Evaluating the Cost and Environmental Implications of Commercial Electric Vehicles in the LTL Delivery Industry

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Abstract

A prominent national food company is replacing 20 conventional Internal Combustion Engine trucks with Smith's Newton model electric delivery trucks. This research quantifies the total costs associated with this change given present costs and external factors. It is shown that with current energy prices, the company will spend more money to serve their current delivery route, although it is likely that changing conditions and rising fuel prices will allow the company to save money over the lifetime of the trucks. Breakeven points are identified at which the cost of operating a conventional fleet and electrical fleet are identical, and various ideas for incentivizing the cleaner technologies are analyzed. Environmental benefits are quantified both in terms of local, tailpipe emissions reductions and total emissions reduction using "wells-to-wheels" methodology.

1. Introduction

In the last few years, a new generation of electric vehicles (EVs) has begun to enter the marketplace as various political and economic factors have combined to form an environment more conducive to these vehicles. In 2009, the economic stimulus package passed in the US included $2.4 billion in DOE grants to spur "the manufacturing and deployment of the next generation of US batteries and electric vehicles." (USDOE 2009) As a result, a large number of new types and models of EV's have are currently available to consumers, and the beginnings of charging infrastructures have begun to emerge.

Though electric vehicles have previously been introduced to the marketplace without sustained success, new considerations have emerged which suggest that this generation of EV's could fare better than their predecessors. Improving battery technology has reduced the tradeoff between battery power and energy capacity, thus increasing the weights and ranges of vehicles that can operate purely on battery power. Therefore several models of light and medium duty electric trucks are now available alongside the more publicized electric cars like Nissan's Leaf. Many have attracted buyers, with a variety of companies both local and national in scale introducing EV's to their fleets.

There are several prominent recent examples of electric truck deployments in the US. In 2007, a widely known international company in the food and beverage industry replaced 20 conventional trucks with electric trucks at a distribution center located in Portland, OR; this deployment is part of a larger fleet restructuring that includes adding electric trucks in several other cities (Motavalli 2010). FedEx (2010), Staples (Ramsey 2010), and Coca-Cola (Clancy 2011) are also in the process of large deployments at electric vehicles at the national level, and several smaller companies are beginning have deployed these trucks on a smaller scale as well.

At least some of the appeal of electric vehicles is the potential to reduce emissions of CO2 and other pollutants associated with the transportation sector, both locally (i.e., tailpipe emissions) and in aggregate (i.e., "wells-to-wheels"). To the best of the authors' knowledge, the emissions benefit associated with replacing a conventional delivery truck with a similar electric truck have not been examined in the literature. This research presents a model to quantify these emissions benefits based on the logistical considerations of the truck's route. The research considers the example of the recent deployment in Portland, OR described above as a case study and examines the financial and emissions implications associated with that deployment.

2. Literature Review

The methodology presented in this paper draws upon several distinct bodies of literature to analyze the environmental impacts of replacing conventional delivery trucks with electric trucks.

Davis and Figliozzi (2012) provided the modeling framework for calculating the energy consumption and cost of serving certain routes with an electric truck. That research analyzed the effects of routing parameters and constraints on the total costs and found that the costs and competitiveness of the electric vehicles are heavily dependent on assumptions about battery life and fuel or energy costs, and that the utilization of the trucks was the most predictive logistical parameter.

A key consideration impacting the competitiveness of electric delivery trucks and other electric vehicles is the lifespan and limitations of the battery that powers the vehicle, as this affects both the cost and range of the EV to a great extent. In the mid-90's, electric Toyota RAV-4 cars were briefly popular in California; Knipe et al. (2005) reviewed the performance of Nickel Metal Hydride batteries powering these vehicles after reaching 100,000 miles. They found that these batteries retained about 85% of their initial power storage capacity, although the decrease in range outpaced the decrease capacity. A more recent study (Smith EV 2010) of the lithium ion batteries that power the Smith Newton electric trucks found that they will retain 80% of their initial capacity after 3,000 cycles of fully charging and discharging. The US Electrification Coalition provided projections about battery life and costs, and gave a battery lifespan of about 150,000 miles.

Clearly, much of the interest in EVs stems from the potential to reduce emissions represented by these vehicles. This is evident from the large body of literature exploring methodologies for calculating emissions and offering insights into the potential emissions reductions possible from fleet electrification. The Intergovernmental Panel and Climate Change provided guidance for calculating emissions under a variety of scenarios in the Fourth Assessment Report, issued in 2007 (Pachauri and Reisinger 2007). A recent report from the US Electrification Coalition (2010) made the case that emissions gains can be realized even if electric vehicles are charged entirely with coal, with benefits increasing as the fuel mix becomes cleaner. Samaras and Meisterling (2008) verified this claim with a life cycle assessment of emissions from plug-in hybrid vehicles, finding that they reduced greenhouse gas emissions by 32% compared with conventional vehicles.

In quantifying lifetime EV emissions, the battery is again an important component whose materials and production account for some of the environmental impact of these vehicles. Rydh and Sandén (2005) presented a study of the energy expenditures during the production of various types of batteries and provided useful estimates for the energy associated with the manufacturing and materials of batteries. Samaras and Meisterling (2008) used the values provided by Rydh and Sanden as part of an analysis that estimated that the lithium-ion batteries account for 2-5% of life cycle emissions for plug-in hybrids. Notter et al. (2010) conducted a similar study for purely electric vehicles, finding that the percentage of the emissions resulting from the battery increases to 15% in this case. So while is some disagreement about the total contribution of emissions associated with the battery, the consensus in the literature is that the battery is the only real source of difference between the emissions from the manufacture and salvage of conventional and electric vehicles.

3. Methodology

The case study presented here builds on previous work by Davis and Figliozzi (2012), which presents models for calculating the energy consumption lifetime costs for a fleet of electric trucks to serve a given route.

Using the energy consumption model described in that work, the CO2 emissions can be calculated and compared for the conventional and electric trucks. For conventional vehicles, CO2 emissions are directly related to the fuel consumption; the US Department of Energy gives a value of 22.2 pounds of CO2 emitted per gallon of diesel fuel burned (US DOE). For electric vehicles, the operational energy found according to the methodology from Davis and Figliozzi (2012) can be correlated to emissions if the sources of electricity produced and their resulting emissions rates are known. This information is readily available for most locations and power companies from the US Environmental Protection Agency (2007). Table 1 shows the fuel profiles for three US cities—Portland, OR, New York, NY, and Charleston, WV—along with the CO2 emissions in lbs/MWhr that the fuel mix produces.

Of course, in addition to the CO2 produced simply powering the vehicles, a non-negligible portion of a vehicle's carbon footprint is due to other events in its life cycle, particularly the manufacturing process and salvaging process that bookend the vehicle's lifespan. Much research has been devoted to quantifying the effects of these processes in terms of emissions, with Notter et al. (2010), Majeau-Bettez et al. (2011), and others suggesting that the only significant differences between conventional and electric vehicles come from production and disposal of the battery; the motor, chassis, and other components have largely the same environmental footprint for all vehicle types.

Table 1: Percentages of energy sources and CO2 emissions rates for US regions
Source: (US EPA 2007)

Region	Hyrdo (%)	Non-hydro renewable (%)	Nuclear (%)	Oil (%)	Gas (%)	Coal (%)	CO2 Emissions Rate z_{rate} per MWhr
Portland, OR	48.4	3.3	3.0	0.2	12.8	32.0	859 lbs (390 kg)
New York, NY	0.0	0.5	37.8	5.0	56.3	0.0	705 lbs (320 kg)
Charleston, WV	0.6	0.5	22.3	0.3	2.9	72.9	1552 lbs (704 kg)
US Averages	5.8	2.5	19.4	1.6	21.7	48.5	1293 lbs (586 kg)

Rydh and Sandén (2005) quantified the energy required to produce lithium-ion batteries and found that 1,200 MJ (888 million ft-lbs) of energy are used in production of the battery for each kWhr of storage capacity. Additionally, they find between 310 and 670 MJ per kWhr are spent producing materials from the battery. Following the methodology applied by Samaras and Meisterling (2008), we assume the round middle value of 500 MJ/kWhr (370 million ft-lbs/kWhr) for the energy spent in material production for the battery. This yields a total of 1700 MJ/kWhr (1258 M ft-lbs/kwhr) of energy associated with the production of the battery.

Because there are several different plants and manufacture location for these batteries, calculations of the emissions associated with battery production assume the US average CO2 emissions rate from Table 2, 1293 lbs/MWhr. As an example, a 1 kWhr Li-Ion battery has an associated energy cost of 1,700 MJ (472.222 kWhr), and thus a CO2 footprint of about 611 lbs (277 kg). This research assumes the relationship between battery size and energy cost is linear, i.e., there is no incremental benefit in producing larger batteries. The research also follows the methodology of Samaras and Meisterling (2008) in assuming that, in cases where battery replacement is necessary at some future point, the energy requirements for the production of the battery will remain at today's values.

4. Case Study

The Portland distribution center for a large national company has a total of 27 trucks conventional straight trucks with a 24-foot box and a GVW of 26,000 lbs (Class 6 in the US). The average fuel economy of these trucks is 5-6 mpg. The trucks depart the depot between 3:00 AM and 7:00 AM and return between 12:00 PM and 4:00 PM, depending upon the time windows of the customers. 20 of these 27 vehicles will be replaced with Smith Electric Vehicles'

Newton electric truck. The specifications for these two trucks, along with other parameters used in the analysis, are provided in Table 2.

Table 2: Parameter values and specifications for the trucks

Parameter	Value
Air density ρ	0.002378
Drag coefficient C_D	0.7
Frontal area A_f	50 ft^2
EV engine efficiency	0.8
EV charging efficiency	0.8
Regenerative braking percentage	0.2
Chassis cost	\$50,000 for conventional vehicle \$98,000 for electric vehicle
Battery cost (current)	\$600/kWhr
Battery cost at replacement	\$400/kWhr
Approximate battery lifespan	7.5 yrs
Diesel Cost	\$4.07/gal
Electricity cost	\$0.1106/kWhr
Maintenance costs	\$0.20/mi for conventional vehicle \$0.10/mi for electric vehicle
Average route weight	16,000 lbs for conventional vehicle 18,000 for electric vehicle
Daily total route distance	812 miles.
Diesel truck base MPG	6.5
EV tax incentive	\$22,500
Discount factor	6.5%
Fuel inflation rate	2.5%

The Smith Newton trucks used in the evaluation Class 6 model with a GVW of 26,000 lbs. The battery pack is customizable, available as a 40, 60, 80, 100, or 120 kWhr battery pack. Using the daily mileages provided by the company, the battery energy necessary to serve the route is calculated for each truck according to the methodology presented above. This is repeated for three different MOVES drive schedules (US EPA 2009)—203, 206, and 253—chosen to represent lower, medium, and higher speed operational routes. A battery size is then selected to satisfy the energy need; in order to ensure adequate energy capacity and to account for some of the effects of "range anxiety" described by Botsford and Szczepanek (2009) and elsewhere, we assume a lower bound for battery capacity of 120% of the route energy. The smallest possible battery size that is greater than this value is chosen.

For simplicity, the calculations assume some level of interchangeability between the trucks and battery packs, i.e. the battery packs will be utilized in such a way that their lifespans are optimized. Treating these uniformly, we next must assign a cost to battery deterioration or replacement in the electric vehicle. Unfortunately, no real consensus exists in the literature regarding the lifetime of the batteries used in the electric trucks considered here, although Knipe et. al (2005) have found earlier generations of batteries like those used in the Toyota Rav4 are capable of powering the cars in excess of 100,000 miles. Based on the data provided by the company, electric trucks added to the fleet presently will have travelled 100,000 miles in approximately 7 ½, at which point the batteries will be replaced. Using this data along with projections from Kilcarr (2010), we assume a future cost of $400 per kWhr of capacity, which is discounted in to net present value in the analysis.

With the electric truck's daily route energies and battery sizes known, it is possible to then compare the lifetime CO2 emissions for the two vehicle types. The energy associated with the battery production is found by multiplying the total fleet battery capacity (including the battery replacement) by the 1,700 MJ/kWhr figure suggested by Rydh and Sandén (2005). The associated CO2 emissions are then found by assuming the US average CO2 emissions given in Table 1, since the location of the battery production (and thus the exact emissions rate) is unknown. Route emissions are found for three cities with different fuel mixes. This is compared to the conventional truck's emissions, arising entirely from the combustion of diesel fuel. Note that because emissions associated with the chassis production are assumed to be the same for both truck types, they are not considered in this comparison.

Figure 1 shows the CO2 emissions in pounds per truck per day for each of the three MOVES drive cycles and each of the three fuel mixes. Clearly, there is a substantial reduction in CO2 emissions obtained by replacing the conventional vehicles with electric vehicles. The potential benefit is greatest with the slowest drive schedule, owing to the very small energy usage of the EVs compared to a less-than-optimal fuel economy for conventional vehicles at this speed. The stop-and-go conditions found along the slower operational routes also benefit the EV, as the gains from the efficient engine and regenerative braking are maximized in these conditions. The EV's low-speed advantages are compounded by the fact that the battery capacity requirements (and thus associated emissions) are minimized at low speeds as well. Intuitively, the fuel mix utilized to produce electricity has a significant effect on the total emissions gains possible with EV technology. However, even in the least favorable conditions for the EV—the fastest drive schedule with West Virginia's coal-heavy fuel mix—the EV still reduces lifetime emissions by 1.5%. By contrast, the EV reduces emissions by 70% in the most optimistic scenario—the slowest drive schedule with New York's fuel mix. Using Portland's wind heavy fuel mix, the EVs will reduce emissions by 66%, 58%, or 36% on the slowest, middle, and fastest drive schedules respectively.

While electric trucks appear to have the potential to significantly reduce emissions, the potential of the technology to reduce costs is less certain, and depends heavily upon the assumptions about battery life and the length of the planning horizon. For the most favorable operational route for the EV—drive schedule #203—the conventional vehicle is a slightly less expensive option under present-day conditions, assuming a 10-year planning horizon. The differences between the two technologies are more significant at higher speeds. If the planning horizon is extended to 12 years, however, the electric truck is the less expensive option, even under other assumptions that perhaps favor conventional trucks (e.g., no additional battery at salvage); the conventional truck is still less expensive for the other two drive schedules although the differences are significantly smaller than under the shorter planning horizon. These costs, broken down by category, are shown in Figure 2.

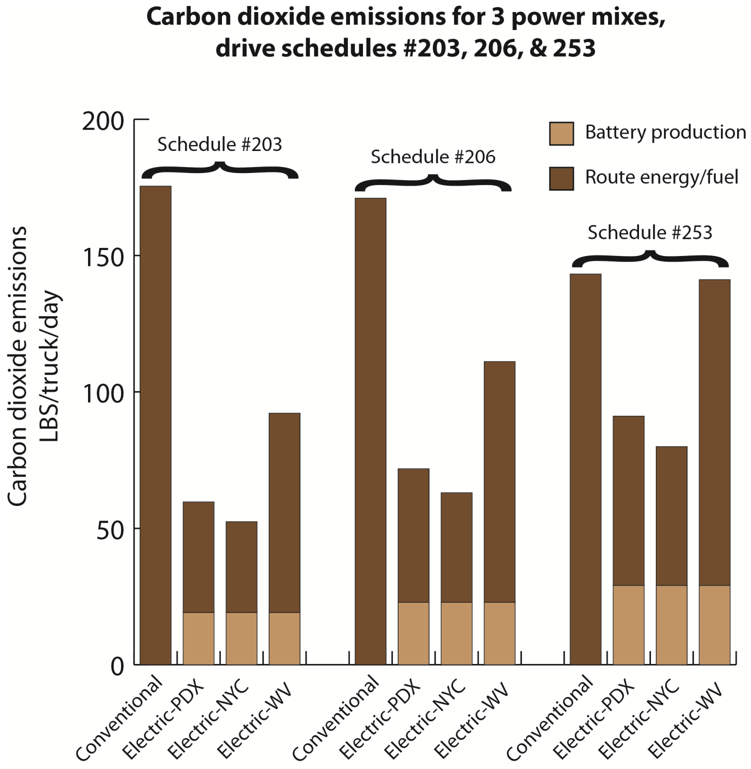

Figure 1: Carbon dioxide emissions in pounds per truck per day for three MOVES drive schedules for three fuel mixes. Lighter part of the bars indicates CO2 associated with battery manufacture, and darker colored bars is associated with route energy.

A key reason for the conventional truck's financial competitiveness, then, is that there is no tax on CO2 in the US. Figure 3 provides a visualization of the relative sizes of the component costs for both types of trucks for drive schedule #203. The left column includes a hypothetical $20/ton CO2 tax, in line with present European rates, while the right column reflects US conditions and assumes no CO2 tax. In either case, an overwhelming majority of the lifetime costs associated with the EV are from the purchase of the chassis and battery. By contrast, a majority of the costs of the conventional vehicle are fuel costs, and in the case where CO2 is taxed, this has a much greater effect on the costs of the conventional vehicle.

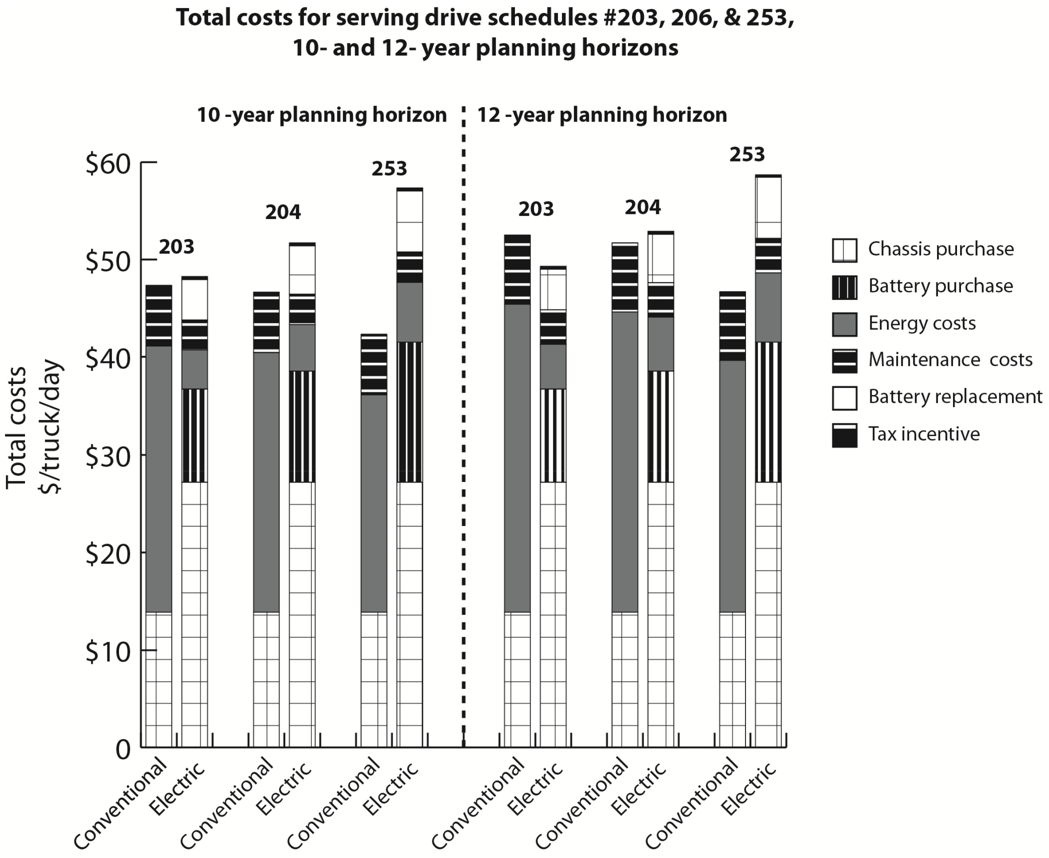

Figure 2: Total costs per truck per day for MOVES drive schedules 203, 206, and 253, assuming 10- and 12-year planning horizon.

More insights about what range of values a CO2 tax would need to take to make a difference can be obtained by finding breakeven values of CO2 in dollars per ton. These are found by calculating the cost per ton of CO2 emitted to equalize the costs of the conventional fleet and the electric fleet, as described by Davis and Figliozzi (2012).

The breakeven values for CO2 in dollars per ton are shown in Table 3 for each of the three drive schedules and each fuel mix previously considered, for both a 10-year and 12-year planning horizon. Following the other results, the breakeven CO2 tax rate for drive schedule #203 is fairly small for the 10-year planning horizon. A breakeven CO2 tax is infeasible for this drive schedule given a 12-year planning horizon, as the EVs are already the lower cost option in this case. For drive schedule #206, the breakeven CO2 costs are somewhat unrealistic for the 10-year planning horizon, but fall well into the realistic range if the planning horizon is extended to 12 years.

For drive schedule 253, the values are fairly unrealistic in either scenario, suggesting that some combination of rising fuel prices and cheaper capital outlays would have to take place for EVs to be competitive in higher speed scenarios. The CO2 tax value for the high-coal Charleston, WV mix in drive schedule #253 is an interesting result. The relatively dirty fuel mix combined with the fast, steady-speed conditions combine to only offer the EV a modest advantage in emissions. This highlights the importance of the fuel mix in determining the competitiveness of the EV in a hypothetical situation where CO2 is taxed. The mix used to create the energy must be clean enough to offer the EV some measurable advantage in terms of route CO2 emitted for a tax on emissions to have any effect on the cost comparison.

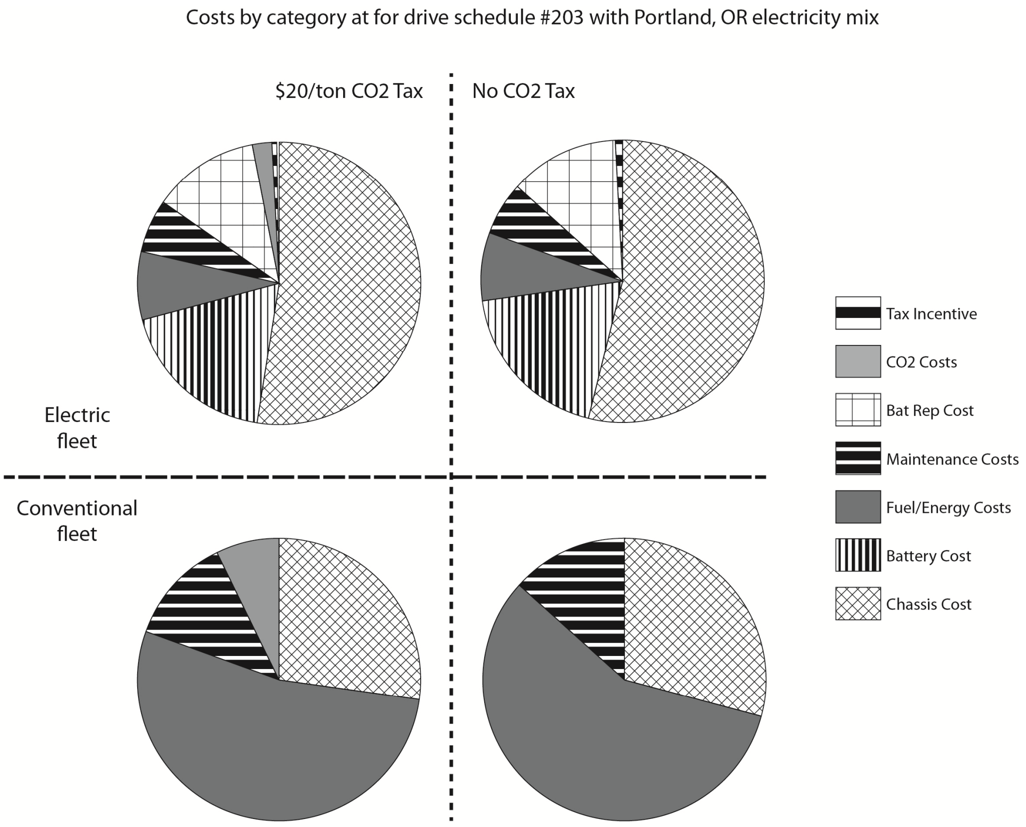

Figure 4: Costs by category for the conventional and electric truck, for MOVES drive schedule #203. The charts on the left use the assume a $20/ton tax on CO2 and assume the Portland, OR CO2 emissions rates for electrical energy.

5. Conclusion

A methodology has been introduced for calculating the differences in CO2 emissions between electric delivery trucks and their conventional counterparts, and comparing the lifetime costs of the two types of vehicles to with and without certain values for a CO2 tax. The results show that the emissions differences from replacing a conventional delivery truck with an electric truck can be substantial. The actual reduction in CO2 emissions depends heavily on the fuel mix used to generate the electricity that powers the electric truck and on the travel speeds encountered serving the routes. While present day conditions render the conventional truck the less expensive option under most scenarios, modest increases on fuel prices or taxes on CO2 would combine to make electric trucks the less expensive option in many scenarios.

Table 3: Breakeven points for CO2 costs in dollars per ton emitted for each of the three fuel mixes and drive schedules.

10-year planning horizon	Drive schedule 203	Drive schedule 206	Drive schedule 253
Portland	$5.10	$89.47	$551.41
New York	$4.80	$82.23	$454.47
West Virginia	$7.10	$148.11	$13,783.18

12-year planning horizon	Drive schedule 203	Drive schedule 206	Drive schedule 253
Portland	Infeasible	$11.75	$437.45
New York	Infeasible	$10.80	$360.54
West Virginia	Infeasible	$19.45	$10,934.47

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