The Financial Implications of Gainesville Regional Transit System Electrification

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Abstract

Battery electric buses (BEB) are becoming increasingly common in the fleets of service providers as a sustainable solution for transportation. Plenty of studies have addressed the many benefits of BEBs, and the direct local environmental benefits of BEBs are not in doubt with this study, nor are the social benefits; however, for BEBs to be considered sustainable, they must also be financially feasible. That is what the question that this study aims to address; the financial implications for the Gainesville Regional Transit System (RTS). A 20-year projection model has been constructed using RTS fleet data to compare the lifetime costs of a diesel, diesel-hybrid, and BEB fleet of buses to demonstrate the positive financial consequences of RTS transitioning to a fully BEB fleet in the long-term.

While BEBs have a much larger upfront cost, the model shows that at the end of the buses lifespan there is a reasonable amount of lifetime cost savings over diesel buses; however, diesel-hybrid buses were found to be the most expensive at the end of a bus's lifespan of approximately 500,000 miles. This contributes positively to the concept that BEBs can be a sustainable source of transportation, but this study is just a small part of what makes a transportation system sustainable and should not be mistaken as a claim that BEBs are without a doubt sustainable. What these findings do show is that smaller transit providers, such as RTS, should begin the transition to BEBs as funds allow to help save operating costs in the long-term which can free up capital elsewhere to make system improvements and expansions.

The Financial Implications of Gainesville Regional Transit System Electrification

Section 1 – Introduction

The Gainesville Regional Transit System (RTS) provides service to the city of Gainesville, Florida. The system operates a fleet of approximately 130 diesel and bio-fuel hybrid buses over 40 fixed routes in addition to providing paratransit and limited micro transit services (RTS, 2019). In 2021, the local transit provider introduced three new buses to its fleet, specifically three Gillig battery electric buses (BEB) (Gainesville, 2021). RTS is a relatively small transit provider, which begs the question if this is the best way for RTS to be spending its capital or could RTS spend its capital in a more efficient manner to improve the operations, efficiency, and reach of the transit service? Basically, is it better for a system such as RTS to use capital towards BEBs, or would they receive more long-term benefits from continuing to utilize diesel buses?

Section 2 – Literature Review

Section 2.1 – Environmental and Social Impacts of Electrification

The average personal vehicle in Europe is in use for only an approximate one hour per day, whereas a public transportation vehicle is in use for 16 or more on average (Glotz-Richter, Koch, 2016). It's easy to see why electrifying bus lines is seen as a popular option to reduce environmental impacts when 90% of Europe's buses are operating on diesel fuel (Glotz-Richter, Koch, 2016). While there are true zero-emission methods of transportation, such as walking or biking, collective transportation can be one of these methods if it is electrified. Consider that according to the research done by Glotz-Richter and Koch in 2016, it would take the electrifying of 100 cars to match the emissions offset of electrifying one 18m diesel bus. This doesn't even account for lifetime emissions from production which would require this number of cars to be much higher. This number may be less significant in the United States where car use is more engrained in the culture, but electrification of any bus is still an opportunity to offset current emissions.

BEBs clearly reduce greenhouse gas emissions at the site of use through the lack of combustion engine, improving local air quality and noise pollution (Dydkowski, et.al., 2021). These reductions provide environmental benefits to the local climate that the bus is operating in and can improve the experience of riders waiting at smelly and loud bus depots creating opportunity for a new social sphere to develop (Dydkowski, et.al., 2021). The direct local environmental benefits of BEBs are not in doubt with this study, nor are the social benefits; however, for BEBs to be considered sustainable, they must also be financially feasible. That is what the question that this study aims to address; the financial implications for RTS. To accomplish this, it is important to understand the various forms of line electrification that are in use or could be in use in the near future.

Section 2.2 – Traditional Methods of Electrification

The typical types of electrification and lack thereof can be condensed into four categories:

1. No electrification – combustion engine
2. Partial electrification – hybrid/combustion engine
3. Full electrification – battery electric
4. Full electrification – overhead/catenary wire

Today, a majority of buses on the road are typical combustion engines that consume diesel, biofuel, or compressed natural gas (cng) (Glotz-Richter, Koch, 2016). These engines can be converted to hybrid engines that operate on similar fuel sources; however, this only reduces the fuel consumption by about 30% (John A. Volpe, 2012). The challenge of electrification is typically the upfront cost (Dydkowski, et.al., 2021).

Historically, the electrification of bus lines was reserved for only the highest capacity routes that warranted the use of overhead wires (Wright, 2021). Additionally, BEBs previously did not hold enough of a charge to cover the travel of long distances; however, recent technological strides in battery technology are making BEBs more feasible for long range routes. According to the city of Gainesville, for example, RTS's new BEBs have a range of 150-200 miles, which is an excess of what is needed in a typical day of operation for RTS (2021). This isn't to say overhead electrification is not a valuable method of electrification. Both methods can coexist within a transit network, and even on the same line. Battery trolley buses allow for the use of overhead lines while the bus is operating to charge on-board batteries that are then used when an overhead line is no longer available (Marquordt, 2019). This can greatly reduce the cost of overhead electrification as it requires the use of less infrastructure and allows for less of the line to operate without installing overhead wires. This is a solution that can combat a need to extend the range of a BEB in some circumstances and can help optimize the charging schedule of a fleet.

Electrifying an entire bus fleet means that the transit provider must adjust its service schedule to account for charging or purchase additional batteries that can charge during the day and be used for battery replacement at night (Zhou, et.al, 2020). Rapid charging is another possibility. What is difficult to consider is how to schedule a mixed bus fleet with some BEBs and some diesel or diesel-hybrid buses. It should be noted that "optimal charging" takes place at night when energy costs are lower (Zhou, et.al, 2020). This is in contrast to the use of overhead wires or charging at stations which charge, or power, buses as needed during the day when energy costs are higher. These have the potential to increase the range of BEBs, but it can also increase the amount of money spent on fuel/energy costs by approximately 8% to 13% (Zhou, et.al, 2020).

Despite these possible increases in price, the efficiency of electric buses in general must not be understated. “The average efficiency of the electric [bus] equates to approximately 17.5 miles per diesel gallon equivalent (DGE) while the average fuel economy of the cng [bus] equates to about 4.5 miles per DGE” according to a study done by the National Renewable Energy Laboratory in 2016. The study was carried out in-operation using Foothill Transit in West Covina, California to compare cng buses to BEBs. Diesel buses are clearly the most inefficient, but even alternative fuels can’t compete with electric vehicles when it comes to efficiency. Cleaner emissions don’t really matter when no emissions are required assuming the electric vehicle is charged using renewable energy sources.

Section 2.3 – Experimental Methods of Electrification

There are multiple experimental methods of electrification as well as many proven methods. One experimental method includes a solar powered BEB that recharges throughout the day while it is in use (Oh, et.al., 2020). This could increase the range of BEBs significantly in the near future. Another method includes underground electrification using magnetic strips that run underneath the transit line that the bus follows (Terra Pass, 2010). This underground technology was first introduced in an amusement attraction in Korea, and only 20% of a line requires the magnetic strip if BEBs are used in conjunction with it, but its feasibility in public transit remains to be seen (Terra Pass, 2010). These experimental methods leave something to be desired and can come across as unnecessary given the proven methods of electrification that already exist. As such, this study will focus on the traditional forms of electrification.

Section 3 – Methodology

Three types of bus systems will be compared through their lifetime costs at the end of their lifespans (approximately 500,000 miles) to understand which fuel system is most financially feasible. The three bus/fuel systems in question are diesel buses, diesel-hybrid buses, and BEBs. Due to the variable nature of overhead/catenary wire infrastructure, it would be impractical to calculate the upfront infrastructure cost and ongoing maintenance costs of the wires with the model proposed. Additionally, RTS has already shown interest in the use of BEBs through its purchase of the new Gillig buses. For these reasons, overhead/catenary wire electrification is not being compared in the model. Additionally, the experimental modes discussed in Section 2.3 will not be compared.

Section 3.1 – Base Data Sets

Before diving into how the bus systems will be compared, clarification is needed on a few main assumptions made in the methodology of this study. First, the fleet statistics used are from the RTS Fiscal Year 2017 (FY17). The FY17 data is the most comprehensive and readily available data published by RTS at the time of this study.

Second, I am assuming a homogenous fleet of the RTS system. While RTS does own several different types of buses of varying engines and fuel types, though primarily diesel, it is easiest to compare a full fleet scenario with their 130 buses in the modeling (Table 3.1.1). The RTS system’s paratransit and micro mobility fleet is not included in this fleet of 130 buses and will not be addressed in the model nor this study. To help standardize the fleet’s engines and fuel sources, I have used the fleet’s total vehicle miles traveled (VMT) for the year 2017 divided by the total gallons of gasoline used that same year to give a standard miles per gallon (mpg) that can be applied to the entire fleet. The VMT is being used rather than the revenue miles traveled (RMT) to properly account for all maintenance and gas costs of the vehicles including travelling to and from the RTS vehicle depot as using RMT would inflate the mpg to be higher than it truly is.

$$\frac{3{,}800{,}000\ VMT}{1{,}300{,}000\ gal} = 2.92mpg$$

This is the figure to be used in the calculations that require the variable of mpg.

Table 3.1.1

2017 Inventory of RTS Fixed-Route Vehicles (RTS, 2017)

Number of Vehicles	Year	Manufacturer	Model	Length (Ft)	Vehicle Locator	Passenger Counter	Signal Priority	Talking Bus
1	2000	Gillig	G21D102N4	40	Yes	No	No	No
1	2000	Gillig	STD Low Floor	35	Yes	No	No	No
11	2001	Gillig	Phantom	35	Yes	No	No	No
8	2001	Gillig	Phantom	40	Yes	No	No	Yes
1	2002	Gillig	Phantom	40	Yes	No	No	No
5	2002	Gillig	Phantom	40	Yes	No	No	No
3	2004	Gillig	Phantom	40	Yes	No	No	Yes
7	2005	Gillig	Phantom	40	Yes	No	No	Yes
4	2006	Gillig	Phantom	40	Yes	Yes	No	Yes
10	2006	Gillig	Low Floor BRT	40	Yes	No	No	No
5	2007	Gillig	Phantom	40	Yes	Yes	No	Yes
12	2007	Gillig	G27D102N4	40	Yes	Yes	No	Yes
1	2007	Gillig	G29D102N4	40	Yes	Yes	No	No
4	2009	Gillig	G27D102N4	40	Yes	Yes	No	Yes
17	2010	Gillig	G27D102N4	40	Yes	Yes	No	Yes
6	2011	Gillig	G27D102N4	40	Yes	Yes	No	Yes
2	2012	Gillig	G30D102N4	40	Yes	Yes	No	Yes
6	2012	Gillig	G27D102N4	40	Yes	Yes	No	Yes
3	2013	Gillig	Low Floor BRT	40	Yes	Yes	No	Yes
2	2015	Gillig	G27D102N4	40	Yes	Yes	No	Yes
7	2016	Gillig	Low Floor	40	Yes	Yes	No	Yes
4	2017	Ford	Glaval	40	No	Yes	No	No
10	2018	Gillig	Low Floor	40	Yes	Yes	No	Yes

Third, I am assuming every bus in the RTS fleet traveled the exact same number of miles each year. While this is not the case and some buses will travel more or less than the fleet average in a year, it will still add up to the total VMT by RTS for 2017 and will not affect the total fleet statistics despite affecting individual vehicle statistics. This is not an issue as this study's purpose is to investigate the electrification or hybridization of the entire RTS fleet, not the individual vehicles.

$$\frac{3{,}800{,}000\ VMT}{130\ Buses} = 29{,}231\ VMT/bus/yr$$

This is the figure to be used in the calculations that require the variable of VMT for a single vehicle in the RTS fleet.

Fourth, I had to determine what year this model would take place in. The mileage and gasoline diesel consumption are from RTS FY17 and can serve as a scenario to measure the financial data against. This allows the use of 2021 financial data against the 2017 mileage statistics to create a hypothetical scenario that can be used to compare the bus systems. Note, this does create a hypothetical scenario in which pre-pandemic fleet statistics are being used on mid/post-pandemic financial data which will be explored more in-depth in the discussion of the results.

Some financial data was obtained from the 2012 "Bus Lifecycle Cost Model for Federal Land Management Agencies" published by the United States Department of Transportation (John A. Volpe). This data has been adjusted for inflation to match the 2021 financial data using a cumulative rate of 20.5% since 2012 (US Inflation Calculator, 2021). The financial data points from 2021 are the Florida Average Fuel price per gallon (diesel) at \$3.35 and the December Florida price per kWh at \$0.1137 (American Automobile Association; Electric Choice). Additionally, a gasoline gallon equivalent (GGE) conversion factor of 0.031 was obtained from the US Department of Energy (USDOE) to properly compare the price of kWh per mile to gallons per mile (2021).

While prices and conversions do fluctuate with the market overtime and do not exist in a vacuum, it would be impractical to make predictions on the price of gasoline or kWh or the GGE conversion factor. Therefore, the final assumption made is that these data points will remain constant and as such, this comparison of electrification and fuel methods should be looked at as a snapshot in time of what would happen if the simulation were to playout today.

Section 3.2 – Comparison Model

When exploring how to compare the cost of different methods of electrification, it became necessary to establish what would be considered in the cost and over what period. Three separate models using the same structure were constructed, one for each bus type being explored in the study (diesel, hybrid-diesel, battery electric). They explore what the lifetime cost (l) of the respective individual bus would be at a given year in its operation and if the entire fleet was made of this same vehicle type. The l for each year consists of several elements:

- Base vehicle/system cost, also referred herein as Base Cost (b)
- Lifetime maintenance in accordance with how many miles were travelled, also referred herein as Maintenance Cost (m)
- Lifetime fuel cost in accordance with how many gallons of diesel or kWh were used, also referred herein as Fuel Cost (f)

Each of these variables have different outcomes based on the system being investigated. Refer to Table 3.2.1 to see how these variables have been calculated for their respective system of electrification. Note that operator cost (wages) is not included in the equation as it would be a constant value for all three fuel systems and is therefore not relevant to the comparison.

Table 3.2.1

Calculations of Variables Used in Model

Type	Base Cost (*b*)	Maintenance Cost (*m*)	Fuel Cost (*f*)
Diesel	$300{,}000 * 1.205$ $= \$361{,}406$	$t(VMT/bus/yr) * \$1.13$	$\frac{t(VMT/bus/yr)}{mpg} * \$3.35$
Diesel-Hybrid	$500{,}000 * 1.205$ $= \$602{,}343$	$t(VMT/bus/yr) * \$1.13$	$[\frac{t(VMT/bus/yr)}{mpg}]0.7 * \$3.35$
Battery Electric	$1{,}000{,}000 * 1.205$ $= \$1{,}204{,}687$	$t(VMT/bus/yr) * \$0.57$	$[\frac{t(VMT/bus/yr)}{mpg}]0.031 * \$0.1137$

These criteria were then considered over the course of 20 years with variable *t* representing what year it is in the model. Each year will utilize the FY17 data.

$$b + t(m) + t(f) = l$$

The *l* variable can then be multiplied by the total number of vehicles in the RTS fleet, 130, to determine *x*, the lifetime cost in a scenario where every vehicle in the fleet is transitioned to the respective fuel type.

$$130l = x$$

Both the equation to solve for *l* and to solve *x* are applied to each of the three systems being investigated to compare the financial results.

Section 4 – Results & Findings

The results of each bus type (diesel, diesel-hybrid, battery electric) were calculated separately using the process explained in the methodology section (Section 3). The full output of the 20-year simulations are shown in the results, but it is important to note the highlighted row, year 17. Year 17 is when the model shows the hypothetical buses reaching their generally accepted lifespan of approximately 500,000 miles (John A Volpe, 2012). At the end of a bus's lifespan, maintenance costs are likely to increase, and a transit provider would look to replace the bus. As such, year 17 will be the key year to compare in cost feasibility.

Section 4.1 – Diesel Bus Results

The standard diesel bus model (Table 4.1.1) shows that diesel buses consume the most gasoline and have high maintenance costs, making it the most expensive bus to operate at a total of $1,132,304; however, it has the lowest base cost. This makes the total lifetime cost only marginally more than the operating cost at $1,493,710 in year 17. If every bus in the 130-bus fleet were diesel and were at the same point in their lifespan, the total lifetime cost would be $194,182,287.

Table 4.1.1
Diesel Bus Model Results

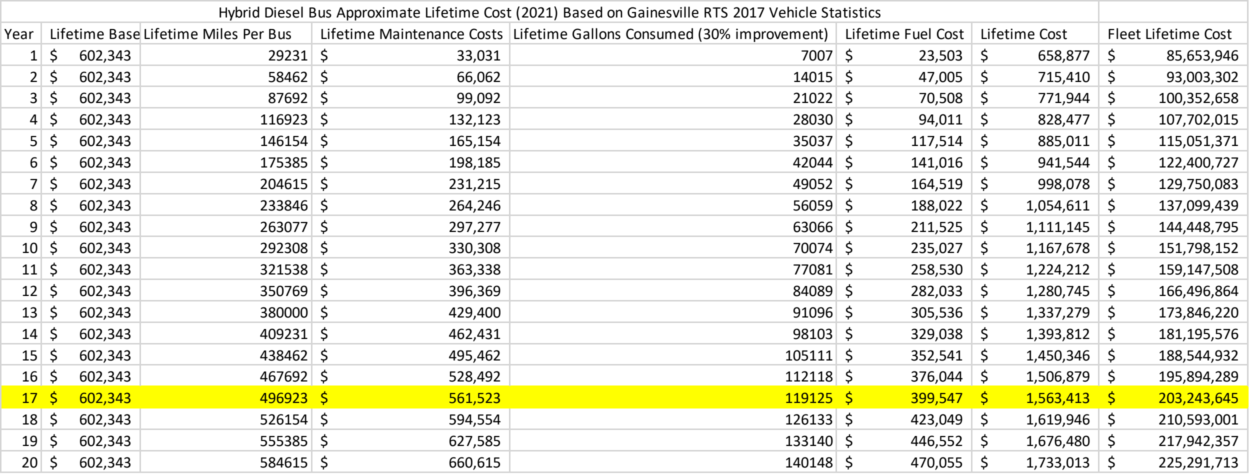
Standard Diesel Bus Approximate Lifetime Cost (2021) Based on Gainesville RTS 2017 Vehicle Statistics							
Year	Lifetime Base	Lifetime Miles Per Bus	Lifetime Maintenance Costs	Lifetime Gallons Consumed	Lifetime Fuel Cost	Lifetime Cost	Fleet Lifetime Cost
1	$ 361,406	29231	$ 33,031	10011	$ 33,575	$ 428,012	$ 55,641,575
2	$ 361,406	58462	$ 66,062	20021	$ 67,151	$ 494,618	$ 64,300,369
3	$ 361,406	87692	$ 99,092	30032	$ 100,726	$ 561,224	$ 72,959,164
4	$ 361,406	116923	$ 132,123	40042	$ 134,301	$ 627,830	$ 81,617,958
5	$ 361,406	146154	$ 165,154	50053	$ 167,877	$ 694,437	$ 90,276,753
6	$ 361,406	175385	$ 198,185	60063	$ 201,452	$ 761,043	$ 98,935,547
7	$ 361,406	204615	$ 231,215	70074	$ 235,027	$ 827,649	$ 107,594,342
8	$ 361,406	233846	$ 264,246	80084	$ 268,603	$ 894,255	$ 116,253,136
9	$ 361,406	263077	$ 297,277	90095	$ 302,178	$ 960,861	$ 124,911,931
10	$ 361,406	292308	$ 330,308	100105	$ 335,753	$ 1,027,467	$ 133,570,725
11	$ 361,406	321538	$ 363,338	110116	$ 369,329	$ 1,094,073	$ 142,229,520
12	$ 361,406	350769	$ 396,369	120126	$ 402,904	$ 1,160,679	$ 150,888,314
13	$ 361,406	380000	$ 429,400	130137	$ 436,479	$ 1,227,285	$ 159,547,109
14	$ 361,406	409231	$ 462,431	140148	$ 470,055	$ 1,293,892	$ 168,205,903
15	$ 361,406	438462	$ 495,462	150158	$ 503,630	$ 1,360,498	$ 176,864,698
16	$ 361,406	467692	$ 528,492	160169	$ 537,205	$ 1,427,104	$ 185,523,492
17	$ 361,406	496923	$ 561,523	170179	$ 570,781	$ 1,493,710	$ 194,182,287
18	$ 361,406	526154	$ 594,554	180190	$ 604,356	$ 1,560,316	$ 202,841,081
19	$ 361,406	555385	$ 627,585	190200	$ 637,932	$ 1,626,922	$ 211,499,876
20	$ 361,406	584615	$ 660,615	200211	$ 671,507	$ 1,693,528	$ 220,158,670

Section 4.2 – Diesel-Hybrid Bus Results

The diesel-hybrid bus model (Table 4.2.1) shows that diesel-hybrid buses still consume a considerable amount of gasoline and have the same maintenance costs as diesel buses, making it just slightly less expensive to operate than its diesel counterpart at a total of $961,070; however, it has a higher base cost. This makes the total lifetime cost $1,563,413 in year 17, which is more expensive than the diesel bus. If every bus in the 130-bus fleet were diesel-hybrid and were at the same point in their lifespan, the fleet lifetime cost would be $203,243,645.

Table 4.2.1

Diesel-Hybrid Bus Model Results



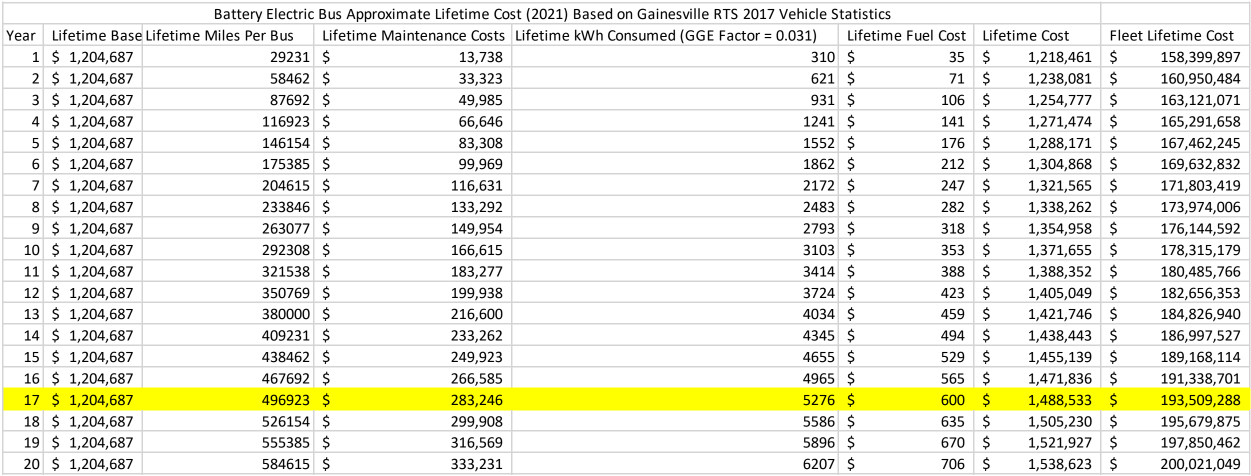
Hybrid Diesel Bus Approximate Lifetime Cost (2021) Based on Gainesville RTS 2017 Vehicle Statistics							
Year	Lifetime Base	Lifetime Miles Per Bus	Lifetime Maintenance Costs	Lifetime Gallons Consumed (30% improvement)	Lifetime Fuel Cost	Lifetime Cost	Fleet Lifetime Cost
1	$ 602,343	29231	$ 33,031	7007	$ 23,503	$ 658,877	$ 85,653,946
2	$ 602,343	58462	$ 66,062	14015	$ 47,005	$ 715,410	$ 93,003,302
3	$ 602,343	87692	$ 99,092	21022	$ 70,508	$ 771,944	$ 100,352,658
4	$ 602,343	116923	$ 132,123	28030	$ 94,011	$ 828,477	$ 107,702,015
5	$ 602,343	146154	$ 165,154	35037	$ 117,514	$ 885,011	$ 115,051,371
6	$ 602,343	175385	$ 198,185	42044	$ 141,016	$ 941,544	$ 122,400,727
7	$ 602,343	204615	$ 231,215	49052	$ 164,519	$ 998,078	$ 129,750,083
8	$ 602,343	233846	$ 264,246	56059	$ 188,022	$ 1,054,611	$ 137,099,439
9	$ 602,343	263077	$ 297,277	63066	$ 211,525	$ 1,111,145	$ 144,448,795
10	$ 602,343	292308	$ 330,308	70074	$ 235,027	$ 1,167,678	$ 151,798,152
11	$ 602,343	321538	$ 363,338	77081	$ 258,530	$ 1,224,212	$ 159,147,508
12	$ 602,343	350769	$ 396,369	84089	$ 282,033	$ 1,280,745	$ 166,496,864
13	$ 602,343	380000	$ 429,400	91096	$ 305,536	$ 1,337,279	$ 173,846,220
14	$ 602,343	409231	$ 462,431	98103	$ 329,038	$ 1,393,812	$ 181,195,576
15	$ 602,343	438462	$ 495,462	105111	$ 352,541	$ 1,450,346	$ 188,544,932
16	$ 602,343	467692	$ 528,492	112118	$ 376,044	$ 1,506,879	$ 195,894,289
17	$ 602,343	496923	$ 561,523	119125	$ 399,547	$ 1,563,413	$ 203,243,645
18	$ 602,343	526154	$ 594,554	126133	$ 423,049	$ 1,619,946	$ 210,593,001
19	$ 602,343	555385	$ 627,585	133140	$ 446,552	$ 1,676,480	$ 217,942,357
20	$ 602,343	584615	$ 660,615	140148	$ 470,055	$ 1,733,013	$ 225,291,713

Section 4.3 – Battery Electric Bus Results

The BEB model (Table 4.3.1) shows that BEBs consume significantly less in energy costs and have relatively low maintenance costs when compared to its combustion counterparts, making it the cheapest option explored in this study to operate at a total of only $283,846; however, it has the highest base cost. This makes the total lifetime cost $1,488,533 in year 17. Even with the significant base cost, BEBs have a lower lifetime cost than diesel or diesel-hybrid buses. If every bus in the 130-bus fleet were BEBs and were at the same point in their lifespan, the fleet lifetime cost would be $193,509,288.

Table 4.3.1

Battery Electric Bus Model Results



Battery Electric Bus Approximate Lifetime Cost (2021) Based on Gainesville RTS 2017 Vehicle Statistics

Year	Lifetime Base	Lifetime Miles Per Bus	Lifetime Maintenance Costs	Lifetime kWh Consumed (GGE Factor = 0.031)	Lifetime Fuel Cost	Lifetime Cost	Fleet Lifetime Cost
1	$ 1,204,687	29231	$ 13,738	310	$ 35	$ 1,218,461	$ 158,399,897
2	$ 1,204,687	58462	$ 33,323	621	$ 71	$ 1,238,081	$ 160,950,484
3	$ 1,204,687	87692	$ 49,985	931	$ 106	$ 1,254,777	$ 163,121,071
4	$ 1,204,687	116923	$ 66,646	1241	$ 141	$ 1,271,474	$ 165,291,658
5	$ 1,204,687	146154	$ 83,308	1552	$ 176	$ 1,288,171	$ 167,462,245
6	$ 1,204,687	175385	$ 99,969	1862	$ 212	$ 1,304,868	$ 169,632,832
7	$ 1,204,687	204615	$ 116,631	2172	$ 247	$ 1,321,565	$ 171,803,419
8	$ 1,204,687	233846	$ 133,292	2483	$ 282	$ 1,338,262	$ 173,974,006
9	$ 1,204,687	263077	$ 149,954	2793	$ 318	$ 1,354,958	$ 176,144,592
10	$ 1,204,687	292308	$ 166,615	3103	$ 353	$ 1,371,655	$ 178,315,179
11	$ 1,204,687	321538	$ 183,277	3414	$ 388	$ 1,388,352	$ 180,485,766
12	$ 1,204,687	350769	$ 199,938	3724	$ 423	$ 1,405,049	$ 182,656,353
13	$ 1,204,687	380000	$ 216,600	4034	$ 459	$ 1,421,746	$ 184,826,940
14	$ 1,204,687	409231	$ 233,262	4345	$ 494	$ 1,438,443	$ 186,997,527
15	$ 1,204,687	438462	$ 249,923	4655	$ 529	$ 1,455,139	$ 189,168,114
16	$ 1,204,687	467692	$ 266,585	4965	$ 565	$ 1,471,836	$ 191,338,701
17	$ 1,204,687	496923	$ 283,246	5276	$ 600	$ 1,488,533	$ 193,509,288
18	$ 1,204,687	526154	$ 299,908	5586	$ 635	$ 1,505,230	$ 195,679,875
19	$ 1,204,687	555385	$ 316,569	5896	$ 670	$ 1,521,927	$ 197,850,462
20	$ 1,204,687	584615	$ 333,231	6207	$ 706	$ 1,538,623	$ 200,021,049

Section 5 – Discussion

Section 5.1 – Analysis of Results

When comparing the results of the models in a vacuum, the BEB beat out diesel and diesel-hybrid buses in lifetime cost. Note Figure 5.1.1. The first yellow line denotes when the BEB becomes more feasible than the diesel-hybrid bus in year 15 and the second yellow line denotes when the BEB becomes more feasible than the diesel bus in year 17. Year 17 being the key year due to it being the end of the bus's lifespan as discussed in Section 4. Notice that the diesel-hybrid bus never becomes more financially feasible than the diesel bus in the 20-year model, though if the model were extended, we could see the diesel-hybrid bus become more feasible; however, after the lifespan of a bus is passed, maintenance costs would be expected to increase offsetting any benefit of the diesel-hybrid bus.

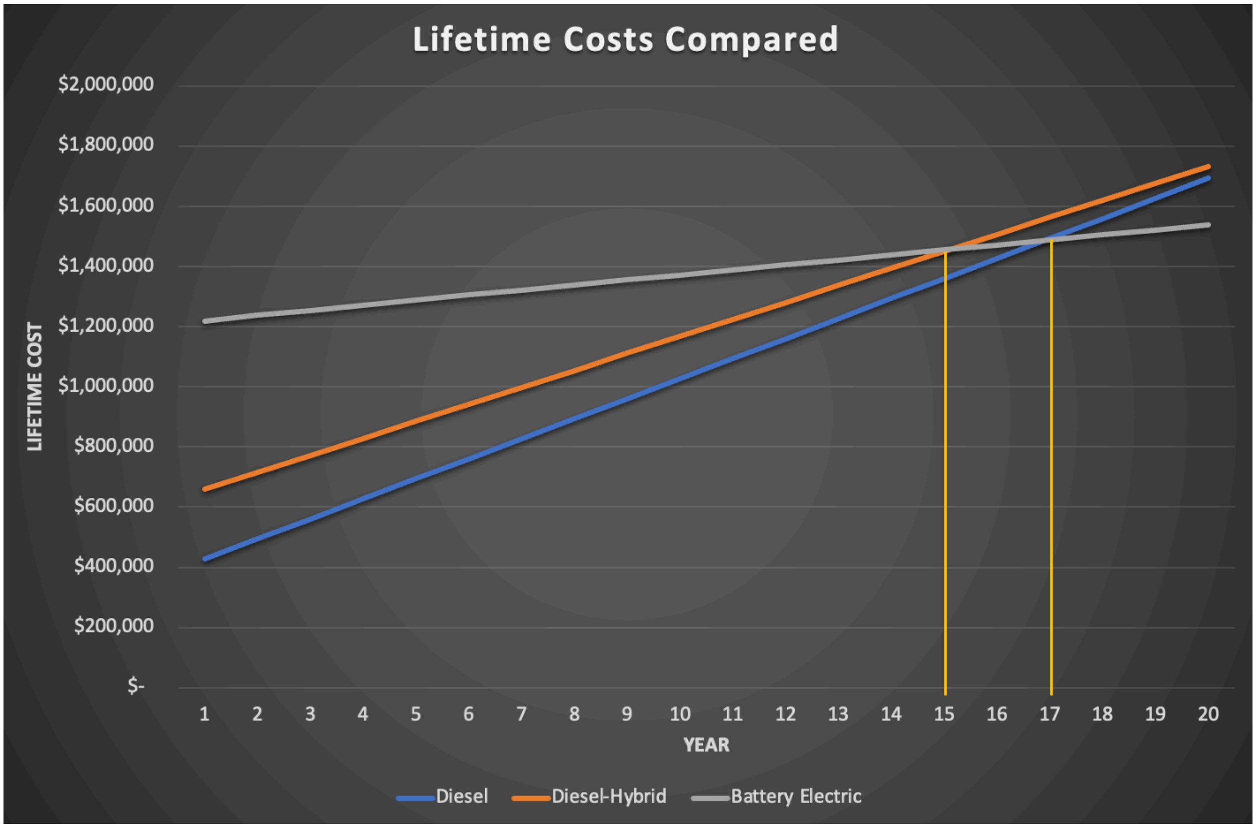


Figure 5.1.1

Diesel, Diesel-Hybrid, and Battery Electric Bus Lifetime Costs Compared

The difference in lifetime cost at year 17 between BEBs and diesel is only around $5,177 per bus, but when that saving is applied to the entire RTS fleet, it is a sizeable savings of $673,010. Grants and outside funding should also be considered when purchasing these buses. While BEBs do have a higher base cost, grants can be used on these capital expenditures which would bring the lifetime cost down significantly when compared to a diesel bus purchased in a similar arrangement (Dydkowski, et. al., 2021). The savings that could be generated from that form of capital expenditure is hard to measure, but it would be significantly more than $5,000 per bus and would likely be closer to $1,000,000 per bus based on this model. While grants and certain funding can only be used on capital expenditures, the millions of dollars saved over the 17-year lifespan of a BEB fleet could be used towards operating costs, such as energy/fuel, maintenance, and wages. The savings could also be used towards additional capital expenditure improvements, including additional bus purchases, stop improvements, route expansions, and other infrastructure improvements. RTS has already moved forward with the direction of using grants towards the BEBs purchasing its three BEB through a grant (Gainesville, 2021).

Section 5.2 – Technology

Regardless of where a transit provider is receiving funding for the capital expenditure to purchase these buses, falling prices of electric vehicles in general should be noted. As technology improves, the cost of producing electric vehicles, and therefore the price of the vehicles themselves, should fall. Even if this price reduction is trivial, it can help make the purchase of BEBs more feasible for smaller transit service providers similar to RTS.

Section 5.3 – Limitations

The model and methodology used in this study have multiple limits when applying them to a real-life scenario. First, the model is constructed in a vacuum with non-variable data. From year to year, it can be expected that VMT, mpg, maintenance costs, and prices for fuel would fluctuate. The largest offender in the model is not accounting for an increase in maintenance costs as the bus in the model surpasses its expected lifespan. Fuel prices would not remain steady over a 20-year period, and electricity prices especially are expected to increase as demand increases. While it would be beneficial to have variable data, this would not be possible with a projection. The model would have to be changed to account for historical data and create a hypothetical scenario beginning in 2001 to create a 20-year historical estimate of lifetime cost; however, BEBs have not been steadily in use for that period of time. This is the reasoning behind the choice of using a projection model rather than a historical model.

Additionally, the trends that the model outputs in the projection would still reveal themselves over time. As prices fluctuate, each type of bus modeled would fluctuate relative based on the grounds that each variable effects each bus type in the model equivalently, except possibly maintenance costs and variable fuel costs. As such, the vacuum economy scenario the model takes place in can still predict the lifetime cost trends of each bus relative to one another. This is the most important factor as the purpose of this study is to compare the bus types to each other.

Second, some of the data used in the model is outdated. While fuel prices are the 2021 averages in Florida, the base cost prices are inflation adjusted from 2012 and the vehicle and fleet statistics for RTS are from 2017 (published in 2019). Then there is the consideration of using 2021 financial data against pre-pandemic operation statistics. The COVID-19 pandemic should not be a limiting factor of the model. Similar to the first limitation, these variables would affect the model and bus type respectively and would still produce a similar trend given a long enough time frame.

Section 6 – Recommendations

Based on the findings of this model, RTS should continue to transition towards a BEB fleet. Regardless of the environmental benefits, RTS will directly benefit through lifetime cost savings of operating their bus fleet. Those lifetime savings have the potential to help expand service over time; however, these results would not be seen right away. While there are significant savings, these savings only occur after approximately 500,000 miles or 17 years of operations. I'd recommend the transition to BEBs occur over an extended period of time and not entirely at once. This will allow RTS to use the operations savings towards the transition to

BEBs. Additionally, the upfront cost is too great for RTS to entirely replace their fleet at one time.

A realistic scenario of replacement would be to replace the buses as needed rather than actively seeking to replace buses with additional years of operation still available. This would occur over an approximately 20-year period, at which point all of the RTS buses would be BEBs, and the cycle of replacement could restart with the first BEBs that were introduced. Any long-term savings accumulated would be well spent on expanding the bus fleet. Expansion of the bus fleet would allow for an increase in frequency on existing lines or the introduction of new lines, either of which would enhance the current service provided by RTS.

Section 7 – Summary of Research

This study presented a model structured around 2017 fleet and operation statistics for RTS to establish a baseline scenario of a typical operating year. This model was then given 2021 financial data that was used to compare the lifetime costs of diesel buses, diesel-hybrid buses, and BEBs. While other forms of electrification exist, it was most feasible and relevant to compare these three types. It was found that diesel-hybrid buses are the most expensive bus at the end of its lifespan. Diesel buses were only slightly less expensive than diesel-hybrid buses; however, BEBs were approximately $5,000 less expensive than diesel buses to operate at lifespan. Despite the large upfront cost associated with BEBs, they are financially feasible in the long-term for service providers such as RTS and they should continue to transition to BEBs over the next 20 years. While there are multiple limitations to the model, the trends seen would occur regardless of the vacuum the model occurs in. The trends would just reveal themselves at a different rate.

If given the opportunity, I would want to expand this study to include electrification of buses using overhead wires and battery electric trolley buses. For the purpose of RTS, it is too difficult to pinpoint what lines would receive overhead treatment and for what length of the lines. I would want to repeat this research on a larger transit provider that already operates lines with overhead electrification and apply a historical model using these lines rather than the projection model used here which has its limits due to the unpredictable nature of the economy.

It has been established that BEBs improve the local environment where they are used and have the potential to improve social areas of interest, but now it can be established that they are financially feasible. These are the three pillars of a sustainable solution: Environment, Social, and Economic. The BEB meets those criteria, at least at the site of use. It is difficult to consider the BEB sustainable without more research into the production of these buses and the rare earth metals required to make these buses or the disposal/recycling of potentially harmful chemicals and batteries when a BEB reaches its lifespan. This study should not be mistaken for a claim that the BEB is completely sustainable, but it is beneficial to the community that it operates in; however, if a future study were to show that the production methods and the disposal methods used are sustainable in all categories, then it could be assumed that the BEB is a sustainable method of transportation similar to that of walking and biking.

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