Fleet Electrification Analysis: University of Mary Washington EXECUTIVE SUMMARY

Prepared by:

Sarah Stalcup-Jones
Research and Heavy-Duty Vehicle Programs Manager
Chief Equity Officer
Virginia Clean Cities
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Executive Summary:

Virginia Clean Cities (VCC) conducted an alternative fuel fleet analysis with the University of Mary Washington (UMW) focused on the feasibility and implementation of alternative fuel vehicle adoption (encompassing full battery electric vehicles (EV), plugin hybrid electric vehicles (PHEV), and hybrid electric vehicles (HEV)). The goals of the study are designed to align with the sustainability goals of the university as well as aligning with the City of Fredericksburg City Councils' wider sustainability vision and goals to achieve powering municipal operations with 100% renewable energy by 2035. The following report covers the analysis of the University of Mary Washington fleets.

After gathering fleet data from the UMW, VCC performed an analysis to create a baseline of UMW's current fleet and vehicle performance indicators, chart out available alternative fuel options, and create cost/benefit performance profiles showing the operational cost comparisons, the total cost of ownership, and total investment/return on investment needed for the city around each vehicle use case. We also provided recommendations on electric vehicle supply equipment (EVSE) site planning at UMW fleet locations based on priority vehicle replacements identified in the analysis and the city's fleet goals. UMW has a diverse fleet of vehicles covering many use cases and vehicle types. For this report, we will focus on the vehicles and use cases that would make the most sense for the replacement of alternative fuel vehicles in the short term while providing guidance for long-term fleet planning. For example, while data for multiple medium and heavy-duty vehicles were provided by the university, there are few viable EV and HEV alternatives on the market at this time. Since few electric alternatives are available, these vehicles should be prioritized for replacement in the long term or propane should be considered as a replacement fuel.

The vehicle use case feasibility profiles were subdivided into three categories: those light-duty use cases eligible for EV and HEV replacement, those medium-to-heavy-duty use cases to consider on a longer-term (4+ years) replacement schedule based on model availability and market factors, and those medium-to heavy-duty vehicles that may be better served by propane replacement. Figure 1 shows the 68-vehicle on-road fleet broken down by use case category.

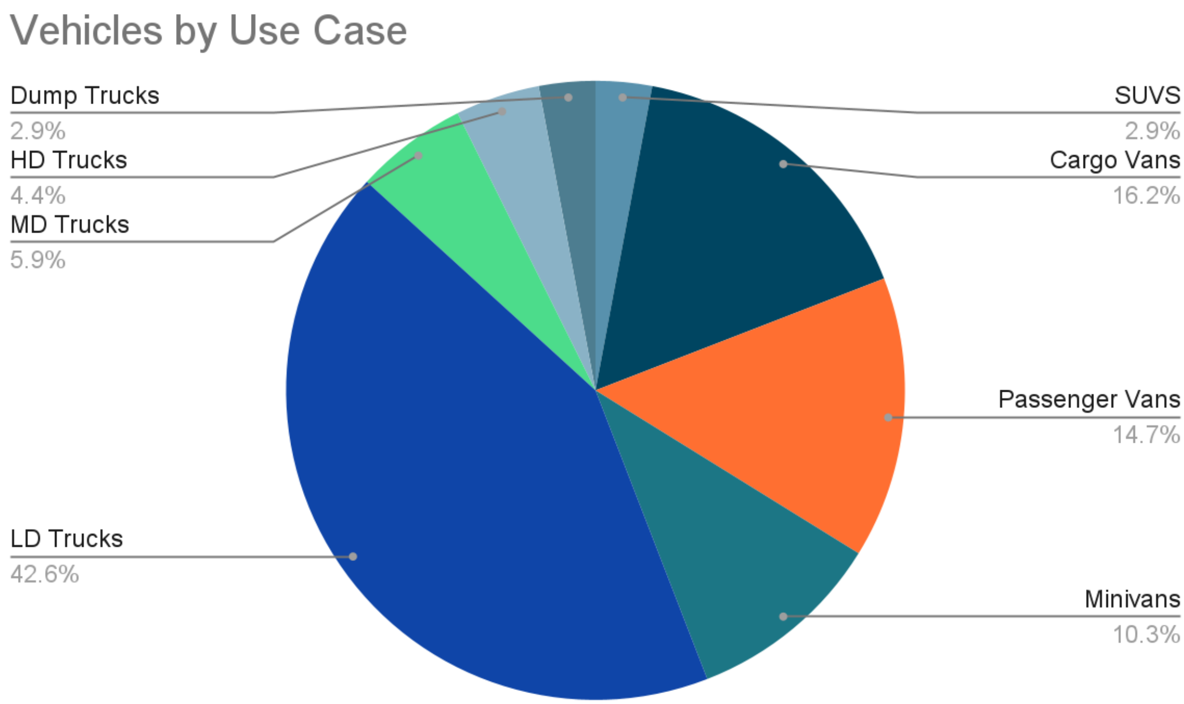

Figure 1: University of Mary Washington Fleet Vehicles by Class

While we enthusiastically support the increased use of alternative fuel vehicles, it is unlikely that the University of Mary Washington fleet will find it cost-effective to fully eliminate gasoline from operations in the near term. In the past, fleets have also been at a disadvantage when it comes to purchasing EVs, as they have been ineligible for the Federal EV Tax Credit. However, this analysis was conducted as a new tax credit was being developed. The Commercial Clean Vehicle Tax Credit could significantly reduce the cost of these electric vehicles. The Treasury Department has issued guidance that tax-exempt organizations qualify for between $7500 and $40,000 per vehicle, depending on vehicle weight. More guidance is forthcoming from Treasury and UMW would need to work with their vehicle vendor to develop a process for utilizing this tax credit. Since this process has not been finalized for public fleets, this incentive was not included in our analysis. Further, many fleets, particularly public fleets, have several advantages when purchasing non-electric fuels. These include exemptions from state fuel taxes and the ability to negotiate attractive pricing based on the large annual fuel volumes purchased. An additional factor that reduces the financial benefit of electric and hybrid vehicles is the low annual mileage of some of the university's vehicles. Vehicles with high annual mileage recognize the benefits of Virginia's stable and low-cost electricity faster than those with low annual mileage. Finally, existing supply chain disruptions are reducing the available supply of EVs and HEVs. However, we believe there are significant benefits to transitioning select areas of fleet operations to EVs in both the near and long term.

Baseline vehicle analysis

Using the EPA ratings for miles per gallon and the fleet's average total annual miles driven per year we can calculate the estimated baseline for fuel consumption (use and cost) and mileage for the University of Mary Washington fleet vehicles we can then sort by class/use case allowed for comparisons to be made, showing the potential effects and outcomes when using EVs, PHEVs, HEVs, and Propane vehicles as replacements to internal combustion engine (ICE) vehicles currently operating in the fleet. We did not include Passenger Vans or Dump truck data provided by UMW in this breakdown as there are currently no alternative fuel replacements on the market that would be cost-effective for the university.

KPI Averages Across Fleet Vehicle Classes											
Vehicle Class	Vehicle count	Average Model Year	Average Annual total Mileage	Miles per day**	2022 EPA MPG	2022 Fuel Gallon Usage (estimate)	2022 Fuel cost per gallon	2022 Fuel cost gas (estimate)	Fuel $/mile	2022 Maintenance $/mile	2022 Fuel +Maintenance $/mile
LD Truck (Ford F-150)	29	2010	3,223	13	21	154	$2.95	$454	$0.14	$0.16*	$0.30
Medium LD Truck (Ford F-250)	4	2005	4,378	18	15	292	$2.95	$862	$0.20	$0.16*	$0.46
Minivan	7	2000	3,703	15	22	168	$2.95	$496	$0.14	$0.24*	$0.38
Cargo Van	11	2002	4,489	18	16	281	$2.95	$829	$0.19	$0.23	$0.42
SUV	2	2011	2,368	9	24	99	$2.95	$292	$0.12	$0.15	$0.27

Table 1: Current KPI Averages Across Fleet Vehicle Classes
*denotes national average used
** based on 5 days a week, 50 weeks a year average

KPI Averages Across Fleet Vehicle Classes												
Conventional Vehicle	Alternative Fuel Vehicle	Average Daily Miles**	Conventional Vehicle MPG	Alternative EPA MPGGE	Efficiency	EPA kWH/ 100 miles	Battery Size (kW)	Range	% battery left after 1 day	Time to full charge from zero-level 2 (hours) ***	Days before full charge is needed	Payback period (years)
SUV	Chevrolet Bolt EUV	9	24	120	0.19	28	65	259	97%	17	29	No Payback
SUV	Ford Mach-E	9	24	103	0.22	33	70	247	96%	16.5	27.5	No Payback
SUV	Ford Explorer HEV	9	24	27	0.85	-	-	486	-	-	-	No Payback
LD Truck	Ford F-150 Lightning	13	21	68	0.31	48	98	230	94%	15	17.5	No Payback
LD Truck	Ford F-150 Hybrid	13	21	25	0.84	-	-	613	-	-	-	36.2 yrs
LD Truck	Ford Maverick Hybrid	13	21	37	0.57	-	-	511	-	-	-	Immediate
LD-MD Truck	Ford F-150 Lightning	18	15	68	0.22	48	98	230	92%	15	13	29.1 yrs
LD-MD Truck	Ford F-150 Hybrid	13	15	25	0.60	-	-	613	-	-	-	Immediate
Cargo Van	Ford E-Transit	18	16	63	0.25	50	68	126	86%	8.5	7	15.2 yrs
Minivan	Chrysler Pacifica PHEV	15	22	30	.73	41**	16	520	53%	2	2	17.7 yrs
Minivan	Chevrolet Bolt EUV	15	22	120	0.18	28	65	259	94%	17	17	Immediate

Table 2: Replacement KPI Averages Across Fleet Vehicle Classes

* based on 5 days a week, 50 weeks a year average
** when using electric drive only
*** Assuming mid-range L2 15kWh

The three (3) lightest fleet vehicle classes assessed (LD Trucks, SUVs, and Minivans) presented the best near-term options for EV replacements capable of resulting in an ROI over a 10-year vehicle lifecycle. The replacement options among these make-and-model use cases, along with their one-to-one EV replacements and approximate battery charging requirements (accounts for idling and in-use battery draws), are represented in Table 2. Note that any replacement with “immediate” payback is recommended for short-term replacement; many replacement options that result in a payback of greater than ten (10) years or are listed as “no payback” is likely related to the fleet’s low annual mileage. Fleet right-sizing could make more EV and HEV replacements viable for the University. An explanation of the minimum annual miles needed to achieve payback can be found in the following section.

Based on our analysis of the use case for each vehicle type and available electric and hybrid vehicles on the Virginia Sheriff's Contract, we have identified several vehicle types that present strong cases for EV and Hybrid replacement. These cases are based on Total Cost of Ownership (TCO) savings potential. For all vehicles, we recommend prioritizing the replacement of the oldest vehicles and those with the greatest annual miles.

Based on the existing truck, SUV, minivan, and cargo van model availability, our recommendations for replacements are as follows:

1) Priority/near-term - The oldest Light Duty pickups with Ford Maverick Hybrids

2) F-250 class trucks with F-150 Lightnings

3) SUVS with Bolt EUVs or Ford Mach-Es

4) Low mileage Minivans that stay on campus with Bolt EUVs

Other vehicles that the University should plan to replace in the medium and long term would be the minivans with Bolt EUVs or Hybrid Chrysler Pacificas, cargo vans with Ford E-transit 350s, and medium and heavy-duty trucks with electric alternatives that are expected to come to market or come down in price over the next decade. The University also should consider replacing the remaining light-duty trucks whose use cases could not be served by Maverick Hybrids with F-150 Lightning battery electric trucks. Figures 2-6 show the TCO comparisons over a 10 to 15-year lifecycle for replacing the average fleet vehicle with EVs/HEVs versus ICE vehicles. Figures 2-6 also include a TCO scenario in which the cost of procuring and installing one Level 2 charging station for every two EVs is included in the upfront capital cost since they are the closest to seeing TCO savings even with that additional purchase.

Total cost of ownership analysis

For this analysis, all vehicle comparisons utilize the base contract price provided on the Virginia Sheriff's contract unless otherwise specified. This rideable contract allows public entities such as local and state governments to purchase vehicles without requiring a procurement process. Fredericksburg would be considered in the "Heritage" region for procurement purposes. These analyses were performed using the AFLEET tool (spreadsheets attached). The AFLEET tool was designed by Argonne National Laboratory to examine both the environmental and economic costs and benefits of alternative fuel. This tool also provides default data that can be used to supplement fleet data. In these analyses, default maintenance and infrastructure cost data was utilized for each vehicle type. Explanation and data sources are provided in the "background data" tab of the AFLEET tool. For EV planning, 1 charger was estimated for every 2 vehicles. For this analysis, the following fuel prices were used as provided by UMW: $2.95/ gallon gas, and $0.08/ kWh for electricity.

For fleet light-duty trucks we recommend prioritizing near-term replacements with Ford Maverick Hybrids. The Ford Maverick Hybrid, while smaller than a Ford F-150, would create an immediate payback due to its higher gas mileage and lower purchase price, as seen in figure 2.

While Ford Maverick Hybrid will not be able to replace every use case for light-duty trucks, it can still serve many use cases and in AWD Configurations can tow up to 4,000 lbs. The Ford F-150 Lightning or Ford F-150 Hybrid would be the closest one-to-one replacements available to the fleet, however, with high purchase prices and high demand on vehicle stock they should be prioritized for longer-term replacement (3 to 4 years down the road). Additionally, with UMW's low average annual mileage, the larger F-150 EV and HEV replacements are unlikely to reach payback within the ten or fifteen-year expected lifetime of the vehicle. In order to reach payback for the fleet a Ford F-150 Lightning would need to be driven at least **13,500** annual miles and a Ford F-150 Hybrid would need to drive at least **12,000** annual miles. With fleet downsizing and redistribution of mileage across remaining vehicles, these annual mileages may be achievable for some vehicles. It is also important to consider that any LD truck replaced with a Ford Maverick Hybrid will reach payback immediately, these savings could be used to offset the costs of the more expensive F-150 Lightnings or F-150 Hybrids for fleet trucks that need a larger vehicle to serve their use cases.

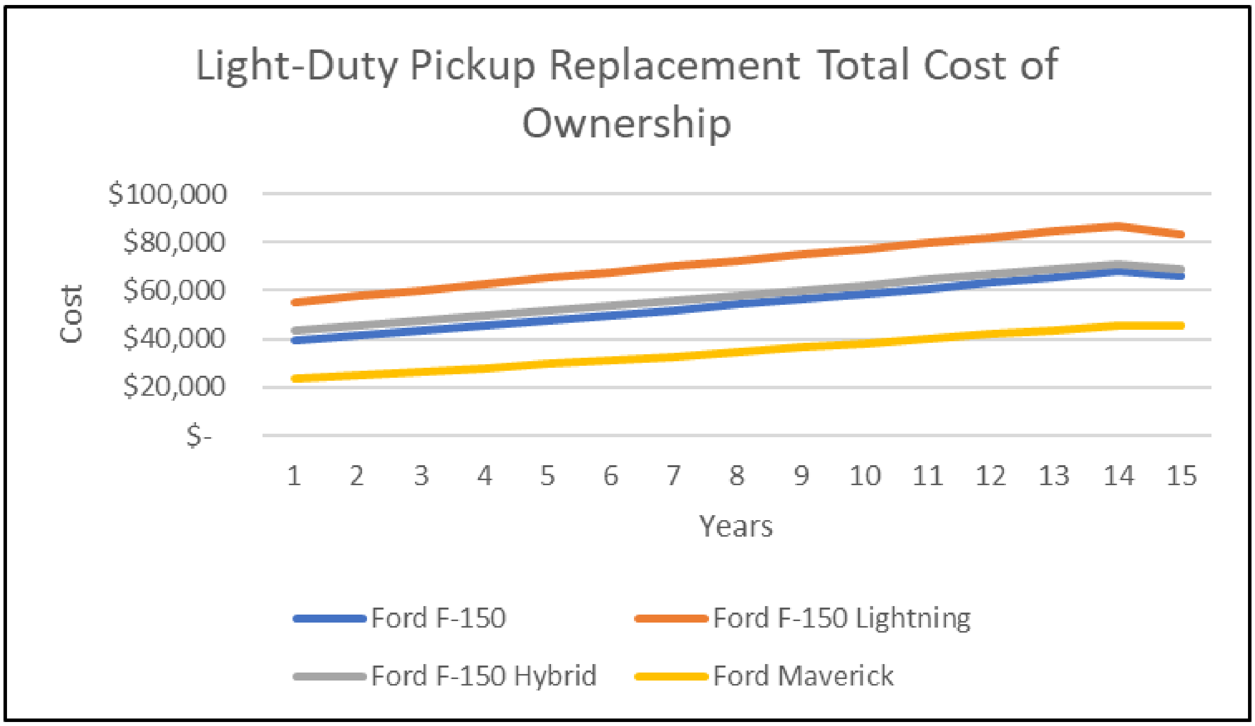

Figure 2: 2022 Light-Duty Truck, TCO Replacement Comparison, Average UMW Utilization of 3,223 annual miles, 15-year Lifecycle

The Ford F-150 Hybrid does make sense in the short-term for replacing slightly larger trucks such as the Ford F-250 and F-350, if the use case allows. The Ford F-150 Hybrid can tow up to 8,200 lbs in its conventional configuration and up to 12,100 lbs with upgraded configurations. Replacement with the Ford F-150 Hybrid would result in immediate payback. The Ford-150 Lightning would only reach payback in 10 years for these medium light-duty trucks if they drove at least **7,500** miles annually (figure3).

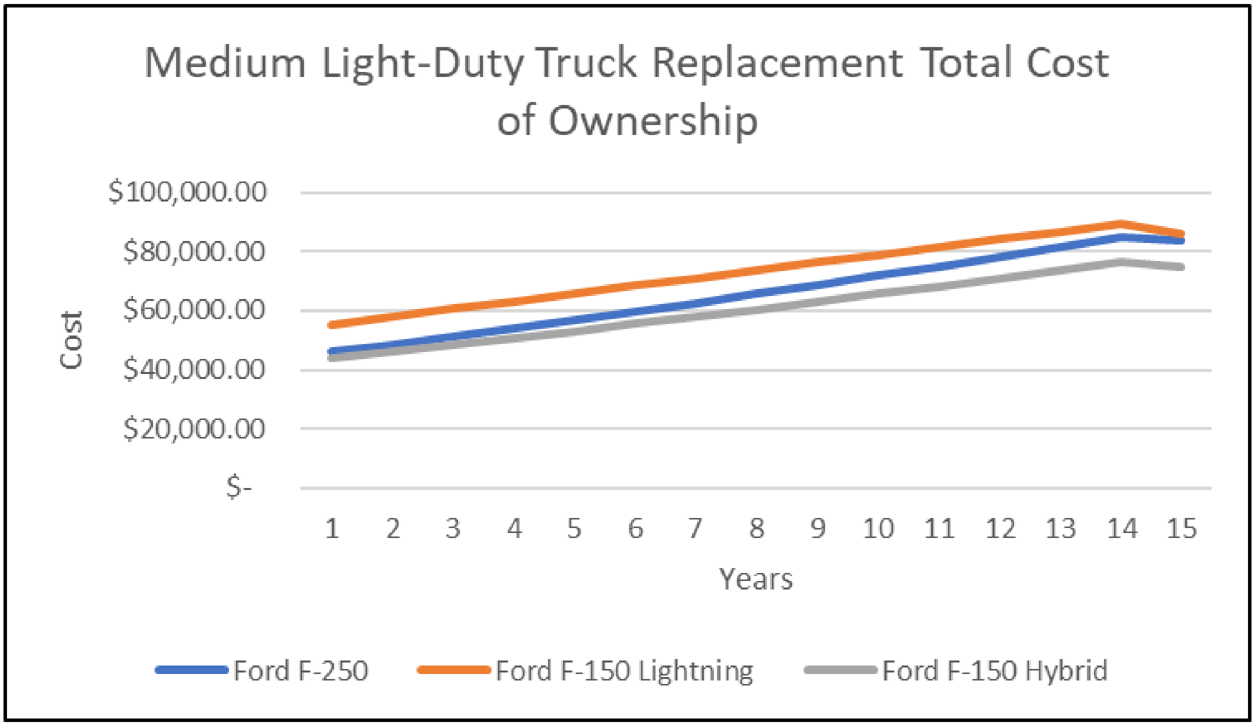

Figure 3: 2022 Medium Light-Duty Pickup, TCO Replacement Comparison, UMW Average Utilization of 4,378 annual miles, 15-year Lifecycle

Heavy and medium-duty trucks or any truck that has a use case that cannot be served by an F-250 or smaller, do not have cost-effective EV or HEV technology available on the market at this time. However, propane autogas conversions or replacements may offer the city GHG reductions and lower TCO. Propane conversions can be completed in most vehicle types and top out at class 7 heavy-duty vehicles with a GVWR of 33,000. Anything larger than 33,000 GVWR does not have a cost-efficient alternative fuel replacement at this time. The City of Fredericksburg is located in an ozone attainment and maintenance area which makes the city eligible for Congestion Mitigation and Air Quality Improvement (CMAQ) funding. The Program provides a reimbursement of up to an average of $10,000 for the incremental cost of a new vehicle or aftermarket conversion to propane autogas. This would only be recommended if UMW was able to utilize another entity's fueling station (such as one owned by the City of Fredericksburg) or if the university were to convert or replace 10 vehicles with propane, this is due to the high cost of building and maintaining a propane fueling station for a small number of vehicles.

For the fleet minivans, we recommend replacement with either Chevrolet Bolt EUVs or Chrysler Pacifica Hybrids (figure 4). Replacement with Chevy Bolt EUVs would result in immediate payback, however, Bolt EUVs are limited to 5 seats and are configured as a compact crossover SUV. For vehicles that require replacement with a transitional minivan configuration, we recommend the Chrysler Pacifica Hybrid. In order for the Pacifica Hybrid to reach payback in under 10 years the vehicle would need to travel at least **7,000** annual miles. The Pacifica Hybrid is a Plug-in Hybrid vehicle which means that it can travel approximately 32 miles on electric propulsion only before switching to gasoline and the hybrid battery. Fleet vehicles that travel less than 7,000 miles annually, but that travel less than 32 miles a day and utilize the vehicle's electric range can also expect to reach payback in less than 10 years.

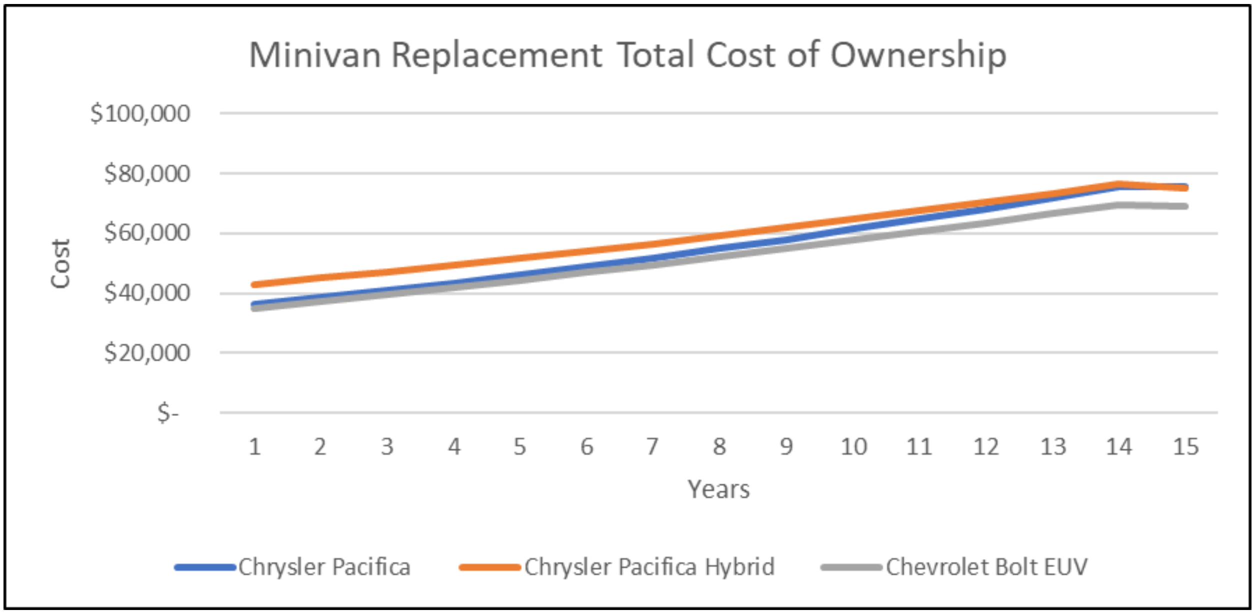

Figure 4: 2022 Minivan, TCO Replacement Comparison, Average UMW Utilization of 3,703 annual miles, 15-year Lifecycle

For fleet cargo Vans we recommend replacement with E-Transit T-350 130" WB Low Roof Cargo Vans on vehicles with higher annual mileage. Since specific van configurations were not provided, the standard 130" wheelbase, low roof configuration was used for this comparison (figure 5). In order for these vehicle replacements to reach payback in 10 years or less, vehicle miles will need to exceed **5,000** miles annually. At this time, we do not recommend the replacement of passenger vans with alternative fuel vehicles due to the high cost of the vehicles. While EV passenger vans are available on the market, their configurations often exceed $100,000, making payback unachievable at this time. As the cost of EV passenger vans decreases, this replacement may become a possibility for UMW fleets. Until that time we recommend the fleet consider if any passenger vans could be replaced by minivans or SUVs that do have viable EV and hybrid alternatives.

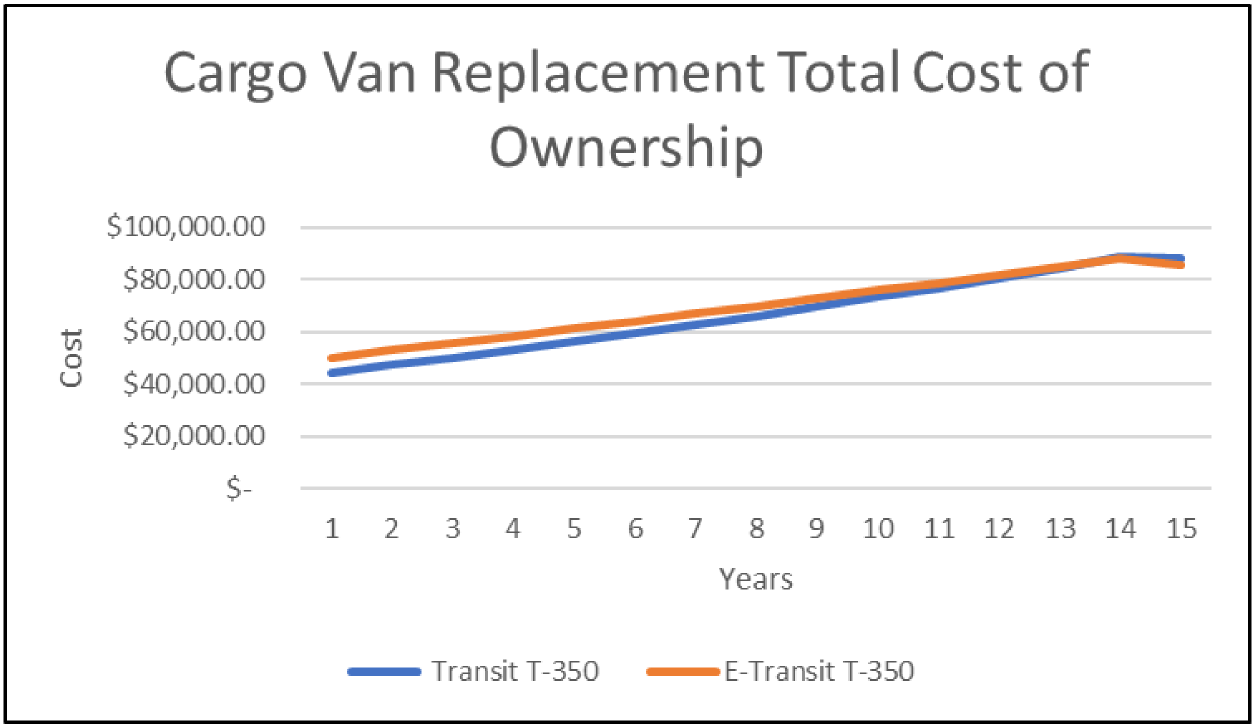

Figure 5: 2022 Cargo Van, TCO Replacement Comparison, Average UMW Utilization of 4,489 annual miles, 15-year Lifecycle

Full-sized SUVs, such as Ford Explorers, traveling at least **4,500** annual miles would expect to reach immediate payback if replaced with a Chevrolet Bolt EUV. Bolt EUVs may not be a one-to-one replacement for every SUV due to their smaller size and limit of only 5 seats. Ford Mach-Es have a larger cargo capacity (24 ft3) compared to the Bolt EUVs (16 ft^3) but will not achieve payback as quickly as the Bolt EUV due to their higher purchase price and lower MPGGE. In cases where a larger SUV-type vehicle is required, we recommend the Hybrid Ford Explorer for lower GHG emissions, especially in vehicles that frequently idle. However, at the current purchase price and MPG, the Hybrid Ford explorer is not expected to reach payback during the vehicle's life cycle, especially due to UMW's low contract price for gasoline. Price savings from replacements that produce immediate payback in other parts of the fleet may be able to offset this cost difference for Hybrid Explorer vehicles. Please see figure 6 for an SUV Total Cost of Ownership Comparison.

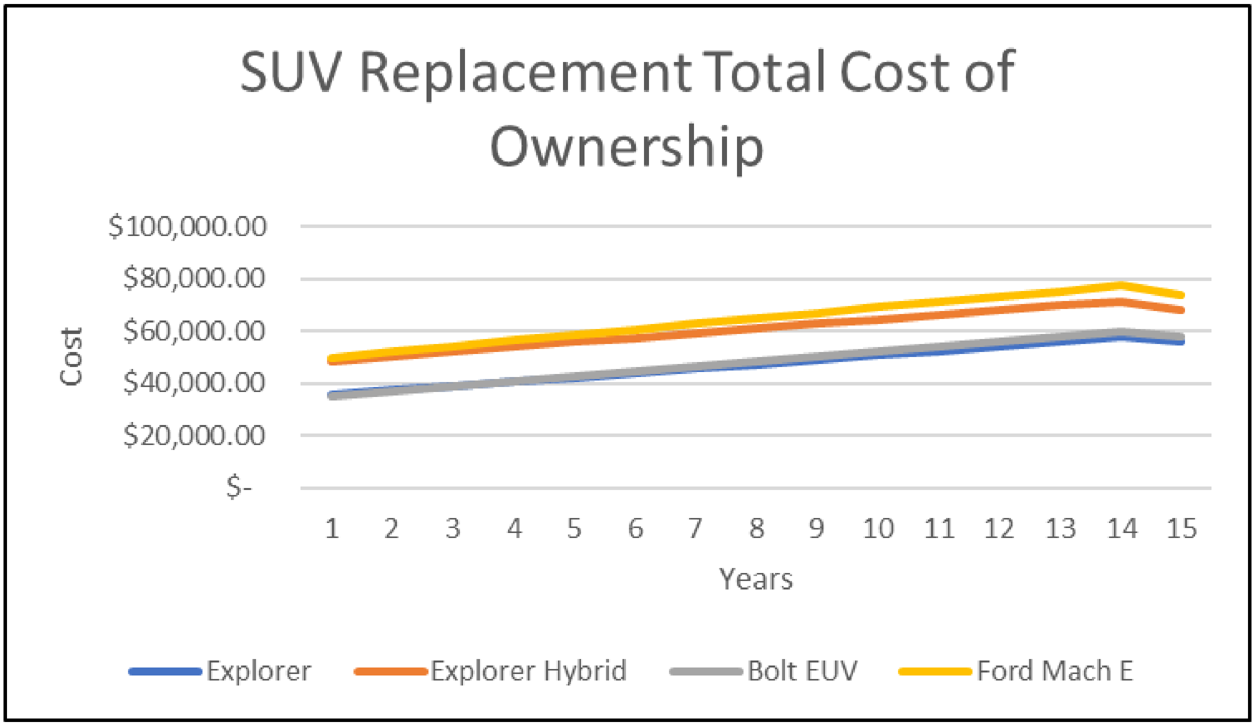

Figure 6: 2022 Ford Explorer, TCO Replacement Comparison, Average UMW Utilization of 2,368 annual miles, 15-year Lifecycle

GHG Emissions Savings

In this section, we compare the annual and lifetime GHG emissions savings for each vehicle replacement based on the average fleet vehicle. Replacement with EVs will always result in a higher reduction of GHGs than their HEV counterparts. These GHG reduction comparisons along with the previous total cost of ownership analysis can help the UMW weigh its environmental goals with its budget. EVs and PHEVs running only on electricity have zero tailpipe emissions, but emissions may be produced by the source of electrical power, such as a power plant. In geographic areas that use relatively low-polluting energy sources for electricity generation, PHEVs and EVs typically have a well-to-wheel emissions advantage over similar conventional vehicles running on gasoline or diesel. These GHG emission calculations were created using Fredericksburg's local energy mix breakdown, detailed in figure 7.

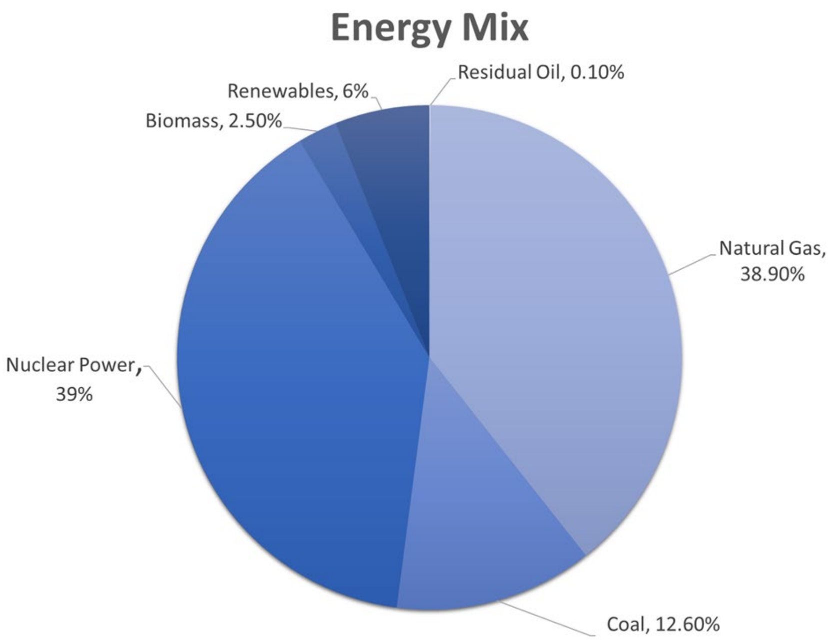

Figure 7: Fredericksburg, VA electric grid mix https://www.epa.gov/egrid/power-profiler#/SRVC

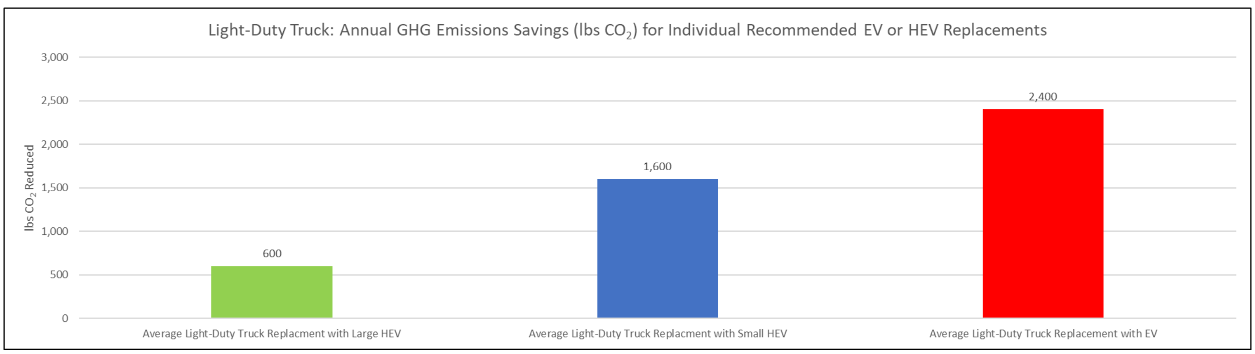

Figure 8: Light-Duty Truck Annual GHG Emissions Savings

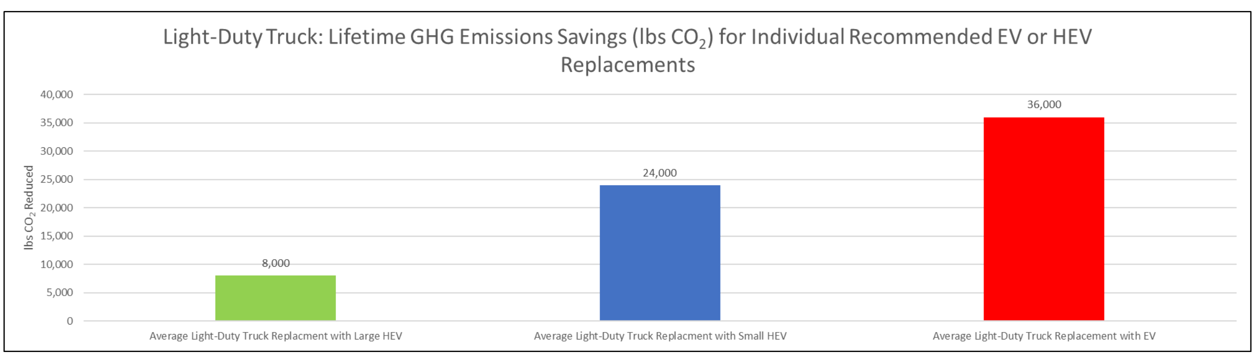

Figure 9: Light-Duty Truck Lifetime GHG Emissions Savings

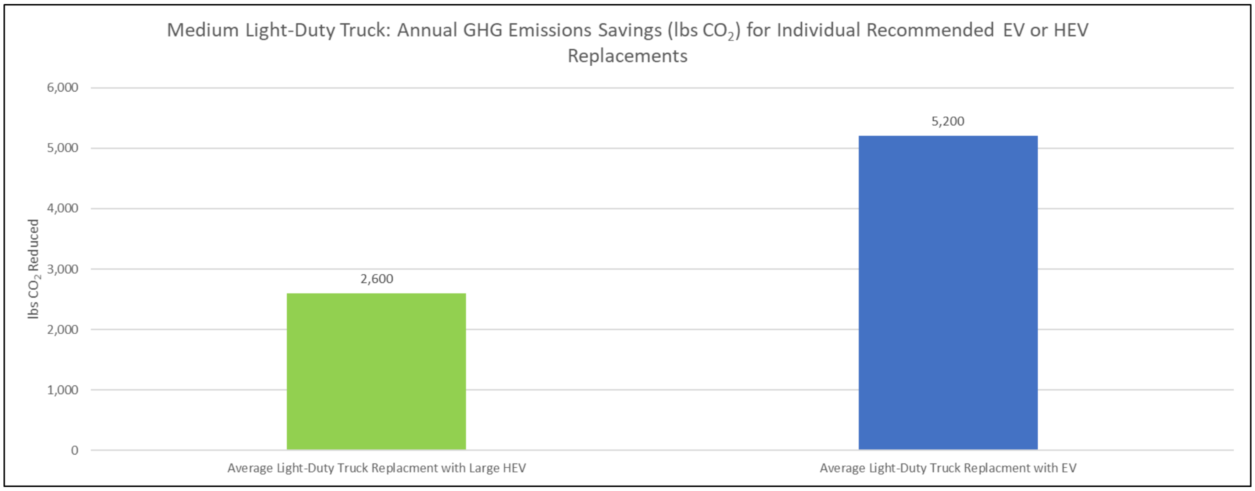

Figure 10: Medium Light-Duty Truck Annual GHG Emissions Savings

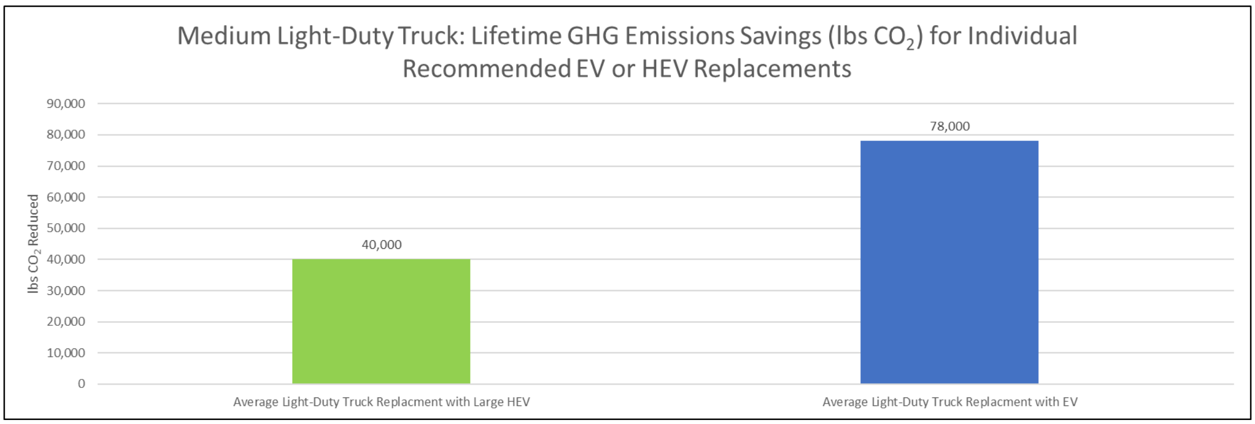

Figure 11: Medium Light-Duty Truck Lifetime GHG Emissions Savings

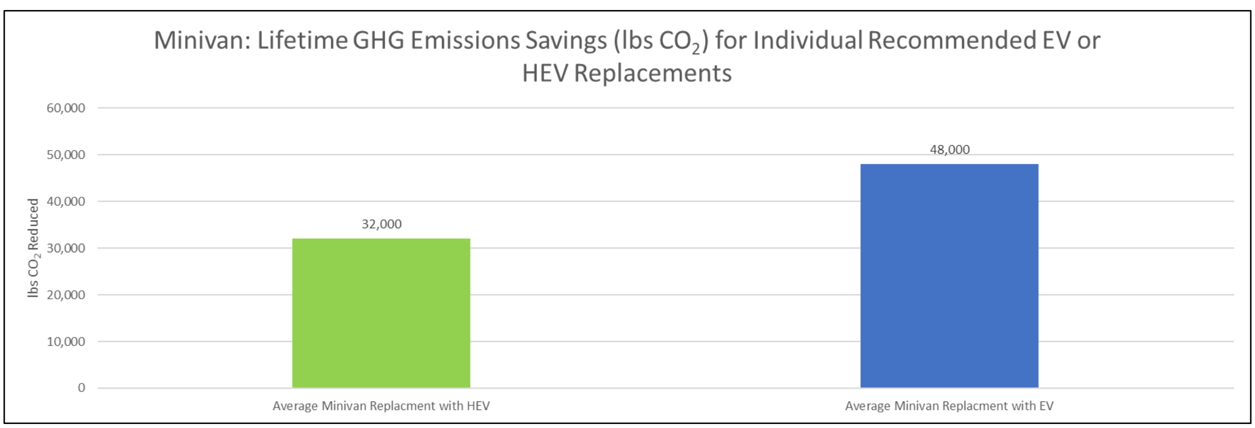

Figure 12: Minivan Annual GHG Emissions Savings

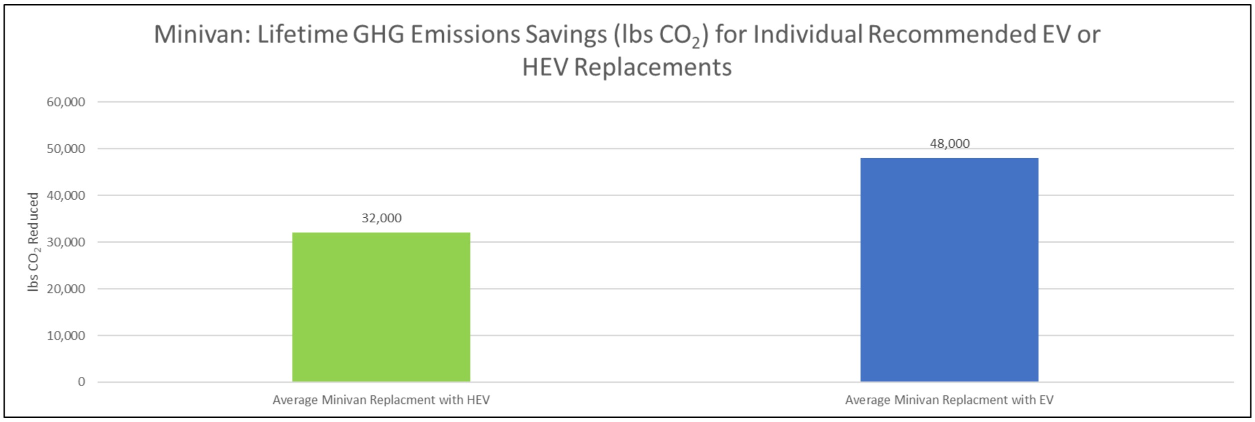

Figure 13: Minivan Lifetime GHG Emissions Savings

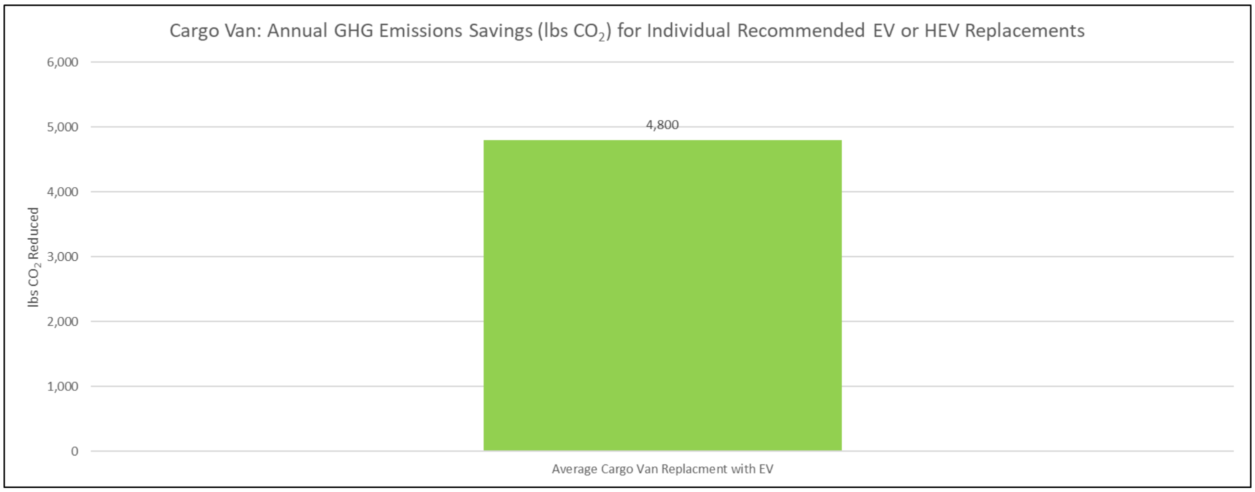

Figure 14: Cargo Van Annual GHG Emissions Savings

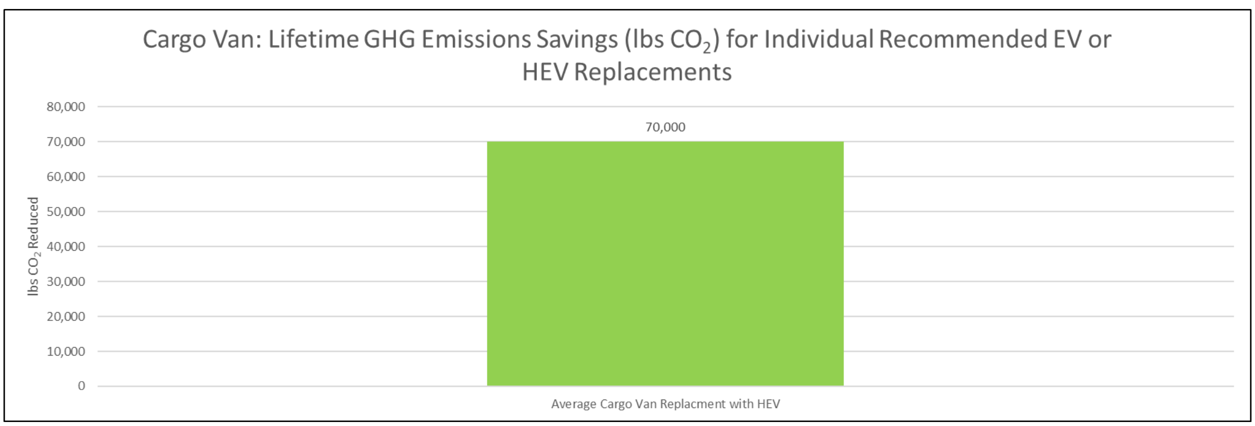

Figure 15: Cargo Van Lifetime GHG Emissions Savings

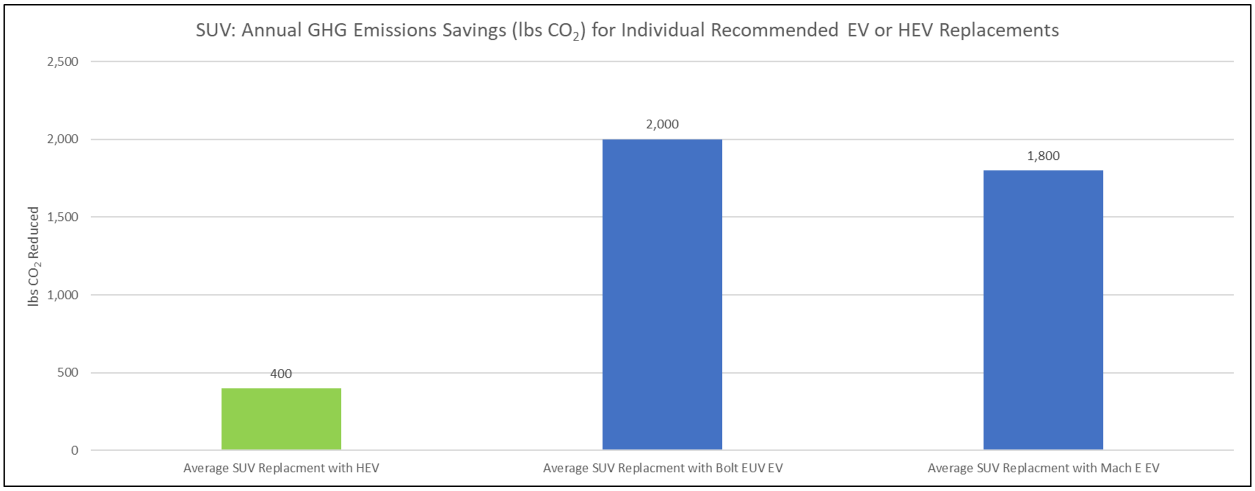

Figure 16: SUV Annual GHG Emissions Savings

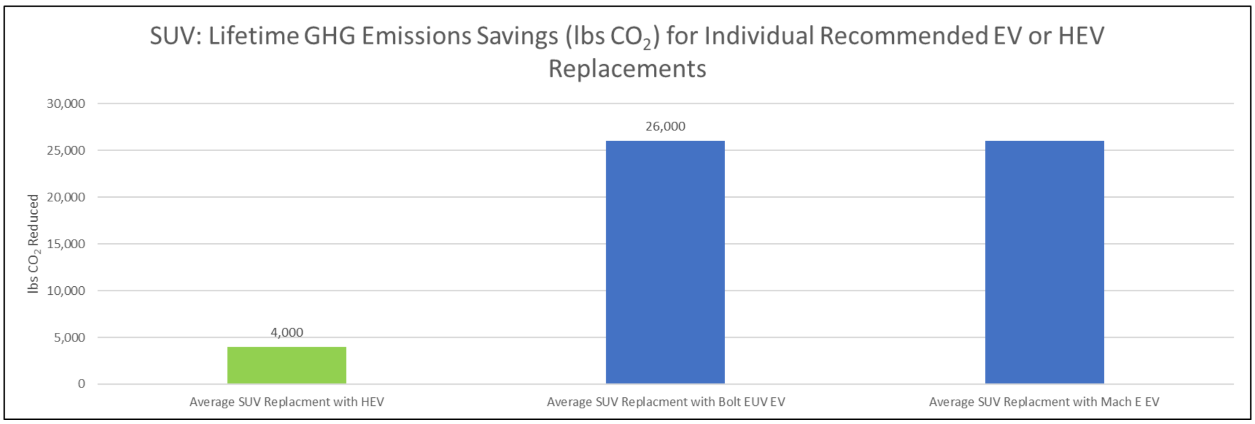

Figure 17: SUV Lifetime GHG Emissions Savings

Fleet and vehicle right-sizing

Fleet right-sizing is also a valuable strategy for reducing operations and maintenance costs and should be one of the first steps taken when considering alternative fuel replacements. Fleet right-sizing can be done in two ways, first by reducing the number of vehicles in a fleet, and second by decreasing the size of the vehicle in a fleet. Alternative fuels achieve higher TCO savings at higher utilization rates. This is because the biggest money-saving factor of alternative fuel vehicles is their less expensive fuel costs. By removing lesser-used vehicles from their fleet and distributing those miles across the remaining vehicles, the University of Mary Washington could increase the impact of alternative fuel vehicle replacements through less expensive fuels and fewer vehicles to maintain. UMW could also decrease its vehicle costs and emissions by vehicle right-sizing. As an example, please see UMW expected TCO for SUVs and Light- Duty trucks in the Total Cost of Ownership section.

UMW should also engage in right-sizing their charger planning. Not all vehicles need their gas tanks refilled daily, and the principle same applies to EVs. Planning charging infrastructure that allows vehicles with lower daily mileage to share a charger can significantly reduce infrastructure costs. If vehicles are parked alone, but have consistent dwell times such as overnight, you may consider a slower but less expensive charger option.

Key Recommended Actions

EV Options Assessment

1. **Near term (next two to three years)**
   a. **Consider where fleet right-sizing can occur**
      i. **Remove vehicles that accumulate low annual miles and redistribute their use across remaining vehicles**
      ii. **Consider what vehicles can be replaced with smaller vehicles ex: Ford F-150s that can be replaced with smaller Ford Hybrid Mavericks or Ford Explorers that can be replaced with smaller Bolt EUVs**
   b. **Phase in the procurement of Ford Maverick Hybrids for fleet light-duty trucks. Phase in procurement of Chevrolet Bolt EUVs for fleet SUVs and fleet Minivans. Phase in procurement of Ford F-150 Lightnings for medium light-duty trucks (Ford F-250s and F-350s).**
      i. **Prioritize replacement of older vehicles and those with the highest annual mileage first**
      ii. **Utilize immediate payback from replacements with Maverick Hybrids and Bolt EUVs to offset the more expensive Ford F-150 Lightning replacements for light-duty trucks that have use cases that cannot be served by Maverick Hybrids**

2. **Long Term (next 4+ years)**
   a. ***Ford F-Series Pickup Trucks and Comparable Models***
      i. ***The forthcoming 2022 Ford F-150 Lightning is very close to producing an ROI for the average use case in the fleet: should the MSRP drop from a 48% price increase to a 31% price increase compared to the ICE F-150, or the average mileage utilization of the fleet F-Series vehicles increase to 13,500 miles annually (from ~3000 miles), these should be considered feasible replacement options.***
      ii. ***Currently, the Ford Lightning only comes in the F-150 pickup option: should Ford begin releasing similar options for the rest of the F-Series, these should be considered under comparable market and utilization conditions.***

b. ***Passenger/Cargo Vans***
   i. ***The forthcoming 2022 Ford E-Transit series can produce a positive ROI should the MSRP drop from a 34% price differential to a 16% price differential compared to the ICE Transit van (high-roof, regular wheelbase version) and these should be considered feasible replacement options on the medium-term replacement schedule.***
   ii. ***Currently, the E-Transit only comes in cargo van options: should Ford begin releasing similar options for passenger vans, these should be considered under comparable market and utilization conditions.***
      1. ***Customization for passenger van configurations is available, however, current price estimates exceed $100,000.***

c. ***If downsizing minivans to smaller vehicle types is not feasible in the short term, replacement with Chrysler Pacifica Hybrids in the medium term should be considered as the cost of the technology decreases or as savings are accumulated from other vehicle replacements.***

EVSE Procurement and Installation Recommendations

1. ***Consider level 1 chargers for vehicles running 35 miles/day or less, approximately 8,500 annual miles, if they can be charged overnight for 8 hours after each use.***

2. ***Based on the above EV assessment and the data provided, the following are our recommendations for prioritizing the procurement and installation of Level 2 charging stations:***
   a. ***Prioritize installations at locations where multiple vehicles park. The creation of central hub locations for charging infrastructure, that allow multiple vehicles to share one charger, has the best current financial case for electrifying. Like conventional ICE vehicles, most EVs will not need to be charged every day, so can share a charger.***
   b. ***Prioritize charging stations at locations where fleet vehicles frequently travel to on campus such as maintenance shops, and athletic fields***
      i. ***Consider if these chargers would be available for public use***
   c. ***At UMWs current vehicle use rate level 3 chargers are unnecessary***

Exploring Fleet Management Options

1. ***Create Right-Sizing Policies and Procedures for all new vehicle and equipment acquisitions.***

2. ***Conduct a detailed fleet vehicle utilization study and develop a process for regular review. Establish procedures to ensure fleet size matches current staffing levels and overall***

operational needs. Coordinate strategic higher utilization and down-sizing when appropriate to increase cases where an EV replacement results in TCO savings.
3. ***Create new procedures to establish vehicle lifecycle and replacement schedules that will maximize useful life of equipment while reducing operational and maintenance costs.***
4. Develop procedures to track and eliminate unnecessary vehicle idling including: ***a. Creation of a clear tracking system*** ***b. Development of Idle Reduction Training Program for Equipment Operators*** ***c. Deployment of cost-effective technologies such as GPS tracking systems, engine timers, auxiliary power systems, and automatic engine shutdown devices***

Additional Background

Hybrid Electric Vehicles

Today's hybrid electric vehicles (HEVs) are powered by an internal combustion engine in combination with one or more electric motors that use energy stored in batteries. HEVs combine the benefits of high fuel economy and low tailpipe emissions with the power and range of conventional vehicles.

Help from an Electric Motor

In an HEV, the extra power provided by the electric motor may allow for a smaller combustion engine. The battery can also power auxiliary loads and reduce engine idling when the vehicle is stopped. Together, these features result in better fuel economy without sacrificing performance.

An HEV cannot plug in to off-board sources of electricity to charge the battery. Instead, the vehicle uses regenerative braking and the internal combustion engine to charge. The vehicle captures energy normally lost during braking by using the electric motor as a generator and storing the captured energy in the battery.

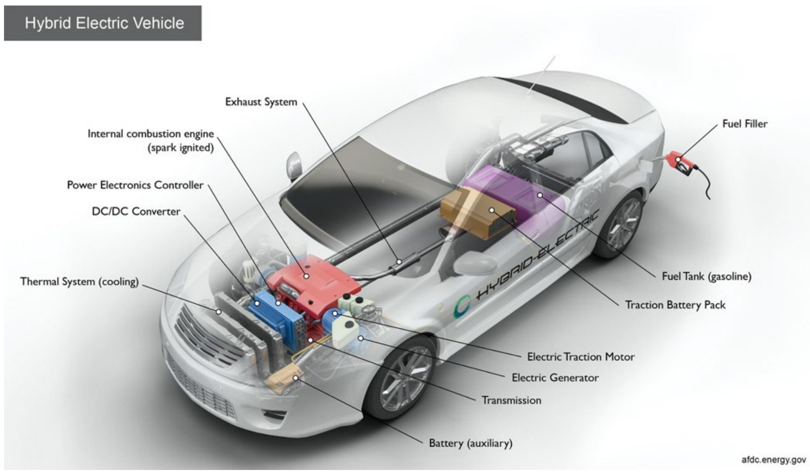

Figure 1: Key Components of a Hybrid Electric Car

HEVs can be either mild or full hybrids, and full hybrids can be designed in series or parallel configurations.

- **Mild hybrids**—also called micro hybrids—use a battery and electric motor to help power the vehicle and can allow the engine to shut off when the vehicle stops (such as at traffic lights or in stop-and-go traffic), further improving fuel economy. Mild hybrid systems cannot power the vehicle using electricity alone. These vehicles generally cost less than full hybrids but provide less fuel economy benefit than full hybrids.

- **Full hybrids** have larger batteries and more powerful electric motors, which can power the vehicle for short distances and at low speeds. These vehicles cost more than mild hybrids but provide better fuel economy benefits.

Plug-in Hybrid Electric (PHEV)

Plug-in hybrid electric vehicles (PHEVs) use batteries to power an electric motor, as well as another fuel, such as gasoline or diesel, to power an internal combustion engine or other propulsion source. PHEVs can charge their batteries through charging equipment and regenerative braking. Using electricity from the grid to run the vehicle some or all of the time reduces operating costs and fuel use, relative to conventional vehicles. PHEVs may also produce lower levels of emissions, depending on the electricity source and how often the vehicle is operated in all-electric mode.

PHEVs have an internal combustion engine and an electric motor, which uses energy stored in batteries. PHEVs generally have larger battery packs than hybrid electric vehicles. This makes it possible to drive moderate distances using just electricity (about 15 to 60-plus miles in current models), commonly referred to as the "electric range" of the vehicle.

During urban driving, most of a PHEV's power can come from stored electricity. For example, a light-duty PHEV driver might drive to and from work on all-electric power, plug the vehicle in to charge at night, and be ready for another all-electric commute the next day. The internal combustion engine powers the vehicle when the battery is mostly depleted, during rapid acceleration, or when intensive heating or air conditioning loads are present.

PHEV batteries can be charged by an outside electric power source, by the internal combustion engine, or through regenerative braking. During braking, the electric motor acts as a generator, using the energy to charge the battery, thereby recapturing energy that would have been lost.

PHEV fuel consumption depends on the distance driven between battery charges. For example, if the vehicle is never plugged in to charge, fuel economy will be about the same as a similarly sized hybrid electric vehicle. If the vehicle is driven a shorter distance than its all-electric range and plugged in to charge between trips, it may be possible to use only electric power. Therefore, consistently charging the vehicle is the best way to maximize the electric benefits.

Battery Electric Vehicles (EV)

All-electric vehicles (EVs), also referred to as battery electric vehicles, use a battery pack to store the electrical energy that powers the motor. EV batteries are charged by plugging the vehicle in to an electric power source. Although electricity production may contribute to air pollution, the U.S. Environmental Protection Agency categorizes all-electric vehicles as zero-emission vehicles because they produce no direct exhaust or tailpipe emissions.

Light-duty EVs are commercially available. EVs are typically more expensive than similar conventional and hybrid vehicles, although some cost can be recovered through fuel savings, a federal tax credit, or state incentives.

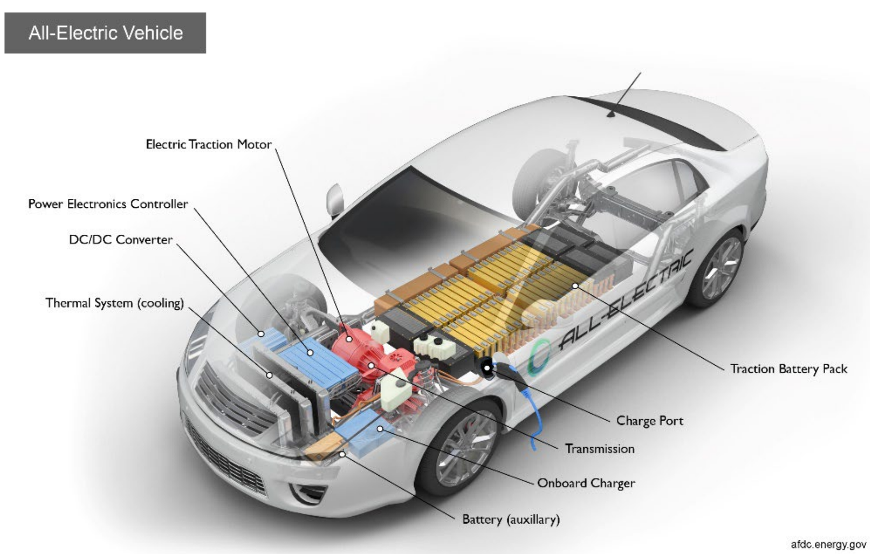

Figure 2: Key Components of an Electric Vehicle

Today's EVs generally have a shorter range (per charge) than comparable conventional vehicles have (per tank of gas). However, the increasing range of new models and the continued development of high-powered charging equipment is reducing this gap. The efficiency and driving range of EVs varies substantially based on driving conditions. Extreme outside temperatures tend to reduce range, because more energy must be used to heat or cool the cabin. EVs are more efficient under city driving than highway travel. City driving conditions have more frequent stops, which maximize the benefits of regenerative braking, while highway travel typically requires more energy to overcome the increased drag at higher speeds. Compared with gradual acceleration, rapid acceleration reduces vehicle range. Hauling heavy loads or driving up significant inclines also has the potential to reduce range

For PHEVs and electric vehicles additional infrastructure will be necessary. These electric police vehicles are designed to charge on a J1772 standard electric vehicle chargers operating at medium amperage. While equipment for medium amp electric vehicle chargers are currently listed at between $200 to $2,000 from many vendors, the installation, wiring, conduit, and appropriate siting of the charger may represent a project of far greater cost. For pilot projects, ease of installation of equipment and lowering costs with close proximity to available electrical equipment and limited trenching should be considered.

An example of a portable 15-amp level 1 electric vehicle charger which would charge vehicles at up to 1 kWh. All EVs come equipped with this equipment.

An example of a wall or pedestal mounted 40-amp level 2 electric vehicle charger capable of charging vehicles at up to 7.7 kWh.

Battery Overview

Energy storage systems, usually batteries, are essential for all-electric vehicles, plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs).

Lithium-ion batteries are currently used in most portable consumer electronics such as cell phones and laptops because of their high energy per unit mass relative to other electrical energy storage systems. They also have a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge. Most components of lithium-ion batteries can be recycled, but the cost of material recovery remains a challenge for the industry. The U.S. Department of Energy is also supporting the Lithium-Ion Battery Recycling Prize to develop and demonstrate profitable solutions for collecting, sorting, storing, and transporting spent and discarded lithium-ion batteries for eventual recycling and materials recovery. Most of today's all-electric vehicles and PHEVs use lithium-ion batteries, though the exact chemistry often varies from that of consumer electronics batteries. Research and development are ongoing to reduce their relatively high cost, extend their useful life, and address safety concerns in regard to overheating.

Since Electric-drive vehicles are relatively new to the U.S. auto market, only a small number of them have approached the end of their useful lives. As electric-drive vehicles become increasingly common, the battery-recycling market may expand.
Widespread battery recycling would keep hazardous materials from entering the waste stream, both at the end of a battery's useful life and during its production. The material recovery from recycling would also reintroduce critical materials back into the supply chain and would increase the domestic sources for such materials. Work is now underway to develop battery-recycling processes that minimize the life-cycle impacts of using lithium-ion and other kinds of batteries in vehicles. But not all recycling processes are the same and require different methods of separation for material recovery:

- Smelting: Smelting processes recover basic elements or salts. These processes are operational now on a large scale and can accept multiple kinds of batteries, including lithium-ion and nickel-metal hydride. Smelting takes place at high temperatures where organic materials, including the electrolyte and carbon anodes, are burned as fuel or reductant. The valuable metals are recovered and sent to refining so that the product is suitable for any use. The other materials, including lithium, are contained in the slag, which is now used as an additive in concrete.
- Direct recovery: At the other extreme, some recycling processes directly recover battery-grade materials. Components are separated by a variety of physical and chemical processes, and all active materials and metals can be recovered. Direct recovery is a low-temperature process with minimal energy requirement.
- Intermediate processes: The third type of process is between the two extremes. Such processes may accept multiple kinds of batteries, unlike direct recovery, but recover materials further along the production chain than smelting does.
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Separating the different kinds of battery materials is often a stumbling block in recovering high-value materials. Therefore, battery design that considers disassembly and recycling is important in order for electric-drive vehicles to succeed from a sustainability standpoint. Standardizing batteries, materials, and cell design would also make recycling easier and more cost-effective.

The U.S. Department of Energy (DOE) and its national laboratories are researching ways to reduce the lifecycle impacts of lithium-ion batteries. One of the National Renewable Energy Laboratory's (NREL) research objectives is to achieve a circular vision for lithium-ion batteries (e.g., see the following study https://www.nrel.gov/news/program/2021/pathways-to-achieve-new-circular-vision-for-lithium-ion-batteries.html).

In addition to battery recycling, second-life applications for batteries can extend the useful life of the technology. There are currently growing opportunities for EV batteries to be reused for a second life, such as to support the electricity grid. Here in Virginia, Dominion Energy is planning to pilot this technology with their deployment of electric school buses. By using a battery in a post-vehicle application, the lifetime value of the battery increases, and the cost of the battery can be shared between both the primary and secondary users. This could help resolve lithium-ion battery cost barriers to the deployment of both EVs and grid-connected energy storage.

This and more alternative fuel information can be found on the U.S. Department of Energy's Alternative Fuels Data Center.

About VCC

Virginia Clean Cities at James Madison University (VCC-JMU) is a university hosted government- industry partnership designed to promote healthful air through the reduction of petroleum consumption in the transportation sector by advancing the use of alternative fuels and vehicles, idle reduction technologies, hybrid electric vehicles, fuel blends, and fuel economy. Virginia Clean Cities is one of nearly 100 Department of Energy (DOE) sponsored coalitions across the U.S. that help meet the objectives of improving air quality, developing regional economic opportunities, and reducing the use of imported petroleum. Virginia Clean Cities was incorporated in November 2001 as a 501 (c) (3) non-profit corporation.

Appendix: Federal Tax Incentives and Programs

Alternative Fuels Excise Tax Credit. Section 13201 extends the $0.50 per gasoline gallon equivalent excise tax credits for alternative fuels from 2021 through 2024. Public transit agencies that fuel their vehicles with compressed natural gas (CNG), liquefied natural gas (LNG), or liquified hydrogen benefit from this tax credit. Transit agencies may file a claim for payment equal to the amount of the alternative fuel credit. The credit is first applied to the applicable excise tax liability under section 26 U.S.C. § 4041 or 26 U.S.C § 4081, and any excess credit may be taken as a payment.

Biodiesel and Renewable Diesel Excise Tax Credit. This section also extends the $1.00 per gallon excise tax credits for biodiesel and renewable diesel from 2022 through 2024. Transit agencies may file a claim for payment equal to the amount of the biodiesel or renewable diesel tax credit.

Alternative Fuel Vehicle Refueling Property Credit. Section 13404 extends the alternative fuel vehicle refueling property credit from 2021 through 2032, and substantially restructures the credit. Refueling property is property for the storage or dispensing of clean-burning fuel or electricity into the vehicle fuel tank or battery. Clean-burning fuels include CNG, LNG, electricity, and hydrogen. The bill clarifies that bidirectional charging equipment is eligible property. Tax credits for refueling property used in a trade or business are part of the general business credit. Generally, in the case of refueling property sold to a tax-exempt entity, the taxpayer selling the property may claim the tax credit.

This section also substantially restructures the tax credit. Under current law, taxpayers may claim a 30 percent credit for an alternative fuel property up to $30,000 per location. The bill provides a base credit of six percent up to $100,000 per project. In addition, it provides a bonus credit totaling 30 percent for expenses up to $100,000 for each project if the taxpayer satisfies Davis-Bacon prevailing wage requirements during construction of the project. In addition, under the bill, the alternative fuel property is only eligible for the credit if the property is placed in service in a low-income community (under 26 U.S.C. § 45D(e)) or rural census tract.

Under the provision, the 2021 rules of the alternative fuel vehicle refueling property credit apply in 2022. In 2023 and subsequent years, the restructured tax credit will apply.

Commercial Clean Vehicle Tax Credit. Section 13403 creates a new tax credit for commercial clean vehicles (e.g., zero-emission buses). The amount of the credit with respect to a qualified commercial electric vehicle is equal to the lesser of 30 percent of the cost of the vehicle or the incremental cost of the vehicle. The limit of the credit is $7,500 for a vehicle that weighs less than 14,000 pounds and $40,000 for all other vehicles. Commercial clean vehicles include battery electric and fuel cell vehicles. This 10-year tax credit takes effect in 2023 and expires December 31, 2032. In January 2023 the IRS issued guidance that tax-exempt organizations qualify for this tax incentive (https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit).

$1 Billion for Clean Heavy-Duty Vehicles. Section 60101 provides $1 billion to EPA to carry out a new Clean Heavy-Duty Vehicles program. Under the program, EPA will make grants and rebates to states, municipalities, Indian tribes, and eligible contractors to replace Class 6 or Class 7 heavy-duty vehicles as defined in 40 CFR 1037.801 (i.e., vehicles with a gross vehicle weight between 19,501 pounds and 33,000 pounds) with zero-emission vehicles.

The grants may pay up to 100 percent of costs for:

- the incremental cost of replacing eligible vehicles with zero-emission vehicles;
- purchasing, installing, operating, and maintaining zero-emission infrastructure;
- workforce development and training for zero-emission vehicles; and
- planning and technical activities to support adoption and deployment of zero-emission vehicles.