Electric Fleet: An examination of the environmental benefits and economic feasibility of Villanova University Department of Public Safety fleet electrification

GEV 1051: Environmental Science II

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April 28, 2013

Abstract

Anthropogenic greenhouse gas emissions that contribute to global climate change, particularly carbon dioxide (CO_2), have been increasing dramatically in recent decades. A major contributor to CO_2 emissions in the United States is the transportation sector, particularly gasoline-powered light-duty vehicles. The purpose of this study was to examine the possibility of converting the Villanova University Department of Public Safety vehicle fleet to electric vehicles, thereby reducing the University's CO_2 emissions. Data was obtained through research and from the Department of Public Safety in order to calculate the potential environmental benefits of fleet electrification, as well as examine the economic feasibility of such a transition. We found that a conversion to an all-electric fleet would slash the fleet's CO_2 emissions by 58%; the additional investment of 7.5 kW of solar power, sufficient to power half of the vehicles in the fleet, would cut emissions by 78%. An in-depth economic analysis revealed that, with one vehicle replaced annually, either low-carbon scenario would pay for itself and provide cost benefits in the form of either $15,472 or $30,985 in fuel savings within a decade. Simply converting the conventional fleet to electric vehicles would have an economic payback period of 6 years, while adding solar power would extend the payback period to 8 years but would provide even greater environmental benefit. The results of this study show that fleet electrification would be an essential step toward the University's long-term plan to become carbon neutral by 2050, and not only would be economically viable but would in fact provide long-term economic benefit; such a transformation would also provide a great deal of positive publicity and contribute significantly to the University's environmentally responsible reputation. This study also provides strong evidence against the "long tailpipe" criticism of electric vehicles and indicates that the United States would benefit greatly, both environmentally and economically, from a large-scale transition to electrified personal transportation.

Introduction

As greenhouse gas (GHG) emissions continue to rise, the world continues to search for alternative fuel sources as a way to combat global climate change associated with anthropogenic GHG emissions. One of the largest contributors to these emissions is carbon dioxide. In the United States, a major contributor to the release of CO_2 is the transportation sector, which accounts for 29% of total GHG emissions nationwide. 95% of these transportation emissions are CO_2, mainly due to the combustion of gasoline and diesel fuel (U.S. DOT 2010, p 35). The Environmental Protection Agency provides a similar projection, claiming that the transportation sector is responsible for 31% of CO_2 emissions and 26% of total GHG emissions in the United States (EPA Climate Change 2012). The amount of CO_2 released by the U.S. transportation sector is significant even on a global scale, comprising 7% of all CO_2 emissions from all sources across the world (U.S. DOT 2010, p 37).

These transportation emissions make up such a significant portion of the total for two main reasons: Americans drive a lot, and burning gasoline releases a lot of carbon dioxide. On-road vehicles account for 79% of transportation greenhouse gas emissions, and light-duty vehicles account for 59% (U.S. DOT 2010, p 19). These light-duty vehicles include passenger cars and light trucks that comprise the majority of the U.S. vehicle fleet. Such light-duty vehicles travel nearly an astounding 3 trillion miles per year, and almost all run on gasoline (U.S. DOT 2010, p 40). This is significant because burning a single gallon of gasoline produces 19.4 lbs of CO_2 (Engber 2006). These two factors combine to result in massive quantities of atmospheric CO_2 created by light-duty vehicle travel, meaning that low-carbon transportation solutions are imperative to mitigating climate change.

One alternative to the traditional internal combustion engine (ICE) vehicle that is here now and is already a mature technology ready for large-scale deployment is the electric vehicle, or EV. Electric vehicles run entirely on electricity supplied by the energy grid; therefore, their CO_2 emissions depend on the source of electricity. In most cases it will be a combination of coal, natural gas, nuclear, and renewables that supply the electricity to power the car, and the CO_2 released is a function of the ratio of these sources. As natural gas and renewable energy sources replace coal in the electricity grid, electric vehicle transportation becomes cleaner as a result of lowered CO_2 emissions from electricity generation (Liu et al., 2012). Implementing solar power directly at the charging point, as in a solar-powered charging station, creates an entirely emission-free mode of transportation at zero fueling cost assuming adequate solar insolation. No matter the source, however, electric vehicles are far more efficient than traditional internal combustion engine vehicles. The equivalent fuel economy (a number based on the energy content of a gallon of gasoline vs. a kilowatt-hour of electricity) of a typical EV is around 99 miles per gallon equivalent, or MPGe (EPA Electric Vehicle Label 2012). A 2009 Ford Escape, on the other hand, achieves an EPA-estimated 22 MPG overall according to www.fueleconomy.gov. This is because electric vehicles by nature are far more efficient than their conventional counterparts: whereas the internal combustion engine loses large amounts of energy as heat and thus achieves a maximum of 30% efficiency, the electric motor achieves efficiencies as high as 90% due to its simplicity and lack of moving parts (U.S. DOE 2013). This increased efficiency, combined with the relatively low cost of electricity and the high cost of gasoline, means that an electric vehicle owner could save as much as $9,600 in fuel costs over 5 years compared to a comparable internal combustion engine vehicle (EPA Electric Vehicle Label 2012). It is clear, then, that electric vehicles have two distinct advantages over their conventional counterparts: reduced emissions and reduced fuel costs. Both advantages are great incentive for individual car owners as well as vehicle fleet owners to consider making the switch to electrics.

Villanova University is one such party that could benefit from fleet electrification. The University emits a significant amount of CO_2 through transportation; in addition to personal cars brought to campus by students and the on-campus shuttle, an important contributing factor to campus transportation emissions is the Department of Public Safety vehicle fleet. Villanova University currently has a fleet of four Ford Escapes and one Ford Taurus, which are contracted to the university by the Ford Motor Company. The five vehicles are recorded to drive a total of approximately 86,000 miles per year (Hall, personal communication). This, as a rough estimate, equates to well over 70,000 lbs of CO_2 emitted on an annual basis. In this experiment, we analyze the possibility of converting the current fleet of internal combustion engine vehicles to electric vehicles. This transition would help reduce the amount of CO_2 produced by Villanova University annually, and additionally would allow the University to save significantly on fuel costs. We hypothesize that a complete conversion to an all-electric fleet plus the additional investment of solar energy to power half the fleet will cut the Department of Public Safety's CO_2 emissions by 75% and will have long-term economic benefits, with the electric vehicles and solar panels paying back their higher capital cost within 8 years through dramatically lowered fuel costs; without solar power, the fleet's emissions will still be reduced by over 50% and the economic payback period could be as early as 4 years.

Methods

We conducted an interview with Clifford Hall, the Event Manager for Villanova University Public Safety, via email regarding the current Public Safety fleet (see Table 1 below). Mr. Hall indicated that, due to the University's contract with Ford Motor Company, the Department of Public Safety uses four Ford Escapes in their current fleet as well as a recently purchased Ford Taurus. Our group elected to consider electric vehicles as a possible replacement for the existing fleet of internal combustion vehicles.

In analyzing the existing fleet, we calculated the real-world fuel efficiency from the data provided to us by Mr. Hall and researched the efficiency of an internal combustion engine, CO_2 emissions per gallon of gasoline burned, purchase cost of a new vehicle, and the rising cost of gasoline. For the proposed electric vehicle fleet, we researched various models currently on the market and selected the Ford Focus EV for our study. The Focus EV is relatively inexpensive for an electric, achieves adequate range, and would allow the University to maintain its contract with Ford. We then determined the generator, distributor, and cost of Villanova University's electricity through personal correspondence with Robert Morro, the Associate Vice President for Facilities Management at Villanova. Our group also researched the efficiency of electric motors, miles per gallon equivalent of EVs, CO_2 emissions of coal and natural gas power plants, initial cost for implementation of standard Level II charging stations and potential installation cost of solar charging stations, and increasing costs of electricity. This research combined with the information acquired from the interview with Public Safety allowed us to conduct environmental impact and cost-benefit analyses of fleet electrification.

Table 1: Questions from Department of Public Safety interview with Clifford Hall, Event Manager for Villanova University Public Safety

1)	How many vehicles (Ford Escapes) are in the fleet, and what model year are they?
2)	How many vehicles are necessary to fulfill your duties?
3)	When was the fleet last upgraded and how long do you typically keep a vehicle for?
4)	How many total miles does the fleet travel in a year?
5)	How many total gallons of gas does the fleet consume in a year?
6)	What disadvantages to electric cars make them less ideally suited for the needs of Public Safety?
7)	Who determines the budget and spending for Public Safety?

Results

In our calculations, several assumptions were made that were critical to the outcome of the experiment. Our results are replicable as long as the same constants and assumptions are applied. First, we found that each gallon of gasoline burned produces 19.4 lbs of CO_2, a value that does not change with standard gasoline; however, increased ethanol concentration in gasoline would impact this number (Engber 2006). We were also informed that the electricity serving campus comes from PPL Generation and that the University purchases distribution through PECO at a rate of $0.08/kWh (Morro, personal communication). Research of PPL's energy portfolio revealed that the electricity provided to their Pennsylvania costumers is a product of 39% coal, 33% natural gas, 21% nuclear, and 7% hydroelectric and renewable sources (PPL Generation 2013). To determine the CO_2 emissions per kWh of Villanova's electricity, we used given values for the CO_2 content of coal and natural gas. The EPA provided values of 2.25 lbs CO_2/kWh coal and 1.14 lbs CO_2/kWh natural gas (EPA Air Emissions 2012). As noted by Reichmuth et al. (2013), these values will vary depending on the type of coal used, the efficiency of the power plant in question, and many other factors; however, we elected to use the EPA data as our standard because, though an imperfect government agency, it ought to be trusted to provide accurate statistics to the public. The ICE fuel economy of 22.6 MPG found in Table 2 below comes from the data provided to us by Public Safety, and thus is a real-world value reflecting actual fleet driving conditions. Similarly, the vehicle miles traveled was given by Public Safety to be 86,000 total fleet miles per year. The efficiency data for the EV in miles/kWh was taken from the Ford Focus EV webpage, using the stated vehicle range of 76 miles per charge and battery capacity of 23 kWh (Ford Focus Electric 2013).

Important assumptions were also made in the economic analysis. Gasoline was assumed to have a constant price of $4/gallon, while electricity was assumed to remain steady at $0.08/kWh. The gasoline value is higher than the current cost per gallon to account for future price increases over the next decade, while the electricity value is below the national average and so is unique to Villanova's scenario. The base price of a 2013 Ford Taurus, $26,600, was used for the new ICE vehicle purchase price. The listed price of a 2013 Ford Focus EV after a $7,500 tax credit, a total cost of $31,700, was used to represent the new EV purchase price. For a charging station, we determined a single dual-port charger would serve the Department of Public Safety's needs. After researching various options, using the Lowe's online store we chose the GE Durastation Level II dual-port charger with a purchase price of $4,200. Finally, significant assumptions had to be made to properly consider solar power. Through email with Frederick Greenhalgh, a representative for a New England–based company called ReVision Energy specializing in installed solar power, we determined that it requires approximately 2.2 kW of solar photovoltaic panels at ~$3.5/W to power one vehicle for a year. This assumes 1,270 kWh of production per kW per year, or about 3.5 hours of solar exposure per day (Greenhalgh, personal communication). We conservatively adjusted this figure upward to 2.5 kW per vehicle, and using the cost of $3,500/kW calculated an installed cost of $26,250 for sufficient solar panels to power three vehicles. These results may vary by region and solar panel supplier, but they were sufficient for our needs. The final results of our analyses may be found below.

Table 2: Efficiency and annual CO_2 emissions data for Villanova University Department of Public Safety – existing ICE and proposed EV fleets

Miles driven per year: 86,000	
ICE	**EV**
Drivetrain efficiency	Drivetrain efficiency
~30%	~90%
Fuel Economy (mpg)	Miles/kWh*
22.6	3.304
CO_2/gallon gas (lbs)	CO_2/kWh (lbs)**
19.4	1.254
CO_2/mile (lbs)	**CO_2/mile (lbs)**
0.858	0.379
CO_2/year (lbs)	CO_2/year (lbs)
73823	**32629**
* Assuming Ford Focus EV: 76 miles/charge and 23 kWh battery pack	
** Assuming 2.25 lb CO_2/kWh coal, 1.14 lb CO_2/kWh natural gas; electricity at 33% nat. gas and 39% coal	

Table 2 provides a comparison of vehicle efficiency and CO_2 emissions data for a conventional gasoline fleet and an electric fleet. EVs are far more efficient than their ICE counterparts, achieving 3X the drivetrain efficiency; though not shown in the table, according to Ford the Focus EV has an EPA-estimated equivalent fuel economy of 105 MPGe compared to an experimentally obtained 22.6 MPG for the Ford Escapes used by the Department of Public Safety. The MPGe value is a basis for comparing electrics to non-electrics and takes into account the energy content of a gallon of gasoline vs. a kilowatt-hour of electricity. This efficiency, combined with the use of electricity rather than gasoline as a power source, results in an annual reduction in CO_2 emissions from 73,823 lbs to 32,629 lbs. The data presented in this table was obtained using the equations shown in Appendix 1. CO_2 emissions are also represented in Figure 1 shown below.

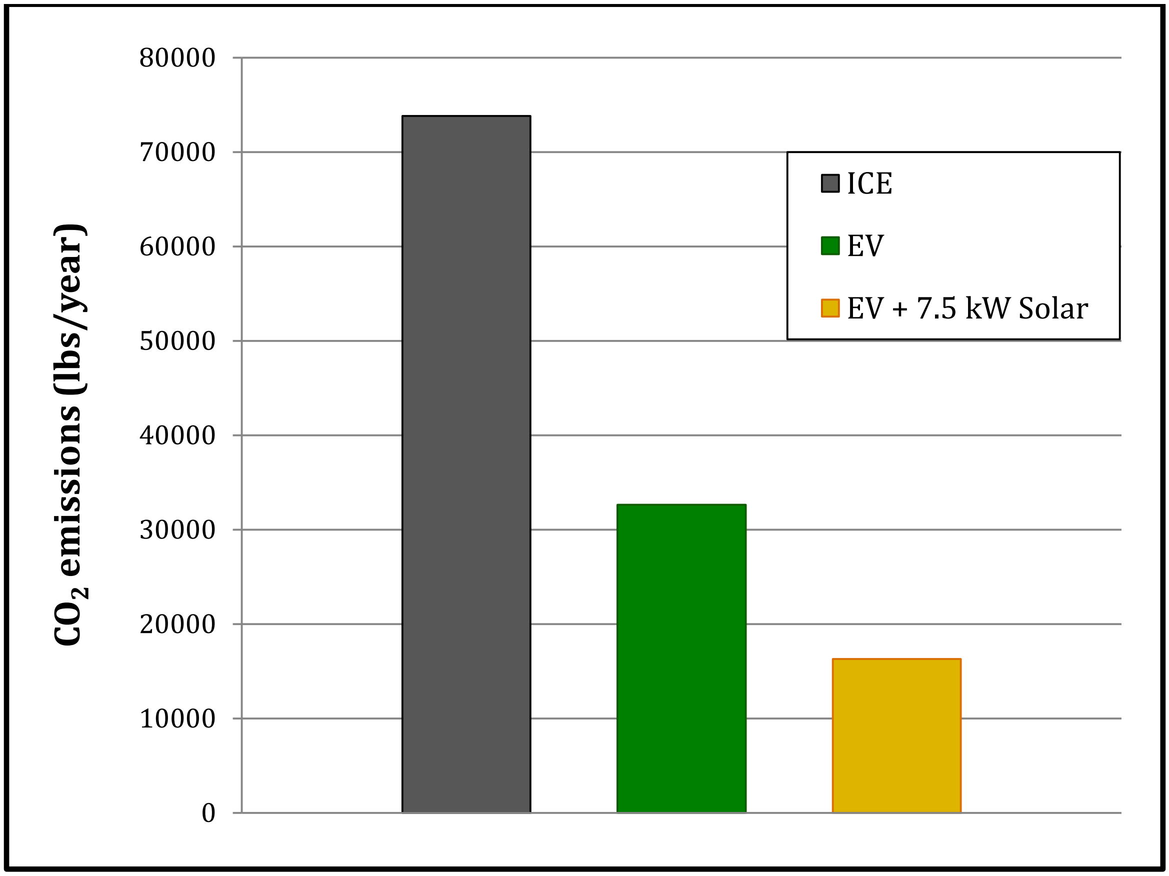

Figure 1: Annual CO_2 emissions of Villanova University Department of Public Safety fleet with ICE, EV, and EV plus solar configurations

Figure 1 shows a graphical representation of the CO_2 emissions data presented in Table 1, with the addition of the effect of solar power. An all-electric fleet represents a 55.8% decrease in annual CO_2 emissions, a reduction of 41,193 lbs CO_2 per year. If half of the electricity required to power the electric fleet was provided by solar photovoltaics, approximated by 7.5 kW of installed panels, then CO_2 emissions fall an additional 16,315 lbs for a 77.9% reduction from continued use of a conventional fleet.

Table 3: Economic analysis, including capital investment and fuel costs, of existing ICE and proposed EV fleets with additional consideration of solar power

Miles driven per year: 86,000		
ICE	**EV**	**Solar**
Cost of fuel ($/gal)	Cost of electricity ($/kWh)	Capacity (kW)*
4	0.08	7.5
Fuel Economy (MPG)	Miles per kWh	Installation cost ($/kW)
22.6	3.304	3500
Cost per mile ($/mi)	Cost per mile ($/mi)	Installed cost ($)
0.177	0.024	26250
Annual Fuel Cost ($)	Annual Fuel Cost ($)	Annual Fuel Cost ($)
15221	**2082**	**1041**
Cost/new vehicle ($)	Cost/new vehicle ($)	*Assuming 2.5 kW/car, 1 kW panels = 1,270 kWh yearly production (3.5 hours/day)
26600	31700	
	Charger cost ($)	
	4200	

Table 3 provides an economic breakdown of gasoline and electric fleets, considering fuel costs and initial capital investment. Assuming a constant price of $0.08/kWh for electricity and $4/gallon for gasoline, the efficiency of the EV leads to significantly lower fuel costs – only $2,082 annually to power an electric fleet compared to $15,221 annually to power a conventional gasoline fleet. Also shown are the new vehicle costs of a Ford Taurus (the most recent vehicle purchased by the Department of Public Safety) and a Ford Focus EV as well as the cost for a dual-port charging station capable of charging two vehicles at once. Additionally, the economic data for implementation of solar power is presented; to install enough solar capacity to power three of the six EVs in the fleet would be an additional up-front investment of $26,250 but would cut annual fuel costs by 50% to $1,041 per year.

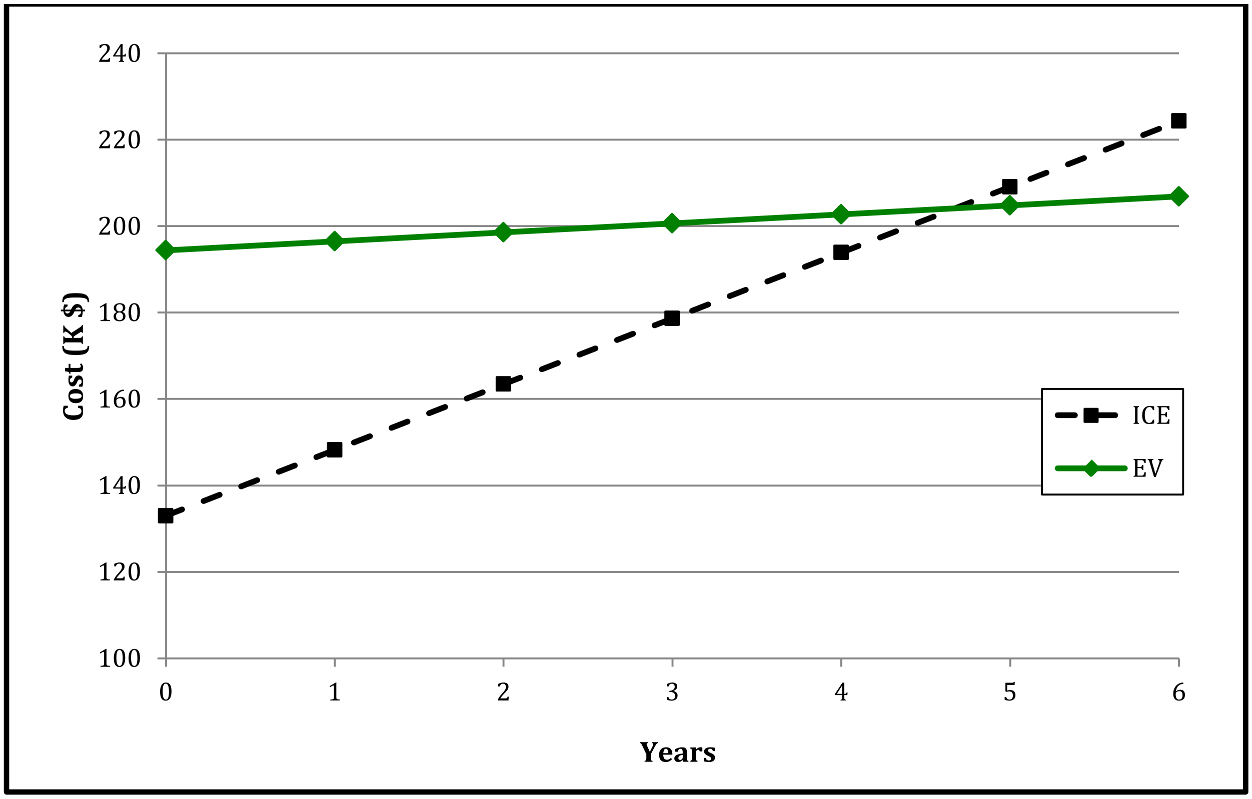

Figure 2: Total cost (vehicle purchase plus annual fuel cost) of existing ICE and proposed EV fleets with immediate total fleet replacement

Figure 2 uses the data presented in Table 3 to show that if the entire 5-vehicle internal combustion engine fleet was to be replaced at once with a 6-vehicle electric fleet the investment would pay for itself in 4.7 years. An all-electric fleet of the Ford Focus EV would have a higher initial cost of implementation than a Ford Taurus ICE fleet replacement, approximately $190,200 to $133,000. However, the electric fleet is less expensive in the long term. This is due to the dramatically decreased fuel costs demonstrated in Table 3.

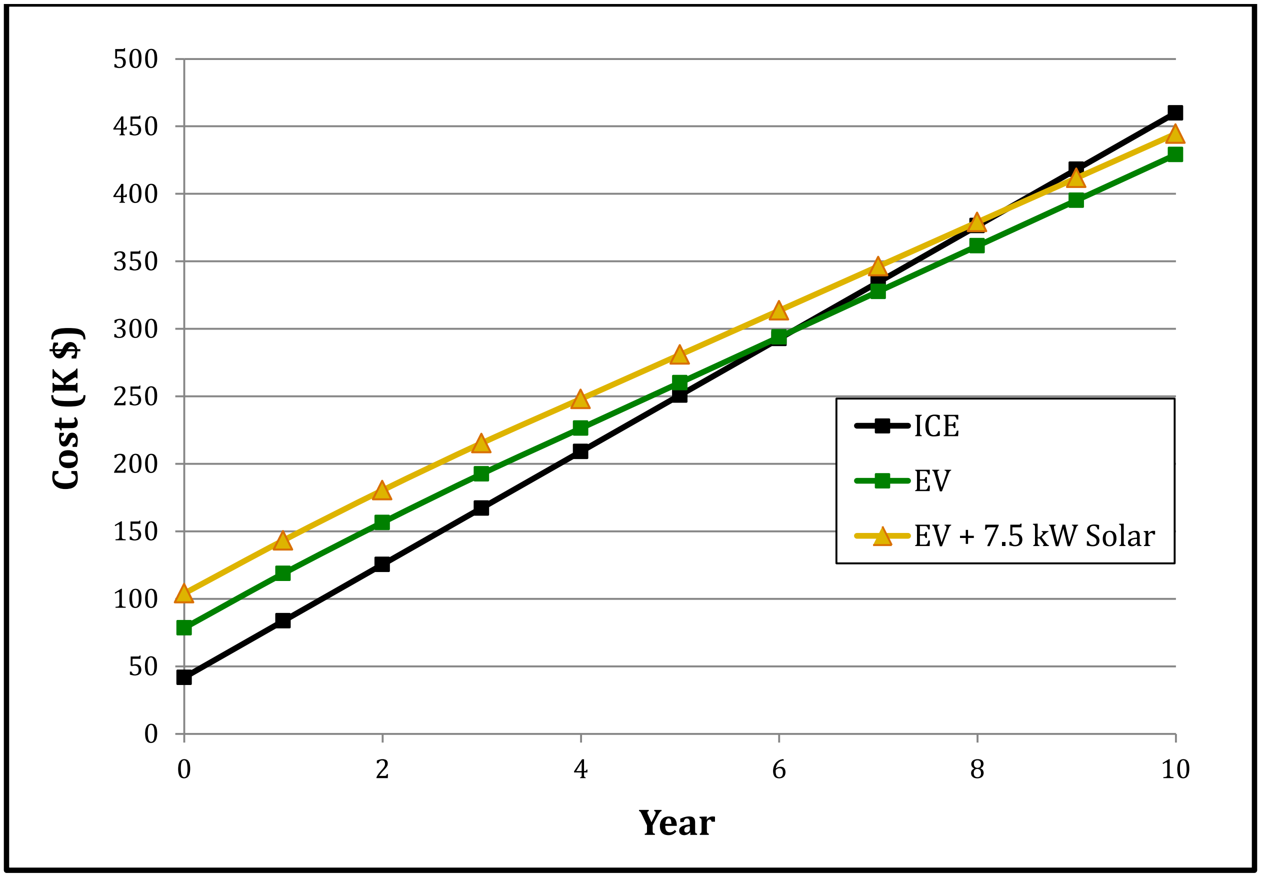

Figure 3: Total cost (vehicle purchase plus annual fuel cost) of existing ICE, proposed EV, and EV plus solar configurations with 1 fleet vehicle replaced annually

Figure 3 represents a scenario, rather than immediate total fleet replacement, that assumes a gradual transition to an electric fleet; the Department of Public Safety currently replaces each vehicle every 4 years at an approximate rate of one vehicle per year, so it is more reasonable to project a single vehicle replacement annually. The ICE scenario represents accumulated cost over 10 years, in vehicle purchase plus annual fuel costs, if one vehicle is replaced every year with a Ford Taurus internal combustion engine vehicle. This scenario reasonably assumes for simplicity that Public Safety will use a given vehicle for 5 years before replacement. In the scenario with EV replacement without solar power, assuming Public Safety will use a given vehicle for 6 years before replacement, by the fourth year the ICE fleet will have been phased out entirely (it assumes two EVs purchased at year zero for a 6-vehicle fleet in order to maintain 5 fully-fueled vehicles at all times). Once again, the initial investment is high at $31,700 per new Focus EV plus the $4,200 cost of a dual-port charging station compared to $26,600 per new Ford Taurus. However, after year six, the graph demonstrates that the cost benefits of EVs begin to manifest themselves. The drastically lower annual fuel costs mean that the University will be saving money after six years and over a 10-year period will accumulate $30,985 in savings. With the same EV scenario and the additional investment of 7.5 kW of solar panels, enough to power half the fleet, the economic payback period is longer at eight years but still results in $15,472 saved over a 10-year period. It is worth noting that this cost analysis assumes outright purchase of all vehicles at base MSRP, taking into account a $7,500 federal EV tax credit, and ignores depreciation and resale value or any specifics unique to Villanova University's contract with the Ford Motor Company. It also assumes a constant price of both vehicles, a constant electricity cost, and constant gasoline cost.

Discussion of Results

The results obtained in this experiment indicate clear benefits, both environmentally and economically, in converting the Department of Public Safety vehicle fleet to electric vehicles. The most pronounced advantage of electrification is in reduced CO_2 emissions; as demonstrated in Table 2 and Figure 1, an all-electric fleet represents a 55.8% decrease while the addition of 7.5 kW of solar PV capacity would cut CO_2 emissions a further 50% to just one-fifth of current levels. Other similar studies on electric vehicles have produced varying results: for example, according to Wilson (2013) a typical electric vehicle in the United States in 2009 would emit 202 g CO_2/km, or 0.718 lbs CO_2/mile. If this were the case for our study, fleet electrification would only achieve a 16.3% reduction in CO_2 emissions rather than our calculated value of 55.8%. However, as noted by Wilson, this value uses the national average for grid-supplied electricity in 2009. In the years since, natural gas has become more prevalent while the percentage of electricity supplied by coal continues to fall. This indicates that electric vehicles emit less as our grid becomes cleaner, and the CO_2 emissions of an electric vehicle will vary significantly depending on location and electricity source. In our case, only 39% of Villanova's electricity is supplied by coal and so a conversion to an electric fleet would be of great benefit from an environmental perspective. Another study by the U.S. Department of Energy yielded similar conclusions: Nguyen and Ward (2010) found that a standard mid-size car achieving 25 MPG emits 0.993 lbs CO_2/mile, while a typical battery electric vehicle emits 0.508 lbs CO_2/mile. The gasoline CO_2 value is higher than our own, which may be due to the study considering factors such as emissions from the extracting and refining of petroleum. The EV value compares favorably to our experimental findings of 0.379 lbs CO_2/mile, though it still likely assumes electricity produced from a higher percentage of coal than that supplied to Villanova. What is certain is that the CO_2 emissions from EVs are directly tied to the emissions from the local electricity grid; in the case of the electricity supplied to Villanova by PPL Generation, these equate to less than half the emissions of a conventional vehicle.

An additional long-term advantage to fleet electrification is economic. As demonstrated in Figure 2, an immediate total fleet conversion would have an economic payback period of only 4.7 years due to dramatically decreased fuel costs. However, it should be noted that the scenario of total fleet replacement may not provide optimal benefit; since the Department of Public Safety currently replaces each vehicle after about four years of service, the economic benefits would be negligible even if they waited the duration of the economic payback period before again replacing the entire fleet. In addition, replacing the entire fleet at once is not a realistic representation of the way Public Safety purchases new vehicles. A more realistic estimate is depicted in Figure 3. This scenario instead assumes the electric fleet would be gradually phased in; it is more reasonable to project a single vehicle replacement annually. The figure shows that, although the economic payback period for an EV fleet without solar power is slightly longer than the total fleet replacement scenario at approximately 6 years, the long-term impact is positive because this scenario accounts for the capital cost increase of an electric vehicle purchase every year and still sees nearly $31,000 in accumulated savings over a 10-year period. The slope of the EV and ICE lines clearly demonstrate that the cost savings will only continue to increase into the future, especially if the price of gasoline increases above $4/gallon and advancements in battery technology bring down the cost of electric vehicles. Figure 3 also presents another intriguing scenario: "EV + 7.5 kW solar" represents the same vehicle replacement scenario but adds the dimension of solar power. Since it would likely be impractical to power an entire 6-vehicle electric fleet exclusively with solar power, a relatively unreliable resource in southeastern Pennsylvania, this graph assumes that half of the fleet will be powered by solar energy and the remainder will be powered by the conventional electric grid. Again, this is making the rough assumption of 1,270 kWh of production per kW per year, or about 3.5 hours of solar exposure per day. The installation cost data provided by ReVision Energy in addition to the resulting decreased fuel costs yielded the trend shown in Figure 3. With solar power, the fleet and solar panels will pay for their investment in just over 8 years and provide economic benefits into the future.

The economic analysis in this study assumes the relatively low price of Villanova's electricity will hold steady at $0.08/kWh, while gasoline will remain at $4/gallon. Considering the nature of gasoline prices and the general upward trend over the last decade, it can be safely assumed that a steady $4/gallon price for gasoline makes this a conservative estimate long-term. Bronski (2013) of Rocky Mountain Institute, a sustainability-minded nonprofit think tank based in Colorado, shows the recent trends in gasoline vs. electricity costs in Figure 4 below. The figure shows clearly that while electricity costs have increased 50% since 1990, gasoline costs have risen sharply (with the exception of the Great Recession of 2008), 250% in the same time period. Bronski (2013) points out that this trend is likely to continue; while increased implementation of more expensive low-carbon sources of electricity will raise the price of electricity going forward, that increase will likely be small compared to the continued increase in gasoline prices due to the volatility of crude oil, a commodity that is influenced by many complex factors and for which demand will only increase in the future. Electricity, on the other hand, is far less volatile because it comes from a diversified portfolio of sources, allowing utilities some flexibility in providing electricity. Making a switch to vehicles powered by electricity means the University would not be at the mercy of fluctuating and exorbitant gasoline costs in the future.

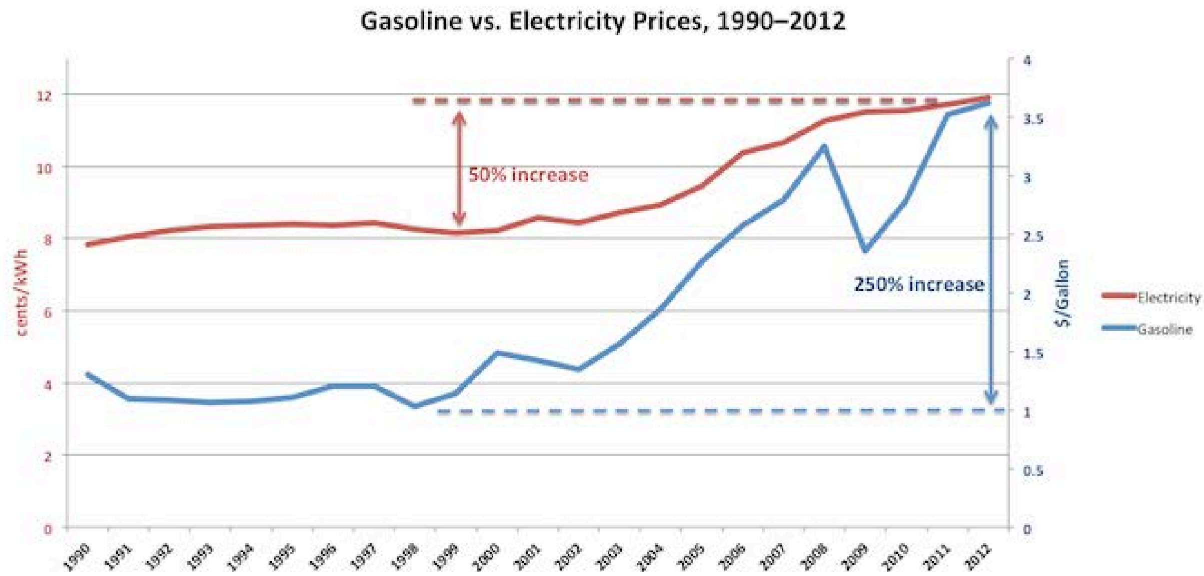

Figure 4: Gasoline vs. electricity prices from 1990–2012, U.S. national average

Regardless of future changes in vehicle and gasoline costs, however, it is simply far cheaper to operate an electric vehicle. Bronski (2013) again demonstrates this with a graph; Figure 5 below shows the cost to fuel an ICE vs. an EV for 100 miles.

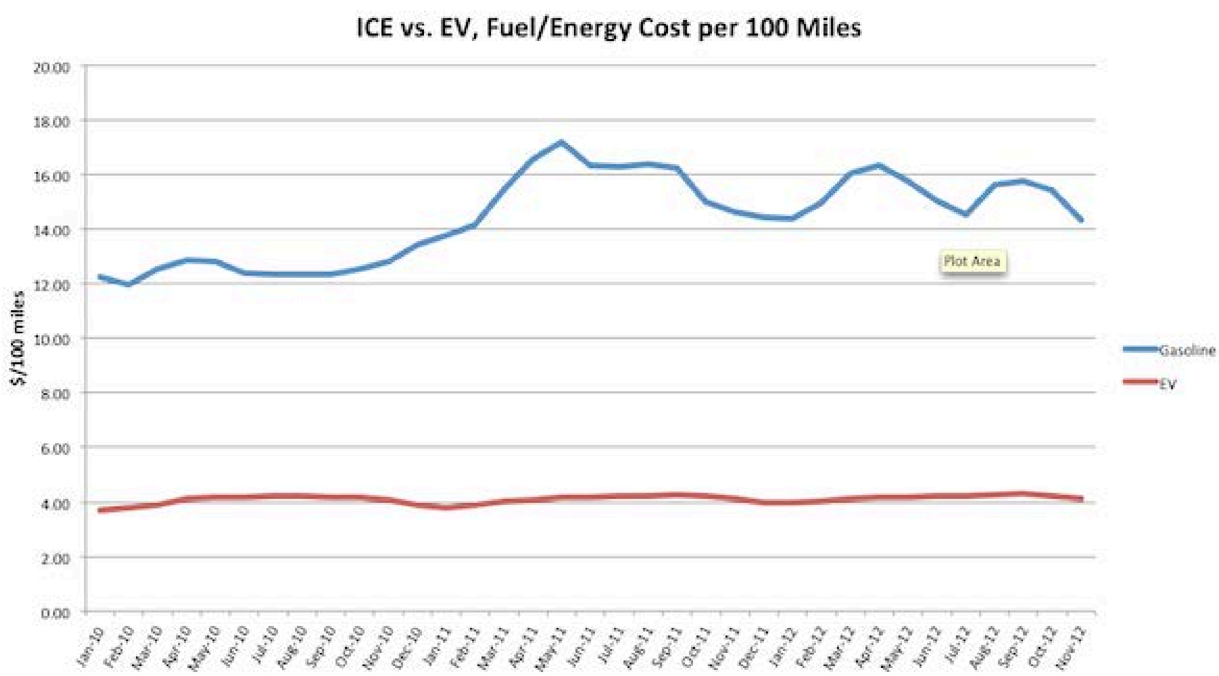

Figure 5: Cost to fuel an ICE vs. EV over 100 miles from January 2010 to November 2012, assuming U.S. national average gasoline and electricity prices

From this figure it is clear that electric vehicles cost far less to fuel, and that cost is more stable than the cost of conventional vehicles that depend on volatile gasoline for fuel. Bronski's results are similar to our own; in Table 3, it was shown that it would cost Villanova just $0.024/mile to operate an electric vehicle, which is equivalent to $2.40/100 miles. This is less than Bronski's value of $4.00/100 miles, but he assumes the national average of $0.12/kWh electricity rather than our local value of $0.08/kWh. He also found a cost averaging roughly $14.00/100 miles for a conventional ICE vehicle, while our data from Table 3 shows $0.177/mile or $17.70/100 miles. This value is slightly higher than Bronski's because we assumed $4/gallon of gasoline, higher than current costs to account for future increases. His data clearly supports ours, however, in that it is far more expensive to fuel an ICE vehicle compared to an EV.

In addition to the environmental and economic benefits, Villanova University would gain an associated "green" reputation and a great deal of positive publicity as a result of this proposed transition. The impact of fleet electrification on the public, alumni, student, and prospective student perceptions of Villanova cannot be overstated. The neutral general public, upon hearing this story, may come to regard Villanova in a favorable light. Alumni who are concerned about climate change and the environment will doubtless shower the University with donations intended to spur additional low-carbon alternatives on campus. Students will have a Public Safety fleet to truly be proud of as well as attractive and high-tech patrol cars to admire. Prospective students touring campus may spot a Focus EV silently rolling by that helps them make the decision to attend Villanova, a school dedicated enough to the environment to invest in a fleet of electric vehicles. The benefits of electrification go far beyond CO_2 emissions and fuel cost savings.

However, several concerns of the Department of Public Safety and one important assumption in our analysis must be addressed. In the interview, Mr. Hall indicated that Public Safety was hesitant about adopting electric vehicles due to concerns about a location to charge and store the vehicles, a need for additional vehicles while they charged, the size of the vehicle, inclement weather performance, and problems with suspension/shocks/brakes due to speed bumps and low speeds (Hall, personal communication). We believe that we have a response to all of these concerns. First, electric vehicles can be stored and charged wherever there is electricity. It would be a simple matter to install a Level II charger where the vehicles are already parked, outside the Department of Public Safety headquarters. The cord for the GE Durastation dual-port charger is 20 feet long and retractable, so that provides some flexibility with location of the charging station relative to the vehicles. To address the need for additional vehicles during charge time, Public Safety would have to upgrade to a 6-vehicle fleet, which we accounted for in our analysis. The Ford Focus EV takes just over 4 hours to fully charge on a 240-volt

Level II charger, and so with 6 vehicles rotating on a 24-hour cycle it would be quite feasible to have 5 vehicles fully charged and available at all times. It is also worth noting that each vehicle would not even need to be charged every day, since the average range is 76 miles and Public Safety currently averages approximately 47 miles per day per vehicle. The size of the vehicle should not be an issue, especially considering the Department's recent decision to purchase a Ford Taurus. Though the Taurus is considered a full-size sedan, the Focus EV has a higher roofline and superior visibility; in addition, the lack of a large internal combustion engine and transmission tunnel allows for more interior space. In fact, despite having a much smaller footprint, the Focus EV manages 89% of the passenger volume of the Taurus (Ford Focus EV 2013; Ford Taurus 2013). To address another of Public Safety's concerns, there are absolutely no indicators that electric vehicles perform any differently than conventional vehicles in inclement weather. The only effect weather has on electric vehicles is a slight reduction in battery range, but even a 10% reduction in range of the Focus EV would still leave a range of 68.4 miles, more than enough to meet the Department's needs. As for the issues with vehicle suspension, shocks, and brakes, electric vehicles will likely experience the same effects as conventional vehicles, as the Focus EV is essentially the standard ICE Focus with the internal combustion removed and replaced with an electric motor and battery pack. Mr. Hall indicated concern about the light weight of an EV presenting problems with speed bumps, but the Focus EV actually weighs 692 pounds more than its ICE twin yet is still 350 pounds lighter than the bulky Taurus (Ford Focus Electric 2013; Ford Taurus 2013). Regardless, performance and wear and tear should be similar. In fact, electric vehicles will incur far lower maintenance costs; since their drivetrain has only one moving part (the rotor) compared with the dozens of moving parts of a conventional drivetrain, they are more durable and reliable.

Finally, one of the most important assumptions of our analysis was the neglect of depreciation and resale value of the vehicles. Since we are ignorant of the details of the University's contract with Ford, we do not know whether the Department of Public Safety gets a discount on new vehicles, how much the old vehicles are worth when they are traded in, or how the resale value of ICE vehicles would compare with that of EVs in this unique case. For a more complete cost analysis to be performed, these factors should be considered. We also assumed in our cost analysis that an electric vehicle would last 6 years before being traded in, for simplicity of calculations. We considered this to be a reasonable assumption, as the current vehicles last 4 years and electrics are generally less prone to wear and tear. The key variable in this equation is the battery pack; we do not yet know how a battery pack will perform after 6 years in the field, and its deterioration (if it occurs) may hurt the resale value of the EV. However, we felt that these considerations have minimal effect on our findings.

On a broader scale, the data collected in this experiment reflect the expected results and those obtained in many research studies on the benefits of electric vehicles. The “long tailpipe” argument against electric vehicles is effectively put to rest in this experiment, as an all-electric fleet powered by coal, natural gas, hydroelectric, and nuclear power slashes CO_2 emissions by more than half. With the additional investment of 7.5 kW of solar panels, the Public Safety fleet would emit just 22.1% of current CO_2 levels. These results can be extrapolated to nationwide personal vehicle electrification as well as large-scale fleet electrification; even assuming electricity produced by 39% coal and 33% natural gas, the CO_2 emissions of an electric vehicle are over 55% less than the CO_2 emissions of a comparable ICE vehicle. The effect will become even more pronounced as the electricity grid transitions to cleaner sources such as solar and wind power and carbon capture and storage (CCS) is added to existing coal plants. As electric vehicles become more commonplace across the United States, the CO_2 emitted by the transportation sector will significantly decrease. This is important because, as previously mentioned, transportation greenhouse gas emissions (95% of which are CO_2) account for 29% of total U.S. greenhouse gas emissions. A movement to electric vehicles and the corresponding CO_2 reduction would have a great impact on our nation’s overall greenhouse gas emissions.

With a vehicle fleet, electrification requires significant capital investment but would pay for itself in reduced fuel costs, with even greater long-term benefits as the price of gas increases and the price of electric vehicles decreases. This effect is enhanced in a typical American individual scenario, with only a single electric vehicle that would last 10 years or more and would make back the initial price premium in the first 4-6 years (depending on various factors such as vehicle price, price of gasoline, miles driven annually, etc.) and provide economic benefit for the remainder of its life. None of these figures account for the additional cost savings in reduced maintenance that is associated with the beautiful simplicity of electric vehicles. On a large scale, the American public would profit from a nationwide switch to electric vehicles given the results obtained in this experiment. In addition to the environmental benefits, there is a long-term economic incentive to go electric. As technological improvements, particularly in battery technology, drive down the cost of electric vehicles and gasoline prices continue to steadily increase, the transportation sector will be motivated to switch to electric vehicles and greatly reduce our environmental impact in the process.

Appendix 1: Equations

ICE: CO_2 emissions

$$CO_2/_{year} = \frac{19.4\ ^{lb\ CO_2}/_{gal}}{22.6\ ^{miles}/_{gal}} * \left(86{,}000\ ^{miles}/_{year}\right) = \mathbf{73,823}\ ^{\boldsymbol{lb\ CO_2}}/_{\boldsymbol{year}}$$

EV: CO_2 emissions

$$CO_2/_{year} = \left(\frac{0.33 * 1.14\ ^{lb\ CO_2}/_{kWh} + 0.39 * 2.25\ ^{lb\ CO_2}/_{kWh}}{\frac{76\ ^{miles}/_{charge}}{23\ ^{kWh}/_{charge}}}\right) * \left(86{,}000\ ^{miles}/_{year}\right) = \mathbf{32,629}\ ^{\boldsymbol{lb\ CO_2}}/_{\boldsymbol{year}}$$

ICE: Fuel cost

$$Annual\ fuel\ cost = \left(^{\$4}/_{gal}\right) * \left(\frac{86{,}000\ ^{miles}/_{year}}{22.6\ ^{miles}/_{gal}}\right) = ^{\$\mathbf{15,221}}/_{\boldsymbol{year}}$$

EV: Fuel cost

$$Annual\ fuel\ cost = \left(\frac{^{\$0.08}/_{kWh}}{3.304\ ^{miles}/_{kWh}}\right) * \left(86{,}000\ ^{miles}/_{year}\right) = ^{\$\mathbf{2,082}}/_{\boldsymbol{year}}$$

References

Bronski, R. 2013. Pain at the Pump. Rocky Mountain Institute. Retrieved April 21, 2013 from <http://blog.rmi.org/blog_2013_03_11_pain_at_the_pump>

Engber, D. 2006. How Gasoline Becomes CO_2. Slate. Retrieved January 28, 2013 from <http://www.slate.com/articles/news_and_politics/explainer/2006/11/how_gasoline_becomes_co2.htm>

Environmental Protection Agency. 2012. Air Emissions. Retrieved January 28, 2013 from < http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html>

Environmental Protection Agency. 2012. Climate Change: Greenhouse Gas Emissions. Retrieved January 28, 2013 from <http://www.epa.gov/climatechange/ghgemissions/gases/co2.html>

Environmental Protection Agency. 2012. Electric Car Label. Retrieved January 28, 2013 from <http://www.epa.gov/otaq/carlabel/electriclabel.htm>

Ford Focus Electric. 2013. Retrieved February 4, 2013 from < http://www.ford.com/cars/focus/trim/electric/>

Ford Taurus. 2013. Retrieved April 23, 2013 from < http://www.ford.com/cars/taurus/specifications/capacities/>

Greenhalgh, F. Personal communication, February 25, 2013.

Hall, C. Personal communication, February 26, 2013.

Morro, R. Personal communication, February 4, 2013.

Nguyen, T. and J. Ward. 2010. Well-to-wheels greenhouse gas emissions and petroleum use for mid-size light-duty vehicles. U.S. D.O.E.: Offices of Vehicle Technologies and Fuel Cell Technologies.

PPL Generation: Our Generation Portfolio. 2013. Retrieved January 28, 2013 from <http://www.pplweb.com/ppl-generation/our-generation-portfolio.aspx>

Reichmuth, D. S., A. E. Lutz, D. K. Manley, and J. O. Keller. 2013. Comparison of the technical potential for hydrogen, battery electric, and conventional light-duty vehicles to reduce greenhouse gas emissions and petroleum consumption in the United States. International Journal of Hydrogen Energy. 38 (2): 1200-1208.

U.S. Department of Energy. 2013. Fuel Economy: Where the Energy Goes. Retrieved January 28, 2013 from <http://www.fueleconomy.gov/feg/atv.shtml>

U.S. Department of Transportation (DOT) Center for Climate Change and Environmental Forecasting. 2010. Transportation's role in reducing U.S. greenhouse gas emissions. Report to Congress. 1: 1-40.

Wilson, L. 2013. Shades of green: electric cars' emissions around the globe. Shrink That Footprint. 1 – 29.