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Power Projection:
Accelerating the Electrification of US Military Ground Vehicles

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The Atlantic Council **Global Energy Center** promotes energy security by working alongside government, industry, civil society, and public stakeholders to devise pragmatic solutions to the geopolitical, sustainability, and economic challenges of the changing global energy landscape.

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Background and Summary

The discussion of electrification of military platforms in the United States has long been framed as one of many measures necessary to mitigate the effects of climate change and its deleterious security and defense impacts. This is a constructive objective, but the motivation for electrification of the US Army's ground vehicle fleet should be viewed through a more expansive lens than addressing the challenges of environmental strain and extreme weather.

Electrifying the army's ground vehicle fleet over the next two-plus decades will be crucial to gaining and sustaining advantage in a future fight in which mobility, stealth, and endurance will be in even higher demand as will new ways of powering the growing number of sensors and systems on which military personnel will rely.

In February 2022, the army laid out its plan to transition most of its non-tactical and tactical vehicles to hybrid over the next ten to fifteen years and then, by 2050, to field purpose-built fully electric vehicles.[1] This transition will begin with non-tactical vehicles (NTVs)—the trucks, cars, buses, vans, and other vehicles used on military installations and for non-operational transport. Much of this requirement can be addressed through the adoption of current or imminent commercially available vehicles. Transitioning the army's tactical wheeled vehicle (TWV) fleet—these vehicles, which include ultralight, light, medium, and heavy vehicles used to transport troops, equipment, water, ammunition, and, to date, fuel, can also carry out reconnaissance and increase mobility of troops—poses a more complicated challenge. Still, there is a growing sense that development of commercial electrification technologies is progressing to the degree that army's electrification objectives are "pretty darn achievable" and could even be accelerated.[2]

From June through September 2022, Atlantic Council experts representing the Global Energy Center and Scowcroft Center for Strategy and Security conducted primary and secondary source research to better understand

1 US Army Public Affairs, "US Army Releases Its Climate Strategy," US Army, February 8, 2022, https://www.army.mil/article/253754/us_army_releases_its_climate_strategy.

2 Andrew Eversden, "Army Electric Vehicle Goals 'Pretty Darn Achievable,' but Challenges Remain," *Breaking Defense*, March 2, 2022, https://breakingdefense.com/2022/03/army-electric-vehicle-goals-pretty-darn-achievable-but-challenges-remain/.

Key Terms and Definitions

Electrification: Incorporation of technologies and capabilities that use electric power rather than fossil fuels or other energy sources. Electrification relies on the storage of energy in and distribution of energy from batteries.

Fully electric vehicles: These vehicles run completely on power stored in and distributed from batteries, which is used to power an electric motor.

Hybrid electric vehicles (HEVs): These vehicles incorporate batteries and electric motors in conjunction with fuel-powered engines.

the motivations, advantages, opportunities, timelines, and challenges associated with army vehicle electrification.

While this report considers electrification of all categories of army vehicles, the main focus of this paper is on the prospects of transitioning the army's TWV fleet. Advancing the full electrification of the propulsion of heavier-tracked and combat ground vehicles should remain an objective of the army's electrification plans. However, technological and design issues associated with powering these much heavier vehicles using existing and expected battery technologies will only be resolved along much longer timelines than the more immediate opportunity to transition existing elements of the TWV fleet in the next decade. In the interim, batteries could be integrated into heavier combat vehicles to power systems such as air-conditioning or heating systems, directed-energy weapons, radios, and auxiliary power units.

Our analysis stresses three high-level findings and offers three related recommendations:

Findings

- **Electrification of the army's vehicle fleets will deliver competitive advantages both on and off the battlefield.** In terms of performance, EVs (and hybrid-electric vehicles) are quieter, possess a reduced heat signature, handle better, and, over time, will simplify vehicle sustainment and reduce risks associated with fuel resupply.
- **The benefits of electrification are not limited to propulsion and performance.** EV batteries will accelerate the army's ability to operate on an increasingly electrified battlefield by powering the on- and off-board systems (such as uncrewed systems, sensors, soldier systems, and active protection systems) necessary to achieve advantage in the future fight. In this environment, many military EVs can serve as power generation and distribution hubs for other critical systems.
- **Development of the technologies underlying electrification of the army's TWV fleets are more advanced in the commercial automotive and utilities sectors than generally appreciated.** Many EV technologies, such as improved battery energy density and power generation and distribution, can be adapted and implemented in existing TWVs today—or in the immediate future—to support the development and demonstration of both fully electric and hybrid vehicles.

Recommendations

Achieving for ground forces the advantages of electrification requires sustained commitment of funding, technology development, experimentation, and commercial-industry engagement. Specifically, the army should—

- **Follow a two-track approach to operationalizing electrification that adapts existing technologies to near-term needs while simultaneously investing to develop the battery and recharging technologies needed to achieve the army's long-term, broad-ranging electrification goals.**
- **Accelerate development of operational concepts which animate how EVs will contribute to the future fight and inform requirements for acquisition.**
- **Create deliberate pathways for commercial automotive and utilities companies to address the technological, design, and infrastructure challenges of electrifying military ground vehicles.**

Battlefield Electrification and the Future Fight

In May 2022, reports described how Ukrainian forces were using electric motorbikes, or e-bikes, to avoid detection and increase mobility in support of a range of missions against the invading Russian army, including reconnaissance, demining, medical deliveries, sniper attacks, and anti-tank operations. One photo posted on the Twitter account of California-based e-bike manufacturer Delfast showed two Ukrainian soldiers on

Fuel Truck Convoy. Fossil fuel powered vehicles necessitate large, and highly vulnerable, fuel logistics convoys. A shift to electrified vehicles could reduce this issue. Photo by Spc. Thomas Crough, 361st Theater Public Affairs Support Element, https://www.dvidshub.net/unit/361PAOC.

a Delfast bike with one soldier holding a Next-generation Light Anti-Tank Weapon (NLAW).[3]

The Ukrainian Armed Forces' use of e-bikes is notable for many reasons, not the least of which is that it provides a glimpse into a major—and in many circles underappreciated—trend shaping the future of conflict, force structures, and military operations: the electrification of the battlefield.

Defense planners and analysts considering the future fight have dedicated attention to the emerging technologies shaping the dimensions, dynamics, and pace of conflict. At the top of the list is the more complete integration of artificial intelligence (AI) and supporting technologies and enabled capabilities into most, if not all, aspects of military operations. This "intelligentization" of conflict will enable higher degrees of autonomy for uncrewed aerial and ground systems; facilitate the scaling of human-machine teaming; help detect emerging threats; speed up the processing of complex data sets, including at the tactical edge; and enhance and accelerate decision-making.

In addition, autonomous systems; advanced offensive and defensive weapons, including on-board directed energy weapons; and pervasive and networked sensors will be increasingly incorporated across multiple domains in support of ground forces.[4]

However, these visions of the future fight will go unfulfilled absent development of the ability to reliably produce, use, and disseminate the electricity necessary to power these new force-multiplying capabilities. As the "British Army Approach to Battlefield Electrification" rightly assesses,

3 Rachel Pannett, "Ukrainian Fighters Take to Electric Bikes in the War against Russia," *Washington Post*, May 26, 2022, https://www.washingtonpost.com/world/2022/05/26/ukraine-russia-war-electric-bikes-weapons/ and Micah Toll, "Ukraine Is Now Using These 200-Mile-Range Electric Bikes with NLAW Rockets to Take Out Russian Tanks," Electrek, May 17, 2022, https://electrek.co/2022/05/17/ukraine-soldiers-electric-bikes/.

4 British Army, "British Army Approach to Battlefield Electrification," May 2022, 1, https://www.army.mod.uk/media/17010/british-army-approach-to-battlefield-electrification.pdf.

"the electrification of the battlefield is the underpinning enabler of this new paradigm that sees lighter more mobile forces with increased human-machine teaming achieving far more while reducing human exposure to risk."[5]

Military Electric Vehicles and Climate Change

While their application to the future fight deserves significant attention, to date, military EVs have attracted most interest for their utility in reducing greenhouse gas (GHG) emissions. EVs and hybrid electric vehicles (HEVs) have demonstrated their utility in commercial markets and have gained impressive adoption rates globally due to their energy efficiency and reduced consumption of fossil fuels. A May 2022 report from the International Energy Agency captures the surging demand for EVs:

> "Sales of electric vehicles (EVs) doubled in 2021 from the previous year to a new record of 6.6 million. Back in 2012, just 120 000 (sic) electric cars were sold worldwide. In 2021, more than that many are sold each week. Nearly 10% of global car sales were electric in 2021, four times the market share in 2019. This brought the total number of electric cars on the world's roads to about 16.5 million, triple the amount in 2018. Global sales of electric cars have kept rising strongly in 2022, with 2 million sold in the first quarter [of 2022], up 75% from the same period in 2021."[6]

Reflecting this trend and the growing interest in electrification of military vehicles, most of the initial arguments for electrification of military vehicle fleets both in the United States and abroad have been couched in similar terms: as part of broader efforts to curb GHG emissions, slow environmental degradation, and meet government carbon neutrality objectives by 2050.

After all, militaries, particularly the US military, are massive consumers of diesel fuels—JP-8 for the US Army. In 2020, DoD's Office of the Undersecretary of Defense for Acquisition and Sustainment reported that DoD consumed almost 78 million barrels of oil with estimates of over 82 million barrels to be used in 2021 and 2022. While most of this is consumed by military aviation, ground units in the army also constitute a significant source of diesel fuel demand, with sustained land-combat or logistic operations requiring the ability to traverse distances spanning hundreds of miles.

For example, the US Army's plan to electrify its vehicle fleet was published as part of the service's Climate Strategy, which was released in February 2022. The document lays out a series of "effective mitigation and adaptation measures against the key effects of climate change consistent with Army modernization efforts," including:

- Achieving 50 percent reduction in army net GHG pollution by 2030, compared to 2005 levels;
- Attaining net-zero army GHG emissions by 2050; and
- Proactively considering the security implications of strategy, planning, acquisition, supply chain, and programming documents in processes.[7]

The Climate Strategy also describes the army's vision for electrifying its fleet of vehicles, starting with the non-tactical vehicle (NTV) fleet. According to its Climate Strategy, the army is on track to field an all-electric light-duty NTV fleet by 2027 and "use hybrid options as a bridging solution to field an all-electric Army NTV fleet by 2035." The plan also calls for building "purpose-built hybrid-drive tactical vehicles by 2035 and fully electric tactical vehicles by 2050."[8]

US allies are also pursuing electrification of ground vehicles, at least in part, as a component of broader efforts to reduce GHG. In March 2021, the United Kingdom's Ministry of Defence (MoD) released its Ministry of Defence Climate Change and Sustainability Strategic Approach, which revealed that the MoD "accounts for 50% of the UK central government's emissions."[9] As part of efforts to reduce this contribution, the document commits the British Army to a "fast follower" approach on adoption of technologies to reduce emissions and to the incorporation of "new energy systems," including EVs, into

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5 Ibid, 1.

6 International Energy Agency, *Global EV Outlook 2022*, May 2022, https://www.iea.org/reports/global-ev-outlook-2022.

7 US Army Public Affairs, "US Army Releases Its Climate Strategy," United States Army, February 2022, https://www.army.mil/article/253754/us_army_releases_its_climate_strategy.

8 Ibid.

9 UK Ministry of Defence, *Ministry of Defence Climate Change and Sustainability Strategic Approach*, March 30, 2021, 6, https://www.gov.uk/government/publications/ministry-of-defence-climate-change-and-sustainability-strategic-approach.

Figure 1. Operational Advantages and Efficiencies of Electrification of Military Vehicle Fleets, Especially the US Army's TWV Fleet

Source: Tate Nurkin. Icons by Shmidt Sergey, Abdulloh Fauzan, faldan, Thuy Nguyen, Bahrul Ulum, and Kartika Sholehatin.

its operations.[10] The British Army is already experimenting with hybrid electric drives (HEDs) and anticipates a hybrid TWV prototype by 2025. Hybrid drives have been installed on a MAN SV truck, Foxhound protected patrol vehicle, and Jackal tactical support vehicle for testing.[11]

More recently, in March 2022, the French Ministry of the Armed Forces released its first defense strategy related to climate change. The strategy articulated plans for the ministry to transition away from fossil fuels, including the development of hybrid armored vehicles. A "hybrid vehicle demonstrator" is expected to be fielded by 2025.[12]

The Military Value of Electric Vehicles

The DoD's efforts to reduce fossil fuel use are welcomed and encouraged. However, electric (and hybrid) TWVs offer a range of tactical, operational, and strategic benefits over internal combustion engine (ICE) vehicles in performance, power distribution, sustainment, and logistics. These benefits can provide real and potentially sustained advantages to the DoD as it seeks to counter competitors, deter adversaries, reduce risks to warfighters, and develop means of winning future conflicts.

Certainly, the DoD and the army are aware of this imperative. Messaging around the need for electrification now more frequently embraces the operational advantages that EVs will bring. As Deputy Secretary of Defense Kathleen Hicks observed in December 2021, "electrical vehicles are quiet. They have low heat signature, and incredible torque, and because they tend to be low maintenance with fewer moving parts, they have the potential to reduce logistics requirements. All… these attributes can help give our troops an edge on the battlefield."[13]

Continued and enhanced emphasis on the operational utility of military EVs is necessary to reinforce the crucial message that electrification of tactical vehicles in the coming decade and of combat vehicles over a longer timeline is not being done at the expense of operational capability, but rather to enhance it.

Specifically, electrification of US TWVs will bring the layered military advantages listed in Figure 1 and discussed in the narrative below.

Improved vehicle performance

EVs and hybrid vehicles offer several performance advantages over diesel vehicles. Most notably, EVs are quiet with a much smaller acoustic and thermal signature, making them—and the humans inside them—difficult to detect and, therefore, more survivable. EVs also have more torque and handle better at lower speed, providing increasing acceleration and towing capacity and an

10 Ibid.

11 Alistair Beard and Sarah Ashbridge, "Greening Defence: The British Army's Bet on Electrification," Royal United Services Institute, March 23, 2022, https://rusi.org/explore-our-research/publications/commentary/greening-defence-british-armys-bet-electrification.

12 Vivienne Machi, "French Military Eyes Tech Solutions to Deal with Climate Change," *Defense News*, June 10, 2022, https://www.defensenews.com/global/europe/2022/06/10/french-military-eyes-tech-solutions-to-deal-with-climate-change/.

13 Andrew Eversden and Aaron Mehta, "Electric Vehicles for Military Just a 'Matter of Timeline': BAE Systems Inc CEO," *Breaking Defense*, December 13, 2021, https://breakingdefense.com/2021/12/electric-vehicles-for-military-just-a-matter-of-timeline-bae-systems-ceo/.

Newly unveiled Australian Electric Bushmaster Protected Mobility Vehicle fitted with ruggedized solar panels. Electric vehicles do have some drawbacks compared to fossil fuel variants, such as reduced operating range. However, they also have advantages such as improved vehicle performance and silent watch capabilities. Photo provided by Australian Ministry of Defense.

enhanced ability to operate in off-road environments. These are all capabilities that support improved mobility and flexibility.

One real-world example of performance advantages of electric and hybrid tactical vehicles was seen in the UK Army's Testing Demonstration 6. This exercise, involving electrified versions of the MAN SV, Foxhound, and Jackal hybrid electric drives, showed "improved cross-country performance, easier handling due to instant torque, greater steering precision and training times reduced by 30%; wheeled platforms can now conduct neutral turns akin to their tracked equivalents."[14]

Silent watch and new and enhanced capabilities

One of the most frequently referenced benefits of electrified TWVs is their ability to provide "silent watch"—a potentially high-risk intelligence-gathering operation that puts vehicles and soldiers in close proximity to enemy forces or other reconnaissance targets. During silent watch operations, an electric TWV can run power from its batteries to its sensors and systems without running a noisy combustion engine. As a result, the vehicle can sit undetected or surveil an environment in a quiet stationary position.[15]

The US Army is already beginning to modernize its existing vehicle fleet with stopgap electrification kits that will enable silent watch even in diesel-powered vehicles, demonstrating that electrification can take place in stages and is not necessarily an all-or-nothing proposition.

In March 2022, the army and manufacturer Oshkosh began retrofitting diesel-fueled Joint Light Tactical Vehicles (JLTVs) with anti-idle Tactical Vehicle Electrification Kits (TVEKs) that allow vehicles to cut engine power during periods of extended idling. The objective of the retrofit is to achieve

14 Beard and Ashbridge, "Greening Defence."

15 Jr Ng, "Australian Army Reveals Electric Bushmaster Development," *Asian Military Review*, August 12, 2022, https://www.asianmilitaryreview.com/2022/08/australian-army-reveals-electric-bushmaster-development/.

"20 percent in fuel savings with 50 percent less engine run time" and to double the amount of silent watch time, according to Dean McGrew, branch chief for powertrain electrification with the army's Ground Vehicle Systems Center (GVSC).[16] By reducing fuel usage in the idling stage, the kits can also extend the duration between resupply operations that introduce increased risk to both personnel and overall operations.

Power distribution

Electric TWVs will also serve as power generation and distribution platforms that will be critical to the army's efforts to gain advantage on the future electrified battlefield by charging and recharging the abundance of power-hungry systems that will populate the future fight, including:

- Active protection systems;
- Directed-energy counter-uncrewed aerial systems (C-UAS);
- Connected sensors;
- Soldier systems;
- Onboard and dismounted soldier communication systems; and
- Uncrewed systems.

Without a reliable and rechargeable energy source, keeping these battery-reliant systems operational for distributed expeditionary forces at the tactical edge will be challenging. EVs can play this role, though (as discussed later in this paper) they, too, will require a forward-deployed means of recharging or the capacity to distribute energy from a distance to forward-deployed vehicles.

The UK MoD's testing of hybrid TWVs has shown that a single MAN SV truck "can produce 500 kW of power, the equivalent of nine generators, meaning two-and-a-half MAN SV trucks can power an entire Role 3 hospital."[17] This is an impressive accomplishment—Role 3 hospitals are large facilities that can perform all the functions of medical care—but not necessarily one all TWVs should be able to achieve. The MAN SV is a large truck designed for logistic support operations. Most TWVs will not have a similar capacity or requirement for this scale of power distribution. Still, the capacity to power equipment and other assets from select electric or hybrid TWVs will increase the mobility, resilience, and duration of expeditionary operations while reducing the need to carry heavy generators and the risks to human operators associated with the resupply of fuel.

Uncrewed systems and human-machine teaming

Electrification of the TWV fleet and, over time, heavier combat and tracked vehicles, will also have implications for the use and effectiveness of uncrewed systems in at least two ways.

First, some observers believe that uncrewed ground vehicles can be a conduit for innovation and experimentation for fully electric combat vehicles. Brig. Gen. Glenn Dean, the US Army's program executive officer for ground combat vehicles, told Defense News in June 2021 that, while electrification of the crewed combat vehicle fleet is decades away, the timeline for fully electric robotic combat vehicles could be shorter. Dean assessed that robotic platforms "might be the first use case" for electric combat vehicles.[18]

But of even more immediate and tangible significance is the ability to facilitate increased use of small uncrewed aerial and ground systems by ensuring they have reliable power supplies when forward deployed. Micro- and small-reconnaissance uncrewed aerial systems (UASs) for small unit or vehicle protection, forward-deployed uncrewed ground vehicles (UGVs), and the human-machine teams they enable will serve as valuable force multipliers for small, dispersed, but networked, expeditionary units operating in or near contested environments while also reducing the risk to human operators.

Data, sustainment, and life cycle

Digital operating control systems for EVs and hybrid vehicles will support collection and utilization of more data about the health of a vehicle and its systems both individually and across the fleet.[19] This data can be used to expedite the transition to predictive maintenance and

16 Jerome Aliotta, "Anti-Idle Technology Reduces Fuel, Extends Silent Watch," US Army, March 29, 2022, https://www.army.mil/article/255156/anti_idle_technology_reduces_fuel_extends_silent_watch.

17 Beard and Ashbridge, "Greening Defence."

18 Jen Judson, "Is the Army Warming up to Electric Vehicles in Its Fleet?" *Defense News*, July 12, 2021, https://www.defensenews.com/land/2021/07/12/is-the-army-warming-up-to-electric-vehicles-in-its-fleet/.

19 British Army, "British Army Approach."

anticipatory logistics models in which the army can push logistic support to the field rather than "being solely reliant on requests from the field."[20] Leveraging data from EVs in the field to "predict repair and maintenance demand in advance" and to "optimize parts inventories and gain supply chain efficiencies" will increase fleet readiness and performance.[21]

Logistics simplification and risk reduction

Electrification of the army's ground vehicle fleet, especially TWVs, holds the potential to transform army and DoD logistics in support of ground operations and reduce the risks of interdiction and casualties associated with the transport of fossil fuels to combat environments. It will also reduce the need to transport expensive fossil fuel-powered generators to help charge the increasing number of energy-dependent systems that forward-deployed and expeditionary units will have to carry.

Understanding the Challenges of Electric Vehicle Adoption

Considerable advantages can be delivered through electrification of the army's TWV fleet over the next ten to fifteen years. Indeed, the technologies to begin electrifying lighter TWVs are already available in some instances as demonstrated by the army's experimentation with a fully electric Infantry Squad Vehicle and testing of multiple electric Light Reconnaissance Vehicle (eLRV) designs in 2022.[22] Accelerating army TWV electrification will require the army to address a handful of resolvable challenges and constraints.

Ironically, as battery and distribution technologies advance to keep pace with growing demand for commercial EVs and hybrid vehicles, technology is unlikely to be the most daunting of the potential hurdles to broader adoption of electric and hybrid tactical vehicles. New infrastructure, concepts of operations, and means of incentivizing, engaging, and buying from both traditional and nontraditional defense suppliers will pose more stubborn challenges to the DoD's electrification efforts.

This section explores the five key technological, logistic, organizational, and industry challenges to the advancement and adoption of army TWV fleet electrification listed in Figure 2 below.

Technologies

Electrification of the army's vehicle fleet will rest on continued technology development across all three elements of the electricity value chain: (1) onboard power supply/output on the vehicle itself, (2) charging capabilities for that power supply, and (3) sufficient electricity generation to supply that power at a scale that meets the voltage demands of electrification across the size of the fleet in question.

Onboard power supply: The technological transformation of the onboard power supply for the vehicle itself is fundamental to achieving the advantages of electrification of TWVs at scale within the US military. Specifically, the army will need to develop and adopt a battery that meets the energy density requirements associated with powering the vehicle drivetrain, any onboard computing, and cooling of the vehicle and its inhabitants.

While the onboard supply of sufficient power to electrify onboard services is well within reach, or otherwise readily deployed with current technologies, electrification of the drivetrain speaks to a larger set of tensions and trade-offs within transportation electrification: the weight, desired speed, and intended range of the vehicle all shape the opportunities for electrification, as more powerful batteries are needed to power heavier, faster, or further-reaching vehicles.

Scaling full electrification across all types of TWVs, therefore, will demand improvements to the current battery technology landscape. Recent innovation in battery capabilities has been monumental. From 2008 to 2020, the volumetric energy density of the predominating lithium-ion battery technology increased by over a factor of eight. However, it remains to be seen whether lithium-ion batteries will be able to achieve significantly higher energy densities without compromising stability. Lithium-ion batteries are approaching their material limitations. Next-generation lithium-metal solid-state batteries may enable a 50–100 percent increase in energy density, but to meet the demands of electrifying battlefield propulsion across a broad range of use cases, battery energy density will need to improve. Further research and development will be necessary, particularly in the realm of lithium-sulfur batteries where ample room may remain to maximize both energy and power, two characteristics that often compete

20 US Army Public Affairs, "US Army Releases."

21 Ibid.

22 Jen Judson, "Army wraps up industry demo for future electric light reconnaissance vehicle", *Defense News*, May 21, 2021, https://www.defensenews.com/land/2021/05/21/army-wraps-up-industry-demo-for-future-electric-light-recon-vehicle/

in battery design.[23] The DOD will not need to traverse the path of battery R&D alone, although its unique R&D enterprise will be important. Critically, the DOD will also be able to coordinate its technological progression with the Federal Consortium for Advanced Batteries, an effort to coordinate research efforts for batteries across the Departments of Energy, Defense, State, and Commerce.[24]

It is also important to note that improvements in battery energy density will need to be made with the unique and exacting requirements for resilience and ruggedization of the systems and subsystems that go in and on TWVs in mind. TWV batteries will need to be able to withstand the rigors of combat, including potentially sustaining damage from enemy fire without catching fire, and enduring the harsh conditions in which militaries are deployed, conditions likely to become more extreme as the effects of environmental strain and degradation and extreme weather are more prominently felt.

Charging capabilities: The availability of components to recharge an electrified fleet is also a current technology constraint. Recharging technologies may be more readily available given advancements in the consumer vehicle fleet considering the core design requirements of charging an electrified tactical or non-tactical commercial vehicle are largely the same. Customizing the design of charging stations to meet the organizational needs of the army may be necessary, but these challenges are easier to overcome.

To mirror the refueling efficiency of military jet fuel JP8, charging infrastructure capable of recharging a brigade combat team-sized element (thirty vehicles) in 15 minutes, which would require 35 megawatts (MW) in total of mobile charging capacity, would need to be fielded. While one charger may not need this much power on its own, a new individual charging system with about 15 MW of power would likely be needed, according to GVSC's McGrew.[25] This is considerably more than the current recharging technologies available to the army, which are limited to below 1 MW. However, the distributed nature of future warfare and the tactical advantages offered by electrified propulsion systems may give light to a new architecture for recharging, which may not be entirely analogous to traditional models for refueling.

Indeed, certain technological challenges associated with charging may arise depending on the army's requirements for fast-charging capacity—challenges that are also slowly being addressed in the consumer vehicle fleet. These challenges may be more easily avoided by the new operational concepts accompanying transportation electrification: an electrified fleet may represent similarly electrified fleets in the commercial space wherein the patterns of vehicle use (rotational duty, single points of return for charging) can be organized to accommodate the current timeline of technological development of charging infrastructure.

Electricity generation: The third part of the electricity value chain is the availability of technologies to generate sufficient electricity for the vehicle. This requirement is equally as dependent on context as it is on the electricity output of the technologies themselves. A detachment of light tactical vehicles will not require the same amount of energy as an armored division, which consumes as much as six hundred thousand gallons of fuel per day while on the move.[26] The size of the fleet being charged will also determine the amount of power needed to be generated, as will the weight of the platform being charged and the desired range of its mission.

While there is a clear pathway to generating and distributing sufficient electricity on a base, the limitations of power generation and distribution in a contested or forward-deployed setting will be more challenging and will eliminate a number of energy-generating resources, such as wind or solar.

These limitations have driven the DoD to look increasingly to small modular nuclear reactors in its examination of electrified operations, with Project Pele—the DoD's effort to demonstrate the utility of small nuclear reactors—being

23 "FOTW #1234, April 18, 2022: Volumetric Energy Density of Lithium-Ion Batteries Increased by More than Eight Times between 2008 and 2020," Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy, Department of Energy, April 18, 2022, https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries; Terry Persun, "Advancing Battery Technology for Modern Innovations," American Society of Mechanical Engineers, May 18, 2021, https://www.asme.org/topics-resources/content/advancing-battery-technology-for-modern-innovations; ViPER Group, "Research," ViPER Research, accessed September 12, 2022, https://engineering.purdue.edu/ViPER/research.html; and Heide Budde-Meiwes et al., "A Review of Current Automotive Battery Technology and Future Prospects," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 227 (5): 761–776, DOI: 10.1177/0954407013485567.

24 "Federal Consortium for Advanced Batteries (FCAB)," Energy.gov, accessed October 20, 2022, https://www.energy.gov/eere/vehicles/federal-consortium-advanced-batteries-fcab.

25 Eversden, "Army Electric Vehicle Goals."

26 Ray Wojcik and Łukasz Antas, "Running on Empty," Center for European Policy Analysis, May 13, 2020, https://cepa.org/running-on-empty/.

Figure 2. Five Challenges to Speeding Up Development and Adoption of EVs in the US Military

Source: Tate Nurkin and Reed Blakemore. Icons by Eagle Eye, Nina Karlos, Larea, and David Khai.

a frequently cited example of how this issue could be resolved. Project Pele aims to field a 1 to 5 MW mobile nuclear reactor with the capability to generate power in austere, disconnected environments.[27]

Mini nuclear reactors do hold potential for operational energy generation, but this potential is far from imminent. The technology remains is scheduled for demonstration, as the full-scale microreactor will not become operational until 2024, after which it will undergo three years of testing to validate performance. Microreactors are not likely to be commercially available until the 2030s, but the DoD will need to clear other hurdles beyond technological viability to integrate them into the force, such as safety and fuel-procurement concerns.[28]

Power beaming is another option being investigated. Power beaming is a wireless means of delivering power to distant or disconnected environments using directed energy. One individual interviewed for the project who works in the power beaming industry described the effect as delivering “kilowatts over kilometers.”[29] In April 2022, the US Naval Research Laboratory completed the most significant power beaming demonstration in 50 years, which indicated the technology is close to being demonstrated as a deployable DOD application, although the timeline for this process remains unclear.[30] Towed batteries also may hold promise, but only power beaming can fulfill the ultimate goal of facilitating independent operational movement given the logistic constraints of towing batteries whose energy-storage capacity is presently two orders of magnitude below conventional fuel.[31]

A final point of opportunity for the Army related to electrification would be the adoption of hydrogen fuel cell electric vehicles (FCEVs) as an alternative to battery storage. Hydrogen fuel cells have been highlighted for certain use cases as the Army begins its exploration of non-fossil fuel pathways.[32] Indeed, hydrogen offers certain advantages for the Army in comparison to battery storage that parallel some of the challenges in civilian auto electrification, specifically for applications with high energy density-to-vehicle weight ratios which have limited the scaled adoption of batteries to power trucking. The patterns of use for Army transport may initially parallel the contexts where hydrogen fuel cells have been successful in the civilian sector, specifically the adoption of hydrogen trucks in ports or delivery routes, where fixed recharging

27 Aaron Mehta, “Pentagon Awards Contracts to Design Mobile Nuclear Reactor,” *Defense News*, March 9, 2020, https://www.defensenews.com/smr/nuclear-arsenal/2020/03/09/pentagon-to-award-mobile-nuclear-reactor-contracts-this-week/.

28 “DOD to Build Project Pele Mobile Microreactor and Perform Demonstration at Idaho National,” US Department of Defense, April 13, 2022, https://www.defense.gov/News/Releases/Release/Article/2998460/dod-to-build-project-pele-mobile-microreactor-and-perform-demonstration-at-idah/.

29 Interview with Mike Hartnett, VP Business Development, PowerLight Technologies, August 16, 2022

30 “NRL Conducts Successful Terrestrial Microwave Power Beaming Demonstration,” United States Navy Press Office, April 20, 2022, https://www.navy.mil/Press-Office/Press-Releases/display-pressreleases/Article/3005392/nrl-conducts-successful-terrestrial-microwave-power-beaming-demonstration/.

31 Courtney Albon, “Pentagon Chooses Design for ‘Project Pele’ Portable Nuclear Reactor Prototype,” C4ISRNet, June 9, 2022, https://www.c4isrnet.com/battlefield-tech/2022/06/09/pentagon-chooses-design-for-project-pele-portable-nuclear-reactor-prototype/ and National Academies of Sciences, Engineering, and Medicine, *Powering the U.S. Army of the Future* (Washington, DC: National Academies Press, 2021), https://doi.org/10.17226/26052.

32 Walker Mills, “The Promise of Hydrogen: An Alternative Fuel at the Intersection of Climate Policy and Lethality,” Modern War Institute, December 27, 2021, https://mwi.usma.edu/the-promise-of-hydrogen-an-alternative-fuel-at-the-intersection-of-climate-policy-and-lethality/.

Switchblade 300 loitering munition. Uncrewed drones and loitering munitions require electric charging to operate. Electric vehicles could serve as mobile battery packs to support these systems. Photo by US Army, https://www.army.mil/article/169916/army_develops_critical_components_for_lethal_miniature_aerial_missile_system.

infrastructure and planned routes make hydrogen a more readily adoptable solution.

That said, hydrogen fuel cell adoption will also come with adoption challenges for the army's electrification planning. Among the most pressing challenges are considerations surrounding hydrogen storage and forward deployment of refueling infrastructure, which presents security and safety risks and would require additional infrastructure deployment in order to generate hydrogen supplies from electrolysis. It also places army electrification at the center of the ongoing debate in the energy sector over the development of a market for hydrogen, which is decidedly more nascent than battery storage. There might be a future where certain army transportation use cases are electrified via battery (Li-ion) storage and hydrogen fuel cells help resolve the propulsion problem for heavier TWVs, but this would require two sets of infrastructure to meet both needs.

These technological challenges aside, transportation electrification will most certainly be a phased process that encompasses both the electrification of the drivetrain as well as the onboard support systems of the vehicle itself.

This scale of electrification is an important guideline to understanding the timeline over which army transportation can—and likely will—electrify. In broad strokes, for the deployable storage and charging technologies that will be required for long-duration, distributed multi-domain operations, new solutions to store large amounts of energy and carry it over long distances will need to be developed. Yet there are crucial differences within the timelines for such technologies relevant to different classes of vehicles. For example, lightweight reconnaissance vehicles such as those the army has already begun experimenting with electrification will not have the same energy storage, charging, or power-generation requirements as troop-carrying platforms or armored strike platforms.[33]

This distinction highlights a critical point that many of the opportunities offered by electrification, such as silent watch, can be realized with electrification technologies available today given lower power output (and, therefore, lower energy storage) requirements. The advancement of technologically ready or near-to-mature solutions, such as the 6T lithium-ion battery, will facilitate longer silent watch and serve as a capable bridge to more electrification on the battlefield.[34] Furthermore, seizing these opportunities in the short term might position the army to help guide—or otherwise accelerate—the technological advancements that are needed over the long term to achieve a fuller version of the electrified fleet.

In fact, for vehicles for which battery and recharging technologies have not sufficiently matured, hybrid vehicles can serve as a bridge to further electrification of onboard systems and propulsion alike. This can be achieved both through the use of purpose-built hybrid drive tactical vehicles—which the army's Climate Strategy aims to field by 2035—as well as tactical vehicle electrification kits, a retrofit technology which enables existing platforms to

33 Yasmin Tadjdeh, "Electric Vehicles for the Military Still a Pipedream," *National Defense Magazine*, October 6, 2021, https://www.nationaldefensemagazine.org/articles/2021/10/6/electric-vehicles-for-the-military-still-a-pipedream.

34 Andrew Eversden, "Army Ground Vehicle Lab Researches Different Batteries in Quest for Electrified Fleet," *Breaking Defense*, August 4, 2022, https://breakingdefense.com/2022/08/army-ground-vehicle-lab-researches-different-batteries-in-quest-for-electrified-fleet/.

benefit from reduced fuel consumption and increased electrical power.[35]

While not completely untethered from fuel, these solutions enable a reduction in the "amount of fuel that must be transported into combat zones, reducing the demand on, and risk to, logistics supply chains," according to Ben Richardson, director of the energy portfolio at the Defense Innovation Unit.[36] Purpose-built hybrid vehicles will similarly provide the warfighter with an immediate sense of the benefits of electrification and help avoid near-term downfalls and infrastructural challenges while meaningfully integrating electrified platforms into existing arsenals in a manner that accelerates development of the infrastructure that will enable full electrification in the long term.

Transforming the Logistic Tether

Adoption at scale of EVs across the army's TWV fleet and, over a much longer time horizon, tracked and heavy combat vehicle fleets, will necessitate new infrastructure to produce and deliver sufficient power to sustain an electrified fleet, both on base and in a forward-deployed context.

This new logistics infrastructure will further need to meet the demands of the army to be deployed quickly, deliver power at sufficient scale, and, importantly, depart quickly from the battlespace if needed. Electrification of transportation alleviates much of the risks of the "tether of fuel" referenced by retired Marine Corps Gen. James Mattis, a former US secretary of defense, while also providing new operational opportunities. However, the overhaul of logistical support associated with electrification can also be viewed as presenting a new type of logistical "tether" with which service planners will need to grapple, barring leaps in technologies such as power beaming or monumental shifts in chemical or electrochemical storage technologies.[37]

The development and integration of the electrification infrastructure deserves significant consideration, first in terms of the timeline over which such a transition occurs during which both legacy fuel supply chains and electrified infrastructure will likely be needed in parallel. Second, consideration should be given to the circumstances under which certain forms of electrified infrastructure will be better suited to certain theaters than others, particularly as it pertains to sufficient power generation in a forward-deployed, tactical context.

This set of challenges underscores the credibility of the Department of the Army's evaluation and eventual deployment timelines for transportation electrification, which codifies the aim to deploy a fully electric tactical vehicle by 2050, although elements of the army's innovation enterprise had previously made statements targeting a demonstration by 2025.[38] An iterative, phased approach to transportation electrification will likely improve the opportunity to realize the full scope of possible benefits associated with both a departure from fuel supply chains and the opportunities of battlespace electrification by limiting the friction inherent in any transition of operational logistics.

Strategic commitment to electrification over decades, rather than merely a handful of years, also positions the army to adopt more readily available opportunities within the electrification of transportation, namely support and secondary systems such as sensors and weapons systems, leveraging or contributing to the broader opportunities stemming from the push to electrify the battlefield. This approach will ease the need for an immediate, wholesale shift in the army's energy logistics by incrementally increasing its electricity demand over time and offering a steady pathway to deliver the infrastructure needed to meet that demand.

This dual approach of moving toward full electrification quickly for vehicles, such as the Infantry Squad Vehicle, where it is more achievable while also taking a more phased approach for other vehicles does, however, require some willingness on behalf of the army to:

- Absorb the added costs of acquiring, managing, and operating two infrastructure tethers (that of both traditional fuels and electrified supply chains); and

35 David Vergun, "Prototype Aims to Reduce Fuel Use, Improve Tactical Vehicle Performance," DOD News, US Department of Defense, November 24, 2021, https://www.defense.gov/News/News-Stories/Article/Article/2853649/prototype-aims-to-reduce-fuel-use-improve-tactical-vehicle-performance/.

36 Ibid.

37 Bill Lynn, "Energy for the War Fighter: The Department of Defense Operational Energy Strategy," Department of Energy, Energy.gov, June 14, 2011, https://www.energy.gov/articles/energy-war-fighter-department-defense-operational-energy-strategy and Paul Jaffe, "Practical Power Beaming Gets Real," *IEEE Spectrum*, May 21, 2022, https://spectrum.ieee.org/power-beaming.

38 Yasmin Tadjdeh, "Army Aims to Develop Light Electric Vehicle by 2025," *National Defense Magazine*, March 16, 2021, https://www.nationaldefensemagazine.org/articles/2021/3/16/army-aims-to-develop-light-electric-vehicle-by-2025 and US Army Public Affairs, "US Army Releases."

- Declare and sustain a clearly defined set of requirements for the electrification of transportation and/or the battlespace writ large in order to effectively integrate electrification within a thirty-year time horizon.

Concepts and Requirements

Technology development is just one, and perhaps the least burdensome, constraint to electrifying the army's vehicle fleet. Among the pressing nontechnical challenges affecting this process is the need for further development of requirements and operational concepts for EVs and the subsequent communication of these requirements across the force and to industry.

It is only once the army and DoD have established the need and use cases for electrified TWVs that resources and funding can be allotted to scale the acquisition and integration of EVs and hybrid vehicles. For example, to begin the process of building the case for electrification at a bureaucratic and institutional level, the DoD will first need to develop a more precise and defensible sense of what the energy requirements on the future electrified, intelligentized, dispersed, fast-moving, and highly contested battlefield will be and what specific vehicle capabilities will be required to effectively operate in this environment.

Declaring ambitions for electrified transport alone does little to support rapid technological uptake given the sweeping changes across the energy and transportation value chain that will be needed to make those ambitions possible. Given that incremental change is likely to characterize the electrification of the technologies shaping the future of military mobility, such change will be highly capabilities driven and require significant guidance from the army on questions such as:

- What is the problem that needs to be solved with electrification?
- What is the gap that EVs can fill?
- What are the types of solutions that are required to meet the demands and gain advantage in the future fight?
- How will EVs and hybrid vehicles be used and sustained to achieve advantage on the future battlefield?

The army has articulated some requirements and components of its vision for the electrified fleet of the future and has started experimenting with smaller, light TWVs. For example, the army ran a demonstration of ten possible solutions for an eLRV in May 2021, though future funding for that program is still in question.[39]

In addition, the tactical combat vehicle electrification (TaCV-E) plan approved by the army in December 2021 does inform, according to the House of Representatives' Subcommittee on Tactical Air and Land Forces, "the transition to advancing electrification capabilities and operational requirements generation for the ground vehicles fleet."[40]

Still, these requirements and concepts need to be generated, experimented with, tested, and refined. More detail is required about the army's overall electrification strategy to focus industry investments and activities on the correct army priorities, as the current lack of clarity and communication limits the ability of industry to support electrification with existing technologies and develop the custom technologies and capabilities that meet the army's highly specific needs.

This issue of improving communication of longer-term visions for the army's TWV fleet was at the center of a July 2021 Government Accountability Office (GAO) report, Tactical Wheeled Vehicles: Army Should Routinely Update Strategy and Improve Communication with Industry.[41] The report found that companies that could contribute to the TWV industrial base are disincentivized from participating in the defense market due to a lack of clear and consistent communication about the long-term future of the TWV fleet, including electrification plans.

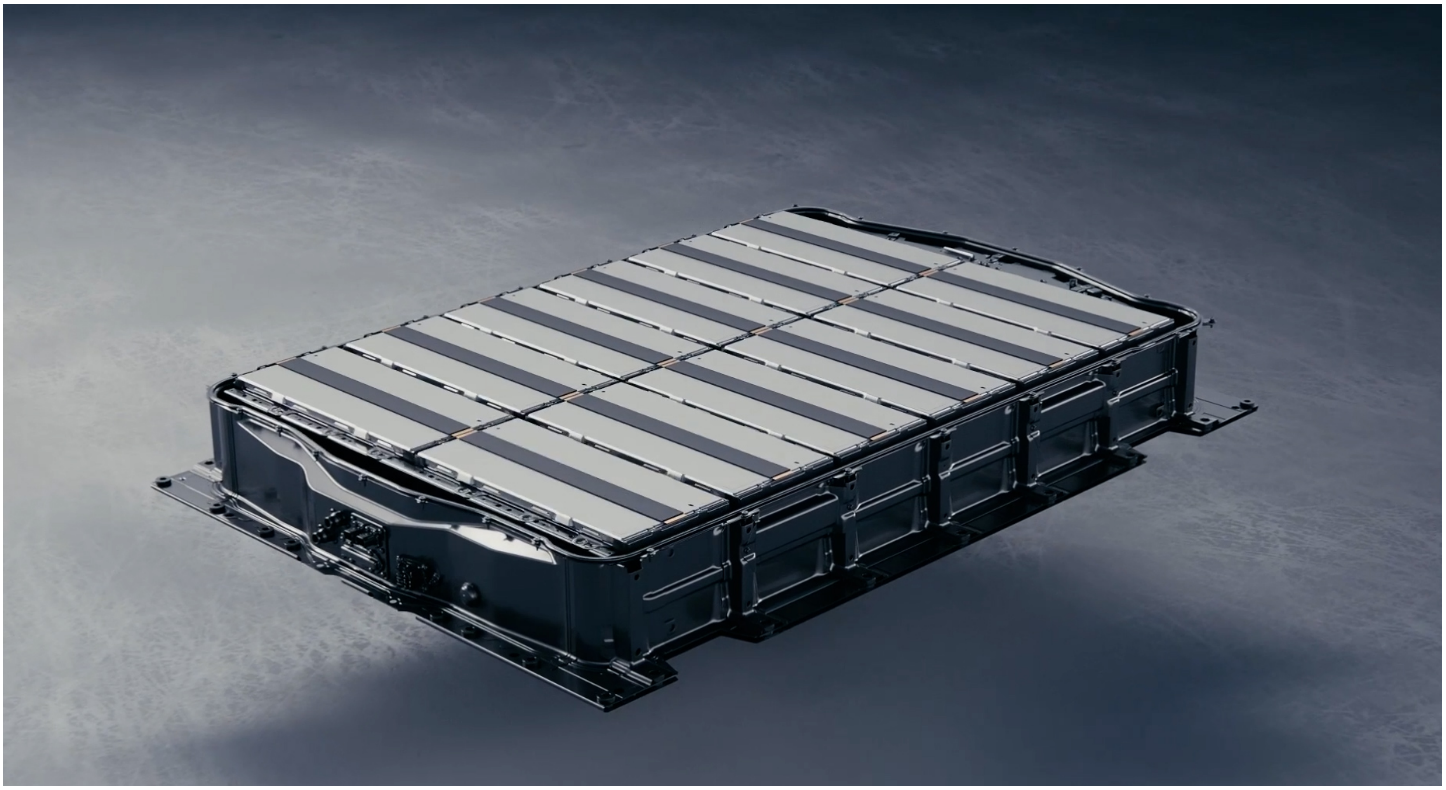
According to the GAO report, "in the past, the Army has communicated the need for improved capabilities, which causes the companies to then expend their own funds. When the Army chose not to pursue these capabilities, the companies then lost their investment and thus were less likely to be involved in future efforts."[42] While this

39 Jen Judson, "Lawmakers Want Army to Set up Program to Experiment with Electrical Tactical Vehicle Operations," *Defense News*, June 9, 2022, https://www.defensenews.com/land/2022/06/09/lawmakers-want-army-to-set-up-program-to-experiment-with-electrical-tactical-vehicle-operations/.

40 Ibid.

41 *Tactical Wheeled Vehicles: Army Should Routinely Update Strategy and Improve Communication with Industry*, US Government Accountability Office, July 15, 2021, https://www.gao.gov/products/gao-21-460.

42 Ibid.



GM Defense will leverage GM's Ultium Platform to develop a battery pack prototype to be tested on Department of Defense platforms. Image courtesy GM Defense.

critique was focused on the overall TWV strategy and not just electrification of TWVs, the report does reference research on next-generation batteries and electrification as examples of significant initiatives that could affect the strategy.[43]

Industry Engagement and Acquisition

The GAO report reveals a broader need to shift how the army engages with industry. The army's pursuit of transportation electrification is happening in parallel with a shift toward vehicle electrification that is already in progress and being led predominantly by commercial industry. Legacy original equipment manufacturers in the United States, not the legacy defense suppliers, are leading the charge toward transportation electrification. Utilities are leading the development of new electricity generation and transmission technologies. While a rapidly evolving technology, battery storage solutions are increasingly dominated by a range of international players, both allied and otherwise. Currently, about 75 percent of EV battery manufacturing capacity is located in China.[44]

Electrification of military vehicles is hardly the only key emerging technology or capability area in which the DoD's bureaucracy has lagged in developing means of acquisition and engagement that incentivize more participation from nontraditional defense suppliers. A growing body of literature has emerged that details the disconnect in expectations of development and buying experiences between the government, commercial industry, and traditional defense contractors, especially in areas such as software and AI development and acquisition.[45]

43 Ibid.

44 *Global Supply Chains of EV Batteries*, International Energy Agency, July 2022, https://www.iea.org/reports/global-supply-chains-of-ev-batteries.

45 One recent example of Atlantic Council analysis of the challenges facing the DoD when it comes to adopting AI, in particular, is found here: Margarita Konaev and Tate Nurkin, *Eye to Eye in AI: Developing Artificial Intelligence for National Security and Defense*, Atlantic Council, May 25, 2022, https://www.atlanticcouncil.org/in-depth-research-reports/report/eye-to-eye-in-ai/.

The common theme across these critiques is the need to overhaul the way in which the DoD buys and fields military equipment to greatly accelerate acquisition and optimize the engine of US commercial innovation to support US national security and retain advantage over competitors that appear to be less constrained in this area. At the Government Contracting Pricing Summit in July 2022, US Air Force Maj. Gen. Cameron Holt, the then deputy assistant secretary for acquisition (contracting) with the Air Force, highlighted some of the implications of these delays for the United States' ability to sustain an advantage over competitors, assessing that China was able to procure weapons systems "five to six" times faster than the United States.[46]

Certainly, these challenges apply to DoD engagement with the commercial automotive and utilities industries. Engaging these industrial players will be necessary, and both the DoD and industry will need to quickly understand the DoD's needs and speedily deliver upon those needs without imposing burdensome costs.

Here again, and as noted above, clear communication of army concepts and requirements associated with electrification will be the foundation of engagement with the companies and wider industries emerging as a result of a broader transition of energy systems around the world. Needs unique to the defense community, such as enhanced cybersecurity and system classification, will need to be developed in partnership with new industry players. Further still, the integration of commercially available technologies, like EVs or chemical energy storage, will require adjustments to the defense acquisition process in order to solicit, design, and reach purchase agreements with the commercial energy sector.

Resilient Supply Chains

The army's electrification of transportation will further place the US defense community at the center of a supply chain for minerals, materials, and metals that is increasingly constrained due to a lack of resilient supply.

The associated infrastructure of transportation electrification, specifically battery storage and, to a lesser extent, grid distribution and charging, will force the army to compete for resources such as lithium, cobalt, graphite, copper, rare earth elements, and magnesium that have already been identified as critical for other defense purposes, but are also significantly in demand elsewhere in the commercial sector thanks to their relevance to commercial EVs and other clean energy technologies. Demand for lithium, a battery metal, will grow by a factor of over forty times by 2040, and the market for the metal may enter a structural deficit of as much as 1.75 million metric tons by 2030.[47] Electrification of the army's ground vehicle fleet, which in totality numbers two hundred and twenty-five thousand tactical and non-tactical vehicles, will represent an important demand-side addition to this deficit.[48]

While concerns about the resiliency of these supply chains—specifically, the concentration of key supply chain nodes in China and a lack of flexible capacity throughout the supply chain—are already significant for the commercial sector, such concerns are of critical importance to the army. This is a two-part problem. First, as a general principle, the army must ensure that adjustments to its logistic and infrastructure footprint are not subject to disruptions in the supply chain that underpins that footprint. Second, supply chain resiliency also bears strongly upon the viability of contracting with commercial entities that might be overly exposed to supply chain risks, a dynamic that the current commercial landscape is struggling to grapple with due to a lack of resilient alternatives in the supply chain.

Conclusions and Recommendations

The challenges discussed above will shape the contours of the US Army's pursuit of transportation electrification, but the steady electrification of the battlefield suggests that electrification is more likely a question of "when" and "how" as opposed to "whether or not." This suggests that, while grounded in its Climate Strategy, the army's commitment to the electrification of its tactical and non-tactical fleets is an opportunity to enable the United States to begin to address the logistic, operational, and technological questions posed by battlespace

46 Thomas Newdick, "China Acquiring New Weapons Five Times Faster Than U.S. [sic] Warns Top Official," *War Zone*, Drive, July 6, 2022, https://www.thedrive.com/the-war-zone/china-acquiring-new-weapons-five-times-faster-than-u-s-warns-top-official.

47 "Mineral Requirements for Clean Energy Transitions" in *The Role of Critical Minerals in Clean Energy Transitions*, World Energy Outlook Special Report, International Energy Agency, March 2022, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/mineral-requirements-for-clean-energy-transitions.

48 Daniel Goure, "The U.S. Army's All-but Forgotten Vehicle Fleet," *RealClearDefense*, August 22, 2017, https://www.realcleardefense.com/articles/2017/08/22/the_us_armys_all-but_forgotten_vehicle_fleet_112116.html.

electrification while immediately realizing some of the benefits in the short term.

As these discussions and electrification efforts progress, it will be important for stakeholders within the DoD, Congress, industry, and the policy community to keep in mind three key insights from this paper as well as three high-level recommendations for pursuing electrification.

Findings

1. **Electrification of the army's vehicle fleets will deliver competitive advantages both on and off the battlefield.** The example of the successful use of e-bikes by the Ukrainian Armed Forces at the outset of the Russian invasion highlights this point. So long as the trajectory of the future fight bends toward electrification, enabling US leadership in this next-generational shift in warfighting must be a priority for the DoD. Moreover, the technology-, military-, and climate-related risks of *not* pursuing electrification of the army's ground vehicle fleets should also motivate acceleration of development, experimentation, and adoption of EVs and hybrid vehicles.

2. **The benefits of electrification are not limited to propulsion and performance.** EV batteries will also play a prominent role in accelerating the army's ability to operate on the electrified battlefield of the future by powering the on- and off-board systems (such as uncrewed systems, sensors, soldier systems, and active protection systems) necessary to achieve advantage in the future fight. Even though electrifying propulsion systems is essential to army transportation electrification, the electrification of specific support systems within the vehicle can enable certain tactical benefits which will also support the future fight. Electrifying auxiliary power systems depends on more readily available technologies. This is a critical piece of the broader electrification story, especially as battery technologies necessary to meet the energy density and charging requirements of heavier combat vehicles take time to develop.

3. **Development of the technologies underlying electrification of the army's TWV fleets are more advanced in the commercial automotive and utilities sectors than generally appreciated.** Many EV technologies developed in these sectors can be adapted for military use and applied today—or in the immediate future—to support the development and demonstration of both fully electric and hybrid vehicles.

Recommendations

1. **Adopt a two-track approach to operationalizing electrification that adapts existing technologies to near-term needs while simultaneously investing to develop the battery and recharging technologies needed to achieve the army's long-term, broad-ranging electrification goals.**

   This approach should feature three main components:

   - Achieving short-term and on-going "wins" and experimentation through adapting / upgrading the existing fleet: Most immediately, the army should prioritize incorporation of readily available commercial electrification technologies into existing vehicle designs where possible to begin the process of experimentation and setting of requirements for future vehicles.
   - While the timelines for electrification of military vehicle fleets are often discussed in decades, there are much more achievable opportunities for various stages of electrification. Using existing or imminent technologies to realize the benefits of and experimenting with electrification can occur through electrification of existing vehicle designs (Infantry Squad Vehicle); developing hybrid technology demonstrators as an interim step toward full electrification (AbramsX hybrid tank); and incorporation of tactical electrification kits on existing vehicles (JLTV).[49]
   - Building the infrastructure tether: The army should simultaneously advance investment in the recharging, electricity generation, and other infrastructure technologies and concepts required to build the new logistics and sustainment infrastructure. DoD is currently exploring several technologies that could facilitate the objective

49 Flavio Camargos Pereira, "AUSA 2022-GDLS unveils the next generation of Abrams and Stryker," *Shephard Media*, October 10, 2022, https://www.shephardmedia.com/news/landwarfareintl/ausa-2022-gdls-unveils-the-next-generation-of-abrams-and-stryker/.

of a sustainable and deployable EV recharging infrastructure, though further development and experimentation of these technologies and the capabilities they enable over the next several years is required before they can be effectively deployed to support scaled EV deployment.

– Invest in the research and development to propagate electrification across the full spectrum of army vehicles, to include purpose-built electrical vehicles. Improved battery energy density is necessary to scale the electrification of heavier TWVs and especially combat and tracked vehicles and to the design of purpose-built combat vehicles.

2. **Accelerate development of operational concepts which animate how EVs will contribute to the future fight and inform requirements for acquisition.**

The DoD and the services have outlined some operational concepts and requirements for EVs and have taken encouraging, if tentative, first steps toward electrification. Nonetheless, experts interviewed for this effort repeatedly stressed the need for more detailed requirements and operational concepts to guide EV and infrastructure development.

Specifically, these experts sought a more comprehensive and detailed vision that would address questions such as: "What is the problem that needs to be solved with electrification? What is the gap that EVs can fill? What are the types of solutions that are required to meet the demands and gain advantage in the future fight? How will electric and hybrid vehicles be used to achieve advantage on the future battlefield? What is the fielding strategy? Will the army seek to electrify specific fleets or all vehicles over time?"

Experts also highlighted the iterative and interactive nature of efforts to gaining advantage on the battlefield by asking how competitors or adversaries may respond to army electrification. How might the army harden EVs against electro-magnetic pulses or other novel threats and what do efforts to protect EVs mean for the requirements for design and development?

This effort must also include a refined approach to aligning and communicating the army's electrification requirements, properly attuning the outlook for adopting electrified transport technologies with both the current trajectory of commercial EV technologies and the broad range of propulsion- and support-service-based opportunities throughout the fleet. Only then can the DoD take the next step of providing guidance to the industrial base for tailored solutions.

3. **Create deliberate pathways for commercial automotive and utilities companies to address the technological, design, and infrastructure challenges of electrifying military ground vehicles.**

The companies leading the push on vehicle electrification are largely commercially focused, given the advanced stages of consumer automobile electrification. Similar trends abound throughout the electrification value chain, from storage to transmission to distribution. Continued commercial investment and development will necessarily help guide and influence the army and DoD's efforts to militarize EV and hybrid vehicle technology. As a result, partnerships between the DoD and commercial industry are essential for meeting the army and DoD's objectives. Unfortunately, and as with other areas where DoD increasingly finds itself relying on commercial industry for vital technology such as software, the DoD has struggled to exploit commercial innovation in this age of rapid innovation. New engagement and acquisition practices are needed to incentivize industry to invest in and partner with the services to achieve electrification objectives.

Reaching the army's goals and seizing the benefits of electrification will be no small task. Success will rest on deep consideration from the DoD's operational planning and logistics management bodies, continued engagement and support from Congress and the broader policy community, and creative engagement with the commercial electrification of transport that is already underway. Yet, if done with a clear line of sight of the opportunities at hand and the technological challenges to be overcome, transportation electrification can be a key steppingstone in that effort.

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