**Enhancing the Expeditionary Capabilities of the Marine Corps with “Green” Tactical Vehicles**

*ABSTRACT (MAXIMUM 200 WORDS)*

The shift to alternative fuel sources for ground tactical vehicles is necessary for the Marine Air Ground Task Force to remain a light, agile, and lethal force for the Nation. The Marine Corps can leverage existing and future technology to field tactical ground tactical vehicles that do not directly require fossil fuels.
MASTER OF OPERATIONAL STUDIES

TITLE:
Enhancing the Expeditionary Capability of the Marine Corps with "Green" Tactical Vehicles

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF OPERATIONAL STUDIES

AUTHOR:
Major Eric R. Quehl, USMC

AY 09-10

Mentor: Dr. Gordon Rudd

Approved: ✓

Date: 27 May 2010
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EXECUTIVE SUMMARY

Title: Enhancing the Expeditionary Capability of the Marine Corps with “Green” Tactical Vehicles

Author: Major Eric Quehl, United States Marine Corps

Thesis: The Marine Corps can leverage existing and future technology to field ground tactical vehicles that do not directly require fossil fuels.

Discussion: Since World War I the motorization of Marine combat formations significantly enhanced mobility and firepower, and it continues to do so in the current operating environment. The Marine Air Ground Task Force of today is heavy with rolling stock and, as a result, excessively dependent on fossil fuels. This over-reliance on fossil fuel has a direct and negative effect on the combat effectiveness and efficiency of the MAGTF, and it needs an innovative solution to correct. Numerous commercial companies offer cars and trucks that use rechargeable batteries to power electric motors, which propel the vehicle. While they do not meet the Marine Corps’ need for rugged and expeditionary vehicles, they do show that the use of electric systems to power tactical vehicles is promising, and it does not require a major scientific breakthrough to apply to said systems. Current recharging methods (electric grid), promising photovoltaic solar cell technology, and small-scale wind power make electric-powered vehicles a feasible system for the future operating environment. The positive implications are many: it greatly decreases fossil fuel requirements; enhances tactical mobility and operational reach; and “lightens the load” of the force—all of which enhance the expeditionary capabilities of the Marine Corps.

Conclusion: The shift to alternative fuel sources for ground tactical vehicles is necessary for the MAGTF to remain a light, flexible, and lethal force for the Nation. The Marine Corps can make this shift by leveraging existing and future technology to electrify ground tactical vehicles.
Introduction

The first large-scale use of motorized transportation by the United States Marine Corps occurred during World War I in France. Since that time, the Marine Corps has generally kept pace with advances in automotive technology and has employed several types of motor transport vehicles in nearly every major conflict. The overwhelming majority of these ground transportation systems were and continue to be powered by fossil fuels and internal combustion engines. The motorization of Marine combat formations significantly enhanced mobility and firepower, and it continues to do so on the modern battlefield. However, because of the geography of current operating environments, dispersed location of the force, and mission requirements, the Marine Air Ground Task Force (MAGTF) of today is heavy with motor transport assets. As a result, the Marine Corps is excessively dependent on fossil fuels to sustain that rolling stock. This problem requires an innovative and feasible solution to reduce the MAGTF’s reliance on fossil fuels while improving tactical mobility and expeditionary capability. *The Marine Corps can leverage existing and future technology to field ground tactical vehicles that do not directly require fossil fuels.* The Marine Corps should shift to a fleet of electric-powered tactical vehicles, specifically, those that use conventional utility electric, solar, and small-scale wind power.

This paper consists of four parts. The first portion frames the issue and briefly explains the requirement for electric-powered tactical vehicles. The next section describes the current “green” technology in use by civilian automotive manufacturers that is germane to this essay. The third section discusses the required attributes of an electric-powered tactical vehicle. The last section of the paper considers the implications of fielding these vehicles.
**Problem**

Marine forces fighting in a counterinsurgency or conventional operating environment are heavily dependent on fossil fuels. A typical Marine Expeditionary Brigade requires approximately 498,000 gallons of fuel per day, of which ground combat and logistics forces consume 28%. This requires tremendous resources to procure, transport, and store fuel—in both personnel and equipment. Ironically, the vast majority (90%) of fuel used in support of ground mobility by I Marine Expeditionary Force during the initial stages of Operation Iraqi Freedom was for tactical wheeled vehicles (High Mobility Multipurpose Wheeled Vehicle/Medium Tactical Vehicle Replacement/Logistics Vehicle System) rather than combat vehicles, such as Assault Amphibian Vehicles, Light Armored Vehicles, and M1A1 tanks. This backward and inefficient equation prompted then-Lieutenant General James Mattis, who led First Marine Division during Operation Iraqi Freedom I, to challenge officials of the Department of the Navy to “unleash us from the tether of fuel.”

General Mattis was not alone in his frustrations. While serving as the Commanding General of Multi-National Forces-West, then-Major General Richard Zilmer realized that his extended supply lines in the expansive Iraqi province of Al Anbar were a critical vulnerability, and he placed an urgent request to the Joint Chiefs of Staff in 2006 for alternative fuel systems because, “by reducing the need for [petroleum-based fuels] at our outlying bases, we can decrease the frequency of logistics convoys on the road, thereby reducing the danger to our Marines, soldiers, and sailors.”

The increasing requirement for fuel drains personnel and logistical assets, and it directly and negatively affects the combat effectiveness, efficiency, and mobility of Marine forces. This
reliance on fossil fuels on the battlefield does not conform to Marine Corps doctrine, specifically, “one of our key objectives must be to ensure that limits imposed by logistics do not inhibit effective operations.” This problem is not new. The larger communications architecture, heavier wheeled vehicles, and the “tyranny of distance” of the current operating environment exacerbate the requirement.

**Current Technology**

Concern for the environment and an increasing, worldwide demand for finite petroleum resources coupled with unstable prices continue to inspire interest in electric-powered vehicles by private enterprise, consumers, and environmental groups. These factors, as well as hefty fiscal incentives offered by the governments of France, United Kingdom, Japan, and the United States, should motivate the international automotive industry to develop new and better electric-powered vehicles.

Several automotive companies offer reliable, albeit somewhat expensive, electric cars that rely on plug-in, conventional electric power to recharge the car’s system. Tesla Motors of Silicon Valley, California, sells a sports car that can accelerate from zero to sixty in under four seconds. Nissan Motor Company plans to sell a family friendly car that can travel over 100 miles between charges. The Chevrolet Volt, which General Motors will launch in 2010, can travel up to 40 miles using only power from its battery, but it also has a gasoline engine that can recharge the system, if necessary.

Numerous commercial companies offer trucks that use rechargeable batteries to power electric motors; like the cars, those trucks rely on external power to recharge their batteries. The firm Electric Vehicles International sells several light and medium duty trucks; the MD 80
version boasts a maximum speed of 60 miles per hour and an average range of 80 miles on one charge.\textsuperscript{8} Smith Electric Vehicles, located in the United Kingdom, sells numerous configurations of trucks and panel vans. Their medium panel van has a range of 100 miles, a payload of 1220 kilograms (2689 pounds), and a top speed of 50 miles per hour.\textsuperscript{9} Another British manufacturer, Modec, produces numerous light-duty trucks in chassis cab, panel van, or drop-side configurations. The Modec vehicles have maximum speed of 50 miles per hour, a range of up to 100 miles, and a payload of two tons.\textsuperscript{10}

All the vehicles mentioned use lithium-ion batteries, which are the same type of batteries commonly used in computer notebooks, iPods, and mobile phones. Lithium-ion are much lighter, smaller, and more powerful than other rechargeable batteries, such as lead-acid ones used in conventional automobiles, or nickel metal hydride and nickel cadmium batteries that are found in cordless power tools and older electronic devices.\textsuperscript{11}

These vehicles, while safe and appropriate for civilian use, do not meet the need of the Marine Corps for a rugged and survivable tactical vehicle. However, they do demonstrate that the technology to power vehicles without fossil fuels exists. It also indicates that the automotive industry is willing to develop and market electric vehicles that are cost-competitive with vehicles powered by fossil fuels.

There is no evidence of a suitable car or truck powered solely by solar power. Several prototypes exist, but their expense, size, speed, and range limit consideration as an alternative to conventional automobiles powered by fossil fuels, much less as military vehicles.\textsuperscript{12} Solar power as the main source for a car or truck may not be feasible for the next ten to fifteen years.
However, these solar vehicle prototypes, coupled with steady advances in photovoltaic solar cell technology, show promise for use as supplemental power on an electric vehicle.

Photovoltaic cell technology is the one of two primary methods in use today for converting sunlight into electricity, also known as solar power. First generation photovoltaic cells are made up of crystalline silicon, a bulky, yet efficient material. These solar cells were developed by two Bell Telephone scientists in 1954, and they are still widely used today for small-scale home solar power and large-scale solar farms.13

Thin film solar cells use amorphous silicon or cadmium telluride as the main ingredient and are often referred to as second generation solar cells. The thickness of this type of photovoltaic cell is measured in micrometers, and it is ideal for use on roofs, windows, and south-facing sides of buildings; however, it is generally less efficient than first generation photovoltaic cells.14

Solar researchers have experimented with different materials and ideas to produce ideal photovoltaic cells, to include: porous silicon, nano particles embedded in plastics, and dye-sensitized solar cells. Universities, government agencies, and industry are investing time and energy in third generation photovoltaic cell technologies, as well as first and second generation photovoltaic cell technology, to produce a cost-effective solution than can compete with fossil fuels.15 One of the most promising third generation photovoltaic cell is the multijunction solar cell; these cells use mirrors and lenses to concentrate the sun’s rays, and they potentially reap up to 41% efficiency—a tremendous improvement over first and second generation photovoltaic cells.16
Given these factors, the use of electric systems to power wheeled vehicles is promising, and it does not require a major scientific breakthrough to apply to a rugged and survivable ground tactical vehicle; it is feasible with continued research and design. Next generation technologies are critical to the success of electric-powered vehicles.

**Specific Vehicle Attributes**

The use of electricity to power the drive systems of ground tactical vehicles does not require a change to the basic design and characteristics of Marine Corps’ current rolling stock, save the method of powering the drive train. Major components required for electric-powered vehicles can be retrofitted to the existing fleet of light, medium, and heavy vehicles. The vehicle would need an electric motor and a rechargeable battery (in lieu of an internal combustion engine) and a transmission that converts electrical energy into mechanical energy.17

The vehicle would transfer electrical energy (from wind, conventional electric source, or solar) through an on-board voltage regulator to a small, lightweight, and high-capacity lithium-air battery. Lithium-air batteries feature promising technology that will potentially provide ten times more storage capacity than lithium-ion batteries used in most electric vehicles of today.18 The battery would provide electric power on demand to an electric motor that produces electrical energy and subsequently converts it to mechanical energy through the transmission. This mechanical energy will propel the drive system.

An electric-powered tactical vehicle would have several methods to recharge the battery in an expeditionary environment. The primary recharging method would be to plug the vehicle into an external power source, which is the current method to power electrical vehicles. The most common external power source is the conventional electric grid. Because of different electrical
standards throughout the world, each vehicle will be capable of handling a wide variety of voltage and using either alternating current or direct current power sources.

Another power source would be mobile electric power farms that consist of solar arrays or lightweight generators powered by fuel-efficient internal combustion engines. Any ground combat element or aviation combat element unit that possesses electric-powered vehicles will have limited capability to generate expedient power through small-scale solar arrays or internal combustion engine generators. However, the Marines of the logistics combat element, specifically, task-organized units of the Engineer Support Battalions or external engineer forces, such as the Naval Construction Force, would be responsible to provide mobile electric power by supply point distribution or unit distribution. These units would erect rugged and modular solar arrays. In addition, they will retain the capability to generate substantial electricity with internal combustion engine generators. Both the arrays and generators will be transportable on trailers or mobile-loaded on tactical vehicles. These forces could establish and maintain electrical power farms at rear areas, forward operating bases, or repair and replenishment points; the location of the farms would depend on the tactical situation and operating environment.

Naval shipping will also serve as a mobile, external power source. If embarked on amphibious shipping, the electric-powered vehicles could use power from the ship’s internal power supply before going ashore; the electricity would be distributed to vehicles with a system organic to the vessel. In addition, such a ship would require a rugged, multi-pronged system to carry the electric power from ship to shore. Smaller vessels or helicopters will carry the main power lines from ship to shore. Once the main lines are ashore, a Mobile Electric Power
Distribution System-like system would distribute electricity to the vehicles. The latter option would require a benign port.

An additional option is for the aviation combat element to mobile-load high-output, yet fuel-efficient generators on both fixed wing (C-130 Hercules) or rotary wing (CH-53E Super Stallion or MV-22 Osprey) aircraft and fly to forward operating bases or areas to provide electricity. The recharging sites would resemble rapid ground refueling sites; however, instead of providing fossil fuels, the sites rapidly distribute electricity to tactical vehicles.

The alternate recharging method would be small-scale solar power organic to each vehicle. Each vehicle will have an array of solar panels consisting of third generation photovoltaic cells. These panels will be affixed to equatorial mounts on the top and side of the vehicles, which would allow the panels to constantly adjust their position to gain maximum available sunlight.

The contingency method will be small-scale wind power. The vehicles would have several small, low-profile wind turbines attached to the front and top of the vehicle. The blades would be able to rotate fully to garner the most wind. They would also feature a braking mechanism to halt the blade in excessively windy conditions that could potentially harm the turbines. This recharging method would only be used when the vehicle is stationary or going down an incline, otherwise the wind turbine would create unnecessary drag on the vehicle when it is moving uphill or on a level surface. Therefore, the turbines would be enclosed in shells that open only when optimal conditions exist.

For use in emergencies, each vehicle will carry a small, internal combustion engine generator (to recharge the vehicle’s main battery) and an extra, fully-charged battery. The
emergency battery could be connected to the primary, secondary, or contingency recharging methods to maintain its charge or recharge after serving as the main battery.

**Implications**

Electric-powered vehicles are entirely in concert with Marine Corps doctrine, and their use will have numerous positive implications for the Marine Corps. These vehicles will directly enhance the expeditionary capabilities and operational reach of the Marine Air Ground Task Force; they will also reduce its personnel and equipment requirements and overall logistical footprint. These vehicles will have significant upfront financial costs, but the near and long term savings are significant.

The flexibility and versatility that electric-powered vehicles provide a MAGTF operating in an expeditionary environment is entirely in concert with the central warfighting philosophy of the Marine Corps—maneuver warfare. Vehicles that use efficient power sources, such as electricity, enhance two concepts critical to generating combat power—speed and focus.19 These vehicles will provide tactical mobility that generates a higher tempo than an enemy without this capability. Furthermore, electric-powered vehicles will increase the MAGTF’s ability to exploit fleeting opportunities and attack the enemy at “not only the decisive location but also at the decisive moment.”20 In addition, these aspects meet the doctrinal and traditional requirements of the Marine Corps to acquire equipment that forces will employ and maintain in “undeveloped theaters with limited supporting infrastructure.”21

Electric-powered vehicles will enhance the expeditionary capabilities of the MAGTF. The vehicles could use the existing electrical grid to recharge their batteries, whether operating in friendly or hostile nations. The use of existing electrical infrastructure would require accurate
information about its condition and capabilities or a timely plan to reconnoiter it with qualified personnel. This may necessitate the early seizure of critical electrical infrastructure in a hostile nation or enhancing the security of it in a friendly nation. Furthermore, these vehicles will enable a small maneuver unit to self-generate some of its own power needs because the alternate and contingency methods to recharge the vehicle battery use sustainable energy. This would also permit electric-powered vehicles to serve as a primary or additive power source for expeditionary forward bases by generating or transferring electrical energy. This capability could provide electric power in support of climate control, command and control equipment, or other needs. These vehicles will allow units to focus on tactical rather than internal logistical tasks, such as procuring large amount of fossil fuels; it would also enhance unit self-sufficiency.

The use of electric-powered vehicles will reduce the logistical footprint of the MAGTF, specifically, the requirement to procure and transport fuel in the operating environment. For example, a Marine Expeditionary Brigade consumes approximately 498,000 of fuel a day. Given that tactical wheeled vehicles used 90% of the 28% fuel allocated to I Marine Expeditionary Force ground forces during Operation Iraqi Freedom I—an approximate amount of fuel saved per day by a brigade equals 125,496 gallons. This decreased fuel usage would have a concomitant reduction of the size and amount of fossil fuel storage sites ashore in rear areas or forward operating bases, which require extensive man-hours to construct, maintain, and secure. Furthermore, it will reduce the fuel storage requirement of amphibious and Maritime Prepositioning Force shipping.

These vehicles will enhance the survivability of the force. A decrease of fossil fuel aboard tactical vehicles would reduce the chance of high-order detonation following an
improvised explosive device attack or complex ambush. Less fossil fuel storage sites will reduce lucrative targets for the enemy to target and attack. The decrease of logistical convoys during conventional or irregular warfare would minimize unnecessary movement on the battlefield and permit Marines to focus on primary tasks.

Electric-powered vehicles will lessen the MAGTF requirement for heavy and medium tactical vehicles to deliver fossil fuel within its assigned area of operations. The logistics combat element could focus on providing fuel in support of the ground combat element and aviation combat element vice internal requirements, as the vast majority of fossil fuel they transport would be for ground combat vehicles, engineer equipment, and aviation assets. Hence, this will reduce the requirement of medium and heavy lift motor transport vehicles to support the force.

These vehicles will extend the operational reach of the MAGTF by “lightening the load” of the force. This would permit farther maneuver inland or away from large forward operating bases while maximizing organic logistical support to sustain operations. This effective logistical system could also mitigate the risk of offensive action reaching a premature culminating point.

Electric-powered vehicles will reduce personnel requirements for logistics support. The MAGTF, particularly the logistics combat element, would require less ground tactical vehicle operators and maintainers and fewer Marines to establish, operate, and maintain bulk fuel assets, such as the Amphibious Assault Fuel System.

The fielding of electric-powered ground tactical vehicles would affect the entry-level training of automotive mechanics and motor transport operators as well as follow-on courses for non-commissioned and staff non-commissioned officers. The existing curricula for these formal schools will require revision. The Marines of those career fields will require new equipment
training to learn how to operate and maintain the electric-powered vehicles. Operating Force units will need manufacturer field-service representatives during the initial stages of fielding to conduct organizational maintenance and training for Marines.

The introduction of electric-powered vehicles will require rigorous evaluation in realistic field conditions. Following the initial testing of vehicle capabilities and limitations, the vehicles would need to participate fully in a training exercise with all elements of the Marine Air Ground Task Force, such as Mojave Viper or Combined Arms Exercise. The complete evaluation will identify planning considerations for employment in austere operating environments and refine the development of tactics, techniques, and procedures. It will also provide Marines an opportunity to forward recommendations to improve the vehicle. The full evaluation and subsequent feedback should give Marines confidence in these vehicles and ease the transition of the Marine Corps’ tactical vehicle fleet from fossil fuel to electric power—which is critical before they are used in combat.

The initial cost of developing, testing, and installing the necessary equipment to power tactical vehicles with electricity will be substantial relative to ordinary vehicles powered by internal combustion engines. However, the short and long-term financial savings realized from the reduced requirement to procure and transport fossil fuels and procure and maintain excessive tactical vehicles will make the shift economical. The future cost to improve and modify such electrical components or acquire new systems will depend on the progress of the automotive industry’s efforts to design, build, and sell vehicles that use alternative fuels, whether electricity, wind, or solar.
A limitation of current electric vehicles as a platform is they are not cost competitive with their counterparts powered by conventional means—if only compared strictly as a platform. Most economists believe that only sustained high crude oil prices will provide a clear price signal that vehicles that use alternative fuels can be produced on a mass market and turn a profit. Environmental considerations are not the driving force behind the Marine Corps’ need to shift to electric-powered vehicles; however, its effect to the marketplace will impact the acquisition cost and future development of electric-powered vehicles for military use.

**Conclusion**

The recent experiences Marine Corps in Iraq and the ongoing operations in southern Afghanistan highlight the dependence of the MAGTF on fossil fuels. The dispersed location of maneuver units conducting irregular warfare in the expansive Al Anbar province and the rapid advance to Baghdad in 2003—while successful operations—illustrated this critical vulnerability. While not a new problem in warfare, this reliance on one source of power for expeditionary operations is problematic, continues today in Afghanistan, and remains a risk of the future operating environment. The shift to alternative fuel sources for ground tactical vehicles is necessary for the Marine Corps to remain a light, flexible, and lethal force for the Nation. The Corps can make this shift by leveraging existing and future technology to electrify ground tactical vehicles.
Notes


17 Note to reader: Vehicles that incorporate lighter metals and advanced designs would certainly benefit the survivability of the force and enhance tactical mobility, whether powered by electricity or internal combustion engines. However, that topic is beyond the scope of this essay.


20 MCDP 1, 41.

21 MCDP 1, 65.
Bibliography


