An Environmental and Economic Analysis of Converting Duke University's Police Fleet to Alternatively Powered Vehicles

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Abstract

Despite contributing only a small portion of total campus greenhouse gas emissions (GHG), Duke University's Police fleet serves as a visible platform for demonstrating progress toward the University's commitment to be carbon neutral by 2024. However, before the fleet can be modernized, adequate vehicle replacements are needed. By working with the Duke University's Police Department and Duke's Sustainability Office, an in-depth analysis of fleet characteristics and officer needs was performed with the intention of identifying suitable alternatively fueled or powered replacement fleet vehicles. By focusing on minimizing lifetime costs, annual fuel costs, and lifetime carbon dioxide (CO_2) emissions, multiple vehicles and technologies have shown the potential to reduce lifetime fuel costs by over $100,000 and lifetime GHG emissions by 200 tons.

Introduction

Society's awareness of the impact greenhouse gas (GHG) emissions have on the global climate has been increasing rapidly. Due to this mindfulness, new emission sources are being placed under intense scrutiny. One of the new sources are academic institutions. In December 2006, as a response to this pressure, twelve universities made a "highly-visibility effort to address global climate disruption" by making institutional commitments under the American College & University Presidents' Climate Commitment (ACUPCC).[i] As part of this pledge, both large and small schools agreed to complete an emissions inventory, set a target date for achieving climate neutrality, take immediate steps to reduce GHG emissions, integrate sustainability into their curricula, and develop a publicly available climate action plan.[i]

In June 2007 Duke University joined the ACUPCC and formed the Campus Sustainability Committee (CSC).[ii] The CSC went about taking an inventory of all campus emissions, incorporating sustainability into campus activities, class work, and research, and released the official Climate Action Plan (CAP) for Duke University in the Fall of 2009.[iii] The chief objective of the CAP is achieving climate neutrality for the entire university campus by 2024, the 100th anniversary of Duke University as it stands today.

The CAP has five focus areas: *Energy*, *Transportation*, *Offsets*, *Communications*, and *Education*. Among these spheres of influence *Energy* has the greatest potential for directly reducing GHG emissions linked to the university because it represents the largest portion of Duke's GHG emissions. However, despite large achievements like the elimination of coal use on campus in 2011 and the unique carbon dioxide (CO_2) offset venture between Google, Duke Energy, and Duke University GHG reductions remain a top priority. Furthermore, the *Transportation* focus remains the most difficult to improve and is, therefore, central to effectively directing campus culture towards a more sustainable future.[iv,v]

In 2007, Duke's baseline GHG inventory found that 23% of the campus's emissions were transportation related.[vi] Of that portion, 52% is from commuter-related travel, 43% from institution sanctioned and financed air travel, and the final 5% is from the campus service and transit fleet.

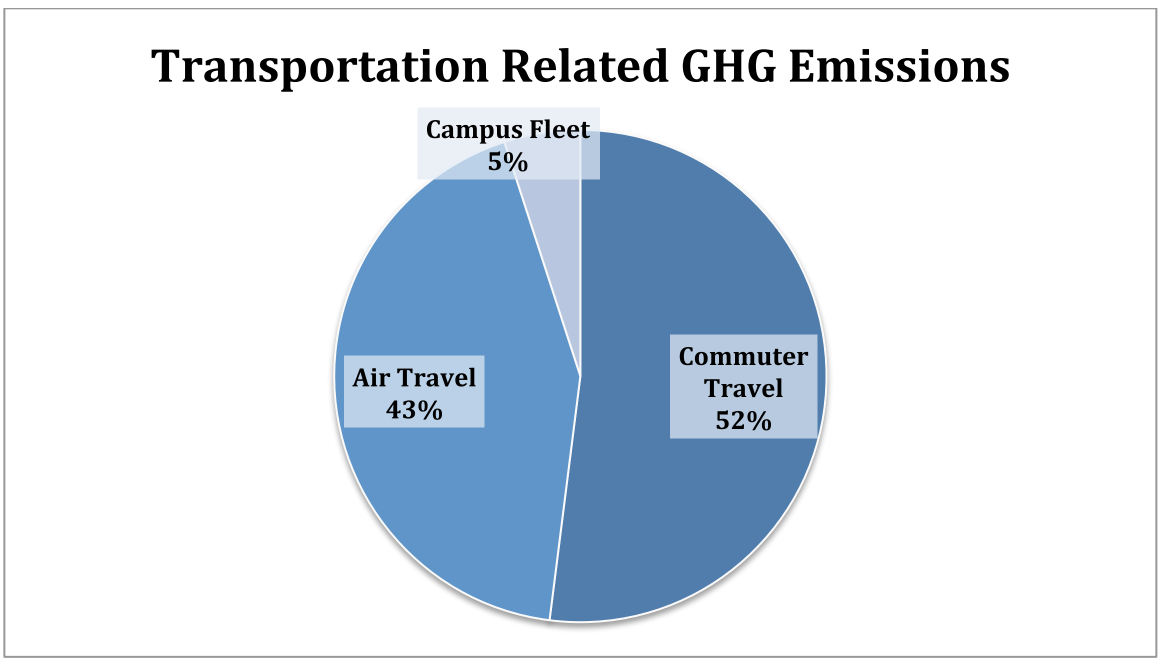

Figure 1. Transportation Emissions

As of 2013, Duke has hired a full-time transportation demand manager, worked with the city of Durham to develop a fare-free bus system for students and staff, and has developed new programs to encourage alternative methods of transportation to and from campus.[vii] Despite these improvements, emissions related to transportation have risen 15% since 2007.[vii] The increase is thought to be due to employees living farther from campus and growth in the University workforce. As the Raleigh-Durham area continues to grow, these two factors are likely to increase, which means Duke University needs to pursue fleet emission reductions in some other way.

A promising solution for preventing any further increase in transportation emissions is focusing on improvements to the campus fleet vehicles. Despite campus fleet emissions accounting for 5% of all transportation emissions, and just over 1% of total campus emissions, it is the most likely candidate for sustained change since the university has nearly complete control over emissions related to this portion of transportation. As such Duke is in the process of rolling out 10 buses with large, articulated hybrid buses and has established a "Green Policy" for fleet vehicle replacement.[viii] The "Green Policy" focuses on vehicle efficiency and emission performance in order to achieve a 50% reduction in emissions.[viii] Additionally, there has been positive feedback surrounding the use of bi-fuel vehicles, those that can run on gasoline or compressed natural gas (CNG), among the facility services fleet. However, up to this point there has been no movement on the university's police vehicles, arguably the most visible aspect of Duke's fleet.

This study hopes to identify new, alternatively powered vehicles that could adequately serve the police department while simultaneously reducing costs and CO_2 emissions. First, in order to identify these vehicles it is important to better understand the current fleet's demands and performance requirements. Following that review, an analysis of the performance and characteristics of alternatively powered vehicles presently on the market or in use by other police departments will be conducted. Finally, the results from the current fleet vehicles and the proposed replacement vehicles will be compared to one another on a series of metrics. These metrics will look at potential cost and emission savings from making the switch to alternatively powered vehicles.

Duke University Police Fleet

Duke University's Police Department (DUPD) maintains a fleet of 13 patrol vehicles, 11 sedans and two SUVs. Over the last year, DUPD vehicles have traveled over 250,000miles, averaging 15,807 miles each, and have emitted over 100 tonnes of CO_2. Ideally DUPD vehicles will remain in service for three years or 50,000 miles, whichever comes first.[ix] Additionally, DUPD is always looking to save money on vehicle costs. Currently the department is only taking purchase price in to account because operational costs have been very similar from one vehicle to another due to the similar fuel and engine choices available on the automotive market.

Duke's newer sedan police vehicles are Chevrolet Caprices, which are built specifically for use by police, security, or government fleets and is unavailable for purchase by the public. Each vehicle cost $32,475 before any police specific modifications or department badging, have an estimated MPG of 19.2, and emit 7,300 kg of CO_2 each year. The older sedans, which DUPD is currently phasing out in favor of the Caprice, are Chevrolet Impalas, which have an initial cost of $27,340, have a MPG of 18.65, and emit over 7,500 kg of CO_2 each year. DUPD also employs Chevrolet Tahoes, identical to those available for purchase from any car dealer. Each vehicle cost $43,600, have a MPG of 15.9, and emit over 8,800 kg of CO_2 each year.

Table 1. Current DUPD Fleet Summary

	Gasoline Fleet		
	Chevy Caprice	Chevy Impala	Chevy Tahoe
Initial Cost	$32,475	$27,340	$43,600
Annual Miles	15,807	15,807	15,807
MPGe	19.2	18.65	15.9
Annual Gallons Consumed	823	848	994
Fuel Cost per Year	$3,211	$3,305	$3,877
Department Lifetime Cost	$42,107	$37,256	$55,232
Annual CO_2 Emissions (kg)	7,316	7,532	8,835
Annual Total CO_2	7,316	7,532	8,835
Annual Operational Cost/Mile	$0.20	$0.21	$0.25
Lifetime Cost/Mile	$0.89	$0.79	$1.16

There are four teams of officers who work in groups of two teams. For three days two of the four teams are on duty and then rest the next three days while the other pair of teams work. Of the two of the teams in each rotation, one works the night shift and the other works the day shift.

Table 2. DUPD Monthly Patrol Shift

		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Week 1	Day Shift	Squad 1	Squad 1	Squad 1	Squad 3	Squad 3	Squad 3	Squad 1
	Day Shift	Squad 2	Squad 2	Squad 2	Squad 4	Squad 4	Squad 4	Squad 2
Week 2	Night Shift	Squad 1	Squad 1	Squad 3	Squad 3	Squad 3	Squad 1	Squad 1
	Day Shift	Squad 2	Squad 2	Squad 4	Squad 4	Squad 4	Squad 2	Squad 2
Week 3	Night Shift	Squad 1	Squad 3	Squad 3	Squad 3	Squad 1	Squad 1	Squad 1
	Day Shift	Squad 2	Squad 4	Squad 4	Squad 4	Squad 2	Squad 2	Squad 2
Week 4	Night Shift	Squad 3	Squad 3	Squad 3	Squad 1	Squad 1	Squad 1	Squad 3
	Day Shift	Squad 4	Squad 4	Squad 4	Squad 2	Squad 2	Squad 2	Squad 4

When teams are on duty they work in four car groups for the entirety of their twelve-hour shift. An additional fifth car is also on duty but is reserved for the Shift Commander and isn't necessarily patrolling campus for the full twelve hours. When the officers are off duty so are their patrol cars. This lessens the wear and tear on the vehicles and streamlines the scheduling of routine maintenance. DUPD is able to operate a seemingly small fleet because Durham City Police share jurisdiction with the University. Taking advantage this additional fleet ensures a safe campus 24/7 but doesn't necessarily reduce the GHG emissions related to campus activities; this collaborative effort transfers emissions from Scope 1 to Scope 3[1].[x] This mission critical and constantly adapting fleet provides an excellent opportunity for reducing GHG emission related to transportation and the university as a whole. Today, many different vehicle types could replace the traditional gasoline vehicles.

According to DUPD officers, campus police vehicles need to be comfortable, large enough to accommodate additional electronic police equipment, and able to operate for an entire twelve-hour shift. High top speeds, enhanced structural safety equipment, and advanced maneuverability are typically required for police vehicles but, for this unique sector of law enforcement, are not needed for campus patrol vehicles. Additionally, the traditional measures of "power" and "performance" for police vehicles, horsepower, torque, top speed, and acceleration, are not the driving force behind which vehicles officers choose to operate. Instead, officers place technology and its role in simplifying everyday duties as a priority when selecting patrol vehicles. The need to reduce GHG emissions from fleet vehicles, the standard usage and attributes required for a campus police vehicle, and the promise of lower fuel costs all lend themselves to the use of alternatively fueled and powered vehicles.

The most promising vehicle technologies capable of filling that profile for DUPD are hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), electric vehicles (EV), and CNG vehicles. Each of these vehicles technologies is currently available for purchase by consumers but has yet to be designed

[1] Scope 1 Emissions- GHGs that are directly from sources controlled or owned by the entity, in this case Duke University.
Scope 3 Emissions- indirect GHG emission from sources not directly owned or operated by the entity but related to its operations

specifically for police use. Each has its advantages and disadvantages, but all are expected to reduce the GHG emissions and costs related to the DUPD fleet.

Hybrid Electric Vehicle

The HEV, simply put, is what most people think of when they hear the term hybrid. A HEV is a vehicle that combines a battery-powered motor with a traditional internal combustion engine (ICE) to provide propulsion.[xi] There are three distinct designs for a HEV--series, parallel, and parallel-series--with the difference determined by how the different motors interact. The series HEV uses an electric motor to drive the wheels and an ICE to charge the battery, which powers the electric motor. The parallel HEV uses both an electric motor and an ICE to drive the wheels simultaneously. The parallel-series also uses both an electric motor and an ICE to drive the wheels but they can be use in combination or independently from one another. Each of these HEV designs has their own strengths and weaknesses. For example, the ICE in a series HEV can run at its optimal speed continuously by varying the output of the electric motor. This combination increases the overall efficiency of the vehicle. The parallel HEV is less efficient during common city driving, but performs well at highway speeds. A Parallel-series HEV is very efficient in stop-and-go traffic but can be more expensive to purchase.

Each of these vehicles typically has relatively small ICEs and electric motors. For example, the Toyota Prius, the best selling hybrid car to date and a good example of a parallel-series HEV, has a 98 horsepower ICE and a 36 horsepower equivalent electric motor.[xii] These vehicles excel in city traffic because the motors are able to shut off while not moving and the battery is recharged while slowing down or braking. One downside to all HEVs is that they cannot accelerate as quickly and typically cannot achieve as high of a top speed as conventional gasoline vehicles because the ICEs onboard are significantly less powerful than non-hybrid ICEs.

As a whole, HEVs are expected to reduce GHG emissions compared to conventional gasoline vehicles because they consume a significantly smaller amount of gasoline. For example, a Toyota Prius that can travel an estimated 51 miles per gallon (MPG) versus a standard sedan capable of driving 20 miles per gallon would consume approximately 450 fewer gallons of gasoline over 15,000 miles. That savings equates to more than four tonnes of CO_2 and thousands of dollars.

Plug-in Hybrid Electric Vehicles

PHEVs are very similar to HEVs and are almost always series HEVs. The main difference is that an external source of electricity is needed to fully charge the batteries. A well-known PHEV is the Chevrolet Volt. This vehicle is capable of driving over 38 miles without using an ounce of gasoline. This performance combined with the fact that, according to DUPD records, campus police vehicles travel an average of 43 miles per day mean significant GHG and fuel cost savings are possible with this drivetrain.

Some additional infrastructure is needed to recharge these vehicles but with their increasing popularity the cost of an advance-charging unit, capable of fully charging a Volt in four hours, is only $490[xiii]. Furthermore, the Chevrolet Marketing Director has claimed that Volt owners are "achieving fantastic performance numbers with their vehicles as many are beating the EPA label estimate," which is

98 miles per gallon equivalent (MPGe[2]).[xiv] There have even been numerous consumer reports of vehicles traveling over 9,000 miles on just two tanks of gas.[xiii]

PHEVs are expected to have even fewer emissions than HEVs because the majority of the energy is sourced from the electricity grid, which in North Carolina emits less CO_2 than a HEV. A standard Volt, traveling 15,000 miles, could to emit less than 2.5 tonnes of CO_2. Furthermore, if a PHEV was connected to an electricity source deriving its energy from a renewable energy source such as solar or wind, instead of today's coal and natural gas, that emissions number would reduced even further.

Electric Vehicles

EVs use one or more electric motors to propel the car down the road. There is no ICE on board to serve as a supplemental or reserve power source. These vehicles are powered by stored energy in the form of batteries and are charged by an external source of electricity. EVs can accelerate much quicker than gasoline vehicles because there are no gears to shift through and 100% of the torque is available from a standstill, unlike ICEs which develop more torque at higher engine revolutions per minute.[xv] Additionally these vehicles have zero tailpipe emissions. This does not mean that the vehicles have zero emissions; it means that the local air quality will not be directly affected by the use of the vehicle. Finally, because there isn't a conventional engine and transmission present significantly more space is available in the cabin of the driver, passenger, and additional vehicle equipment.

[2] MPGe- Miles per Gallon equivalent. Developed by the EPA for the use of comparing vehicles that use fuel sources other than gasoline or diesel to those that do, i.e. Comparing a CNG vehicle to a ICE vehicle

The largest downside for EVs is battery energy density, or the amount of stored energy per volume of mass. Gasoline has an energy density of 44.4 MJ/kg while a lithium-ion battery, a common EV and hybrid battery, has an energy density of 0.36-0.875 MJ/kg.[xvi] [xvii] This means that EVs must be very heavy and carry large batteries if they want to have the range of a gasoline vehicle.

Similar to PHEVs, EVs have GHG emissions far lower than conventional gasoline vehicles. If the EV receives its electricity from conventional power plants the emissions could be two to three times lower than a gasoline vehicle. Furthermore, if an EV sources its electricity from a renewable energy source, such a solar PV or wind, zero GHG emissions will be linked to propelling the vehicle.

Compressed Natural Gas Vehicle

CNG vehicles utilize compressed methane in much the same way gasoline is used in conventional vehicles and are becoming very popular around the world. As of 2012 there were over 16.7 million CNG vehicles in use around the world, with Iran and Pakistan leading the charge with 3 million and 2.9 million vehicles, respectively.[xviii] In the U.S. there are approximately 118,000 CNG vehicles on the road, most of which are heavy-duty trucks or shipping vehicles.[xix] The performance and driver sensation of a CNG vehicle is almost identical to that of a gasoline vehicle due to the use of an ICE.

One criticism is that the mileage of a CNG vehicle is worse than that of a gasoline vehicle. While that is true, it costs about half as much to completely fill up a CNG vehicle compared to a gasoline vehicle. Another factor deterring the use of CNG vehicles in the U.S. is the lack of fueling stations. Today, there is a gasoline gas station, or two, on nearly every street in America. However, as of 2012, there are only 1,197 CNG fueling sites in the U.S.[xvi] On Duke's campus there is currently one fueling station that has been supplying the university's bi-fuel fleet since the late 1990's.[xx]

CNG vehicles have the potential to emit less GHG per mile than a conventional gasoline vehicle but that isn't always true. For the vehicle examined in this report, the CNG vehicle emits more GHG than its ICE counterpart but far fewer than the vehicles it would be replacing at Duke. Since CNG is composed of methane, a single carbon compound, physically less CO_2 has the potential to be released during combustion. However, since more CNG will be required per mile than gasoline, CO_2 savings will be realized when using a CNG vehicle, just not as much as other alternatively powered vehicles.

Methods

Baseline Data

All subsequent information pertaining to the current DUPD fleet was collected from two DUPD officers.[xxi, xxii] This data included the type of vehicles used by the DUPD, the manner in which the vehicles are used, the attributes necessary for a patrol vehicle, and the maintenance and replacement schedule for DUPD vehicles. Daily miles and vehicle specific miles traveled were deemed confidential but total fleet miles traveled, per month and year, for fiscal year (FY) 2012 is available. Additionally, by using the fuel purchase records from FY 2005-2013 and the observed cost per mile from of $0.13/mile, both provided and calculated by the Sustainability Office, an estimate of miles driven and GHG emissions for those years was calculated. All refueling information for the department's vehicles is strictly monitored and tracked, so mileage and GHG estimates are assumed to be accurate. Below is a table showing the fuel costs and mileage of the fleet. The FY 2012 "Miles/Year" value is abnormally low due to a change in fuel accounting methods during which some data was lost. The average monthly mileage for the known months was interpolated to cover the missing data but based upon its deviation from the rest of the given years is it is likely an inaccurate estimation.

Table 3. Yearly Mileage Estimates.

Gasoline	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY2011	FY 2012	FY 2013
DUPD Purchase Based Fuel Estimate	$37,419	$41,287	$35,859	$37,511	$36,138	$34,149	$36,157	$27,372	$34,256
Miles/Year	276,263	304,822	264,746	276,948	266,805	252,123	266,948	202,088	252,911
Miles/Month	23,022	25,402	22,062	23,079	22,234	21,010	22,246	16,841	21,076
Miles/Vehicle	17,266	19,051	16,547	17,309	16,675	15,758	16,684	12,631	15,807

Comparison Data

Quantitative and qualitative information on the current fleet vehicles, plus potential HEV, PHEV, EV, and CNG vehicles was gathered from the manufacture's websites. The information of interest was MPG or MPGe, fuel tank size, fuel type, kWhs consumed, battery size, gas-free range, starting price, and potential infrastructure costs. Each of these attributes was recorded, where applicable. Below is a section of a much larger spreadsheet that lists all of the pertinent vehicle data.

	Potential Alternatively Powered Fleet Vehicles				
Vehicle Type	Hybrid				
Model Name	Chevy Volt	Ford Focus Electric	Ford Fusion Hybrid S	Ford Fusion Energi	Honda Civic
Initial Cost	$34,185	$35,170	$26,270	$34,700	$24,635
Optional Infrastructure Cost	$490	$0	$0	$0	$0
Annual Miles	15,807	15,807	15,807	15,807	15,807
Daily Miles	43	43	43	43	43
Battery Miles	38	76	0	21	0
MPGe	98	108	47	100	45
Annual Gallons Consumed (GGE)	20	-	336	81	351
Fuel Cost per Year	$77	-	$1,312	$318	$1,370
kWh/100miles	34.7	12	-	28.6	-
Annual kWh Consumed	5,491	1,913	-	4,516	-
Electricity Costs per Year	$615	$214	$0	$506	$0
Total Annual Fuel Costs	$692	$214	$1,312	$823	$1,370
Department Lifetime Cost	$36,751	$35,813	$30,205	$37,170	$28,745
Lifetime Savings Per Vehicle	$3,644	$4,582	$10,190	$3,225	$11,650
Lifetime Savings Per Fleet	$47,369	$59,567	$132,471	$41,924	$151,452
Annual CO2 Emissions (kg)	2,756	899	2,989	2,846	3,122
Annual Operational Cost/Mile	$0.044	$0.014	$0.083	$0.052	$0.087
Lifetime Cost/Mile	$0.78	$0.76	$0.64	$0.78	$0.61
CO2 kg/mile	0.17	0.06	0.19	0.18	0.20
Miles/kg CO2	5.7	17.6	5.3	5.6	5.1

Table 4. Alternatively Powered Vehicle Summary-Partial

CO_2 and Cost Model

With the collected data a basic Excel model was created to display and compare the respective CO_2 emissions and lifetime costs in relation to each vehicle. Below is a portion of the summary page of the aforementioned Excel model. On this page it is possible to vary the price of gasoline ($/gallon), electricity ($/kWh), and

CNG ($/GGE). This page also displays key performance indicators for individual vehicles, such as Annual Fuel Cost, Lifetime Savings/Vehicle, Lifetime Savings/Fleet, Annual CO_2 emissions (kg), Annual Operational Cost/Mile, and Lifetime Cost/Mile. Furthermore, the primary conversion factors necessary for calculating CO_2 emissions for each vehicle are listed on this front page of the Excel model.

Duke University Police Fleet Fuel Analysis

source	http://www.epa.gov/otaq/climate/documents/420f11041.pdf					http://www.epa.gov/climateleadership/documents/resources/mobilesource_guidance.pdf				eGRID SRVC F
Gasoline	per gallon	Cost/Gallon	GWP		COE		g/mile	NG Cost/GGE		lbs/kWh
kg CO2 Gasoline	8.887	$4.10	CO2	1	$0.112	N2O from gas	0.0197	$2.10	CO2	1.03587
kg CO2 Diesel	10.18		CH4	25		CH4 from gas	0.178		CH4	0.0000215
lbs --> kg	2.2046		N2O	298		N2O from diesel	0.0012		N2O	0.0000174
						CH4 from diesel	0.0006			

	Gasoline Fleet		
	Caprice 3.6L	Impala Limited	Tahoe 2WD PPV
Initial Cost	$32,475	$27,340	$43,600
Annual Miles	15807	15807	15807
MPGe	19.2	18.65	15.9
nual Gallons Consumed	823	848	994
Fuel Cost per Year	$3,375	$3,475	$4,076
partment Lifetime Cost	$42,601	$37,765	$55,828
ıual CO2 Emissions (kg)	7,316	7,532	8,835
nual CH4 Emissions (kg)	2.81	2.81	2.81
ıual N2O Emissions (kg)	0.31	0.31	0.31
Annual Total GWP	7,480	7,695	8,998

	Potential Alternatively Fuel Fleet Vehciles								
Vehicle Type	Hybrid							Electric	Compressed Natural Gas
Model Name	Chevy Volt	Ford Fusion Hybrid S	Ford Fusion Energi	Honda Civic	Honda Accord	Toyota Prius	Toyota Prius Plug-In	Nissan Leaf	Honda Civic CNG
Initial Cost	$34,185	$26,270	$34,700	$24,635	$29,155	$24,200	$29,900	$21,300	$26,640
Annual Miles	15807	15807	15807	15807	15807	15807	15807	15807	15807
Battery Miles	38	0	21	0	0	13	0	73	0
MPGe	98	47	100	45	47	50	95	125	29
l Gallons Consumed (GGE)	20	336	81	351	336	221	166	0	552
Fuel Cost per Year	$81.04	$1,378.90	$333.82	$1,440.19	$1,378.90	$907.08	$682.19	$0	$1,158.62
nnual kWh Consumed	4,818	0	2,190	0	0	0	1,278	3,504	0
ectricity Costs per Year	$540	$0	$245	$0	$0	$0	$143	$392	$0
otal Annual Fuel Costs	$621	$1,379	$579	$1,440	$1,379	$907	$825	$392	$1,159
partment Lifetime Cost	$36,537	$30,407	$36,437	$28,956	$33,292	$26,921	$32,376	$22,477	$30,116
ıual CO2 Emissions (kg)	2,439	2,989	1,753	3,122	2,989	1,966	2,079	1,646	0
nual CH4 Emissions (kg)	2.86	2.81	2.84	2.81	2.81	2.81	2.83	0.03	0
ıual N2O Emissions (kg)	0.35	0.31	0.33	0.31	0.31	0.31	0.32	0.03	0
Annual Total GWP	2,615	3,152	1,921	3,285	3,152	2,129	2,245	1,656	0

Figure 2. DUPD Excel Model

The model determined CO_2 values for each vehicle by summing all emissions from the various fuels consumed. For HEVs the fuel was entirely gasoline whereas for PHEVs the fuel consisted of gasoline and electricity. EVs consumed only electricity and CNG vehicles consumed standard compressed natural gas. For the gasoline consuming vehicles, the conversion factor of 8.887 kg CO_2 per gallon was used.[xxiii] For electricity usage, the 2009 SERC Virginia/Carolina eGRID subregion value of

1035.87 lbs CO_2/MWh was used. Finally, for CNG vehicles multiple conversion factors were needed to determine total CO_2 emissions. First, based upon the Gasoline Gallon Equivalent (GGE) value provided by the manufacturer a conversion of 114,000 BTUs/GGE was used.[xxiv] By combining the previous value with the conversion factor 117 lbs of CO_2 per MMBTU, from the EIA, a final value of CO_2 emissions is found.[xxv] Then for all values initially determined in pounds, electricity and CNG, a conversion factor of 2.2046 lbs/kg was used.

Equation 1. GGE to BTU Conversion

$$x\ GGE \times 114{,}000\ \frac{BTU}{GGE} = x\ BTU$$

Equation 2. BTU to MMBTU Conversion

$$x\ BTU\ \div 1{,}000{,}000\ BTU\ = x\ MMBTU$$

Equation 3. MMBTU to lbs CO_2 Conversion

$$x\ MMBTU \times 117\ lbs\ \frac{CO_2}{MMBTU} = x\ lbs\ CO_2$$

Equation 4. lbs CO_2 to kg CO_2 Conversion

$$x\ lbs\ CO_2\ \div 2.2046\ \frac{lbs}{kg} = x\ kg\ CO_2$$

To calculate the lifetime vehicle cost the base purchase price and three years of annual operating costs, consisting of fuel costs, were summed together.

Equation 5. Lifetime Cost

$$Lifetime\ Cost = Purchase\ Cost + Infrastructure\ Cost + \sum_{n=1}^{3} n(Annual\ Fuel\ Cost)$$

Sensitivity Analysis

With the data provided by DUPD, the Sustainability Office, and the vehicle manufacturer's websites sensitivity analyses were performed to compare the many vehicles and determine the various breakeven points where different alternatively powered vehicle models would be preferred over the current fleet. The variables that were manipulated are Price of Gasoline, Price of Natural Gas, Price of Electricity, Vehicle Lifetime, Size of Fleet, and Annual Miles. Not all of these variables were applicable to each vehicle, e.g. the cost and CO_2 emissions of an HEV were unaffected by a change in the price of natural gas, so they were removed where appropriate.

Results

This study has been focused on determining how different alternatively powered vehicles compare to DUPD's current fleet vehicles. It sought to examine CO_2 emissions, costs, and various breakeven and comparison points between the many vehicle models. These values do not include the cost to retrofit a vehicle into a true patrol car, meaning exterior decals and lights or patrol specific equipment inside the car, or maintenance costs. Based upon an initial assessment these costs would likely be equal to or less than the current fleet, but due to many unknowns were removed from the analysis.

CO_2 and Cost Model

Below are the graphs displaying the comparison of lifetime CO_2 emissions and costs. Again, lifetime values incorporate three years of operation by 13 vehicles and are compared to the current fleet breakdown of 13 vehicles for three years. The black line crossing each figure below represent the value associated with the current fleet for each attribute examined.

Fuel Costs

Figures 3 and 4 and Table 6 show how each vehicle compares to the current fleet in terms of cost associated with fuel consumption, albeit gasoline, electricity or natural gas. The black line on Figure 3 is the lifetime fuel cost estimate for the current fleet, which was $132,060.

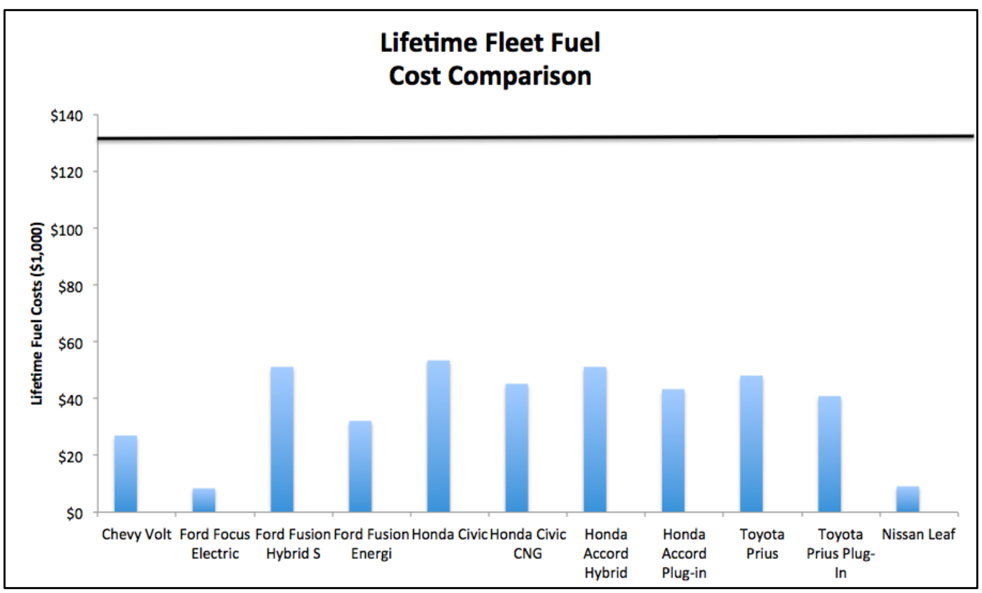

Figure 3. Lifetime Fleet Fuel Cost Comparison

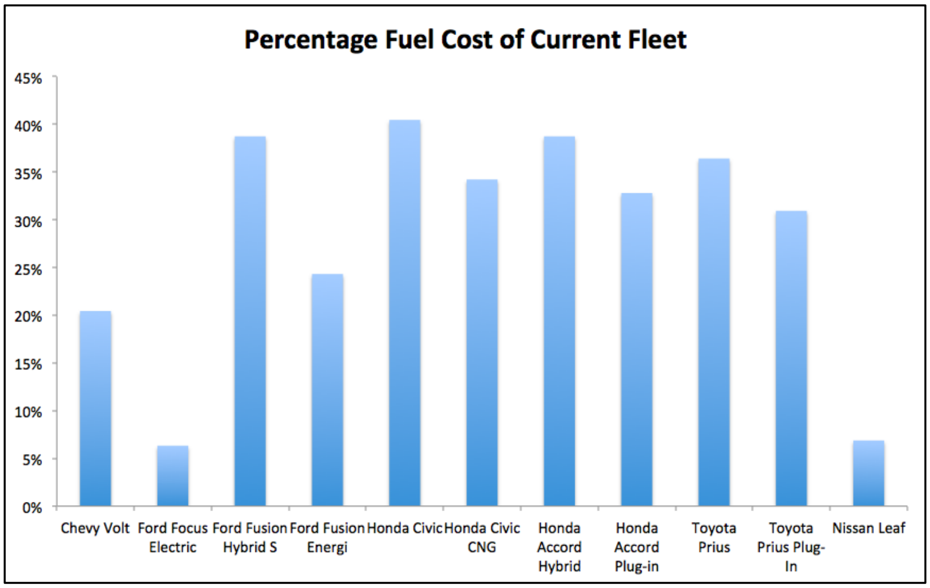

Figure 4. Fuel Cost as Percentage of Current Fleet

Table 5. Lifetime Fleet Fuel Cost and Percentage of Current Fleet Cost

Chevy	Ford			Honda				Toyota		Nissan
Volt	Focus Electric	Fusion Hybrid S	Fusion Energi	Civic	Civic CNG	Accord Hybrid	Accord Plug-in	Prius	Prius Plug-In	Leaf
$26,990	$8,358	$51,154	$32,111	$53,427	$45,186	$51,154	$43,311	$48,085	$40,848	$9,080
20.4%	6.3%	38.7%	24.3%	40.5%	34.2%	38.7%	32.8%	36.4%	30.9%	6.9%

Fleet Costs

The figures and table below show how each potential vehicle compares with the current fleet in terms of the total lifetime cost, meaning purchase price and three years of fuel costs. The black line in Figure 5 represents the lifetime fleet cost of the current fleet, which is $525,135.

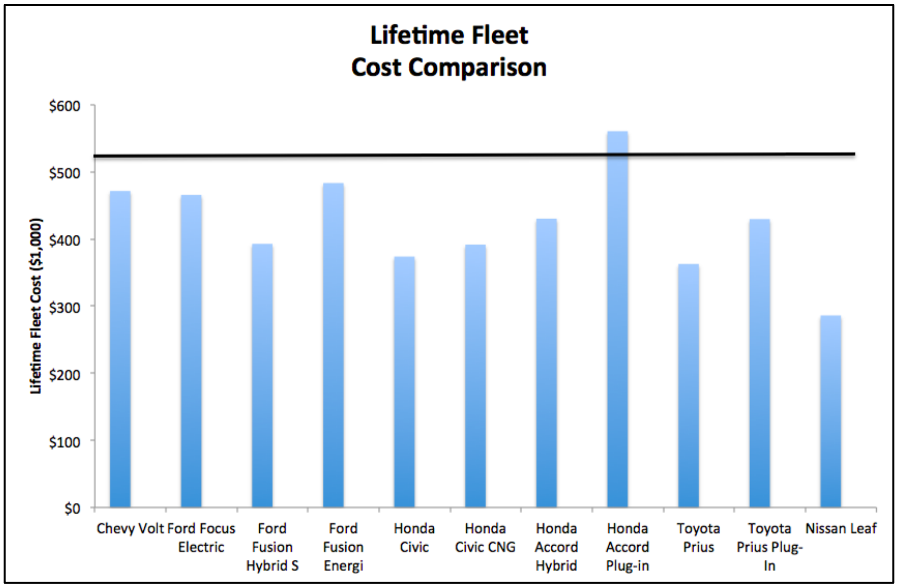

Figure 5. Lifetime Fleet Cost Comparison

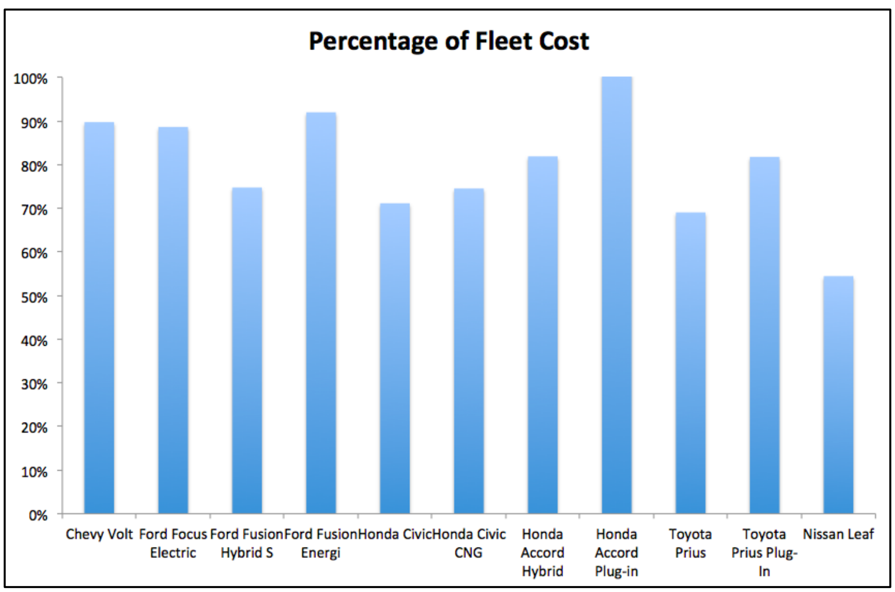

Figure 6. Lifetime Fleet Cost as Percentage of Current Fleet

Table 6. Lifetime Fleet Cost and Percentage

Chevy	Ford			Honda				Toyota		Nissan
Volt	Focus Electric	Fusion Hybrid S	Fusion Energi	Civic	Civic CNG	Accord Hybrid	Accord Plug-in	Prius	Prius Plug-In	Leaf
$471,395	$465,568	$392,664	$483,211	$373,682	$391,506	$430,169	$560,451	$362,685	$429,548	$285,98
89.8%	88.7%	74.8%	92.0%	71.2%	74.6%	81.9%	106.7%	69.1%	81.8%	54.5%

CO_2 Emissions

The figures and table below detail each vehicle's lifetime fleet CO_2 emissions, in kgs, given the current average distance traveled per year, 15,807 miles. The black line on Figure 8 represents the estimated CO_2 emissions released by the current fleet over its lifetime and is just over 300 kg. These emissions do not take in to account the full life cycle of the vehicle so the CO_2 emissions related to the production, processing, or end-of-life were excluded from the analysis. Only emissions directly tied to the operation of the vehicle by a Duke officer or employee were accounted.

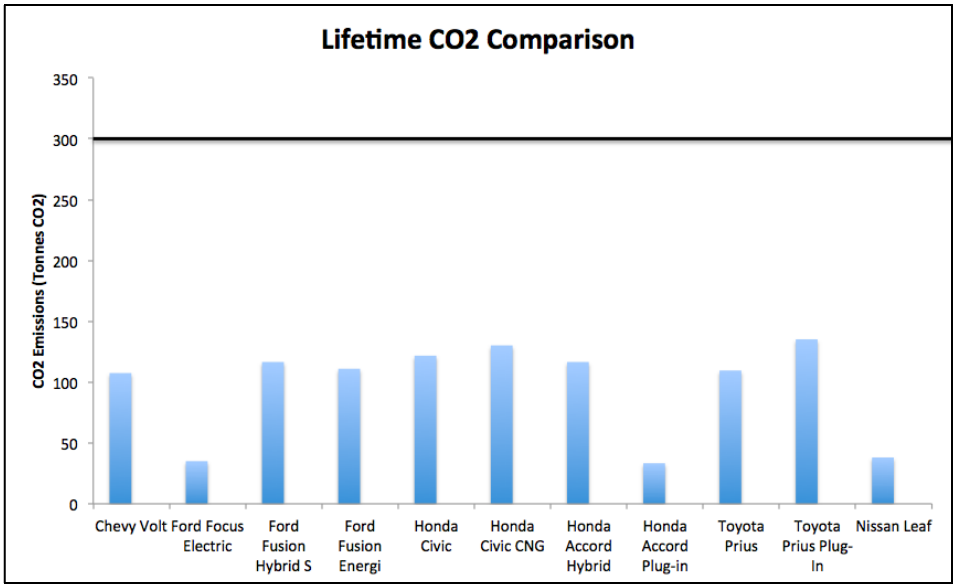

Figure 7. Lifetime CO_2 Emission Comparison

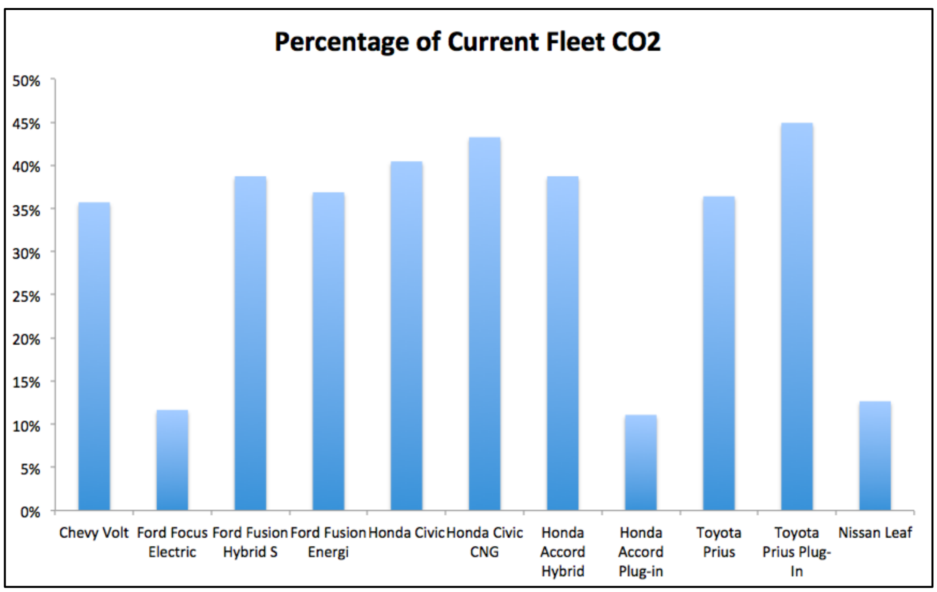

Figure 8. CO_2 Emissions as Percentage of Current Fleet

Table 7. Lifetime CO_2 Emissions and Percentage

Chevy	Ford			Honda				Toyota		Nissan
Volt	Focus Electric	Fusion Hybrid S	Fusion Energi	Civic	Civic CNG	Accord Hybrid	Accord Plug-in	Prius	Prius Plug-In	Leaf
107,469	35,064	116,565	110,979	121,746	130,181	116,565	33,339	109,571	135,185	38,092
35.7%	11.7%	38.7%	36.9%	40.5%	43.3%	38.7%	11.1%	36.4%	44.9%	12.7%

Sensitivity Analysis

Below are the sensitivity analyses performed with the purpose of identifying the breakeven values between the two fleets for important performance indicators. Each of these values are determined by manipulating one of many variables up to the point where the lifetime costs associated with the new fleet are equivalent to the current fleet.

Gasoline Analysis

This breakeven point examines the lifetime fleet gasoline costs. These values display the cost gasoline would need to be in order for the respective vehicle's lifetime fleet (13 vehicles used for three years) costs to be equal to the current fleet's (10 Impalas, two Tahoes, and one Caprice, for three years) cost. These values are based upon a $3.90/gallon cost, used by the university for fleet fuel costs, and the MSRP for each vehicle. The line on the graph below represents that $3.90/gallon current price of gasoline, for perspective.

Table 8. Gasoline Breakeven Prices

Vehicle Model	Chevy Volt	Ford Fusion Hybrid S	Ford Fusion Energi	Honda Civic Hybrid	Honda Accord Hybrid	Honda Accord Plug-In	Toyota Prius	Toyota Prius Plug-In
Cost of Gasoline per Gallon	$73.62	$14.00	$17.10	$14.96	$11.14	-$5.51	$17.08	$25.21

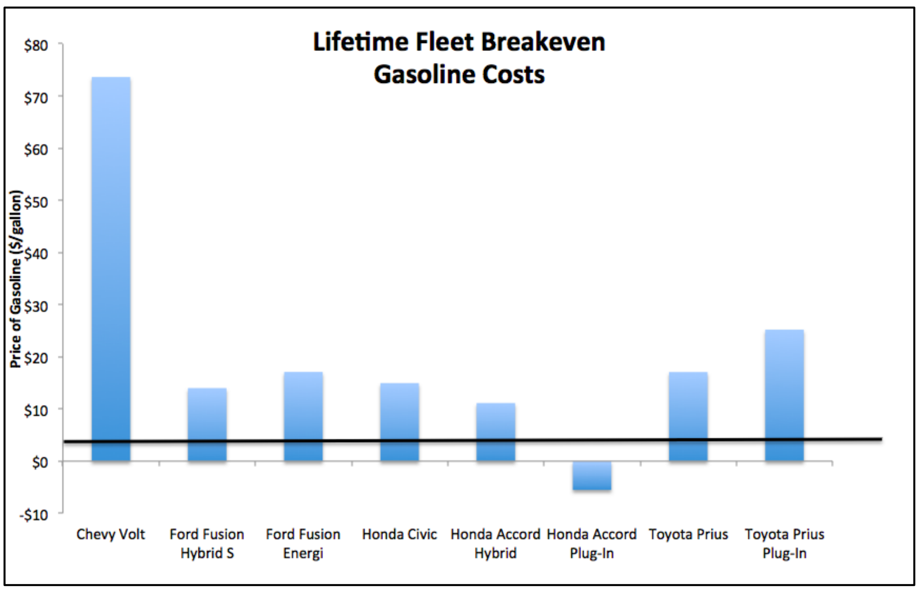

Figure 9. Gasoline Price Equivalents

Electricity Analysis

This breakeven point examines the lifetime fleet electricity costs. These values display the cost electricity would need to be in order for the respective vehicle's lifetime fleet (13 vehicles used for three years) costs to be equal to the current fleet's (10 Impalas, two Tahoes, and one Caprice, for three years) cost. These values are based upon a $0.112/kWh cost, used by the university for operational costs, and the MSRP for each vehicle. The line on the graph below represents that $0.112/kWh current price of electricity, for perspective.

Table 9. Electricity Breakeven Prices

Vehicle Model	Chevy Volt	Ford Focus Electric	Ford Fusion Energi	Honda Accord Plug-In	Toyota Prius Plug-in	Nissan Leaf
Price of Electricity	$0.363	$0.910	$0.350	-$0.026	$0.605	$3.062

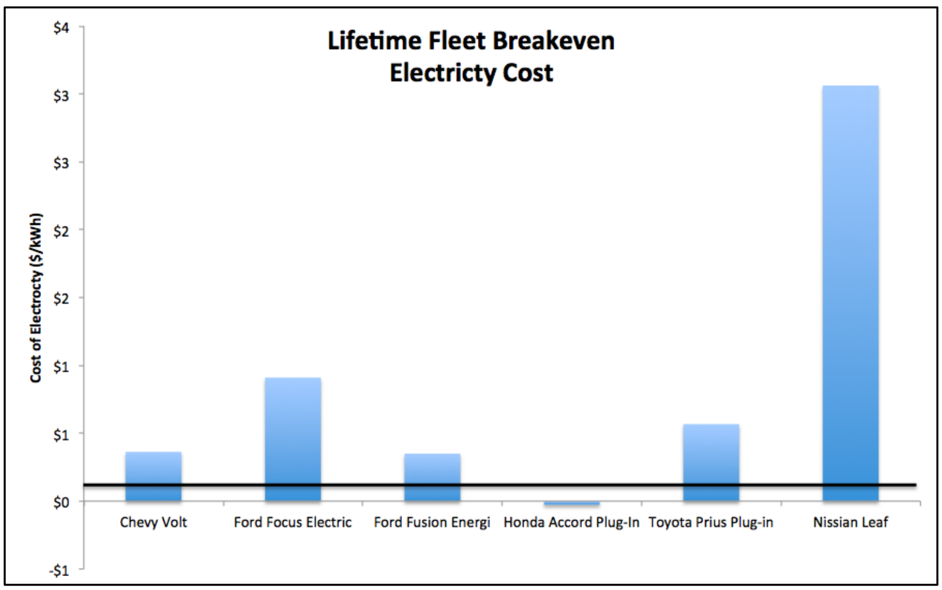

Figure 10. Electricity Price Equivalents.

Natural Gas Analysis

This breakeven point examines the lifetime fleet compressed natural gas costs. These values display the cost compressed natural gas would need to be in order for the respective vehicle's lifetime fleet (13 vehicles used for three years) costs to be equal to the current fleet's (10 Impalas, two Tahoes, and one Caprice, for three years) cost. These values are based upon a $2.10/GGE price, used by the university for fleet fueling, and the MSRP of the vehicle. The line on the graph below represents that $2.10/GGE current price of compressed natural gas, for perspective.

Table 10. CNG Breakeven Price

Vehicle Model	Honda Civic CNG
Price of CNG	$8.31

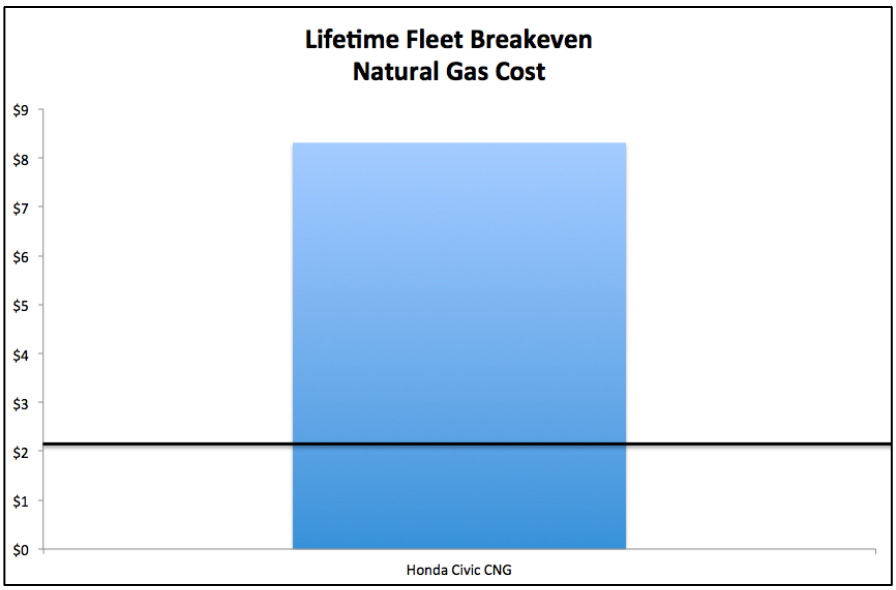

Figure 11. Natural Gas Equivalents.

Lifetime Analysis

This breakeven point is seeking to discover how many years each vehicle could, theoretically, operate until it has the same three-year lifetime cost of the current fleet. The line on the graph below is set at the three-year mark, which is the current fleet's policy limited lifetime.

Table 11. Lifetime Breakeven Points

Vehicle	Chevy	Ford			Honda				Toyota		Nissan
Model	Volt	Focus Electric	Fusion Hybrid S	Fusion Energi	Civic Hybrid	Accord Hybrid	Accord Plug-In	Civic CNG	Prius	Prius Plug-In	Leaf
Lifetime (years)	14.7	47.4	7.7	12.3	7.4	7.7	9.1	8.8	8.2	10	43.6

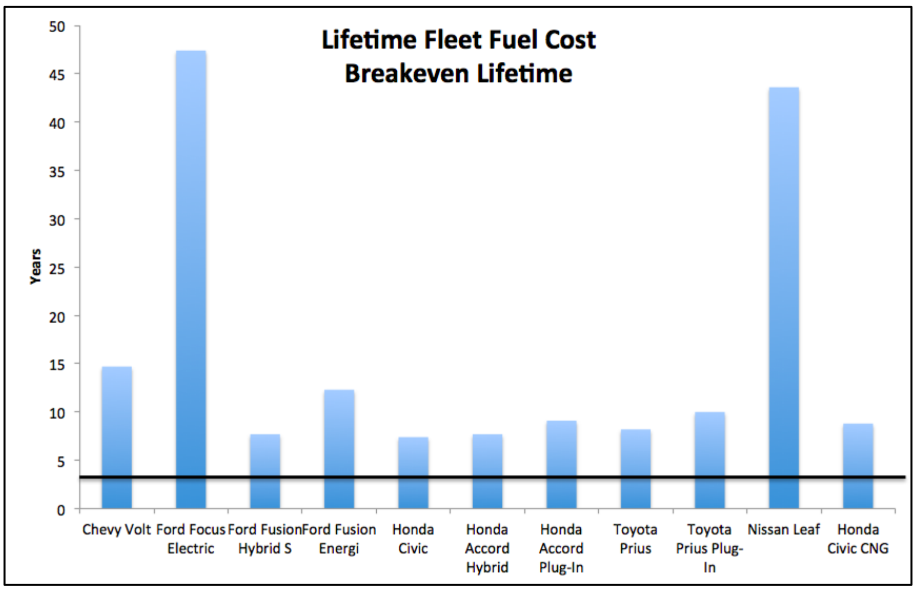

Figure 12. Lifetime Equivalents

Fleet Size Analysis

This analysis determined how many vehicles could be purchased and operated for three years given the current fleet's lifetime costs. These costs include purchase price and fuel costs. The line on the graph below represents the current fleet size of 13 vehicles.

Table 12. Fleet Size Breakeven Points

Vehicle Model	Chevy	Ford			Honda				Toyota		Nissan
	Volt	Focus Electric	Fusion Hybrid S	Fusion Energi	Civic Hybrid	Accord Hybrid	Accord Plug-In	Civic CNG	Prius	Prius Plug-In	Leaf
Fleet Size	14.5	14.7	17.4	14.1	18.3	15.9	12.2	17.4	18.8	15.9	23.9

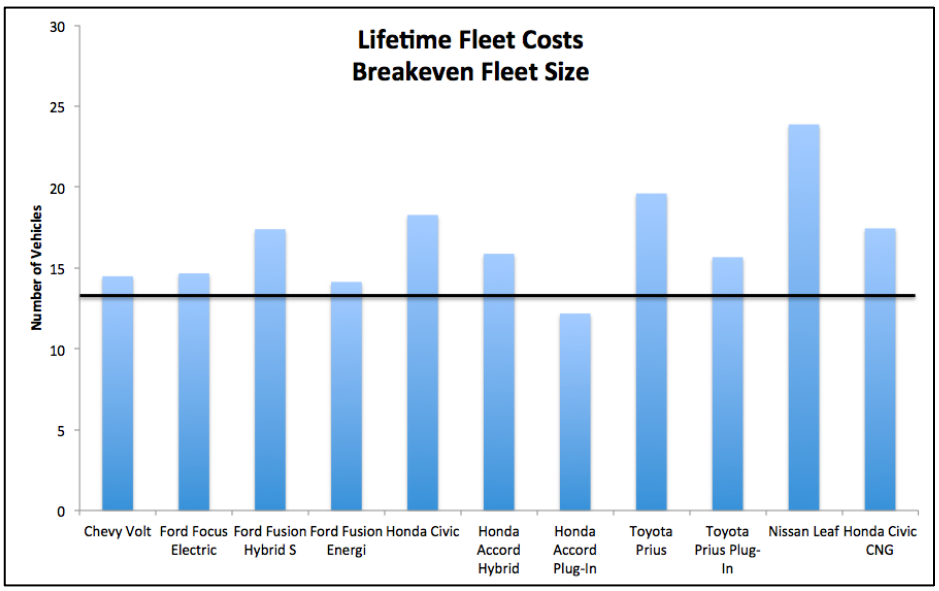

Figure 13. Fleet Size Equivalents.

Annual Miles Analysis

This analysis determined the number of miles each vehicle could travel annually given the budget of the current fleet's annual fuel expenses. The DUPD fleet vehicles each travel approximately 15,807 per year, as displayed on the graph below.

Table 13. Annual Mileage Breakeven Points

Vehicle	Chevy	Ford			Honda				Toyota		Nissar
Model	Volt	Focus Electric	Fusion Hybrid S	Fusion Energi	Civic Hybrid	Accord Hybrid	Accord Plug-In	Civic CNG	Prius	Prius Plug-In	Leaf
Annual Miles	50,039	249,755	40,808	51,903	39,071	40,808	44,098	46,197	43,412	46,694	229,90

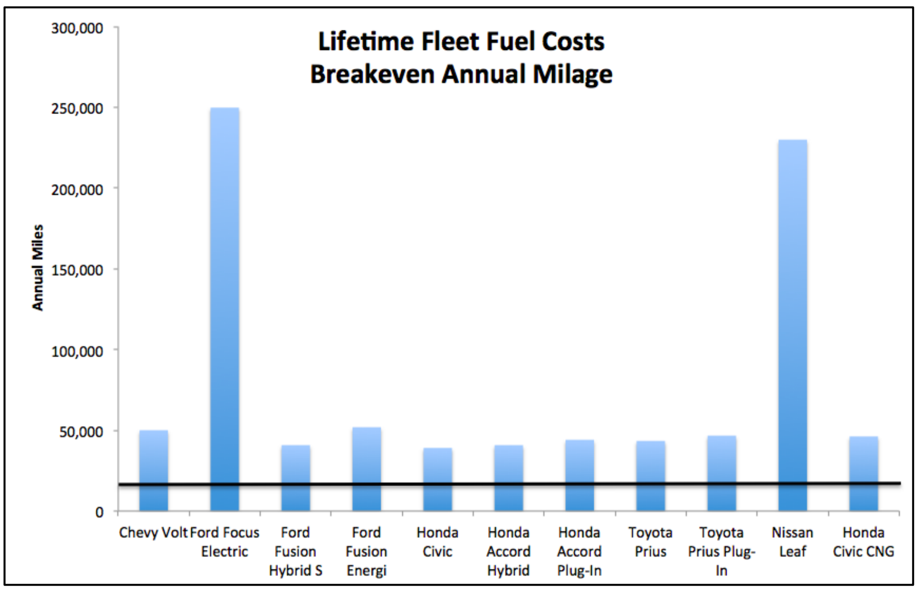

Figure 14. Annual Mileage Equivalents

Discussion

Large financial and environmental savings are possible across the full range of vehicles analyzed. Any where from $40,000 to $240,000 in savings is possible over the three-year lifetime of a new 13-vehicle fleet. CO_2 savings ranging from 165-265 tonnes are possible under that same scenario. These results indicate that alternatively powered fleet vehicles have a place within Duke University's solution to achieving climate neutrality by 2024. To date, no school has a police fleet that is entirely comprised of alternatively powered vehicles. Schools like New Jersey City University and Northern Illinois University have a handful of Toyota Prius's in the police fleets but they only make up a small portion of all the patrol vehicles.[xxvi, xxvii] Additionally, many municipalities and cities have adopted alternatively powered vehicles; Dade City, Santa Monica, New York City, and Shenzhen, China, giving credence to their effectiveness in the real world.[xxviii, xxix, xxx, xxxi] This lack of an academic leader is an opportunity that Duke University could and should take advantage of in order to further stake its claim as an innovative and environmentally conscious institution.

The quantity of driving data and real world fuel consumption associated with officer operation led to many assumptions throughout this analysis. Each has the potential to change the results slightly. However, the assumptions were analyzed in detail in the breakeven and sensitivity sections so the conclusions remain robust, the precise magnitude of savings is all that remains uncertain. Furthermore, since all MPG estimates used in the analysis were gathered from EPA testing their relative rankings should be robust as well, i.e. if there is a flaw they are all flawed equally. Nevertheless, the fact that a potential benefit to the department and university was seen in every test for almost every vehicle signifies that the DUPD should adjust its procurement methods or commission its own study to verify these assumptions before money is committed to new vehicles. In the future, I suggest that the department purchase alternatively powered vehicles as a replacement for its current fleet vehicles as they reach the end of their three-year lifetimes. Little new infrastructure would need to be installed in order for any of the proposed vehicles to put in to service and vendors able to modify the cars for police use already exists. Therefore, by purchasing alternatively powered vehicles at the same point in time when a new traditional police vehicle would be purchased, excess strain will not be placed on the department's budget. Additionally, I recommend that the department purchase or test multiple styles of alternatively powered vehicles in order to determine which functions best on campus. For example, by purchasing a hybrid, an EV, and a PHEV, DUPD will have the opportunity to get a feel for the different technologies before going forward and fully converting the fleet to a specific alternatively powered vehicle.

Conclusion

These results indicate that the DUPD should purchase alternatively powered vehicles in the future. Vehicle selection depends on the relative importance of each vehicle attribute: lifetime costs, annual fuel costs, or lifetime CO_2 emissions. In the case of lifetime vehicle cost the DUPD should pursue the Toyota Prius Plug-in. If priority is placed on annual fuel costs the Ford Focus Electric or the Nissan Leaf should be considered. If lifetime CO_2 emissions are favored DUPD should, again, select the Ford Focus Electric or Nissan Leaf. A fleet of these three vehicles, averaged with the others analyzed, has the potential to save the department between $90,000 and $100,000 and 200 tonnes of CO_2 over a three-year lifetime.

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Captain Rekayi Isley of the Duke University Police Department provided information pertaining to real world demands and needs of a campus officer. Carol Campbell provided vehicle mileage data for FY 2012. Tavey Capps of the Duke University Sustainability Office provided all fuel consumption and mileage data for FY 2005-2011. Dr. Tim Johnson assisted in project development, implementation, and interpretation of results.

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