2016 Freightliner M2

2019 Recology BYD 8R

Charlottesville Waste Collection: *Electrification & Direct Vision*

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INTRODUCTION

In recent years, there has been a surge in pedestrian deaths due to vehicle crashes in the United States.[1] One of the key contributing factors to fatal pedestrian crashes is the visibility of the pedestrian to the driver of the vehicle.[2] After all, a driver cannot avoid what they do not know is there.

Direct Vision refers to what a driver can see directly with their eyes, without the aid of mirrors or sensors. According to a 2024 study conducted by MassDOT and US Volpe Center, vehicles tend to have worse direct vision when they are larger and have an engine placement directly in front of the driver's field of vision[3]. This can prove especially fatal for pedestrians and cyclists when such vehicles operate in areas where pedestrians are simultaneously using adjacent road networks. One type of large vehicle that operates in such areas are waste collection vehicles. Such vehicles are often owned by public fleets.

Recent governmental initiatives to facilitate fleet electrification could be further expanded to include the health and safety of pedestrians in their purview. Many new electric vehicles also employ vehicle designs that improve the direct vision of vehicle operators. Further, they do not directly emit pollutants such as CO, NO_X, exhaust $PM_{2.5}$, or CO_2. While they still produce $PM_{2.5}$ from brake wear and tire wear, their brake wear emissions are generally less than that of diesel vehicles, due in part to new regenerative braking capabilities that not only supply the vehicle with electricity to function, but also reduce wear on the brakes.

In this report, we will consider the vehicle fleet used for waste collection services in the City of Charlottesville. Currently, there are 11 service areas for waste collection in the city, each of them representing a distinct collection route. All 11 routes are serviced by a waste services contractor, Green For Life (GFL). The daily weekday route, covering uptown and downtown Charlottesville primarily along W Main Street, is serviced twice a day: once in the morning by GFL, and once in the afternoon by the City of Charlottesville.

To operate this daily collection route, the City of Charlottesville currently uses one diesel-powered 2016 Freightliner M2, a medium-duty (Class 6) truck with a standard truck cab for its collection services. We introduce electric alternatives to this vehicle that have cab designs that prioritize direct vision for the driver, and through both a sustainability and a financial analysis, we compare diesel-powered trucks against their electric counterparts. Following this, we make a few policy recommendations that could help facilitate a fleet electrification initiative that simultaneously improves direct vision in the fleet and reduces the social cost of operating a diesel waste collection vehicle.

PRECEDENTS FOR OUR PROPOSAL

There are many examples of electric heavy garbage truck models implemented in the US. Because of the high up-front cost of the sustainable models, they are still uncommon, but their existence can help us to envision how an electric garbage truck could function in our community.

One of the first functioning electric trash trucks in the US was introduced in Seattle in 2019. The vehicle, called the Recology BYD 8R, became the first electric rear-loading class 8 garbage truck in the US[4]. It has a 295kWh battery pack, goes a maximum of 65 miles per hour, and has a 56-mile range, which equates to around 600 pickups in Seattle. This was a good start in introducing the technology to practical use, but several models have been manufactured since then that can outperform these numbers. For example, in 2024, Cambridge, MA purchased a Mack LR Electric Trash Truck and has concrete plans for three more to enter their fleet[5]. The Mack LR Electric has a 376-kWh battery, giving it a much longer range than the BYD 8R. Seattle also reports that their bus will take 9 hours to charge their vehicle with 33kW AC Outlet, while a DC fast charger would hypothetically take 2.5 to 1.5 hours[6]. In Cambridge, there are already two DC chargers installed, allowing for a quicker turnaround and for more vehicles to be used. In just 5 years, there is already a lot of advancement of innovation and resources for electric vehicles, showing how electric trucks will only get better along with the infrastructure to justify using them.

New Haven, CT is another city in New England that has begun investing in Electric trucks. In 2024, They purchased a Battle Motors LET 2 EV, which has an even higher 400kWh battery, which will last an estimated 9 hours on a single charge[7]. Their current level 2 charger can charge the truck in 6 hours, and the city has plans to not only replace this with a faster alternative but populate the city with chargers, allowing for the truck to reach farther routes from the station. This is more than enough to accommodate their current garbage truck schedule which operates for 7 hours a day, 5 days a week. The only concern that remains is the up-front cost which Connecticut and several other states have accounted for as well. State and federal subsidies allowed New Haven to purchase their truck for just $336,000, which is less than even the diesel-powered trucks that go for $416,000. Similarly, in Cambridge, The Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) program provided a $99,000 rebate for the first truck they bought[8]. After purchases, electric trucks usually require only $3500 per year to refuel and maintain, compared to the $15-30,000 that diesel trucks require[9]. With these subsidies and rebates added on, it is a no brainer that investing in electric garbage trucks and the necessary infrastructure is the right choice over buying more diesel trucks.

Using these examples, it is clear to see that the technology and infrastructure is improving, and buying an electric garbage truck can be a great start for even smaller communities because federal and state governments are willing to help with paying for them.

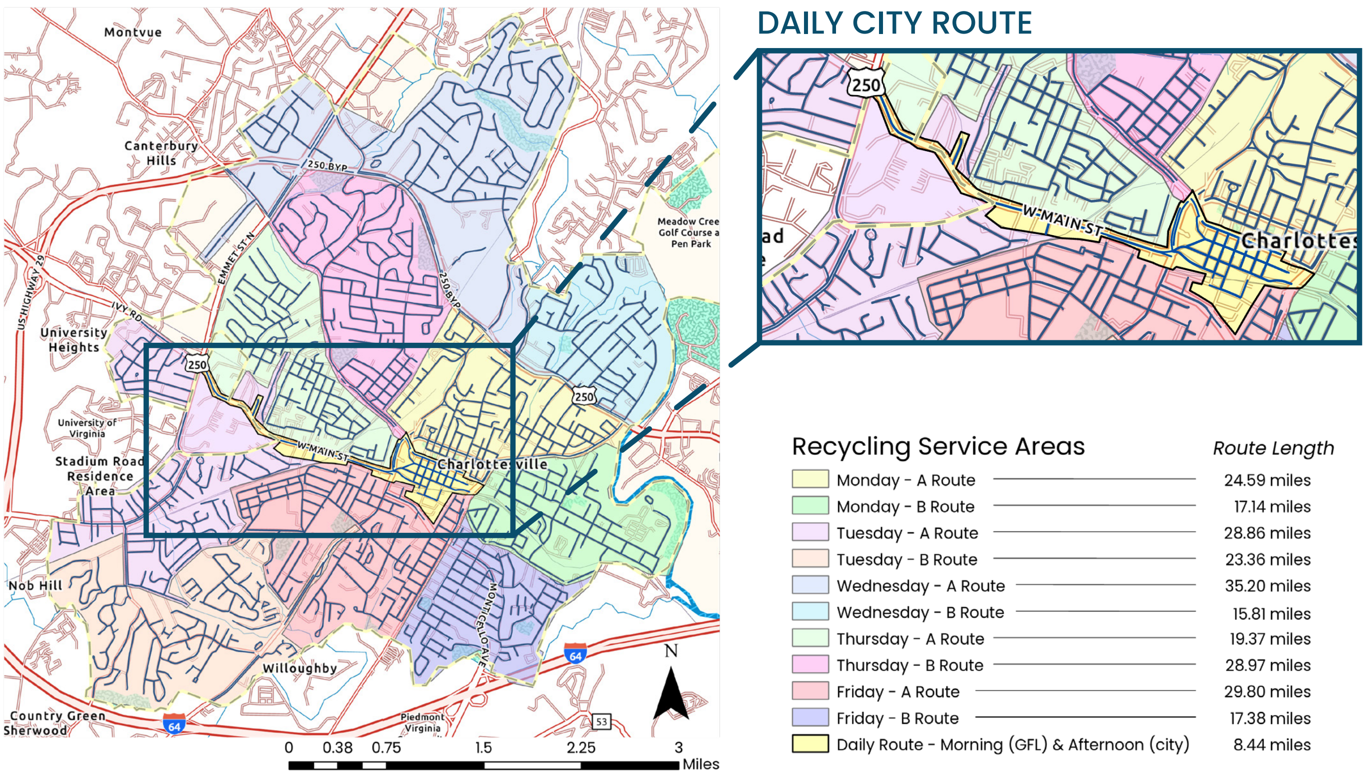
SUSTAINABILITY ANALYSIS

Route Service Parameters

In total, there are 11 weekly collection routes in Charlottesville. For our calculations, we make the simplifying assumption that the trucks drive along all the road centerlines within their service area. By taking the lengths of the street centerlines completely within each service area in ArcGIS Pro, we estimated the length of each service area route, which are listed in the legend of the map on the next page.

All 11 routes are serviced by a waste services contractor, Green For Life (GFL). The daily weekday route, covering uptown and downtown Charlottesville primarily along W Main Street, is serviced twice a day: once in the morning by GFL, and once in the afternoon by the City of Charlottesville. Thus, out of the eleven routes, Charlottesville only operates one of them, once a day. This daily route is 8.44 miles long.

From our conversation with Jonathan Dean, the Public Services Manager for the City of Charlottesville, we learned that when the city truck is full, the same vehicle is used to drive



Map created April 16, 2025 by Miranda Lao. Road Centerlines and Waste Collection Polygons from City of Charlottesville Open Data Portal (Accessed April 9, 2025). Basemap Credits:WVU Facilities, VGIN, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

its load to the GFL Transfer Station in Troy, VA. Assuming the shortest route, the length of the trip between Charlottesville (starting at the intersection of Emmet St and University Rd, which is the end of the daily route that is closer to Troy, VA) and the GFL Transfer Station is 18.8 miles one-way (37.6 miles round-trip). Mr. Dean also told us that currently, there is one city truck, a diesel-powered 2016 Freightliner M2, which performs trash collection. For 2024, the annual mileage of this truck was 3,870, and its fuel costs were $1,500. If this truck drove to the transfer station following its daily weekday route every day (a 46.04-mile trip), the total annual mileage would come out to 11,970.4 miles. Because this is not the case, we made the assumption that the truck only goes to the transfer station when it is full, once a week. Assuming 50 weeks of service a year, this comes out to 3,990 miles annually (79.80 weekly), which is much closer to the number supplied to us by Mr. Dean.

In extending the analysis to hypothetical situation where the city also operates the other 10 routes, it is assumed that each route is performed by one truck, and that every truck must drive to the transfer station following its route, including the twice-daily uptown/downtown route (we make this assumption assuming that most of the waste is collected in the morning, and the waste collected in the afternoon along the same route is therefore much less). The same one-way distance between Charlottesville and the transfer station of 18.8 miles (round trip 37.6 miles) that was used in the other calculation is used for each of these routes, even though these trucks may travel slightly more or less depending on the endpoint of their respective routes. The total distance of collection routes within their service areas based on road centerlines is 248.93 miles. Including the round-trip between Charlottesville and the transfer station, the total distance traveled for each week of collection along the routes is 926.49 miles. Assuming 50 weeks of collection, this comes out to 46,324.49 miles traveled per year to complete waste collection for Charlottesville.

Emissions Parameters

The 2016 Freightliner M2 used by the city is a diesel-powered heavy-duty vehicle. Emissions values used in our calculations can be found in the following tables. Because electric vehicles do not have exhaust emissions, there is no exhaust CO, NO_X, $PM_{2.5}$, or CO_2. However, they still generate brake wear and tire wear $PM_{2.5}$.

Table 1: US EPA Emissions Data

Heavy Duty Vehicles (other than buses) - DIESEL

Pollutants	grams/mile	µg/mile
Exhaust CO	1.96	1,960,000
Exhaust NO_X	4.151	4,151,000
Exhaust $PM_{2.5}$	0.104	104,000
Brake Wear $PM_{2.5}$	0.029	29,000
Tire Wear $PM_{2.5}$	0.004	4,000
Total $PM_{2.5}$	0.137	137,000
Exhaust CO_2	1,507	1,507,000,000
Energy Consumption (Btu/mile)	19,271	19,271,000,000

Heavy Duty Vehicles (other than buses) - ELECTRIC

Pollutants	grams/mile	µg/mile
Brake Wear $PM_{2.5}$	0.010	10,000
Tire Wear $PM_{2.5}$	0.004	4,000
Energy Consumption (Btu/mile)	10,427	10,426,560,000

Values used in our analysis are from the 2021 (Revised) values from the US Environmental Protection Agency (US EPA) emissions data from Table 4-43: Estimated National Average Vehicle Emissions Rates per Vehicle-by-Vehicle Type using Gasoline, Diesel, and Electric (grams per mile).

Analysis Results

For a detailed methodology used in the sustainability analysis, please see **Appendix 1**. Full sustainability analysis results are found in **Appendix 2**.

While neither the collection route emissions for the current city route only nor the emissions for all routes in Charlottesville come close to exceeding the National Ambient Air Quality Standards requirements for CO, NO_X, and $PM_{2.5}$[10], it is useful to consider that the regular operation of 12 trucks increases ambient NOx in Charlottesville by 11.21 µg/m³ (5.96 ppb)[11] (**Appendix 2**), while the annual mean for the standard is 53ppb. This means that the regular operation of 100 such diesel-powered heavy trucks would indeed exceed this standard. Indeed, there are a large number of heavy trucks moving construction materials currently on the roads of Charlottesville, many of them making multiple trips a day. The increase of delivery vehicles or 18-wheelers in regular operation in Charlottesville will similarly contribute such emissions along streets with pedestrian traffic. If we were to reduce the number of diesel-powered heavy trucks on Charlottesville's streets, then, we could affect non-negligible change in Charlottesville's relation to the standard.

Electric trucks do not have tailpipe (exhaust) emissions, though they still have brake wear and tire wear emissions. In comparing the criteria

Table 2: Social Costs of Emissions

	CURRENT CITY ROUTE ONLY		ALL CHARLOTTESVILLE ROUTES	
Pollutants	**Metric tons of emissions per year (annual mileage)**	**Dollar cost per year (annual mileage)**	**Metric tons of emissions per year (annual mileage)**	**Dollar cost per year (annual mileage)**
Heavy-duty vehicles (other than buses) - DIESEL				
Exhaust NO_X[22]	0.016064	**$1140.57**	0.192292	**$13,652.80**
Total $PM_{2.5}$	0.000530	**$88.54**	0.006346	**$1,059.86**
Exhaust CO_2	5.832090	**$1241.36**	69.811012	**$14,859.27**
Heavy-duty vehicles (other than buses) - ELECTRIC				
Brake Wear $PM_{2.5}$	0.000038	**$6.46**	0.000463	**$77.36**
Tire Wear $PM_{2.5}$	0.000015	**$2.59**	0.000185	**$30.94**

Metric tons of emissions per year for the current city route only is based on the annual mileage (3870 miles) given to us by Jonathan Dean, Public Services Manager for the City of Charlottesville. Metric tons of emissions per year for all Charlottesville waste collection routes is based on the annual mileage (46,324.49 miles) calculated from length of the routes within the city and the round-trip distance between Charlottesville and the waste transfer station in Troy, VA. See **Appendix 1** for further explanation of methodology.

pollutants for diesel and electric heavy vehicles, we see that on the basis of $PM_{2.5}$, ***diesel-powered vehicles emit almost 10 times more $PM_{2.5}$ than their equivalent electric-powered counterparts.*** Perhaps the comparison is clearest when viewed through the lens of social costs: based on the annual mileage of the vehicle supplied to us by Mr. Dean, the annual social cost from emitted NO_X, $PM_{2.5}$, and CO_2 of operating one heavy-duty diesel truck on the city's current daily route is **$2,470.47**. Because electric trucks do not have tailpipe emissions, the social cost for operating a comparable electric truck is only related to the $PM_{2.5}$ from brake wear and tire wear, and its total social costs from these same categories is **$9.04**. When comparing the social costs attributable to a full fleet of vehicles operating Charlottesville's waste collection routes, the annual totals come out to **$29,571.93** for a diesel fleet, versus **$108.31** for an electric fleet.

FINANCIAL ANALYSIS

It is crucial to understand the financial impact of electrification of waste trucks. With charging infrastructure already existing at the lot where the trucks are parked overnight, no additional capital expenditures will be included outside of the purchase of the vehicle. For comparison purposes, the purchasing of a new diesel truck of the same model has been included to evaluate the overall ROI and other financial measures.

As noted before, the BYD 8R-ER (extended range) provides ample services to the needs of the City of Charlottesville's municipal operated route. The BYD 8R-ER has a sticker price of $120,000. However, the Clean Heavy Duty Vehicles Grant provided by the EPA covers 40% of total replacement for the singular vehicle or fleet[12]. Previous winners have included the replacement of old diesel refuse trucks for battery electric like the current situation here. If awarded this grant, the City of Charlottesville would only be required to pay $72,000 in capital expenditures. If the city were to move ahead and purchase a new model of their current freightliner, the estimated cost would be $124,000[13]. Dominion energy's "Super Off Peak" rates of $0.099636 per kWh between the hours of 12AM-5AM year-round[14] means that a full charge of the 403 kWh ER battery will cost $28.00 ($27.997). The time to reach full charge is only 2.5 hours, so proper timing will prevent any additional charging costs. A full charge can last 115.75 mi which leads to a rate of 0.287 miles per/kWh. Assuming the annual mileage remains at 3870 miles, the annual fuel cost will be approximately $1,343.52 in comparison to the diesel fuel cost of $1,620.00 using an estimation of $3.60 per gallon and 8.6 mpg. Additionally, the maintenance costs will differ between the two vehicles. The reported cost for the current diesel truck is $1,600, but our estimates for the BYD vehicles to be approximately $750[15]. Annual project costs for the diesel trucks will then be $3,220.00 while the electric vehicle will be $2,093.52. For revenue, an estimation of $5.00 per mile was used given the significant benefit of garbage removal from commercial districts such as the route detailed in this report.

For the calculations on the return on investments, the analysis has been broken into three potential categories: diesel, electric, and electric subsidy. Each of these has a different capital expenditure as well as different ROI measures. Table 3 displays the results of the financial analysis.

Table 3: Financial Analysis Results

	Diesel	Electric	Electric Subsidy
IRR (%)	5.09%	7%	20%
NPV($), at 5% discount rate	$551.58	$13,249.94	$61,249.94
Payback Period (Years)	7.69	5.95	4.17

This table displays the payback period, net present value (with a 5% discount rate), and IRR within a 10-year context. For the full analysis, please see **Appendix 3**.

While each project sees a positive return on investment, the degrees vary dramatically. When comparing diesel to electric, the payback period is over a year and a half faster for the electric bus, but the overall IRR is only 2% higher after 10 years. However, the subsidy of the electric bus blows both values out of the water seeing a payback period nearly half of the diesel bus and a Net Present Value of over $61,000. Removing the discount rate, the cumulative cash flow of the electric subsidy would be over 100% of the initial capital investment. One significant caveat of these calculations in regard to payback is the estimation of the revenue per mile. There is possible fluctuation in the perceived revenue by the city, but the overall cost difference should remain the same in which case the electric truck will provide significant environmental benefits.

POLICY RECOMMENDATIONS

To support the transition toward cleaner, safer, and more economical waste trucks, we recommend a policy framework built around four parts: financial incentives, infrastructure investments, environmental accountability, and safety enhancement.

1. Financial incentives

- Diverse funding strategy: Encouraging capital funding to purchase and maintain electric vehicles should be jointly supported by federal, state, and local sources.

  The Inflation Reduction Act (IRA) includes provisions to revitalize American manufacturing and provides additional resources to improve access to EVs and EV charging infrastructure. The IRA will enable several EV-related programs across multiple Federal agencies, including USDOT, DOE, EPA, HUD, and the Department of the Treasury. Among these, The Clean Heavy-Duty Vehicle (CHDV) program aims to incentivize and accelerate the replacement of existing internal combustion engine heavy-duty vehicles with zero-emission vehicles. The grant program funding may also be used for zero-emission vehicle refueling infrastructure, workforce development and training, and project implementation costs[16]. Additionally, Diesel Emissions Reduction Act (DERA) facilitates the retrofit or replacement of existing diesel engines, vehicles and equipment with EPA certified engine configurations and verified retrofit and idle reduction technologies[17]. The Commercial Clean Vehicle Credit program offers businesses and tax-exempt organizations a clean vehicle tax credit of up to $40,000 under Internal Revenue Code (IRC) 45W[18]. At the state level, the Virginia Department of Energy is offering the EVCAP subaward program to work at the community level to understand and address issues surrounding the deployment of electric vehicle (EV) charging stations. The focus is on specific underserved communities and the results will inform current and future EV charging deployment[19].
- Establishing a green transportation fund to ensure sustainable financing for vehicle purchases and infrastructure maintenance could also be a policy mechanism to establish a financial incentive.
- Public-utility collaborations can be pursued under a "Regional Transit Governance and Funding Mechanism" model to encourage regional cost-sharing. Virginia Clean Energy Innovation Bank can bridge financing gaps that might exist after applying federal and state grants[20].

2. Infrastructure investment

- Adopt managed charging systems in adjusting charging time and speed to optimize grid stability, reduce electricity costs, and extend equipment life.
- Implement a battery leasing model to mitigate high upfront battery replacement costs. The Alternative Fuel Buses report recommends the leasing model, noting that BYD offers warranties of up to 12 years and supports instalment replacement contracts[21].

3. Environmental assessment

- Require the fleet department to publish annual emission reports with PM2.5, NOx, and GHG emission reductions.
- Designate residential or sensitive land use areas as low-emission zones, restricting access for high-pollution vehicles.

4. Safety

- Provide training on electric vehicle safety for drivers, maintenance personnel, and emergency responders.
- Fatigue monitoring should be implemented through tracking of driving hours and drivers' physical conditions to prevent incidents.

OFFICIAL RECOMMENDATION

We recommend the City of Charlottesville to purchase an electric garbage truck, more specifically the BYD-8R-ER, due to the extreme environmental benefits compared to their current diesel garbage truck. The City of Charlottesville should seek to employ some of the listed grant credits when purchasing the new vehicle to maximize overall financial return.

ENDNOTES

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APPENDIX 1: SUSTAINABILITY ANALYSIS METHODOLOGY

There are a couple simplifying assumptions that we use in our sustainability analysis.

1. For average concentrations, we will only be limiting emissions analysis to the length of the collection routes (not including the round-trip to the transfer station) to calculate the emissions concentrations in residential neighborhoods. However, values used for social cost analysis use the full length of the route.

2. For average concentrations, we assume that the wind disperses the suspended emitted particles every 15 minutes with a linear rate of dispersion.

3. To calculate the volume of the emissions band of the vehicle, we assume that particulate matter is suspended in a 25-meter by 4-meter band behind the vehicle (total area 100 meters^2), with its length parameter determined by the distance travelled by the vehicle within 15 minutes. According to the Neighborhood Refuse Truck Cycle developed by the US DOE National Renewable Energy Laboratory (NREL) for the US EPA Smartway program[1], the average speed of a neighborhood refuse truck over the length of its route, including stops, is 11.2 miles per hour. The distance traveled in 15 minutes, then, would be 2.8 miles. The volume of the emissions band in cubic meters, then, is 448,000 m^3.

Within a 15-minute emissions band, the average concentration over 15 minutes of each emitted pollutant is half of the calculated emissions concentration within the emissions band, because we have assumed a linear rate of wind dispersion. Similarly, within the 15-minute band, the average concentration over 1 hour is a quarter of the concentration over 15 minutes.

However, each truck will not finish its route in 15 minutes, so the average 24-hour increase in concentration is calculated by taking the number of 15-minute emissions bands the truck will create during its route, which can be found by dividing the total length of the route by the length of the 15-minute segments. For example, in the city's case, its 8.44-mile route contains 3.01 2.8-mile segments. The average 24-hour concentration is found by taking the average hourly concentration (one-quarter of the average 15-minute concentration), multiplying it by the number of 15-minute emissions bands segments, and dividing it by 24 (for the number of hours in a day): the truck only runs its route once a day. The average yearly increase is found by taking the average daily concentration and multiplying it by the number of days of collection service, then dividing it by the number of days in a year.

To calculate the length of the average daily route, the total weekly route distance was calculated and divided by the number of weekly days of service (5).

Social costs used in the sustainability analysis are from the US EPA.

APPENDIX 2: SUSTAINABILITY ANALYSIS SPREADSHEET

Link to spreadsheet

APPENDIX 3: FINANCIAL ANALYSIS SPREADSHEET

Link to spreadsheet

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