Proposal Title: Go Electric: Analysis of an All-Electric Transportation Fleet at Rutgers University

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Project Summary:

Using a systematic approach to modeling the current bus transportation system, a streamlined and more efficient bus transportation network is proposed to decrease the size of the Rutgers transportation fleet from ~50 biodiesel buses to ~40 electric buses. The environmental and financial impact of the transition from biodiesel buses to electric buses is also analyzed and presented in this proposal. Over a 12-year period, switching from the current biodiesel fleet to an all-electric bus fleet can prevent 23,640 metric tons of CO_2 gas emissions and save $12.4 million.

Go Electric: Analysis of an All-Electric Transportation Fleet at Rutgers University

Timothy Lee

I. Research Problem and Potential Impact

Over the past several years, the admittance and attendance of students at Rutgers University has continued to increase rapidly.[1] In order to accommodate this immense scale of growth, Rutgers has created the *Rutgers 2030 Master Plan.* The most notable change undergoing development is the *University Transportation Master Plan*, which will outline the physical growth of Rutgers over the next 15 to 20 years to match the growth in attendance.[2] With eleven routes, over 50 buses, and a ridership of more than six million daily, the Rutgers-New Brunswick bus transportation system is both a large cost and a hefty energy expenditure. Thus, the goal of this proposal is to minimize costs and infrastructural changes while improving upon transportation and energy efficiencies within the Rutgers campus transportation system. In the first part of this proposal, I propose to reduce the Rutgers transportation network in alignment with the goals of Rutgers 2030 in order to cut costs and lower our carbon footprint while maintaining high mobility of the campus bus network. In the latter part, I propose and analyze a switch to an all-electric transportation fleet with the resizing from the former part.

II. Reducing the Rutgers Transportation Network

In light of my last year's proposal, a working model of the current transportation system during peak hours was developed using Nextbus tracking systems. Using Google Maps, I created a new model to show that changing the routes can decrease intercampus travel times and increase students transported across campuses while reducing the amount by six fewer buses.[3] For this year's proposal, several changes to the proposed model are made to account for changes at Rutgers over the past year as well as to create a starting point for the next part of the proposal:

1. Intracampus routes used to navigate within a campus and their buses are removed.
2. The proposed model now focuses on Seminary Place (at the foot of the Academic Building) instead of the RSC as the campus center for College Avenue Campus.
3. Travel times are updated slightly using Google Maps.

The updated proposed model can be summarized with six redesigned bus routes. (See Tables in Appendix for more details.) The distribution of these buses are calculated such that the proposed model can transport 24.5% more students across campuses and can transport students between campus centers from 15.1% to 66.0% faster than the current bus network. The design of the three-campus connections in the “Main” and “Back” routes allows for distribution of buses in alignment with ridership frequency.[4] Using these models, the current transportation fleet size can be reduced from 44 active buses during peak hours to 32 active buses during peak hours. Considering the purchase of inactive or back-up buses, fleet sizes of 50 current diesel buses and 40 proposed electric buses will be used in the latter part of this proposal.

The reason for the change to eliminate intracampus travel is to redefine the purpose of the bus transportation network for intercampus traveling, or to travel between different campuses. In order to accommodate these changes, several approaches to ameliorate intracampus travel are already in development, such as an extended bike-share program.[5] Additional considerations for each campus can be made as well. For the Livingston campus, additional accommodations are not necessary because of the small size and close proximity of the LSC to major buildings. Within a five-minute walk (quarter mile radius on Google Maps) from the LSC, students can reach the Livingston Apartments, the Rutgers Business School, and Lucy Stone Hall/Tillett Hall. Similarly, moving the College Avenue Campus main bus stop from RSC to the foot of the Academic Building on Seminary Place allows students to reach the RSC, Brower Dining Hall, Records Hall, Voorhees Mall, the Academic Buildings, the Yard Apartments, and the SAC within a five-minute walk. For Cook/Douglass, having stops at both the DCC and CCC (currently the Biel Road bus stop) similarly covers most of the main buildings on campus within a five-minute walk to a bus stop. For Busch Campus, continuing use of the "C" commuter loop can help accommodate for intracampus travel.

III. Go Electric: Greenhouse-Gas Emission Analysis

Electric vehicles can reduce the amount of pollution and greenhouse gases emitted and can reduce the operating and maintenance annual costs compared to conventional fuel-based engines. Eventually, the lower annual costs overcome the initial investment in purchasing an all-electric fleet, making such an investment a notable decision for the future. In this part of the proposal, I will look at the projected savings for investing in electric vehicles from an environmental and financial standpoint.

In order to calculate the emissions from each bus in the Rutgers fleet, it is important to analyze the model and design of the bus in the current system. The Rutgers fleet mainly uses New Flyer buses with 20% biodiesel (B20). Consider one of these buses on the "A" route. Using Google Maps, the entire route takes about 29 minutes in 7.8 miles for an average speed of 16.1 MPH. This speed closely matches the Urban Dynamometer Drive Speed (UDDS) cycle of 18.9 MPH, which is a model used by the Altoona Bus Research & Testing Center to test New Flyer bus emissions. This test concludes that the total carbon-dioxide gas equivalent emission (CO_2-e) per mile by a New-Flyer diesel bus (Model XD40, 2011) at UDDS cycle speed is 1.723 kilograms CO_2-e per mile.[6] According to the American Public Transportation Association, the average annual mileage for a U.S. commuter bus in 2015 is 38,600 miles per year per bus.[7] Thus, the emission factor for each diesel bus is about 66,500 kg CO_2-e. Because the New Flyer buses use B20, the off-set from using biofuels must also be calculated. This results in approximately a 14.8% reduction of total GHG emissions.[8] With a fleet size of 50 buses, the total current CO_2-e emission at Rutgers University from the bus network is ~2830 metric tons of CO_2-e per year.

The proposed change from 50 New Flyer buses to 40 electric buses lowers the amount of CO_2-e emitted, but the amount depends on the type of bus purchased. For this proposal, I will analyze experimental data based on an NREL independent study on 12 Proterra (EcoRide BE35) electric buses. The NREL notes that these Proterra electric buses average 2.15 kWh/mile.[9] Since each bus will have an annual mileage of 38,600 miles, the amount of energy used per bus is 83,000 kWh for a 40-bus electric fleet per year. In New Jersey, the average carbon dioxide emissions produced from energy power plants is 573 lbs/MWh.[10] Thus, the total emissions from electric vehicles for the fleet of 40 buses is ~863 metric tons of CO_2 per year. By switching from the current Rutgers biodiesel bus fleet to a total electric fleet, Rutgers can reduce GHG emissions by ~1970 metric tons of CO_2 per year.

$$\frac{1.723\ kg\ CO_2}{1\ mile} * \frac{38{,}600\ miles}{1\ bus\ per\ year} * \frac{1\ metric\ ton}{1000\ kg} * 85.2\% * 50\ buses = \frac{2833\ metric\ tons\ CO_2}{1\ year}$$

$$\frac{2.15\ kWh}{1\ mile} * \frac{38{,}600\ miles}{1\ bus\ per\ year} * \frac{573\ lbs\ CO_2}{1000\ kWh} * \frac{1\ metric\ ton}{2204\ lbs} * 40\ buses = \frac{863\ metric\ tons\ CO_2}{1\ year}$$

Figure 1. Calculations for CO_2 emissions from 50 current New Flyer buses (top) and from 40 proposed Proterra electric buses (bottom)

IV. <u>Go Electric: Financial Analysis</u>

According to the US EIA from the past decade, the average price for diesel is \$3.26.[11] Biodiesel B20 follows a similar fluctuation pattern, but on average costs \$0.11 more than diesel.[12] Thus, the average price for biodiesel fuel used in New Flyer buses for the upcoming years will be estimated at ~\$3.37 per gallon. According to the US EIA from the past decade, the average price for electricity (commercial) in New Jersey is $0.1316.[13] Thus, the average price for a kilowatt-hour of electricity for the upcoming years will be ~$0.13 in NJ.

To cover the same amount of mileage (38,600 annually), the fuel economy for the two types of buses must be evaluated. Under the UDDS Cycle, a New Flyer diesel bus has a fuel economy of 8.03 miles per diesel gallon equivalent.[6] Using $3.36 per gallon, the fuel for a New Flyer diesel bus costs ~$16,150 annually. For a Proterra electric bus, the experimental fuel economy is 2.15 kWh per mile. Using $0.13 per kWh, the cost for electricity for a Proterra electric bus is ~$10,790 annually ($0.28 per mile). Also, it is important to note that this comparison uses an older generation Proterra bus; their website currently advertises their newer Catalyst buses at a better fuel economy of $0.19 per mile, so the savings may actually be greater with newer buses.[14] However, using these experimental numbers, the difference in fuel costs per bus per year is ~$5,360.

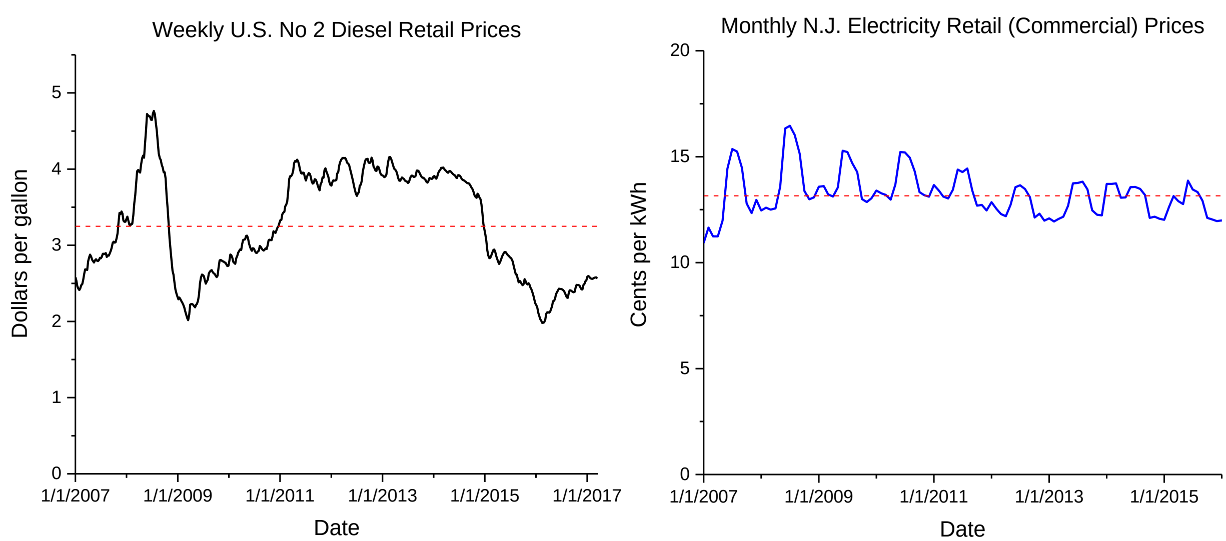

Figure 2. Weekly U.S. diesel retail prices from 2007 to present and monthly N.J. electricity retail (commercial) prices from 2007 to 2016 (Averages in red dotted line)

$$\frac{38{,}600\ miles}{1\ year\ per\ bus} * \frac{1\ diesel\ gallon\ eq}{8.03\ miles} * \frac{\$3.36}{1\ diesel\ gallon} = \frac{\$16{,}151}{1\ year\ per\ bus}$$

$$\frac{38{,}600\ miles}{1\ year\ per\ bus} * \frac{2.15\ kWh}{1\ mile} * \frac{\$0.13}{1\ kWh} = \frac{\$10{,}789}{1\ year\ per\ bus}$$

Figure 3. Calculations for fuel costs using diesel (top) and electricity (bottom)

Maintenance costs for biodiesel buses are typically much higher than electric buses because of the internal combustion engine. These engines have more moving parts compared to an electric motor, making them more expensive to maintain. Analyzing data from over 100,000 miles, the NREL finds that a biodiesel vehicle costs $0.58 per mile, while an electric vehicle costs $0.17 per mile for maintenance costs.[9,15] Using an annual 38,600 miles, a biodiesel bus costs ~$22,400 while an electric bus costs ~$6,560 per year for maintenance.

Vehicle costs are more difficult to calculate. Typically, retail prices for buses are not available because they vary based on features desired, contract negotiations, and quantity ordered. Fortunately, there are two previous purchases as case studies to understand a general price range for these kinds of buses. In 2010, the City of Ottawa purchased 306 New Flyer clean diesel buses for $190 million.[16] This translates to $621,000 per bus. In 2017, King County in Washington purchased 73 Proterra Catalyst electric buses for $55 million with another $6 million for an appropriate charging station.[17] This translates to $836,000 per bus. The difference in price is ~$215,000 for the more expensive, electric buses.

To summarize, the costs of diesel versus electric buses are shown in Table 1. The combined annual costs show that electric buses have a savings of $21,188 per bus. Meanwhile, the difference in the initial investment per electric vehicle is an additional $215,000. In order to justify this proposal, the combined annual savings from the lower annual costs must outweigh the vehicle costs within the appropriate lifespan of a commuter bus.

Table 1. Summary of Costs of Diesel vs. Electric Buses			
Costs	Diesel	Electric	Difference
Annual Fuel ($)	16,151	10,789	5,362
Annual Maintenance ($)	22,388	6,562	15,826
Combined Annual Costs ($)	38,539	17,351	21,188
Vehicle Costs ($)	621,000	836,000	-215,000

According to the American Public Transportation Association the average lifespan of a commuter bus is 12 years.[7] However, since the vehicle costs can vary, it is important to show the differences in vehicle cost (using present value calculations) over various pay-back years to understand the timescale of this investment. Table 2 shows the pay-back time in years with an interest rate of 2.50% to combat inflation. Using the price difference of $215,000 from vehicles presented in earlier deals will successfully meet the pay-back time for each bus purchased in under 12 years. Negotiations with bus manufacturers to seek better deals than the ones analyzed are not necessary but helpful in order to maximize profits from the annual financial savings.

Table 2. Pay-back Time for Initial Investment with Differing Vehicle Negotiated Prices							
Pay-back time (years)	8	9	10	11	**12**	13	14
Savings ($/year)	-21,188	-21,188	-21,188	-21,188	**-21,188**	-21,188	-21,188
Interest Rate	2.50%	2.50%	2.50%	2.50%	**2.50%**	2.50%	2.50%
Vehicle cost difference	$151,921	$168,887	$185,439	$201,587	**$217,342**	$232,712	$247,707

V. Conclusion

As transportation grows larger over time, several measures are imperative to reduce costs and environmental impact. Streamlining the Rutgers transportation routes from large, campus loops to faster and smaller routes can increase the maximum students transported across campuses by 24.5% and transport students between campus centers from 15.1% to 66.0% faster than the current bus network. This increase in efficiency dramatically reduces the number of buses needed, resulting in lower costs and a lower carbon footprint. Also, a total switch from a fleet-size of ~50 biodiesel New Flyer buses to ~40 electric Proterra buses to be used for transportation can accumulate impressive savings over time. Table 3 shows the price and CO_2 gas emissions for the current and proposed bus fleets (as if purchased brand new instantly). Over a 12-year period, this switch to an all-electric bus fleet can save ~$12.4 million and prevent ~23,640 metric tons of CO_2 gas emissions.

Table 3. Current vs. Proposed Rutgers Bus Fleets

	Current	Proposed	Difference
Number of Buses	50 Biodiesel	40 Electric	10
CO_2 Emissions (metric tons/year)	2,833	863	1,970
Annual Fuel Costs ($/year)	807,550	431,560	375,990
Annual Maintenance Costs ($/year)	1,119,400	262,480	856,920
Combined Annual Costs ($/year)	1,926,950	694,040	1,232,910
Individual Vehicle Cost ($/bus)	621,000	836,000	-215,000
Total 12-Year Emissions (metric tons)	33,996	10,356	23,640
Total 12-Year Costs ($)	23,123,400	8,328,480	14,794,920
Total Vehicle Costs ($)	31,050,000	33,440,000	-2,390,000
Total Costs ($)	**54,173,400**	**41,768,480**	**12,404,920**

VI. Implementation

In Summer 2017, check the proposed routes for any issues necessary with road turns or bus stops. In Fall 2017, begin construction on temporary "Transit Hubs" for the desired main bus stops as well as any road development or assistance necessary to facilitate streamlined routes. In Spring 2018, initiate the new transportation routes and take feedback on new routes and purchase the first Proterra Catalyst electric bus as a test pilot. Then, extrapolate the projected savings and continue to negotiate a contract deal to purchase new Proterra buses and a charger station. Over the next twelve years, begin replacing New Flyer diesel buses with Proterra Electric buses as NF diesel buses break down over time. The fleet will reach fully-electric status by 2030!

VII. Appendix

Table 1A. Proposed Bus System - Breakdown of Travel Times											
Main		**Back**		**F**		**REXB**		**REXL**		**EE**	
LSC	5	LSC	8.5	SP	7	BCC	9	LSC	12	RSC	1.5
BCC	7	SP	9	DCC	3	DCC	10	DCC	10	Scott Hall	1
SP	8	BCC	5	CCC	3					Train Station	2
				DCC	6					Paterson	2
										Rockoff	3
										Public Safe	2
										DCC	3
										CCC	3
										DCC	2
										Public Safe	1
										Liberty	1
										Train Station	3
										SAC	2

Table 2A. Distribution of Buses in Current and Proposed			
Bus Route	Total Time	# of Buses	Min/Bus
A	29.5	4	7.4
B	24.5	6	4.1
EE	35.0	5	7.0
F	28.0	6	4.7
H	30.5	5	6.1
LX	27.0	9	3.0
REXB	32.0	4	8.0
REXL	32.0	5	6.4
Total Buses Used:		44	
Main	20.0	8	2.5
Back	22.5	8	2.8
F	19.0	4	4.8
REXB	19.0	4	4.8
REXL	22.0	4	5.5
EE	26.5	4	6.6
Total Buses Used:		32	

Table 3A. Travel Times between Campus Centers						
Campus Centers	Current (mins)		Proposed (mins)		% Decrease	
BCC ↔ LSC	10.6	22.1	7.8	7.5	26.2%	66.0%
BCC ↔ RSC	14.4	19.6	9.5	11.8	33.9%	39.7%
BCC ↔ DCC	25.0	20.0	13.8	14.8	45.0%	26.3%
RSC ↔ LSC	19.0	14.0	10.5	11.3	44.7%	19.2%
RSC ↔ DCC	15.2	12.7	11.8	10.8	22.5%	15.1%
LSC ↔ DCC	26.4	18.4	17.5	15.5	33.7%	15.8%

Table 4A. Max. Students Transported in 30 Mins				
Between Campuses		Current	Proposed	% Increase
Busch	Livi	1102	1700	54.3%
Busch	CAC	1348	1700	26.1%
Busch	C/D	563	947	68.4%
CAC	Livi	1500	1700	13.3%
CAC	C/D	1607	1627	1.2%
Livi	C/D	703	818	16.4%
All Campuses		6823	8492	24.5%

Additional Notes:

- How to use: The number to the right of the bus stop location determines how much time it takes to go to the next stop on the list. For instance, in the "Main" route, it takes 5 minutes to go from the LSC to the BCC. Nextbus/Google Maps used for times.
- NB1, NB2, and C remain untouched in current and proposed model
- Bus distribution in current model taken from Rutgers DOTS (Spring 2014)
- Formula for 3A: Min/Bus + Travel time between campus centers
- Formula for 4A: [30 / (Minutes/Bus) * 75 students per bus] per route and direction
- To download a copy of a spreadsheet with all formulaic tables used in this proposal, please see one of the following links:
    - https://drive.google.com/file/d/0Bzl50ucWMz1cbWZ1SFhFaERsTUU/view
    - http://www.mediafire.com/file/uoc924xz950do75/Bus_Proposal_Spreadsheet_2017_REI_TL_SI.xlsx

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