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Perspective: Insights and Opportunities for the U.S. Department of Defense Zero-Emissions Vehicle Transition

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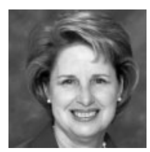

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In this Report

The Biden Administration's Executive Order 14008, "*Tackling the Climate Crisis at Home and Abroad*," and Executive Order 14057, "*Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*," directed the Department of Defense (DoD) and the service branches to develop plans and strategies for transitioning fossil fuel-based internal combustion engine (ICE) vehicle fleets to zero-emission vehicles (ZEVs). ASP created this report to educate and inform policymakers and key stakeholders about the objectives, challenges, and opportunities which exist during DoD's enterprise-wide fleet transition.

IN BRIEF

- According to FY21 statistics, DoD had 71,579 passenger vehicles, 103,694 trucks, and 5,767 other vehicles (e.g. ambulances and buses). Of the total 181,040 non-tactical vehicles, 178,317 vehicles were ICE vehicles. DoD has the second largest vehicle fleet in the federal government, behind the U.S. postal service.
- Reducing energy demand and greenhouse gas (GHG) emissions is a priority for DoD and is a key enabler for energy security and overall resilience. DoD's emissions have trended downward since reporting began in 2010. DoD has issued guidance that outlines specific GHG reduction metrics and milestones in several recent publications, including the *Department of Defense Plan to Reduce Greenhouse Gas Emissions.*
- DoD's transition from ICE vehicle fleets to ZEVs and plug-in hybrid electric vehicles (PHEVs) aims to serve three primary purposes: 1) reduce overall financial costs; 2) reduce DoD GHG emissions and; 3) reduce casualties and increase lethality on the battlefield.
- DoD and each service branch have developed plans to transition ICE vehicles to ZEVs.
  - DoD is working with the General Services Administration (GSA) and private automakers to acquire ZEVs.
  - The Department of the Air Force has developed plans for 100% zero-emission non-tactical vehicle acquisitions by FY35, including 100% zero-emission light-duty vehicles by FY27 and zero-emission aircraft support equipment acquisitions by FY32.
  - The Department of the Army outlined its plans to field all-electric non-tactical vehicle fleets by 2035 and tactical vehicles by 2050.
  - The Department of the Navy aims to acquire 100% ZEVs by 2035, including 100% light-duty ZEVs by 2027.
- Defense vehicle electrification faces technological and logistical challenges, but ongoing research, development, testing, and evaluation lines of effort are already underway to facilitate the transition. Highlighted in this report are:
  - Tactical ZEVs
  - Non-tactical ZEVs
  - EV charging
  - EV batteries.

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Background

In 2021, the Biden Administration issued Executive Order 14008, "*Tackling the Climate Crisis at Home and Abroad*," which, among other things, requires federal agencies to achieve or facilitate clean and zero-emission vehicles (ZEVs) procurement for federal, state, local, and tribal government vehicle fleets.[1] Similarly, Executive Order 14057, "*Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*," mandates federal government agencies acquire 100% ZEVs by 2035, with 100% zero-emission light-duty vehicles by 2027.[2] This guidance has profound implications for the Department of Defense (DoD), as it operates the second biggest federal fleet in the government behind the U.S. Postal Service.

A ZEV is any vehicle that produces no tailpipe exhaust emissions when stationary or operating, and it includes battery electric vehicles (EVs) that are powered by a battery and fuel cell electric vehicles that are powered by batteries run on hydrogen.[3] In addition, plug-in hybrid electric vehicles (PHEV) that have both an internal combustion engine and a battery produce zero direct emissions when in all-electric mode. Even when using their internal combustion engine, they usually produce less direct emissions than conventional internal combustion engine (ICE) vehicles.[4]

ZEVs and PHEVs have several advantages over ICE vehicles:

- ZEVs, especially battery electric vehicles, do not require fossil fuel, thereby reducing fuel expenditures and potential risks of hazards and incidents.
- EVs themselves can function as backup power when grid electricity is disrupted.[5] EVs have the potential to be used in the battlespace to power unmanned aircraft systems and offensive weapon systems.[6]
- Compared to ICE vehicles, ZEVs are often less complex and consist of fewer parts and require less periodic maintenance.[7]
- EVs emit less heat and noise, which in turn bolsters military operations by lowering the chances of being detected by enemies and causing noise pollution.[8]
- ZEVs do not emit air pollutants while idling. A typical diesel truck consumes 1,800 gallons of fuel per year in idling, and idling a vehicle every day for one year could waste as much as $950.[9]

According to FY21 statistics, DoD had 71,579 passenger vehicles, 103,694 trucks, and 5,767 other vehicles (ambulances and buses). Of the total 181,040 non-tactical vehicles, 178,317 vehicles were ICEs. DoD's transition to ZEVs promises to lower its dependence on fossil fuels and reduce or avoid risks both on installations (non-combat vehicles) and on the battlefield (combat vehicles). In addition to meeting the requirements set out via federal guidance, DoD's transition away from fossil fuels serves three primary purposes: 1) reducing financial costs; 2) reducing DoD greenhouse gas (GHG) emissions and; 3) reducing casualties and increasing lethality on the battlefield.

DoD's Non-Tactical Vehicle Fleet					
	Battery Electric	Plug-in Hybrid	Hydrogen Fuel Cell	ICEs	Total
Corps of Engineers, Civil Works	30	53	0	7,032	7,115
Defense Agencies	162	56	0	9,305	9,523
Department of the Air Force	68	23	0	54,277	54,368
Department of the Army	184	162	0	59,467	59,813
Department of the Navy	977	178	0	36,221	37,376
U.S. Marine Corps	789	41	0	12,015	12,845
Total Military Agencies	2,210	513	0	178,317	181,040

Department of Defense Non-Tactical Vehicles by Energy Source; 2021; GSA Federal Fleet Report Open Date Set.
https://www.gsa.gov/policy-regulations/policy/vehicle-management-policy/ffr-open-data-set-library

Reducing Financial Costs

The DoD enterprise is the U.S. government's largest bulk fuel purchaser and consumer[10], accounting for about 77% of the entire federal government's energy consumption.[11] In FY 2021, DoD spent more than $3 billion to purchase fuels, including $140 million to fuel its 180,000 non-tactical vehicles.[12] Given that the massive volume of fuels is required, the volatility of global fuel prices adds risk to DoD's dependence on fossil fuels. Gasoline, diesel, and Avgas can be stored for up to 6 months or 1 year under the right conditions and the DoD lacks the storage capacity to hold a year's worth of fuel on-site, so fuel is purchased in real-time for each execution year,[13, 14, 15] which renders them exposed to fuel price volatility.

The burden of fuel costs can be detrimental to battlefield operations as it requires fuel transportation over long distances. For example, when the price of fuel increases from $2 a gallon to $4 a gallon, the actual costs to deliver fuels to battlefields such as Iraq or Afghanistan can be an additional $20, $40, or $200 a gallon. In some places, the fully burdened cost of fuel can increase to $1,000 per gallon.[16]

Similarly, fuel storage requires attentive management as it can cause catastrophic damage. For example, about 1 million military and civilian and their families at Camp Lejune in North Carolina were exposed to water contamination due to chemicals from a leaking fuel depot from the 1950s through the 1980s.[17] Similarly, in 2021, a jet fuel spill at the Red Hill Bulk Fuel Facility in Hawaii contaminated drinking water and is continuing to impact more than 9,000 military personnel and civilians.[18] Cleanup and remediation continue to this day. More recently, the Navy acknowledged in 2023 that no one knew a US aircraft carrier had jet fuel in the drinking water system for more than a year.[19]

Reducing GHG Emissions

DoD's GHG emissions have trended downward since reporting began in 2010, and continuing to reduce energy demand and GHG emissions remains a priority for DoD as it is a key enabler for energy security and overall resilience.[20] Because transportation makes up almost 30% of U.S. GHG total emissions, transitioning to ZEVs as much as possible is crucial for meeting national climate goals.[21] It can also help boost American competitiveness by not ceding the growing ZEV market to foreign competitors and enhance national security by reducing our dependence on foreign-produced fossil fuels.

In FY 2022, DoD's Scope 1 and 2 emissions totaled 48 million metric tons of carbon dioxide equivalent (MMTCO_2e): 18 from standard operations and 30 from non-standard operations (combat support, combat service support, tactical or relief operations, etc.). Non-tactical vehicle fleets and equipment account for about 6% of the total emissions from standard operations. Tactical vehicle fleet and equipment account for more than 99% of the total emissions from non-standard operations.[22]

GHG EMISSION SOURCES BY SCOPE

Scope 1: Direct emissions from sources that are owned or controlled by DoD, including fossil fuel combustion from stationary and mobile sources and fugitive emissions (such as refrigerant leaks).

Scope 2: Emissions resulting from the generation of electricity, heat, or steam purchased by DoD.

Scope 3: Emissions that result from DoD activities but are from sources not owned or directly controlled by DoD, such as DoD procurement of goods and services, including business travel, in addition to emissions from commuting.

DoD GHG Emissions Sources by Scope; Department of Defense Plan to Reduce Greenhouse Gas Emissions.

Reducing Casualties/Increasing Lethality on the Battlefield

DoD has identified the security implications of climate change and made efforts to integrate climate considerations into the Department's strategies and plans.[23] The continued use of ICE vehicles also poses a risk to forces on the battlefield, as the military spends approximately $81 billion annually protecting oil infrastructure.[24] Less ICE and fossil fuel dependence means fewer fuel convoys and fewer casualties.[25] A recent study showed that fuel convoy attacks killed more than 3,000 soldiers and contractors in Iraq and Afghanistan between 2003 and 2007.[26]

Although the technology and feasibility are still in the testing phase, DoD recognizes that ZEVs and EVs can provide other key tactical advantages on the battlefield. As Deputy Secretary of Defense Dr. Kathleen Hicks recently stated, "Electric vehicles are quiet. They have a 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 of which can help give our troops an edge on the battlefield."[27]

DoD and Service Branch Plans

DoD

In April 2023, DoD released its first-ever enterprise wide "*Plan to Reduce Greenhouse Gas Emissions*" which provides strategies for both installations and operations. The focus "is to enhance capability and lethality while increasing the readiness and resilience of the force."[28] Pursuing ZEVs and the associated charging infrastructure is one line of effort for reducing DoD's overall GHG emissions. DoD has a target to acquire zero-emissions (ZEV) non-tactical vehicles by 2035, primarily through the General Services Administration (GSA) Fleet Leasing Program.[29] In addition to ordering light-duty ZEVs, DoD is working with GSA and automakers to acquire special-purpose pursuit-related law enforcement ZEVs with a target of more than 3,500 by 2026.[30]

DoD is also optimizing new ZEV allocation by acquiring innovative charging infrastructure including portable, solar-powered charging equipment, which simultaneously enhances energy resilience at military installations. Specifically, bi-directional charging infrastructure and the ability to connect electric vehicles to onboard electric power and on-base microgrids can reduce the reliance on fossil fuels, thus enhancing energy resilience.[31]

Through the Defense Innovation Unit (DIU), DoD has focused on fielding and scaling commercial technology across the U.S. military, with the following focus areas:[32]

- Tactical vehicle electrification
- Electric vehicle support equipment
- Advanced batteries
- Sustainable Aviation Fuel
- Solar unmanned aerial vehicles (UAVs)

Department of the Air Force (DAF)

In October 2022, the DAF published its Climate Action Plan, which included its objectives and key results for pursuing alternative energy sources. DAF aims for 100% zero-emission non-tactical vehicle acquisitions by FY35, including 100% zero-emission light-duty vehicles by FY27 and zero-emission aircraft support equipment acquisitions by FY32.[33] In July 2023, DAF also released its Climate Campaign Plan which included detailed implementation plans and performance metrics.[34] Key actions include:

- Assessing opportunities for fleet electrification vehicle eligibility and potential risks to missions, force and security and developing guidance for ZEV and electric vehicle support equipment (EVSE) acquisitions and availability. (FY23)
- Transitioning the non-tactical vehicle fleet to 100 percent ZEV acquisition. (FY27)
- Transitioning to 100 percent zero-emissions aircraft support equipment acquisition. (FY32)

Given that the majority of DAF's GHG emissions come from aviation fuel, there is also a significant push toward developing and deploying sustainable aviation fuel (SAF) to reduce emissions. Pilot projects of drop-in sustainable aviation fuel will be completed by FY26.[35] The DAF Climate Campaign Plan listed detailed action plans, which included the below actions and milestones: [36]

- Establish DAF SAF working group to perform SAF evaluation and develop pilot program criteria. (01DEC23)
- Develop SAF site survey template and evaluation program to understand the current/project SAF supply chain to prioritize the top 10 locations for SAF pilot evaluation. (15MAR24)
- Identify technical guidance requirements for aviation and ground systems' use of SAF with Program Offices and Program Managers/Equipment Specialists. (01DEC24)
- Evaluate and down-select two primary and one alternate location for SAF pilot evaluation. (15MAY26).

Department of the Army

In February 2022, the U.S. Army released its Climate Strategy to outline its plans for ZEV transitions. The Army aims to:

- Field an all-electric light-duty non-tactical vehicle fleet by 2027.
- Field an all-electric non-tactical vehicle fleet and purpose-built hybrid-drive tactical vehicles by 2035.
- Field fully electric tactical vehicles and develop the charging capability required by 2050.[37]

The Army has been working since 2005 to reduce fossil fuel use in the non-tactical vehicle (NTV) fleet and by the end of 2020, had already removed 18,000 NTVs.[38] Army Materiel Command's (AMC) September 2021 mandate required that all new vehicle leases, lease renewals, and purchases must select all-electric NTVs first, hybrids when electric options are not available, and conventional gas vehicles by exception only.[39] In 2022, the Army contracted with Canoo and GM Defense to provide a battery-electric vehicle, the GMC Hummer EV equipped with GM's Ultium Platform, for analysis and demonstration.[40]

SELECT DOD EV TRANSITION HIGHLIGHTS

Colorado Army National Guard (COARNG)

The COARNG's environmental quality program replaced its non-tactical vehicles with EVs and hybrid vehicles from 2019 to 2020. Each EV replacement is estimated to save $2,000 a year in fuel and maintenance costs. COARNG plans to achieve 12% battery-electric and 18% plug-in hybrid vehicles in its fleet of state and federal vehicles by 2026.

U.S. Army Reserve

The U.S. Army Reserve launched a multi-phase electric vehicle pilot program in 2022, and the Phase 1 is in progress. They aim to include over 2,000 electric vehicles at 763 facilities with the following plans:

- Phase 2: Add 96 EVs to 9 facilities.
- Phase 3: Rollout 934 electric vehicles to 101 facilities.
- Phase 4: Add 962 electric vehicles at the remaining 650 facilities.

In 2023, the U.S. Army Reserve launched another pilot program in partnership with the Defense Innovation Unit (DIU) to install EV charging stations at the selected locations.

- Parks Reserve Forces Training Area (Dublin, CA) installed five level 2 dual-port chargers and two level 3 dual-port chargers.
- The 63rd Readiness Division Headquarters in Mountain View, CA installed three level 2 dual-port chargers.

In celebration of its 248th birthday festival in June 2023, the Army showed how they are tackling the challenges of climate change and promoting energy resilience via carbon pollution-free energy, transportation, and logistics. The Army's newest non-tactical electric vehicles, the Ford F-150 Lightning pick-up truck and the Chevrolet Bolt, were introduced.[41] The Army also worked with the U.S. Army Corps of Engineers, Engineering and Support Center in Huntsville, Alabama to provide acquisition services, contract management, and technical expertise for installing EV charging stations.[42]

Department of the Navy (DON)

In May 2022, the Department of the Navy released Climate Action 2030 to guide climate action for both the U.S. Navy (USN) and the U.S. Marine Corps (USMC).[43] To build climate resilience and reduce climate threats, the DON aims to acquire 100% ZEVs by 2035, including 100% light-duty ZEVs by 2027.[44]

The DON is developing specifications and strategies for hybridization and electrification of tactical ground vehicles, and it will also explore hybrid and advanced propulsion options for Navy ships.[45] The DON is in the process of qualifying low-carbon fuels that are currently developed and approved by the commercial sector while collaborating with the Army to implement a standardized lithium version of the vehicle standard "6T" battery.[46] The DON announced that it will leverage public and private ventures and third-party financing for its NTV transitions and explore options to share power between tactical vehicles and ground generation systems for warfighting efficacy, including fuel demand reduction and resilience enhancement.[47]

In 2022, Marine Corps Base Camp Lejune partnered with the Department of Energy's National Renewable Energy Laboratory (NREL) Tiger Team for the deployment of EVs and EV charging stations around base facilities. The Tiger Team provided technical assistance to help identify ideal opportunities to replace incumbent ICE vehicles and evaluate the electrical infrastructure capacity at parking lots. The project identified a total of 204 PHEVs and BEVs as opportunities for EV deployment and recommended 111 level 2 EV charging ports for installation at 14 parking lots to be shared across three different military branches.[48]

EV Research, Development, Testing, and Evaluations Lines of Effort

Transition to ZEVs can provide DoD with financial, operational, and tactical advantages, and each branch has made lines of effort to move forward. While defense vehicle electrification still faces technological and logistical challenges, there is ongoing research and development to reduce DoD's dependence on fossil fuels. Highlighted below are four lines of effort already underway that can make or break the ZEV transition.

ZEVs (Non-Tactical)

DoD's non-tactical vehicles consist of light-, medium-, and heavy-duty vehicles, the same as those in industry and commercial sectors. DoD's medium- and heavy-duty vehicle fleets range from cargo vans and buses to construction equipment and emergency response vehicles. Current technologies and the auto market/industry have made significant progress and outcomes in electrifying light-duty vehicles, but electrification of medium- and heavy-duty vehicles still requires additional efforts.

Prototype Commercial Technologies

DoD and the service branches are already taking advantage of technological progress in the commercial vehicle industry to modernize their non-tactical vehicles. The U.S. deployed more than 1,000 ZEVs, and about 140,000 zero-emission trucks are expected to be delivered over the next 10 years.[49] The number of electric transit buses on order or operating increased by 112% from 2018 to 2021.[50]

DoD is already working with industry partners to test and demonstrate the capabilities of EVs, which signals the industry to develop medium- and heavy-duty ZEV alternatives. For example, DoD is evaluating the viability of battery-powered heavy-duty modular mobility platforms for various tasks from construction to cargo handling.[51]

Alternative Fuel

DoD has built upon the "single fuel concept" to simplify logistics,[52] but the modern military calls for alternative fuels not only for its emissions reduction benefits but also for its tactical performance. The FY23 NDAA directed a cost-benefit analysis for the adoption of alternative fuel vehicles including EVs, hydrogen-powered vehicles, and advanced biofuel-powered vehicles.[53]

Fuel cell technology can be a potential option both for non-tactical and tactical vehicles.[54] Fuel cell electric vehicles are powered by hydrogen. DoD is interested in using hydrogen for its medium- and heavy-duty vehicles as the Department of Energy moves this technology closer to commercialization.[55] The Army has already tested General Motor's ZH2 fuel cell-powered truck that runs on hydrogen instead of batteries.[56] Similarly, the Air Force has already demonstrated the use of a hydrogen fuel cell-powered U-30 Aircraft Tow Tractor at the Hawaii Air National Guard.[57]

ZEVs (Tactical)

For tactical vehicles, the interest in a transition to ZEVs has many drivers, including reduced detectability, increased survivability, reduced maintenance requirements, reduced logistics footprints, and improved onboard export power capability.[58]

In FY 2021, DoD's tactical vehicle fleet and associated equipment accounted for more than 99% of the total non-standard operations: 76% from aircraft, 17% from ships, and 6% from tactical vehicles.[59] As such, a comprehensive ZEV transition cannot be completed without transitioning tactical vehicles into ZEVs. While the demands of combat currently preclude many types of vehicles from replacement by ZEVs in the immediate future, technologies that are in the development and pilot stages are showing great promise.

Tactical vehicles spend about 75% of their operational time idling and burn 30-60% of their fuel while stationary.

The Army expects to begin testing the prototype Electric Light Reconnaissance Vehicle (eLRV) before September 2023.[60] The National Training Center at Fort Irwin will test out six electric infantry squad vehicles in early 2025, and the Army's 25th Infantry Division will conduct field tests of a multi-ton wheeled battery pack sometime after early 2025.[61] Meanwhile, the Army and the Navy collaborated in the process of implementing a standardized lithium version of the vehicle standard "6T" battery for tactical ground vehicles.[62]

The Air Force is exploring the electrification of rotorcraft and small mobility aircraft through its Agility Prime program. The program conducts prototype projects to assess the transformative vertical flight market and applicable hybrid or electric vertical takeoff and landing aircraft technologies. These will decrease the risks of fuel logistics while driving resupply and recovery capabilities closer to the front lines.[63] The Air Force has recently signed a contract with Archer Aviation with about $142 million value for electric vertical takeoff and landing (eVTOL) aircraft development.[64] These technologies may ultimately form a basis of knowledge and equipment that leads to tactical employment. For instance, one could conceive of upscaling an electric-powered consumer-style drone into a full-size helicopter gunship.

Hybrid Vehicles

DoD's current strategy for the tactical vehicle fleet is to reduce energy demand through energy efficiency enhancement and hybrid technologies. Given that tactical vehicles spend about 75% of their operational time idling and burn 30-60% of their fuel while stationary, the Defense Innovation Unit (DIU) is leveraging existing commercial technology to retrofit tactical vehicle fleets with hybrid energy-capture systems to reduce fuel consumption by at least 20% across all fielded vehicles.[65] DIU is also leveraging commercial technology for electric personal watercraft and small boats to prototype and demonstrate the utility of an all-electric personal watercraft-sized vehicle.[66]

DoD began testing its first hybrid-electric Bradley Infantry Fighting Vehicle demonstrator in January 2022, and is continuing to field test capabilities.[67] Similarly, Oshkosh Defense has developed a hybrid electric Joint Light Tactical Vehicle (eJLTV). The eJLTV provides the Army and Marine Corps with the same level of performance as the base JLTV while offering additional benefits such as exportable power, improved fuel economy, and extended silent watch. The eJLTV charges the battery while in use, which eliminates the need for charging infrastructure.[68]

Hybrid electric Joint Light Tactical Vehicle; Photo Credit: Defense News

"Series hybrid" electric vehicles equipped with electric motors that are run by batteries which can be charged by an external source or via an onboard petroleum-fueled generator can be ideal candidates for the next tactical ground vehicles. They provide ground forces immediate benefits that contribute to lethality, including nearly silent operation, lower fuel consumption through higher efficiency, higher instantaneous torque for towing and acceleration, and fewer maintenance requirements.[69] Although none have been deployed in the field yet, the Army is also developing hybrid combat vehicles.[70] The Army is researching hybrid vehicle propulsion and integrating hybrid electric technologies into its platforms, and they have demonstrated the benefits of Tactical Vehicle Electrification Kits, including a 25% reduction in fuel consumption and its anti-idle function, a capability to shut off its engine during halts while still providing power to vehicles.[71]

Alternative Fuel

Fuel cell electric vehicles that are operated on hydrogen can be a viable choice for tactical vehicles.[72] Hydrogen vehicles and platforms can provide similar tactical advantages as all-electric vehicles, and hydrogen can even be generated and used on the battlefield, reducing reliance on fuel imports and the risks of supply chain disruptions.[73] The Defense Department has already produced hydrogen in the field, and federal agencies can order a tank of hydrogen from the Defense Logistics Agency's Aerospace division.[74]

The Army is investing more than $3 million to develop hydrogen storage and generator systems to quickly refuel vehicles when the main fuel tanks are empty in combat settings.[75] The Army's Ground Vehicle Systems Center has worked with industry to develop hydrogen-fueled prototype ground vehicles.[76] The Navy has demonstrated the 48-hour flight of its hydrogen-powered UAV.[77] Critics have raised logistics and safety concerns of hydrogen, but studies and technological advancement have discovered new processes and management practices.[78]

DIU (Defense Innovation Unit), the Air Force Research Laboratory, the Department of Energy and the Office of the Under Secretary of Defense for Acquisition & Sustainment are working with the industry on a prototype to create fuel via electricity and carbon for air, ground, and maritime vehicles.[79] In 2020, the Air Force launched a pilot program to demonstrate the technology of converting CO_2 into operationally viable aviation fuel, and later DIU also launched its program to create small, mobile fuel production systems that can be deployed in combat scenarios.[80]

EV Charging

Transitioning to a ZEV fleet is impossible without adequate charging infrastructure. Batteries are usually tested in controlled environments, but in order to support mission requirements in a stable and secure way, the military needs to field test EVs and batteries in consistent worst-case scenarios, day in and day out.[81] Given that the U.S. military installations mostly rely on the commercial grid for electricity, it is critical that grid security and capacity are also appropriately planned and resourced. While a deep dive in grid modernization and energy demand is outside the scope of this paper, there are related important aspects worth mentioning at a broad level. Likewise, "range anxiety" especially in deserts, cold weather, mountain ranges, or locations without reliable electricity poses a serious challenge to ZEV adoption, especially in a combat/battlefield scenario.

Standardization of EV batteries and charging infrastructure is critical to maximizing the benefits of EVs and ZEVs. In addition, lithium-ion batteries are common energy storage technologies for EVs, but they can degrade in harsh environments such as cold temperatures, which must be accounted for. In addition to the number of charging stations and infrastructure required, charging speed is also an essential element to meeting DoD's ZEV transition goals. For example, it would require a 17 MW charging station to charge a 50-ton tracked combat vehicle within 15 minutes—which is over 20 times greater than the Army's existing mobile generator capacity.[82]

Fortunately, there is existing research happening to address many of these key challenges. The Operational Energy Prototyping Fund (OEPF) and the Defense Innovation Unit (DIU) are funding retrofits to existing fleets that support onboard power storage for electronic warfare and command and control systems; heating, ventilation, and air conditioning; and vehicle-to-grid/vehicle-to-vehicle power sharing.[83] DIU has partnered with Marine Corps Systems Command (MCSC) to fund the STEEP (Stable Tactical Expeditionary Electric Power) Program. The objective of the STEEP program is to develop a modular, vehicle-transportable system that provides energy storage and management for tactical/mobile microgrids.[84]

The Office of the Secretary of Defense (OSD), the U.S. Army's Combat Capabilities Development Command (DEVCOM) Ground Vehicle Systems Center (GVSC), the Department of the Navy Operational Energy (DON-OE), and DIU have partnered on the Jumpstart for Advanced Battery Standardization (JABS) project to prototype commercial batteries for future military platforms.[85] In this program, GM Defense will conduct different phases of testing from a single Ultium battery to its four-seat Infantry Squad Vehicle outfitted with a battery module.[86] The JABS will help the U.S. national blueprint for lithium batteries by meeting the objectives to develop form-fit-function battery standards for defense and to meet critical defense battery demand with multiple-source domestic suppliers.[87]

Partnerships

The USN has partnered with the California Energy Commission (CEC) and obtained nearly $2 million for electrification programs at various Navy and Marine Corps installations in California. The CEC funds will be used to install Level 2 and 3 chargers at Naval Base San Diego and to create the Electrification Blueprints project that will conduct cost-benefit analysis of innovative technologies in the electrification of transportation infrastructure, particularly related to vehicle-to-grid integration.[88] DOE has also awarded $9.5 million to Corvias Military Living to demonstrate the electric vehicle-inclusive microgrids at Fort Riley in Kansas, which will enhance energy resilience and the independence of military housing and critical facilities.[89]

Similarly, in late 2023, DIU announced a contract with Leidos to provide Electric Vehicle Charging-a-Service infrastructure for non-tactical vehicles at U.S. Air Force bases across the continental U.S.[90] These types of public-private partnerships are demonstrating how the latest commercially available technological innovations can be leveraged to minimize construction costs and enhance energy resilience.

Solar Charging Stations

DoD is already working to address its reliance on the commercial electricity grid, especially for charging its vehicles. For example, the U.S. Army Corps of Engineers (USACE) Engineering and Support Center in Huntsville, Alabama has awarded contracts for 367 solar-powered charging stations at 50 installations for the U.S. Army Installation Management Command (IMCOM) and 112 stations at 21 sites for the Army Materiel Command.[91] Fort Moore installed 34 solar charging stations, which will charge EVs up to a range of around 265 miles per charge.[92]

Solar charging stations at Fort Moore (Georgia). Photo Credit: U.S. Army

USACE has also partnered with TechFlow for electric vehicle charging stations over 50 installation sites. TechFlow will install Beam Global's EV ARC 2020 solar electric vehicle charging system for the sites.[93]

Naval Facilities Engineering Systems Command (NAVFAC) partnered with an NREL Tiger Team to plan for EV charging stations and PV installations at the Marine Corps Base Camp Blaz in Guam, which will begin operations in 2028. When complete, it will have over 12 MW of roof top PV installations, 115 government owned EVs, and up to 118 EV charging ports. The smart charge management helps time EV charging events during periods of high PV generation and mitigate the curtailment of generated PV energy.[94]

EV Batteries

Different EVs have different batteries, which, in turn, require different supply chains. But as Deputy Secretary of Defense Dr. Kathleen Hicks has stated, "battery technology, and lithium-ion batteries specifically, are the lifeblood of electrification and the future auto industry, but… [they] are also essential to thousands of military systems…A healthy battery supply chain is essential to the military. The problem, however, is that China presently dominates that supply chain."[95] As such, building a secure supply chain is a high priority for both DoD and the national security enterprise writ large.

In February 2021, the Biden Administration issued EO 14017 *America's Supply Chains* which required DoD and several other cabinet agencies to complete an assessment of supply chains and the defense industrial base (DIB).[96] The subsequent 100-day review and one-year report focused on five critical supply chain areas, two of which were 1) energy storage and batteries and 2) strategic and critical minerals.[97] The report provides recommendations and roadmaps for securing related supply chains and fostering interagency and public-private partnerships. Though not discussed in length in this report, these strategies and plans are guiding development and deployment of battery technology and storage.

Battery Management

DoD has also published the Lithium Battery Strategy 2023-2030, which outlines objectives and actions to achieve the goals outlined in the National Defense Strategy, DoD's industrial base policy, and DoD' action plan in response to EO 14017.[98] As part of this strategy, DoD is "evaluating policy changes to improve its buying power, incentivize allied and domestic markets" and allowing DoD to pursue actions necessary to provide "reliable, assured, and efficient energy storage necessary to meet the warfighter's tactical and operational demands." [99] Likewise, DIU (Defense Innovation Unit) is working with private industry to develop a proprietary process which enables the production of Lithium-Sulfur (Li-S) batteries. These batteries are expected to provide three times more usable energy than lithium-ion batteries while simultaneously being safer and less vulnerable to fire and explosion.[100] In addition, DIU has launched the Family of Advanced Standard Batteries (FASB) where they are engaging battery manufacturing through the standardization of a variety of battery form factors and use cases.[101]

Alternatives to Lithium-Ion Batteries

There are alternative battery options other than lithium-ion batteries. Lead-acid batteries are relatively inexpensive, safe, and reliable, and they can have high power. Advanced high-power lead-acid batteries are being developed, but poor cold-temperature performance and short lifecycle are their main challenges. Nickel-metal hydride batteries have been used in hydrogen electric vehicles. These batteries have a longer life cycle than lead-acid batteries and are safe and abuse-tolerant. However, their high cost, high self-discharge, and heat generation at high temperatures are challenges. Ultracapacitors that store energy in a polarized liquid between an electrode and an electrolyte can provide vehicles additional power during acceleration and hill climbing.[102] Meanwhile, a new lithium-ion battery can deliver an energy density of 500 Wh/kg, 1300 Wh/L than the current one, and higher energy is important for longer run times, range, and endurance.[103]

Emerging EV Charging Technologies

In addition, there are several other emerging technologies that are showing great promise. EV battery swapping stations provide platforms where EV drivers can exchange their discharged battery pack for a charged one instead of plugging their vehicle into a charging station. This technology provides faster services than charging and has the potential to lower EV costs as its infrastructure requires less capital investment.[104] Wireless charging is also emerging as a potential option, with automakers already field-testing wireless capabilities with the target year 2025. When the vehicle is parked in the right spot, wireless charging will beam into the battery via magnetic resonance. This new type of charging infrastructure could provide advantages over wired-plug charging, particularly in terms of convenience and universality.[105] These new technologies are under development in commercial settings. However, once developed at full scale and integrated into the defense setting, this technology will provide procedural and tactical advantages both for non-tactical vehicles and tactical vehicles.

Conclusion

Current technological limitations pose a challenge to rapidly replacing ICE defense vehicles with ZEVs, but various R&D efforts both in defense and commercial industry are demonstrating great promise. The Biden Administration's policies to address climate change have already helped the development and deployment of ZEVs in the civilian sector, and it is showing widespread potential for the military as well. The benefits are not only seen economically, environmentally, and via public health, the transition is bolstering resilience and national security by reducing demand on foreign-owned fossil fuel resources. It's also laying the groundwork for an entirely new clean-energy economy, with domestic and allied energy sources and partnerships spurring innovative solutions and next generation technologies.

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