Technical Appendix for the Tennessee Volunteer Emission Reduction Strategy (TVERS): Strategic Emissions Reduction Programming

Fleet Vehicle Electrification Program (Measures 1.1 and 1.2)

GHG Reduction Estimate Method

The following sections explain the methodology and assumptions for estimating GHG and co-pollutant reductions from the proposed replacement of light-, medium-, and heavy-duty conventional vehicles with electric vehicles (EV) through a TDEC-led competitive grant program. TDEC developed estimates for this measure utilizing modeling. A technical spreadsheet is provided to show step-by-step calculations for this measure.

Models/Tools Used

The emissions benefits of the proposed EV replacement program were estimated using the 2023 version of the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET)[1] tool developed by Argonne National Laboratory in collaboration with the U.S. Department of Energy (DOE). Specifically, TDEC used the On-Road Simple Payback Calculator tool within AFLEET (AFLEET-Payback-Onroad Output tab). This tool estimates atmospheric emissions associated with the operation of a wide range of vehicle classes and fuel types. AFLEET output is provided as aggregated "GHGs." Details on the individual contributions of CO_2, CH_4, and N_2O are not provided directly as outputs. As such, we have reported GHG as CO_2e and assume it is approximately 95 to 99% CO_2 based on EPA guidance.[2]

Measure Implementation Assumptions

Emissions benefits were estimated following an implementation schedule listed in Table 1. A phased-in implementation was employed, resulting in the full implementation of replacements by the end of calendar year 2029. The benefits of full implementation in 2029 were carried forward through the calendar year 2050.

Table 1. Implementation Grant for EV Replacement

Year	% Vehicles Converted to EV
2025	0%
2026	10%
2027	60%
2028	80%
2029	100%
2030	100%

[1] https://afleet.es.anl.gov/home/
[2] Tailpipe Greenhouse Gas Emissions from a Typical Passenger Vehicle, U.S. EPA Office of Transportation and Air Quality, EPA-420-F-23-014, June 2023.

GHG Reduction Estimate Assumptions

TDEC evaluated the benefits of converting three different classes of vehicles to EVs. AFLEET inputs, as shown in Table 2, were used. Table 2 also shows the number of vehicle replacements of each type that it is expected could be accommodated (charging infrastructure included) by the requested funding. It was assumed that 100% of EVs would be purchased in all cases. No hybrid vehicles of any type were modeled. Note that due to the limitations of AFLEET, a "heavy-duty" vehicle class was used to represent a medium-duty vehicle. The "single unit short-haul truck" was selected as most representative of medium-duty vehicles.

Table 2. AFLEET Vehicle Assumptions by Class and Fuel Type

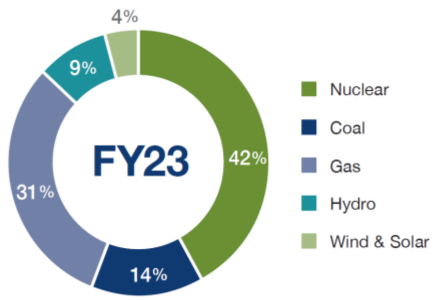
Vehicle Type (Class)	Fuel	Annual Vehicle Miles Traveled	Fuel Economy (MPGGE)	Purchase Price	Units Converted to EV
Passenger Vehicles (Light-Duty)					
Car (Class 1 to 3)	Gasoline	12,400	30.7	NA	151
	EV		118.2	$37,000	
Pickup Truck (Class 1 to 3)	Diesel	11,400	25.1	NA	38
	EV		73.5	$77,000	
Single-Unit Short-Haul Truck (Medium-Duty)					
Truck or Van (Class 4)	Diesel	16,500	6.5	NA	184
	EV		26.1	$150,000	
Bus (Heavy Duty)					
Transit or School Bus (Class 8)	Diesel	45,000	4.4	NA	22
	EV		11.1	$900,000	

Note that the $20 million grant request associated with this measure cannot convert all the vehicles in Table 2. The grant will be structured to accommodate 100% of the light-duty conversion AND a combination of some medium-duty trucks and heavy-duty buses. A high-range case (100% of the medium-duty trucks) and a low-range case (100% of the heavy-duty buses) were modeled to model a range of reduced emissions. The high-range case is presented in the workplan and the full range is presented in the technical materials. The implemented grant program's anticipated emissions reduction will fall within the range based on the proportion of converted medium-duty and heavy-duty vehicles.

The grant program would require a 50% subrecipient match for light-duty or medium-duty vehicle replacements and a 25% match for heavy-duty vehicle replacements. Therefore, CPRG funds cover 50% of the emissions reductions for light-duty and medium-duty calculations and 75% for heavy-duty calculations. The emissions reduced due to CPRG funds specifically are reflected in Table 3 alongside the total emissions reductions anticipated (CPRG funds and subrecipient match).

EV emissions are affected by the energy mix used in AFLEET. Instead of using the default mix for the Southeastern region, a custom electricity generation mix for 2023 provided by the Tennessee Valley Authority (TVA), a federally owned electric utility corporation that provides electricity to approximately 99.7% of Tennessee's electricity service territory, was used in this analysis. Figure 1 shows the TVA energy generation broken down by source, consisting mainly of nuclear, gas, and coal-powered energy sources. This energy mix was assumed constant throughout the implementation period (2025-2030) and through 2050.

Figure 1. TVA Fiscal Year 2023 Electricity Generation Mix



For all model runs, Tennessee was selected as the primary vehicle location state, and no county location was specified. It is expected that all counties will be eligible to participate.

Reference Case Scenario

The reference case scenario assumed that annual emissions from the existing, unconverted fossil-fueled vehicles would be constant for each year through 2050. The annual emissions in Year 1 of the program (when 0% of vehicles are converted) represent the reference case. Each year, as the vehicles are replaced with EVs, the benefit of EV replacement reduces the annual emissions until 2029, when fossil-fueled vehicle emissions are replaced entirely by EV emissions.

Measure-Specific Activity Data

Activity data used to derive GHG emissions is the quantity of petroleum fuels that different classes of fossil-fueled vehicles would consume. AFLEET provides barrels (bbls) of gasoline[3] and diesel fuel based on assumed annual vehicle miles traveled and government fuel economy estimates. As shown in the technical spreadsheet provided for this measure, consumption of the following annual fuel quantities would be offset by the measure when fully implemented:

- 151 light-duty cars and 38 light-duty trucks: 1,263.6 bbls gasoline and 371.8 bbls diesel; AND
- A maximum of 184 single unit short-haul trucks: 11,674.2 bbls diesel OR a minimum of 22 transit buses: 5,597.7 bbls diesel.

GHG and Co-Pollutant Emissions Reduced

The emissions output in AFLEET reflects the benefit of using EVs instead of gasoline or diesel-powered vehicles. The emissions from internal combustion vehicles are offset by EV adoption and its associated electricity generation emissions. Table 3 shows the emissions benefits of CO2e, CO, NOx, PM10, PM2.5, VOC, and SOx for the timeframes of 2025 through 2030 and 2025 through 2050.

[3] 1 Barrel is equivalent to 42 gallons.

Table 3. Emissions Benefits (Avoided Emissions) for EV Vehicle Replacement

Vehicle Class	CO_2e	CO	NOx	PM_{10}	$PM_{2.5}$	VOC	SOx
	----- metric tons -----						
2025 through 2030							
Light-Duty	2,128	10.0	0.5	0.03	0.02	0.9	0.01
Light-Duty (CPRG only; 50%)	1,063.99	5.01	0.26	0.02	0.01	0.47	0.01
Case 1: Medium-Duty	15,449	10.7	12.6	0.05	0.05	0.9	0.1
Case 1: Medium-Duty (CPRG only; 50%)	7,724.51	5.35	6.31	0.03	0.02	0.45	0.06
Case 2: Heavy-Duty	6,419	6.2	8.8	0.02	0.01	0.3	0.06
Case 2: Heavy-Duty (CPRG only; 75%)	4,814.58	4.64	6.60	0.01	0.01	0.22	0.04
2025 through 2050							
Light-Duty	14,279	67.2	3.5	0.2	0.2	6.3	0.1
Light-Duty (CPRG only; 50%)	7,139.41	33.60	1.74	0.11	0.08	3.15	0.05
Case 1: Medium-Duty	103,866	71.9	84.9	0.4	0.3	6.1	0.8
Case 1: Medium-Duty (CPRG only; 50%)	51,933.06	35.94	42.44	0.18	0.15	3.03	0.39
Case 2: Heavy-Duty	43,102	41.5	59.1	0.1	0.1	2.0	0.4
Case 2: Heavy-Duty (CPRG only; 75%)	32,326.76	31.12	44.31	0.08	0.07	1.49	0.28

Public EV Charging Infrastructure Program (Measure 1.3)

GHG Reduction Estimate Method

The following sections explain the methodology and assumptions for estimating GHG reductions from Tennessee's proposed EV charging infrastructure expansion through a TDEC-led grant program. As discussed below, modeling was used to develop estimates for this measure. A technical spreadsheet is provided to show step-by-step calculations for this measure.

Models/Tools Used

The emissions benefits of the proposed EV charging infrastructure were estimated using the 2023 version of the AFLEET tool developed by Argonne National Laboratory in collaboration with the U.S. DOE. Specifically, the Charging and Fueling Infrastructure tool within AFLEET (AFLEET CFI) was used. This tool estimates the net benefits of charging station utilization from increased EV adoption balanced with energy generation for vehicle charging. Emissions benefits for this measure were developed by expanding Tennessee's EV charging infrastructure for both level 2 (L2) and direct current fast charge (DCFC) infrastructure in communities across Tennessee. As discussed above, AFLEET output provides CO_2e, which is assumed to be 95 to 99% CO_2.

Measure Implementation Assumptions

The total funding requested for this measure was estimated to accommodate 204 EV charging units across 51 sites. Of the 204 EV chargers, the number of L2 and DCFC chargers was proportioned based on the funding requested and the cost associated with procuring, installing, and maintaining the chargers. Table 4 displays the distribution of L2 and DCFC chargers. The chargers were modeled in parking lots, retail/leisure, and educational spaces to reflect the community-based theme of this proposed measure.

Table 4. Estimated EV Charging Port Mapping to AFLEET CFI

Location:	Level 2	DC Fast Charge
Parking lot	62	18
Retail/leisure	78	22
Education	20	4
Total:	160	44

Emissions benefits were estimated following an implementation schedule in Table 5. A phased-in implementation was employed, resulting in the full implementation of all 204 charging stations by the end of 2029. The benefits resulting from the full implementation of the charging stations in 2029 were carried forward through 2050.

Table 5. Implementation Grant for Charger Installation

Year	% Chargers Installed
2025	0%
2026	10%
2027	60%
2028	80%
2029	100%
2030	100%

GHG Reduction Estimate Assumptions

The energy mix used in AFLEET affects EV and charging infrastructure emissions. Instead of using the default mix for the Southeastern region, a custom electricity generation mix for 2023 provided by TVA was used in this analysis. Figure 1 shows the TVA energy generation broken down by source, consisting largely of nuclear, gas, and coal-powered energy sources. This energy mix was assumed constant throughout the implementation period (2025-2030) and through 2050.

Default parameters for charger utilization, charge time, electricity dispensed, and annual EV miles were employed. These default parameters were based on a “Moderate” level of weekly utilization based on actual charging data from several U.S. cities.[4]

The grant program funded by this measure would provide 80% of the project costs and require a 20% match by subrecipients. Therefore, 80% of the total emissions reductions estimated for this measure are attributable to CPRG funds.

Reference Case Scenario

The business-as-usual (BAU) scenario assumes that fossil-fueled vehicles would continue to generate GHG emissions without the proposed charging infrastructure. The proposed EV charging infrastructure fills in charging gaps in Tennessee, which would increase the adoption of EVs across Tennessee. The

[4] User Guide for AFLLET Tool 2020, (2021)

emissions benefits estimated for this measure reflect the GHG emissions offset by using EVs rather than gasoline or diesel-powered vehicles that align with the BAU scenario.

Measure-Specific Activity Data

Most measure-specific activity data is discussed above, along with the number and types of charging stations anticipated with the requested grant funds. AFLEET CFI was adjusted with the current custom electricity mix from the TVA. The remaining assumptions in the AFLEET CFI tool, like charger utilization rate (moderate), annual vehicle miles, and average charge time, were left at the default setting to ensure conservative assumptions since detailed activity data is unavailable.

With 204 EV charging stations, AFLEET CFI estimated that the proposed charging infrastructure expansion would offset 1,480 petroleum barrels annually by increasing the adoption of EVs.

GHG and Co-Pollutant Emissions Reduced

The emissions output in AFLEET reflects the benefit of using EVs instead of gasoline-powered light-duty vehicles. The emissions from light-duty internal combustion gasoline-powered vehicles are offset by EV adoption and its associated electricity generation emissions. The emissions benefits of CO_2e, CO, NO_X, PM_{10}, $PM_{2.5}$, VOC, and SOx for 2025 through 2030 and 2025 through 2050 are in Table 6 below.

Table 6. Emissions Benefits (Avoided Emissions) for EV Charging Infrastructure

	CO_2e	CO	NO_X	PM_{10}	$PM_{2.5}$	VOC	SOx
	----- metric tons -----						
2025 through 2030							
Full Implementation	1,956.02	8.19	0.17	0.02	0.02	0.84	0.01
CPRG only; 80%	1,564.81	6.55	0.14	0.02	0.01	0.67	0.01
2025 through 2050							
Full Implementation	13,133.24	55.01	1.15	0.14	0.12	5.62	0.09
CPRG only; 80%	10,506.60	44.01	0.92	0.11	0.09	4.50	0.07

<u>**REducing Food in LandfilLs (TN REFILL) Program (Measure 2)**</u>

GHG Reduction Estimate Method

The following sections explain the methodology and assumptions for estimating GHG from the proposed food waste reduction, specifically composting and food recovery, through a TDEC-led competitive granting program. As discussed below, modeling was used to develop estimates for this measure. A technical spreadsheet is provided to show step-by-step calculations for this measure.

Models/Tools Used

The emissions benefits of the proposed food waste diversion program were estimated using the EPA's Waste Reduction Model (WARM) Version 16. This tool estimates greenhouse gas reductions associated with reducing landfilled materials. WARM provides emissions in CO_2e but does not estimate GHG-type emissions (i.e., carbon dioxide, methane, or nitrous oxide).

Measure Implementation Assumptions

Emissions benefits were estimated following an implementation schedule listed in Table 7. A phased-in implementation was assumed, fully implementing food waste recovery and composting by 2029. The tonnage of food waste recovered and diverted to composting was estimated by inventorying the infrastructure and operational costs for organics collection, composting facilities, food banks, and other food recovery operations in Tennessee to arrive at a cost rate per ton of food recovered or diverted. Estimated total tons reduced were then calculated based on the CPRG program funding requested ($20,081,797 for the food waste grant program) and the per ton rate of food recovery and diversion. An assumption of $10 million in funding for food recovery and $10 million to support organics collection and composting infrastructure was used. Organics collection infrastructure costs were incorporated into the per-ton diversion cost rate. The food recovery tonnage was entered into WARM as "Ton Source Reduced." The benefits of full implementation in 2029 were carried forward through the calendar year 2050.

Table 7. Implementation Grant for Food Waste Reduction

	Food Recovery Tons	**Composting Tons**
2025	0.00	0.00
2026	5,135.84	1,604.51
2027	30,815.05	9,627.08
2028	41,086.73	12,836.10
2029	51,358.41	16,045.13
2030 - 2050	51,358.41	16,045.13

GHG Reduction Estimate Assumptions

In EPA's WARM, Tennessee was selected as the state. Landfill gas recovery was assumed to be aligned with the national average, landfill gas recovered was assumed to be flared, and landfill gas recovery control efficiency was assumed to follow typical landfill operation. The wet moisture condition was selected based on data from the National Centers for Environmental Information and the National Oceanic and Atmospheric Administration for Tennessee. Distances for the transportation of materials to the management facility were assumed to be the default, given the number of facility locations in Tennessee.

Additionally, EPA's WARM uses global warming potentials from the Intergovernmental Panel on Climate Change 2007 Report, which under-reports CO_2e emissions compared to the current Intergovernmental Panel on Climate Change 2014 Report global warming potentials. Since methane is the primary driver of landfill emissions, using the 2007 methane global warming potential of 25 is more conservative than the 2014 value of 28.59.

Modeling assumptions did not include subrecipient match; therefore, all emissions reduced are attributable to CPRG funding.

Baseline Scenario

In WARM, the baseline amount of landfill tonnage without any reduction measures is modeled. To determine the amount of food waste generated, the per capita food waste generation was assumed to be 1.058 lb/day. The per capita food waste was multiplied by Tennessee's estimated population from 2025 to 2050 to determine the total tonnage landfilled annually.

Measure-Specific Activity Data

The primary activity data used to estimate GHG is the amount of food waste diverted from the landfill, either through composting or food recovery. The model calculates this value based on the user-specified composted and source reduced tonnage.

GHG Emissions Reduced

The emissions output from WARM reflects the benefit of reducing landfilled food waste. The GHG emissions benefits for the timeframes of 2025 through 2030 and 2025 through 2050 are contained in Table 8 below. As discussed earlier, WARM provided GHG emissions in CO2e. Likely, the majority of the emission factors are related to methane. However, emission factors for food recovery include other GHG (such as CO_2) related to reducing food processing. Composting and landfilling emission factors include GHG emissions (such as CO_2 and NO_x) related to combustion from transportation and equipment use at the compost facility.

Table 8. Emissions Benefits (Avoided Emissions) for Food Waste Reduction

	Avoided Emissions (MT CO_2e)
2025 through 2030	791,935
2025 through 2050	5,317,277

Renewable Energy Program (Measure 3)

GHG Reduction Estimate Method

The following sections explain the methodology and assumptions used to estimate GHG and co-pollutant reductions from the proposed installation of photovoltaic (PV) arrays. Computer modeling was used to develop these estimates. A technical spreadsheet is provided to show step-by-step calculations for this measure.

Models/Tools Used

Synapse Energy Economics, Inc., estimated the proposed PV installation program's emissions benefits. Specifically, the Renewable Energy (RE) resources module was used. AVERT provides emissions of CO_2 and the co-pollutants SO_2, NO_x, $PM_{2.5}$, VOC, and ammonia (NH_3). AVERT does not provide emission estimates for other GHGs (e.g., methane or nitrous oxide).

Measure Implementation Assumptions

Emissions benefits were estimated following two different implementation schedules, as shown in Table 9. In Case 1, it was assumed that 100% of the grant money would be applied to smaller rooftop solar installations. The phased-in schedule for smaller projects is assumed to be faster than for the Case 2 utility-scale projects, as shown. In both cases, it was assumed that 30 MW_{DC} of capacity would be installed by the end of Year 5 of the program (CY 2029). Thereafter, it was assumed that the installed capacity would operate through CY 2050 based on the current 25 to 30-year lifetime of current PV arrays.

Table 9. Implementation Grant Schedule for Rooftop and Utility-Scale PV installation

Year	% of Rooftop Capacity Installed	% of Utility-Scale Capacity Installed
2025	0%	0%
2026	10%	10%
2027	60%	40%
2028	80%	70%
2029	100%	100%
2030 - 2050	100%	100%

GHG Reduction Estimate Assumptions

AVERT enables users to specify capacity factors (CF) for rooftop and utility-scale solar performance. The CF indicates how many hours are available daily to produce electricity. The U.S. average for utility-scale solar is about 24%, meaning about 5.8 hours of sunlight (0.24 x 24) are available daily. The AVERT values of 18.36% (rooftop) and 23.25% (utility) were used for this evaluation. These values were specified by the Tennessee Regional Data file (CY 2022 data) that is provided with AVERT. The regional data file also contains a database of fossil electricity generating units (EGUs) specific to Tennessee that are used to estimate the non-baseload emissions that would be avoided by using PV instead.

In addition to CF, an assumption was made concerning the available alternating current (AC) output from a given PV array based on its direct current (DC) rating. The general rule of thumb applied here is that 90% of the rated DC capacity can be delivered as AC output to the end user (before AVERT automatically accounts for transmission and distribution losses). Based on this assumption, 30 MW_{DC} will generate 27 MW_{AC}.

The grant program funded by this measure would provide 70% of the project costs and require a 30% match by subrecipients. Therefore, 70% of the total emissions reductions estimated for this measure are attributable to CPRG funds.

Reference Case Scenario

The reference case scenario assumed that annual emissions associated with generating up to 30 MW_{DC} of electricity with the existing fossil EGUs in the area would be constant annually through 2050.

Measure-Specific Activity Data

The primary activity data to estimate GHG and co-pollutant emissions is the megawatt-hours (MWh) of electricity the PV array will produce. The model calculates this value based on the user-specified array capacity and the CF. The model develops pollutant emission rates for CO_2 and co-pollutants based on its database of fossil EGUs.

GHG and Co-Pollutant Emissions Reduced

The emissions output from AVERT reflects the benefit of using PV electricity instead of fossil EGUs. Table 10 shows avoided emissions of CO_2, SO_2, NO_X, $PM_{2.5}$, VOC, and NH_3 for the timeframes of 2025 through 2030 and 2025 through 2050.

Table 10. Emissions Benefits (Avoided Emissions) for PV Array Installation

	CO_2	SO_2	NO_x	$PM_{2.5}$	VOC	NH_3
Case	----- metric tons -----					
2025 through 2030						
Case 1: Rooftop	99,006	43	37	9	2	3
Case 1: Rooftop (CPRG only)	69,304	30	26	6	2	2
Case 2: Utility	106,322	46	39	10	3	4
Case 2: Utility (CPRG only)	74,425	33	28	7	2	3
2025 through 2050						
Case 1: Rooftop	664,740	289	247	60	16	23
Case 1: Rooftop (CPRG only)	465,318	202	173	42	11	16
Case 2: Utility	770,769	337	286	70	18	28
Case 2: Utility (CPRG only)	539,539	236	200	49	13	20

The two cases are expected to bracket the range of possible benefits for any combination of rooftop and utility PV solar, totaling 30 MW_{DC}.