

during stability operations, commanders are reluctant to tie into existing infrastructure because of power continuity. As TQGs replaced the older version of generators first used in Iraq and Afghanistan fuel efficiency improved minimally. The introduction of the new AMMPS generators fielded in late 2012 increased fuel efficiency 20 percent.

Implementing the new generators and rightsizing them to provide the right amount of power at the right time provided significant fuel savings. This was a result of redesigning the employment of generators to ensure peak power production is regulated using micro-grid technology. Matching power generating capacity to the unit's power needs reduced excess power generation and leads to reductions in fuel used.⁶ This helped to eliminate unnecessary generators and regulate power production to further save fuel. The introduction of solar technology on the battlefield also became a game changer because it is one hundred percent fuel independent. If unit power demands are not high, such as an infantry company, they can rely on solar technology to power a host of systems continuously without the need for generators. Many different systems plug into generators to draw power to support operational functions on bases. Secondary consumers of generator capacity are ECUs, field tents and tent lighting. All of these elements contribute to fuel utilization on bases. Improvements in secondary systems such as IECUs, have produced a 20 percent energy savings compared with older ECU models. Field tents lined with insulating properties produce a 50 percent energy savings compared to older tent materials. Tents are also available with solar coverings to provide power to lights and computers for the tents occupants. Improved lighting systems such as LEDs have also increased efficiency of generators because they do not require as much energy as the older CFL systems. Motion sensors also aided in turning lights off when the tents

are not occupied. Both LEDs and motion sensors produced significant results in supporting the energy optimization strategy not only for battlefield applications but also for garrison installations.

Since the initial invasion of Iraq in March 2003, military commanders have sought ways to increase operational reach without extending beyond fuel supply lines. This military problem has been a contentious issue since the introduction of motorized vehicles and equipment on the battlefield. This is a known problem and overcoming it is a slow and expensive process. The military realized this capability gap but it continues to invest in equipment and systems that are inefficient. Increases in fuel prices and a shrinking DOD budget might just be the major catalyst for significant change. This is to some degree a relatively simple problem. Reducing fuel consumption equals saving money. Applying the DOTMLPF-P problem-solving construct to assess current capabilities and manage change the military can be proactive about reducing its dependency on fuel visé reactive.⁷ By changing doctrine and training as well as investing in commercial off the shelf-technology, the military can produce a modern military less dependent on fuel. A reduction of fuel consumption of 10-20 percent saves billions of dollars per year the DOD can use for other areas in the budget. In the past technology was not readily available or affordable to assist the military in reducing fuel usage. The technology was either too expensive or did not produce sufficient savings in fuel to merit adapting to the new technology. Now that reliable and cheaper hybrid electric technology is available, this is now a viable solution to pursue. Generator technology also improved to produce over 20 percent energy savings. In addition, solar power is now cheaper and harvested more efficiently than in the past that is a great alternative to fossil fuel

generators. Even though new and affordable technology is available, the fuel problem is complex and will take more than one type of technology to solve. It will take a variety of different equipment to optimize the technological benefits to reducing fuel consumption.

Research Questions

The research conducted answers the originally proposed question; what must the DOD do to be prepared logistically for future warfare at the tactical level recognizing that current ground equipment systems have a massive dependency on non-renewable energy resources? This broad question was narrowed in scope. Through the research, the author narrowed the subject to address the systems that have the highest consumption rates on the battlefield. After identifying the current platforms of tactical wheeled vehicles and generators as the largest fuel consumers of ground equipment the author was able to show through a quantitative comparative analysis the fuel savings for each of the specific equipment sets. The equipment platforms analyzed for fuel efficiency are the HEMTT, MTVR, AMMPS generators, ECUs, field tent insulation, and lighting systems. The equipment sets identified for the study either directly or indirectly contribute to excessive consumption. The analysis identified that one specific piece of equipment showing a twenty percent increase of efficiency will not significantly show a large reduction in fuel consumption. However, the savings in fuel had the most impact when summed for all like equipment systems within a battalion size element and larger. In addition, when analyzing a group of different equipment systems which all contribute to increased efficiency of 20 percent or more the cumulative impact is a substantial fuel savings. Through implementing this practice energy optimization can reduce fuel demand for the military and improve logistics sustainment of ground forces.

Three secondary questions were identified while conducting the research. These questions addressed three issues.

First, if fuel-reducing measures are implemented in the three areas of diesel hybrid electric engines, drop in bio-fuels and solar technology will the data show a 20 percent decrease in fuel consumption? This question was modified because during the review of literature in chapter 2, drop in bio-fuels or alternative fuels blends that mimic the properties of military grade fossil fuels do not produce a significance increase in engine efficiency. They represent a replacement to fossil fuel but without an increase engine efficiency and performance in equipment, so the problem of fuel logistics on the battlefield remains status quo. However, diesel hybrid electric engines and solar power do offer significant savings. Diesel hybrid electric engines that come in two logistic vehicles variants the Army's HEMTT and the Marine Corps MTVR, show a greater than 20 percent fuel savings when compared to the current diesel turbo engine that older models use. Solar power contributes to a 100 percent fuel savings as it can replace generators ranging from 3-KW to 28-KWs. Solar power terminals can integrate into a micro-grid system that can provide additional power and supplement generators that are on the same micro-grid system. They also aid in producing and storing electricity to lessen the peak load burden that generators must provide. They are also ideal for smaller units operating in remote environments when resupply is very difficult.

Second, how effective will ground units be in conducting expeditionary operations with current tactical equipment platforms that are heavily dependent on fuel resources? This question is the basis for conducting the research to answer the primary question. The U.S. military is the most powerful, best equipped and trained force the

world. To some extent, the military has access to an almost unlimited supply of resources and technology to conduct operations worldwide. However, for the first time since Vietnam the military experienced a significant dependence on fuel to run combat operations during stability and counterinsurgency operations in remote locations within Iraq and Afghanistan. Many equipment platforms used in both Iraq and Afghanistan were built in the 1990s and early 2000s are now slowly being replaced with newer equipment that are more fuel-efficient. A lesson learned from Iraq and Afghanistan is how to sustain fuel logistics effectively during expeditionary operations that transition into long-term stability operations. With current equipment platforms, the U.S. military will operate as it has been for the past decade. It will allocate the necessary resources to conduct convoys and resupply units on the battlefield. This question becomes more about commanders accepting operational risk as fuel convoys are a necessity on the battlefield and will continue to play a part in wartime operations. It is how much risk senior level leaders are willing to accept exposing Soldiers and Marines to enemy threats while conducting a high frequency of convoys to resupply fuel across the battlefield. As new technology in efficiency becomes available, it is slowly integrated. Perhaps in the next 10-15 years the military will shift to being much less dependent on fuel as new energy efficient technology is adapted. To operate in expeditionary environments effectively units must be light, agile, and self-sustaining. Current equipment systems make the self-sustaining aspect difficult due to the tether of fuel that determines how long units can operate in expeditionary environments.

Third, what are the risks of investing in platforms that are less dependent on fuel? The associated risks of investing in platforms which are less dependent on fuel is the

technology is rapidly procured through the acquisition process and fielded quickly at higher costs. Since the technology is new, the systems often cost much more to develop during the first and second-generation models. However, the higher costs of these systems will pay back in the amount of fuel they will save in a few years' time. There are also organizational risks associated with developing the organizational structure of personnel needed to support these systems. As the force draws down existing Military Occupational Specialty fields will need to be restructured to provide Soldiers and Marines the necessary training and education to become proficient subject matter experts in the new technology. Equally important is identifying which maintenance Military Occupational Specialty fields will need the advanced training and education to perform the technical maintenance on the systems.

Recommendations

The analysis conducted proves that with new technologies in energy efficient equipment a 20 percent increase in fuel efficiency is achievable. The significant savings achieved in fuel consumption is by implementing an operational energy strategy into the two large fuel consumers of tactical wheeled vehicles and generators. The vision for putting these practices into action in the operating forces spans the DOTMLPF-P construct. The obstacles with implementing the technology is not with the technology itself because many of the concepts employ existing technology and are relatively inexpensive to implement. The obstacles lay with training and educating Soldiers and Marines, to trust and rely on the technology. Soldiers and Marines must believe the equipment is just as reliable as the older models most Soldiers and Marines used in the past. Since the systems are very new and some are still in the testing phase like solar

technology they are not fielded to the operating forces in large quantities. This reduces the exposure of these systems to a large base of personnel. In some cases, the first time personnel see the equipment is out in the field. This is due to a process of quickly developing capability gaps by the Army's Rapid Equipping Force, Marine Corps Systems Command, and the Marine Corps Expeditionary Energy Office for immediate implementation. Once developed the systems were set up in Afghanistan on a small scale. If energy optimization strategies are to take root within the organizational culture of the military, energy optimization must be institutionalized within the service at all levels. Leadership and education are central to implementing change and driving continued innovation.⁸ As concepts in this field are tested and implemented, changes in doctrine, training, leadership, education, and policy must follow. Exposure to these systems is a must occur for Soldiers and Marines at the highest and lowest levels. Only a small percentage of Soldiers and Marines have worked with these systems, experienced the technology and appreciate what it brings to the battlefield. This is why training and educating across the force is imperative to the success of energy optimization programs. It is not just about the numbers in fuel savings these systems produce it is about providing a clear understanding of why these concepts are beneficial to unit security and safety. Energy optimization affects the readiness of forces to conduct operations through reducing the need for more resources in fuel and equipment to support missions. As the technology is continually developed to support new ideas and fill capability gaps in DOTMLPF-P this will only enable Soldiers and Marines to conduct operations in the most efficient, lethal and safest manner possible. Continued training and implementation

of fielding these systems is imperative to enable combat effective units to perform while operating in expeditionary and austere environments.

Recommendations for Further Study

This study indicates a multitude of opportunities to identify capability gaps in equipment systems where energy efficient technologies can help increase battlefield reach and longevity. As new technologies in fuel-efficient hybrid engines are developed and become more affordable to the military studies on the effects this will have for tracked vehicles is important to the overall fuel reduction of all ground vehicles. Front line tracked vehicles are at the tip of the spear during mobile offensive operations. Tracked vehicles account for close to 50 percent of ground fuel consumed during combat operations. The fuel-efficient designs that increase range on tracked vehicles can have devastating effects on enemy forces. Tracked vehicles increased fuel efficiency can also change fuel logistics during combat operation further improving military operations agility and flexibility on the battlefield. Another focus area for further study is bio-fuels and alternate fuels as these fuels can have a large impact on overall DOD fossil fuel reduction. As refining techniques become increasingly cost effective in bio-fuels and alternate fuels, further study in addressing how bio-fuels and alternate fuels can impact ground logistics is another area of important study.

¹Meyer and Talley, 13.

²Assistant Secretary of Defense for Operational Energy, Plans, and Programs, *Operational Energy Strategy*, 3.

³Meyer and Talley, 13.

⁴Ibid.

⁵LCDR Chris Garvin, P.E., USN (Ret.), and Jim Codling, P.E., “Making Grid Connection Happen,” The Military Engineer, <http://themilitaryengineer.com/index.php/tme-articles/tme-past-articles/item/111-making-grid-connection-happen> (accessed April 1, 2014).

⁶Meyer and Talley, 14.

⁷Headquarters, Department of the Army, Army Regulation 5-22, 2.

⁸Pollman, 70.

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