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# Model study of a fuel cell range extender for a neighborhood electric vehicle (NEV)

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ABSTRACT

Fuel cell systems have the potential to provide high-efficiency, low-cost power for Neighborhood Electric Vehicles (NEVs). Model results are presented examining the utility of placing a hydrogen PEM fuel cell on-board a Miles Electric ZX40ST work truck NEV as an "after-market add-on" range extender to the existing battery electric drive train, thereby creating a NEVx. Through the development and use of the Sandia-Miles-Altergy Range Test (SMART) model, we have examined the potential for a number of PEM fuel cell stack systems (with varying output power), combined with various hydrogen storage and electrical storage system configurations to achieve the desired range extension for a single 8-h work shift. Furthermore, we have evaluated the "well-to-wheels" (WTW) and greenhouse gas (GHG) reductions, and assessed the costs (both capital and O&M) for the different NEVx configurations and operating profiles.

This analysis demonstrates that a NEVx incorporating a PEM fuel cell range extender provides a viable means of providing the desired range (or equivalently the runtime) while increasing the vehicle's versatility and maintaining its zero-emissions rating. A 5 kW fuel cell system with 2.6 kg of hydrogen stored at 2265 psi in conventional steel cylinders can meet the demands of the low-power duty cycles envisioned for the NEVx. A slightly higher powered NEVx with a 7.5 kW fuel cell offers the same advantages in operating profiles that require more power, for example with frequent starts, sustained higher speeds, or hilly routes. While currently expensive, the total cost per mile of the fuel cell range extender is comparable to conventional gasoline vehicles. The WTW GHG emissions of the NEVx are 40%–85% lower than those for a comparable gasoline powered vehicle, depending on the particular drive profile and sources of both hydrogen and electricity. The analysis shows that a fuel cell range extender can maintain the vehicle battery pack at a high state of charge (SOC) throughout the operating profile, thereby extending overall battery life and reducing charging time. The fuel cell range extender is currently envisioned as a drop-in retrofit for the existing Miles Electric ZX40ST work truck. However, with sufficient demand, a fully integrated new vehicle system could be both more efficient and less expensive. If designed into the NEVx from the start, the cost, weight, and emissions could all be reduced while increasing the payload space and versatility.



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## Introduction

Neighborhood Electric Vehicles (NEVs) are a special class of vehicle with a top speed on a flat, paved surface of 20–25 mph. Also called Low-Speed Vehicles (LSVs), most states permit these vehicles on public roads with a posted speed of 35 mph or less. In the United States, NEVs, like highway speed vehicles, fall under the jurisdiction of the National Highway Traffic Safety Administration (NHTSA), and are classified under Federal Motor Vehicle Safety Standard (FMVSS) 49 CFR 571.500, or more simply, standard 500 [1,2]. Standard 500 requires low-speed vehicles to be equipped with headlamps, stop lamps, turn signal lamps, tail lamps, reflex reflectors, parking brakes, rearview mirrors, Department of Transportation (DOT) compliant windshields, DOT compliant seat belts, and vehicle identification numbers. There are currently ~500,000 NEVs on the road world-wide [3].

Battery powered NEVs are best suited for uses that do not require long-range daily driving, as the range of most NEVs is far less than a traditional highway speed vehicle. Fleet customers who have adopted NEVs for regular use include colleges, cities and towns, corporate campuses, airports, power companies, parks departments, the military and prison facilities. Uses for NEVs include security patrols, landscaping, refuse hauling, maintenance, groundskeeping, baggage hauling, mail delivery and people movers. Consumers who use NEVs generally use the vehicles for short commutes or for local transportation needs.

The Miles Electric ZX40ST work truck was selected for this study, and is considered representative of the class of NEVs for our discussion. The Miles ZX40ST is shown in Fig. 1.

The ZX40ST was originally a highway speed internal combustion engine (ICE) work truck that had been sold primarily in the Asian automotive market. This vehicle was subsequently converted to an all-electric, battery-powered NEV which is fully compliant with Standard 500. With all steel construction and reinforced side impact beams, crash resistant bumpers, and DOT compliant safety glass throughout, the ZX40ST actually offers a safety element not commonly found in other NEVs, many of which can best be described as golf cart variations. The ZX40ST underwent testing as required by the California Air Resources Board (CARB) to be classified and certified as a Zero Emission Vehicle (ZEV).

The U.S. federal government has issued many initiatives which require all federal fleets to substantially reduce fossil fuel consumption in order to comply with EPACT 2005, EISA 2007, and Executive Order 13514. It has been determined that all-electric vehicles provide a viable alternative fuel solution for achieving these goals. As an example, each gallon of petroleum-based fuel burned by an internal combustion vehicles creates about 20 lbs. of carbon dioxide ($CO_2$), resulting in the release of about 1.65 billion tons (1.5 billion metric tonnes) of greenhouse gases (GHGs) into the atmosphere in the United States each year [4]. All electric, zero emission vehicles create zero GHGs at the point of use.

The battery electric ZX40ST has a top speed of 24.9 MPH, and a range of 30–40 miles when fully charged. Charging the battery pack, which is comprised of six 12 V, 150 Ah AGM deep-cycle lead-acid batteries, is accomplished through an on-board 1200 W Delta-Q intelligent charger which uses standard 110 V AC grid electricity. To completely recharge a battery pack that has been discharged to the maximum recommended depth of discharge of 80% requires from 9 to 11 h and uses 9–11 kWh of electricity. A 25 foot charge cord which plugs into a charge receptacle on the ZX40ST vehicle is standard equipment. A Curtis Instruments programmable 550Ah controller communicates with the electrical components of the vehicle and sets parameters for a variety of functions such as speed, maximum RPM's, torque, state of charge (SOC), voltage thresholds, acceleration and braking. An AC 3-phase induction, 35 peak horsepower electric motor provides the power required to drive the vehicle at the rated speed. A single speed transmission is used with forward, reverse and neutral positions. The curb weight of the unladen ZX40ST is 2553 lbs, and the fully-loaded Gross Vehicle Weight Rating (GVWR) has been established at 2998 lbs in keeping within the maximum allowed NHTSA GVWR of 3000 lbs.

Most current users will typically drive the vehicle for a shift, and then return to their home base and plug in the vehicle for overnight charging. In the morning, the vehicle battery pack will be completely recharged. Although the current power train with the existing battery pack on the Miles ZX40ST meets the range requirements of many NEV customers, there have been requests for extended runtimes in instances where customers need the ability to drive the vehicles for a complete eight (8) hour shift without recharging the battery pack. For example, prison perimeter patrols require constant driving at slow speeds over an eight hour shift. Standard NEV lead acid battery packs do not store sufficient energy to run for these extended time periods. Security patrols on college campuses are another example where an increased range would eliminate the need to have additional vehicles in reserve so they can be switched out during a shift.


**Fig. 1 – Photographs of the Miles Electric ZX40ST battery electric work truck. Photos reproduced with permission from Miles Electric.**