Charging into the Future:

An economic and GHG analysis of fleet conversion to electric buses

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Acronyms:

UCD -- The University of California at Davis.
CNG -- Compressed Natural Gas.
GHG -- Greenhouse Gas
FTA -- Federal Transit Authority
CO2e -- Carbon Dioxide equivalent
BYD -- Build Your Dreams, electric bus company
WAPA -- Western Area Power Administration
CARB -- California Air Resources Board
CH_4 -- Methane, a greenhouse gas
N_2O -- Nitrous Oxide, a greenhouse gas
US EPA -- United States Environmental Protection Agency
Therm -- a non-SI unit of heat energy equal to 100,000 British thermal units (BTU)
kWh/mi -- kilowatt hour per mile; measure of fuel economy for electric vehicles

Charging into the Future

By: Colin Mickle, Jessica Siegel, & Katrina Sutton

I. Executive Summary

Unitrans is the bus service that serves UC Davis and the surrounding community. Their 20 routes and 49 operational buses are powered mostly by CNG, run over 1 million miles each year, and carry an average an average of 4.5 passengers per vehicle mile. These buses emit greenhouse gases which are contributing to climate change. Rather than purchasing more CNG buses, Unitrans is considering adding electric buses to their fleet to save money and reduce greenhouse gas emissions. Electric buses emit zero tail-pipe emissions, and their well to wheels emissions are determined by the electricity they use. UC Davis is already working to add renewable energy to their electricity portfolio by installing large PV solar arrays and rooftop system on their buildings. This clean energy makes the buses cleaner than CNG. Our analysis shows that one electric bus on the UC Davis grid can save at least 22.7 metric ton of CO_2e in a year per CNG bus replaced with an electric bus. As more solar becomes available, the savings will increase.

Electric buses at UC Davis could save money and reduce carbon emissions. With federal grant incentives and technological advances in maintenance costs, electric buses are cheaper for Unitrans to run. Our research reports that the electric bus maintenance costs per mile are lower than Unitrans current fleet; we believe that this number can be even lower due to most maintenance is done in-house and with students who have an interest in learning about the buses. We expect over the 12 year lifetime of the bus, Unitrans will save roughly $212,000 per bus.

Having students working on electric and CNG buses allows them to be cross-disciplinary and more competitive in the workforce one they graduate. Learning and spreading awareness about the buses can encourage other transit agencies to analyze their fleet for the possibility of electric buses. UC Davis is a top ranked university, and with the help of their Institute of Transportation Studies, we can gleam even more data from the buses and encourage widespread implementation of clean electric buses.

II. Background:

The University of California Regents has pledged that all university campuses will be carbon neutral by 2025. For accounting purposes, emissions are divided into three scopes. Scope 1 is direct emissions from the university, scope 2 is indirect emissions related to utilities such as natural gas, and scope 3 emissions are all other indirect emissions including commuting and business trips. Each UC campus has to determine their own GHG mitigation strategies before looking into offsets.

Unitrans is the transit agency for UC Davis and the City of Davis. They operate 20 bus routes and 49 buses that drive over 1 million miles a year (Unitrans, 2015). Currently, the Unitrans fleet consists of 44 CNG buses and 5 biodiesel buses. Through their operations, Unitrans is responsible for about 2% of UC Davis emissions. We worked with closely with our clients at Unitrans to provide them with an economic and GHG emissions analysis of purchasing electric buses instead of CNG powered buses.

Electric buses would replace 12 year old CNG buses which have reached the end of their lifetime. Unitrans replaces their buses on a rolling basis meaning not every bus needs to be replaced at once. In 2016, 5 buses will need to be replaced and 8 more in 2018. Unitrans has to find the best buses to fit their needs within their budget; they tasked us to determine cost comparison and emissions reduction of electric buses instead of a new CNG bus.

With climate change and sustainability on the forefront of the University Regents mind, we have created a report proving that electric buses are feasible for Unitrans, reduce emissions, and save money over the lifetime of the bus.

III. Literature Review

As government agencies and private companies set increasingly ambitious climate action goals, the need to decarbonize the transportation sector is great. In the United States, transportation is responsible for 27 percent of total greenhouse gas emissions (EPA, 2013). In addition to carbon dioxide emissions, traditional petroleum vehicles present a range of health risks such as respiratory irritation, lung cancer and heart disease (Noel & McCormack, 2014). While hybrid vehicles have shown a 20-40% reduction in the well to wheels emissions of CO_2, hybrid technology does not offer the type of emissions reductions that many agencies require (Miles & Potter, 2014). Currently, three technology options are available to meet carbon neutrality goals: biomethane (RNG), renewably-sourced hydrogen, and battery electric vehicles.

Biomethane has shown promise as a transportation fuel. The City of Sacramento has been fueling refuse trucks and school buses from RNG produced from the Sacramento Biodigester (Tiangco, 2012). However, RNG relies on costly infrastructure, pins production targets on waste streams, and is limited to small scale fueling operations. Renewably-sourced hydrogen may be an excellent fuel source of the future, but the technology is not ready for large-scale deployment. Today, the vast majority of hydrogen produced in the U.S. comes from stream reforming of natural gas, which therefore gives hydrogen a well to wheels emissions factor similar to compressed natural gas (NREL, 2014). Battery electric vehicles represent the most market-ready carbon neutral transportation option (Noel & McCormack, 2014). The electrical infrastructure is largely already in place to allow battery electric vehicle charging and electricity is the easiest fuel to source from renewables and therefore decarbonize.

IV Methodology:

This project was comprised of three significant sections: a review of the currently available electric bus technology in accordance with the Unitrans fleet, an economic feasibility analysis, and a greenhouse gas analysis.

First, a background study of the Unitrans fleet was completed. Over the course of the 10 week quarter in Spring 2015, the team met several times with Anthony Palmere, Unitrans General Manager, and Andy Wyly, the Unitrans maintenance manager, to discuss the unique features and needs of the Unitrans fleet. We toured the Unitrans Maintenance facility, collected information about the current fleet, routes, maintenance needs, and the space and infrastructure available for electric bus implementation. Anthony Palmere provided excel data about the Unitrans fleet, miles traveled per vehicle, route details, and fuel usage.

To determine if any market-available electric bus technology fit the specific needs of Unitrans, we completed a review of several leading electric bus companies including BYD, Proterra, New Flyer, and Complete Coach Works. Data was collected via phone and email correspondence with company representatives, as well as from the information available on their company websites. We collected data about the lifetime, range, battery capacity, bus weight, warranty, efficiency, and price of each electric bus. Additional data collection included information about battery leasing options and cities where each bus company is operating. We also spoke with several transit agencies that have utilized electric vehicles from one of the four bus companies. These contacts provided valuable information about real bus operating costs and pointed us in the direction of useful resources, including CARB workshops focused on current and pending electric bus policies.

For the purposes of our emissions and economic analysis, we made several assumptions about the Unitrans fleet. Based on 2014 data and knowledgeable input from Anthony Palmere about future bus expectations, we assumed each Unitrans bus travels 20,000 miles in any given projected year. This was calculated from 2014 Unitrans mileage data; the entire bus fleet traveled a total of 926,432 miles with an average of 19,711.11 amongst the 48 buses in operation. To take into account future bus expansion, we rounded that number to 20,000 miles per year.

For the economic analysis, we assumed that a new CNG bus would cost $600,000 in 2016, with an increase in price of $25,000 per year through 2019, based on Anthony Palmere's estimates of inflation costs. For the price of an electric bus, we took the average cost of the four electric bus companies for a cost of $725,000 per electric bus. We assumed maintenance costs to be $0.40 per mile for electric buses based on an interview with a Proterra representative; we expect that number may be high according to the Unitrans maintenance manager because most of the bus maintenance is done in-house by students. We assumed fixed maintenance costs of $0.60 per mile for the CNG buses for any given projected year, based on available Unitrans data. We utilized forecasted UC Davis electricity grid and CNG therm prices, provided by the UC Davis Office of Environmental Stewardship and Sustainability. We assumed a fuel economy of 2.8 miles per therm for a new CNG bus, based on average 2014 CNG buses in the Unitrans fleet. We assumed 1.8 kilowatt-hours mile fuel economy for an electric bus based on the average of our four electric bus options. With this data we calculated the cumulative cost over a 20-year span of a new electric bus and a new CNG bus purchased in 2016.

Using the results from the original economic analysis, we also calculated the costs associated with purchasing a new CNG bus versus a new electric bus, assuming Unitrans obtains grant funding for capital costs from the FTA. Based on data from CARB, we assumed that Unitrans could receive $431,000 for a new CNG bus and $656,000 for an electric bus (ARB, 2015). Additional funding is available for the purchase of electric buses, such as $110,000 grants awarded by Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP), but for conservative estimates, we omitted these additional grants from the economic analysis.

For the emissions analysis, we used 2010 eGrid electricity emissions factors and electricity source mix data provided by Camille Kirk, Brian Leung, and Melody Lin of the UC Davis Office of Environmental Stewardship and Sustainability. To calculate the emissions for the fleet in a given year using the data provided, we assumed the Davis grid would be made up of 53% renewables (on-site solar) and 47% WAPA energy. We excluded 2016 energy data, as its energy portfolio was an outlier when compared to the other years of the study. 2016 will have a smaller ratio of renewables because the large off-site solar plant (near Fresno) will contribute 23% of UC Davis electricity starting in 2017. To calculate total CO_2e emissions from CO_2, CH_4, and N_2O emissions, we used conversion factors from the US EPA. Based on the data provided and the EPA conversion factors, the WAPA grid alone produces $3.0 * 10^{-4}$ metric tons of CO_2 equivalent per kilowatt-hour. Factoring in the ratio of UC Davis renewables available in 2017, the UC Davis grid blend will produce approximately 1.4 * 10^{-4} metric tons of CO_2e per kilowatt-hour. For consistency, we again assumed that that each bus will run for 20,000 miles at 2.8 miles per ther, With those assumptions, we assumed that each CNG bus would use 7,142.9 therms in a year.. We also assumed that 0.005302 metric tons of CO_2e would be produced per therm of CNG used, based on data provided by the US EPA.

Using the assumptions listed above, and the data provided, we calculated the total emissions of the Unitrans fleet under 3 different electricity scenarios: (1)100% WAPA grid, (2) UC Davis grid (53% UC Davis renewables and 47% WAPA), and (3) 100% attributed solar. While the WAPA-only grid is not a charging option for Unitrans, we included this analysis as a point of comparison to demonstrate how Unitrans has additional incentive to use electricity over most transit agencies nationwide. For each electricity scenario, we calculated the total emissions produced for the following fleet scenarios: (1) all 49 Unitrans buses are new CNG, (2) 5 buses are electric and 44 are new CNG, (3) 13 of the buses are electric and 36 are new CNG, and (4) all 49 buses are electric. These scenarios align with the bus replacement schedule of Unitrans for the next four years.

V. Results and Discussion:

A. Technology Assessment

Using Unitrans route data, we found that a Unitrans bus travels an average of 140 miles on any given day of operation during the academic year, with a median of 135 miles per day.

Bus Company	**Price ($)**	**Range (miles)**	**Warranty (years)**	**Efficiency (kWh/mile)**	**Gross Weight (lbs.)**
BYD	800,000	155+	12	1.92	40,786
Proterra	750,000	96-215	12	1.7	39,050
New Flyer	700,000	120	12	N/A	42,540-44,312
Complete Coach Works	650,000	85-115	12	1.7 - 2.0	37,740

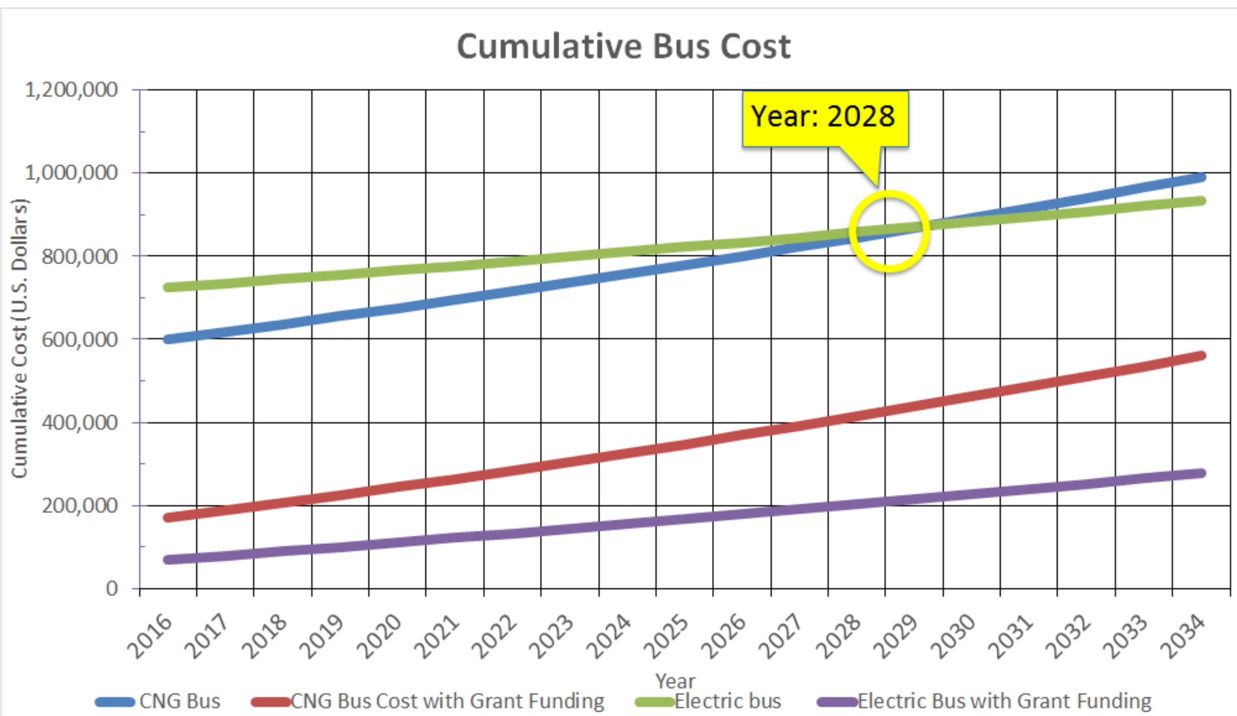
Table 1: The table above shows data for four leading electric bus companies

In conversations with the four bus companies, we found that BYD buses can travel at least 155 miles on one charge, depending on the amount of battery packs installed, a Proterra bus can travel 96-215 miles, a New Flyer bus can travel 120 miles, and a Complete Coach Works bus can travel 85-115 miles. A BYD electric bus and a Proterra electric bus with an 8-pack battery can safely complete the average 140 miles a day on one charge that a Unitrans bus is expected to run.

Additionally, CA Code 35554 mandates that each new bus be of equal or lesser weight on each axle than the bus it is replacing (CA Vehicle Code, 2012). The buses scheduled to be replaced in 2016 are all Orion model VII, with a gross weight of 42,540 lbs. The buses to be replaced in 2018 and 2019 are all Orion model V, with a gross weight of 40,600 lbs. Therefore, in terms of weight, BYD, Proterra, and Complete Coach Works are eligible to replace Orion VII model CNG buses, and Proterra and Complete Coach Works are eligible to replace Orion V model.

Given the data about efficiency, warranty, range, and gross weight, we conclude that BYD and Proterra 40' electric buses would likely be the best purchase decision for Unitrans, without considering capital costs.

B. Economic Analysis



Graph 1: Cumulative Cost Analysis, years 2016-2034

The results of our economic analysis are summarized in the graph above. According to our calculations, without grant funding, an electric bus will have a payback period of 14 years in relation to a new CNG bus. The life span of a bus is 12 years, so without federal funding, electric buses would not be less expensive than a CNG according to our fuel and maintenance assumptions. Since our analysis includes multiple uncertainties, it is possible that the actual payback period is several years shorter or longer than our model predicts. However, if we assume Unitrans receives FTA funding for electric buses, as it has historically received for CNG buses in the past, capital costs for an electric bus will be reduced below the cost of a CNG bus. Additionally, fuel and maintenance costs are consistently lower for an electric bus; the rate of increase of cumulative costs is lower for an electric bus than for that of a CNG bus. After 12 years with the assumed FTA funding, fuel, and maintenance costs, Unitrans will save approximately $212,700 per electric bus purchased in 2016 after the 12 year life life-span. The chart below shows the cost breakdown over the years 2016-2034.

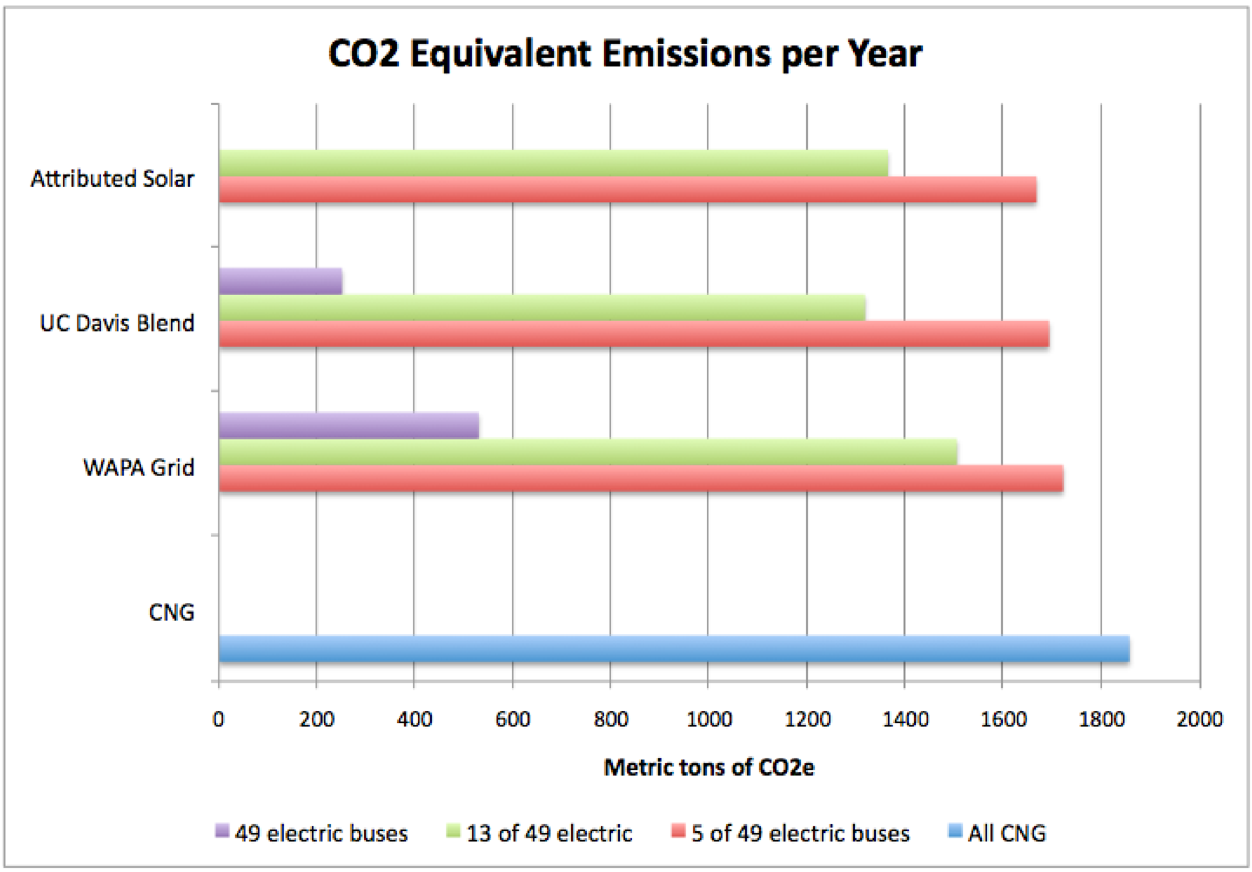
Year	CNG Bus Cost	CNG Bus Cost with Grant Funding	Electric Bus Cost	Electric Bus with Grant Funding
2016	$600,000.00	$169,000.00	$725,000.00	$69,000.00
2017	$618,210.70	$187,210.70	$735,200.93	$79,200.93
2018	$636,834.76	$205,834.76	$745,507.26	$89,507.26
2019	$655,872.16	$224,872.16	$755,944.96	$99,944.96
2020	$675,322.92	$244,322.92	$766,578.97	$110,578.97
2021	$695,187.02	$264,187.02	$777,387.92	$121,387.92
2022	$715,464.47	$284,464.47	$788,363.79	$132,363.79
2023	$736,155.28	$305,155.28	$799,504.16	$143,504.16
2024	$757,259.43	$326,259.43	$810,808.98	$154,808.98
2025	$778,776.93	$347,776.93	$822,301.67	$166,301.67
2026	$800,707.79	$369,707.79	$834,008.80	$178,008.80
2027	$823,051.99	$392,051.99	$845,940.72	$189,940.72
2028	$845,809.54	$414,809.54	$858,118.91	$202,118.91
2029	$868,980.44	$437,980.44	$870,433.23	$214,433.23
2030	$892,564.70	$461,564.70	$882,892.74	$226,892.74

2031	$916,562.30	$485,562.30	$895,507.29	$239,507.29
2032	$940,973.25	$509,973.25	$908,287.59	$252,287.59
2033	$965,797.55	$534,797.55	$921,245.29	$265,245.29
2034	$991,035.20	$560,035.20	$934,303.54	$278,303.54

Table 2: Costs over the years 2016-2034

It is important to note the uncertainty of the forecasted electricity and CNG prices. Because CNG prices are unpredictable and dependent on the domestic and foreign energy market and evolving regulatory policies, it is difficult to determine how accurate the forecasted CNG prices are. The future of CNG and electricity prices over the next 19 years will significantly influence the accuracy of our results.

C. Greenhouse Gas Analysis



Graph 2: CO_2e emissions per year with different energy sources and fleet scenarios

A new CNG bus with a fuel efficiency of 2.8 miles per therm, emissions of $5.302 * 10^{-3}$ metric tons of CO_2e (11.69 lbs) per therm, driving approximately 20,000 in a year, would produce approximately 37.9 metric tons of CO_2e in a year. If all 49 Unitrans buses were new CNG buses, the emissions would be approximately 1,856 metric tons of CO_2e per year. This is shown in the blue bar in the graph above.

For the sake of comparison, we included the analysis below for a typical transit agency on the west coast using WAPA power for electric buses. If charged with the WAPA grid, assuming a fuel efficiency of 1.8 kWh/mi, 20,000 miles per year of use, and emissions of $3*10^{-4}$ metric tons of CO_2e/kWh, each electric bus will produce approximately 10.8 metric tons of CO_2e a year. That is a savings of 27 metric tons of CO_2e emissions for a single CNG bus in a year. If 5 buses are electric buses, and 44 are new CNG buses, charged on the WAPA grid, the emissions will be approximately 1,720 metric ton of CO_2e in a year. With 13 electric buses, and 36 new CNG buses, emissions will be approximately 1,504 metric tons of CO_2e in a year. If all 49 buses are replaced with new electric buses and charged on WAPA power, fleet emissions will be approximately 29 metric ton of CO_2e in a year.

The UC Davis grid is the most realistic electricity scenario, with 47% of campus electricity coming from WAPA and 53% from UC Davis renewables. In this scenario, a single electric bus charged on the UC Davis grid will emit approximately 5 metric ton of CO_2e in a year, assuming 20,000 miles and 1.8 kWh/mi fuel economy. That is a reduction of 22.7 metric ton of CO_2e in a year per CNG bus replaced with an electric bus. It is also less than half of the emissions produced by an electric bus charged on the conventional WAPA grid. With 5 electric buses and 44 CNG buses, the fleet will emit approximately 1,692 metric ton of CO_2e in a year. With 13 electric buses 36 new CNG buses, the fleet will emit approximately 1,316 metric ton of CO_2e in a year. Finally, with all 49 electric buses charged on the UC Davis grid blend, the fleet will emit 251 metric ton of CO_2e in a year.

The best case electricity scenario would occur if electric buses in the Unitrans fleet could be charged on electricity that is 100% allocated from the large offsite-solar project. In this scenario, any electric bus would have zero emissions of CO_2e for the duration of its use. All fleet emissions would come from CNG buses. In this case, if the fleet was made up of 5 electric buses and 44 CNG buses, the fleet would emit a total of 1,666 metric ton of CO_2e in a year. With 13 electric and 36 CNG, the fleet would emit 1,363 metric ton of CO_2e in a year. If all 49 buses are charged with attributed solar energy, with the assumptions in this study, use phase emissions would be zero.

Finally, in all cases, the electricity the buses will use to charge is minimal. Assuming 1.8 kWh/mi and 20,000 mi/year, one electric bus will use 36,000 kWh each year. Therefore, even if we assume an entirely electric fleet, the cumulative annual electricity use would be 0.0075% of total campus electricity use.

VI. Conclusions and Recommendations:

Our results indicate that electric buses can feasibly replace some CNG buses in the Unitrans fleet. Three of the four electric buses reviewed in this report have the range and charging capacity to meet Unitrans' needs without the use of inductive "in-route" charging. Furthermore, while dependent on initial capital costs and energy prices, electric buses are likely to have lower lifetime costs compared to CNG. Finally, the emissions reductions associated with electric buses are significant. For instance, if the buses are powered by attributed solar electricity, the bus and its fuel would have zero greenhouse gas emissions associated with its use phase. Even without attributed solar, GHG emissions and UCD scope 1 emissions are reduced by 22.7 metric tons of CO2e when one electric bus is charged on the UCD grid.

UCD has reduced, and continues to reduce, its electricity usage (and therefore emissions) through a number of energy efficiency retrofits. In addition to a number of campus-wide infrastructure projects, UCD has completed over 120 projects in 75 buildings. Currently, the UC Davis Energy Efficiency Office is performing energy retrofits of laboratories on campus, which use roughly two thirds of cumulative emissions on campus. Unitrans represents another opportunity to reduce emissions on campus. The easy access to renewable energy and opportunity to eliminate CNG consumption will bring UCD one step closer to meeting the 2025 goal of carbon neutrality.

Further research should determine how many electric buses are feasible for Unitrans and what infrastructure is required to transition to a majority electric fleet. Unitrans should also test the amount of energy they can get back from regenerative braking in their routes and the energy needed to power their climate control system.

VII. Electric Bus Contacts:

- BYD:
  - Zach Kahn
    Northern California BYD Representative
    (213)-400-7279
    zach.kahn@byd.com
  - Ward Thomas
    Transportation Operations, Stanford University
    Parking & Transportation Services
    650-736-1619
    ewthomas@stanford.edu

- Complete Coach Works:
    - Ryne A. Shetterly
      ZEPS Sales Manager
      Mobile: 951-836-0815
      Office: 951-684-9585 **Ext**. 174
      Email: RShetterly@Completecoach.com
- Proterra: Robert Aguirre (323) 717-9566

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IX. Appendix:

Table 1.1

Vehicle #	Manufacturer	Model	Year	Replacement	Fuel
BD 20 Diesel Buses (including most Double-deck buses and one minibus)					
742	AEC	RT	1948	N/A	B20 Biodiesel
4735	AEC	RT	1954	N/A	B20 Biodiesel
2062	El Dorado	Aerotech	2002	N/A	B20 Biodiesel
8185	Alexander Dennis	Enviro500	2010	2022	B20 Biodiesel
8186	Alexander Dennis	Enviro500	2010	2022	B20 Biodiesel
CNG (Heavy-duty Single-deck Buses, one Doubledeck bus, three minibuses)					
2819	AEC	RT	1952	N/A	CNG
4344	Orion	Orion V	1996	N/A	CNG
4347	Orion	Orion V	1996	N/A	CNG
4348	Orion	Orion V	1996	N/A	CNG
4349	Orion	Orion V	1996	N/A	CNG
4063	Orion	Orion VII	2003	2015	CNG
4064	Orion	Orion VII	2003	2015	CNG
4065	Orion	Orion VII	2003	2015	CNG

4066	Orion	Orion VII	2003	2015	CNG
4067	Orion	Orion VII	2003	2015	CNG
2068	El Dorado	Aerotech	2004	2016	CNG
2069	El Dorado	Aerotech	2004	2016	CNG
2070	El Dorado	Aerotech	2004	2016	CNG
4171	Orion	Orion V	2006	2018	CNG
4172	Orion	Orion V	2006	2018	CNG
4173	Orion	Orion V	2006	2018	CNG
4174	Orion	Orion V	2006	2018	CNG
4175	Orion	Orion V	2007	2019	CNG
4176	Orion	Orion V	2007	2019	CNG
4177	Orion	Orion V	2007	2019	CNG
4178	Orion	Orion V	2007	2019	CNG
4000	New Flyer	C40LFR	2009	2021	CNG
4001	New Flyer	C40LFR	2009	2021	CNG
4002	New Flyer	C40LFR	2009	2021	CNG
4003	New Flyer	C40LFR	2009	2021	CNG
4004	New Flyer	C40LFR	2009	2021	CNG
4005	New Flyer	C40LFR	2009	2021	CNG
4079	New Flyer	C40LFR	2009	2021	CNG
4080	New Flyer	C40LFR	2009	2021	CNG
4081	New Flyer	C40LFR	2009	2021	CNG
4082	New Flyer	C40LFR	2009	2021	CNG
4083	New Flyer	C40LFR	2009	2021	CNG
4084	New Flyer	C40LFR	2009	2021	CNG
4087	New Flyer	C40LFR	2009	2021	CNG
4088	New Flyer	C40LFR	2009	2021	CNG
4089	New Flyer	C40LFR	2009	2021	CNG
4090	New Flyer	C40LFR	2009	2021	CNG
4091	New Flyer	C40LFR	2009	2021	CNG
4092	New Flyer	C40LFR	2009	2021	CNG
4093	New Flyer	C40LFR	2009	2021	CNG
4094	New Flyer	C40LFR	2009	2021	CNG
4095	New Flyer	C40LFR	2009	2021	CNG
4096	New Flyer	C40LFR	2009	2021	CNG
4097	New Flyer	C40LFR	2009	2021	CNG
4098	New Flyer	C40LFR	2009	2021	CNG
4099	New Flyer	C40LFR	2009	2021	CNG
4006	New Flyer	Xcelsior	2014	2026	CNG
4007	New Flyer	Xcelsior	2014	2026	CNG
4008	New Flyer	Xcelsior	2014	2026	CNG

Table 1.2

Job	**Miles Scheduled per day**
1	131
2	141
3	138
4	123
5	136
6	160
7	202
21	159
22	137
23	142
24	124
25	140
26	125
27	219
28	219
43	134
44	134
45	102
46	110
47	97
48	97
50	120
51	120
52	110
57	164
58	164
Mean	140
Median	135