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*United States Marine Corps
School of Advanced Warfighting
Marine Corps University
3070 Moreell Avenue
Marine Corps Combat Development Command
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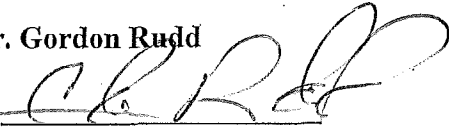
Bringing a Tesla to War: Military Applications of Electric Vehicle Technology

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

***Major Brian J. Donlon,
United States Marine Corps***

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Mentor: Dr. Gordon Rudd

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April 2030- A United States peer competitor seizes a large archipelago from a weaker nation and threatens commercial sea lanes. The international community condemns the aggression and a joint force is assembled to retake the islands and deter further hostile acts. The 3rd Marine Expeditionary Brigade (MEB), as the amphibious component of this force, is ordered to seize a lodgment to destroy key enemy defenses and allow follow-on deployment of a larger coalition force.

The enemy, possessing robust land, sea and air assets, and advanced Anti-Access/Area Denial (A2AD) technology, credibly contests control of the air and sea. Enemy propaganda claims that an “iron-bottomed sound” will be made with ships that linger offshore. Though confident that their forces can penetrate the enemy defenses, the Joint Force Air and Maritime Component Commanders are both concerned about how long an Amphibious Objective Area can be maintained. The MEB must land quickly and be ready to self-sustain until the enemy is eliminated. Because the archipelago is within range of enemy mainland-based aircraft and ballistic missiles, once ashore, the MEB’s “tail” must maintain a reduced signature, especially in fuel distribution and consumption.

Fortunately, the MEB has been optimized to fight effectively in this environment. The MEB is prepared to fight austere. Command and control nodes are energy efficient, to include portable solar and wind power generation. Most importantly, the combat vehicles of the MEB, from tanks to medium trucks, use electric vehicle technology to significantly reduce their appetite for fuel. This capability allows the MEB to fight ashore without being dragged back to the beach by the “tether of fuel.”¹

With the support of the joint force, the MEB rapidly lands and establishes a lodgment. Logistics areas within the lodgment are kept well camouflaged and highly mobile. When Naval shipping departs, the MEB fights with what they have on hand, repelling counterattacks and systematically eliminating the enemy's A2AD threat.

Hybrid-electric light tactical vehicles are among the first elements out of the lodgment. Designed with an external high efficiency generator that "sips" fuel as it charges modular batteries, the vehicle possesses neither a mechanical transmission nor an exhaust, instead using individual electric motors in each wheel. As a result of this design flexibility, the light tactical vehicle easily incorporates ballistic protection, mine and IED survivability, and a low thermal signature. Hard to find and hard to kill, they can outpace an enemy relying on traditional logistics.

As the hybrid-electric light tactical vehicles make contact with pockets of stronger enemy resistance, the hybrid-electric main battle tanks come forward to support the infantry assault. Though this main battle tank possesses the same jet turbines as the venerable Abrams tank, they have been enhanced with powerful electric motors and banks of batteries. When idling or at low speed, the tank is electrically powered to conserve fuel. Energy reclamation systems transfer jet engine inefficiencies to charge banks of batteries. Because electric motors possess their highest torque at start-up, when these tanks start to move they are hard to hit, accelerating like a race car from a dead stop into a full sprint.

Supporting these attacks are battery-electric medium trucks. Benefitting from the same flexible engineering as the light tactical vehicle, these trucks are lightweight and aerodynamic. Powered only by batteries, they cycle between the logistics hubs and the battle area, using

minimal energy before rapidly recharging their supercapacitors at energy points. Efficiency in logistical delivery is this vehicle's hallmark.

The enemy struggles to respond. Dominated by friendly combat air patrols, they cannot impede the rapid landings. Where unmanned reconnaissance aircraft penetrate the air defense bubble, the reduced thermal signature of the vehicle fleet makes it difficult to find concentrated units. Unable to locate significant logistics areas in the lodgment, enemy aviation is stymied. With the United States Navy operating beyond the range of enemy sensors, anti-ship cruise and ballistic missiles on the archipelago and mainland are useless, unable to hinder the sea power supporting the MEB's deliberate reduction of enemy defenses. The logistics tail which enemy doctrine defined as the Joint Force's "Achilles' heel" in the "battle of signatures" has proven elusive, allowing the MEB to set conditions for decisive follow-on operations.

The vignette above presents possible implications of the military application of electric vehicle technology. Implicit in this discussion is the logistical challenge that expeditionary energy presents for the entire Joint Force but especially for the Marine Corps as the Nation's expeditionary force-in-readiness. The growing challenge of expeditionary energy consumption impacts fuel storage, distribution, and the vulnerability of bulk fuel to targeting. If Napoleon's Grand Armee "marched on its stomach," then today's Marine Corps "fights on its gas tank." Electric vehicle technology presents a possible answer to this challenge as the ongoing evolution of batteries, electric motors, and super-capacitors could provide a viable solution to the problem of fuel consumption.

Since World War II, requirements for fuel have outpaced those for other classes of supply. During Operation ANVIL in 1944, three US Army Infantry Divisions needed approximately 100,000 gallons of fuel a day to operate.² Of note, during this operation, the Allies had nearly unchallenged air supremacy and sea control, allowing massed Liberty ships to anchor unmolested. In comparison to this historical example, a 2015 Naval Postgraduate School study estimated that during a 24 hour period of high intensity combat, a single Regimental Combat Team demanded almost 49,000 gallons of fuel.³ Similarly, a Naval War College assessment indicates that a reinforced detachment of F-35B Lighting IIs, operating from mobile forward arming and refueling points and seabases, would require between 544 and 1,337 tons of fuel ashore a day.⁴ To supply this quantity would require the commitment of nearly the entirety of a MEB's assault support detachment. These examples both point to the questionable sustainability of the current model for fuel supply. This dilemma is further emphasized by the estimate that a MEB, doctrinally advertised to self-sustain for 30 days, will actually run out of fuel after only 7 days of forcible entry operations.⁵ With the increased fuel appetite of emerging technology and new aviation platforms, this hunger for fossil fuels will only deepen, with a direct impact on the true operational reach of the Marine Air Ground Task Force (MAGTF).⁶

This worrisome disparity appears even starker when compared to another class of supply, ammunition. Since World War II, precision guided munitions have improved the accuracy of aviation strikes by a factor of greater than 20:1, with a corresponding reduction in the demand for sorties and tonnage.⁷ Yet, while fires have become "smarter," fuel consumption has remained as "dumb" as ever with no similar method to ensure the "precision" consumption of fuel. As a result, a 21st century fuel farm looks not much unlike its 1944 ancestor.

Simultaneously, the operating environment has become less permissive. While history shows that even the most formidable logistical challenges can be overcome, for example, Guadalcanal and the Falklands, the recent emergence of unmanned vehicles, long range missiles, and irregular tactics could make air superiority and force protection increasingly difficult to achieve and maintain. Sophisticated anti-ship cruise and ballistic missiles, such as the Chinese DF-21, threaten shipping, especially in restricted sea space.⁸ Proliferation of similar capabilities has expanded to non-state actors such as Hezbollah and the Houthis of Yemen, both of whom sit astride major commercial routes.⁹ The Houthis have taken a further step with the recent use of a drone boat.¹⁰ The Islamic State of Iraq and Syria (ISIS) has weaponized commercial drones and proven capable of dropping explosives with pinpoint accuracy into a target as small as an open tank hatch.¹¹ If the attack on Camp Bastion in 2012 teaches anything, it is that a determined adversary will eventually find a way to strike soft targets. In the face of such growing threats, as the 2016 *Marine Operating Concept* states, “iron mountains of supply and lakes of liquid fuel” are no longer viable, presenting too lucrative a target for an adaptive enemy.¹² This dilemma of protecting and distributing bulk fuel only intensifies against an integrated A2AD threat, where the ability of Naval shipping to provide long duration logistics across the beach can no longer be taken for granted.

While these threats can be partially mitigated with fifth-generation fighter aircraft, Aegis missile defense, and air defense artillery, there is a direct correlation between the challenge of protecting logistics hubs and the signature their size provides to enemy targeting. While fuel consumption can never be completely eliminated, improved efficiency could reduce demand and lower risk to the Joint Force. Since a dramatic technological revolution in the design of jet and rotary wing aircraft is highly unlikely, it is safe to assume that unless current aircraft are rapidly

transitioned to unmanned platforms, the MAGTF's Air Combat Element (ACE) will continue its high fuel intake. Therefore, the Ground Combat Element (GCE) and Logistics Combat Element (LCE) are the best candidates to reduce fuel usage through a more energy efficient vehicle fleet that requires much smaller gas tanks or perhaps, no gas tank at all.

Electric vehicles fall in two main classes: hybrid-electric and battery-electric vehicles. Hybrid-electric vehicles, with the Toyota Prius the best-known model, have parallel propulsion systems for both electrical power and fossil fuels.¹³ A variant of these vehicles, known as plug-in hybrid-electric vehicles, can also charge using external power sources. Not all hybrid-electric vehicles are high-efficiency commuter cars. Of note, current Formula One cars are hybrid-electric, combining fuel efficiency with powerful electric motors and energy regeneration from brake systems to produce a race car that burns less fuel, swiftly accelerates out of turns and efficiently reclaims energy for use in the next straightaway.¹⁴ At first glance, the flexibility of parallel power sources and drive trains makes it logically the most practical for military application. However, beyond the example of Formula One race cars, most vehicles of this class are handicapped by the weight of their redundant systems, demanding precise engineering to muster even moderate handling.¹⁵

In contrast to traditional hybrid-electric vehicles, battery-electric vehicles use only electric propulsion from power stored in batteries. All battery-electric vehicles use plug-in technology to recharge. This class, led most famously by the Tesla line, continues to improve in recharge time and range, with handling that can offer sports car level performance. These improvements are the fruit of successful research and development in battery and electric motor design. Additionally, lacking an exhaust, mechanical drive train, and transmission, the battery-electric vehicle can be designed from the battery up, an engineer's dream when seeking high

performance. Unfortunately, the battery-electric vehicle class possesses a critical constraint, namely that it depends on external power to charge batteries, limiting self-sustainability. Despite this limitation, some defense studies consider battery-electric vehicles the technology of choice to revolutionize future vehicle design.¹⁶

The only exception to the primary electric vehicle classes are vehicles similar to the hybrid-electric Chevrolet Volt. As with other hybrids, the Volt combines fossil fuel power generation with electric batteries. However, while the typical parallel hybrid-electric vehicle possesses redundant propulsion systems, the Volt is unique in that it possesses only a single, or series, propulsion system. The batteries of this system are charged by an internal generator operating at peak efficiency, thus combining the power generation advantages of the internal combustion engine with the superior energy conversion capabilities of batteries and electric motors.¹⁷ Conceptually, this design is the same as a modern diesel electric locomotive. Vehicles like the Volt capitalize on the advantages of both classes, marrying the open design of the battery-electric vehicle with the ability of the hybrid-electric vehicle to make its own power using fossil fuels. This sub-class of hybrid-electric vehicles may provide one of the best models for incorporation in future combat vehicles.¹⁸

Enthusiasm for the military application of electric vehicle technology is not new. The Marine Corps has experimented with both major classes of electric vehicles.¹⁹ The defense industry continues to conduct ongoing experimentation with electric vehicles.²⁰ Some defense studies have even suggested that electric vehicle technology could revolutionize future combat vehicle design.²¹ Though challenges of battery degradation, fire hazard and cost, supercapacitor size and the expense of high end electric motors remain daunting, the potential impact of electric vehicle technology on expeditionary energy warrants more extensive study.

The current state of electric vehicles and associated technologies gives cause for optimism regarding its military application. Over the last several decades, market forces of high fuel cost, improved battery and electric motor design, and falling costs of mass production have increased the number of electric vehicles on the road.²² Research in battery chemistries has produced new lithium-ion designs, particularly those containing manganese and titanium, which promise improved performance in power, energy, longevity, safety, and cost.²³ Supercapacitors, a combination of battery and capacitor technology which allows the rapid storage and release of energy, also show promise for electric vehicles, enabling a vehicle to charge or release energy in microseconds.²⁴ Nanotechnology-based solar paint can add to energy regeneration, making every visible inch of a surface capable of energy production.²⁵ Similarly, portable wind turbines can provide further efficiencies for vehicles while static. Large corporations, to include commercial giant Walmart, have begun to modernize their trucking fleet, incorporating aerodynamic design and lightweight materials to improve fuel efficiency.²⁶ Active protection systems and machine-man teaming also offer further complementary means to sharpen the teeth of future combat vehicles while reducing the vulnerability of the tail.²⁷

Based on these advances, there is a foreseeable tipping point, perhaps as close as 10-15 years in the future, in which electric vehicle technology could rival in weight and volume the energy density of fossil fuels.²⁸ This can be illustrated in simple terms. If a current 85 kilowatt hour Tesla battery weighs approximately 1200 lbs. with a maximum range of 265 miles, then a future battery with half the weight and size, with a range of 500 miles, could effectively compete, pound for pound, with liquid fuel. The main differences would be the rechargeable nature of the batteries, the superior storage and conversion of energy, and the overall decrease in bulk fuel logistics. In such circumstances, emerging electric vehicle technology could have an

impact comparable to the tactical innovations of Napoleon or Sherman cutting free from logistics trains, or the technical applications of Guderian or Rommel fearlessly surging mechanized forces deep into their opponent's rear. Electric vehicle technology could shatter current rates of movement and expeditionary logistics requirements, providing a powerful asymmetry to the side that best employed the technology.

With such innovation, vehicles could be designed from the battery up with hybrid-electric or battery-electric designs, suitably configured to meet the demands of more fuel efficient main battle tanks, light tactical vehicles or medium trucks. Each could be designed to optimize energy consumption. Firepower, mobility, survivability, and utility could be incorporated to a degree appropriate to the respective vehicle class, replacing vehicles such as the M1 Abrams Main Battle Tank, Light Armored Vehicle (LAV), High Mobility Multipurpose Wheeled Vehicle (HMMWV) or Medium Truck Vehicle Replacement (MTVR) "Seven Ton," with electric variants equally lethal but more efficient.

As a modern Main Battle Tank is both heavy and fast, designing an electric-vehicle variant presents a difficult engineering challenge. While a battery-electric variant is likely impractical in the next fifteen years, a hybrid-electric version could improve fuel efficiency while still maintaining comparable performance metrics. This vehicle, a hybrid-electric Main Battle Tank, would use an internal-combustion engine as the prime mover. Banks of batteries and a high-torque electric motor could allow the tank to use electric power while at low speed or while idling. Supercapacitors, paired with electric motors, could rapidly accelerate the tank forward in the same manner as a hybrid-electric Formula One car, limiting the amount of fuel used to transition the tank into a sprint. Solar paint on the armor could help charge electric

systems. Such a vehicle could achieve markedly improved fuel efficiency and perhaps even improved overall capability.

Lighter multi-role vehicles, such as the LAV, HMMWV, and Mine-Resistant Ambush Protected (MRAP) and MRAP All-Terrain Vehicle (MATV) families, are more fertile ground for electric vehicle technology. An electric vehicle designed to replace the diverse roles these vehicles perform, ranging from reconnaissance and fire support to small unit logistics and transport, would need long cruising range, efficiency at all RPMs, the power to handle varying loads based on armor and armaments, and a low signature. A hybrid-electric multipurpose light tactical vehicle could use a design similar to the series hybrid design of the Chevrolet Volt, with a highly efficient internal combustion engine powering banks of batteries and supercapacitors. This would provide the vehicle an open design, allowing for four or six wheeled variants with space for additional troops, cargo or heavier armor and armaments. Motors located in each wheel could improve mobility over rough terrain, reduce the chance of a mobility kill in combat, and allow for the quick replacement of a damaged motor or wheel as a single "leg." Supercapacitors could support rapid recharge while regenerative braking and solar paint could further enhance energy efficiency. While in loiter mode, the vehicle would use only battery power, reducing audible and thermal signature. Because of the lower suspension afforded by the individual motors, the vehicle would also feature a reduced silhouette.²⁹ Once in contact, the high torque of the electric motors would provide split-second acceleration. Flexibly designed and able to operate with reduced logistics, a light tactical vehicle using electric vehicle technology could provide long duration persistent support to dismounted elements.

With the exception of Tank and Light Armored Vehicle battalions, no other element in the GCE or LCE demands as much fuel as the rolling stock contained in logistics units.³⁰ As a

result, an electric vehicle replacement for the MTVR could have a significant impact on fuel consumption in the MAGTF. Such a vehicle would have to equal the MTVR's durability, payload, independent suspension and all terrain capability. Keeping in mind these design requirements and in anticipation of frequent movement between logistics hubs in rear areas, engineers could base an MTVR replacement on the battery-electric class of vehicles, with strong electric motors and banks of batteries capable of an extended logistics road march. On travel to more austere locations, a flatbed-mounted high efficiency generator could charge batteries using fossil fuels in much the same manner as the design of the hybrid-electric multipurpose light tactical vehicle. The independent suspension of the current MTVR could be mimicked with wheel mounted motors, with the same benefits imagined in the hybrid electric light tactical vehicle. The absence of an engine and transmission would allow for greater design flexibility. This could result in improved crew survivability or vehicle configurations that allow cargo storage forward of the crew. Machine-man teaming could further improve efficiency, as predictable logistics routes could allow the use of an unmanned chase vehicle that would require neither armor for crew survivability nor possess the drawbacks of a conventional trailer. Aerodynamic design and lighter materials, especially in the unmanned cargo bed of the vehicle, could reduce vehicle drag and weight, with further improvements in vehicle efficiency on improved surfaces. Ultimately the goal of an electric medium truck would be to field a vehicle that consumed less energy than it delivered.

Adjunct to the consideration of electric vehicle variants is the utility of developing a standard family of batteries shared by all classes of vehicles. All vehicles should possess a common open infrastructure to allow the rapid installation or removal of battery cells. As battery technology improves in efficiency and power, upgrades could then be simultaneously made to all

combat vehicles in the MAGTF. If possible, military batteries should be based on civilian designs, allowing the use of commercial-of-the-shelf technology for development and, when required, rapid purchase. In combat, batteries could be exchanged between vehicles or transported by any vehicle with the space and payload. Such batteries would be designed in components small and light enough to be handled by a one or two-man lift. This would allow supply of forward units via air drop or assault support. These components could then be rapidly installed in vehicles. Such batteries would still require external power generation to gain a charge, however, unlike fossil fuel, once expended they would still be available for recharge and reuse.

Tactically, all three of these hypothetical EV families could be fought in the same manner as current mechanized and motorized assets. The key difference would be their extended range and reduced sustainment requirements. This could translate into more advanced tactics for breakthrough battle. Such tactics could capitalize on the ability of the MAGTF to project combat power deep into a contested area with a lightened logistics tail. These tactics could be married with the improved capability inherent in the V-22. Future GCEs could operate not at the limits of the "tether" of fuel supply but rather at the edge of the V-22's range. This would have the greatest impact in the A2AD environment, where electric vehicle technology could allow the MAGTF to operate distributed with a reduced, and thereby less targetable, force signature.

While employing such vehicles to attack deep with limited sustainment is exciting to consider in terms of maneuver, the greatest impact would lie in logistics. Though a transition to electric vehicle technology would not completely eliminate energy demand, it could transition energy usage to a medium and scope better able to operate within enemy threat rings. Existing concepts of logistical support may have to be modified to support electrical power generation

and distribution. This may also require new Military Occupational Specialties as Bulk Fuel Marines become “Energy Production and Distribution Marines” with new, likely more technology-intensive, training and skills. The Single Battle Concept is a useful model to visualize this new energy logistics dynamic.

In the rear, expeditionary energy hubs would provide power generation from a variety of sources and storage using compact modular batteries and supercapacitors. As with current fuel farms or ammunition supply points, these facilities would remain static for long periods. Well defended nuclear Small, Sealed, Transportable Autonomous Reactors (SSTAR) could provide nearly limitless power. Solar panels and windmills could be erected to collect renewable energy. Finally, to ensure energy efficiency, a Vehicle to Grid (V2G) system could be established where unused energy could be transferred from vehicles back to the power grid or into other vehicles.

Further forward, in the close fight, energy distribution would need to be more mobile. Energy farms, designed to support a specific-sized friendly unit would be capable of power generation from fossil fuel generators or rapidly assembled solar panels and wind turbines. As a unit advanced, it could pause to top off its charge. Forward of these positions, a land-based imitation of the German Type XIV “Milk Cow” U-Boat concept could be used. Instead of a U-Boat coming alongside at sea to resupply fuel and torpedoes, a medium truck with a flatbed-mounted high efficiency power generator and charging station could allow vehicles to recharge in-stride. Once again, V2G systems could be incorporated into all vehicles so that during periods of inactivity, energy could be shared.

In the deep fight, mobility and stealth would be critical. Here, the metrics of operating hours and redundancy of power source would be critical. Vehicles could have the ability to

harvest energy from the enemy's power grid or fossil fuels. V2G sharing, rapidly assembled solar and wind farms, and aerial resupply of portable batteries could further complement vehicle energy efficiency. Ultimately, the key condition any concept of sustainment - deep, close or rear - will have to meet is whether it improves overall operational reach of the MAGTF, outperforming the sluggardly, predictable, and easily targetable pace of current fuel farms and the logistics over the beach that sustain them.

Programmatically, electric vehicle technology presents a significant challenge as initial costs could be high and results uncertain. However, while military interest in this emerging technology is driven by operational necessity, there is also growing civilian concern for the issue of climate change. According to a 2016 Gallup poll, approximately 64% of Americans are concerned about global warming. As a result, there may exist bipartisan political appeal for designing combat vehicles that are more fuel efficient.³¹ Accurate evaluation of the fully burdened cost of energy, that is the anticipated energy expenses for the lifespan of the vehicle, could reinforce such environmental concerns with budgetary frugality. Properly managed, resulting political support could translate into research and development funds for an improved combat vehicle fleet.

With budgetary backing, a practical methodology for testing and fielding could be employed to achieve military application. The goal would be to inspire innovation in both traditional defense firms and electric vehicle industry companies who don't typically interact with the military market. A Defense Advanced Research Projects Agency competition could minimize upfront expense to the Marine Corps budget. After an initial test of all prototypes, the best entries would undergo further competitive field testing. At a minimum, this process could produce unanticipated technology to benefit existing systems.

As prototypes are refined, they could be sourced forward as early as possible for testing by actual units. This deck plate level approach would avoid the regression witnessed in past acquisitions, such as the F-35B Lightning II's targeting pod, where the platform meets the warfighter and is found lacking, with expensive and counterproductive redesign to follow.³² To avoid similar mistakes and begin development of tactics, intermediate vehicle prototypes could be sourced with an open architecture of common frames and modular batteries so that more advanced technology could be added later. Commonality with existing successful hull designs such as the MRAP family could also mitigate cost and ease transition to the Operating Forces.

Finally, the entire process should be guided by key performance parameters that are energy-friendly. Evaluated criteria for a military electric vehicle should include range, operating hours, loitering, battery degradation, reliance on fossil fuels, recharge time, survivability, weight, and maintenance hours. However, pursuing too perfect a vehicle, such as the failed Expeditionary Fighting Vehicle, could prove prohibitively expensive and excessively delayed. Clarity, balance and prioritization will be critical, with energy efficiency at the forefront. Regardless of other capabilities, if an electric vehicle fails to improve overall fuel consumption then it may not justify the price of research, development and fielding.

A means for accurately and cheaply forecasting the impact of a future electric combat vehicle exists in the MAGTF Power and Energy Model (MPEM), a computer program designed to calculate fuel and energy consumption over time.³³ MPEM can measure the effect of improvements to the characteristics of simulated vehicles and units operating in hypothetical combat situations. Using this system, developers could determine the optimal energy efficiency to maximize operational reach and minimize logistical demand. Metrics devised from this

software could be used both to evaluate prototype suitability and to establish goals for energy efficiency in future systems.

As imagined above, electric vehicle technology presents both risk and benefit. Up front technological cost could be high. Electric vehicles will not produce a logistical miracle as the MAGTF will retain some dependence on conventional fuels. This leads to the clear risk that the investment in capital may not produce tangible benefits worth the expense. If, however, improvements in electric technology proceed on the anticipated pace, the aforementioned inflection point could occur. If this is reached, and the deployable cost of electric vehicle technology is comparable to or exceeds traditional vehicle design, this energy efficiency could lead to greater extended operational reach.

Of course, the United States military is not alone in its hunger for fuel. Nor is electric vehicle innovation unique to Silicon Valley. China has become the largest and fastest growing vehicle market on the globe, with pollution and limited energy resources driving extensive research in electric vehicles.³⁴ Russia has also recently increased its research in electric vehicle technology.³⁵ Electric vehicle research for either nation could overlap into military spheres. Just as the Marine Corps might use electric vehicles to gain an advantage, an adversary with significantly reduced logistical needs could limit the ability of the Joint Force to bring its traditionally superior firepower to bear. Ultimately, inadequate research in electric vehicle technology could result in a failure to maintain or surpass the pace of possible adversaries.

In conclusion, without changes to equipment or doctrine, the Joint Force's current appetite for fuel in a contested expeditionary environment will likely prove unsustainable, a risk both to mission and force when facing capable adversaries. Conventional logistics are too easily

targeted and our way of war is too predictable. Operations which imitate the massive and gradual build-up of Desert Shield could face significant challenges from a capable 21st century opponent. This situation will likely grow worse with the emergence of energy hungry aviation platforms such as the F-35 and V-22, and new technologies such as cyber, robotics, and advanced command and control, each with price tags measured both in dollars and kilowatt hours. Ongoing technological advances in the field suggest that electric vehicles could mitigate such challenges over the next 10-15 years, improving fuel efficiency and changing the way an expeditionary force fights. In the race between the United States and its aggressive and ever more capable peer competitors, the Joint Force should take steps to integrate emerging electric vehicle technology into future combat systems, building an expeditionary force-in-readiness that can stay "one car length ahead of the enemy," moving farther and faster with a smaller footprint.

Endnotes

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