White Paper - Electrification of U.S. Army Ground Force (An Evolutionary Revolution)

Introduction

As the World changes, so must the Army change how it fights. Electric powered vehicles offer the potential to double ground force operational reach, increase performance, and reduce the Army's logistics burden by half if electrification technology is fully implemented.[i] Leading automotive manufacturers are evolving from internal combustion engine power to electric power for future vehicles. Tesla has attracted significant attention across the automotive industry in part by breaking the stereotype for electric vehicles. Their offerings are sleek, practical, powerful, and affordable. The automotive industry is undergoing dramatic transformation as the overall global demand for electric vehicles has grown at a rate of 60 percent per year over the last four years.[ii] Ominously, China has taken a leading role in this transformation. The rapid and widespread adaptation of vehicle electrification, from Hybrid-Electric (HE) to All-Electric (AE) vehicles, has begun to alter the automotive landscape from passenger cars, to heavy transport and construction platforms, to how we sustain and maintain. Across the globe, this movement has overturned century old wisdom about internal combustion powered vehicles. The very concept of what constitutes a vehicle has changed. Electrification has transformed vehicles into sensor platforms, communication nodes, and mobile computational hubs. From their design and construction, to the strategic materials and resources required, to the supply chain changes that support this revolution, they have begun to reshape the environment around us. The most significant of these changes is ground transportation energy. Unlike impractical electric vehicles of the past, just hoping to emulate their petroleum powered brethren, the emerging breed of electric powered vehicles are disrupting and transforming the energy logistics of ground transportation. As the Army prepares for the future, now is the time to increase the investment in and electrification of Army tactical vehicles - the first priority - and combat vehicles, the greatest challenge.

This paper presents a brief discussion on how electric powered vehicles can be an important enabler to ensure the United States Army continues to be the world's premier ground combat force, articulating a business and operational case for how they can best provide decisive capabilities on the future battlefield. Further, this paper discusses the feasibility of future electrification from tactical and combat vehicles to a transition of the enterprise supply chain and distribution. The paper then presents a potential transition strategy stressing practicality and the need to consider electric powered vehicles as a major component of transportation energy logistics, rather than simply the consumer. The purpose of this paper is to present a call for capability development of electrified platforms and initiate momentum towards increased investment now. As part of this initiative, the Army will need to conduct vehicle electrification studies and experimentation. These studies would need to examine electrification as a whole. These would include the electric vehicles, electric power generation systems and electric distribution networks. These studies would then be used to assess and gain the greatest advantage from electrified vehicles, by informing future concepts and operations. The Army Modernization Enterprise should increase investments in modeling, simulation, and prototyping for electrified vehicles.

Business Case

This paper defines electrification as the use of electrical power for the primary operation of automotive drivetrains, auxiliary systems, turret motors/drives, and other mechanical subsystems. In this regard, electricity, either supplied by a battery, capacitor, auxiliary engine, or some other means of electricity production, becomes the prime power source for military ground tactical and combat vehicles. Electrification covers a range of applications from the introduction of high power architectures combined with Internal Combustion Engines (ICE) to total electric vehicles. To maintain focus, the scope of this paper is on the conversion or replacement of portions of the Army's petroleum powered ground vehicle fleet with electric powered propulsion systems, either HE or AE.

In the coming decades, electric powered vehicles will provide reliable, agile, and independent maneuver from the Strategic Support Area to the Deep Maneuver Area. Electric powered vehicles will do this by overcoming the energy logistics challenges of the future battlefield, while providing increased reliability, agility, stealth, efficiency and effectiveness.

Electric powered vehicles provide a means to address two pressing challenges on the future battlefield, ***energy logistics,*** and ***formation endurance***. Today, near-peer adversaries will contest us in all operational domains, land, sea, air, space, and cyberspace. The future operational environment will be a complex, contested, and expanded battlespace characterized by persistent sensors, weapons of increased range and lethality, with the integrated employment of political, social, and economic tools used to create strategic and tactical vulnerabilities and opportunities. Adversaries will threaten and disrupt the ability of Joint Forces to stage, deploy, and deliver capabilities and sustain operations by using multiple and overlapping layers of Anti-Access/Area Denial (A2/AD) systems. The Army Futures Command and the Joint Force are answering these challenges with new operational concepts - the Army's Multi-Domain Operations (MDO) concept and Joint All Domain Operations (JADO) concept. Key tenets of the MDO concept are calibrated force posture, multi-domain formations, and convergence; inherent in these tenets is the conduct of dispersed operations with the ability to operate independently. These operational tenets require the energy independence that electrification promises.

A traditional vulnerability of forward deployed ground forces over the last century is their reliance on liquid petroleum fuels. Petroleum fuel is essential for movement and maneuver today, and powers all manner of weapons, information, and communication systems. Ground force combat effectiveness and endurance are defined by the amount of fuel they can carry or get access to and the efficiency of its use. Without fuel and mobility, no decisive actions occur. Throughout modern history, adversaries have consistently recognized this weakness and predictably attacked refineries, pipelines, and fuel convoys. During recent conflicts in the Middle East, fuel convoys have been under continuous attack, and account for more than half of all US casualties.[iii]

> Energy has always been a source of vulnerability for the Army. One of many instances where energy created a crisis occurred in the summer and fall of 1944 when the lack of gasoline caused General Patton to halt the advance of his Third Army which led some historians' to wonder if this may have delayed the end of World War II.
>
> http://www.historyisnowmagazine.com/blog/2015/8/12/the-red-ball-express-the-unknown-link-in-winning-world-war-two by Greg Bailey
>
> Further reading: The United States Army in World War II, Logistical Support of the Armies, by Roland G. Ruppenthal

The expansion of the battlespace and the employment of A2/AD systems will continue to exacerbate already difficult fuel distribution challenges. Access to oil will continue to be a source of friction and political leverage throughout the world. Adversaries will attack petroleum fuel logistics across the entire energy enterprise, from well-heads and refineries (both at home and abroad) to fuel depots and convoys in a theater of operations. These attacks will be concerted and protracted. Social, political, and economic tools will be used to create doubt and separation between the U.S. and its energy partners. Cyber tools and direct military forces will be used to coerce, seize, and/or attack the petroleum fuels infrastructure. All of this will be done in an effort to diminish the capabilities of ground forces reliant on petroleum fuels. In the future, similar attacks by near peer adversaries will make it improbable that petroleum fuels (and other sustainment resources) can be reliably delivered during protracted conflicts.

> The Army must drive fundamental demand reduction across the force. This transformational change will take time as well as a whole Army approach to reshape areas such as energy and power. The operational benefits of demand reduction include extended operational reach; improved platform and device energy efficiency and endurance; reduced mission risk; and less dependence on logistics overhead.
>
> Citation: Army Tactical Wheeled Vehicle Framework, 2019

In recognition of this challenge the Army has focused on increasing the endurance and ability of ground forces to operate independently. In fact, the U.S. Army Maneuver Center of Excellence's Movement and Maneuver Functional Concept sets as a goal for a MDO capable Brigade Combat Team (BCT) to operate up to seven days independently without resupply.[iv] Solving for this ambitious goal includes improving fuel efficiency, effectiveness of use, and overall demand reduction. But these improvements can only achieve a marginal advance on this issue. Electric powered vehicles coupled with organic power generation and energy management will be key to meeting these endurance objectives.

Fielding electric powered vehicles, in concert with organic persistent power generation capabilities, provides several distinct advantages over existing petroleum fuel systems. The most prominent of these advantages is the dramatic increase in the amount of time units can sustain operations without external logistical support. An initial projection from the U.S. Army Sustainment Capabilities Development Integration Directorate identified electrification of Tactical Wheeled Vehicles (TWV) could reduce fuel demand by almost 50 percent.

The use of electric powered vehicles provides a means for vehicles to be either partially or completely 'refueled' using power generation systems organic to deployed forces. This *localization* of energy logistics, not without its challenges, substantially decouples ground forces from logistic vulnerabilities in the strategic and operational theaters. It dramatically increases unit independence and endurance, while acting as a strategic deterrent. The transition from strategic to tactically focused energy logistics tends to negate the effectiveness of strategic A2/AD systems by removing large strategic energy targets, while increasing the operational energy resilience. This increased resilience results from the ability to deliver electric energy through a wider number of sources, including host nation infrastructure and prepositioned power-nodes recharged by a variety of renewable or alternative energy systems.

Electric powered tactical and combat vehicles have significantly fewer moving parts and will be inherently more reliable than those with traditional drivetrains powered by internal combustion engines (ICE). The reduced number of moving parts is the result of electric vehicles that do not need complicated transmissions and lubrication systems, or fuel distribution and air management systems. This simplicity greatly reduces the number of moving and essential parts. As a broad estimate, an electric vehicle may have as few as 20 moving parts in the drivetrain, while a comparable ICE (commercially available light duty) vehicle may have as many as 2,000 moving parts.[v] The significant reduction in moving parts and use of more modular components (computers, displays, batteries) will have a pronounced effect on electric vehicle reliability and the logistics chain needed to support them. If, for example, a deployed tactical AE vehicle has 100 consumable or failure prone parts, while its traditional ICE counterpart has 1000 comparable parts, the logistic package (LOGPAC) that supports the AE vehicle could be reduced by up to 90 percent.[vi] This reduction in LOGPAC size to forward units decreases the tactical and operational risk to the logistical supply chain. The effect of increased reliability generates reductions in logistical support demands. Increased reliability directly translates into fewer maintenance man-hours, less cargo space needed to carry spare and repair parts, smaller logistic support areas, and more combat systems available at any given time. All these benefits will allow our formations to operate longer, faster, and degrades the enemy's ability to target them leading to improved survivability. These savings can also be repurposed into new combat capabilities within the Army's personnel and equipment capabilities.

In addition to extending operational endurance and vehicle readiness, electric powered vehicles can expand the lethality and effectiveness of ground forces. These vehicles have several distinct advantages over traditional ICE vehicles. These advantages arise from their electric drive motors and embedded electrical energy storage and distribution systems.

Electric powered vehicles are well known for their ability to instantly deliver high torque and rapid acceleration. A commercial example is the Tesla S P90D, a mass produced and mass marketed, four door all-wheel drive sedan, delivering 762 HP and 713 lb-ft of torque, and able to accelerate from 0 to 60 miles per hour in an astonishing 2.4 seconds.[vii] A comparable ICE vehicle, the Lexus 500 LS, has a similar price, weight, and all-wheel drive, delivering 416 HP, 442 lb-ft, and 0-60 mph in 4.6 seconds.[viii] Until the emergence of the modern electric vehicle, this type of performance was found only in exotic high performance vehicles, not production ICE sedans. On the battlefield, this type of performance can save lives and provide decisive lethality.

Studies completed by Army Futures Command (AFC) Ground Vehicle Systems Center (GVSC) over the past decade have shown that improving a vehicle's ability to sprint can improve vehicle and Soldier survivability, by reducing exposure time when vehicles move from cover. According to these studies, a five percent increase in a vehicle's acceleration can result in a 10 percent decrease in vehicle strikes.[ix] The employment of electric powered vehicles will provide this improved acceleration with subsequent increases in vehicle and Soldier survivability.

Further improving electric powered vehicle effectiveness and survivability is their potential for quiet operations. These vehicles can 'idle' or operate in a stationary overwatch position and/or move slowly with exceptional stealth. Electrification can reduce vehicle thermal signatures by a factor of ten (10:1 reduction), while reducing audible signatures by a factor of five (5:1

reduction).[x] On the future battlefield, this can be decisive in terms of survivability as well as lethality.

AFC GVSC already has a hybrid electric modification kit for the M977 Cargo Heavy Expanded Mobility Tactical Truck (HEMTT) as demonstrated in the Tactical Vehicle Electrification Kit (TVEK) study from November 2019. The study achieved operational fuel savings of 15-25 percent, with 56 percent reduced overall engine run time, and positive Return on Investment (ROI) in under 24 months. TVEK has twice the silent watch capability, triple the power generation capability, import/export power capability, and 600 volt Direct Current (DC) bus for future capability expansion.

In addition to these performance advantages, electric powered vehicles offer other benefits beyond traditional drivetrains. As the employment of electric powered vehicles continues to expand, it is likely their design and configuration will evolve. Previous Army investments in electrified propulsion were limited during the early 21st century by costs and the maturity of battery and power technologies. The use of hub motors or electric assist axles, and conformable batteries, will dramatically affect design considerations. By no longer designing a vehicle around heavy and bulky engines and transmissions, electric powered vehicles can alter: how and where equipment and personnel are distributed; their shape and profile; how they are armored, and how they are armed. Modular electronic and mechanical components with software control merged with remote diagnostics or updates will allow predictive maintenance not possible today. This allows them to be designed to better meet their ever growing roles as weapons and sensor systems, communication nodes, and computational hubs.

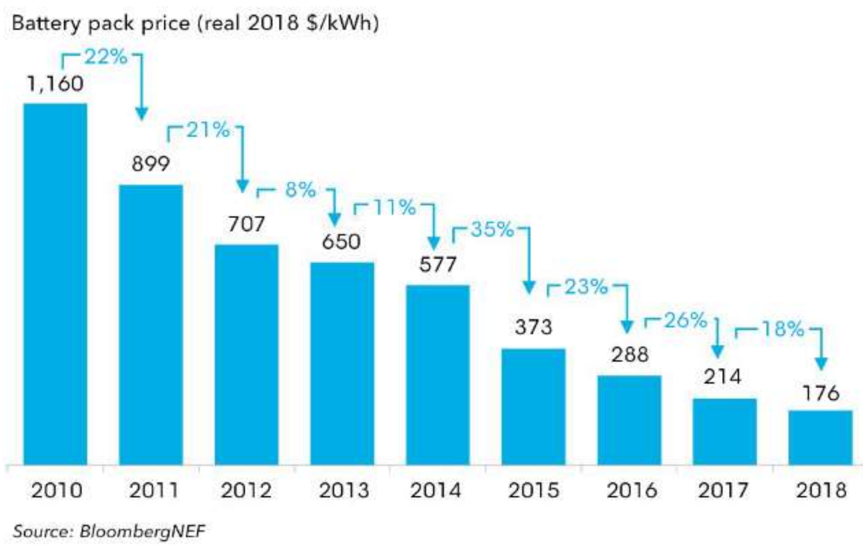
Feasibility

The electrification of vehicles has long been impractical for commercial use, and more importantly for military purposes. Over the last 20 years, commercial vehicle propulsion has expanded from pure internal combustion, through routine availability of hybrid electric vehicles to increasing availability of purely electric propulsion. Past battery technology, the core technology in electric powered vehicles, was expensive, heavy, and offered very limited operational range (on the order or 20-40 miles). However, over the last several decades, battery advancements, petroleum fuel costs, and social drivers have dramatically altered the cost and performance of electric powered vehicles. Investments in battery technology continues a long standing trend of improved performance at reduced costs. Similarly, innovations in electric motor drive systems and power electronics continues to improve vehicle reliability. As these trends continue, the case for electric powered Army tactical vehicles first, and then combat vehicles continues to grow.

While not central to this electric vehicle discussion, it is important to briefly address the issue of organic power generation and distribution. Similar to the rapid transformation that is taking place for vehicles, there is an ongoing revolution in the electric power generation and distribution industry. In response to many of the economic, social and technological pressures driving commercial vehicle electrification, the electric power industry is shifting to smaller, more distributed technologies and capabilities. They are employing concepts and technologies that lower costs, while providing increased agility, and resilience, by bringing power generation closer to the end-user. These technologies include, secure micro-grids, renewable power, battery storage systems; and on the near horizon small modular nuclear reactors. Through continued industry and defense partner investments, such as the Strategic Capabilities Office mobile nuclear reactor program, Program Pele, future deployed forces will have cost effective, organically generated power at scale.

Costs are a driving factor in establishing the feasibility of the Army adopting electric powered tactical and combat vehicles. Costs include, initial procurement costs, operational costs (the combination of fuel costs for traditional vehicles, and battery costs for electric powered vehicles), life-cycle costs (maintenance and disposal), and transition costs. As discussed previously, the life-cycle costs for electric vehicles are expected to continue a downward trend, while hybrid systems are approaching or are now considered cost neutral compared to traditional petroleum systems.[xi] Importantly, the cost for AE vehicles has decreased substantially over the last decade, while it is expected that future ICE vehicle costs will continue to rise with inflation and lower demand.

The decreased costs of AE vehicles has been primarily driven by the reduced cost of batteries. Batteries constitute a substantial portion of a vehicle's initial cost, as well as the long term cost. Over the last decade, battery costs have dropped annually, resulting in an overall reduction of 80 percent (see figure below).[xii] Following this trend, the tipping point where purchase cost and total ownership costs for AE vehicles becomes lower than ICE platforms is estimated to be in 2022 (only a year and a half away from publication of this paper). It is expected that these trends will be as applicable to Army combat vehicles, as they are to commercial vehicles.



Lithium-Ion Battery prices have dropped ~80% over the past seven years.

Operational range is another significant factor in establishing the feasibility of electric powered tactical and combat vehicles. It is clear that light vehicles are suitable for electrification. Many light-duty electric vehicles, such as passenger vehicles, already have ranges comparable to traditionally powered vehicles, typically several hundred miles.[xiii] The sale of over one million of these vehicles in 2018, demonstrates their viability.[xiv] However, this electrification is also occurring in medium and heavy vehicles.

Electrification is beginning for medium duty (3.5 to 15 tons) and heavy duty freight vehicles (greater than 15 tons). Initial demonstrations and trials for these vehicles have shown promise and corporate buyers of these medium and heavy duty electric powered vehicles include WalMart, FedEx, United Parcel Service (UPS), Amazon, and PepsiCo. The United States Postal Service (USPS) is investing $6 Billion to replace 140,000 vehicles (Grumman Long Life Vehicles) and some of this fleet may be HE/AE.[xv] In 2019, FedEx made the largest commercial AE vehicle buy to date of 1000 medium duty [6000lbs cargo capacity] fully electric trucks.[xvi] While these vehicles are primarily used in urban and/or suburban areas, their size and weight make them good analogs to understand the applicability of electrification for future combat vehicles. In terms of weight and operational range, the continued improvement in this area demonstrates that heavy, long ranged electric powered vehicles can compete with petroleum based ICE vehicles. More importantly, if USPS is investing $6 Billion into electrification and if FedEx has already sought to integrate 1,000 electric vehicles into its fleet, how can the Army justify – at a minimum – an absent strategy?

In addition to operational range, vehicle manufacturers are making more rugged electric powered vehicles. Today, automobile manufacturers are marketing electric powered 4x4 off-road sport utility vehicles, and large trucks are also pending deployment.[xvii] These developments indicate that future electric powered Army tactical and combat vehicles can achieve militarily relevant operational ranges and durability.

The GVSC TVEK, mentioned above, provides a power architecture that enables integration of electric powered warfighting capabilities (directed energy weapons, radar, high power jamming, communications, etc.), and provides a high voltage backbone supporting system upgrades for high power variants. This technology and ability to upgrade can be expanded across the Army's TWV fleet today. TVEK could very well be the technology that ignites the electrification of our TWV fleet and subsequently the combat vehicle fleet.

Another significant trend in vehicle electrification is the committed investment by established vehicle makers, including manufacturers that have long supported U.S. Army vehicle development and design. U.S. manufacturers such as Ford, GM, in tandem with foreign manufactures Mercedes, Audi, Toyota, and Nissan will be investing an estimated $90 Billion to develop and build electric powered vehicles over the next decade. Unfortunately, much of this investment will occur overseas.[xviii] These and other investments will drive future innovation and continue the trends in improved performance, while altering the sustainment of petroleum fueled vehicles.

By 2030, it is estimated that 130 million AE vehicles will be sold worldwide, accounting for 30 percent of all vehicle sales.[xix] Further estimates project that by 2050 greater than 80 percent of all new vehicles, will be AE.[xx] This will have profound impacts on the sustainment costs for electric powered vehicles as well as legacy petroleum systems. Electrified systems will be the market focus, while ICE systems will become niche markets. Continued improvements in ICE will be costly and borne by an increasingly smaller manufacturing base. If the Army does not transition to electric powered vehicles, it will find itself investing more in the development of its ICE systems.

Experimenting now with HE or AE light tactical vehicles is a critical step toward development of future force mobility. The Army must analyze validated operational scenarios with updated models and simulation and establish an internal systems integration organization for electrification. The Army is in the initial stage of fielding the Joint Light Tactical Vehicle (JLTV) and is looking for solutions to replace the High Mobility Multi-purpose Wheeled Vehicle (HMMWV) that JLTV does not. The ultra-light Infantry Squad Vehicle (ISV) is now a program of record and several prototypes were assessed during the recent demonstrations and Soldier Touch Points. An electric prototype representative of the ISV proved it could be whisper quiet, achieve sprint speed immediately, and offered excess power for extended silent watch mode exceeding current objectives. The prototype showed the promise of electric drive for military application is close at hand. The U.S. Army should consider this, and other Commercial Off-The-Shelf (COTS) or Non-Developmental Item (NDI) prototypes for experimentation or demonstration by Soldiers in an operational setting. This should determine if the electric light tactical vehicle is capable of performing at least as well as the HMMWV or JLTV. In many mobility areas, the electrification of light tactical vehicle powertrains could allow us to achieve the objective requirements for vehicles with similar missions and roles.

> Technology advancements will come from a healthy industrial base which can afford the ability to adapt and respond to changing or emerging Army TWV requirements. To achieve these technology advancements industry-developed vehicle technology must be leveraged. As well as monitoring to ensure the TWV fleet does not diverge from the commercial market such that the TWV fleet can no longer be sustained.
>
> Citation: Army Tactical Wheeled Vehicle Framework, 2019

The Army must leverage industry-developed vehicle technologies to achieve our mobility goals. The Army must monitor industrial development to ensure the TWV fleet does not diverge from the commercial market such that the fleet can no longer be sustained. The initial conversion of Army platforms from ICE should focus on lighter vehicles first, then medium/heavy vehicles, and finally tracked combat platforms. As the commercial markets become more and more AE vehicle focused, future sustainment of internal combustion powered systems for Army platforms will continue to see increased costs that may not be a sustainable burden for the Army compared to the lower costs for HE and AE vehicles.

Way Forward

To gain momentum, align resources, and integrate its efforts, the Army needs a coherent, common perspective of the opportunities inherent in electrification. As such, it must publish a holistic electrification transition strategy similar to the Army Power and Battery Strategy pending publication by Army Futures Command. This strategy would declare the Army's intent to pursue transition over the next 20 years to electric propulsion across Army's tactical and combat vehicle fleets to the degree feasible and suitable.[xxi] A separate publication is required relative to the Army Modernization Strategy (AMS) or the Annual Modernization Guidance (AMG) because electrification cuts across the enterprise and it entails, at the same time, both a holistic look at the supply chain (distinct from that of the last century) and a highly technical (yet uncertain) focused and linked foundation. The purpose of the electrification transition strategy is three-fold:

- To alert industry, Army leaders, DoD leaders, and national leaders that the Army is serious about eliminating reliance on fossil fuels and to seek assistance and support in the process.
- To establish a mark on the wall to drive capability development and materiel development communities to begin work immediately on transition activities.
- To ensure the enterprise moves forward in a coherent, unified manner.

> *"In 10 years, some of our brigade combat teams will be all-electric… that's a generational change. It's significant; and we're going to do it; and we're going to need industry's help. There's plenty of people who say we can't do it."*
>
> Mr. Donald Sando, Maneuver Center of Excellence - Deputy to the Commanding General, at AUSA Annual Meeting October 2017

This is not to say the Army has not been working to bring electrified vehicles to fruition. By building and publishing a coherent electrification strategy, the Army can harness development of the Light Reconnaissance Vehicle (LRV) to gain a successful foothold in the Army Tactical Wheeled Vehicle fleet. Army Futures Command is developing the LRV with the intent of propelling it with a hybrid-electric or all-electric power plant. This will carry Infantry Brigade Combat Team scouts in a mounted weapon platform, with light armor, higher mobility and range, and silent creep capabilities. Industry has already shown this is achievable and with further development, can produce a quality hybrid or all-electric platform quickly. Along with the LRV, Army Futures Command is proposing an Initial Capabilities Document (ICD) to cover the broad expanse of Tactical and Combat Vehicle-Electrification (TaCV-E). This document will be broad enough to cover light, medium, and heavy combat vehicles; both wheeled and tracked. Approval of the TaCV-E ICD will be a huge success for the AME and signaling to industry our desire to move away from the fossil fuel tether. Using these two nascent documents, coupled to a coherent electrification strategy, should propel the Army significantly further forward than by use of each individual document.

Beyond the strategy, there are four areas in which the Army can and must take action now.

1. The Army should begin to adjust systems, vehicle, and platform requirements across the enterprise to drive development and industry to consider electrification "objective" requirements to enable future transition. Writing the TaCV-E ICD, should help accomplish this, especially if it is broad enough to apply across the AME's capability development directorates.

2. The Army should decide to field a low density fleet of electric propulsion vehicles to a select unit (perhaps National Training Center (NTC) Observer/Coach-Trainers (OC-Ts) or opposing force (OPFOR) units; or a single Army National Guard Battalion) to obtain feedback from the field and to learn what we need to know about charging infrastructure, supply chain, operating costs, and other relevant military application of electric vehicles at the enterprise level. This data

can inform Army requirements and return on investment decisions needed for evolutionary electrification. Again, the LRV seems to be the perfect candidate for experimentation and R&D.

3. The Army should stand up either an Electrification Cross Functional Team (CFT) or a matrixed organization to develop the electrification transition strategy and to advise, monitor, manage the transition, study efforts, and perhaps even execute the transition. Capability Developers and Materiel Developers must be integrated and synchronized to efficiently electrify ground vehicles and sustainment. This team should also write and develop the TaCV-E ICD to ensure that capability can be used for the entire logistics chain from the vehicle back to resupply areas and depots.

4. In parallel with the activities described above, the Army should prepare for the fielding of persistent organic power capabilities. Systems, such as Program Pele described earlier in this paper, currently being developed by DoD, are disruptive technologies capable of dramatically altering operational energy logistics and theater capabilities. The Army should volunteer to perform a doctrine, organization, training, materiel, leader development, personnel, facilities, and policy (DOTMLPF-P) analysis, specifically for MNPP systems, to understand their full implications and inform Senior Army Leaders.

To close, the Army must act decisively now and seize upon the opportunities with LRV and TaCV-E. With the recent exponential maturation of battery storage and electric generation, the Army has an opportunity to seize and retain the initiative to lengthen operational reach in MDO. The Army needs to leverage the lead of the automotive industry and invest with them in the critical technologies that will free our maneuver force from the petroleum tether. The United States must not allow potential adversaries to first achieve the enormous strategic advantage in competition and in armed conflict gained by the increased freedom that becomes evident with electrification.

NOTES:

[i] David Eady et al. "Sustain the Mission Project Decision Support – Casualty Factors for Fuel and Water Resupply Convoys," 17 September 2009, Army Environmental Policy Institute, Arlington VA.

[ii] Patrick Hertzke, Nicolai Müller, Patrick Schaufuss, Stephanie Schenk, and Ting Wu, "Expanding electric-vehicle adoption despite early growing pains," McKinsey and Company, August 2019 https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/expanding-electric-vehicle-adoption-despite-early-growing-pains

[iii] James Conca, "U.S. Military Eyes Mini Nuclear Reactors to Reduce Convoy Casualties," Forbes, Mar 12, 2019, https://www.forbes.com/sites/jamesconca/2019/03/12/our-military-wants-small-nukes-to-reduce-convoy-casualties/#329cbe43ba2b; and "Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys", AEPI Final Technical Report, Sept 2009

[iv] TRADOC Pamphlet 525-3-6, THE U.S. ARMY FUNCTIONAL CONCEPT FOR MOVEMENT AND MANEUVER 2020-2040 pg 39, 24 February 2017

[v] Jeff McMahon, "More Electric Cars Mean Fewer Mechanical Jobs", Forbes, 30 May 2019 https://www.forbes.com/sites/jeffmcmahon/2019/05/30/more-electric-cars-fewer-manufacturing-jobs/#6ad250ff3378, "Conventional powertrains may have as many as 2,000 moving parts, Canis notes, while electric powertrains may have as few as 20." Patrick Hummel, Q-Series Reports, UBS Global Research, "USB Evidence Lab Electric Car Teardown-Disruption Ahead?", 18 May 2017, https://neo.ubs.com/shared/d1wkuDlEbYPjF/. Drive Electric Inc., "What is an EV?", https://driveelectric.org.nz/individuals/what-is-an-ev/, "only around 20 moving parts in an electric engine compared with 2000 in an ICE." Market Watch, https://www.marketwatch.com/story/10-things-that-make-the-tesla-a-great-car-2016-08-19, "17 moving parts in Tesla drivetrain vs about 200 in conventional ICE drivetrain."

[vi] Patrick Hummel, Q-Series Reports, UBS Global Research, "USB Evidence Lab Electric Car Teardown-Disruption Ahead?", 18 May 2017, https://neo.ubs.com/shared/d1wkuDlEbYPjF/.

[vii] Tesla, "Model S Performance", https://www.tesla.com/models

[viii] Lexus, "Model 500 LS Performance", https://www.lexus.com/models/LS/specifications/ls-500-awd#engine

[ix] Richard J Gerth, Robert Hart, "Impact of Combat Vehicle Weight on Combat Effectiveness and Operational Energy," U.S. Army Tank Automotive Research Development, and Engineering Center Detroit Arsenal, Warren Michigan 48397-5000, 31 August 2017

[x] Darin Kowalski, "GM Fuel Cell ZH2 Acoustic Evaluation May 2017," U.S. Army Tank Automotive Research Development, and Engineering Center Detroit Arsenal, Warren Michigan 48397-5000, Technical Report May 2017

[xi] Andrew Winston, "Inside UPS's Electric Vehicle Strategy", Harvard Business Review, March 29, 2018, https://hbr.org/2018/03/inside-upss-electric-vehicle-strategy?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+harvardbusiness+%28HBR.org%29

[xii] Logan Goldie-Scot, Head of Energy Storage, "A Behind the Scenes Take on Lithium-ion Battery Prices," March 5, 2019, Bloomberg NEF, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

[xiii] Nic Lutsey and Michael Nicholas, "Update On Electric Vehicle Costs In The United States Through 2030", The International Council on Clean Vehicles, WORKING PAPER 2019-06, pg 2, April 2, 2019, https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

[xiv] Amanda Myers, "4 U.S. Electric Vehicle Trends to Watch in 2019," US News and World Report, Jan 2, 2019, https://www.forbes.com/sites/energyinnovation/2019/01/02/4-u-s-electric-vehicle-trends-to-watch-in-2019/#630978315a3c

[xv] Postal Updates, "USPS plans for new mail delivery trucks to replace aging fleet", Jan 12 2020, (Next Generation Delivery Vehicles) planning for orders by Summer 2020, https://www.linns.com/news/us-stamps-postal-history/usps-plans-for-new-mail-delivery-trucks-to-replace-aging-fleet

[xvi] Seth Skydel, "FedEx makes the largest commercial electric vehicle purchase in the U.S., continues the zero-emissions trend", Fleet Equipment Magazine, 14 Jan 2019, https://www.fleetequipmentmag.com/fed-ex-largest-electric-truck-purchase-zero-emission/

[xvii] Car and Driver Magazine reports that Toyota, Acura, Jeep, Lexus, Mercedes, Ford, and Honda have HE SUVs for sale now; and Bollinger, Formula E, Audi, Rivian, Tesla, and Fiat/Chrysler are about to market additional electric powered 4x4 trucks. See: https://www.caranddriver.com/news/a29890843/full-electric-pickup-trucks/

Every Hybrid Crossover and SUV you can buy in 2019-2020 at: https://www.caranddriver.com/features/g26134577/hybrid-crossovers-suvs/

Or https://www.outsideonline.com/2402729/bollinger-electric-4x4

Or https://www.theverge.com/2019/7/6/20684239/formula-e-extreme-offroad-suv-goodwood

Or https://insideevs.com/news/389721/video-rivian-r1t-r1s-tank-turn/

Or https://www.cnbc.com/2020/01/06/fiat-chrysler-showcases-new-hybrid-electric-jeeps-at-ces-this-week.html

[xviii] Paul Lienert, "Global carmakers to invest at least $90 billion in electric vehicles," Reuters Technology News, Jan 15, 2018, https://www.reuters.com/article/us-autoshow-detroit-electric/global-carmakers-to-invest-at-least-90-billion-in-electric-vehicles-idUSKBN1F42NW

[xix] International Energy Agency, "Global EV outlook 2019", IEA Publications, May 2019, https://www.iea.org/reports/global-ev-outlook-2019.

[xx] Bloomberg, NEF; IBID

[xxi] AFC pending publication of the U.S. Army Power and Battery Strategy - see Annex B Page 26. Final draft of the Power and Battery Strategy, "Electric propulsion will increase unit operational reach during continuous operations. Furthermore, this capability is required to produce enough reserve power to support increased tempo of the operating force and reduce sustainment demands during the Penetrate, Dis-Integrate, and Exploit phases of Multi-Domain Operations (MDO)."