Kirkwood Fleet Electrification: A Benefit-Cost Analysis

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Executive Summary

In its 2022 Strategic Plan, the City of Kirkwood commits to mitigating climate change through targeted environmental initiatives. As a part of this commitment, the City proposes transitioning its fleet of passenger and service vehicles to electric models, prioritizing light and medium-sized vehicles. This benefit-cost analysis assesses the financial implications of this policy over the next decade, culminating in a recommendation derived from the policy's net impact on the citizens of Kirkwood, MO.

Our analysis shows that transitioning from internal combustion engine (ICE) vehicles to electric vehicles (EVs) over a 10-year period would result in a net reduction in costs of **$691,000** ($1.592M for EVs vs. $2.283M for ICE vehicles). Under various sensitivity analysis scenarios, savings range from $339,000 to $950,000.

1. Impact Categories

Monetary costs for this program include the retail price of new vehicles, routine maintenance and repair, insurance, depreciation of vehicles, fuel consumption, and charging equipment for the electric vehicles. Non-monetary costs under consideration here only include global carbon impacts. As a note, we use a global standing for carbon impacts because of the underlying mission statement for the policy initiative: "Kirkwood will mitigate climate change by making environmentally focused decisions." (2022 City of Kirkwood 5-year Plan)

2. Vehicle Specific Costs

For our new car purchase prices, gas mileage, depreciation, terminal vehicle sales values, and maintenance costs we utilize data provided by Edmunds.com. Edmunds.com is a reliable source for automotive information and enjoys a longstanding reputation in the automotive industry. It offers detailed reviews, pricing information, and specifications for a wide range of vehicles. Data is gathered from a variety of sources, including direct vehicle testing, manufacturer information, and industry data. All dollar values provided are in current (2024) dollars.

Of note, the Ford E-Transit and F-150 Lightning were too new to have maintenance cost data. Ford's website promises much lower maintenance and repair costs and as a result we used the Bolt EUV values for imputation. The substitute vehicles used in our analysis and their derived costs are given below in Tables 1 and 2.

Table 1: ICE Vehicle Replacements by Class

Class	Model	MPG	CO_2/mile (lbs)	Energy Cost/Mile	MSRP	5yr Maintenance Costs
Medium Truck	Silverado 2500	14	1.939	$0.266	$48,310	$11,480
Light Truck	Ford F-150	18	1.508	$0.155	$44,951	$8,217
Van	2023 Chevy Express	14	1.939	$0.199	$42,899	$8,217
SUV	Chevy Tahoe	17	1.597	$0.164	$57,180	$9,455
Minivan	Toyota Sienna	36	0.754	$0.078	$38,581	$6,136

Class	Model	MPG	CO2/mile (lbs)	Energy Cost/Mile	MSRP	5yr Maintenance Costs
Sedan	Ford Fusion	30	0.905	$0.093	$31,924	$5,350

Table 2: EV Vehicle Replacements by Class

Class	Model	kWH/100Miles	CO2/mile (lbs)	Energy Cost/Mile	MSRP	5yr Maintenance Costs
Medium Truck	F-150 Lightning	48	0.581	$0.055	$50,542	$5,510
Light Truck	F-150 Lightning	48	0.581	$0.055	$50,542	$5,510
Van	Ford E-Transit	50	0.605	$0.058	$46,163	$5,510
SUV	Chevrolet Bolt EUV	28	0.339	$0.032	$28,791	$5,510
Minivan	Chevrolet Bolt EUV	28	0.339	$0.032	$28,791	$5,510
Sedan	Chevrolet Bolt EV	28	0.339	$0.032	$27,404	$5,510

3. CO2 Emission Measurements

In order to calculate CO2 emissions resulting from the vehicles' consumption of energy sources (unleaded gasoline for ICE vehicles, City of Kirkwood grid electricity for EVs) we needed to find out the CO2 output resulting from a one-unit use of each fuel type - one-gallon unleaded gasoline and 1 kilowatt hour (kWh) of electricity.

The value used for average CO2 emissions resulting from internal combustion engines (new cars) is recommended by the Environmental Protection Agency in their GHG Emission Factors Hub document (EPAghgEmissionFactors). The figure includes the carbon impact of fossil fuel extraction and refining and is calculated to be 23.7 lbs. CO2e/gallon (Table 3).

Calculating CO2 emissions for EVs is not quite as straightforward, but still concrete and feasible. Utility companies provide information on the mix of energy sources in various company documents and because the City of Kirkwood purchases its electricity from Ameren Missouri, we were able to find these figures in their 2023 Integrated Resource Plan (66% coal, 23% nuclear, 11% renewable). By 2035 they hope to transition to an energy mix similar to California's (82% low-carbon sources), but in its base analysis this study is not so optimistic – we assume a status quo 2022 composition throughout the study period.

Now, given the energy source composition we can refer to the GHG Emission Factors Hub report and figure out the mean CO2 emissions per kWh of electricity consumed, 1.21 lbs. CO2e/kWh (Table 3).

Table 3: Plug-In Values

Variable	Value	Source
Discount Rate	2%	Circular A-94, 2023
Carbon Cost	$100/ton	Ad hoc. See discussion.
Gasoline, unleaded	$2.79/gallon	FRED, 5-year average (end Feb. 2024)
Gasoline, unleaded	23.7 lbs. CO2e/gallon	EPA (Emission Factor for Greenhouse Inventories)
Electricity	$0.115/kWh	Kirkwood Utilities website
Electricity	1.21 lbs. CO2e/kWh	Ameren Missouri Energy Report
EV terminal sale value	40% of base	Edmunds.com
ICE final sale value	50% of base	Edmunds.com

4. The Social Cost of Carbon (SCC)

The concentration of CO2 in the atmosphere is currently a topic of great interest due to the broad range and massive scale of its impacts. Likewise, estimates result in large confidence intervals and are often the product of complex models.

A 2022 article in the journal Nature, authored by many notable academics, states that "our preferred mean SC-CO2 estimate is $224 per ton of CO2 ($53–$500 per tCO2: 5%–95% range, 2024 US dollars) at a near-term risk-free discount rate of 2%, a value 3.6 times higher than the US government's current value of $51 per tCO2." (Rennert et al. 2022)

Another 2022 paper looked at the additional cost in statistical value of human life (VSL) resulting from increased CO2 concentrations in the atmosphere. This study scaled the values by the income of those impacted and the expected lost years of life per ton of CO2. The results suggested a cost of $30.5-$94.5 for the reduction in VSL due to increased CO2 atmospheric concentrations. (Carleton et al. 2022)

Also worth considering are the values set by various governments. Germany's 2020 guidance presented two values: €195 (US$235) and €680 ($820). In contrast, "Former president Donald Trump changed the terms for the SCC from 2017. He limited damages to those within the United States, omitting impacts that will be felt in other countries. And he gave an unrealistically low estimate of the costs of future damages as counted in today's dollars. Together, these changes slashed the SCC to $1–7 per tonne: too low to influence policy" (Wagner et al 2021)

As a result of the variability within methodologies, estimates and government recommendations, there is a great amount of flexibility that can be afforded the biased BCA practitioner – enough so that any staunch environmentalist or petrochemical lobbyist could cherry-pick a value to justify any policy regarding CO2 emissions. For our study we will be using a base value of $100 per ton CO2 to reflect the uncertainty and lack of precision in the estimate. This cost is assumed to increase at the same rate as the discount rate. Thus, the two factors offset each other and result in a constant unit cost over the study period.

5. Charging Infrastructure

Electric vehicle charging hardware ranges from low kWh capacity – level 1 – to super high capacity – level 3. Below we very briefly discuss each type of charger and the reasoning behind their selection for each vehicle.

Level 1: These chargers are the slowest, using a standard 120-volt wall outlet. You get roughly 4-5 miles of range per hour of charging. These are "purchased" for vehicles that drive 6000 miles a year or less and are afforded a purchase + installation budget of $1185. This is a high estimate because level 1 charging equipment can be purchased for $100 and be plugged into a standard 20A receptacle.

Level 2: For faster charging, you need a 240-volt outlet. With Level 2 chargers, you can expect around 25-30 miles of range added per hour of charging. They're the most common choice for homes and businesses (ev-lectron.com). These are "purchased" for vehicles that drive more than 6000 miles per year and are afforded a purchase + installation budget of $2780.

Level 3 DC Fast Charger: This is the fastest type of charger. As the name suggests, DC chargers supply direct current to the car's battery, bypassing the onboard charger. Operating at 480 volts, they can charge your EV to 80% in about 30 minutes (ev-lectron.com). The EV charger alone can range from $10,000 to $50,000, depending on the power output – this does not factor in installation costs and site preparation requirements (wattlogic.com). Due to the prohibitive costs for these high-capacity chargers, they are not considered in this analysis.

Insurance: Insurance costs and their composition are complicated and dependent on many factors. A higher deductible reduces the cost contribution from insured vehicle repair costs and results in liability and bodily injury coverage making up the bulk of the cost composition. As a result, we have not included insurance costs in our comparative policy analysis because the same coverage will be required, regardless of the car model. In a more comprehensive analysis, we would discuss the insurance needs of the government entity and receive quotes from several approved insurers for the vehicles chosen in our model.

A Note on Right-Sizing: Right-sizing is the procedure of reducing vehicle weight, size, and carbon footprint to the smallest size possible while still allowing it to efficiently execute its duties. Given the anticipated future prevalence of benefit-costs analyses on electric fleets, it would certainly be a worthwhile endeavor to assess the change in user utility resulting from right-sizing their work vehicle. This could be done with a professionally conducted contingent valuation survey. A priori we would expect an increase in costs from adopting EVs (and especially the Bolt EUV in our analysis) arising from this omitted impact category.

6. Data

In addition to answering important technical questions for the study, Christopher J Wenom Sr., the Director of Fleet Services for the City of Kirkwood, provided complete and detailed Capital Analysis spreadsheets for fiscal years 2023 and 2024. The below information is provided in these spreadsheets:

- VIN numbers (primary key for joins)
- Mileage
- Make
- Model
- Year
- Department
- Replacement score
  - Fleet manager provided
  - Black box
  - Starts at 0, retire vehicle when > 15

In addition to fleet-specific data, we pulled data from Edmunds.com for general cost and performance information on the various models of vehicle examined.

Finally, the St. Louis Fed provides zip code specific cost information on unleaded gasoline and was utilized for our mean cost of unleaded gasoline calculation.

7. Methodology

Step 1: Determine covered vehicles

Our initial task involves identifying relevant vehicles from a dataset comprising over 200 items for our analysis. We evaluated three factors to determine the inclusion of vehicles: vehicle class, minimum usage, and charging availability.

We exclude heavy weight class vehicles from the proposal based solely on their classification. Next, we apply the fleet manager's replacement metric and calculate its year-to-year difference, eliminating any vehicle from our analysis that would not meet the replacement threshold within the 10-year study period. Finally, we remove vehicles employed in a "hot-seat" fashion—constant use with driver changes between shifts. This operation pattern does not provide sufficient charging time, even with the most powerful level 2 chargers.

Although level 1 DC chargers could be suitable for this scenario, their cost is currently exorbitant. Moreover, we automatically rule out vehicles already in use as electric vehicles (EVs).

After applying these criteria, we found that only 29 vehicles were eligible for our analysis.

Step 2: Select EV Substitutes

Our next task involves selecting suitable replacements for ICE vehicles. One constraint imposed in the selection process is that the manufacturer should be American. Next, the selected EV should be able to perform all of the same duties as its ICE counterpart. Given these two criteria, the substitutes presented in Table 1 and Table 2 were selected. Notably absent from these criteria is the size/luxury factor of the vehicles (discussed in the section on right-sizing).

Step 3: Drive the cars for 10-years

Using Python, we simulate driving each vehicle for 10 years. This process is succinctly summarized in the below pseudocode. Vehicle usage parameters are based on changes between FY2023 and FY2024 observations.

Simulation Pseudocode: * For each car: * Start as ICE * Drive for one year * Increment costs, replacement score * If replacement score > 15 at year end: * If ICE: * Buy a charger * If Car driven < x: * buy a level 1 charger * Else buy a level 2 charger * Update operating cost to EV values * Replace with a new EV * Sell old car at terminal value * Repeat for 9 more years * Return discounted fuel, maintenance, replacement, and carbon costs for car

8. Results

After driving the 29 fleet vehicles for 10 years we realize a net reduction in costs from transitioning to EVs of $691,000 ($1.592M for EVs and $2.283M for ICE vehicles). These findings are presented in Table 4. Referring to Figure 1, the greatest gains to switching to EVs comes from a reduction in fuel expenditures (43% of savings). Reductions in CO2 emissions, vehicle purchase costs, and maintenance+repair costs all contributed to the savings in a significant way (roughly 20% for each category).

Table 4: Impact Category Estimates (Base Case)

Category	Replace w/ EV	Share	Replace w/ ICE	Share
Used Car Sales	$1,488,000	-	$1,845,000	-
Carbon Output	$100,000	3%	$250,000	6%
Maintenance & Repair	$375,000	12%	$548,000	13%
Fuel	$184,000	6%	$481,000	12%
Vehicle Purchases	$2,362,000	77%	$2,849,000	69%
Charger Costs	$59,000	2%	$0	0%
Total Costs	**$3,080,000**	100%	**$4,128,000**	100%
Net Costs	**$1,592,000**		**$2,283,000**	

9. Sensitivity Analysis

Next, we run two additional simulations in order to establish reasonable bounds on the expectations of our results: one favorable to internal combustion engine (ICE) vehicle replacements and another favorable to electric vehicle replacements.

First, we consider a situation in which expensive commercial EV chargers must be purchased and/or installation costs for many of these chargers are much more costly than anticipated. As a result, we assess a $10,000 initial charger cost for each EV transition. Next, we consider a higher discount rate to reduce the net present value costs associated with CO2 emissions and also reduce our assessed CO2 costs at $50 per ton.

The following results (Table 5) show that under conditions favorable to ICE vehicles, we still observe a net benefit of $339,000 ($1.61M cost for EVs vs $2M cost for ICE vehicles).

Table 5: Ideal Scenario for ICE Vehicles

$10k per charge, 5% discount rate, $50 carbon cost

Category	Replace w/ EV	Share	Replace w/ ICE	Share
Used Car Sales	$1,292,000	-	$1,574,000	-
Carbon Output	$50,000	2%	$125,000	4%
Maintenance & Repair	$326,000	11%	$472,000	13%
Fuel	$164,000	6%	$414,000	12%
Vehicle Purchases	$2,094,000	72%	$2,518,000	71%
Charger Costs	$274,000	9%	$0	0%
Total Costs	**$2,908,000**	100%	**$3,529,000**	100%
Net Costs	**$1,616,000**		**$1,955,000**	

Finally, we consider a scenario more favorable to the adoption of electric vehicles. This scenario considers a terminal sales value for the EVs on par with ICE vehicles (50%), a transition of the Missouri energy mix to something akin to California (less than 15% of energy from dirty energy sources), as proposed in Ameren Missouri's 2023 Integrated Resource Plan. Third, we consider a $200 social cost of CO2 (which is likely closer to the mean estimate than the base case). The results are presented in Table 6.

Overall, we now see a cost savings of nearly $1 million. The largest share of these cost savings are now provided through carbon emission reduction – 37.5% vs 22% in the base case.

Table 6: Ideal Scenario for EVs

50% EV terminal value, MO eliminates coal, $200 carbon cost

Category	Replace w/ EV	Share	Replace w/ ICE	Share
Used Car Sales	$1,539,000	-	$1,845,000	-
Carbon Output	$139,000	4%	$499,000	11%
Maintenance & Repair	$375,000	12%	$548,000	13%
Fuel	$184,000	6%	$481,000	11%
Vehicle Purchases	$2,362,000	76%	$2,849,000	65%
Charger Costs	$59,000	2%	$0	0%
Total Costs	**$3,119,000**	100%	**$4,377,000**	100%
Net Costs	**$1,580,000**		**$2,532,000**	

10. Recommendation

From our sensitivity analysis we conclude that under various conditions we can expect an increase in net benefits between $339,000 to $952,000 with an "average" expected increase of $691,000. Also of note is that some benefits accrue regardless of CO2 emission considerations. As a result, it is recommended that the City of Kirkwood adopt a policy of transitioning its light and medium vehicles to electric versions in pursuit of its underlying goal to mitigate climate change through targeted environmental initiatives.

11. Limitations and Considerations for Further Research

While our study yielded positive net benefits, it is worth considering that the impact of the policy, as outlined in the BCA, is modest in impact. With Kirkwood's population of roughly 30,000 each citizen would realize a net benefit of about $23 over the 10-year study period ($2.30 per year).

Impact categories not included in this study due to limitations in time and resources included: * Insurance costs * Right-sizing * Trend of decreasing costs of electric vehicles * Trend of improved battery performance * Possibility of government subsidies for electric vehicles and chargers (e.g. Commercial Clean Vehicle Credit, 15% of vehicle cost)

Also worth considering in a more thorough analysis would be over-sizing hot-seated portions of the fleet to allow for the electrification of high-use vehicles. As an example, suppose the police department operates patrols on 8 hour shifts and uses 30 cars. If it takes 8 hours to completely recharge a vehicle, an additional 10 car inventory could be maintained allowing for an appropriate portion of the fleet to charge-up on level 2 chargers. While this would pose an initial increase in costs due inventory growth, overall usage would remain the same and vehicles could be used for 33% longer. The conclusion is that the losses under this system would simply be the opportunity cost of the additional capital employed to upsize the fleet.

Consider that the police force accounted for over 50% of the Kirkwood fleet's CO2 emissions and, that under our EV-favorable scenario, CO2 is reduced by 3.6 million lbs. Furthermore, if we assume all US cities have similar fleets and their sizes are in proportion to their populations, we can use the US population (~340 million as of April 2024) to get a multiplier of 340,000,000/30,000 = 11,333. This multiplier can be doubled if we assume that police fleets are electrified: 11,333*2 = 22,667. With this information we realize a US carbon reduction of roughly 81,600,000 tons of CO2 emissions over a 10 year period. This quantity is approximately 1.6% of the US's 2022 CO2 production(https://ourworldindata.org/co2/country/united-states) – a sizeable reduction in CO2 output with a very nice price tag (that is, a negative price) which should certainly be considered in tandem with many other policies in order to meet US emissions goals.

In conclusion, small positive changes over a large enough period of time with a large number people contributing can have a large positive impact.

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