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Electrification of Monroe County’s Vehicle Fleet: A Cost Benefit Analysis

Jordan Kirkpatrick
jk3474@rit.edu

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Jordan Kirkpatrick

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Committee Approval

Eric Hittinger Date
Faculty Thesis Advisor
Public Policy Graduate Director

Franz Foltz Date
Committee Member

Michael Garland Date
Committee Member
Monroe County Director of Environmental Services

Abstract

This analysis determines the financial and environmental value in electrifying the vehicle fleet owned and operated by Monroe County, New York. Due to economies of scale, the capital cost of Battery Electric Vehicles (BEVs), Plug-in Hybrid Vehicles (PHEVs), and Hybrid Electric Vehicles (HEVs) have dropped to a point that regardless of environmental benefits, these vehicles can be cost effective in their own right. Monroe County has consistent turnover in its fleet anyway, replacing older vehicles with new ones.

I conducted a cost benefit analysis of converting Monroe County's vehicle fleet to electric alternatives in order to maximize financial value. To do this, I delineate between Total Conversion plans, in which the entire fleet is converted to a specific alternative, and Optimized Conversion plans, in which a vehicle-by-vehicle conversion is conducted. The Total Conversion plans will generate greater emissions reductions but at higher costs, while the Optimized Conversion plans generate cost savings but at much lower emissions reductions. I assess these two conversion plans under five different scenarios, which account for rapidly changing input variables like EV capital cost, gasoline price, and discount rate.

Prior to the quantitative analysis, I conducted qualitative surveys with vehicle coordinators to determine which vehicles are even candidates for electrification, considering the unique range and charging requirements for the electric alternatives.

Overall, because of projected future capital cost reductions for EVs, the County's best financial choice in the long-term is to invest in BEVs. In the short-term, there are few conditions in which Total Conversion to EVs generates cost savings. To achieve significant immediate emissions reductions, the County would have to incur a financial loss. To put it another way, the County would have to make a financial investment in immediate emissions reductions. These emissions reductions are more cost-efficient as time goes on. However, cost savings are available immediately in the form of Optimized Conversions across all possible market scenarios.

1 - Introduction

As automakers continue to expand their offerings of electric-style vehicles and market trends create economies of scale that lower consumer prices, it becomes increasingly feasible for individuals, corporations and municipalities to consider purchasing electric vehicles for their fleets. While they are currently more expensive to purchase than conventional automobiles, their maintenance and fuel costs are only a fraction of the same costs for their conventional counterparts, while offering the potential for significant environmental benefits.

County government in Monroe County, New York ("the County,") utilizes a fleet of approximately 250 light and medium duty vehicles. The emissions benefits of converting the County's vehicle fleet from Internal Combustion Engines (ICEs) to electric would be substantial – however there remain significant financial and operational barriers to electrification. Municipalities have little flexibility in their budgets and seek to squeeze every ounce out of every dollar. Unless such a move is at least cost neutral, it is a difficult policy decision. At the same time, because of range concerns and charging patterns, full Battery Electric Vehicles (BEVs) may not be a viable alternative. For municipalities focusing on fiscal and operational perspectives, these concerns must be addressed prior to consideration of electrification.

It is the purpose of this analysis to take an inventory of the County's current vehicle fleet, evaluate the feasibility of replacing conventional vehicles with Electric Vehicles (EVs), and perform a cost-benefit analysis of such a decision. This analysis will attempt to answer the question of whether or not Monroe County can realize cost savings through total or partial electrification of its fleet. Furthermore, the analysis will attempt to identify the effects that different market forces have on potential cost savings. Finally, the analysis will also quantify the environmental benefits of electrification.

Value of Analysis

There are several reasons this analysis will add value. First, it will share insight with the County and policy-makers on how to best utilize public resources. Second, the addition of potentially hundreds of BEVs and Plug-in Hybrids (PHEVs) on the streets of Monroe County will also have an unquantifiable effect on the general perception of those vehicles. Observing EVs on the roads could reduce the skepticism that many drivers hold, in addition to the experiences of the County employees actually operating the vehicles (Bakker and Trip, 2013). Because of their experience, those employees may consider purchasing their own EV for personal use or recommending the technology to a friend or family member. Third, if the County electrifies its fleet, the County will have to invest in charging infrastructure, or Electric Vehicle Supply Equipment (EVSE). With greater public visibility, this expansion of EVSE could have an added benefit of reducing the range anxiety associated with EVs.

There is an additional added value deriving from the potential for emissions reductions. Converting from ICEs to BEVs will significantly reduce the release of Carbon Dioxide (CO2), Methane (CH4), and localized emissions that have a negative impact on human health. These emissions will be quantified and translated to financial benefits of electrification.

The final added value will derive from an academic perspective. Currently, only a few analyses of the feasibility of converting municipal fleets have been conducted and made public. Private consultants are willing to conduct the analysis for a fee, but there is a relative shortage of academic literature on the topic. This analysis will create an externally valid methodology that can be duplicated in cities and counties across the U.S. and provide guidance to other municipalities on the costs and benefits of such a decision, rather than just Monroe County.

Demographics of Monroe County

Monroe County is located in the Western portion of New York State, situated just south of Lake Ontario. The City of Rochester is the County seat, having initially developed around the Genesee River. Monroe County has an estimated population of 747,000 residents – 70% of whom are Caucasian, 16% are Black/African American, and 9% are Hispanic or Latino. 90% of residents 25 years or older have received a High School diploma, while 37% have received a Bachelor's degree or higher. The median household income is $55,272. The land area is roughly 657 square miles. (U.S. Census Bureau)

Monroe County government serves the City of Rochester as well as 19 surrounding Towns and Villages. County government is responsible for providing a variety of public services, ranging from provision of social programs and public safety to managing a network of 21 public parks and protecting the environment (Monroe County, NY.) With the exception of the Monroe County Sheriff's Office, the vehicles used by all County Departments are maintained by the Fleet Services Division in the County's Department of Environmental Services (DES). This analysis excludes the vehicles operated by the Sheriff's Office.

2 - Literature Review

There is a relative shortage of academic literature on the topic of municipal fleet electrification that focuses on light and medium duty vehicles. For this reason, I chose to divide the literature review into two different categories, discussing two different topics that impact my analysis. The two topics are: the general state of the EV industry and the viability of E-85 biofuel technologies; and the existing research on municipal fleet conversion to EV's.

State of the Automotive Industry

Cultural ties to conventional automobiles run deep in the American psyche and lack of charging infrastructure remains a sizeable barrier to widespread embrace of EVs. Furthermore, because the technologies are still in relative infancy and production economies of scale are only beginning to expand, the up-front capital cost of an EV often deters the average consumer from investing, despite the savings on the back-end through reduced fuel costs and diminished maintenance costs.

There is a growing amount of academic literature evaluating the impact that different public policies can have on EV adoption. Vassileva and Campilo (2017) surveyed early adopters of EVs in Sweden, finding that EV owners tend to be male, well-educated, affluent, and use the vehicles primarily for private purposes and charge them at home. Furthermore, they concluded that one of the most meaningful policy solutions to facilitate EV integration is to incorporate smart-charging coordination to prevent outages in electric grids. Mercier, et al. (2015) evaluated the costs and benefits of Quebec's *Drive Electric* Program, a program in which the government gave rebates to private consumers purchasing EVs, then measured the benefits as savings on gasoline purchases, oil changes, and emissions reductions. Overall, the analysis found a NPV of $173,000 when considering the cost of the rebates for the government.

Green, et al. (2014), Shafiei, et al. (2018), Bakker and Trip (2013), Sen, et al. (2017), and Contestabile, et al. (2017) all evaluated the different micro- and macroeconomic policy options that can help generate greater EV market growth. Green, et al. (2014) found that government policies should focus on niche markets rather than mainstream consumers, because the latter are costly and inefficient. Shafiei, et al. (2018) simulated different taxes and subsidies on vehicles and fuels in Iceland, finding that the most effective method to promote EV growth is to reduce

the up-front cost. Bakker and Trip (2013) found that the top policies to promote EV growth in an urban environment were to lobby for universal charging infrastructure, build a network of charging infrastructure, and then actually lead on the issue by investing in EVs for the government fleet. Sen, et al. (2017) examined CAFÉ standards and found that they are only effective in increasing EV market share if they are paired with other existing government incentives like the purchase subsidy. Contestabile, et al. (2017) found that it was more difficult to sustain incentives that are biased towards BEVs in the long run because of the higher cost. Instead, a mix of BEVs and PHEVs will be able to incorporate more EVs into the market with lower risk. Traut, et al. (2012) found that PHEVs only offer modest emissions reductions, although they conclude this is because of a "dirty" electricity grid. By contrast, HEVs are more effective because they are much cheaper, and BEVs are unattainable because of cost and range restrictions. However, this study was performed in 2012 and technology evolves rapidly.

In the U.S., momentum continues to build for EV market growth. In 2017, 199,826 EVs were purchased, a number that rose almost 25% from 158,614 in 2016 (Loveday, 2018). Improvements in battery technology, faster charging rates, continued expansion of charging infrastructure, reductions in sticker price, and reductions in EV stigma provide sources of optimism that EVs and PHEVs could eventually replace ICEs as the light duty vehicle of choice for American consumers. This trend has even been nominally embraced by American automakers, who announced in 2017 they would be joining their foreign competitors in releasing more EV models and increasing their production levels (Shivdas, 2018).

While there is no academic literature evaluating the many EV options on the market (nor is there really a need for such literature), many consumer websites have compiled this

information. Plugin.com, a leading EV consumer site, details the 14 EVs and the 24 PHEVs that are on the market in 2019.

Table 1			
Make/Model	**Range (miles/charge)**	**Price ($)**	**Style**
BMW i3	114	43,400	Sedan
Chevrolet Bolt	238	37,500	Sedan
Fiat 500e	84	32,600	Coupe
Ford Focus Electric	115	29,200	Sedan
Honda Clarity	89	*	Sedan
Hyundai Ioniq	124	29,500	Sedan
Kia Soul	111	34,500	Sedan
Mercedes B-Class	87	42,400	Sedan
Nissan LEAF	151	29,900	Sedan
Smart Electric Drive	58	23,800	Coupe
Tesla Model 3	220	35,000	Sedan
Tesla Model S	315	71,000	Sedan
Tesla Model X	237	85,000	SUV
Volkswagen E-Golf	125	30,500	Sedan
Average	**147**	**40,331**	

Table 1 – There are 14 BEVs available on consumer markets in 2019. This list does not correlate directly with the vehicles available for purchase on the New York State Contract, but rather captures the a snapshot of where the BEV market is as a whole

Plugin.com also compiles a list of the PHEVs that are on the market in 2019.

Table 2			
Make/Model	**Range (miles/charge)**	**Price ($)**	**Style**
Audi A3 E-Tron	16	38,900	Sedan
BMW 330e	14	43,700	Sedan
BMW 530e	16	52,400	Sedan
BMW 740e xDrive	14	91,000	Sedan
BMW i8	25	137,000	Coupe
BMW X5 xdrive40e	14	64,000	SUV
Cadillac CT6	31	75,000	Sedan
Chevrolet Volt	53	33,200	Sedan
Chrysler Pacifica	33	43,100	Wagon/Van
Ford C-Max Energi	20	27,100	Wagon/Van
Ford Fusion Energi	21	33,900	Sedan
Honda Clarity	48	34,300	Sedan
Hyndai Ioniq	29	25,000	Sedan
Hyndai Sonata	27	35,400	Sedan
Kia Niro	26	27,900	Sedan
Kia Optima	29	35,200	Sedan
Mercedes C350	9	46,400	Sedan
Mercedes S550	14	97,000	Sedan
Mercedes GLE550e	10	67,000	SUV
MINI Cooper SE Countryman All4	12	37,700	SUV
Mitsubishi	22	34,600	SUV
Porsche Cayenne	14	78,000	SUV
Toyota Prius Prime	25	28,000	Sedan
Volvo XC90 T8	19	69,000	SUV
Volvo XC60 T8	18	52,900	SUV
Average	**22**	**52,308**	

Table 2 - There are 25 PHEVs available on consumer markets in 2019. This list does not correlate directly with the vehicles available for purchase on the New York State Contract, but rather captures the a snapshot of where the PHEV market is as a whole

Needless to say, there is not a linear relationship between range and price. As with traditional vehicles, there are many factors affecting price, such as luxury brands, high-end features, etc. These lists are merely supposed to provide an exhaustive list of EVs and PHEVs that are currently available for purchase in the U.S. – but, as will be discussed in the methodology section, specific models will be used for this analysis.

Both Yong, et al. (2015) and Poullikkas (2015) provided an overview of the various EV, PHEV and Hybrid Electric (HEV) technologies that are gaining prominence, while Bhatti, et al. (2016) performed a technological review of PV solar-charging infrastructure for EVs, finding that Vehicle-to-Grid (V2G) technology may not be feasible due to excessive battery degradation. PV-grid charging infrastructure is more effective and more prevalent. Shirazi, et al. (2015) disagreed with Bhatti regarding V2G, finding that a V2G-enabled electric bus is cost-effective at present costs and argues that V2G is a viable technology, even in a relative cold weather environment like Philadelphia. Zhou, et al. (2017) examined the parameter variation effects on EV battery packs, proposing an optimal battery pack model that has 96 cells connected in series. Sujitha and Krithiga (2017) reviewed the different power converters that can be used to connect EV charging infrastructure with the local electric grid.

Perhaps more germane to this analysis, however, is the literature focusing on charging infrastructure itself. Several researchers have evaluated public-private partnerships and the impact of government building charging infrastructure for the public to use, including charging stations that are available at workplaces. Yang, et al. (2016) found that public-private partnerships reduce costs and risk when it comes to constructing charging infrastructure. He, et al. (2016) considered a case study of public charging infrastructure in Beijing, using a p-median model to optimize geographic location across the city They found that proximity to charging

infrastructure encourages drivers to adopt EVs, or at the very least allays range concerns inhibiting purchase. Mouli, et al. (2016) evaluated PV charging infrastructure in the Netherlands, finding that public charging infrastructure that uses solar energy would require an energy storage device to absorb excess power in the summer and supply power in the winter. High intensity insolation rarely happens in the Netherlands, so even with a battery, a connection to the grid is still necessary.

Viability of Biofuel Technology[1]

Flex fuel vehicles (FFVs) are vehicles that operate on blended gasoline-ethanol mixes, primarily E85 (85% ethanol, 15% gasoline.) For many years, these vehicles were viewed as a cost-effective alternative to continued reliance on imported foreign petroleum to operate automobiles. This was especially true prior to the 2008 financial collapse, when the price of petroleum was almost $150/barrel and consumers were looking for alternatives (EIA.gov, 2018). Evidence for the high expectations for E85 can be found in the 2010 Annual Energy Outlook published by the Energy Information Administration (EIA), which provided a thorough discussion on projected biofuel consumption. While it projected traditional gasoline consumption would increase by 0.1 million barrels per day by 2035, E85 would increase by 1.2 million barrels per day over the same time period. (Energy Information Administration, 2010)

In the years since, the inevitability of an FFV revolution has waned, in correlation to (if not caused by) the proliferation of EV technology. While the 2018 Annual Energy Outlook still projected modest increases in E85 use, it projected overall decreases in share of traditional ICE vehicles from 95% in 2017 to 78% by 2050 in the reference case (Energy Information

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[1] This is by no means a comprehensive literature review of the state of flex fuel technology. A brief discussion was included at the request of Monroe County, who has previously invested in FFV's.

Administration, 2018). Furthermore, in testimony delivered by EIA officials to the Congressional Energy and Commerce Committee, EIA elaborated that in general, gasoline with ethanol is projected to decrease from 99.5% of gasoline to 91% by 2050. This is again complemented by only modest increases in FFV sales (Energy Information Administration, 2018). According to EIA, the future of FFVs and the E85 fuel they use is, at best, uncertain.

EIA projections have not proven to be infallible. A simple internet search can provide countless examples of flawed projections. However, there are other reasons to be skeptical of the continued success of FFVs. Sprei (2018) found that FFVs had lost their competitive advantage in Swedish auto markets, and that in light of new alternatives (EVs/HEVs), fuel prices and shifting ethanol incentives, the market share for FFVs had greatly diminished.

And while Pouilot (2017) makes the case for optimal price points for FFV owners to purchase E85 rather than E10, intending to provide DOE more useful data to use in blending the fuel and subsidizing its distribution, he acknowledges that there are only 2,800 E85 fueling stations around the country, mostly in the Midwest. Automakers want to sell FFVs because they enhance their ability to meet CAFÉ standards, but this role can also be filled by EVs.

This, plus current uncertainty surrounding the Trump Administration’s stance on the ethanol mandate, CAFÉ standards, and transportation policy in general, provides little clarity on the future of E85 and FFVs. John Deutch, an MIT Researcher who authored a recent review of biofuel vehicles, wrote that “there is… enormous uncertainty and disagreement surrounding the future of these fuels” (Ekstrom, 2013). Since then, there have been few indications that more clarity is on the way, making it difficult for regional or municipal stakeholders to make a decision either way.

Similar Analyses

There is existing literature that touches on the decision-making process that fleet managers undergo when considering incorporating new technologies. Nesbitt and Sperling (2001) first looked at fleet purchase behavior from an organizational behavior perspective back in 2001. They found four different behavior models, which they call autocratic, bureaucratic, hierarchic, and democratic, which range from High to Low in Formalization and High to Low in Centralization. Their work was later expanded by Sierzchula (2014), who examined fleet purchasing specific to EVs, finding that most early-adopted fleets incorporate EVs to test the new technologies, lower their environmental impact, and improve their public image. Kuppusamy, et al. (2017) simulated a taxicab company and found that the decision whether to adopt or not is a function of average vehicle miles, even when they modeled the potential for fast charging stations and battery swap stations.

In China, due to both urban pollution and traffic congestion issues, there is an increasing amount of literature devoted to electrifying their public transportation networks. Leung (2013) performed a cost benefit analysis of rapidly replacing Hong Kong's buses, finding that using EV buses instead would save 1,260 statistical lives and save HK$26.4 Billion. Lajunen (2014) included hybrid buses into a similar analysis, finding that plug-in electric buses and battery electric buses can greatest reduce energy consumption and emissions, but found that cost-efficiency remained elusive. Hybrid buses can be cost-effective depending on the bus route, but overall the capital costs must be reduced to improve cost-efficiency. Cai, et al. (2017) performed a multi-criteria decision analysis for different alternatives to the fleet of public taxis in Beijing, ranking items like emissions, cost, and policy disturbance. They found that EVs using a projected 2020 electricity generation mix is the optimal solution because of low emissions and

low operational costs, while using EVs with a 2017 electricity generation mix is the second-best option. The worst option: continuing to use ICEs. On the other side of the globe, Kleindorfer, et al. (2012) performed a decision model of replacing the fleet of France's *La Poste* with EVs, using Total Cost of Ownership (TCO) as their central criterion, and found that switching to EVs actually led to cost savings. In a review of Canadian transportation, Mohamed, et al. (2017) conducted qualitative interviews with transit providers to examine barriers to using electric buses. The top concerns are: risk, range, and cost, but transit providers generally agreed they would be willing to try the technology if there was robust political support, standardization, Canadian operational data, and a pilot project that tested the buses first.

The most valuable literature available relates to analyses conducted in Minneapolis, Houston, and New York City. All three cases perform a cost benefit analysis of converting to EVs. A more detailed breakdown of their methodologies is found in Table 3.

Table 3			
	City of Houston	**City of Minneapolis**	**New York City**
Methodology	Cost benefit analysis	Cost benefit analysis	Cost benefit analysis
Vehicle Alternatives	ICE, BEV, PHEV, HEV	ICE, BEV	ICE, HEV, BEV
Offers Implementation Schedule	No	Yes	No
Operational Analysis	No	Interviews with Staff	No
Environmental Analysis	GREET Model (CO2)	Calculates CO2 Emissions/vehicle	No
Charging Infrastructure	One per vehicle	One per vehicle	One per two vehicles
Type of Recommendations	Rooted in type of vehicle	Six implementation timelines	TCO over 10 years

Table 3 – A comparison of the three main analyses used to construct the model for Monroe County; Analyses conducted in the City of Houston by Sengupta and Cohan, as well as the City of Minneapolis and New York City

In Houston, Sengupta and Cohan (2017) considered a range of alternatives, including ICEs, EVs, PHEVs, HEVs, and vehicles that operate using Compressed Natural Gas (CNG). The City of Minneapolis compared only the base-case ICEs to EVs, while New York City compared the Total Cost of Ownership (TCO) of an ICE, a HEV, and a BEV over 9 years. The Minneapolis analysis included operational interviews with City staff to determine implementation feasibility, whereas Sengupta and Cohan skipped this component, as did New York City. Both the Houston and Minneapolis analyses included an environmental component, using similar approaches, and both included the costs of one Electric Vehicle Service Equipment (EVSE), or charging station, for each EV purchased. New York City, however, did not perform an environmental analysis as part of this particular study.

The greatest difference between the analyses, however, is in the format of the recommendations they issued. Sengupta & Cohan offered recommendations rooted in the type of vehicle being implemented – meaning, for each type (EV vs. PHEV vs. HEV, etc.) they gave a final result of both the financial benefits (using Net Present Value) and the environmental benefits. They found that HEVs can achieve 36% lower Greenhouse Gas (GHG) emissions with levelized cost equal to traditional sedans, and that full EVs and PHEVs can both provide further emissions reductions but at far higher costs. In Minneapolis, however, the analysis provided six alternative implementation timelines ranging from aggressive to conservative, focusing exclusively on EVs. Even in the most aggressive timeline, 47% of the vehicles have been replaced after 10 years – in the conservative timeline, only 8% have been replaced. The timelines vary based on procurement resources dedicated to the conversion. These two separate analyses provide valuable insight into how a new analysis could be conducted. The differences in their methodology allow room for building a custom analysis based on the unique characteristics of the municipal fleet under consideration.

The analysis conducted in New York City examines only the TCO of one vehicle across different vehicle types (ICE vs. HEV vs. BEV.) Rather than conduct a fleet-wide assessment, as the analyses in Houston and Minneapolis did, New York City examined the average cost figures for a vehicle in the fleet and found that BEVs can actually be cheaper than ICEs over the 9 year window. An important caveat, however, is that the analysis did not conclude that *all* BEVs generate a positive NPV compared to ICEs. Instead, it looked at capital costs of multiple vehicle types and found that the Nissan Leaf achieved cost savings, but some of the more expensive BEV models did not. Those vehicles are more expensive up front and despite annual operational savings, do not generate a positive NPV over 9 years compared to an ICE vehicle (Coren, 2019).

It is worth noting that as part of this literature review, analyses of both Federal and State fleets were reviewed. In academia, there remains a severe shortage of quantitative analyses that can assess the merits of municipal fleet electrification at the State and Federal levels. At the same time, government itself publishes a large amount of data. With such data, I could likely conduct my own cost benefit analysis of a Federal agency's fleet, but that analysis has not already been conducted. I reviewed the websites of the Congressional Research Service (CRS), Government Accountability Office (GAO), General Services Administration (GSA), and the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy in my search.

Why is this worth mentioning? The United States Energy Policy Act of 1992 required 75% of new light-duty vehicles acquired by Federal agencies to use alternative fuels. This law was expanded in 2008 to include HEVs, fuel cell vehicles, and advanced lean burn vehicles, and in 2016, it required that *all* light duty vehicles purchased had to use alternative fuels. (Office of Energy Efficiency and Renewable Energy.) As part of this mandate, federal agencies are required to submit annual Fleet Management Plans, guidance for which has even been provided by DOE. (Daley, et al., 2017.) However, these published reports vary across departments in scope, format, and level of detail. There is certainly no comparative financial analysis of ICEs and EVs. Perhaps unsurprisingly, DOE offers the most information about their electric vehicle conversion program, but even that document does not have an analysis of the costs and benefits. According to GSA's public fleet data, this Federal mandate has resulted in large increases in agency alternative fuel vehicle acquisition (Federal Fleet Report.) However, no cost benefit analysis was conducted prior to electrification, nor following electrification, that could actually quantify the benefits of this decision.

At the State level, I chose two states that are most likely to have embraced EVs in their public fleets: California and New York. On the websites for both States, there is a significant amount of data available publicly, but still no comparative analysis of ICEs versus EVs. I found this to be unusual and suggest that it is a research gap to be addressed moving forward.

3 - Methodology

This analysis will attempt to answer the question of whether or not Monroe County can realize cost savings through total or partial electrification of its fleet. Furthermore, the analysis will attempt to identify the effects that different market forces have on potential cost savings. Finally, the analysis will also quantify the environmental benefits of electrification.

Data Collection

As an employee of Monroe County, I have access to extensive fleet data through County DES. This includes a list of every vehicle in the fleet, to which County Department it belongs, average annual mileage, maintenance patterns, fuel patterns, and capital costs. This information already exists in the County's Fleet Services Division, which uses the Dossier software to track this data. Using Dossier, I was able to generate quantitative data that would guide the cost benefit analysis. These items - vehicle category (sedan/SUV/pick-up), age of vehicle, average annual mileage, make/model, to which County Department the vehicle belonged – were provided by the County's Fleet Services Division. There were records for 252 vehicles, of which 11 had been recently purchased and were not considered due to insufficient mileage data.

However, when conducting an analysis of the potential for BEV use, annual mileage is not sufficient. I also had to account for *daily* mileage because of charging range. More discussion

of this is included in *Usage Patterns* below. To collect this qualitative data, I developed a survey that was administered to the vehicle coordinator for every single County vehicle. I asked several questions that would help determine if a vehicle was even a candidate for EV conversion. Of these 252 surveys administered, 229 responses were received, a 91% response rate. Only 19 vehicles had range requirements that precluded conversion to BEV. A copy of this survey is included in the Appendix.

Cost Benefit Analysis

I chose to conduct a cost benefit analysis to evaluate the Net Present Value (NPV) of electrification of the County's vehicle fleet. The cost benefit analysis will generate two primary outputs: First, using a term I will call "Total Conversion," I describe conditions if the entire fleet is converted to one technology; Second, using a term I will call "Optimized Conversion," I describe conditions if each vehicle is converted to the alternative with the lowest NPV. Needless to say, the Optimized Conversion schedule is the more practical for policymakers, but I include discussion of Total Conversion scenarios for comparison sake. Further discussion of these outputs is included below under *Total Conversion vs. Optimized Conversion.*

This analysis was conducted primarily from a fleet perspective. Monroe County performs a wide array of services to the public, and as such, has a fleet of vehicles with capabilities needed to perform those services. An analysis of potential conversion to EV's must not sacrifice the integrity of the County's ability to perform those services. Further discussion of this concept is included under ***Usage Patterns*** below.

I evaluated all 241 vehicles in the fleet and compared the different purchase options. For example: Vehicle #2253 is a Chevrolet Impala operated by the Probation Department. I then

compared the different alternatives if that Impala were to be replaced immediately. For replacement options, I considered a new 2019 Malibu to be the base case, with EV alternatives to be the 2019 Chevy Bolt (BEV), the 2019 Chevy Volt (PHEV), and the 2019 Malibu Hybrid (HEV). I kept like with like – that is, I identified a replacement that matched the size and general usage of the existing vehicle. I did not propose conversion of SUVs to sedans or vice versa.

Table 4

	ICE	**HEV**	**PHEV**	**BEV**
Sedan	Chevrolet Malibu	Chevrolet Malibu Hybrid	Chevrolet Volt	Chevrolet Bolt
SUV	Ford Explorer	Ford Explorer Hybrid	Ford Plug-in EV*	Ford Battery EV*
Pick-Up	Ford F-150	Ford F-150 Hybrid	Ford Plug-in EV*	Ford Battery EV*

Table 4 – A list of the vehicles that the County's Fleet Division would replace existing vehicles with; organized by Type and Class. No PHEV and BEV vehicles are currently available at the SUV and Pick-Up levels, so inputs were projected for the analysis for those vehicles.

The 10 year Total Cost of Ownership (TCO) reflects two values: up-front capital costs and operating costs. To identify up-front capital costs, I consulted the County's purchasing guidelines, which mandates that vehicles must be purchased off a pre-negotiated New York State Contract. These prices are set in stone and are found in Table 5. For residential consumers of EVs, a federal subsidy of $7,500 is available when purchasing the vehicle. This subsidy makes the up-front cost more feasible for consumers. However, the County is a municipal government and thus unable to receive that subsidy. For this reason, Capital Cost inputs in the base case reflect New York State Contract prices.

Table 5	
Vehicle Alternative	**Capital Cost ($)**
ICE Sedan – Malibu	$21,000
HEV Sedan – Malibu Hybrid	$26,000
PHEV Sedan – Volt	$35,000
BEV Sedan – Bolt	$32,000
ICE SUV	$31,000
HEV SUV	$34,000
PHEV SUV*	$45,000
BEV SUV*	$42,000
ICE Pick-Up	$28,000
HEV Pick-Up	$33,000
PHEV Pick-Up*	$42,000
BEV Pick-Up*	$39,000

Table 5 - Capital Cost of vehicle alternatives that would be used in the County fleet. Prices for the PHEV/BEV SUVs and Pick-Ups are projected because these models are not available yet.

To determine operating costs, I determined that there are two variables that affect annual cost: fuel and maintenance. For annual fuel costs, I conducted market research to identify vehicle-specific Miles per Gallon (MPG), EV range, and cost to charge fully figures.

Table 6		
Vehicle Alternative	**MPG or Miles/kWh**	**Cost to Charge**
ICE Sedan – Malibu	31	

HEV Sedan – Malibu Hybrid	46	
PHEV Sedan – Volt	53	$1.48
BEV Sedan – Bolt	238	$6.00
ICE SUV	17	
HEV SUV	24	
PHEV SUV*	40	$2.00
BEV SUV*	237	$7.68
ICE Pick-Up	22	
HEV Pick-Up	24	
PHEV Pick-Up*	40	$2.70
BEV Pick-Up*	230	$21.74

Table 6 – A list of the fuel requirements for the replacement vehicles. ICE and HEV models use MPG as a metric, while PHEV and BEV models use Miles/kWh. The cost to charge value reflects not only the Miles/kWh, but the kWh needed to charge the vehicle and then the price per kWh. Values for PHEV/BEV SUVs and Pick-Ups are projections because the models are not available yet.

County Fleet Services, in their 2019 budget, projected $2.20/gallon, which they are able to obtain at wholesale. For the ICE and HEV models, fuel costs are a function of miles driven per year divided by vehicle-specific MPG multiplied by $2.20 for a gallon of gas.

$$Fuel\ Costs\ ICE/HEV = \$2.20(Miles\ driven\ per\ year \div MPG)$$

For BEV and PHEV models, fuel costs are a function of miles driven per year divided by miles per charge, multiplied by the cost to charge fully. I calculated cost per charge by researching the vehicle’s kWh/100 miles rates (using consumer data), determined the levelized kWh/mile rate, multiplied by the Miles per charge (available through consumer data), and multiplied by the cost of 1 kWh of electricity. The County purchases electricity at $0.09/kWh.

$$Fuel\ Costs\ BEV/PHEV = (Miles\ driven\ per\ year\ \div miles\ per\ charge) * (((kWh\ per\ 100\ miles \div 100) * Miles\ per\ charge) * \$0.09\ per\ kWh$$

For annual maintenance costs, I used vehicle-specific recommended maintenance schedules, plus parts and labor costs billable to County Fleet Services, to determine each vehicle's maintenance rate per 10,000 miles. A sample maintenance chart is available in Table 7. I then tied this maintenance rate to the average mileage of each vehicle. For each vehicle, I added fuel costs with maintenance costs to calculate the annual operating cost. I applied a 5% discount rate to determine the Total Cost of Ownership (TCO) of each vehicle.

In Microsoft Excel, I created a separate sheet for each of the 241 vehicles included in the analysis. I tied every sheet to static inputs on the 'Overview' tab, but included variable annual mileage data that were vehicle-specific. On each vehicle's sheet, I was then able to determine the cost benefit analysis for that specific vehicle. I then tied those 10-year TCO projections back to the 'Fleet Data' tab, which enabled me to track individual vehicle cost projections as part of the entire fleet in a central location.

Table 7

Maintenance Item	Cost	Frequency	Total Cost - 150k miles
Rotate Tires	$13.50	Every 5,000 miles	$405.00

Oil Change	$41.75	Every 5,000 miles	$1252.50
Replace cabin air filter	$19.25	Every 22,500 miles	$134.75
Inspect evaporative control system	$54.25	Every 45,000 miles	$162.75
Replace engine air cleaner filter	$12.75	Every 45,000 miles	$38.25
Change transmission fluid	$92.95	150,000 miles	$92.95
Replace spark plugs	$74.25	Every 60,000 miles	$148.50
Drain & fill engine cooling system	$85.50	150,000 miles	$85.50
Inspect accessory drive belts	$13.50	150,000 miles	$13.50
Replace windshield wipers	$10.75	Every 15,000 miles	$107.50
Replace hood/body lift support gas struts	$49.50	Every 75,000 miles	$99.00
Replace brakes	$525.00	Every 40,000 miles	$2,100.00
		Total Cost (150k miles)	$4,640.20
		Cost per 10k miles	**$309.35**

Table 7 - The Maintenance cost schedule for an Chevrolet Malibu, the replacement vehicle for ICE Sedans. Costs are estimates provided by the County's Fleet Division, while the frequency is the recommendation provided by Chevrolet.

Usage Patterns

It is important also to note that there is another element to this discussion. This analysis explored not only the financial and environmental benefits, but also evaluated the operational

barriers inherent to conversion to EV's. Can a County employee, whose job requires daily mileage exceeding 100 to 200 miles, reasonably be expected to drive an EV that must be charged after 50 miles? Especially if charging that vehicle requires several hours?

I already had data on annual mileage for each vehicle, but that data was not sufficient. The probability is high that some County vehicles are driven 300 miles in one day, and not again for two weeks. In such a scenario, the annual mileage would not tell the whole story. For this reason, I administered a qualitative survey to elicit usage *patterns* that expand on the usage *rates*. I asked questions like "How many days per week is this vehicle driven? What is the maximum daily miles driven? Where is this car stored, and for how long in between uses?" Answers to these questions helped identify whether an EV or PHEV is operationally viable. In some cases, an EV will not be a functional possibility.

The survey was administered to the vehicle coordinators in every County department. These individuals had a better handle on these behaviors. Once I elicited usage pattern data from the survey, I determined the 19 vehicles that could not be converted to BEV. For those 19 vehicles, when evaluating BEV costs and benefits, I instead assumed that the Department would purchase a HEV. I used HEV cost inputs and HEV environmental inputs. While this solution is not perfect, it had a minimal impact on the overall cost projections.

Total Conversion vs. Optimized Conversion

To calculate Total Conversion costs, I first calculated the TCO for all 241 vehicles across each of the alternatives: ICE, HEV, PHEV and BEV. Once the Total Conversion TCOs for these

alternatives were calculated, I subtracted the NPV of ICEs from the NPV of the other vehicle alternatives to determine how much more it would cost to perform a Total Conversion to a more expensive alternative. This comparison allowed me to generate a vehicle alternative's NPV in comparison to ICE. For the sake of clarity, I will use TCO to describe the 10 year cumulative costs of a vehicle or the entire fleet, and will use NPV as the comparative measure to describe the value of a conversion plan vs. the status quo.

Under the Optimized Conversion schedule, I assume that the amount of miles a vehicle is driven annually has a direct impact on which alternative makes the most financial sense. What if, in some scenarios, it is financially optimal to purchase 100 ICEs, 75 HEVs, 45 BEVs, and 21 PHEVs? To determine this, I conducted an optimization that projected, based on my inputs, the break-down of vehicle alternatives that generated the lowest TCO, hence the greatest NPV, for the fleet. For each of the ***Scenarios*** discussed in **Results**, I also projected the optimized portfolio of each vehicle alternative. For example: a Total Conversion to BEVs might cost X, but an Optimized Conversion to 100 ICEs, 75 HEVs, 45 BEVs, and 21 PHEVs might cost Y, saving the County $100,000. The County would likely pursue the Optimized Conversion schedule instead. The emissions reductions would be smaller in this situation, but far more financially viable.

Environmental Analysis

No cost benefit analysis of fleet electrification would be complete without quantifying the environmental benefits to reducing emissions. Considering that the emissions benefits rely

primarily on sources of electricity generation in the grid, in regions that rely heavily on fossil fuels, fleet electrification can actually have the opposite effect, causing greater emission levels than an ICE fleet (Alternative Fuels Data Center). In Monroe County, however, this is not the case. Western New York has one of the cleanest electric grids in the nation due to hydropower, nuclear power, and minimal use of coal generation (U.S. Energy Information Administration).

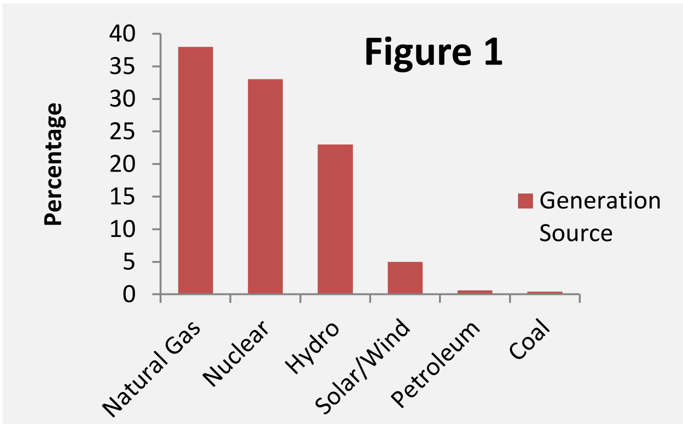


Figure 1 - In Western New York, most electricity is generated from natural gas, nuclear, and hydro power plants. Increasing amounts are generated from solar/wind. The generation portfolio is one of the cleanest in the nation.

To conduct the environmental analysis, I used the GREET Model, developed by DOE's Argonne National Laboratory. GREET calculates Well-to-Wheel emissions rates for vehicle types of all shapes and sizes. By expanding emissions beyond the tailpipe emissions, GREET also accounts for upstream emissions used during production (ie drilling, transportation, electricity generation, etc.) I input the electricity generation portfolio for Western New York, which affected the upstream emissions rates for any vehicle alternative using electricity.

GREET then projected emissions rates for all vehicle alternatives being considered by this analysis. The emissions are normalized to a per mile rate, which made it easy to calculate for each vehicle. I included a few important emissions: Carbon Dioxide (CO2) and Methane Gas

(CH4) were both combined into Carbon Dioxide equivalents (CO2e) to quantify GHGs emitted by the Fleet; as well as Nitrous Oxide (NOx) and PM2.5 (particulate matter with a diameter of up to 2.5 inches), which are localized emissions that affect human health.

Table 8				
	CO2 (g/mile)	**CH4 (g/mile)**	**NOx (g/mile)**	**PM2.5 (g/mile)**
ICE Sedan	400	0.5	0.27	0.0145
HEV Sedan	290	0.36	0.21	0.01181
PHEV Sedan	160	0.26	0.13	0.0066
BEV Sedan	60.7	0.18	0.0579	0.00186
ICE SUV	520	0.66	0.37	0.01891
HEV SUV	390	0.49	0.3	0.01577
PHEV SUV*	220	0.34	0.18	0.00882
BEV SUV*	69.17	0.21	0.066	0.00212
ICE Pick-Up	630	0.8	0.76	0.02582
HEV Pick-Up	490	0.63	0.59	0.02243
PHEV Pick-Up*	311	0.48	0.25	0.01248
BEV Pick-Up*	202	0.61	0.19	0.00618

Table 8 - Well to Wheel Emission Rates for each vehicle alternative. Rates calculated using GREET software. Values for PHEV/BEV SUVs and Pick-ups are projections because these models are not available yet.

Once each individual vehicle's emissions were projected, I tied those numbers to the 'Fleet Data' spreadsheet as well, allowing me to calculate cumulative emissions over the 10 year period for the entire fleet across different vehicle alternatives.

Once I had cumulative emissions totals, there are several models that translate emissions to dollars. The United States Environmental Protection Agency (EPA) estimates that there is a Social Cost of $42 for every metric tonne of CO2e (U.S. Environmental Protection Agency).

Furthermore, I used the Estimating Air pollution Social Impact Using Regression Model (EASIUR) to estimate the Social Costs of NOx and PM2.5 emissions specific to the longitude and latitude of Monroe County. EASIUR projects Social Costs of $168,542/metric tonne of PM2.5 and $14,146/metric tonne of NOx.

Table 9	
Emission	**Social Cost (per tonne)**
CO2e	$42
NOx	$14,146.50
PM2.5	$168,542.53

Table 9 - Social cost of different emissions species

It is worth noting that while I calculate emissions totals and translate them into social costs, these costs are not factored into the final computation for the cost benefit analysis. Monroe County, like many municipalities, operates under strict budgetary constraints, and would base a conversion decision based on the financial merits. The social costs are discussed under each of the ***Scenarios*** below, but as a supplement to the primary findings.

Parameters and Assumptions

To conduct this analysis, I set a few parameters. First, I excluded from this analysis the almost 750 “vehicles” which are not light or medium duty, road-ready vehicles. This includes

vehicles like front-end loaders, dump trucks, tractors, golf carts, lawn mowers, de-icers, etc. There are currently no viable EV alternatives available for these vehicles. This left me with 252 light and medium duty vehicles. I then excluded 11 additional vehicles which had only been purchased within the last 12 months and thus had insufficient mileage data to warrant inclusion.

The cost benefit analysis also examined TCO over a 10 year window. 10 years is the current life expectancy for vehicles in the County's fleet, although admittedly these vehicles have predominantly been traditional vehicles. The expectation is that EVs will be more durable and last longer, but because the market is still in the early stages, that remains to be proven definitively. Therefore, the 10 year window establishes whether a cost savings can be realized without introducing an additional, untestable variable.

I also assumed that each vehicle is a current candidate for replacement. For example, I did not differentiate between the Department of Public Health's five 2018 Chevrolet Malibu's, five 2015 Malibu's and 20 Malibu's from 2010 (all numbers approximate). For the purposes of this analysis, I assumed every vehicle is ready to be replaced. Furthermore, I did not account for re-sale value of the vehicles on the back end. There remains a lack of data regarding re-sale value of EVs because of how new they are, and a comparison would not provide much value. At the same time, the County does not have a uniform re-sale policy that could provide useful data – in some cases, vehicles are shuffled and re-purposed, but in others, they are sold at auction for pennies on the dollar. Rather than attempt to quantify this broad array of outcomes, I will ignore any potential resale value of both ICEs and EVs.

One major assumption pertains to SUVs and pickup trucks, which have no BEV/PHEV options currently available on the New York State Contract. Some of these technologies exist but are not yet on State Contract, while other technologies are still in development. I chose to include

these vehicles anyway, expecting that the technologies will soon be ready and available for purchase on State Contract. Without existing capital cost, mileage, MPG/range, or emissions figures readily available, I had to estimate these numbers based on the relationships between their ICE counterparts.

With respect to Electric Vehicle Supply Equipment (EVSE), I only included the capital cost of purchasing the EVSE. I did not include labor or construction costs to install the equipment. Furthermore, the charging infrastructure installed by the County during a pilot project had cords to charge two vehicles at once. The cost of one EVSE is $7,000, so I estimated that the EVSE capital cost for each BEV/PHEV vehicle was $3,500. I did not conduct a separate spatial analysis to optimize where charging infrastructure could be built to maximize utility. There may be a synergistic effect in which fewer charging stations must be purchased, but I used a 2:1 EV to charging station ratio.

4 – Results and Discussion

Overview

The results section of this paper will be split into five different sub-categories, with varying input values. This is important because some of the variables, especially price of gasoline and capital cost of EVs, are changing rapidly. Gasoline has historically been one of the most volatile commodities available on global markets, and thus significant consideration should be given to changes in the price of a gallon. At the same time, EV technology continues to improve rapidly, and as the batteries improve, the cost plummets. EV prices in 2018 will look radically different than EV prices in 2021. For this reason, I have organized the **Results** section

based on five different ***Scenarios***, which use different values for the variables most likely to change. The different scenarios will double as the Sensitivity Analysis for this paper. To structure each ***Scenario***, I will first provide results for the Total Conversion plan, followed afterward by the Optimized Conversion plan.

Scenario 1 – Base Case

The first Scenario I tested is, of course, the Base Case. This Scenario represents the cost benefit analysis with the input numbers as they exist at this moment in time. The price of a gallon of gas is $2.20, there is a 5% financial discount rate, the capital cost of the vehicle alternatives mirror those found in ***Cost Benefit Analysis***, as do the remaining variables for operating costs. Further discussion of these variables exists above.

Total Conversion

Under these conditions, the status quo option (ICEs) produces the lowest TCO fleet-wide. The County would generate a negative NPV by converting to any alternative other than ICEs. From a purely financial perspective, the County should continue to purchase ICE vehicles for its fleet. Purchasing HEVs across the board would require a TCO of $9.1 million, equal to a NPV of -$703,000 compared to purchasing ICEs. Along the same lines, converting to PHEVs would require a TCO of $11.7 million, with a NPV of -$3.3 million compared to ICEs. Converting to BEVs would require a $10.8 million TCO, with a NPV of $-2.3 million compared to ICEs. These cost figures are found in Table 10.

Table 10

	TCO	NPV
ICE	$8,475,000	**$0**
HEV	$9,177,000	**-$703,000**
PHEV	$11,745,000	**-$3,270,000**
BEV	$10,781,000	**-$2,306,000**

Table 10 - Total Cost of Ownership when considering a Total Conversion to an alternative; NPV when comparing the alternative to ICEs

The Base Case Scenario implies that the County should maintain status quo for financial reasons. But what about the environmental benefits? There are certainly emissions benefits to converting to one of the other alternatives. Table 11 details the Cumulative Emissions totals, in metric tonnes, for the four vehicle alternatives over 10 years.

Table 11			
	CO2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

Table 11 - The cumulative emissions generated over 10 years across the entire fleet, assuming Total Conversion to an alternative

Clearly, emissions totals are far higher for ICE alternatives than for their EV counterparts. Significant emissions reductions could be realized by conversion to any of the other three alternatives, but to determine exactly how much, a closer look at the comparative emissions is required. Total Conversion from ICEs to BEVs could reduce CO2e emissions by over 8,100 tonnes over the 10 year window, while eliminating 7.31 tonnes of NOx and 0.32 tonnes of PM2.5 emissions. Smaller emissions reductions are possible by converting to PHEVs or HEVs.

Table 13			
Social Costs	**CO2e**	**Local Emissions**	**Total**
ICE	$0	$0	**$0**
HEV	$118,000	$42,000	**$160,000**
PHEV	$264,000	$124,000	**$388,000**
BEV	$344,000	$158,000	**$502,000**

Table 13 - The social costs of Fleet-wide emissions over 10 years. Or, the benefits of converting to a non-ICE alternative

When factoring in the social costs of these emissions, there are additional financial benefits to conversion. Table 13 details the social cost of emissions over 10 years when considering Total Conversion alternatives. There are significant financial benefits to reducing emissions through converting to BEVs, and smaller financial benefits to converting to PHEVs or HEVs. However, even when the social cost of emissions is factored into the cost benefit analysis, the County still generates a negative NPV over 10 years when considering Total Conversion to an EV.

Table 14		
	NPV of Conversion	**NPV of Conversion With Social Costs**
ICE	$0	$0
HEV	-$703,000	-$543,000

PHEV	-$3,270,000	-$2,882,000
BEV	-$2,306,000	-$1,804,000

Table 14 - The NPV of Total Conversion to an alternative vs. the NPV of Total Conversion including the social costs of emissions

Factoring in the social costs into the overall cost benefit analysis makes the NPV of conversion more palatable for the budget-oriented County decision-makers. If driven purely by dollars and cents, though, Total Conversion to BEVs, PHEVs, or HEVs still represents a net loss. The County would have to decide if realizing the emissions reductions are worth the financial costs.

Optimized Conversion

Despite costs that warrant continued purchase of ICEs under Total Conversion, when evaluating the Optimized Conversion, there are 23 vehicles with a different optimal alternative.

Table 15		
	Quantity (241)	**Percentage (%)**
ICE	218	90%
HEV	22	9%
PHEV	0	0%
BEV	1	0%

Table 15 - Portfolio of vehicles under an Optimized Conversion in the Base Case

What do these 23 vehicles have in common? They are all SUV. The capital cost difference between the ICE and HEV SUV is only $3,000, so there is less difference to make up over the 10 year lifespan of the vehicle. Additionally, all 23 vehicles are extremely high mileage.

The average annual mileage that warrants HEV conversion is 13,370, with a range of 10,780 to 18,669. The vehicle converted to BEV is an SUV driven an average of 19,302 miles annually. Due to operational savings over 10 years, this vehicle warrants the higher BEV Capital Cost.

Table 16		
	TCO	**NPV of Conversion**
Optimized	$8,452,000	$23,000
ICE	$8,475,000	$0
HEV	$9,177,000	-$703,000
PHEV	$11,745,000	-$3,270,000
BEV	$10,781,000	-$2,306,000

Table 16 - A comparison of the Total Cost of Ownership for Total Conversion plans vs. the Optimized Conversion Plan

If the Optimized Conversion were pursued, an additional cost savings of $23,000 over 10 years could be realized through a vehicle-specific conversion when compared to the Total Conversion ICE choice, even in the base case. Under the Optimized Conversion, there is are small emissions reductions of 485 CO2e tonnes, 0.02 PM2.5 tonnes, and 0.25 tonnes of NOx over 10 years. This equates to approximately $26,000 in environmental savings.

Table 17			
	CO2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
Optimized	10,960.13	0.41	9.89

ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

When evaluating the conversion options and including social costs, the Optimized Conversion generates $23,000 in savings over 10 years with an additional $26,000 in social

Table 17 - The cumulative emissions over 10 years comparing Total Conversion plans to the Optimized Conversion

benefits, totaling $49,000. The other Total Conversion plans all have a negative NPV.

Finding the Optimal Vehicle Alternative

There is clearly a spectrum for which vehicle alternative is the optimal choice depending on the annual mileage. As annual mileage increases, the NPV of non-ICE alternatives increases as well. Where are these break-even points, though? How can we determine the annual mileage needed for a HEV to be optimal vs. an ICE? Or a BEV vs. an ICE?

Figures 2 graphs the break-even point for an SUV. In other words, for one specific vehicle, how do changes in average annual mileage affect its TCO (and concurrently, its NPV relative to other alternatives.) Similar graphs for sedans and pickups, which do not have break-even points, are available in the Appendix.

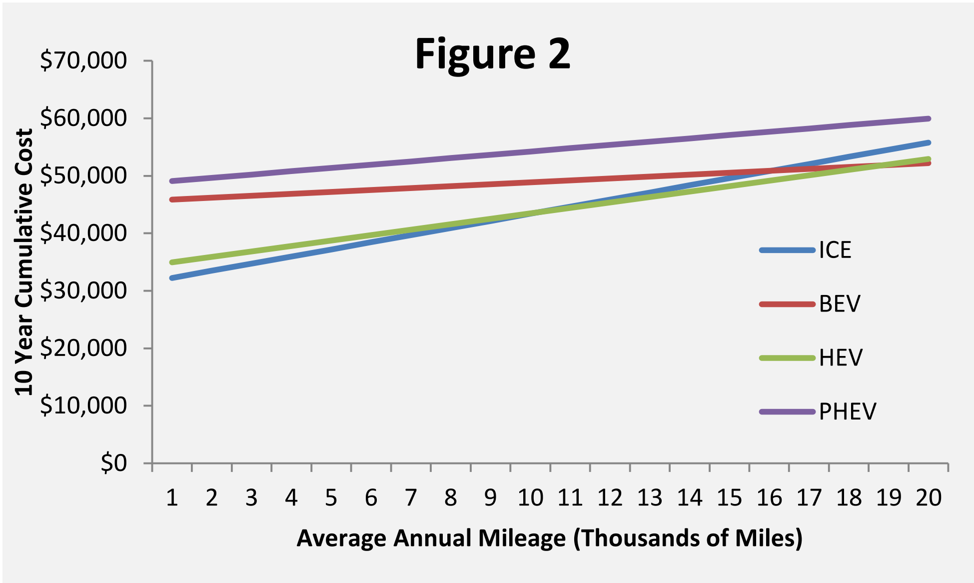


Figure 2 - Total Cost of Ownership break-even point for an SUV in the Base Case

For a sedan, even at the maximum of 20,000 annual miles, there is never a break-even point – it is always the case that the ICE is the optimal vehicle, although it is very close. For an SUV, however, the ICE, and HEV alternatives are the optimal vehicle at different annual mileage counts. The PHEV never is. For a pickup, the same is true as a sedan – the ICE is always the optimal vehicle.

Scenario 2 – 0% Discount Rate / 20% Discount Rate

The second Scenario I tested is an alteration of the discount rate. While important, the time value of money can vary across different organizations of different types. Some organizations discount at lower rates, like 5%, especially in cases where liquid capital is not paramount. Government organizations and municipalities tend to have lower discount rates. Private companies often have higher discount rates because they need to earn higher profits *now* in order to even exist years down the road. These discount rates can be as high as 20%. In some

cases, organizations do not apply a discount rate at all, operating under the principle that X money now is effectively the same as X money in 10 years.

Total Conversion

The Base Case Scenario assumed a 5% discount rate as a starting point, but what if the County more highly valued its resources in the present, thus requiring a 20% discount rate? Conversely, as a municipal government, the County is not going anywhere, so what if it did not discount at all (a 0% discount rate.) These two ends of the spectrum are tested in ***Scenario 2***. Ideally, because these are two different values for the same data input, I would have separated these two discount rates into two separate ***Scenarios***. I kept them organized under one ***Scenario*** because I did not expect this to significantly alter my results in either direction.

Table 18						
	5% Discount Rate (Base Case)		**0% Discount Rate**		**20% Discount Rate**	
	TCO	**NPV**	**TCO**	**NPV**	**TCO**	**NPV**
ICE	$8,475,000	$0	$9,106,000	$0	$7,498,000	$0
HEV	$9,177,000	-$703,000	$9,699,000	-$593,000	$8,370,000	-$872,000
PHEV	$11,745,000	-$3,270,000	$12,096,000	-$2,990,000	$11,201,000	-$3,703,000
BEV	$10,781,000	-$2,306,000	$11,116,000	-$2,010,000	$10,261,000	-$2,764,000

Table 18 - Cost benefit analysis of Total Conversion plans, including comparisons to the status quo, at different discount rates

This assumption proved to be correct, as Table 18 shows. Using a 20% discount rate decreased the NPV of converting to BEVs by over $450,000, with a similar loss in NPV for

PHEVs and a smaller loss for HEVs. As expected, the higher discount rate moves the County further away from its goal of obtaining cost savings. Conversely, though, if the County chose to forego a financial discount rate in its investment strategy, almost $300,000 in NPV is added for both the BEV and PHEV alternatives. This brings the 10 year NPV when compared to ICEs for BEVs to -$2 million or -$3 million for PHEVs.

Because I decided against applying a discount rate to the emissions, I will forego including data pertaining to the raw tonnage of emissions in this section – the cumulative 10 year tonnage is identical to the tonnage detailed in the Base Case. What will change, however, is how the social costs affect the overall NPV of conversion. With different discount rates, would the social cost of emissions have a greater impact?

Table 19			
	5% Discount Rate (Base Case)	**0% Discount Rate**	**20% Discount Rate**
ICE	$0	$0	$0
HEV	-$543,000	-$433,000	-$712,000
PHEV	-$2,882,000	-$2,602,000	-$3,315,000
BEV	-$1,804,000	-$1,508,000	-$2,262,000

Table 19 - Cost benefit analysis of Total Conversion plans at different discount rates, factoring in social costs

Again, as expected, the 20% discount rate decreases the NPV of investing in Total Conversion to alternative vehicles, even when considering the social costs. Meanwhile, the combination of 0% discount rate and factoring in social costs make the NPV of Total Conversion even more palatable for the County. A break-even point is still not reached, though.

Optimized Conversion

When evaluating an Optimized Conversion, reducing the discount rate to 0% would increase the amount of HEVs in the fleet from 22 to 37 and increase the BEVs from 1 to 2.

Table 20		
	Quantity (241)	**Percentage (%)**
ICE	202	84%
HEV	37	15%
PHEV	0	0%
BEV	2	1%

Table 20 - Portfolio of vehicles under an Optimized Conversion at 0% Discount Rate

All vehicles converted to HEVs and BEVs are still SUVs. The average annual mileage of a vehicle converted to HEV is 11,575, with a range extending from 7,975 to 18,669. The BEV candidates, meanwhile, have annual mileages of 14,737 and 19,302. The overlap between the higher-mileage HEVs and lower-mileage BEVs seems illogical, except for the aforementioned assumption that vehicles with operational range concerns would be precluded from BEV consideration and would convert to HEVs instead. For these vehicles, the BEV *would* be the choice except for the range issue.

Table 21		
	TCO	**NPV of Conversion**
Optimized	$9,045,000	$61,000
ICE	$9,106,000	$0
HEV	$9,699,000	-$593,000
PHEV	$12,096,000	-$2,990,000
BEV	$11,116,000	-$2,010,000

Table 21 - When considering the Optimized Conversion at a 0% discount rate, there is an estimated $61,000 in savings over 10 years

The Optimized Conversion generates small emissions reductions of 730 tonnes of CO2e, 0.41 tonnes of NOx, and 0.03 tonnes of PM2.5. Altogether, these reductions equate to almost $40,000 in human health benefits. The total benefit to pursuing the Optimized Conversion in this ***Scenario*** is $101,000 when considering the social costs.

Table 22			
	CO2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
Optimized	10,714.37	0.41	9.75
ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

Table 22 - The cumulative emissions over 10 years comparing Total Conversion plans to the Optimized Conversion, at a 0% discount rate

If the discount rate was 20%, almost every vehicle is precluded from Optimized Conversion consideration. This is because the operating savings over 10 years are negligible because of the high discount rate. There is only one vehicle that is still worth converting to HEV: the SUV driven an average of 19,302 miles every year. As the highest annual mileage vehicle in the fleet, this will likely always be the first candidate for conversion in an Optimized plan.

Table 23		
	Quantity (241)	**Percentage (%)**
ICE	240	99%
HEV	1	1%
PHEV	0	0%
BEV	0	0%

Table 23 - Portfolio of vehicles under Optimized Conversion at a 20% Discount Rate

The difference in TCO is negligible. In Table 24, I include extra significant figures to communicate how small the difference is – only an estimated $55. Along the same lines, I will forego a comparison of the emissions because the difference is negligible.

Table 24	
	TCO
Optimized	$7,497,676
ICE	$7,497,731
HEV	$8,370,000
PHEV	$11,201,000
BEV	$10,261,000

Table 24 - A comparison of the TCO of Total Conversion plans vs. the Optimized Conversion at a 20% Discount Rate

Finding the Optimal Vehicle Alternative

What do the break-even points look like in the Optimized Conversion schedule? For sedans, even with no discount rate, there is still no break-even point. This demonstrates that there is never an amount of annual mileage that justifies purchase of a sedan other than an ICE. For SUVs, the break-even point is around 17,000 annual miles. Any vehicle above that threshold is best converted to HEV to maximize its NPV.

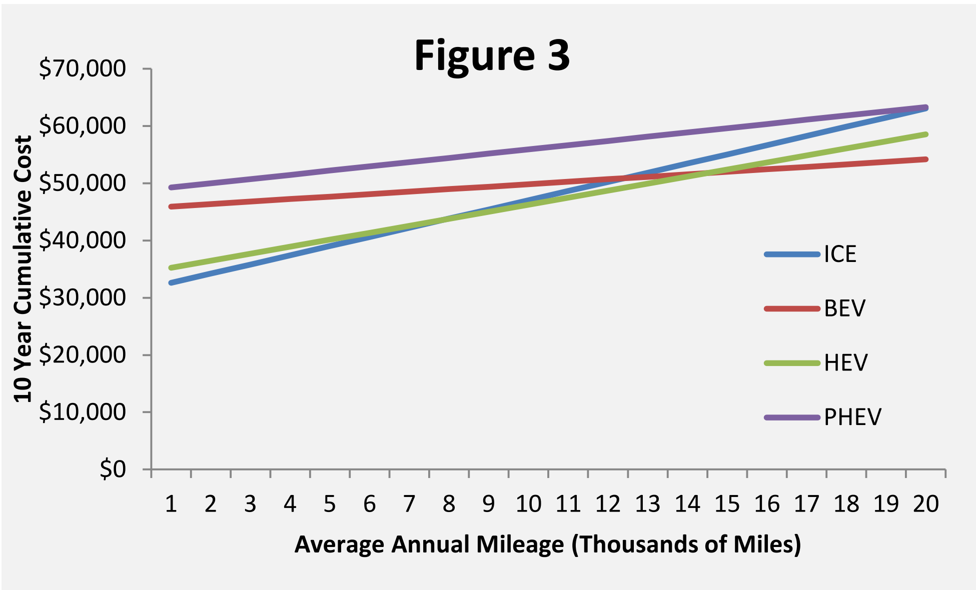


Figure 3 - Total Cost of Ownership break-even point for an SUV at a 0% Discount Rate

For pickup trucks, similar to sedans, there is no situation in which anything other than an ICE should be purchased. Even with no discount rate, the operational savings are not enough to overcome the steeper capital costs. At a 20% discount rate, the break-even points are further out. Both sedans and pickups should not be converted to EVs, and even SUVs have a higher annual mileage break-even point.

Scenario 3 – Change in the Price of Gasoline

The price of a gallon of gasoline often fluctuates wildly and rapidly because oil is traded in a global market. County DES projected $2.20/gallon in its 2019 budget, but that price has likely already changed. The 2019 EIA Annual Report makes three plausible projections for gas prices in the coming years: the Reference Case, the Low Case, and the High Case (Energy Information Administration, 2019. *Annual Energy Outlook 2019.*) In ***Scenario 3,*** we conduct the cost benefit analysis using these three gasoline price estimates as benchmarks.

Table 25	
EIA Model	**Gasoline price per gallon**
Base Case	*$2.20*
EIA Low Case	$1.70
EIA Reference Case	$2.96
EIA High Case	$4.80

Table 25 - EIA Projections for Gasoline Price

Total Conversion - EIA Reference Case vs. Base Case

When using EIA's Reference Case as the gasoline price estimate ($2.96/gallon), TCOs increase significantly for ICE and HEV models. TCOs for PHEV and BEV models are mostly stagnant, with small exceptions for BEVs in cases where there were range limitations and HEV alternatives were used instead. For this reason, the NPV increases significantly for PHEV and BEV conversion and increases slightly for HEV conversion. This scenario requires a total cost of only $1,790,000 over 10 years to implement Total Conversion to BEVs.

Table 26				
	Base Case		**EIA Reference Case**	
	TCO	**NPV**	**TCO**	**NPV**
ICE	$8,475,000	$0	$9,036,000	$0
HEV	$9,177,000	-$703,000	$9,611,000	-$575,000
PHEV	$11,745,000	-$3,270,000	$11,745,000	-$2,709,000
BEV	$10,781,000	-$2,306,000	$10,826,000	-$1,790,000

Table 26 - Cost benefit analysis of Total Conversion plans in the EIA Reference Case for gasoline price, including comparison to the status quo

The cumulative emissions have not changed from ***Scenario 1.*** When factoring in the social cost of emissions into the EIA Reference Case analysis, the NPV increase is even greater – with a required investment of only $1,287,000 over 10 years for Total Conversion to BEVs.

Total Conversion - EIA Low Case vs. Base Case

When using the EIA Low Case, the TCOs for both ICE and HEV Total Conversion decrease because their annual fuel costs decrease. There is no change in TCOs for PHEV and BEV Total Conversion. Because it is even cheaper to invest in ICEs over 10 years in this scenario, the NPV of converting to another alternative plummets.

Table 27				
	Base Case		**EIA Low Case**	
	TCO	**NPV**	**TCO**	**NPV**
ICE	$8,475,000	$0	$8,106,000	$0
HEV	$9,177,000	-$703,000	$8,892,000	-$787,000
PHEV	$11,745,000	-$3,270,000	$11,745,000	-$3,639,000
BEV	$10,781,000	-$2,306,000	$10,751,000	-$2,645,000

Table 27 - Cost benefit analysis of Total Conversion plans in the EIA Low Case for gasoline price, including comparison to the status quo

When factoring in the social costs to the 10 year NPV, it drops because it is cheaper to operate an ICE. These findings are consistent with conventional wisdom: that EV technology is most cost-effective in situations where the price of gasoline is high. When the price of gasoline drops, EV sales tend to dip because they are comparatively more expensive.

Total Conversion - EIA High Case vs. Base Case

The High Case estimate by EIA, which projects a maximum price of gasoline at $4.80, is considered to be unlikely because despite high oil prices, demand for gasoline will continue to drop due to EV growth. However, EIA still considers this a possibility.

Table 28				
	Base Case		**EIA High Case**	
	TCO	**NPV**	**TCO**	**NPV**
ICE	$8,475,000	$0	$10,395,000	$0
HEV	$9,177,000	-$703,000	$10,660,000	-$265,000
PHEV	$11,745,000	-$3,270,000	$11,745,000	-$1,350,5000
BEV	$10,781,000	-$2,306,000	$10,935,000	-$540,000

Table 28 - Cost benefit analysis of Total Conversion plans in the EIA High Case for gasoline price, including comparison to the status quo

At this price point, the NPV of vehicle alternatives makes conversion much more feasible. Because TCOs for ICEs and HEVs increase so much, PHEVs and BEVs are much more viable. In fact, the NPV for Total Conversion to BEVs is only about -$540,000 compared to the status quo. When social costs are factored in, the NPV increases even more. The NPV of BEV conversion is only -$38,000, while the NPV of PHEV conversion increases to above $-1 million for the first time. HEV conversion improves due to mileage efficiencies.

Optimized Conversion – EIA Reference Case

If Total Conversion was not pursued, how would changes in the price of gasoline affect the potential for Optimized Conversion? In the Reference Case, the County's vehicle fleet still consists primarily of ICEs, but with a few more HEVs and BEVs sprinkled in.

Table 29		
	Quantity (241)	**Percentage (%)**
ICE	201	83%
HEV	34	14%
PHEV	0	0%
BEV	6	2%

Table 29 - Portfolio of vehicles under Optimized Conversion, EIA Reference Case gasoline price

The vehicles converted to HEV and BEV are all, once again, SUVs. The average mileage for these HEV candidates is 11,081 with a range of 7,938 to 18,669. The vehicles converted to BEVs had an average annual mileage of 15,281 with a range of 14,260 miles to 19,302 miles. When considering the EIA Reference Case gasoline price, there is an estimated $73,000 savings over 10 years if the Optimized Conversion is pursued.

Table 30		
	TCO	**NPV of Conversion**
Optimized	$8,963,000	$73,000
ICE	$9,036,000	$0
HEV	$9,611,000	-$575,000
PHEV	$11,745,000	-$2,709,000
BEV	$10,826,000	-$1,790,000

Table 30 - Cost benefit analysis, Total Conversion plans vs. Optimized Conversion plan

Under the Optimized Conversion, emissions reductions of 930 tonnes of CO_2e, 0.3 tonnes of PM2.5, and 0.54 tonnes of NOx can be realized over 10 years, generating a social benefit of $51,000.

Table 31			
	CO2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
Optimized	10,514.72	0.40	9.61
ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

Table 31 - Cumulative emissions of Total Conversion plans vs. Optimized Conversion

When factoring in social costs to the cost benefit analysis, the Optimized Conversion plan generates a 10 year savings of $124,000.

Finding the Optimal Vehicle Alternative – EIA Reference Case

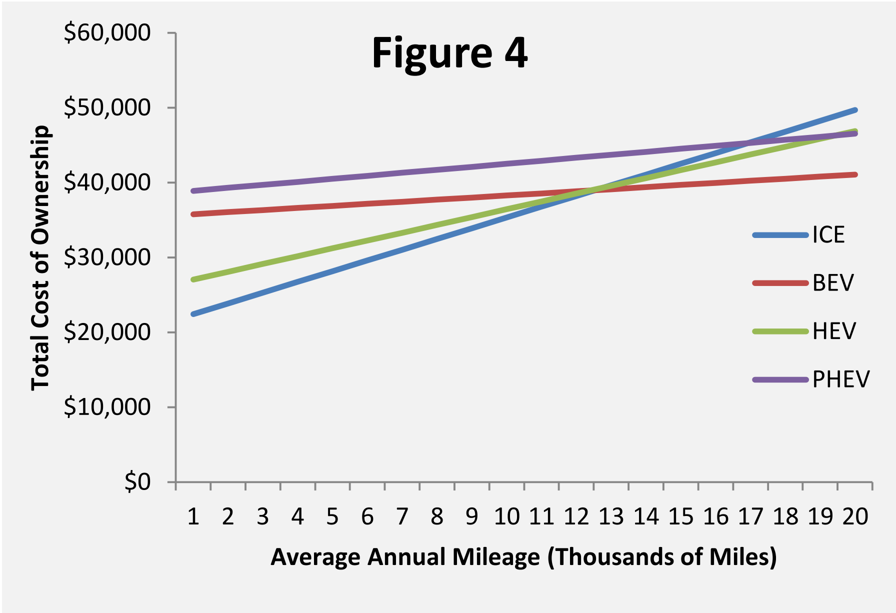


Figure 4 - Total Cost of Ownership break-even point for a sedan in the EIA Reference Case gasoline price

In the EIA Reference Case gasoline price, all of the break-even points arrive at lower annual mileages. For the first time, there are conditions under which it is optimal to convert a sedan to an alternative vehicle – it is actually optimal to convert it to everything else at higher mileages. For SUVs, all but the lowest-mileage vehicles should be replaced with alternatives other than ICEs. Any SUV driven more than 9,000 miles annually should be replaced with a BEV.

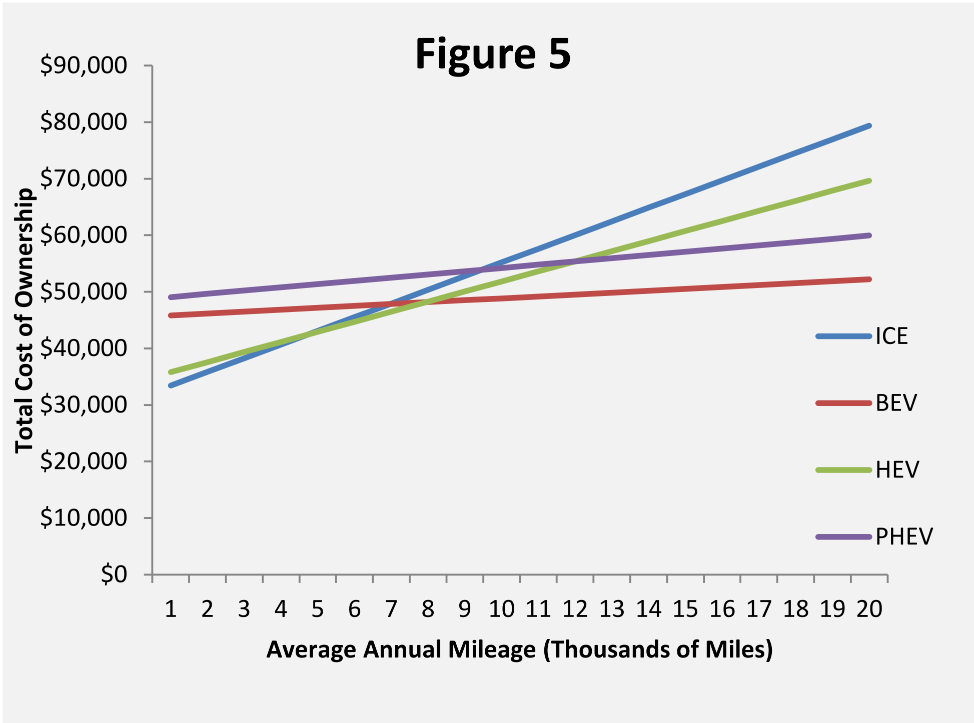


Figure 5 - Total Cost of Ownership break-even point for an SUV in the EIA Reference Case gasoline price

For pickups, the break-even points happen later than their sedan and SUV counterparts, but they still happen. The highest mileage pickups are still best converted to BEVs.

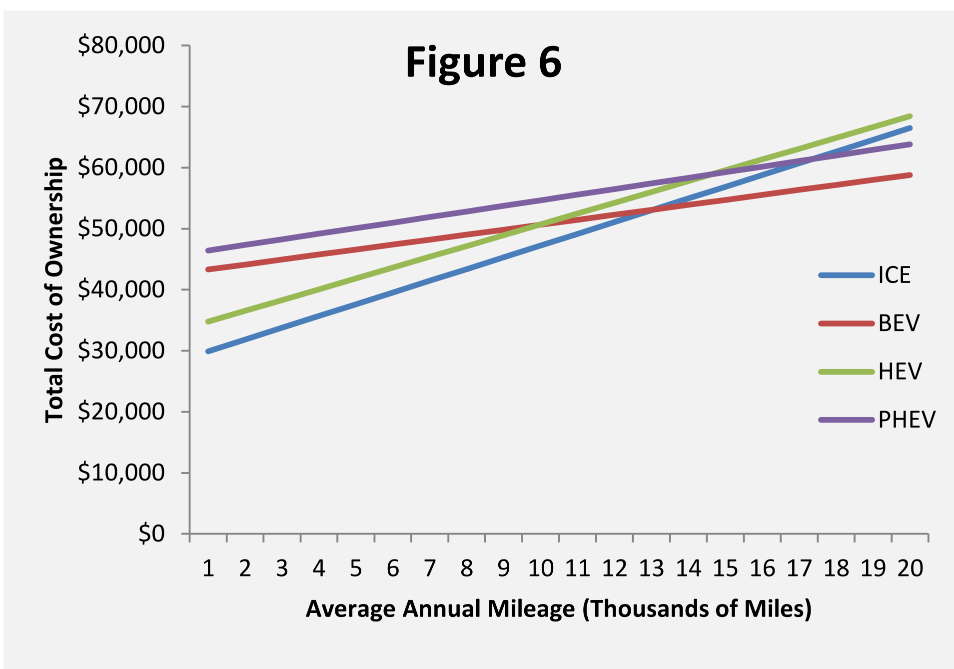


Figure 6 - Total Cost of Ownership break-even point for a PickUp in the EIA Reference Case gasoline price

Optimized Conversion – EIA Low Case

In the Low Case, the fleet is almost entirely ICEs. A drop in the price of gasoline excludes all but 10 vehicles from conversion to EVs. These 10 vehicles have an average annual mileage of 15,516 and a range of 13,355 miles to 19,302 miles.

Table 32		
	Quantity (241)	**Percentage (%)**
ICE	231	96%
HEV	10	4%
PHEV	0	0%
BEV	0	0%

Table 32 - Quantity of vehicles at EIA Low Case gasoline price

When considering the EIA Low Case gasoline price, there is only a potential for $5,000 in cost savings over 10 years when doing an Optimized Conversion.

Table 33		
	TCO	**NPV of Conversion**
Optimized	$8,101,000	$5,000
ICE	$8,106,000	$0
HEV	$8,892,000	-$787,000
PHEV	$11,745,000	-$3,639,000
BEV	$10,751,000	-$2,645,000

Table 33 - Cost benefit analysis, Total Conversion plans vs. Optimized Conversion

Under the Optimized Conversion, emissions reductions of 210 tonnes CO2e, 0.1 tonnes PM2.5, and 0.11 tonnes NOx are realized over 10 years, generating a social benefit of $11,000.

Table 34			
	CO2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
Optimized	11,235.90	0.42	10.05
ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

Table 34 - Cumulative emissions over 10 years, Total Conversion plans vs. Optimized Conversion

When factoring in social costs to the cost benefit analysis, the Optimized Conversion plan generates a 10 year savings of $16,000.

Finding the Optimal Vehicle Alternative – EIA Low Case

Not unexpectedly, but when the price of gasoline drops to the EIA – Low Case estimate, ICEs are the most optimal vehicle alternative almost across the board. For both sedans and pickups, ICEs are best at even the highest annual mileage. For SUVs with an annual mileage higher than 13,000, HEVs are the optimal choice. But otherwise, ICE is still the best financial value.

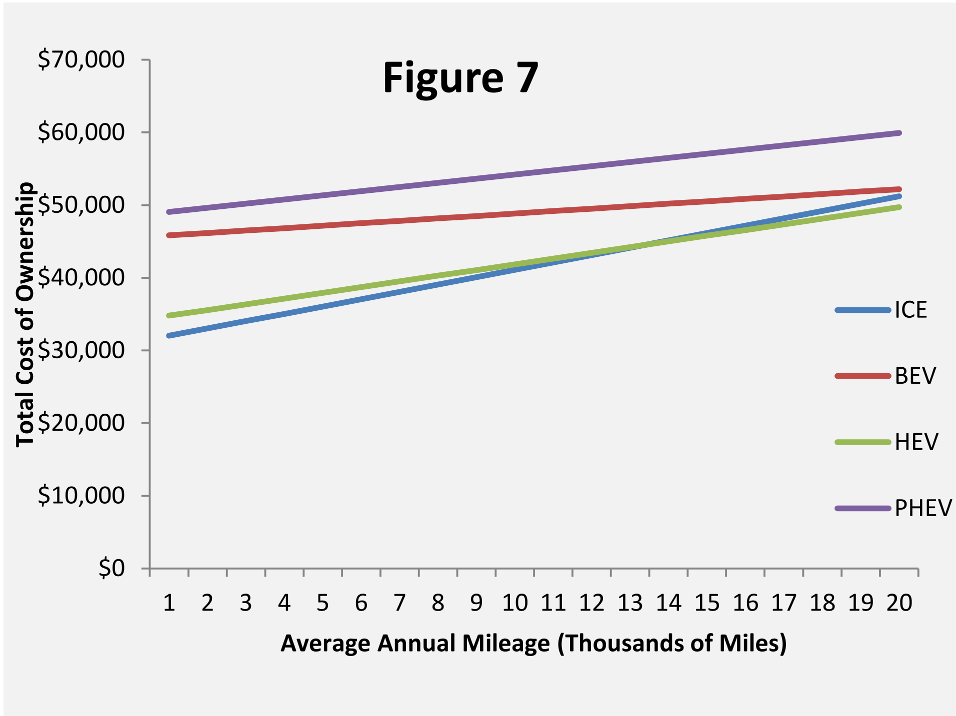


Figure 7 - Total Cost of Ownership break-even point for an SUV in the EIA Low Case gasoline price

Optimized Conversion – EIA High Case

In the EIA High Case, we get much higher degrees of variation. 65% of the County's fleet would still consist of ICEs, but we see the highest proportion of BEV conversion yet, with the first PHEVs incorporated into the fleet. Significantly, conversion schedules extend beyond SUVs for the first time.

Table 35		
	Quantity (241)	**Percentage (%)**
ICE	157	65%

HEV	21	9%
PHEV	8	3%
BEV	55	23%

Table 35 - Portfolio of vehicles under Optimized Conversion, EIA High Case gasoline price

The average annual mileage of a vehicle converted to HEV is 6,566, with a range of 5,326 to 11,301 miles (the vehicle driven 11,301 miles would have been a BEV except for range concerns.) The vehicles converted to BEVs, on the other hand, have an average annual mileage of 12,591 and a range of 7,975 to 19,302 miles per year. The vehicles converted to PHEV have an average annual mileage of 16,022, indicating that these 8 are among the highest mileage in the fleet. Interestingly, all 8 have range concerns precluding BEV conversion. In these cases, where HEV projections were used instead, the PHEV emerges as the most cost-effective.

Table 36		
	TCO	**NPV of Conversion**
Optimized	$9,968,000	$427,000
ICE	$10,395,000	$0
HEV	$10,660,000	-$265,000
PHEV	$11,745,000	-$1,350,5000
BEV	$10,934,000	-$540,000

Table 36 - Cost benefit analysis in the EIA High Case gasoline price, Total Conversion plans vs. Optimized Conversion

When considering the EIA High gasoline price, there is the potential for an estimated $427,000 in cost savings over 10 years if an Optimized Conversion is pursued.

Under the Optimized Conversion, emissions reductions of 3,550 tonnes of CO_2e, 0.13 tonnes of PM2.5, and almost 3 tonnes of NOx can be realized over 10 years. These reductions would generate a social benefit of over $210,000.

Table 37			
	CO_2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
Optimized	7,902.97	0.29	7.33
ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

Table 37 - Cumulative emissions of Total Conversion plans vs. Optimized Conversion, EIA High Case gasoline price

When factoring in the social costs, an estimated $637,000 could be saved over 10 years if the Optimized Conversion is pursued.

Finding the Optimal Vehicle Alternative – EIA High Case

The EIA High Case gasoline price is where we see the earliest break-even points and the most variability. For sedans, any ICE over 12,000 miles should be replaced with a BEV. There is little space for even a HEV to be worthwhile under these conditions.

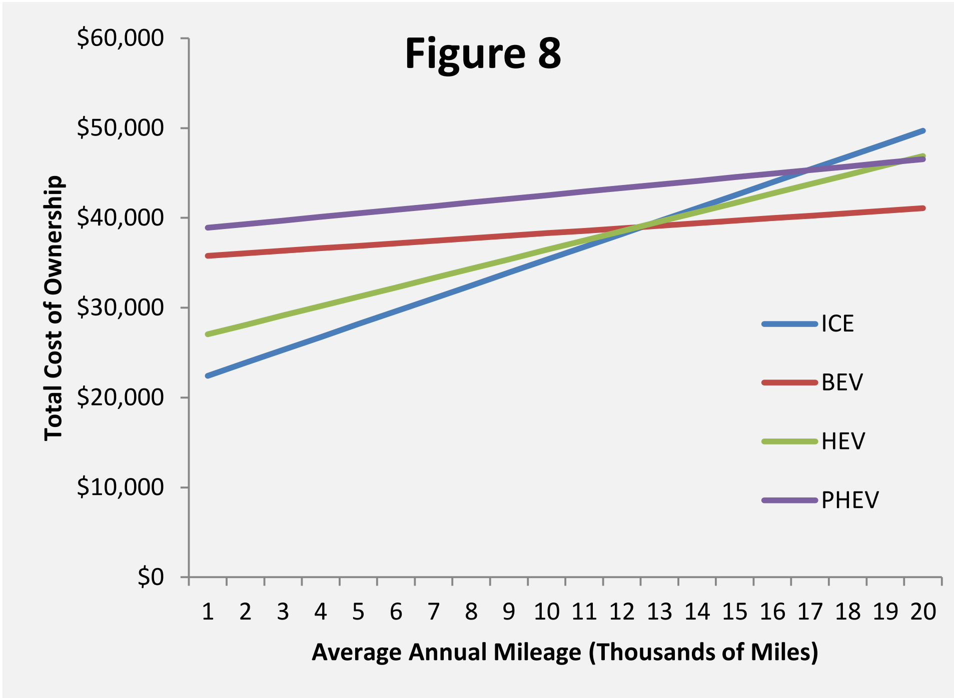


Figure 8 - Total Cost of Ownership break-even point for a sedan in the EIA High Case gasoline price

Under these conditions, almost every SUV should be replaced with a HEV or a BEV. In fact, the break-even point sits at 4,000 annual miles – only 7 SUVs have annual miles below 4,000.

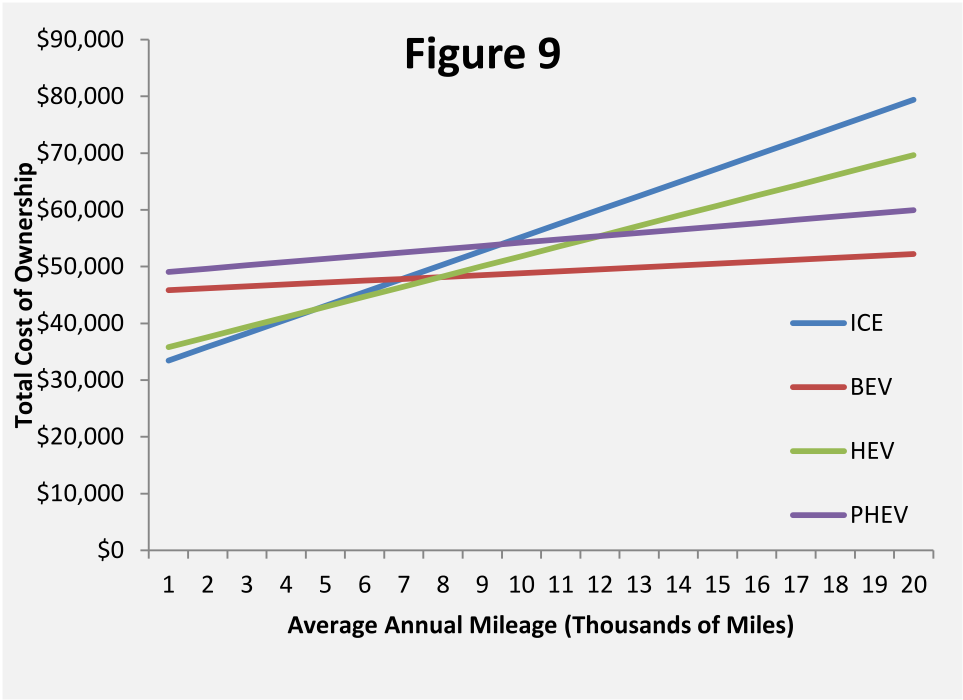


Figure 9 - Total Cost of Ownership break-even point for an SUV in the EIA High Case gasoline price

For pickups in the fleet, any vehicle over 12,000 annual miles should be replaced by a BEV.

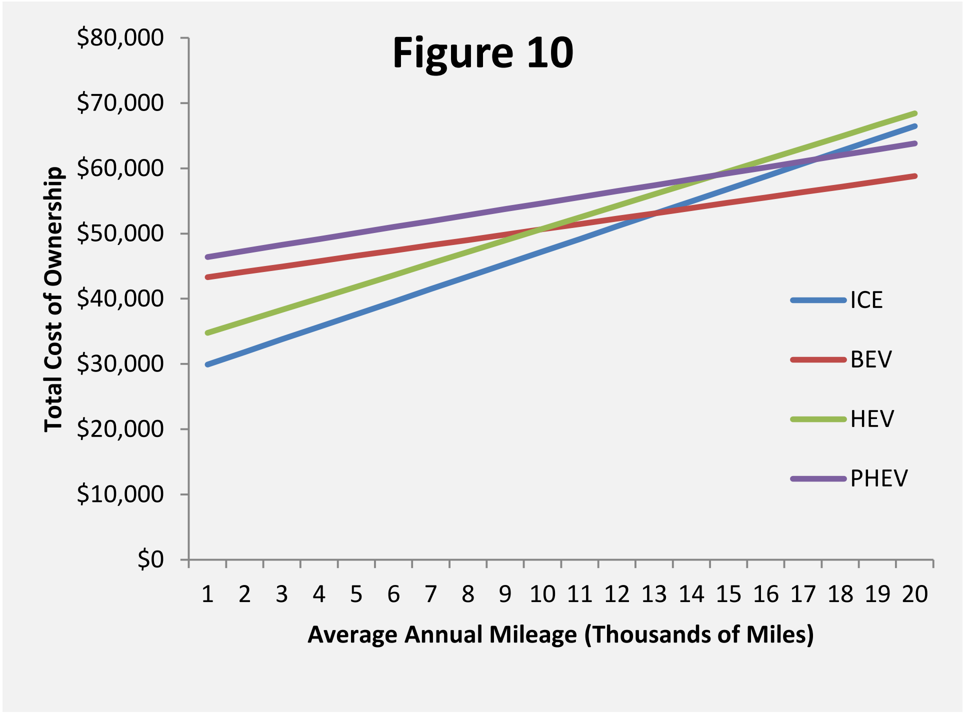


Figure 10 - Total Cost of Ownership break-even point for a PickUp in the EIA High Case gasoline price

Scenario 4 – BEV/PHEV Cost of Battery Decreases 45%

For an ICE, the engine accounts for ~20% of the price. For an EV, however, the battery accounts for ~50% of the price. Considering that the price of a Lithium-ion battery has fallen 80% since 2010, EV prices are more competitive (Myers). With unprecedented supply of lithium being exported from Chile, the price will continue to drop even in light of growing EV demand (Sanderson). While pricing forecasts vary, an estimate from Morgan Stanley projects a 45% decrease in the price of lithium-ion batteries by 2021 (Myers). Table 38 details updated capital costs for ***Scenario 4.*** These prices do not account for the cost of the charging infrastructure, which represents an additional $3,500 cost for PHEV and BEV alternatives.

Table 38		
Vehicle Alternative	**Capital Cost ($) – Base Case**	**Capital Cost – 45% Battery Price Reduction**
ICE Sedan – Malibu	$21,000	**$21,000**
HEV Sedan – Malibu Hybrid	$26,000	**$26,000**
PHEV Sedan – Volt	$35,000	**$27,125**
BEV Sedan – Bolt	$32,000	**$24,800**
ICE SUV	$31,000	**$31,000**
HEV SUV	$34,000	**$34,000**
PHEV SUV*	$45,000	**$34,875**
BEV SUV*	$42,000	**$32,550**
ICE Pick-Up	$28,000	**$28,000**
HEV Pick-Up	$33,000	**$33,000**
PHEV Pick-Up*	$42,000	**$32,550**
BEV Pick-Up*	$39,000	**$30,225**

Table 38 - Comparison of vehicle Capital Cost, base case vs. 45% battery price reduction. Costs for PHEV and BEV models of SUV and Pickup class are projections because these models are not available yet.

Total Conversion

When performing the cost benefit analysis with these updated capital cost inputs for PHEV and BEV alternatives, there are significant changes over 10 years, detailed in Table 39. PHEV models save an estimated $2.2 million over 10 years and BEV models save $1.9 million.

Table 39				
	Base Case		**45% Battery Price Reduction**	
	TCO	**NPV**	**TCO**	**NPV**
ICE	$8,475,000	$0	$8,475,000	$0
HEV	$9,177,000	-$703,000	$9,177,000	-$703,000
PHEV	$11,745,000	-$3,270,000	$9,560,000	-$1,085,000
BEV	$10,781,000	-$2,306,000	$8,909,000	-$434,000

Table 39 - Cost benefit analysis at 45% Battery Price Reduction, Total Conversion plans vs. Optimized Conversion, including comparison to status quo

Not only does this reduce the TCOs for PHEV and BEV models, but it brings both models, especially BEVs, to a level of much greater parity with their ICE and HEV counterparts.

Optimized Conversion

Table 40		
	Quantity (241)	**Percentage (%)**
ICE	180	75%
HEV	0	0%
PHEV	7	3%
BEV	54	22%

Table 40 - Portfolio of vehicles under Optimized Conversion

How would a 45% reduction in EV battery cost affect an Optimized Conversion? 75% of the fleet still consists of ICEs, but there is an increasing share of PHEVs and BEVs. The vehicles converted to BEV are predominantly SUVs with an average annual mileage of 10,543. The range is 5,787 to 19,302. There are no pickups included in this selection, but the five highest annual mileage sedans are converted to BEVs (annual mileage of 14,757; 15,076; 15,210; 16,501; and 16,371.) The seven PHEVs, on the other hand, are all high mileage SUVs that cannot be converted to BEVs because of range concerns. Their average annual mileage is 14,111 but they are often driven 300-450 miles in a day. Due to the threshold of >200 daily miles warranting removal from BEV consideration, these vehicles are best converted to PHEVs.

Table 41		
	TCO	**NPV of Conversion**
Optimized	$8,279,000	$200,000
ICE	$8,475,000	$0
HEV	$9,177,000	-$703,000
PHEV	$9,560,000	-$1,085,000
BEV	$8,909,000	-$434,000

Table 41 - Cost benefit analysis at 45% battery price reduction, Total Conversion plans vs. Optimized Conversion

If this Optimized Conversion is pursued, there is the potential for even greater financial benefits. The County could realize a savings of almost $200,000 over 10 years by implementing this conversion schedule, albeit for fewer emissions reductions. There are also emissions reductions

of 2,800 tonnes of CO2e, 0.10 tonnes of PM2.5, and 1.8 tonnes of NOx could be realized over 10 years. This equates to a social benefit of $160,000.

Table 42			
	CO2e (tonnes)	**PM2.5 (tonnes)**	**NOx (tonnes)**
Optimized	8,633.71	0.32	8.34
ICE	11,444.20	0.43	10.16
HEV	8,650.46	0.36	7.97
PHEV	5,157.03	0.20	4.05
BEV	3,254.84	0.10	2.84

Table 42 - Cumulative emissions over 10 years at 45% battery price reduction, Total Conversion plans vs. Optimized Conversion

Finding the Optimal Vehicle Alternative

What does the spectrum look like for optimal vehicle considering the 45% battery price reduction? Where are the break-even points in this Optimized Conversion plan?

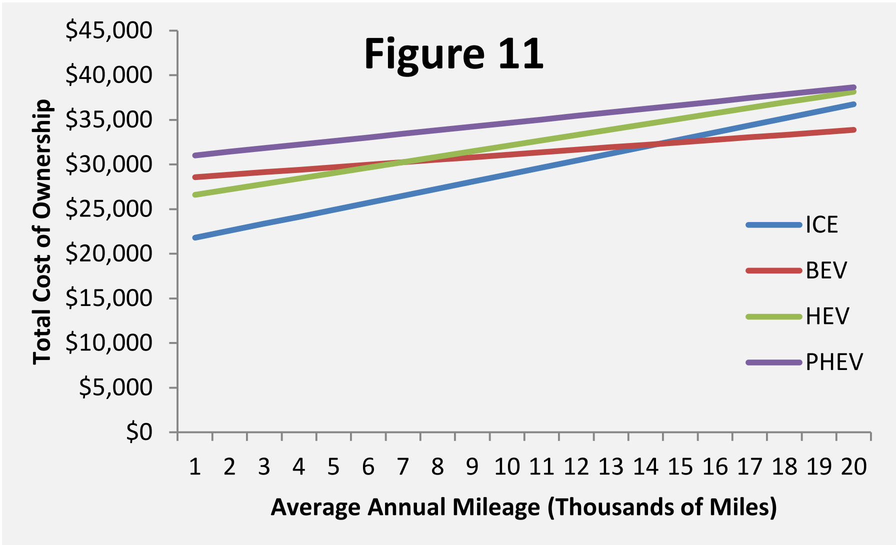


Figure 11 - Total Cost of Ownership break-even point for a sedan at a 45% battery price reduction

For sedans, the break-even point occurs around 14,000 annual miles – consistent with the five sedans discussed above. Sedans below this annual mileage threshold are best kept as ICEs.

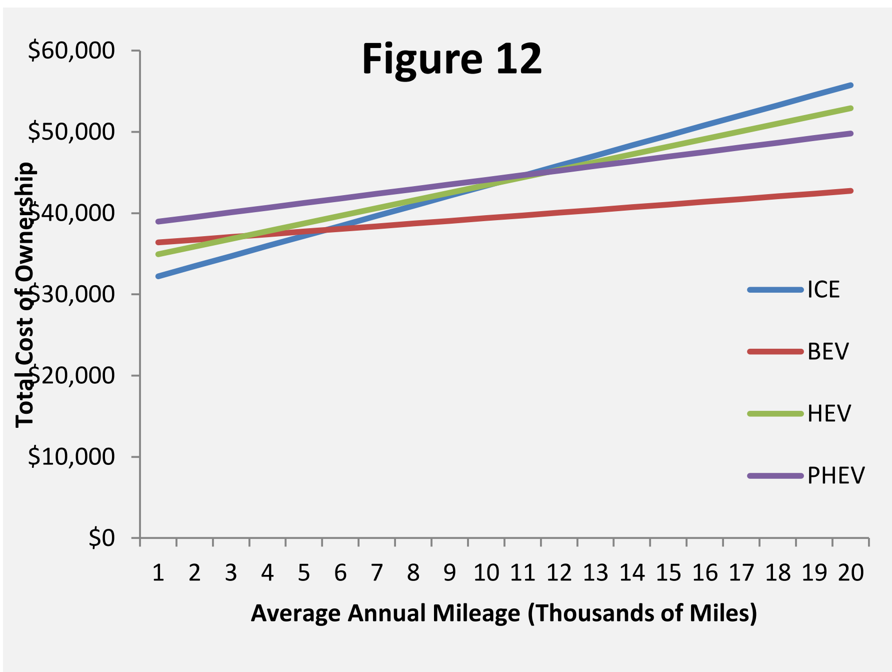


Figure 12 - Total Cost of Ownership break-even point for an SUV at a 45% battery price reduction

For SUVs, the break-even point happens at much lower annual mileage – around 6,000. This is why the vast majority of SUVs are best converted to BEVs. The seven vehicles converted to PHEVs all have average annual mileages higher than 13,000, which is where the PHEV price drops below ICE and HEV alternatives. For pickups, there is no break-even point. Even with the 45% battery price reduction, it is not worth it to convert any truck to anything other than an ICE vehicle.

Scenario 5 – BEV/PHEV Cost of Battery Decreases 15% Annually

Another projection from JP Morgan estimates that the cost of a lithium-ion battery will drop 15% every year. For this reason, ***Scenario 5*** is structured differently. Rather than assess a one-year battery price decrease of 15%, which obviously will make less of a difference than the 45% decrease detailed in ***Scenario 4***, we will now look at the progression of EV costs over time. If EVs are not financially viable in the Base Case in 2019, nor are they likely to be totally viable in 2020 at a 15% decrease in battery cost, what about the following year, when costs drop another 15% Or the year after, with another 15% battery price decrease?

Total Conversion

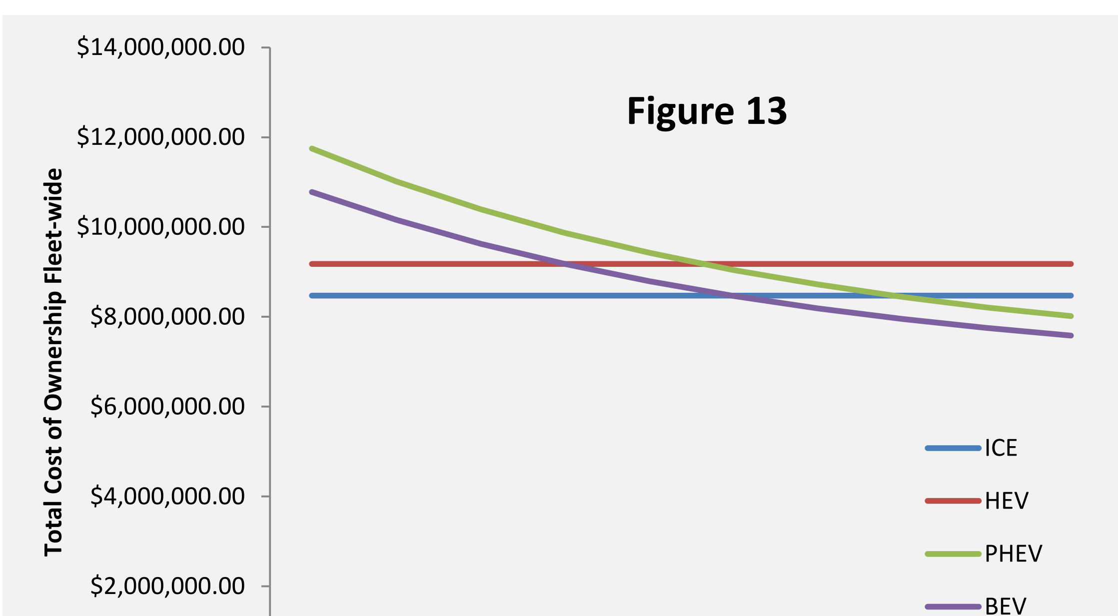


Figure 13 - Change in Fleet-wide Total Cost of Ownership under a Total Conversion Plan if conversion is delayed

In Figure 13, 2019 represents the TCOs as they exist in the present. 2020 represents the TCOs after a 15% battery price reduction for BEVs and PHEVs, 2021 represents the TCOs after an additional 15% battery price reduction, and so on. I control for all other variables, so the TCOs for ICE and HEV models do not change – only the TCOs for BEV and PHEV models.

An important clarification for this analysis is that Figure 13 does not portray costs to the County if Total Conversion were pursued immediately. Instead, it portrays the TCOs over 10 years if Total Conversion is delayed until the Year along the X-axis. For example: if the County initiates Total Conversion immediately, the TCO begins in 2019 and extends 10 years through 2029. However, if the County does nothing until 2024, then the 10 year window would extend from 2024 through 2034. The TCO for BEVs would be $8,793,000 over 10 years *starting in 2024*. This is in contrast to TCO for ICEs – which would be a 10 year cost of $8,475,000 *starting in 2024.* So even if Total Conversion waits until 2024, there is still a net loss in converting to any alternative except for ICEs. The same is not true for 2025 and beyond, in which the TCO for a

BEV Total Conversion drops below ICEs for the first time and remains so for the foreseeable future.

To look at it another way, Figure 14 examines the NPV of conversion alternatives when compared to ICEs. BEVs cross the threshold into positive NPV compared to ICEs in 2025, much sooner than PHEVs or HEVs. This means that if the County waits 6 years to initiate Total Conversion, that would be the first year they would realize a positive savings over the 10 year window than ensues.

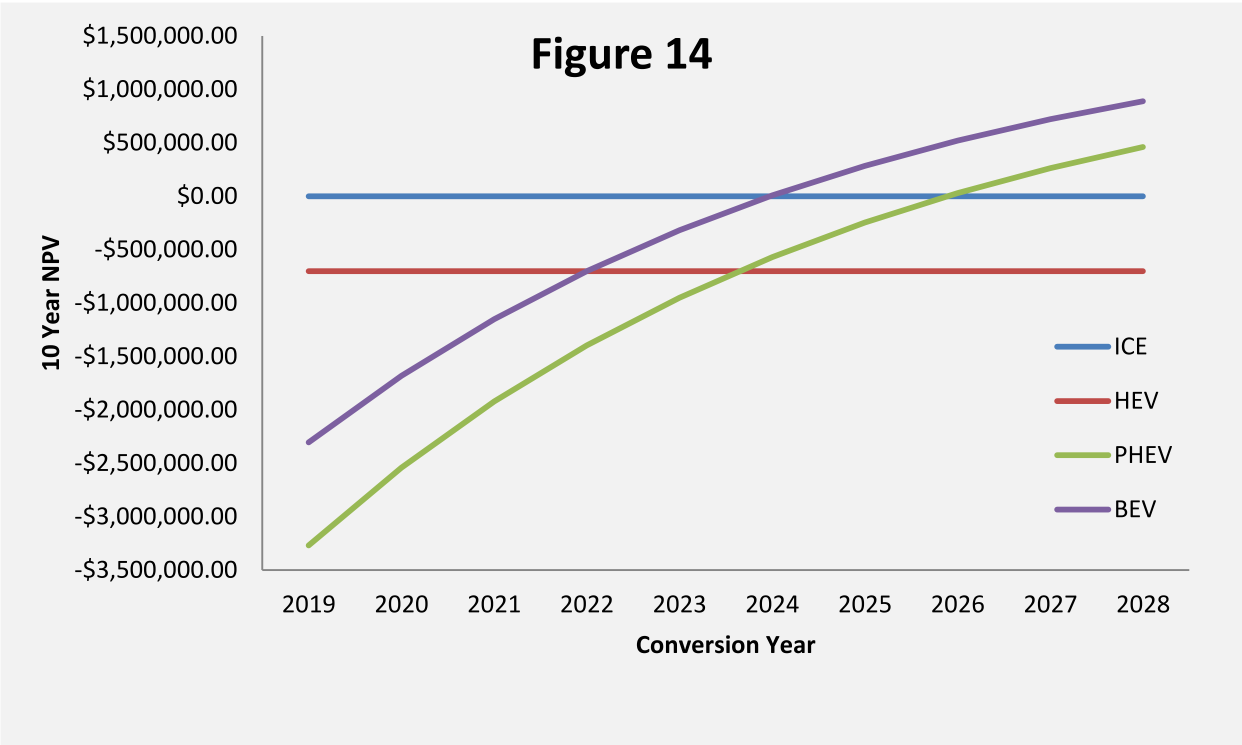


Figure 14 - Change in NPV compared to status quo, under Total Conversion plans, if conversion is delayed

What about the impact of emissions? Does the inclusion of social costs change the timeline for when conversion away from ICEs is financially viable? When factoring in the social cost of emissions, the timeline for viable Total Conversion away from ICEs is moved up a year into Year 2023. Under these conditions, 2023 is when the County should begin Total Conversion

to BEVs. The same is true when examining the NPV of Total Conversion in Figure 14. BEVs cross the threshold into positive NPV when compared to ICEs a year earlier, in Year 2023.

Optimized Conversion

In ***Scenario 5***, we have thus far only examined Total Conversion options under the annual 15% battery price reduction. Similar to the other ***Scenarios***, there may be merit to an Optimized Conversion in order to minimize cost. At different cost inputs, different vehicle alternatives are sometimes the optimal choice for that vehicle. As the price of the batteries declines over time, thus the Capital Cost of BEVs and PHEVs declines over time, some vehicles are best converted to BEVs while others are still best kept as ICEs.

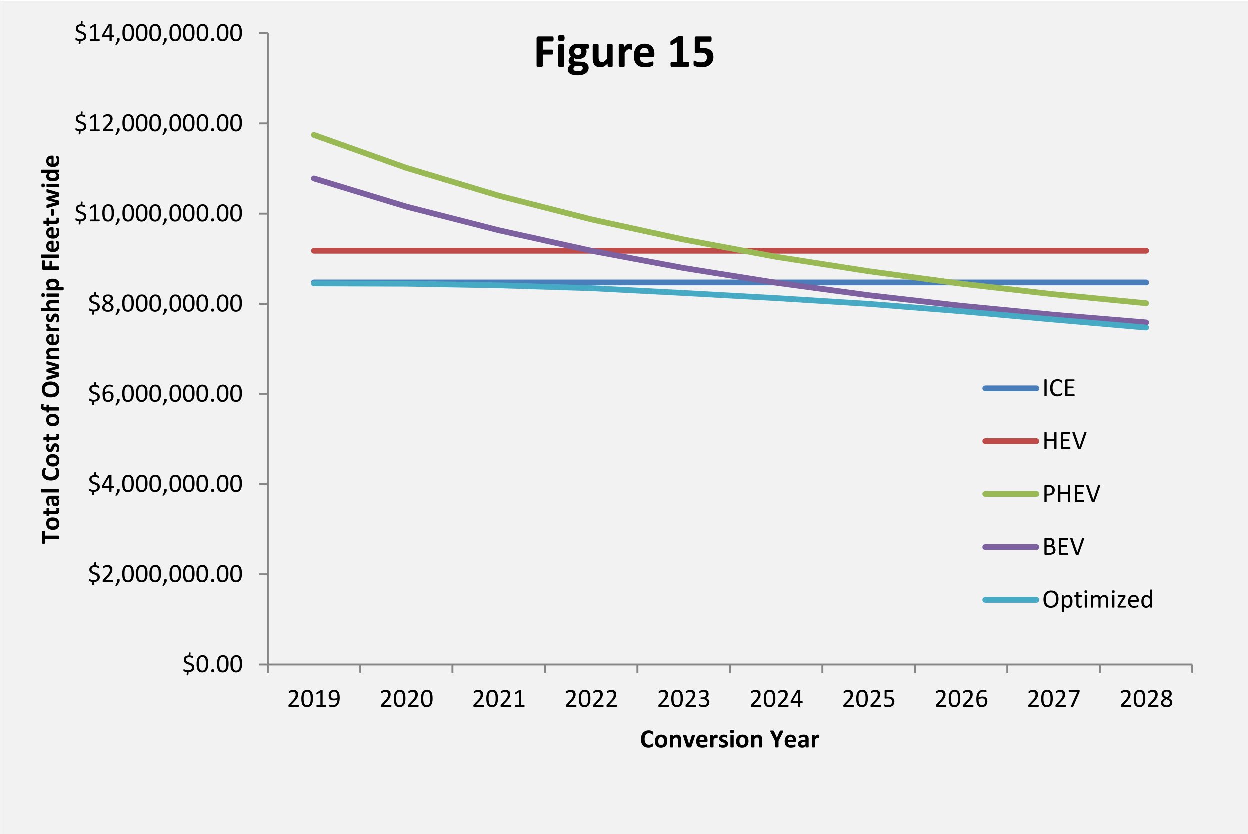


Figure 15 - Change in Fleetwide Total Cost of Ownership, Total Conversion plans vs. Optimized Conversion, if conversion is delayed

When accounting for these different cost values, we add a 5th cost curve in Figure 15 to include the Optimized Conversion, which generates additional financial value for the County. This is especially true in years 2023-2025, where there is a wide variety in Optimized Conversions. If the County waits until one of these years to implement an Optimized Conversion, there are significant cost savings with pursuing conversion based on a vehicle-by-vehicle basis rather than a one-size-fits-all approach. There are still cost savings associated with the optimized approach in the other years, but the savings are lower.

What are the vehicles in this optimized approach? What is the breakdown in vehicles converted to BEVs, PHEVs, HEVs, or kept as ICEs? Figure 16 portrays how the breakdown changes if implementation of conversion is delayed.

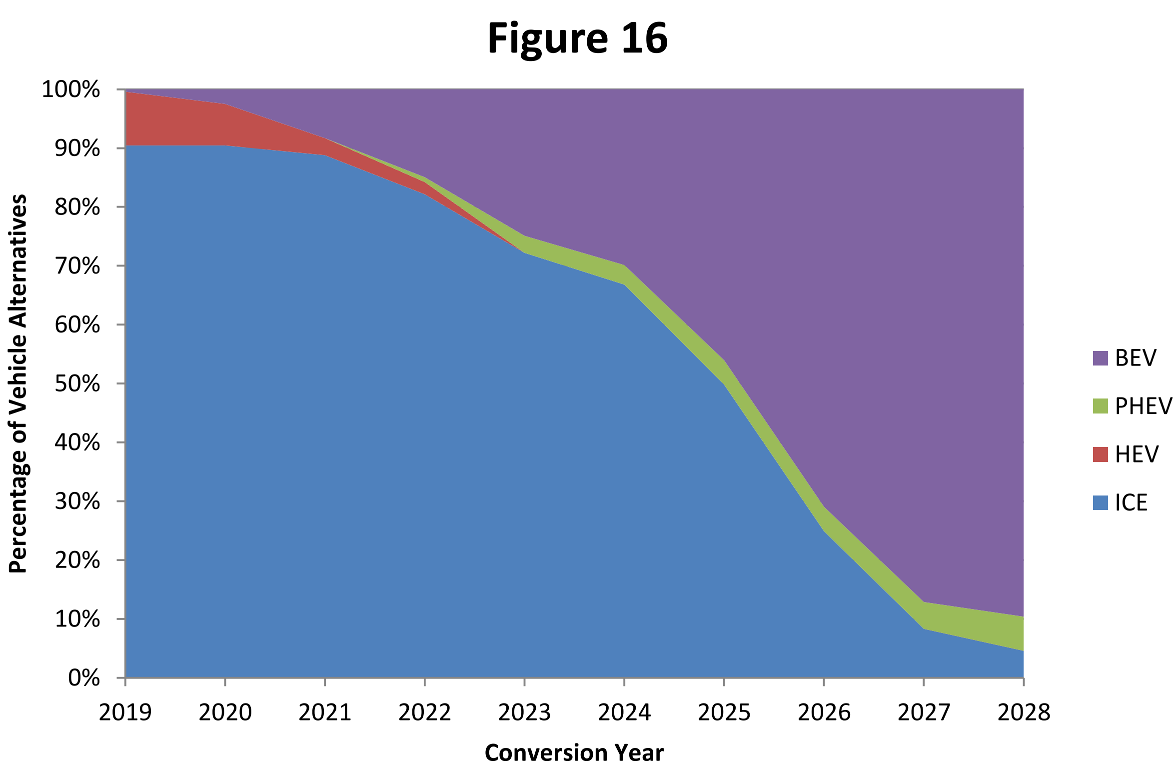


Figure 16 - Quantity of Vehicles under an Optimized Conversion if conversion is delayed

In 2019, the conversion consists almost entirely of ICEs with a few HEVs. As time passes, however, and the cost of BEVs and PHEVs decreases, the savings associated with these alternatives increase. For this reason, every year the County waits increases the optimal quantity of vehicles converted to BEV. The amount of BEVs in the fleet crosses 50% around 2025 and beyond year 2023, it is not beneficial to purchase any HEVs for the fleet.

Concurrently, as the portfolio of EVs in the fleet changes at different conversion timelines, the emissions generated also changes. Figure 17 projects emissions reductions over 10 years if the portfolio of vehicles is optimized by cost.

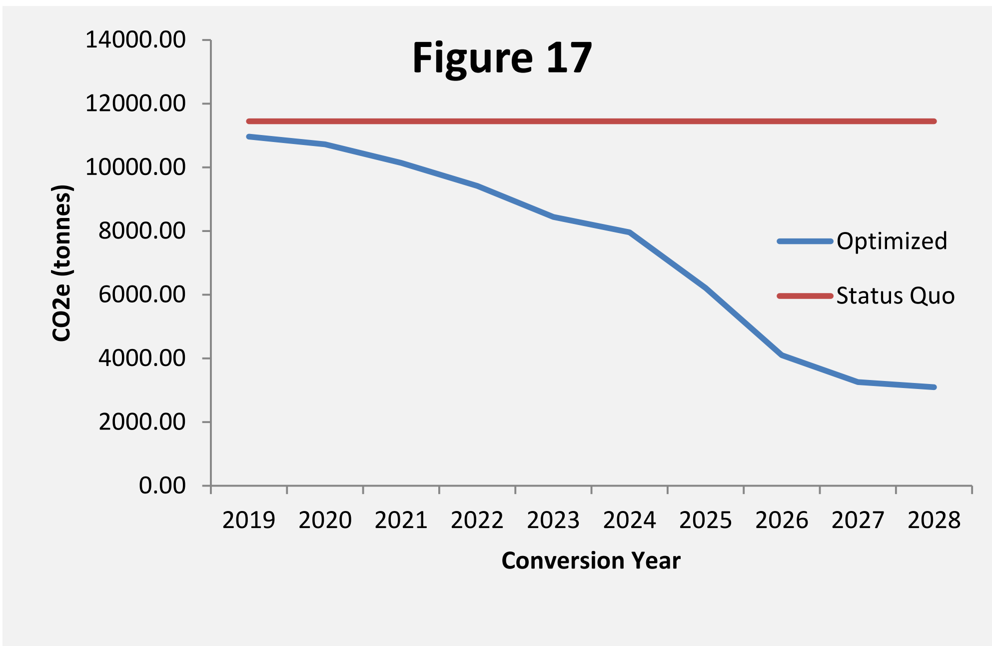


Figure 17 - 10 year CO2e emissions projections if implementation is delayed until a given year, using the vehicle portfolio at that year, given a 15% annual battery cost reduction

It is logical for all three emissions species to follow the same trend lines, as they are tied directly to the portfolio of vehicles in the fleet. It should be noted, however, that these graphs do not fully represent the social costs of fleet conversion – for example, given these results, the County should do nothing until 2028 and then begin conversion to maximize the emissions reduction. In reality, the vehicles in the fleet are still releasing emissions in the years between.

Summary of Results

In Scenario 1, with Base Case conditions, investing in a Total Conversion to BEV reduces approximately 72% of emissions but costs $2.3 million above the status quo, a 27% increase. On the other hand, pursuing an Optimized Conversion reduces approximately 4% of emissions while saving $23,000 over 10 years – less than 1% of costs. So there is clearly some low-hanging fruit in the County fleet to convert to HEV/EV to reduce emissions and save some money, although the cost savings are negligible.

Table 43

Scenario 1	**TCO**	**NPV**	**Social Benefits**	**CO2e (tonnes) NOx PM2.5**
Status Quo – ICE	$8,475,000	$0	$0	11,444.20 10.16 0.43
Optimized Conversion	$8,452,000	$23,000	$26,000	10,960.13 9.89 0.41
Total Conversion - BEV	$10,781,000	-$2,300,000	$502,000	3,254.84 2.84 0.10

Table 43 - Summary table of Scenario 1. A Total Conversion to BEV would reduce 72% of emissions but cost $2.3 million above the status quo, a 27% increase, while an Optimized Conversion reduces 4% of emissions while saving under 1% of costs.

For Scenario 2, I will skip the potential 20% Discount Rate, instead focusing on the 0% Discount Rate possibility, as that is more likely to be used by County decision-makers. A Total Conversion to BEV would reduce approximately 72% of emissions and cost $2 million above the status quo, a 22% increase. On the other hand, pursuing an Optimized Conversion reduces emissions by 5% while saving $60,000 over 10 years – still less than 1% of costs.

Table 44				
Scenario 2	**TCO**	**NPV**	**Social Benefits**	**CO2e (tonnes)** **NOx** **PM2.5**
Status Quo – ICE	$9,105,000	$0	$0	11,444.20 10.16 0.43
Optimized Conversion	$9,045,000	$60,000	$40,000	10,714.37 9.75 0.41
Total Conversion - BEV	$11,116,000	-$2,011,000	$502,000	3,254.84 2.84 0.10

Table 44 - Summary table of Scenario 2. A Total Conversion to BEV would reduce 72% of emissions but cost $2 million above the status quo, a 22% increase, while an Optimized Conversion reduces 5% of emissions while saving under 1% of costs.

In Scenario 3, I focus on the EIA Reference Case, where the price of gas is $2.96/gallon. Under these conditions, a Total Conversion to BEVs would reduce emissions by 72% and cost $1.8 million above the status quo, a 20% increase. On the other hand, an Optimized Conversion would reduce emissions by 7% and save $73,000 over 10 years - still less than 1% of costs.

Table 45				
Scenario 3	**TCO**	**NPV**	**Social Benefits**	**CO2e** **NOx** **PM2.5**
Status Quo – ICE	$9,036,000	$0	$0	11,444.20 10.16 0.43
Optimized Conversion	$8,963,000	$73,000	$51,000	10,514.72 9.61 0.40
Total Conversion - BEV	$10,826,000	-$1,790,000	$502,000	3,254.84 2.84 0.10

Table 45 - Summary table of Scenario 3. A Total Conversion to BEV would reduce 72% of emissions but cost $1.8 million above the status quo, a 20% increase, while an Optimized Conversion reduces 7% of emissions while saving under 1% of costs.

In Scenario 4, which assumes a 45% drop in the battery price, EVs become much more cost-effective. Total Conversion to BEVs reduces emissions by 72% and only costs $434,000 above the status quo, a 5% increase. On the other hand, an Optimized Conversion reduces emissions by 23% and saves the County almost $200,000 over 10 years, more than 2% of costs.

Table 46				
Scenario 4	**TCO**	**NPV**	**Social Benefits**	**CO2e** **NOx** **PM2.5**
Status Quo – ICE	$8,475,000	$0	$0	11,444.20 10.16 0.43
Optimized Conversion	$8,279,000	$196,000	$161,000	8,633.71 2.84 0.10
Total Conversion - BEV	$8,909,000	-$434,000	$502,000	3,254.84 2.84 0.10

Table 46 - Summary table of Scenario 4. A Total Conversion to BEV would reduce 72% of emissions but cost $434,000 above the status quo, a 5% increase, while an Optimized Conversion reduces 23% of emissions while saving over 2% of costs.

In Scenario 5, which is structured differently because of the annual change in battery price over time, I capture how conversion costs and social benefits change depending on conversion year. 2019, the current year, Base Case conditions apply. But if conversion begins two years later in 2021, a Total Conversion to BEV would generate a 72% emissions reduction, equal to $502,000 in social benefits, at a cost of $1.1 million above the status quo – a 14% increase. An Optimized Conversion would generate a 5% emissions reduction, equal to $75,000 in social benefits, while saving $63,000 over 10 years – less than 1% of the cost.

Table 47						
Scenario 5		**2019**	**2021**	**2023**	**2025**	**2027**
Status Quo – ICE	NPV	$8,475,000	$8,475,000	$8,475,000	$8,475,000	$8,475,000
	Social Benefits	$0	$0	$0	$0	$0
Optimized Conversion	NPV	$23,000	$63,000	$233,000	$475,000	$825,000
	Social Benefits	$26,000	$75,000	$172,000	$311,000	$504,000
Total Conversion - BEV	NPV	-$2,306,000	-$1,152,000	-$318,000	$285,000	$720,000
	Social Benefits	$502,000	$502,000	$502,000	$502,000	$502,000

Table 47 - Summary table of Scenario 5. In any year, Total Conversions to BEV would generated greater emissions reductions at high but diminishing cost values above the status quo. An Optimized Conversion generates increasing emissions reductions as time goes on, while generating increasing cost savings for the County. Only odd numbered years are included in Table 47 for space reasons.

If conversion were to be delayed two more years, in 2023, a Total Conversion to BEV would generate the same 72% emissions reduction but at a smaller price tag of $318,000 above the status quo – a 4% increase. An Optimized Conversion would generate a 24% emissions

reduction, equal to $172,000 in social benefits, while saving $172,000 over 10 years – over 2% of the cost. This trend continues through the end of the time horizon I evaluated.

Table 48				
	Total BEV Conversion vs. Optimized Conversion	**TCO ($)**	**NPV Compared to Status Quo ($)**	**Social Benefits of Emissions Reduction ($)**
Scenario 1 – Base Case	Total	$10,781,000	-$2,306,000	$502,000
	Optimized	$8,452,000	$23,000	$26,000
Scenario 2 – 0% Discount Rate	Total	$11,116,000	-$2,010,000	$502,000
	Optimized	$9,045,000	$61,000	$40,000
Scenario 2 – 20% Discount Rate	Total	$10,261,000	-$2,764,000	$502,000
	Optimized	$7,498,000	$55	$0
Scenario 3 – EIA Reference Case gasoline price	Total	$10,826,000	-$1,790,000	$502,000
	Optimized	$8,963,000	$73,000	$51,000
Scenario 3 – EIA Low Case gasoline price	Total	$10,751,000	-$2,645,000	$502,000
	Optimized	$8,101,000	$5,000	$11,000

Scenario 3 – EIA High Case gasoline price	Total	$10,935,000	-$540,000	$502,000
	Optimized	$9,968,000	$427,000	$210,000
Scenario 4 – 45% battery price reduction	Total	$8,909,000	-$434,000	$502,000
	Optimized	$8,279,000	$196,000	$160,000
Scenario 5 – Begin conversion in 2021	Total	$9,627,000	-$1,152,000	$502,000
	Optimized	$8,412,000	$63,000	$75,000
Scenario 5 – Begin conversion in 2025	Total	$8,190,000	$285,000	$502,000
	Optimized	$8,000,000	$475,000	$311,000

Table 48 - Summary Table of financial results across all scenarios.

5 – Discussion

My results showed the costs and benefits associated with multiple EV conversion schedules, including both Total Conversions as well as Optimized Conversions away from ICEs to BEVs, PHEVs, and HEVs for the County's fleet of vehicles. Multiple input variables were changed to test how they would impact cost figures over 10 years, especially the estimates for price of gasoline, capital cost, and discount rate.

These results are comparable to those of the three analyses performed in Minneapolis, Houston, and New York City. In Minneapolis, the analysis assumed conversion to BEVs but provided six alternative conversion timelines, generating a negative NPV in all six. Meaning, all six timelines require a commitment of resources to implement. In Houston, the results mirror mine: HEVs can achieve tangible emissions reductions at a comparable financial cost, while significant emissions reductions are possible through Total Conversions to BEVs or PHEVs but at significantly higher costs. In New York City, the City's Fleet Division found that some BEV

models were cheaper than their ICE counterparts (using a comparable methodology) – but with a striking difference. Their Capital Cost figure for the Nissan Leaf was $25,797 (plus $2,656 for the charging infrastructure), which is $6,000 cheaper than the Chevrolet Bolt price used in my analysis. It's possible that New York City is able to obtain these vehicles at a much lower price point because of high-volume purchasing, or perhaps with the assistance of grant funding. Altogether, the methodology is consistent with mine albeit with a different result.

One major departure from these three analyses, however, is the inclusion of the Optimized Conversion plan. None of the existing literature examines a vehicle-specific conversion plan based on the mileage and usage patterns of every individual vehicle. In most cases, the Optimized Conversion plan is not all that distinct from the status quo or a Total Conversion to BEVs, but there are still some vehicles that are never good candidates for conversion to specific alternatives. Seeing how an Optimized Conversion is a likely course of action for most Fleets, conducting this portion of the analysis is a very practical step.

Policy Implications

The first place to start in practical takeaways for Monroe County is awareness that all five scenarios discussed in this analysis are possible. They do not necessarily represent a choice, but rather conditions that will be dictated by the market. Therefore, County decision-makers should be prepared to decide the future of their fleet depending on the scenario that actually occurs.

Once the County determines under which ***Scenario*** it is operating, it must determine its ultimate objectives: cost savings or emissions reductions. While changing these inputs generates

varying TCOs, there are very few conversion schedules that generate a positive NPV compared to status quo. This is significant because a positive NPV indicates an overall cost savings for the County over 10 years, while a negative NPV indicates a net loss for the County.

If cost considerations were the only thing that mattered, there are only two scenarios that generate a positive NPV: first, the County could wait six years to begin Total Conversion to BEVs, as detailed in Figure 14; or the County could pursue an Optimized Conversion schedule, detailed in Figure 15. The vehicle portfolio of the optimization, which depends on changing battery costs, would shift over time and is detailed in Figure 16. Even in Figure 16, however, when Base Case inputs still apply, there are very few vehicles that are candidates for conversion until Years 2022 and 2023 when the share of EVs in the fleet increases from 10% to 20%, a share that continues to grow after that. While these two options are successful in achieving a positive NPV, they are not successful in taking immediate action to reduce emissions.

For County decision-makers, if the goal is to maximize emissions reductions, a Total Conversion to BEVs should be pursued. This plan would eliminate an estimated 8,100 tonnes of CO2 emissions, 7.3 tonnes of NOx emissions, and 0.32 tonnes of PM2.5 over the 10 year window (and continue beyond), translating to over $500,000 in social benefits that result from global climate change mitigation and prevention of human health conditions like heart and lung diseases. So while an immediate Total Conversion to BEV's results in a large financial cost (which varies depending on the ***Scenario)***, there is still a benefit to be realized from making an *investment* in BEV's. That investment decreases in size depending on input variables.

Furthermore, ***Scenario 5*** details overall cost projections as they change over time, in light of the expected continued reduction in EV battery price. While ***Scenario 5*** assumed that

conversion would be delayed until the Year in question, its assumptions about price hold true if conversion is initiated immediately. The County might incur a net financial loss in the first few years, but vehicles purchased beyond the break-even threshold would generate a net cost savings. For this reason, an actual conversion schedule which accounts for the age of the vehicles currently in the fleet could generate further financial benefit, as a recently-purchased vehicle would not be replaced until the costs of BEV conversion are more beneficial. This hypothetical analysis is a candidate for future study.

Ultimately, County decision-makers need to weigh emissions reductions against financial cost. Major emissions reductions are possible through a Total Conversion to BEVs but at a major financial cost. At the same time, moderate to limited emissions reductions are possible through Optimized Conversion plans that actually save the County money. The overall costs to these plans will vary depending on external factors, such as battery cost and gasoline cost, so the County should monitor these variables to best project the market conditions they are operating under.

Furthermore, even in Optimized Conversion scenarios, these results do not necessarily indicate that these vehicles should be converted immediately. The most practical course of action for the County is to identify the optimal alternative for each vehicle in the fleet, and replace each vehicle with that alternative *once it is ready to be replaced*. Some vehicles are candidates to be replaced in 2019, while others will not be replaced for another 10 years. Spreading out this conversion is the most practical and the most likely course of action for the County. Older, higher mileage vehicles should be replaced first because they are closer to the end of their lifespan and have a high possibility of total vehicle failure (not to mention higher maintenance

costs.) Newer ICE vehicles in the fleet should be replaced further down the road, which is advantageous considering market projections for the next 10 years.

Limitations

In order to conduct this analysis, certain variables had to be excluded. Much of that discussion is included above in ***Assumptions***. Due to these exclusions, there are a number of limitations on this study that prevent the model from an exact replica of the way a conversion would have to be approached. First and foremost, this analysis is limited by the lack of availability of SUV and PickUp EV models. Neither vehicle class has BEV or PHEV models, and SUVs only have HEV models available. There is a significant amount of uncertainty surrounding the cost, mileage, battery, and maintenance projections I used.

Second, there is uncertainty surrounding the longevity of EVs and the technical issues that come inherent to a nascent technology. Considering that in 2019, we are only approximately 10 years into the EV "revolution," there remain significant questions surrounding the long-term viability of the batteries, how well they will retain a charge after 10 years, the cost and viability of battery replacements, and the potential for future operational practices like battery swaps. Rather than attempt to project the declining capacity of batteries to hold a charge over time, this is a variable that I excluded, among other technical components of the vehicles. This analysis assumes that technical issues 10 years from now will be as they are in 2019.

An additional limitation of this analysis is the re-sale value of the vehicles. This generates uncertainty in two ways: first, the ICE vehicles that are currently in the fleet do not have a uniform re-sale policy. In some cases, they are shuffled around until they die; in other cases, they are auctioned for highly volatile return prices. Second, re-sale value of EVs after 10 years is highly speculative. It seems likely they will maintain value better than ICEs, but it's far too early

to know for sure. EV technology is far superior than what existed 10 years ago, so it's incredibly difficult to determine what the value of an EV purchased today will look like after a decade. For these two reasons, and the incredible potential for fluctuations in these variables, I excluded them from my analysis.

Further Study

There are certainly candidates for future study. One opportunity to evaluate additional cost savings relates to employee behavior. It is possible that certain vehicles could be down-sized – meaning that employees or departments that use an SUV or a PickUp could actually use a sedan. This would generate cost savings. My analysis did not consider a potential change in driver behavior, but if such an analysis was performed, updated vehicle alternatives could be plugged into my model to evaluate costs and benefits.

Furthermore, even in the Base Case - Optimized Conversion, Monroe County has $23,000 in savings sitting there as low-hanging fruit. If nothing else changes, the County could save that money (with a strong possibility for more.) If that is true in Monroe County alone, there is a real potential for massive savings if such an analysis were applied nationwide. At the end of the day, my analysis is a Case Study for Monroe County. The U.S. Census Bureau reports there are 3,481 counties in the U.S. If the same cost projection were true across all of them, there exists the potential for over $80 million in municipal budget savings – entities that are notoriously cash strapped. This does not include other entities like cities, towns, villages, school districts, and more. A future analysis could expand these findings to every single municipal government in the country in order to best utilize public dollars nationwide.

6 – Conclusion

This study performed a cost benefit analysis of full and optimized conversions away from ICEs to BEVs, PHEVs, and HEVs for Monroe County's fleet of vehicles. Multiple cost inputs were tested to see how different variables affect final NPV projections. If conversion were initiated immediately, under various input conditions, the result would be a negative compared to status quo. However, according to ***Scenario 5,*** in just a few years, conversion to BEVs will be the financially optimal course of action because of battery price reductions, which make emissions reductions much more attainable. Ultimately, because of the inevitability of the changing price of these vehicles, County decision-makers have a choice between immediate conversion or delayed conversion.

There are a number of scenarios that would be successful in realizing significant environmental benefits with only moderate investment costs, if conversion were pursued immediately. Policymakers at the County need to evaluate these investment costs to determine if the environmental benefits warrant immediate or delayed conversion.

One thing that remains clear throughout is that vehicle usage has a direct correlation on the optimal vehicle choice. In fact, if all else is the same, higher mileage vehicles are more likely to be candidates for electrification than their lower-mileage counterparts. This trend is true across all vehicle classes and all ***Scenarios.***

And last, these cost projections ultimately do not reflect the real price that would be paid by the County. Grant funding and incentives are certainly available to purchase EVs and charging infrastructure, and those funding sources would help to off-set the capital cost of these myriad conversion plans. The County should be aware of and pursue all funding sources available for such a policy.

Appendix

Finding the Optimal Alternative – Graphs that do not show break-even points

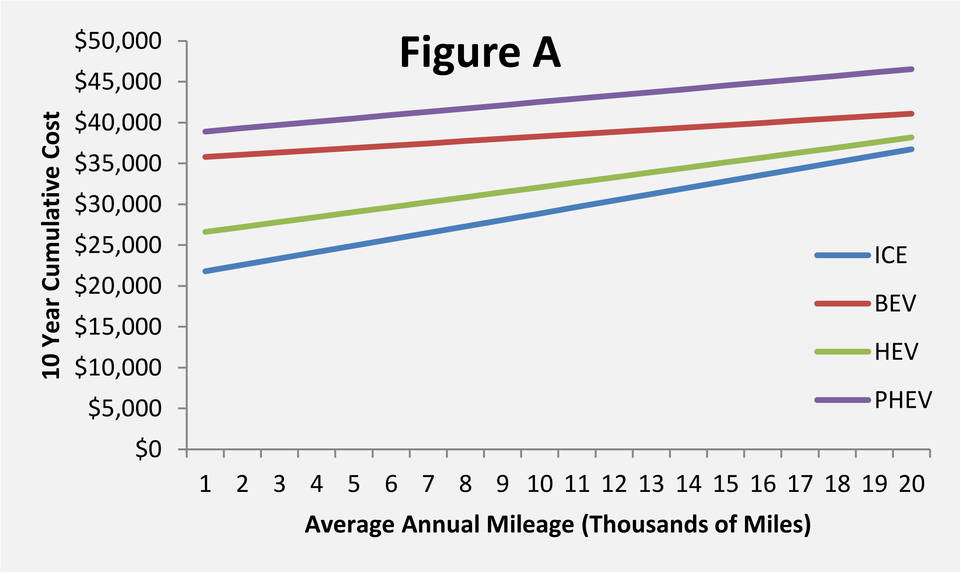


Figure A - Total Cost of Ownership break-even point for a sedan in the Base Case

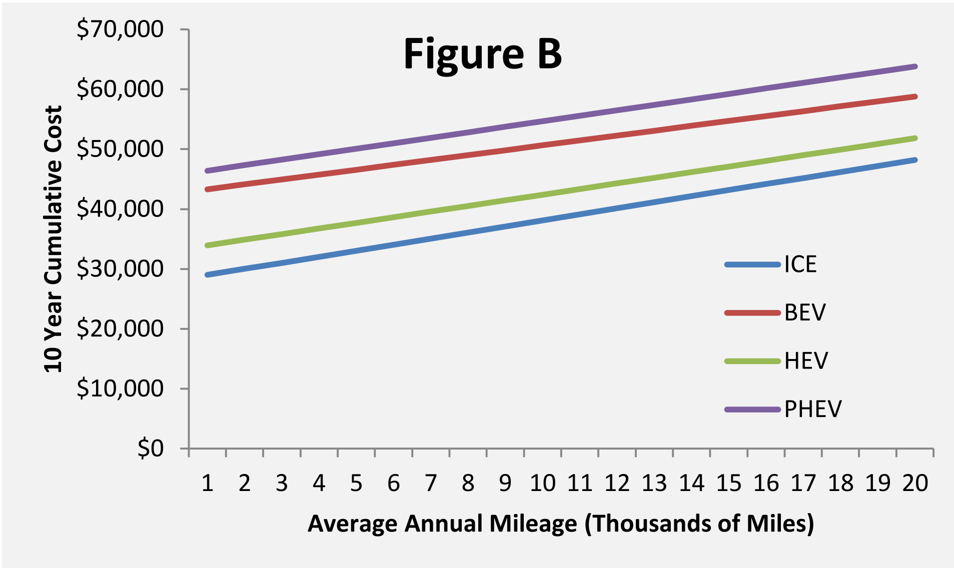


Figure B - Total Cost of Ownership break-even point for a PickUp in the Base Case

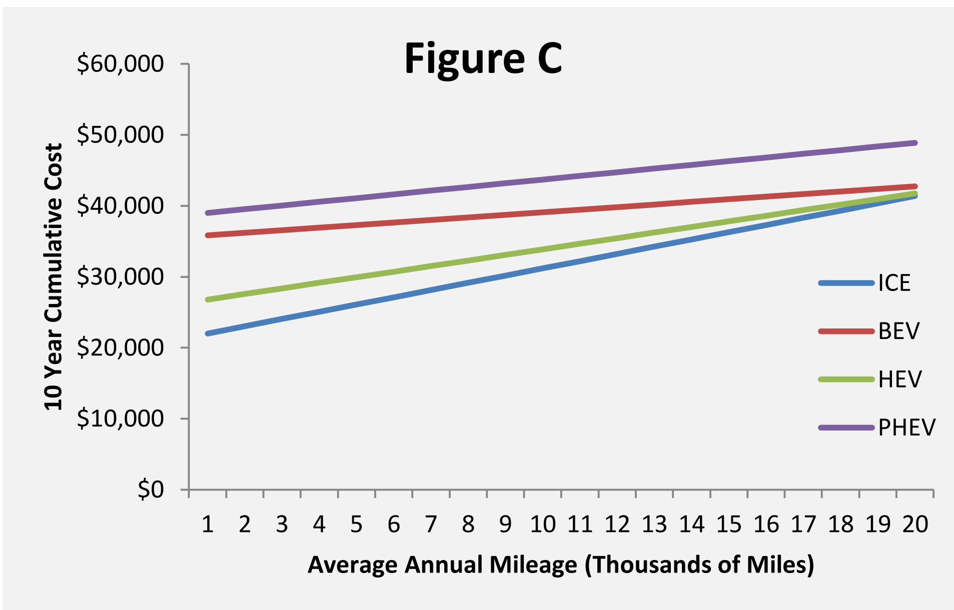


Figure C - Total Cost of Ownership break-even point for a sedan at a 0% Discount Rate

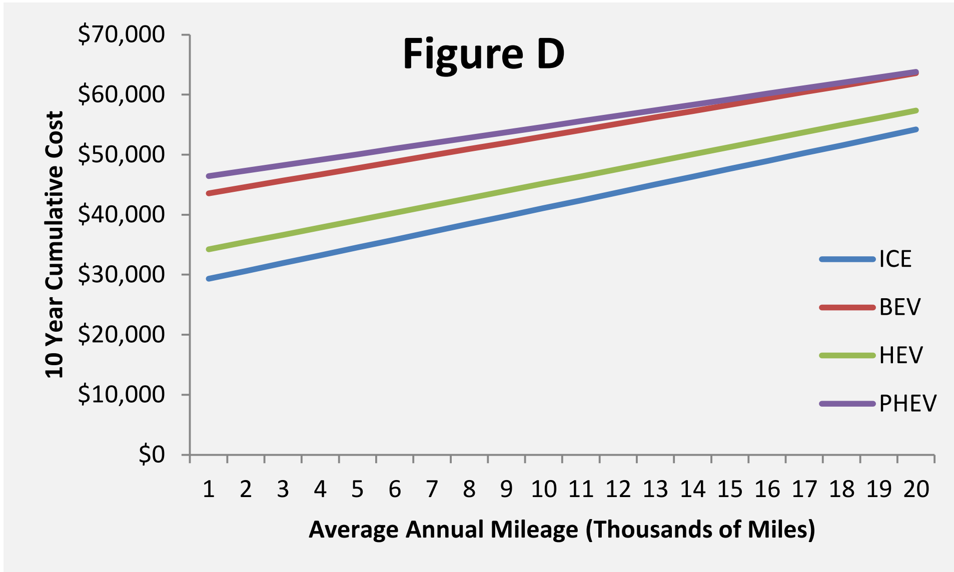
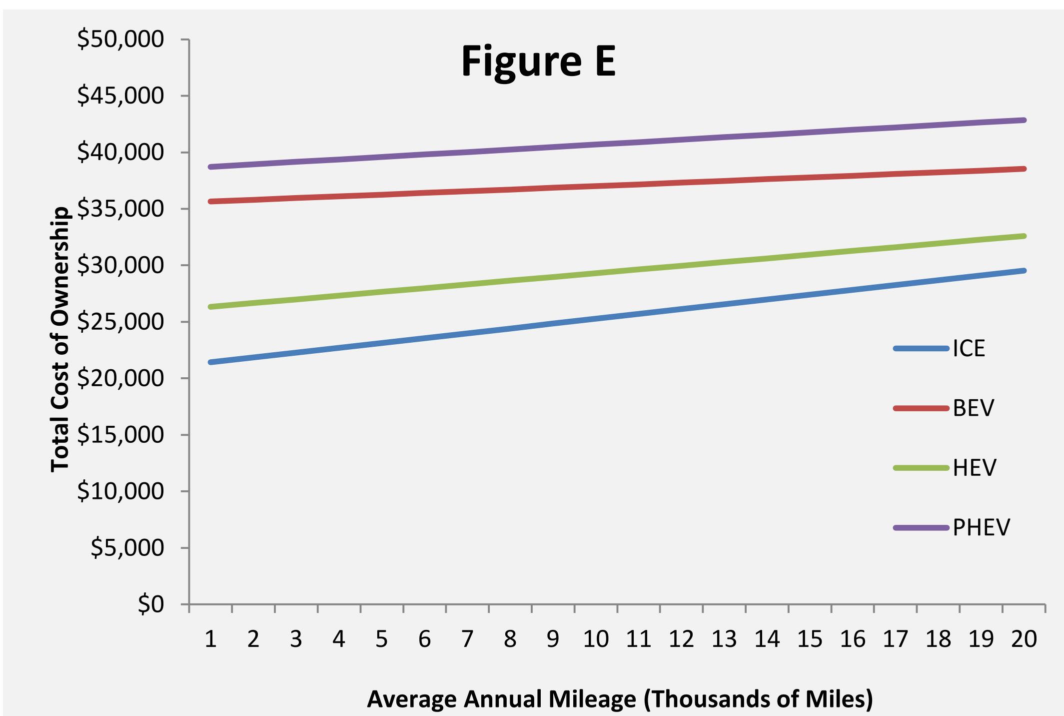


Figure D - Total Cost of Ownership break-even point for a PickUp at a 0% Discount Rate



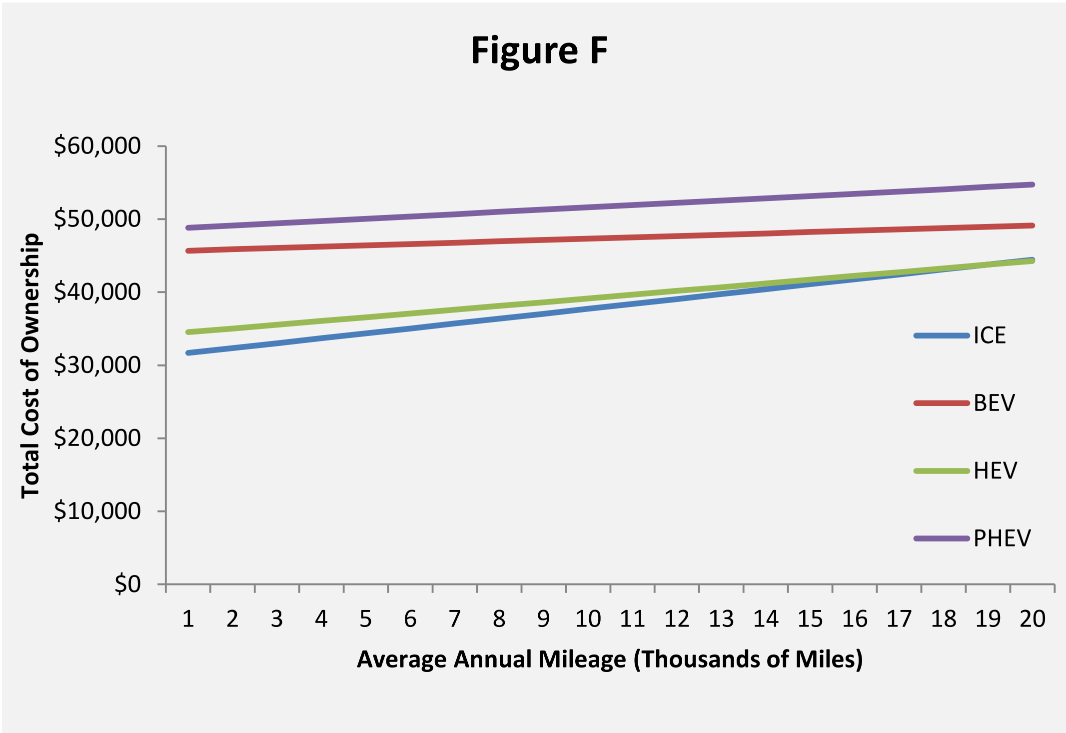


Figure F - Total Cost of Ownership break-even point for an SUV at a 20% Discount Rate

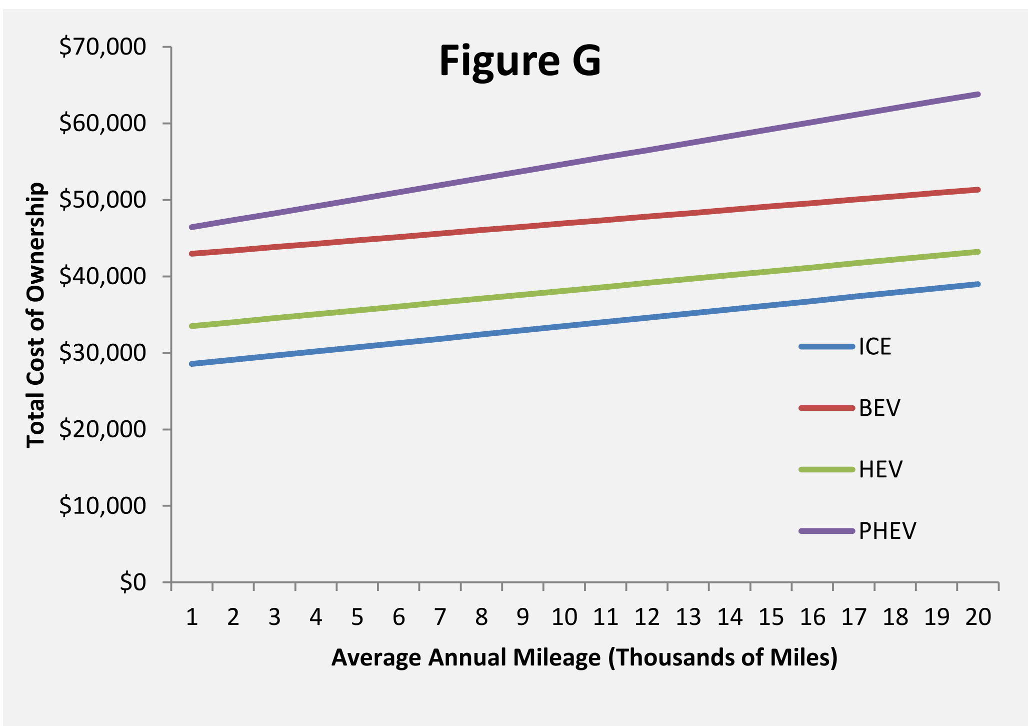


Figure G - Total Cost of Ownership break-even point for a PickUp at a 20% Discount Rate

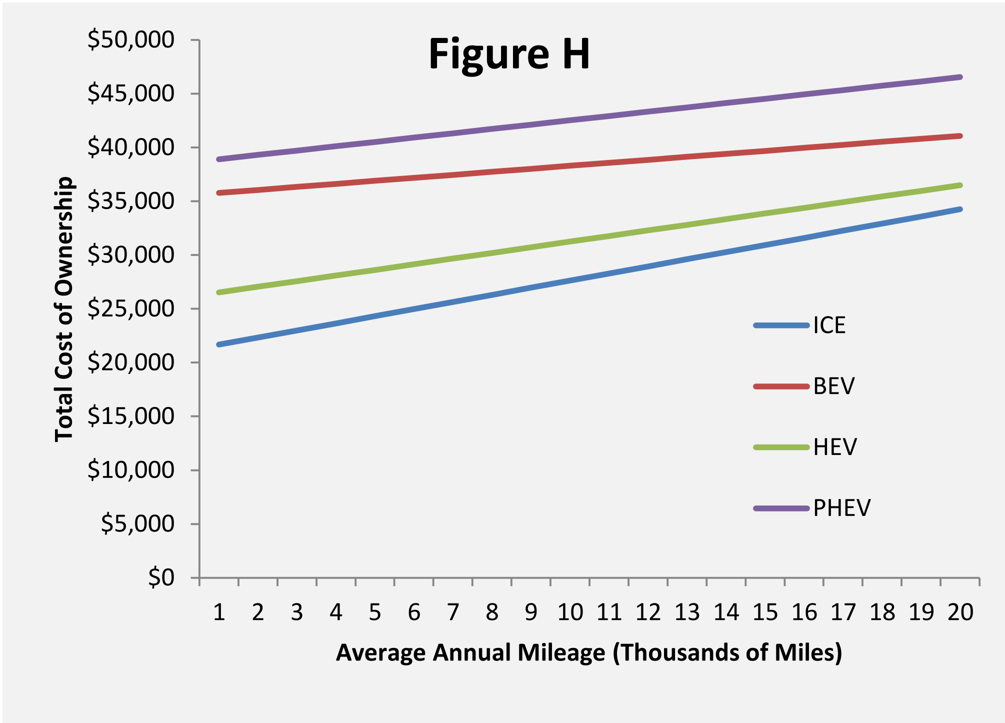


Figure H - Total Cost of Ownership break-even point for a sedan in the EIA Low Case gasoline price

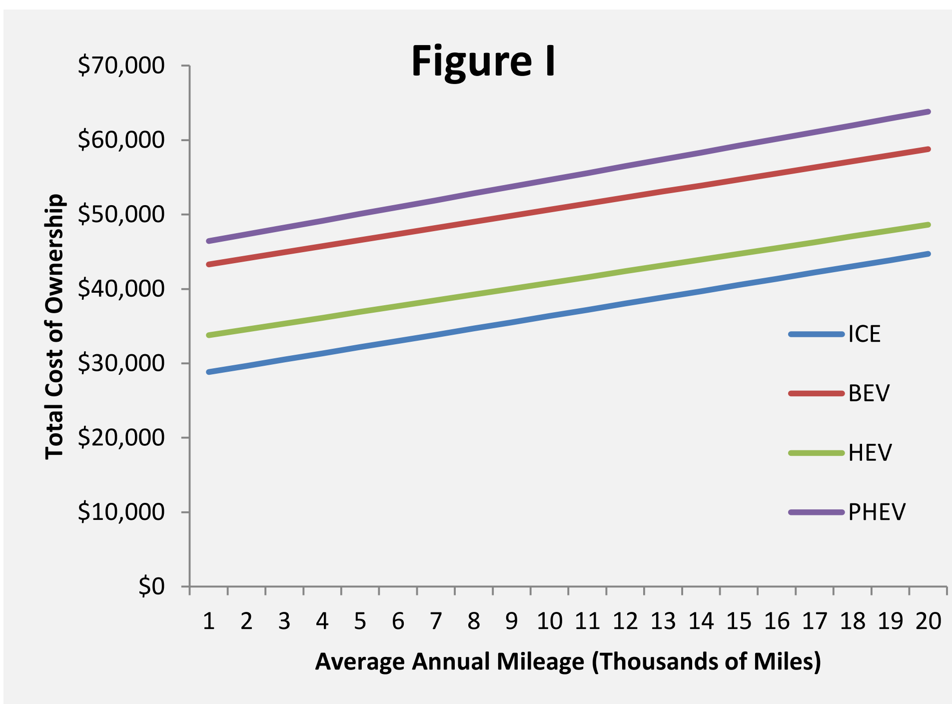


Figure I - Total Cost of Ownership break-even point for a PickUp in the EIA Low Case gasoline price

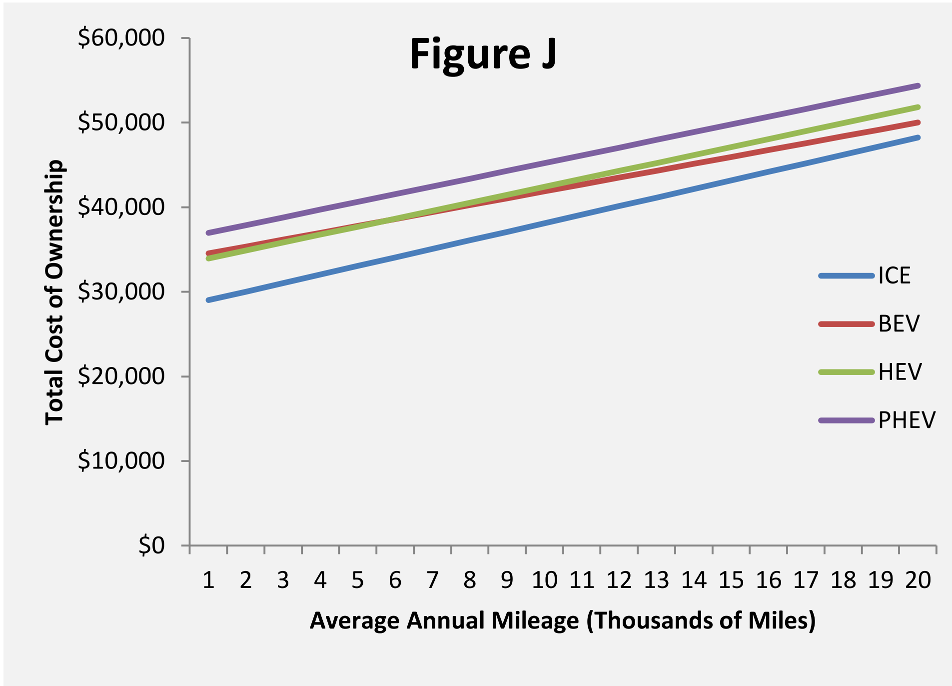


Figure J - Total Cost of Ownership break-even point for a PickUp at a 45% battery price reduction

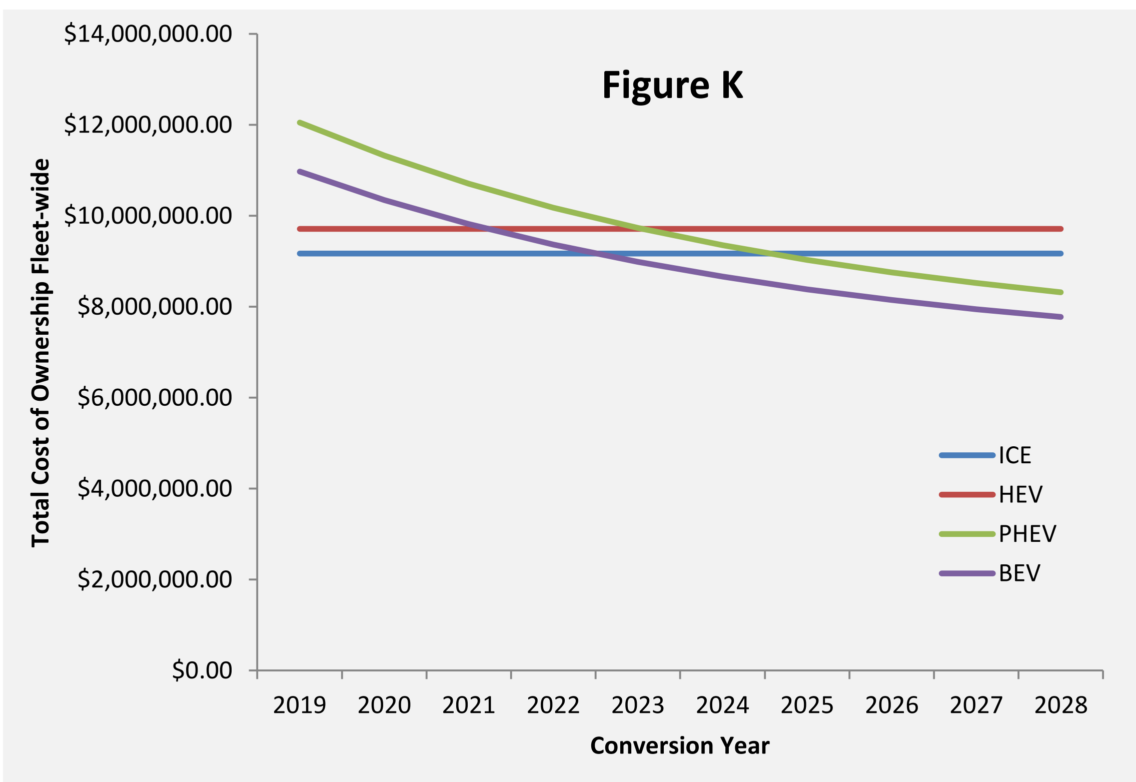


Figure K - Change in Fleetwide Total Cost of Ownership, factoring in social costs, under Total Conversion plans, if conversion is delayed

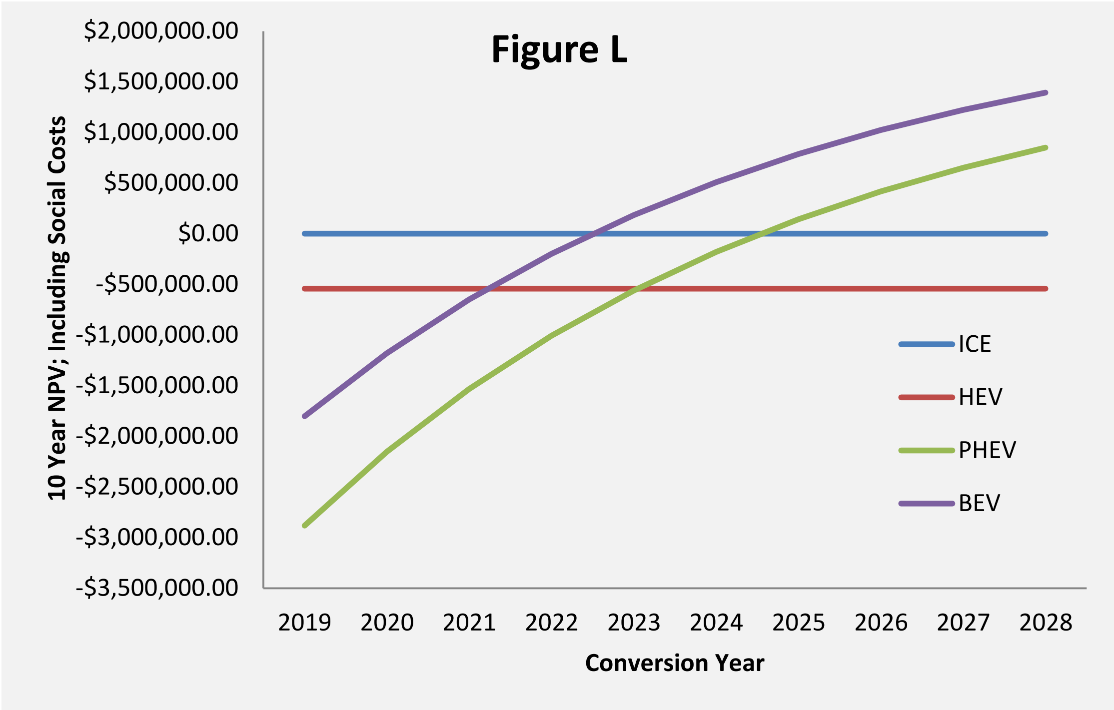


Figure L - Change in NPV compared to status quo, factoring in social costs, under Total Conversion plans, if conversion is delayed

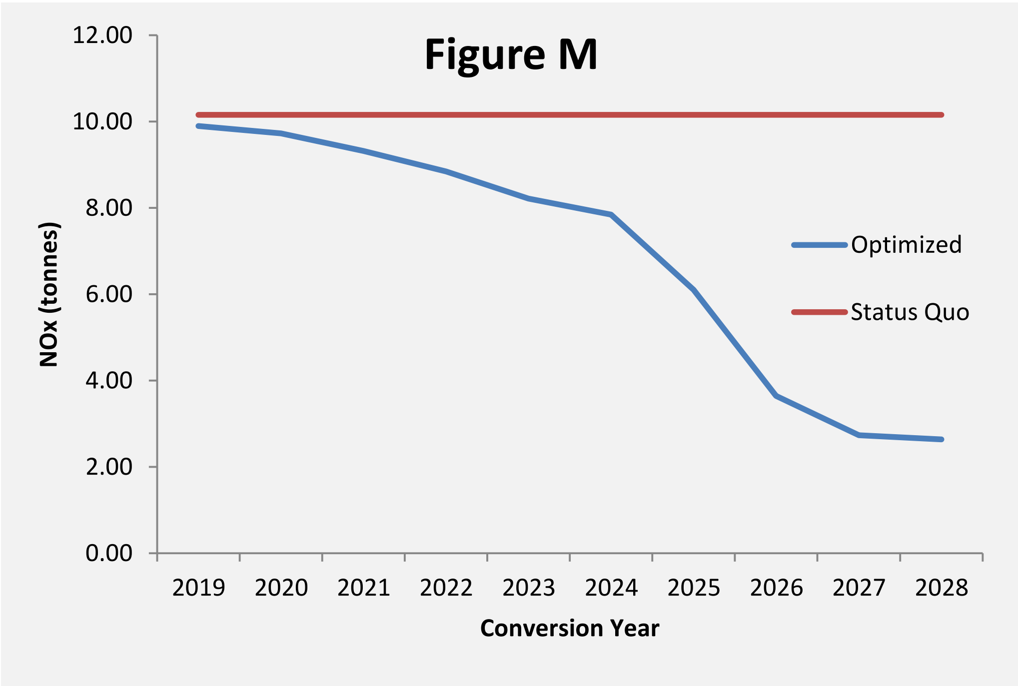


Figure M - 10 year NOx emissions projections if implementation is delayed until a given year, using the vehicle portfolio at that year, given a 15% annual battery cost reduction

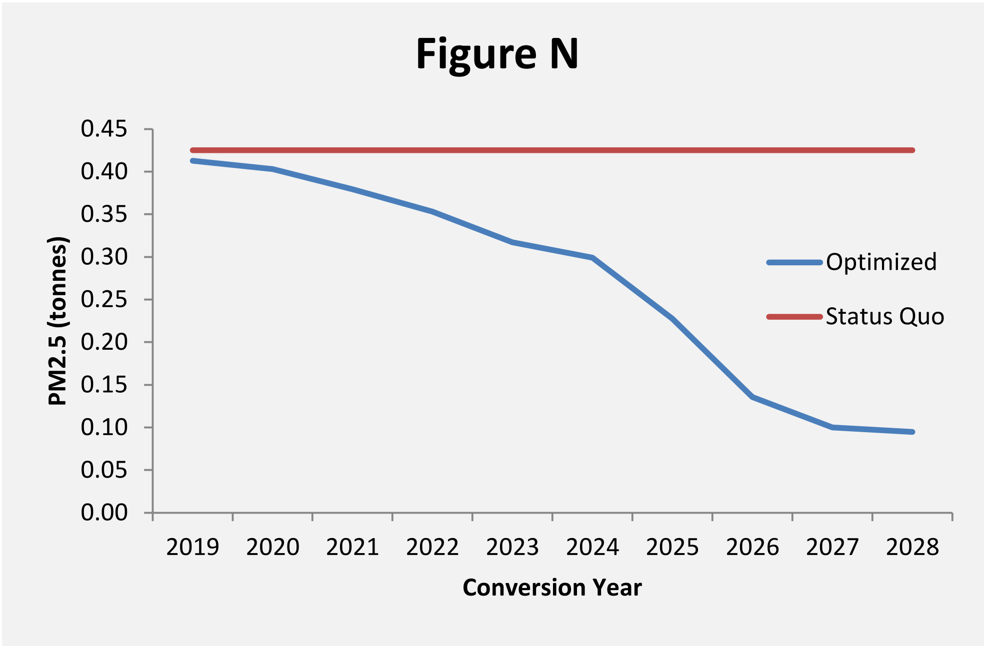


Figure N - 10 year PM2.5 emissions projections if implementation is delayed until a given year, using the vehicle portfolio at that year, given a 15% annual battery cost reduction

Copy of survey

Monroe County Fleet Analysis

Survey to be completed by Department Fleet Coordinators

Department:

Coordinator:

Vehicle Fleet #:

Current Miles:

Category: Sedan / SUV / PickUp

Make/Model/Model Year:

1. Vehicle assignment: (Please circle one)
   a. 24 Hour Use
   b. Commuter Use
   c. Pool

2. Fuel Type: (Please circle one)

a. Gasoline
b. Hybrid
c. Electric

3. Is the vehicle used every day? If not, how many days per week is it used?

4. What is the maximum amount of miles this vehicle is driven in a day?

5. How many days per year must this vehicle be driven more than 100 miles in a day?

6. Where is the vehicle parked most often when not in use? (Please circle one)
    a. Parking Garage
    b. County Parking Lot
    c. Street Parking
    d. Residential Garage
    e. Residential Driveway
    f. Other

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