NATIONAL CENTER FOR MANUFACTURING SCIENCES

A Road Map to Electrification: Accelerating the Transition from Gas-Powered to Electric Vehicles

Overview

From heatwaves and wildfires to hurricanes and floods, climate change contributes to extreme weather around the globe, with dire impacts on the planet's ecosystems and human habitation. The annual mean global near-surface temperature for each year between 2023 and 2027 is predicted to be between 1.1° Celsius and 1.8° Celsius higher than the 1850-1900 average. Recent research indicates that an increase in global temperatures above 1.5 degrees Celsius is likely to trigger catastrophic tipping points—including the collapse of the Greenland Ice Sheet and West Antarctic Ice Sheet—which the Intergovernmental Panel on Climate Change (IPCC) has said could occur in the 2030s. The scientific consensus calls for urgent action to mitigate climate change through reductions in greenhouse gases (GHGs).

The United States is the world's second-largest emitter of GHGs, and 77% of US GHG emissions come from fossil fuel combustion. In 2021, transportation accounted for the largest portion (29%) of total US GHG emissions, and passenger cars were the largest source of emissions, accounting for approximately 39% of global transportation emissions. Experts recommend that the transportation sector reduce CO_2 emissions by more than 3% per year to 2030.

To reduce CO_2 emissions, Americans in both private and public sectors are working to increase the adoption of electric vehicles (EVs). Compared to conventional vehicles, EVs have significantly lower greenhouse emissions, so they mitigate climate change, reduce air pollution, and provide health benefits. Moreover, EVs lower fuel costs while increasing American energy security by reducing dependence on foreign oil. The EV industry also helps to create American jobs: nearly 300,000 new energy jobs were created nationwide in 2022 according to the US Department of Energy's 2023 US Energy and Employment Report.

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Yet widespread adoption of EVs is hampered by challenges related to affordability, batteries, and the supply chain for electrical component production. A recent NCMS initiative sought solutions to these issues by researching vehicle electrification and potential crossovers between the civilian and military domains. The team completed a comprehensive investigation into twenty-one companies that build, All-Electric Vehicle (AEV) Major Component Schematic

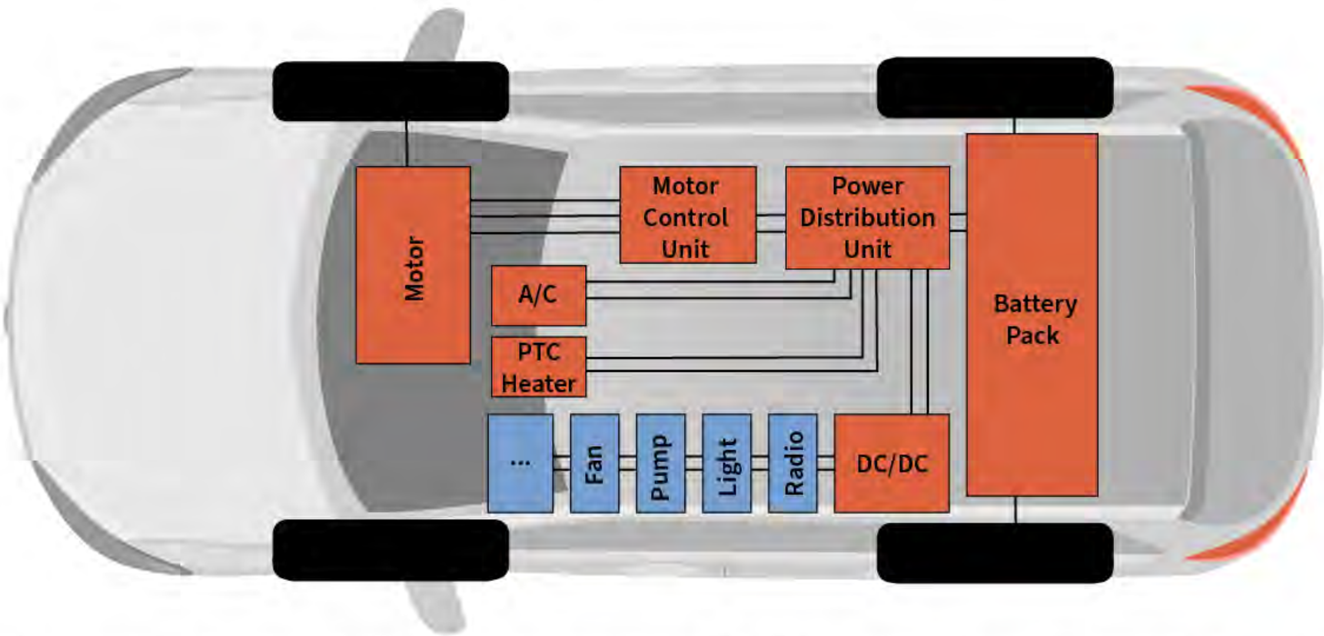

Figure 1. AEVs use the battery pack as the main energy source, which distributes power through the Power Distribution Unit (PDU) to the various energy conversion sources until power is applied directly to the wheels through the drive motor.

supply, and support electric vehicles. Based on this research, they designed a road map for transitioning from gas-powered vehicles to fully electric vehicles. While this road map focused on transitioning Army vehicles to a fully electric fleet, it can also be applied to other organizations with large vehicle fleets including federal agencies, state and local governments, universities, and commercial industries such as food and beverage, retail, utilities, construction, sanitation, landscaping, and more.

The road map can guide industry executives and public policymakers along the transition from gas-powered to fully electric commercial and passenger vehicles. In addition to this road map, the initiative provides a vehicle technology outlook with key insights into improving EV batteries and securing the strategic materials needed for EV production.

Moving from Gas-Powered to Electric Vehicles

The US government's goal is to have half of new vehicles sold to be zero emissions by 2030 and is making investments in 500,000 EV rapid chargers. By 2035, the US government will end purchases of gas-powered vehicles and the US Army will move to an all-electric (AE) non-tactical vehicle (NTV) fleet. To support these objectives, this initiative has produced a road map—called an Electrification Campaign Plan—for moving to an AE NTV fleet by 2035, then to AE, for *all* Army vehicles, by 2070. The study recommended a gradual transition, beginning with hybrid electric (HE) vehicles, which significantly reduce fossil fuel consumption, to ease the logistics of going from fossil fuel-powered vehicles to AE.

The initiative identifies three key decision points along a timeline for the Army to move from current fossil fuel-powered vehicles, to HE vehicles, then to AE vehicles:

- **By 2028, procure HE vehicles that are purpose built for upgrades to full AE later.** The initiative recommends parallel hybrid-electric vehicles (PHEVs), with an upgradeable configuration to AE. PHEVs are optimal because they can use either an electric battery or a motor/generator to power the vehicle if one of the systems is damaged.
- **Between 2030 and 2065, establish a mixed HE and AE fleet.** This builds in time for phasing out internal combustion engine (ICE) components and parts, phasing out HE parts, and allowing for the maturity of AE vehicles.
- **By 2070, upgrade all HE vehicles to AE and purchase AE vehicles to achieve a fully AE fleet.** To accomplish this objective, the study emphasized the importance of improving energy storage technology and securing access to the strategic materials needed for EVs.

Improving Energy Storage Technology

Improving EV battery performance is critical to increasing the adoption of EVs. Current Lithium-ion (Li-ion) batteries contribute to "range anxiety"—the fear of driving an electric car and running out of power. In addition, they are flammable if punctured or if they experience high temperatures. Additionally, Li-ion batteries depend on nickel, cobalt, and manganese, which are expensive and have supply chain challenges.

The study found that recent technological developments have made supercapacitors (SCAPs) a feasible option for energy storage. In contrast to batteries, which use chemistry in the form of chemical potential, to store energy, SCAPs store energy in the form of electrical charge. This allows for rapid charge times (on the order of a few seconds). Moreover, unlike batteries, SCAPs do not experience degraded power under extreme weather conditions.

While it is unlikely that SCAPs will replace batteries completely, they can have supplemental benefits in combination with a system's battery. A battery provides higher specific energy—the total amount of energy an energy storage device holds—so it can run for much longer than SCAPs. However, SCAPs have far higher specific power—the speed at which the power can be discharged—meaning they can provide a higher current. SCAPs need further development for mass production, but they are projected to be a feasible mass-produced technology in the mid-term future. Therefore, the study recommends:

- **Blending SCAPs with batteries into one combined energy storage system that harnesses the benefits of both.** The high-power density of SCAPS complements the high energy density of batteries. Further development of SCAPs and stable batteries is important for the energy storage future.
- **PHEVs should contain a SCAP hybrid system where SCAPs are used to store energy and then disburse it to electric components.** SCAPs are best used with Kinetic Energy Recapture Systems (KERS), which work by converting the energy of motion when the vehicle decelerates into electrical energy that is stored in a battery, supercapacitor, or as mechanical energy in a flywheel. SCAP hybrid systems, when paired with KERS, have the capability to self-charge in austere environments.

Securing Access to Strategic Materials for EVs

Another obstacle to widespread American EV adoption is the fact that the US effectively relies on imports for 70% of its strategic metals, including those used in HE and AE batteries, as indicated by a 2017 USGS report. Moreover, China is home to at least 85% of the world's capacity to process rare earth ores into material that manufacturers can use for EV batteries.

Rare earth materials that are required to produce electrical components include terbium, praseodymium, neodymium, lanthanum, and dysprosium. Strategic materials that are essential for battery manufacturing and production include nickel, manganese, cobalt, copper, aluminum, graphite, and lithium.

The study emphasized that:

- The US must secure its rare earth and strategic materials supply chains. It is imperative to invest R&D funding into the US capability to expand rare earth materials mining and processing, along with alternative rare earth materials.
- The US must reopen rare earth material mining sites and lithium sites, along with modifying regulations that impede our ability to secure rare earth and strategic materials. Both steps are necessary to develop a full domestic supply chain.