Carbon Reduction Challenge:

Electrification of Baggage Tractor Fleet

Delta Air Lines Ground Support Equipment Engineering Co-Op Team:
GSEmission Mission

Louis Lammers

Louis.lammers@delta.com

Maddie Gorke

Madeline.r.gorke@delta.com

Danielle Khalil

Danielle.khalil@delta.com

GSEmission Mission Co-op team recommends electrifying Delta's baggage tractor fleet at Hartsfield-Jackson International Airport (ATL). At ATL, Delta operates 1028 baggage tractors, of which 831 are internal combustion powered units. Assuming a year of typical air traffic, the 831 IC bag tractors emit approximately 2.7 million kg of CO_2 annually. If all 831 of these tractors were electrified, the emissions from producing the power to charge the electric tractors is approximately 1.0 million kg of CO_2 annually, thus cutting a total of 1.7 million kg of CO_2 annually. The estimated annual fuel cost of these 831 bag tractors is around $7.5 million, where the cost of charging the same tractors is estimated at $0.47 million, saving a total of $7 million annually.

This electrification project has a high initial investment due to the high costs of electric chargers and electric parts for the tractors but will produce significant annual fuel savings. Delta's GSE Safety recommends providing 1 electric charger per 1.5 electric GSE, therefore this project would require 554 additional chargers, with an average price of $96,859 per charger. The cost of all necessary electric parts and labor for installing parts is approximately $45,700 per unit. The annual savings on fuel per unit was calculated to be $10,556. Because there are hundreds of IC bag tractors, the electrification can be split into phases, where the first phase of electrification retrofits the oldest IC models, and the second, third, and fourth phases each retrofit newer IC models respectively. Since the initial investment and fuel savings are both proportional to the number of bag tractors, the payback periods for each phase and for the entire fleet all at once are approximately 13 years.

In order to make increase feasibility of the GSEmission Mission's proposal, the team discussed a workaround to maximize carbon savings while also minimizing cost: electrifying the 62 oldest (before 1980), highest-emitting tractors. The lower cost and proportionally higher carbon savings potential is intended to make the project more practical to Delta executives. The team estimates that this 9.323% of the Atlanta baggage tractors contributes 32.262% of the fleet's entire carbon emissions, making it metaphorical low-hanging fruit. The proposal is explained in more detail in the *Anticipated Obstacles* section of this report.

Since the electrification will require the removal of many IC components, Delta can reservice IC components that are still operable within the belt loader fleet, which uses similar components as the bag tractors. This will save Delta money on servicing belt loaders in the future years to come but will require the implementation of the later phases since the initial phases involve the oldest tractors, and thus less reliable parts. Reservicing these parts will have no impact on Delta's emissions, since the belt loaders have always operated on IC components.

Summary of Proposed Change

The Delta Air Lines Ground Support Equipment CoOp team (Team GSEmission Mission) recommends retrofitting Delta's 831 internal combustion baggage tractors at the Atlanta airport with electric drivetrains, necessitating the purchase of 554 electric chargers in addition to those in use in Atlanta today. A consequence of these additional chargers is the increased cost of electricity to the Delta operation; however, fuel cost and consumption will decrease. The difference in these costs is explained in the *Cost Savings Analysis* section of this report. Though the cost for project implementation is significant, team GSEmission Mission determined that carbon emissions would be cut roughly in half over the course of a year's worth of normal airline operation. Another change that would need to be implemented is fitting the tractors with new parts. Retrofitting the baggage tractors requires the removal of components related to the internal combustion engine that currently exists in the 831 tractors of interest, as well as the purchase and installation of specific electric components.

Motivation and Background

The Carbon Reduction Challenge is a Georgia Tech-sponsored project that encourages interns at various companies to unearth and help solve the pertinent issue of carbon emissions in the workplace. Though it is not required to be interning at a company to participate in the Challenge, it may be helpful in finding deficiencies in carbon emissions at a corporate level. Team GSEmission Mission is a three-person team of CoOps working at Delta Air Lines over the summer of 2021. Delta Air Lines is a major US airline headquartered in Atlanta, Georgia with a mission of reducing aircraft emissions by 50% between 2005 and 2050 [1].

Though the Ground Support Equipment (GSE) group is part of Delta, because the department oversees management and innovation in the equipment *supporting* Delta's planes, GSEmission Mission's carbon reduction project does not focus on aircraft emissions. Delta currently owns and operates more than 3,500 units of bag tractors whose purpose is to transport passengers' bags through and around the airport. Approximately 300 of the 3,500 units across the entire Delta system are electric units. Carbon emissions and fuel costs could be cut tremendously if the entire fleet of baggage tractors was electrified, and since Delta is based out of Atlanta, the project involves the baggage tractor fleet in Atlanta. Baggage tractors transport passengers' bags to and from aircraft, and only 197 of 1,028 of these units in Atlanta are electric vehicles. Therefore, the goal of the project is to devise a plan to retrofit the 831 existing internal combustion tractors. It is important to note that the team planned the retrofit of 831 baggage tractors, but only approximately 80% of tractors across the system are being used at one time due to routine maintenance, accidents, etc. Thus, for fuel and electricity calculations, GSEmission Mission used 80% of the total number of internal combustion baggage tractors in Atlanta for a more accurate representation of the fuel and electricity consumption yearly since not all of the tractors are in use at one time.

Team GSEmission Mission's carbon reduction project involves replacing internal combustion engines with electric machines in a series of phases to spread out capital expenditure time into more manageable segments. Phase One involves the oldest 135 baggage tractor's in Atlanta's fleet – tractors that were produced between 1974 and 1990. Phase Two electrifies the next 197 units that were produced before 2000. Phases Three and Four are the most ambitious and costly of the rollout plan, but they will also likely yield the highest return on investment, since most of their parts are able to be used on another GSE fleet, the belt loader. Phase Three electrifies the next 289 units that are older than 2010. This brings the total number of electrified units in the system up to 621. Finally, Phase Four converts the remaining 210 baggage tractors older than 2021, under the assumption that all baggage tractors from 2021 and later will be electric. Figure 1 details the rollout plan.

This project was comprised of three main bodies of work: electrification logistics, current carbon emissions calculations, the method of electrification, and cost analyses. Logistics of electrification included the planning and evaluation of current and future assets, such as charger locations and quantities, as well as power allocation.

The current carbon emissions of the baggage tractor fleet at Delta required knowledge of daily usage of fleet, gasoline/diesel consumption, gasoline/diesel cost, and tractor characteristics and specifications to estimate emissions per vehicle, for the entire fleet, etc. Assuming that the converted electric tractors would get as much use as the internal combustion tractors, the time and distance metrics were used to determine emissions of the electric fleet, cost of operation, recharge times, etc. and compared them to metrics of the IC baggage tractors.

To develop a method of electrification, the internal combustion components to be replaced and the components staying in the drivetrain were determined. The monetary implications of this task were also considered because new components would need to be purchased, and labor costs for switching out parts would need to be factored into the equation. Figuring out how to recycle, sell, or dispose of old components is also factored into this consideration.

Carbon Reductions and Cost Savings

Carbon Emission Calculations

The goal of the Carbon Reduction Challenge is to minimize carbon emissions, but in order to *minimize* carbon emissions, Team GSEmission Mission first had to determine how much carbon the baggage tractors were emitting. Carbon emission calculations were broken down into three main steps.

Step 1 involved extracting an Excel file with the current model years of the baggage tractors in service in Atlanta. The team had access to average horsepowers by model year of baggage tractors via Delta's database. In some instances the database listed exact horsepower statistics, but in other scenarios, an educated guess was made by interpolating the horsepowers between two surrounding years. (For instance, we had data for 1981 and 1988, but not 1983-1987, so we were able to determine the horsepowers of years 1981 and 1988 to fill in the gaps in the data.)

Step 2 required looking at Figures 2 and 3 to determine the Carbon Emission Factor (g/bhp-hr) based on engine model year and horsepower found in Step 1. Knowing this factor and the horsepower allowed us to determine the carbon emissions per tractor in grams per hour. Then, after surveying baggage tractor operators, the team approximated that the tractors are in use for 15 hours per day, which, multiplied by the carbon emissions per hour yields grams of carbon emitted per day. The next part of Step 2 was to then multiply by 365 to obtain carbon emissions of one tractor (grams per year), then, to standardize the data, divided by 1000 to convert from grams to kilograms.

Step 3, the third and final step, allowed the team to determine the total amount of carbon all of the Atlanta baggage tractors emit in a year. This assumes that all of the tractors are being used (i.e., not out of service for maintenance) each day of the year. After finding the carbon emissions per tractor per model year, the team extracted more data from the initial Excel file used in Step 1: the number of these model years that had IC engines (rather than electric). Multiplying the number of tractors per model year by the carbon emissions (kg/yr) yielded the carbon emissions in kg/year for all of the IC engine tractors in that year. Finally, adding up all of the model years' carbon emissions and multiplying by .8 (to account for the 80% of tractors in use per day) produced the final result of 2,708,283.04 kilograms of carbon emitted by baggage tractors per year in Atlanta as shown in Figure 4. These calculations can be seen in the following calculations:

$$Step\ 2a\text{: } \frac{\#\ g}{bhp - hr}\ (Carbon\ Emission\ Factor) * hp = \frac{\#\ g}{hr}\ (per\ one\ tractor\ in\ a\ model\ year)$$

$$Step\ 2b\text{: } \frac{\#\ g}{hr} * \frac{15\ hr}{1\ day} * \frac{365\ days}{1\ year} * \frac{1\ kg}{1000\ g} = \frac{\#\ kg}{year}\ (per\ one\ tractor\ in\ a\ model\ year)$$

$$Step\ 3a\text{: } \frac{\#\ kg}{year} * \frac{\#\ tractors}{model\ year} = \frac{\#\ kg}{year}\ (total\ tractors'\ emissions\ in\ a\ modeal\ year)$$

$$Step\ 3b\text{: } \sum_{Model\ Year\ 1}^{Model\ Year\ 41} \frac{\#\ kg}{year}\ (tractors'\ emissions\ in\ a\ model\ year)$$

$$= TOTAL\ Carbon\ Emissions\ \left(\frac{kg}{yr}\right) for\ all\ ATL\ baggage\ tractors\ across\ all\ model\ years$$

$$= 3{,}385{,}353.794 \frac{kg}{yr} * 80\%\ tractors\ in\ use$$

$$= 2{,}708{,}283.04 \frac{kg}{yr} = 2{,}708.283\ metric\ tons\ of\ carbon\ emitted\ per\ year$$

While electrifying the bag tractors will cut back-of-the-pipe emissions to zero, the electricity used to charge the tractors must be generated, which will introduce emissions. Georgia Power is the current airport's power provider. Figure 5 shows Georgia Power's energy profile, which include emissions per plant type [2]. On average, Georgia Power's emission rate is 0.274 kg of CO2 per kWh. To determine the amount of power required by an entire electrified fleet, the daily use of the tractors must be determined. By surveying ramp workers who operate electric bag tractors as well as talking with technical analysts within GSE, it was determined that electric bag tractors use an "opportunity charge" approach while on the ramp. To preserve the longevity of the batteries, the tractors are charged about every 3 hours quickly, gaining an average of 20% charge. Over a 15 hour period of use, an electric bag tractor will be charged a full 100% of charge, which equates to 16 kWh of power per tractor (the tractors are equipped with a 16 kWh battery). The following equation shows the calculation of emissions from the power demand of the electrified bag tractor fleet.

$$0.274 \frac{kg\ CO_2}{kWh} * 16 \frac{kWh}{day} * 665\ units * 365 \frac{day}{year} = 1{,}064{,}106.4\ kg\ CO_2\ per\ year$$

Magnitude of Carbon Savings:

To better understand the impact GSEmission Mission's Carbon Reduction Project has on the quantity of carbon emissions, the team researched other carbon emitters with which to compare the baggage tractors' emissions of 2,708,283.04 kilograms per year. Because powering these vehicles with electricity produces 1,315,331 kg/yr of emissions, there is a net carbon emissions savings of 1,392,952 kg/yr. In comparison, in one year, the average passenger vehicle emits 4,600 kilograms of carbon [3]. In the same amount of time, these in-use tractors (80% of total) collectively save approximately 302.81565 times more carbon emissions. In other words, electrifying the bag tractor fleet offsets emissions of approximately 300 passenger vehicles in one year. According to the Center for Sustainable Systems at the University of Michigan, the average US household produces 48,000 kilograms per year, meaning that 80% of the in-use 831 baggage tractors in Atlanta save more than 29.019833 times more carbon per year [4]. This means that electrifying the baggage tractor fleet offsets emissions of almost thirty households annually. This means that electrifying the baggage tractor fleet offsets emissions of almost thirty households annually.

Charger Cost Analysis:

In order to estimate the financial effects of electrifying the baggage tractors in Atlanta, it was crucial to assess the cost of installing the proper number of chargers across the airport. Too many chargers would cause hundreds of thousands of dollars more than necessary, and too few chargers would not provide enough charging stations for the baggage tractors for the carbon reduction plan to be advantageous. Through internal research and surveying, it was found that as the number of chargers purchased and installed increases, the cost per unit *does not, in fact, decrease*. This is due to the addition of necessary power supply infrastructure to support the electricity that the chargers draw. In addition, charger installation prices rely on a multitude of variables, including, but not limited to: permits, contractor overhead, authority signoffs, routing of conduits, and available power. The calculations in Figure 6 account for the chargers that are required for *electrification* rollout in this Carbon Reduction Challenge project. (In other words, if more chargers are required for previously purchased electric tractors, this has not been accounted for, as it is not within the scope of the project.)

As a result of these variables, it was difficult to pinpoint an exact cost per charger; however, using extrapolation of existing charger vs. cost data and three different types of trendlines, a relatively accurate cost per charger could be determined. Using Figure 7, the team was able to develop three different graphs with the data: one with a logarithmic trendline, one with an exponential trendline, and one with a linear trendline. An equation was associated with each of these trendlines. Since one charger is needed for approximately every 1.5 baggage tractors (each charger could fit two electric baggage tractor, but 1.5 is a safer estimate if Delta Air Lines decides to implement the project), the team estimated that 554 chargers would be needed at the last phase of the rollout process. Therefore, by substituting in the number of chargers needed by each trendline equation, a total cost per charger was determined. Finally, multiplying this number by the 554 chargers required would produce a *total* cost for the charger installation. The calculations are as follows:

$$\boldsymbol{Logarithmic\ Trendline\ Equation}:$$

$$y = 3{,}267.7 \ln(X) + 79{,}133$$

$$y = 3{,}267.7 \ln(554) + 79{,}133$$

$$Cost\ per\ charger, y = \$100{,}478.06$$

$$Total\ charger\ install\ cost = \$100{,}478.06 * 554 = \ \$55{,}64{,}845.24$$

$$\boldsymbol{Exponential\ Trendline\ Equation}$$

$$y = 85{,}152e^{.0002x}$$

$$y = 85{,}152e^{.0002(554)}$$

$$Cost\ per\ charger, y = \$97{,}693.78$$

$$Total\ Charger\ Install\ Cost = \$97{,}693.78 * 554 = \ \$54{,}122{,}354.23$$

$$\boldsymbol{Linear\ Trendline\ Equation}$$

$$y = 4.0215x + 89{,}643$$

$$y = 4.0215(554) + 89643$$

$$Cost\ per\ charger, y = \$92{,}405.77$$

$$Total\ charger\ install\ cost = \$92{,}405.77 * 554 = \ \$51{,}192{,}796.86$$

Figures 8 through 10 display the three different trendlines, as well as the calculations relevant to each trendline. Averaging these three equations yields a total cost of charger installation of $53,659,998.78, where an individual charger costs $96,859.20.

Fuel Cost Analysis:

To find an approximation for the fuel costs being saved by using electric vehicles rather than vehicles with internal combustion engines, the team found statistics for the national average of gas (all grades, all formulations, retail price) per month in the United States from January 2015 through July 2021 [5] as shown in Figure 11. The next step was to average the monthly values per year to arrive at an average gas price per year for the last six and a half years. The final step was to average these seven values to yield $2.57 per gallon. It is our belief that averaging the last six and a half years is sufficient to capture the fluctuations in gas prices resulting from natural causes, political unrest, unforeseen pipeline hacking, global pandemics, etc.

After the cost of fuel per gallon was determined, the next step was to factor in the baggage tractors' fuel efficiency and approximate distance traveled per day. Because the existing telematics on Delta's baggage tractors is rather primitive, it does not include vehicle runtime or time between fuel refills. Thus, a survey of the workers who use the vehicles the most was necessary to determine tractor usage details. After surveying ramp workers, it was determined that baggage tractors use approximately 4 gallons of gas per shift. Since gas is $2.57 per gallon, the tractor uses $10.28 in fuel per shift. Since there are 3 shifts per day, the total fuel cost per day per tractor is $30.84. Since there are 831 IC tractors in Atlanta and each tractor uses $30.84 of fuel per day, the total cost of fuel for all the Atlanta tractors is $20,508.60 per day. If used every day for a year, the approximate fuel cost for 80% of the in-use tractors in Atlanta yearly is $7,485,639.00. The calculations for determining fuel cost for all Atlanta internal combustion tractors are broken down more clearly below:

$$\frac{\$2.57}{gal} * \frac{4\ gal}{shift} * \frac{3\ shifts}{day} * 665\ IC\ Tractors\ in\ use\ per\ day\ (\sim 80\%) * \frac{365\ days}{1\ year}$$

$$= \$\mathbf{7,485,639}\ \boldsymbol{per\ year\ in\ fuel}$$

Electric Parts Costs:

The cost of parts for electrifying a single baggage tractor is another significant consideration of the plan. The estimated cost is $45,700 per tractor; therefore all 831 tractors will sum to a grand total of $37,976,700. This cost can be broken down into labor and parts, with labor making up $5,700 of the cost and parts making up the remaining $40,000 (per tractor). The parts required to electrify the tractors include a lithium battery, sheet metal, custom steering hydraulic hoses, custom brake lines, hydraulic pump and motor, wiring, contactors, solenoids, engine controls, breakers, relays, and power converters. The cost of labor includes the assembly/disassembly of the tractors and the fabrication/welding of the parts. This breakdown is shown in Figure 12.

Electric Power Analysis:

One major incentive for electrifying the baggage tractor fleet, other than the emission savings, is the savings on fuel. The baggage tractors are recommended to be fitted with an 80 V, 16 kWh battery (Flux Power GSE2 battery). To determine cost savings from converting from IC engines to electric vehicles, the price for charging the baggage tractors was calculated and compared the fuel cost. Atlanta's airport is supplied electricity through Georgia Power, where the average electricity rate is $0.1117 per kWh [6]. For conservative purposes, an average price of $0.12 per kWh is assumed, since ATL has a high demand for power. The following calculation highlights the cost to fully charge a single electric baggage tractor:

$$\frac{\$0.12}{kWh} \times 16\ kWh = \$1.92$$

To determine the amount of time it takes to completely discharge these batteries at ATL, the assumptions mentioned for carbon emission calculated are assumed here as well. Meaning the bag tractors are charged a full 100% over the period of a day of operation. Since there are only 831 IC tractors to be electrified, and we are assuming that on any given day 80% of all tractors are used. Therefore, around 665 tractors will experience a full charge of power a day, which is highlighted in the following equation:

$$\$1.92 \times \frac{1\ charges}{day} \times \frac{365\ days}{year} \times 665\ tractors = \frac{\$466,032}{year}$$

Cost Savings Analysis

This project involves a heavy initial investment due to the high cost of chargers and electric parts. Therefore, to make this initiative more realistic for Delta Air Lines, the project is divided into four rollout phases. This gives Delta financial flexibility and increases the likelihood of pursuing this emission-reducing initiative.

Phase 1 involves the electrification of 135 units, which requires 90 additional chargers. The cost of 90 chargers, based on the analysis mentioned in the charger cost section, is \$8,717,310. The cost of parts and labor for phase 1 is \$6,169,500. Aside from emission reductions, Delta will save money in fuel costs since the cost of charging is significantly cheaper than fueling. During phase 1, Delta would save \$1,140,026.40 in fuel costs annually, as shown in the following equations:

$$\frac{\$2.57}{gal} * 12\frac{gal}{unit\ day} * 0.8 * 135\ unit * 365\ \frac{day}{year} = \$1{,}215{,}712.80\ per\ year$$

$$\frac{\$0.12}{kWh} * \frac{16\ kWh}{day} * 0.8 * 135\ units * \frac{365\ day}{year} = \$75{,}686.40\ per\ year$$

$$\$1{,}215{,}712.80 - \$75{,}686.40 = \$1{,}140{,}026.40\ savings\ per\ year$$

This gives phase 1 a payback period of 13.06 years, as shown:

$$T = \frac{135 * 45700 + 90 * 96859}{1140026.4} = 13.06\ years$$

It is important to note that this does not include any tax cuts or government aid, which can significantly reduce initial costs. Payback periods for phases 2, 3, and 4 were also computed in the same manner and are show in in Figure 13. If Delta were to pursue the entire electrification at once, then the payback period would still be 13 years, because although there will be much more significant initial investments in parts and labor, the annual savings would also increase significantly.

Delta's GSE doesn't have a means for profiting directly from customers, the role of GSE is to support the aircraft, which in turn provides profits through paying customers. Thus, the only income this project entails is the savings from fueling the baggage tractors. The net present value can be modelled as a function of time, as highlighted:

$$NPV = -\left(N_{units} * 45700 + N_{chargers} * 96859\right) + F_s * t$$

Where t is time from project initiation, in years, N_{units} is the number of units electrified, $N_{chargers}$ is the number of chargers, and F_s is the annual cost savings on fuel.

The return on investment for phase 1 is as follows:

$$\frac{Annual\ Fuel\ Savings}{Initial\ Investment} = \frac{\$1{,}140{,}026.40}{135 * \$45700 + 90 * \$96859} = 7.66\%$$

As mention earlier, the investment cost and fuel savings are directly proportional to the number of units, therefore the return on investment will be around 7.7% for all phases.

Co-Benefits

Reducing carbon emissions of these internal combustion vehicles is the target of this project and a huge benefit to the atmosphere, but there are three main co-benefits that arise as a result.

One of these benefits is the health and safety of baggage tractor operators on the ramp. Electric vehicles are much quieter than internal combustion vehicles, and this noise reduction creates a safer atmosphere for the operators. Another health benefit of converting to electric vehicles is the minimization of toxic fumes associated with internal combustion engines. The tractors drive in and out of enclosed or partially enclosed bag rooms at the airport, so internal combustion engines pose a health risk because operators constantly inhale the vehicle's toxic fumes. Because electric vehicles do not produce emissions, electrifying these tractors allows them to operate indoors more safely, making their operation more convenient, efficient, and health conscious.

Not only does electrification allow for more health-conscious indoor use, but electric vehicles tend to require less servicing than their internal combustion engine counterparts because they contain fewer mechanical parts. This saves maintenance and repair time, as well as corporate expenses for labor and parts.

The last major benefit is the social implication of converting from internal combustion units. Not only does society frown upon excessive carbon emissions, but also, the majority of ramp workers are likely in a lower income tier, so minimizing the negative effects of emissions keeps these valued employees healthy and keeps them from paying hefty hospital bills that result from fumes in the workplace environment. All in all, breaking the perpetual cycle of lower-income employees being the most negatively impacted health-wise by daily operations is a significant benefit and consequence of this carbon reduction project.

Anticipated Obstacles

One considerable obstacle in Team GSEmission Mission's project is the conversion of the vehicles themselves. The steps necessary to convert a baggage tractor from internal combustion to electric are to first remove the engine, transmission lines, transmission assembly, fuel system, and drive train. After that it is necessary to fabricate and weld mounting plates for the battery compartment, main electrical components, drive motor, and the hydraulic pump for the steering system. Next, the mechanics must obtain the correct battery for these vehicles, and then adjust and configure the controller for the motor to its proper settings. Finally, wire harnesses and 80 V to 12 V power converters must be fabricated and/or installed.

Another obstacle relevant to the rollout of this project is the cost. The COVID-19 pandemic set Delta Air Lines back financially, and now as travel catches up to pre-COVID levels, Delta's financial situation improves. With that said, since ground support equipment is significantly less expensive than aircraft, GSE's budget is much smaller than departments that work directly with planes. There is a possibility that GSE expenditures have already been decided upon for the coming years, meaning that this project may take a longer time to be implemented than the GSEmission Mission CoOp team had anticipated. This potential pushback of the rollout could lead to differences in prices from the current analysis.

One way to minimize the large cost impact is for Delta to begin a pilot program in which they test out Team GSEmission Mission's project proposal on a smaller scale: retrofitting the oldest 62 units. Using the aforementioned formulas, calculations, etc. and replacing the number of tractors for the full rollout (665) with the "pilot rollout" number, 62, the team was able to approximate cost, cost savings, carbon emission savings, etc. If 62 units were to be retrofitted, 42 chargers would need to be purchased and installed. Using the average of the three trendlines for 42 chargers, each charger costs $89,009.47 and each retrofit costs $45,700, The total cost to rollout the project on 62 tractors would be $6,571,797.74, which is significantly lower than full rollout cost. To determine yearly fuel cost savings, the team determined the fuel cost for the 62 tractors over one year to be $697,909.20 and the electricity cost to be $43,449.60, a cost saving of $654,459.60. The payback period is 10.04 years. The team outfitted the oldest 62 tractors (older than 1980) because these were the biggest carbon emitters. Each year, these tractors emit 873,744.3 kg of carbon. Electricity produced to charge these tractors emits 99,209.92 kg of carbon, so the net carbon emissions by electrifying these tractors is 774,534.38 kg per year. Recalling that the 665 tractors save 2,708,283.035 kg of carbon per year, it is important to note that the 62 oldest tractors, which make up less than 10% of the fleet (9.323%), create over 32% (32.262%) of the carbon emissions of the entire Atlanta-based fleet. In other words, a small fraction of the units contributes tremendously to the overall carbon emissions, making this project's implementation more attractive for Delta. Relating this back to the passenger vehicle emission comparison, electrifying 62 tractors offsets the emissions of slightly more than 168 passenger vehicles.

A third obstacle in the rollout of the project plan is the potential for supply chain and labor bottlenecks. Even if the project is rolled out in multiple phases, the likelihood that suppliers will not be able to keep up with demand for Delta GSE's parts orders is high. Additionally, the labor hours required is more than Delta GSE can currently keep up with, due to current labor shortages following the COVID-19 pandemic.

Next Steps

Potential next steps in this process include sharing this report and GSEmission Mission's supporting documentation to the leaders in the Delta GSE Engineering department. Obtaining feedback and determining feasibility is a large component of the project, as tens of millions of dollars of capital investment would be required. Project rollout would likely require more hiring of Delta GSE personnel, as well.

Summary

GSEmission Mission's goal of converting Atlanta's 831 internal combustion baggage tractors to electric baggage tractors may seem far-fetched and futuristic, but with careful planning, the team believes this investment will pay off. Not only does electrification reduce the amount of carbon emitted by these vehicles, but it is also a safer and healthier alternative with tremendous social benefits.

Appendix

Phase 1	Phase 2	Phase 3	Phase 4
TOTAL number of units older than 1990	**TOTAL** number of units older than 2000	**TOTAL** number of units older than 2010	**TOTAL** number of units older than 2021 (all units)
135	332	621	831
Purpose: Phase 1 involves the electrification of 135 of the oldest bag tractors. This retires the least efficient (and heaviest emissions) tractors in the fleet, while keeping the demand for new charging infrastructure low. This will also allow Delta GSE to evaluate the legitimacy of electrifying the entire bag tractor fleet.	Purpose: Phase 2 involves the electrification of 197 more bag tractors, all of which are older than 2000. This phase will give Delta GSE a more efficient bag tractor fleet, with an estimated TOTAL number of new chargers at around 230.	Purpose: Phase 3 will be the most ambitious electrification phase, with an additional 289 units being electrified. At this point, the units will be relatively new and their parts would be able to be re-serviced within the beltloader fleet where possible. This phase will be costly but would cut emissions significantly.	Purpose: Phase 4 invovles completing the electrification of the entire bag tractor fleet (assuming all new bag tractors acquired past 2021 are electric). This will involve the electrification of an additional 210 units. Once again, these parts will be re-serviced since they will be relatively new.
Chargers per Phase 90 **Units per Phase** 135	**Chargers per Phase** 131 **Units per Phase** 197	**Chargers per Phase** 193 **Units per Phase** 289	**Chargers per Phase** 140 **Units per Phase** 210

Figure 1 details the four phases of the electrification rollout plan.

Table 3-12

Off-Road Diesel Emission Factors by Horsepower and Year (g/bhp-hr) - NOx+HC

Engine Model Year	Horsepower Group							
	25-49	50-74	75-99	100-174	175-299	300-599	600-750	750+
1900-1969	8.3	17.0	17.0	18.3	18.3	17.5	17.5	17.5
1970-1971	8.3	17.0	17.0	17.0	17.0	16.2	16.2	16.2
1972-1979	8.3	17.0	17.0	15.6	15.6	14.9	14.9	14.9
1980-1987	8.3	17.0	17.0	14.4	14.4	13.7	13.7	13.7
1988	8.2	11.4	11.4	10.7	10.7	10.2	10.2	10.2
1989-1995	8.2	11.4	11.4	10.7	10.7	10.2	10.2	10.2
1996	8.2	11.4	11.4	10.7	7.9	7.9	7.9	10.2
1997	8.2	11.4	11.4	7.9	7.9	7.9	7.9	10.2
1998	8.2	7.9	7.9	7.9	7.9	7.9	7.9	10.2

Figure 2 Emission by Horsepower [7]

Table 3-12 Off-Road Diesel Emission Factors by Horsepower and Year (g/bhp-hr) - NOx+HC								
Engine Model Year	Horsepower Group							
	25-49	50-74	75-99	100-174	175-299	300-599	600-750	750+
1999	7.1	7.9	7.9	7.9	7.9	7.9	7.9	10.2
2000	7.1	7.9	7.9	7.9	7.9	7.9	7.9	7.9
2001	7.1	7.9	7.9	7.9	7.9	4.8	7.9	7.9
2002	7.1	7.9	7.9	7.9	7.9	4.8	4.8	7.9
2003	7.1	7.9	7.9	4.9	4.9	4.8	4.8	7.9
2004	5.6	5.6	5.6	4.9	4.9	4.8	4.8	7.9
2005	5.6	5.6	5.6	4.9	4.9	4.8	4.8	7.9
2006	5.6	5.6	5.6	4.9	3.0	3.0	3.0	4.8
2007	5.6	5.6	5.6	3.0	3.0	3.0	3.0	4.8
2008	5.6	3.5	3.5	3.0	3.0	3.0	3.0	4.8
2009	5.6	3.5	3.5	3.0	3.0	3.0	3.0	4.8
2010	5.6	3.5	3.5	3.0	3.0	3.0	3.0	4.8
2011	5.6	3.5	3.5	3.0	1.7	1.7	1.7	2.9
2012	5.6	3.5	2.7	2.7	1.7	1.7	1.7	2.9
2013	3.5	3.5	2.7	2.7	1.7	1.7	1.7	2.9
2014	3.5	3.5	2.7	2.7	0.44	0.44	0.44	2.9
2015+	3.5	3.5	0.44	0.44	0.44	0.44	0.44	2.6

Unshaded: (LFAC NOx factor)/0.87; Shaded: ARB Off-Road emission standard, NOx+HC, except Tier 1 for 50-175HP:(NOx Std)/0.87

Tier 1 Tier 2 Tier 3 Tier 4i/final

Figure 3 Emission Factors by Horsepower and Year [7]

Tractor Year	HP	Carbon Emissions (g/bhp-hr)	Hrs Used/Day	Carbon Emissions (grams/hr) PER TRACTOR	Carbon Emissions (grams/day) PER TRACTOR	Carbon Emissions (grams/year) PER TRACTOR	Carbon Emissions (kg/yr) PER TRACTOR	# IC Tractors per year in ATL	Carbon Emissions (kg/yr) for ALL IC Tractors	Comments/Notes
2003	78.5	7.9	15	620.15	9302.25	3395321.25	3395.32125	1	3395.32125	used the avg of 2002 and 2005 units since
2004	78.5	5.6	15	439.6	6594	2406810	2406.81	3	7220.43	we didn't have stats on these yrs
2005	60	5.6	15	336	5040	1839600	1839.6	3	5518.8	
2006	61	5.6	15	341.6	5124	1870260	1870.26	79	147750.54	
2007	109	3	15	327	4905	1790325	1790.325	90	161129.25	
2010	76	3.5	15	266	3990	1456350	1456.35	26	37865.1	
2011	55	3.5	15	192.5	2887.5	1053937.5	1053.9375	3	3161.8125	
2012	25	5.6	15	140	2100	766500	766.5	19	14563.5	
2015	49	3.5	15	171.5	2572.5	938962.5	938.9625	2	1877.925	
2016	52	3.5	15	182	2730	996450	996.45	10	9964.5	
2017	105	0.44	15	46.2	693	252945	252.945	4	1011.78	
2018	105	0.44	15	46.2	693	252945	252.945	39	9864.855	
2019	182	0.44	15	80.08	1201.2	438438	438.438	47	20606.586	
2020	167	0.44	15	73.48	1102.2	402303	402.303	60	24138.18	
2021	167	0.44	15	73.48	1102.2	402303	402.303	0	0	used same value from 2020
									2708283.035	

Figure 4 Carbon Emissions by Model Year

Georgia Energy Production Profile		
Plant Type	% total production	kg of CO2 per kWh
Petroleum-fired	0.10%	0.41
Natural Gas-Fired	46.40%	0.4
Coal-Fired	9.10%	0.998
Nuclear	30.90%	0
Renewables	13.00%	0
	Avg kg of CO2 per kWh	0.27382

Figure 5 Georgia Power's Chart [8]

Number of Chargers Phase 1	Number of Chargers Phase 2	Number of Chargers Phase 3	Number of Chargers Phase 4	Concourse
13	20	27	20	T
11	20	27	20	A
11	17	24	17	B
8	12	18	11	C
8	12	16	11	D
9	12	16	11	E
10	14	25	19	F
7	8	17	10	Line Shop
13	16	23	21	GSE Shop
90	**131**	**193**	**140**	**Total**

Figure 6 Charger Implementation Phases

Number of Chargers	Total Cost	Cost per Charger
2	$ 132,488.00	$ 66,244.00
10	$ 1,365,716.00	$ 136,571.60
10	$ 624,957.00	$ 62,495.70
12	$ 723,067.00	$ 60,255.58
13	$ 1,037,450.00	$ 79,803.85
19	$ 1,874,000.00	$ 98,631.58
20	$ 1,239,000.00	$ 61,950.00
25	$ 3,935,275.00	$ 157,411.00
32	$ 3,107,800.00	$ 97,118.75
39	$ 3,990,850.00	$ 102,329.49
43	$ 4,069,233.00	$ 94,633.33
50	$ 2,507,113.00	$ 50,142.26
56	$ 5,333,333.00	$ 95,238.09
59	$ 5,699,791.00	$ 96,606.63
60	$ 5,297,754.00	$ 88,295.90
	AVERAGE	
409	$ 36,814,489.00	$ 90,010.98

Figure 7 Vale Grant Summary [9]

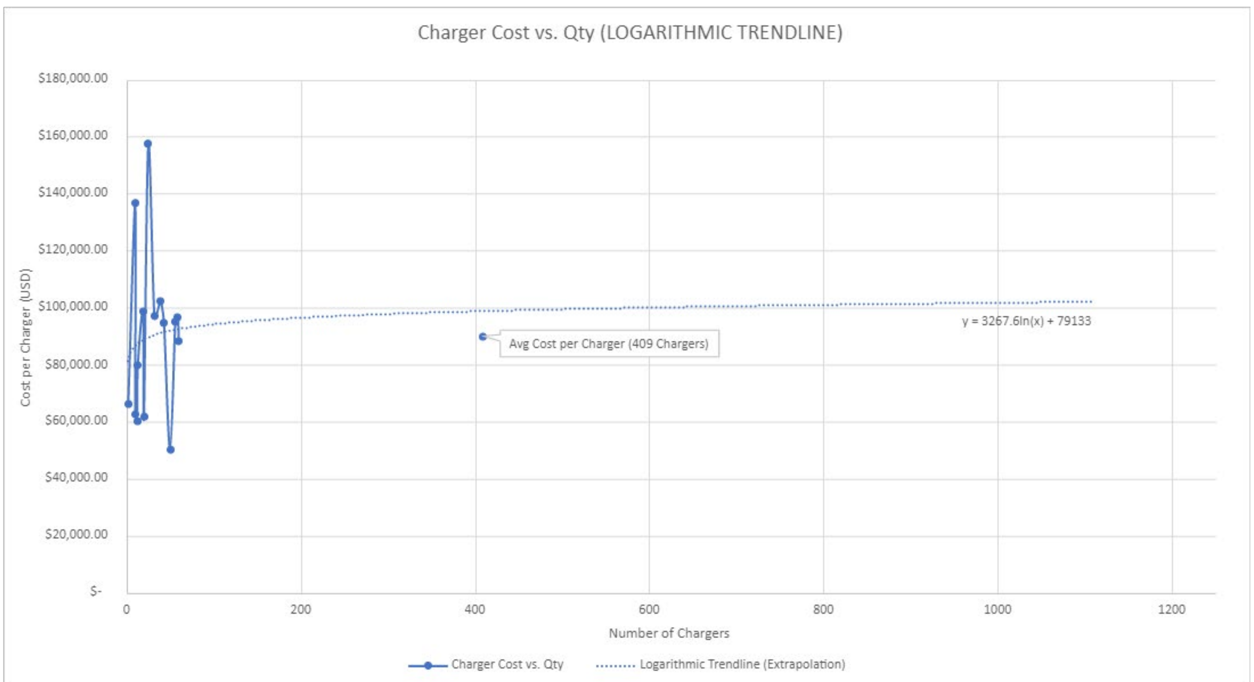

Figure 8 Logarithmic Trendline

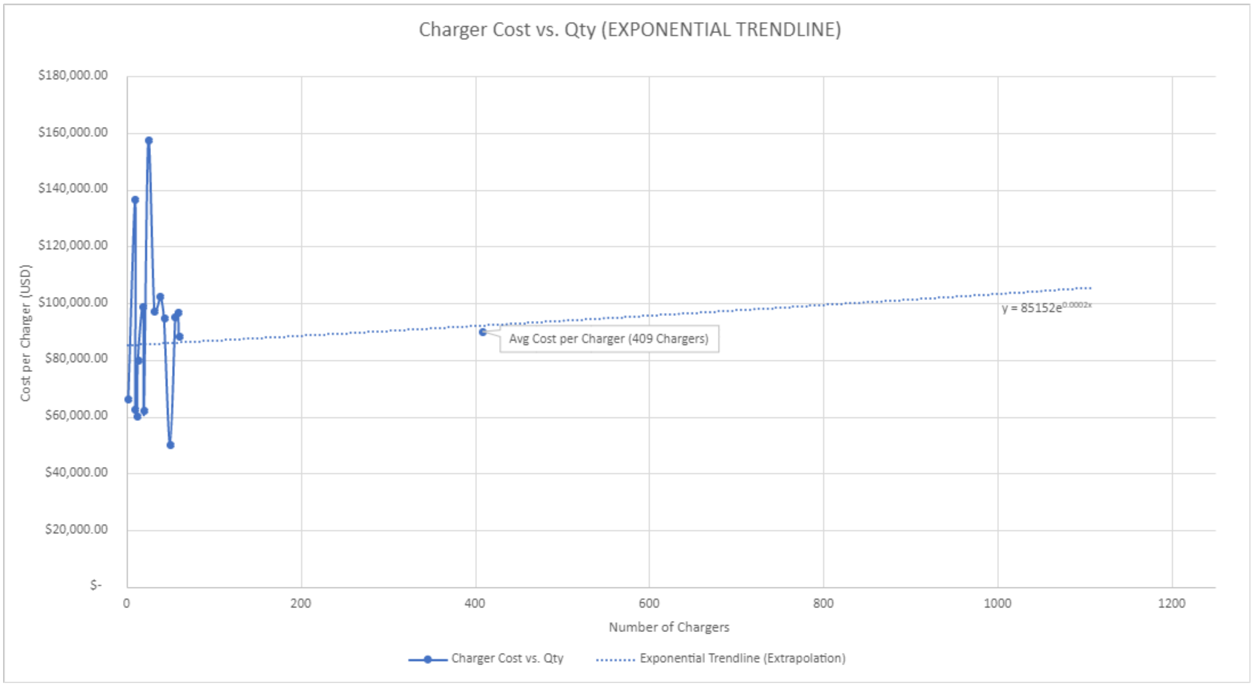

Figure 9 Exponential Trendline

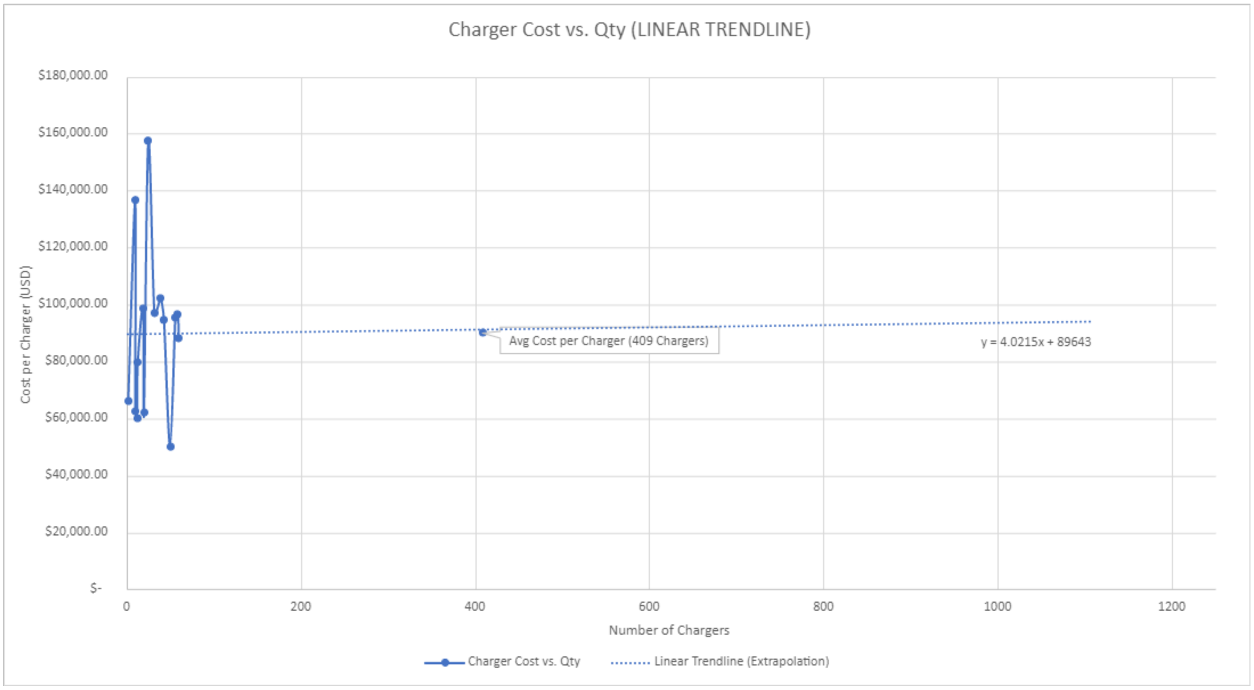

Figure 10 Linear Trendline

Fuel Costs (Jan. 2015 - July 2021)

YEAR/MO	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	AVG
2015	2.208	2.301	2.546	2.555	2.802	2.885	2.88	2.726	2.462	2.387	2.26	2.144	2.513
2016	2.057	1.872	2.071	2.216	2.371	2.467	2.345	2.284	2.327	2.359	2.295	2.366	2.2525
2017	2.458	2.416	2.437	2.528	2.503	2.46	2.414	2.494	2.761	2.621	2.678	2.594	2.530333333
2018	2.671	2.705	2.709	2.873	2.987	2.97	2.928	2.914	2.915	2.943	2.736	2.457	2.817333333
2019	2.338	2.393	2.594	2.881	2.946	2.804	2.823	2.707	2.681	2.724	2.693	2.645	2.68575
2020	2.636	2.533	2.329	1.938	1.961	2.17	2.272	2.272	2.274	2.248	2.2	2.284	2.25975
2021	2.42	2.587	2.898	2.948	3.076	3.157	3.231			N/A			2.902428571
AVERAGE COST													**2.5659**

Figure 11 Fuel Costs

Breakdown of Electrification Cost per Tractor		
Price	**Category**	**Includes**
$5,700	Labor	Disassembly
		Reassembly
		Fabrication
		Welding
$25,000	Battery	300 amp hour Lithium battery
$15,000	Other materials	Sheet metal
		Custom steering hydraulic hoses
		Custom brake lines
		Hydraulic Pump and motor
		Wires
		Contactors
		Solenoids
		Engine controls
		Breakers
		Relays
		Power Converters 80V to 12/24V
		Misc
$45,700	**TOTAL**	

Figure 12 Cost Breakdown of Electrification

Payback Period (years)	
Phase 1	13.06
Phase 2	13.04
Phase 3	13.07
Phase 4	13.06
All phases	13.05

Figure 13 Payback Period Breakdown

References

[1] Charles Gay, "A mission-driven brand: Global impact in Delta's Corporate Responsibility Report," *Delta News HUB,* 2019.

[2] U. E. I. Administration, "Frequently Asked Questions," EIA, 15 December 2020. [Online]. Available: https://www.eia.gov/tools/faqs/faq.php?id=74&t=11. [Accessed 10 August 2021].

[3] U. S. E. P. Agency, "Greenhouse Gas Emissions from a Typical Passenger Vehicle," United States Environmental Protection Agency, 21 July 2021. [Online]. Available: https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle. [Accessed 10 August 2021].

[4] U. o. M. S. f. E. a. Sustainability, "Carbon Footprint Factsheet," University of Michigan, 2020. [Online]. Available: https://css.umich.edu/factsheets/carbon-footprint-factsheet. [Accessed 10 August 2021].

[5] U. E. I. Administration, "Petroleum & Other Liquids," EIA, 1 August 2021. [Online]. Available: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emm_epm0_pte_nus_dpg&f=m. [Accessed 10 August 2021].

[6] E. Local, "Atlanta, GA Electricity Statistics," Electricity Local, 2021. [Online]. Available: https://www.electricitylocal.com/states/georgia/atlanta/. [Accessed 10 August 2021].

[7] A. Skidmore, "Extremely Low Emission Technology Ground Support Equipment Feasibility Study Report," CDM Smith, Irvine, 2013.

[8] U. E. I. Administration, "Georgia State Profile and Energy Estimates," EIA, 15 July 2021. [Online]. Available: https://www.eia.gov/state/data.php?sid=GA#:~:text=Profile%20Data%20Print%20State%20Energ

y%20Profile%20%28overview%2C%20data%2C,%20find%20more%20%208%20more%20rows%20. [Accessed 10 August 2021].

[9] F. A. Administration, "Volunteer Airport Low Emissions Program Grant Summary," 20 October 2020. [Online]. Available: https://www.faa.gov/airports/environmental/vale/media/VALE-grant-summary.pdf. [Accessed 10 August 2021].