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AVTA Federal Fleet PEV Readiness Data Logging and Characterization Study for NASA Glenn Research Center

Stephen Schey
Jim Francfort

October 2014

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Stephen Schey
Jim Francfort[2]

[1]Stephen Schey, Project Manager, Infrastructure Planning and Analysis, Intertek Testing Services, North America, Phoenix, AZ
[2]Jim Francfort, Vehicle Systems Principal Investigator, Idaho National Laboratory operated by Battelle Energy Alliance, Idaho Falls, ID

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://avt.inl.gov

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ABSTRACT

Battelle Energy Alliance, LLC, managing and operating contractor for the U.S. Department of Energy's Idaho National Laboratory, is the lead laboratory for the U.S. Department of Energy's advanced vehicle testing. Battelle Energy Alliance, LLC contracted with Intertek Testing Services, North America (Intertek) to collect and evaluate data on federal fleet operations as part of the Advanced Vehicle Testing Activity's Federal Fleet Vehicle Data Logging and Characterization Study. The Advanced Vehicle Testing Activity's study seeks to collect and evaluate data to validate the utilization of advanced plug-in electric vehicle (PEV) transportation.

This report focuses on the NASA Glenn Research Center (GRC) fleet to identify daily operational characteristics of select vehicles and report findings on vehicle and mission characterizations to support the successful introduction of PEVs into the agencies' fleets.

Individual observations of these selected vehicles provide the basis for recommendations related to electric vehicle adoption and whether a battery electric vehicle or plug-in hybrid electric vehicle (collectively referred to as PEVs) can fulfill the mission requirements.

Intertek acknowledges the support of Idaho National Laboratory and GRC for participation in the study.

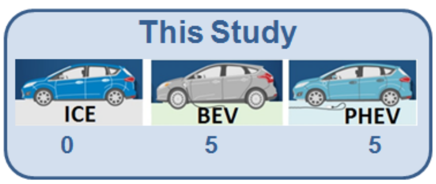
Intertek is pleased to provide this report and is encouraged by the enthusiasm and support from GRC personnel.

EXECUTIVE SUMMARY

Federal agencies are mandated to purchase alternative fuel vehicles, increase consumption of alternative fuels, and reduce petroleum consumption. Available plug-in electric vehicles (PEVs) provide an attractive option in the selection of alternative fuel vehicles. PEVs, which consist of both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), have significant advantages over internal combustion engine (ICE) vehicles in terms of energy efficiency, reduced petroleum consumption, and reduced production of greenhouse gas (GHG) emissions, and they provide performance benefits with quieter, smoother operation. This study is intended to evaluate the extent to which the NASA Glenn Research Center (GRC) could convert part or all of their fleet of vehicles from petroleum-fueled vehicles to PEVs.

It is likely that more fuel-efficient ICE vehicles, including hybrid electric vehicles, exist that may provide improvements for the current fleet; however, this study's focus is on replacing ICE vehicles with suitable PEVs.

BEVs provide the greatest benefit when it comes to fuel and emissions savings because all motive power is provided by the energy stored in the onboard battery pack. These vehicles use no petroleum and emit no pollutants at their point of use. PHEVs provide similar savings when their battery provides the motive power, but they also have the ability to extend their operating range with an onboard ICE. Since a PHEV can meet all transportation range needs, the adoption of a PHEV will be dependent on its ability to meet other transportation needs such as cargo or passenger carrying. Operation of PHEVs in battery-only mode can be increased with opportunity charging at available charging stations. However, it should be noted that not all PHEVs have a mode in which the battery provides all motive power at all speeds. This study focuses on the mission requirements of the fleet of vehicles with the objective to identify vehicles that may be replaced with PEVs, with emphasis on BEVs that provide the maximum benefit.



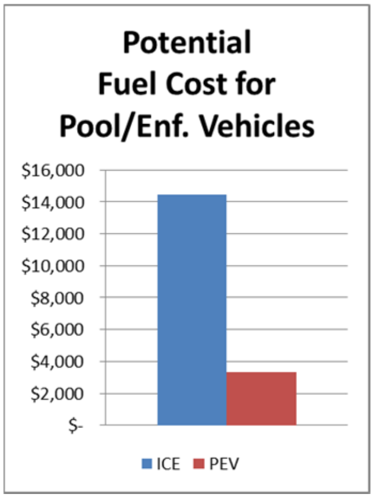
GRC in Cleveland, Ohio researches, designs, develops, and tests innovative technology for aeronautics and spaceflight and is one of ten NASA centers. It employs more than 3,400 people, including civil servants and onsite contractors. A highly skilled workforce of scientists, engineers, technicians, and administrative and support personnel comprise the robust and diverse GRC team. GRC is situated on 350 acres of land and contains over 150 buildings[a].

NASA Plum Brook Station is a remote test installation site for GRC and is located about 50 miles west of GRC at Lewis Field, near Sandusky, Ohio. The 6,400 acres site provides large, clear zone areas to safely conduct aerospace testing. Plum Brook

[a] http://www.nasa.gov/centers/glenn/about/aboutgrc.html [accessed August 25, 2014]

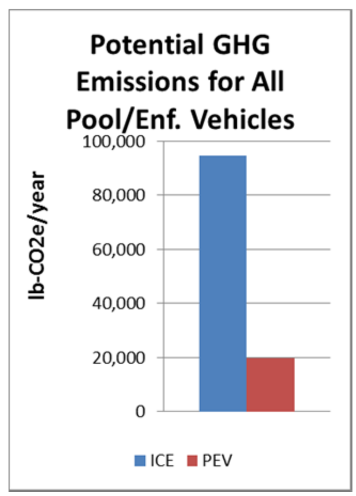
Station employs a minimal NASA civil service staff that provides leadership and oversees strategy, safety, quality, finance, and environmental compliance.[b]

GRC has 108 vehicles in its fleet, with 10 identified as representative of the fleet and instrumented for data collection and analysis. Fleet vehicle mission categories are defined in Section 4 and while the GRC vehicles conduct many different missions, two missions (i.e., pool and enforcement missions) were selected by agency management to be part of this fleet evaluation. These two mission categories accounted for 20 of the 108 total fleet vehicles. The remaining vehicles are support, transport, buses, and specialty vehicles.



This report observes that a mix of BEVs and PHEVs are capable of performing most of the required missions and of providing an alternative vehicle for the pool and enforcement vehicles, because while some vehicles travel long distances, the group could support some BEVs for the short trips and PHEVs for the longer trips. The recommended mix of vehicles will provide sufficient range for individual trips and time is available each day for charging to accommodate multiple trips per day. These charging events could occur at the vehicle home base. Replacement of vehicles in the current fleet would result in significant reductions in the emission of GHGs and in petroleum use, as well as reduced fleet operating costs.

Based on the data collected for the monitored vehicles, the 10-vehicle fleet subset could possibly consist of five BEVs and five PHEVs. The replacement of these 10 ICE vehicles with PEVs could result in an annual GHG savings over 35,140 lb-CO_2e (78% reduction) and an annual fuel cost savings of almost $6,000 (76% reduction).



Based on the data collected from the monitored vehicles and extrapolating to the 20 vehicles in the pool and law enforcement fleets, 11 BEVs and nine PHEVs may meet GRC's needs. Replacement of the 20 ICE vehicles with PEVs could result in an annual GHG savings over 74,800 lb-CO_2e (79% reduction) and an annual fuel cost savings of over $12,400 (77% reduction).

PEV charging stations could be located in various locations of GRC and could benefit not only GRC's own fleet vehicles, but those in the visiting public that own PEVs.

Intertek suggests GRC may wish to move forward in the near future with the replacement of pool, support, and enforcement vehicles with PEVs as current budget and vehicle replacement schedules allow. Certainly, the vehicle types studied in this report may be candidates for immediate replacement.

[b] http://www.nasa.gov/centers/glenn/about/testfacilities/plumbrook.html [accessed August 25, 2014].

CONTENTS

FIGURES

TABLES

ACRONYMS

AC	alternating current
BEV	battery electric vehicle
CD	charge depleting
CS	charge sustaining
DC	direct current
EPA	U.S. Environmental Protection Agency
EVSE	electric vehicle supply equipment
GHG	greenhouse gas emissions
GRC	Glenn Research Center
GSA	General Services Administration
ICE	internal combustion engine
Intertek	Intertek Testing Services, North America
OEM	original equipment manufacturers
PBS	Plum Brook Station
PEV	plug-in electric vehicle (includes BEVs and PHEVs, but not hybrid electric vehicles)
PHEV	plug-in hybrid electric vehicle
SUV	sport utility vehicle
VIN	vehicle identification number

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1. INTRODUCTION

Federal agencies are mandated by the Energy Policy Act of 1992,[3] Energy Policy Act of 2005,[4] Executive Order 13423 (President Bush 2007),[5] Executive Order 13514 (President Obama),[6] and the Energy Independence and Security Act of 2007[7] to purchase alternative fuel vehicles, increase consumption of alternative fuels, reduce petroleum consumption, and reduce greenhouse gas (GHG) emissions.

> *Executive Order 13514: "...makes reduction of GHG emissions a priority for Federal Agencies"*

Battelle Energy Alliance, LLC, managing and operating contractor for Idaho National Laboratory, is the lead laboratory for the U.S. Department of Energy's advanced vehicle testing and manages the Advanced Vehicle Testing Activity Federal Fleet Vehicle Data Logging and Characterization Study, which promotes utilization of advanced electric drive vehicle transportation technologies. The Advanced Vehicle Testing Activity focuses its testing activities on emerging and newly commercialized plug-in electric vehicle (PEV) technologies because of the high-energy efficiencies and reduced consumption of petroleum through use of electric-drive vehicles. Battelle Energy Alliance, LLC selected Intertek Testing Services, North America (Intertek) to collect data on federal fleet operations and report the findings on vehicle and mission characterizations to support the successful introduction of PEVs into federal fleets.

It is likely that more fuel efficient internal combustion engine (ICE) vehicles, including hybrid electric vehicles, exist that may provide improvements for the current fleet; however, they are not the focus of this study.

Because of the large number of vehicles in federal fleets in the United States, these fleets provide a substantial opportunity for the introduction of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) (collectively referred to as PEVs). However, to assess the scale of this opportunity, additional data are required to characterize the various missions performed by each fleet and to determine which existing vehicles are most suitable for replacement by a PEV.

The NASA Glenn Research Center (GRC), located in Cleveland, Ohio, contains over 350 acres of land (Figures 1 and 2) and employs over 3,400 people, including civil servants and onsite contractors. NASA Plum Brook Station (PBS) is a remote test installation site for GRC and is located about 50 miles west of GRC at Lewis Field, near Sandusky, Ohio.

GRC is an excellent site for fleet evaluation because of its size, location, and travel between the site, local destinations, and the PBS location. GRC has an opportunity to be a leader in the adoption of BEVs and PHEVs for its fleet.

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[3] http://thomas.loc.gov/cgi-bin/query/z?c102:h.r.776.enr [accessed January 10, 2014].

[4] http://www.gpo.gov/fdsys/pkg/BILLS-109hr6enr/pdf/BILLS-109hr6enr.pdf [accessed January 10, 2014].

[5] http://www.gsa.gov/portal/content/102452 [accessed January 10, 2014].

[6] https://www.fedcenter.gov/programs/eo13514/ [accessed September 1, 2014].

[7] http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf [accessed January 10, 2014].

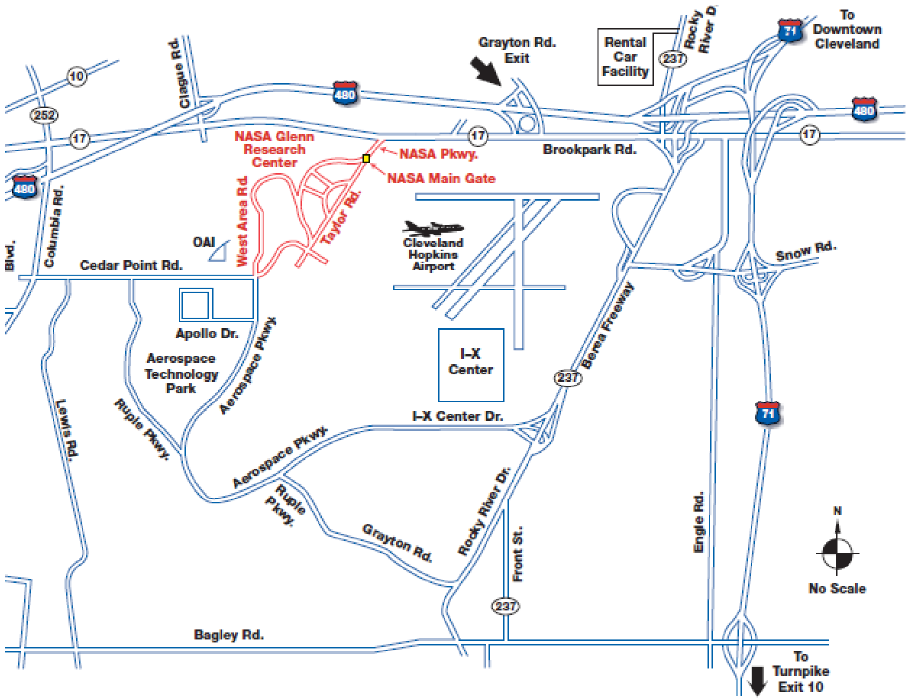

Figure 1. GRC graphical representation.[8]

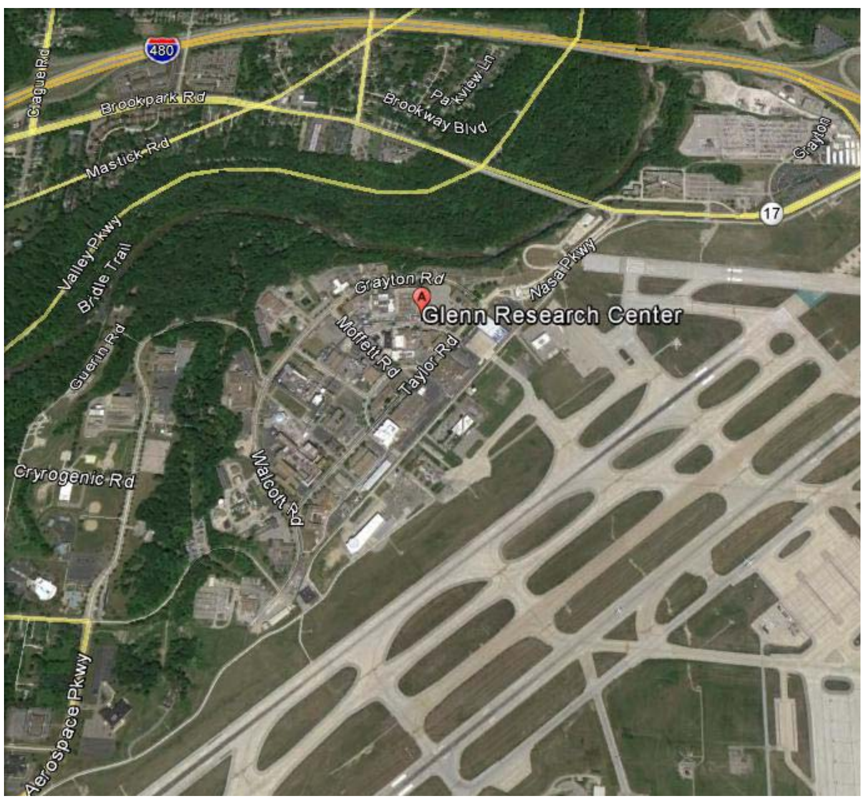

Figure 2. GRC arial view.[9]

[8] http://www.nasa.gov/centers/glenn/pdf/122211main_glenn_map.pdf [accessed August 25, 2014].

2. PROJECT OBJECTIVE

This study explores federal fleet vehicles and their usage characteristics, with a primary goal of supporting the goals of Presidential Executive Order 13514, which includes the following:

- Pursuing opportunities with vendors and contractors to address and incentivize GHG emission reductions and petroleum use reductions
- Implementing strategies and accommodations for transit, travel, training, and conferences that actively reduce carbon emissions associated with commuting and travel by agency staff
- Meeting GHG emissions reductions associated with other federal government sustainability goals
- Implementing innovative policies and practices that address agency-specific Scope 3 GHG emissions.[10]

Because of the large number of vehicles in the federal fleets, there is a substantial opportunity for PHEV and BEV adoption. Federal fleets offer an opportunity as a first market replacement for alternative fuels due to their scale, refueling patterns, and regular vehicle turnover.[11]

This project has the following four defined tasks:

1. **Data collection:** Coordinate with the fleet manager to collect data on agency fleet vehicles. This includes collecting information on the fleet vehicle and installing data loggers on a representative sample of the fleet vehicles to characterize their missions.
2. **Data analysis and review:** Examine the data collected by the loggers and fleet vehicle characteristics to describe typical fleet activity. Incorporate fleet manager's input on introducing PEVs to the agency's fleet.
3. **PEV implementation feedback:** Provide feedback to fleet personnel and Battelle Energy Alliance, LLC on the selection criteria for replacement PEVs in their specific fleet vehicle missions.
4. **Observations and recommendations:** Provide actionable information to introduce PEVs into agency fleet operations and assess any related impacts for the facility.

Data collected from the vehicles include trip distance, idle time, time between uses, and stop locations. Data collection continues for 30 to 60 days using a non-intrusive data logger, which gathers and transmits information using global positioning satellites and cellular service. The loggers collect data at 1-minute intervals and transmit when an active signal is present.

Extrapolating the results of this analysis to the larger fleet provides estimates of potential savings in gasoline consumption and GHG emissions. This report also provides recommendations relating to fleet management of BEVs and PHEVs for additional consideration.

Fleet managers may use the information supplied in this report to help them identify which vehicles are candidates for replacement by BEVs or PHEVs based on their use. BEVs are preferred because of the greater potential reduction of GHG emissions, fuel cost, and petroleum usage; however, they are not likely to be suitable for all vehicle missions.

The information in this report supports a final report to Battelle Energy Alliance, LLC/Idaho National Laboratory and the U.S. Department of Energy. The aggregated results for all agencies' fleets will

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[9] Google Earth [accessed October 28, 2014].

[10] http://energy.gov/sites/prod/files/2013/10/f3/eo13514.pdf [accessed February 5, 2014].

[11] *Fleet Purchase Behavior: Decision Processes and Implications for New Vehicle Technologies and Fuel*, Nesbitt, Sperling, University of California, Davis 2001.

provide an overview of federal fleets, vehicle missions, vehicle uses, and agencies needs to plan and establish a more systematic method for the adoption of BEVs and PHEVs.

3. METHODS

3.1 Fleet Vehicle Survey

Agency fleet managers selected fleet vehicles for this study and provided basic information for each vehicle, including its managing agency, home base for the vehicle, contact information, primary vehicle mission, vehicle ownership, fuel type, and odometer reading.

GRC identified 108 vehicles in their fleet. Vehicle missions were provided by NASA (Table 1). (Note that Section 4 provides descriptions of the vehicle mission types.) Intertek coordinated with the GRC fleet manager to identify the specific vehicles for data collection for inclusion in the study. The fleet manager assessed the wide range of vehicles and made selections of high-interest, representative vehicles based on vehicle missions and vehicle type/class. Selection also favored vehicles used at least twice a week. Because data loggers rely on the vehicle's battery power, non-use of the vehicle can result in the vehicle having a depleted battery. Intertek received no reports of depleted batteries during the study at GRC. Ten vehicles were selected: seven pool vehicles and three enforcement vehicles.

Table 1. Fleet evaluation.

Vehicle Mission	Study Vehicles	Total Fleet Reported	Percentage Studied
Pool Vehicles	7	17	41%
Support Vehicles		83	
Enforcement Vehicles	3	3	100%
Specialty Vehicles		3	
Bus		2	
Total Fleet Vehicles	10	108	9%

3.2 Data Collection

Individual privacy concerns exist when monitoring vehicle movement with data loggers. Data collection occurs by vehicle identification as identified by Intertek, data logger number, VIN, or an agency-assigned vehicle number. Intertek receives no information related to the vehicle operator and provides no raw data to the fleet managers. In this manner, Intertek does not collect, analyze, or report on individual driving habits.

3.2.1 Data Logger

Non-intrusive data loggers, produced by InTouchMVC12 and depicted in Figure 3, were inserted into the vehicle's onboard diagnostic port to collect and transmit the relevant data. Installation of the data logger and manual recording of information about the vehicle that ties the logger and vehicle together in the data typically takes less than 5 minutes. Once installed and activated (during vehicle use), the data loggers collect vehicle information once every minute during vehicle operation and transmit by cellular communication to the data center.

Intertek maintains the data logger's connectivity and verifies data transmission weekly. Missing data (reported as "null" values) are frequently the result of lost global positioning system reception, logger device removal, or extended periods in regions with insufficient cellular reception. Intertek filters the

[12] www.intouchmvc.com [accessed January 10, 2014].

vehicle and data logger information if these null values present a significant impact on the data collected and no resolution is possible. This report also identifies the statistics on this validation process.

Figure 3. InTouchMVC data logger.

GRC requested and installed eleven data loggers into the selected fleet vehicles. The agency removed and shipped the data loggers to Intertek at the conclusion of the data collection period.

3.2.2 Data Captured

Data consist of key-on events, key-off events, and position updates logged every minute while the vehicle is keyed-on. InTouchMVC converted these data points into records of trip events, stop events, and idle events.

From these data points, the following information was available for evaluation:

- Trip start and stop time and location
- Trip distance and duration
- Idle start time, location, and duration
- Stop start time, location, and duration.

3.3 Data Analysis

3.3.1 Definitions

Figure 4 illustrates a vehicle outing, which is comprised of trips, stops, and idle events that may occur during one day or over several days. The following list provides a definition of these terms:

1. **Outing**: An outing is the combination of trips and stops that begin at the home base and includes all travel until the vehicle returns home.
2. **Trip**: A trip begins with a key-on event and ends with the next key-off event.
3. **Vehicle stop**: A vehicle stop includes a key-off/key-on event pair.
4. **Idle time**: Idle time is the amount of time a vehicle spends stationary after a key-on event when the vehicle is not moving for a period of 3 minutes or longer.
5. **Trip travel time**: Trip travel time is the amount of time required to complete a trip, excluding stops but including idle time.

Definitions of additional analysis and survey terms are as follows:

1. **Operating shift**: Fleet manager-defined period worked.
2. **Study days**: Days during which the data loggers are connected.

3. **Vehicle days**: Study days during which a vehicle is used.
4. **Null values**: Data record unusable for analysis for various reasons.

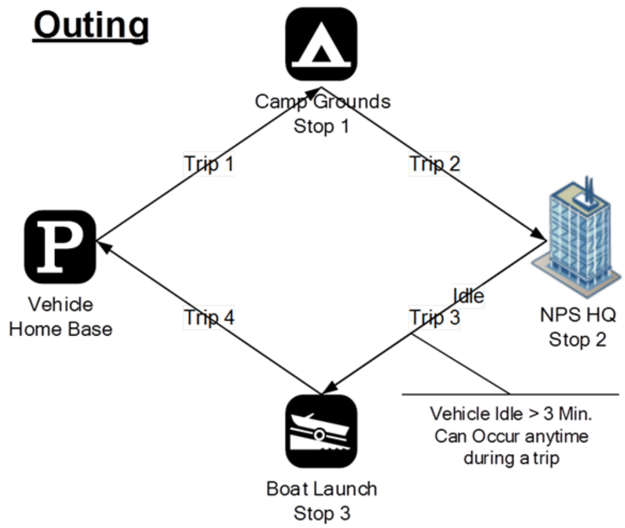

Figure 4. Vehicle outing.

3.3.2 Data Evaluation

Processing the data involves removal of null values and aggregation by different spatial and temporal scales. Aggregation was by day, by trip, and by outing to produce figures showing the patterns of use. Aggregation by vehicle mission followed to characterize use for the agency fleet. Section 5 presents these results. Data were extrapolated to provide the overall fleet usage and benefit analysis when fleet information was provided. Section 6 presents these benefits. Intertek observations are included in Section 7.

Statistical data analysis uses Python 2.7 with the MATLAB Plotting Library graphics environment (Matplotlib) and spatial display with ESRI ArcGIS.[13] Frequency distributions summarize the travel behavior of each vehicle and vehicle mission during the study period. Rounding of the tables and figures are to three significant digits.

4. VEHICLES

4.1 Vehicle Missions

The vehicle mission is an important characteristic in the fleet study. Information used to define the vehicle mission includes the vehicle's configuration, vehicle use, classification per 40 CFR Part 600.315-82 and the Environmental Protection Agency (EPA), the participating agency use, and generally assumed vehicle use. Based on fleet information gathered, Intertek has established the following seven mission/vehicle categories for analysis (examples are depicted in Figure 5):

1. **Pool vehicles**: A pool vehicle is any automobile (other than the low-speed vehicles identified below) manufactured primarily for use in passenger transportation, with not more than 10 passengers.
2. **Enforcement vehicles**: Vehicles specifically approved in an agency's appropriation act for use in apprehension, surveillance, police, or other law enforcement work. This category also includes site

[13] www.esri.com [accessed January 10, 2014].

security vehicles, parking enforcement, and general use, but the vehicles are capable of requirements to support enforcement activities. Appendix A provides further definition.

3. **Support vehicles**: Vehicles assigned to a specific work function or group to support the mission of that group. Vehicles are generally passenger vehicles or light-duty pickup trucks and may contain after-market modifications to support the mission.
4. **Transport vehicles**: Light, medium, or heavy-duty trucks used to transport an operator and tools or equipment of a non-specific design or nature. The vehicle's uses include repair, maintenance, or delivery.
5. **Specialty vehicles**: Vehicles designed to accommodate a specific purpose or mission (such as ambulances, mobile cranes, and handicap controls).
6. **Shuttles/buses**: Vehicles designed to carry more than 12 passengers and further outlined in 49 CFR 532.2.
7. **Low-speed vehicle:** Vehicles that are legally limited to roads with posted speed limits up to 45 mph and that have a limited load-carrying capability.

Figure 5. Vehicle missions.

4.2 Alternative Fuel Vehicles

As the operating agency, GRC has a unique opportunity to plan for the adoption of BEVs and PHEVs, along with planning for the supporting infrastructure. The adoption of PHEVs and BEVs is a primary goal of the General Services Administration (GSA) and supports the directives previously referenced.

As GSA increases its certification of PHEVs and BEVs, agencies can plan for vehicle replacement through GSA for passenger vehicles and trucks. Table 2 presents the replacement requirements for fleet vehicles. Note that both of the age and mileage requirements need to be met in order for the vehicle to qualify for replacement, except where noted as "or."

Table 2. GSA vehicle replacement requirements.

GSA Vehicle Replacement Requirements[14]			
	Fuel Type	Years	Miles
Passenger vehicles	Gasoline or alternative fuel vehicle	3 4 5 Any age	36,000 24,000 Any mileage 75,000
	Hybrid	5	Any miles
	Low-speed BEV	6	Any miles
Light trucks 4 x 2	Non-diesel	7	65,000
	Diesel	8 or	150,000
	Hybrid	7	Any mileage
Light trucks 4 x 4	Non-diesel	7 or	60,000
	Diesel	8 or	150,000
	Hybrid	7	Any mileage

4.3 Battery Electric Vehicle and Plug-In Hybrid Electric Vehicle Benefits/Challenges

BEVs are fully powered by the battery energy storage system available onboard the vehicle. The Nissan Leaf is an example of a BEV. Because the BEV has no other energy source for propulsion, the range, power requirements, and mission of the needed vehicle factor greatly in purchasing decisions. Maximizing BEV capabilities typically requires batteries more than an order of magnitude larger in capacity than the batteries in hybrid electric vehicles.

PHEVs obtain their power from at least two energy sources. The typical PHEV configuration uses a battery and an ICE that is powered by either gasoline or diesel. PHEV designs differ between manufacturers. All have a charge-depleting (CD) mode where the battery is depleted of its stored energy to propel the vehicle and a charge-sustaining (CS) mode (or extended-range mode) that is entered after CD mode is complete and where the battery and ICE work together to provide propulsion, while the state of charge of the battery is maintained between set limits. Some PHEVs' operation in CD modes is purely electric, while others employ the engine to supplement the battery power during the initial battery depletion to a set state of charge (usually below 50%).

4.3.1 Battery Electric Vehicle Benefits/Challenges

EPA identifies the following benefits of BEVs:[15]

- **Energy efficient:** Electric vehicles convert about 59 to 62% of the electrical energy from the grid to power at the wheels, whereas conventional gasoline vehicles only convert about 17 to 21% of the energy stored in gasoline to power at the wheels.
- **Environmentally friendly:** PEVs emit no tailpipe pollutants, although the power plant producing the electricity may emit them. Electricity from nuclear, hydro, solar, or wind-powered plants causes no air pollutants.

[14] http://www.gsa.gov/graphics/fas/VehicleReplacementStandardsJune2011Redux.pdf [accessed January 10, 2014].

[15] http://www.fueleconomy.gov/feg/evtech.shtml [accessed December 27, 2013].

- **Performance benefits:** Electric motors provide quiet, smooth operation and exhibit maximum torque at zero and low speeds, while also requiring less maintenance than ICEs.
- **Reduce energy dependence:** Electricity is a domestic energy source.

EPA also identifies challenges associated with BEVs, including the following:

- **Driving range:** Most BEVs can only travel about 100 to 200 miles (or less) before recharging, whereas gasoline vehicles can often travel over 300 miles before refueling and some much further.
- **Recharge time:** Fully recharging the battery pack can take 4 to 8 hours. With a high-power direct current (DC) fast charger (DCFC), restoration from a depleted state to 80% capacity can take approximately 30 minutes.
- **Battery cost:** The large battery packs are expensive and may need to be replaced one or more times.
- **Bulk and weight**: Battery packs are heavy and take up considerable vehicle space.

4.3.2 Plug-in Hybrid Electric Vehicle Benefits/Challenges

EPA identifies the following benefits of PHEVs:[16]

- **Less petroleum use:** PHEVs are expected to use about 40 to 60% less petroleum than conventional vehicles. Because electricity is produced primarily from domestic resources, PHEVs reduce dependence on oil.
- **Fewer emissions:** PHEVs are expected to emit fewer GHG emissions than conventional vehicles; however, as with BEVs, the difference depends largely on the type of power plant supplying the electricity.
- **Higher vehicle costs, lower fuel costs:** PHEVs will likely cost $1,000 to $7,000 more than comparable non-PHEVs. Fuel will cost less because electricity is much cheaper than gasoline, but the fuel savings depends on how much of the driving is done on the off-board electrical energy.
- **Recharging takes time:** Recharging the battery typically takes several hours. However, PHEVs do not have to be plugged in to be driven. They can be fueled solely with gasoline, but will not achieve maximum range, fuel economy, or fuel savings without charging.
- **Measuring fuel economy:** Because a PHEV can operate on electricity alone, gasoline alone, or a mixture of the two, EPA provides a fuel economy estimate for gasoline-only operation (CS mode), electric-only operation (all-electric CD mode), or combined gasoline and electric operation (blended CD mode).

In most cases, the PEV retail cost is higher than a non-PEV model. This incremental purchase cost may be a fleet budget challenge; however, many original equipment manufacturers (OEMs) have offered incentives to encourage the use and adoption of BEVs and PHEVs. Some OEMs have recently reduced the vehicle cost, while also increasing vehicle range. Additionally, federal and state incentives have increased the attractiveness of purchasing a PEV. A common assumption is that increasing PEV sales will result in a reduction in this incremental purchase cost and a positive feedback loop will ensue.

4.4 Plug-In Electric Vehicle Availability

GSA provides a summary of light and medium-duty passenger vehicles that are available for lease or purchase through the GSA portal[17]; although not all BEVs and PHEVs currently on the market are 'certified' to be GSA replacements. Vehicles not on the GSA list of 'certified' vehicles require an agency

[16] http://www.fueleconomy.gov/feg/phevtech.shtml [accessed July 19, 2013]

[17] http://www.gsa.gov/portal/content/104224 [accessed March 6, 2014]

to self-certify a functional need or provide alternative measures for exemptions. Table 3 summarizes the vehicles that may be suitable replacements and are certified replacements through GSA. Note that the "CD/CS" column provides the EPA fuel economy values for CD and CS modes. The fuel economy of CD mode is provided in units of miles-per-gallon-of-gasoline-equivalent (MPGe). This metric allows for the electricity consumption during CD mode to be compared with fuel consumption during CS mode (or against conventional vehicles). The Nissan Leaf and Mitsubishi i-MiEV are not included in the alternative fuel guide for 2014, but they have appeared in previous guides.

Replacement is dependent on vehicle configuration characteristics and the vehicle mission. Further evaluation related to vehicle purpose and mission follows in Section 5.

Tables 4 through 7 provide summaries of PHEVs and BEVs either currently available or near commercialization in both passenger cars and pickup trucks, but that do not appear on the GSA 'certified' vehicle list. These vehicles may qualify for use by the agency through demonstrating a functional need.

Table 3. GSA certified PEVs.

Make/Model	GSA Class	Type	CD/CS	GSA Incremental Price
Chevrolet Volt	Sedan, Subcompact	PHEV	98 MPGe/37 mpg	$17,087.18
Ford C-MAX Energi	Sedan, Subcompact	PHEV	100 MPGe/38 mpg	$14,899.52
Ford Focus Electric	Sedan, Subcompact	BEV	110 MPGe/99 mpg	$16,573.09
Ford Fusion Energi	Sedan, Compact	PHEV	100 MPGe/38 mpg	$19,289.99

Note that EPA differs in vehicle class. EPA identifies the Volt as a compact, the C_MAX Energi as a midsize, the Fusion Energi as a midsize, and the Focus as a compact.[18]

Table 4. OEM PHEV cars and availability.

Make	Model	Model Year
Audi	A3 eTron PHEV	2015 (estimate)
Chevrolet	Volt	2011
Honda	Accord PHEV	2014
Toyota	Prius PHEV	2012
Volvo	V60 Plug-in	2016 (estimate)
BMW	i3 with range extender	2014

Table 5. OEM BEV cars and availability

Make	Model	Model Year
BMW	i3	2014
Chevrolet	Spark EV	2014
Fiat	500e	2013(California only)
Ford	Focus Electric	2012
Honda	Fit EV	2013
Kia	Soul EV	2014 (estimate)
Mercedes-Benz	B-Class ED	2015 (estimate)

[18] http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=34130 [accessed August 1, 2014].

Make	Model	Model Year
Nissan	Leaf	2011
smart	ED	2014
Tesla	Model S	2012
Tesla	Model X	2015 (estimate)
Volkswagen	Golf	2015 (estimate)
Volvo	C30 Electric	2016 (estimate)

Table 6. OEM PHEV trucks, vans, and availability.

Make	Model	Model Year
Land Rover	Range Rover Sport	2016 (estimate)
Mitsubishi	Outlander PHEV	2015 (estimate)
Via	VTRUX VR300	2013

Table 7. OEM BEV trucks, vans, and availability.

Make	Model	Model Year
Nissan	eNV200	2015 (estimate)
Toyota	RAV4 EV	2013 (California only – elsewhere 2015 estimate)

4.5 Plug-In Electric Vehicle Charging

Refueling electric vehicles presents some challenges and some opportunities not encountered when refueling petroleum-fueled vehicles. Recharging the battery of a PHEV follows the same methodology as that for BEVs. This section provides basic information on recharging PEVs.

4.5.1 Electric Vehicle Supply Equipment Design

4.5.1.1 Charging Components. Electric vehicle supply equipment (EVSE) stations deliver electric power from the utility to the applicable charge port on the vehicle. Figure 6 illustrates the primary components of a typical alternating current (AC) Level 2 EVSE unit.

The electric utility delivers AC current to the charging location. The conversion from AC to the DC electricity necessary for battery charging can occur either on or off board the vehicle. Section 4.5.1.2 provides further explanation of the different EVSE configurations. For onboard conversion, AC current flows through the PEV inlet to the onboard charger. The charger converts AC to the DC current required to charge the battery. A connector attached to the EVSE inserts into a PEV inlet to establish an electrical connection to the PEV for charging and information/data exchange. Off-board conversion, also known as DC charging, proceeds in a similar manner except that the AC to DC conversion occurs in a charger that is off board the vehicle and, thus, bypasses any onboard charger. For both AC and DC charging, the PEV’s battery management system on board the vehicle controls the battery rate of charge, among other functions. All current PEVs have an onboard charger; some BEVs (but no PHEVs currently) accommodate DC charging.

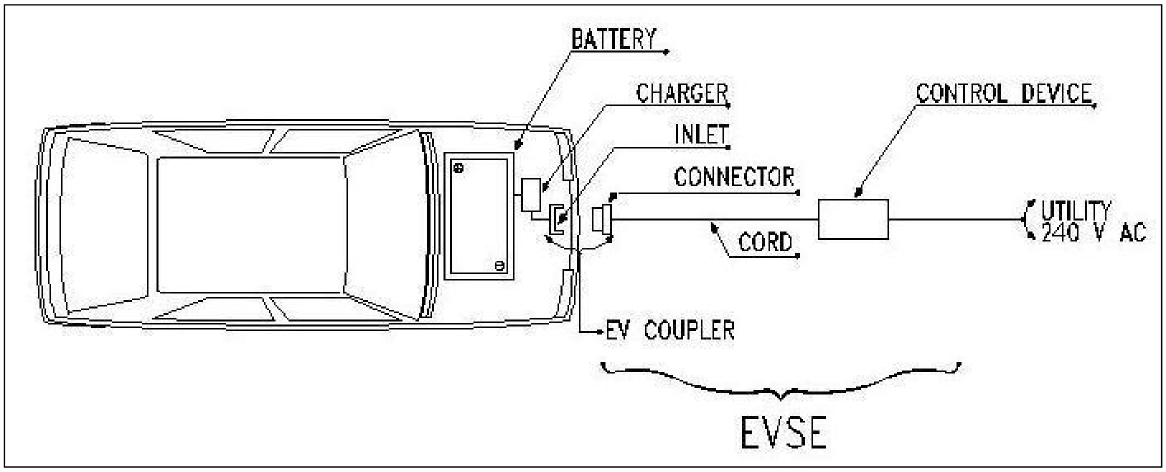

Figure 6. AC Level 2 charging diagram.[19]

4.5.1.2 Charging Configurations and Ratings. The Society of Automotive Engineers standardized the requirements, configurations, and equipment followed by most PEV suppliers in the United States in the J1772 Standard. Figure 7 summarizes these attributes and the estimated recharge times. Actual recharge times depend on the onboard equipment, including the charger, battery, and battery management system.

SAE International	SAE Charging Configurations and Ratings Terminology		
AC level 1 (SAE J1772™)	PEV includes on-board charger	*DC Level 1	EVSE includes an off-board charger
	120V, 1.4 kW @ 12 amp 120V, 1.9 kW @ 16 amp		200-450 V DC, up to 36 kW (80 A)
	Est. charge time:		Est. charge time (20 kW off-board charger):
	PHEV: 7hrs (SOC* - 0% to full)		PHEV: 22 min. (SOC* - 0% to 80%)
	BEV: 17hrs (SOC – 20% to full)		BEV: 1.2 hrs. (SOC – 20% to 100%)
AC level 2 (SAE J1772™)	PEV includes on-board charger (see below for different types)	*DC Level 2	EVSE includes an off-board charger
	240 V, up to 19.2 kW (80 A)		200-450 V DC, up to 90 kW (200 A)
	Est. charge time for 3.3 kW on-board charger		Est. charge time (45 kW off-board charger):
	PEV: 3 hrs (SOC* - 0% to full)		PHEV: 10 min. (SOC* - 0% to 80%)
	BEV: 7 hrs (SOC – 20% to full)		BEV: 20 min. (SOC – 20% to 80%)
	Est. charge time for 7 kW on-board charger		
	PEV: 1.5 hrs (SOC* - 0% to full)	*DC Level 3 (TBD)	EVSE includes an off-board charger
	BEV: 3.5 hrs (SOC – 20% to full)		200-600V DC (proposed) up to 240 kW (400 A)
	Est. charge time for 20 kW on-board charger		Est. charge time (45 kW off-board charger):
	PEV: 22 min. (SOC* - 0% to full)		BEV (only): <10 min. (SOC* - 0% to 80%)
	BEV: 1.2 hrs (SOC – 20% to full)		
*AC Level 3 (TBD)	> 20 kW, single phase and 3 phase		

*Not finalized
Voltages are nominal configuration voltages, not coupler ratings
Rated Power is at nominal configuration operating voltage and coupler rated current
Ideal charge times assume 90% efficient chargers, 150W to 12V loads and no balancing of Traction Battery Pack

Notes:
1) BEV (25 kWh usable pack size) charging always starts at 20% SOC, faster than a 1C rate (total capacity charged in one hour) will also stop at 80% SOC instead of 100%
2) PHEV can start from 0% SOC since the hybrid mode is available. Developed by the SAE Hybrid Committee ver. 031611

Figure 7. Society of Automotive Engineers charging configurations and ratings terminology.[20]

[19] http://www.theevproject.com/downloads/documents/Electric%20Vehicle%20Charging%20Infrastructure%20Deployment%20Guidelines%20for%20the%20Greater%20Phoenix%20Area%20Ver%203.2.pdf [accessed January 15, 2014].

Most PEV manufacturers supply an AC Level 1 cord-set with the vehicle, which provides sufficient capabilities for some drivers, but often provides an emergency backup capability because of the long recharge times. AC recharging capabilities found in the public arena more typically are AC Level 2. Figure 8 depicts a typical J1772-compliant inlet and connector for both AC Levels 1 and 2.

Figure 8. J1772 connector and inlet.[21]

The J1772 standard also identifies requirements for DC charging. For PEVs that accept both AC and DC inputs, the Society of Automotive Engineers approved a single connector and inlet design. Figure 9 shows this connector, which is colloquially known as the J1772 "combo connector."

Figure 9. J1772-compliant combo connector.[22]

Some BEVs introduced in the United States prior to the approval of the J1772 standard for DC charging employ the CHAdeMO (designed in Japan) standard for connector and inlet design. Figure 10

[20] http://www.sae.org/smartgrid/chargingspeeds.pdf [accessed January 15, 2014].

[21] http://carstations.com/types/j09 [accessed January 15, 2014].

[22] http://www.zemotoring.com/news/2012/10/sae-standardizes-j1772-fast-dc-charging-up-to-100-kw [accessed January 15, 2014].

shows this connector. EVSE units that are either J1772-compliant or CHAdeMO-compliant are both known as DCFCs.

Figure 10. CHAdeMO-compliant connector.[23]

The presence of the two separate standards for DC charging presents challenges for vehicle owners to ensure the EVSE accessed provides the appropriate connector for their vehicle inlet. Not all PEV suppliers include DC charging options. BEV suppliers have provided DC inlets where PHEV suppliers have not, because the rapid recharging provides opportunities for expanded vehicle range with minimal operator wait times. PHEV operators can rely on the gasoline drive in the event they deplete the vehicle's battery. At present, no PHEV on the market or near commercialization has DC charging capability (although the Mitsubishi Outlander PHEV is rumored to be offering DC charging capability as an option). It is noted that DC Level 1 and DC Level 2 charging are commonly combined and labeled DCFC.

Because the battery of a BEV is typically much larger than that of a PHEV, recharge times are longer (see Figure 7). BEVs that see daily mileage near the limits of the advertised range do better when recharged using AC Level 2 EVSE or DCFC, because AC Level 1 recharge times are usually extensive. PHEVs, on the other hand, generally can use AC Level 1 EVSE for overnight charging to ensure a fully charged battery at the start of daily use. AC Level 2 EVSE units provide greater range in the shortest amount of time when intermediate or opportunity charging. DCFCs provide the fastest recharge capability for those vehicles equipped with DCFC inlets.

4.5.2 Electric Vehicle Supply Equipment Stations

AC Level 2 charging is the predominant rating of publicly accessible EVSE because of its wide acceptance by auto manufacturers and recharge times that are faster than AC Level 1 charging. Purchase and installation costs are more manageable than DCFCs and less space is required. There are several manufacturers of AC Level 2 equipment and the agency should review brands for comparison purposes. Figure 10 provides an example of a public AC Level 2 EVSE unit.[24]

DCFCs also are available from several manufacturers. Figure 12 illustrates one such charger.[25] This particular charger uses the CHAdeMO connector standard.

In general, installation costs are higher for the DCFC because of the higher voltage requirements and inclusion of the AC to DC converter and other safety and design features. Costs for both types are highly dependent on site characteristics such as distance to the nearest power source, asphalt or concrete cutting and repair, conduit requirements, and payment systems, if any.

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[23] https://radio.azpm.org/p/azspot/2012/5/10/1632-electric-cars/ [accessed January 15, 2014].

[24] www.eaton.com/ [accessed January 29, 2014].

[25] http://evsolutions.avinc.com/products/public_charging/public_charging_b [Accessed April 16, 2014].

Payment and equipment control systems included by some suppliers provide the potential for use by privately owned vehicles for a fee, but can allow agency fleet vehicle use without direct payment. These systems also allow for accurate record keeping of vehicle charging requirements.

Figure 11. Public AC Level 2 EVSE.

Figure 12. Public DCFC unit.

5. NASA GLENN RESEARCH CENTER ANALYSIS

5.1 Glenn Research Center Fleet

GRC reports 108 interior and GSA vehicles in their complete fleet. Table 8 shows the breakdown by EPA vehicle class.

Table 8. GRC fleet vehicles.

	Sedan Compact	Sedan Midsize	Sedan Large	SUV	Mini-van	Cargo Van	Pass Van	Pickup or LD Truck	MD HD Truck	Bus	Specialty	Total
Total Fleet	6	15		2	13	10	6	30	21	2	3	108

Based on GRC input on fleet vehicles, an assessment of mission by vehicle type was completed (Table 9 shows the results of that assessment).

Table 9. GRC fleet mission assessment.

Mission	Sedan Compact	Sedan Midsize	Sedan Large	SUV	Mini -van	Cargo Van	Pass Van	Pickup or LD Truck	HD Truck	Bus	Specialty	Total
Pool	4	6			4			3				17
Support	2	7		1	9	10	6	27	21			83
Law Enforce.		2		1								3
Transport												0
Specialty											3	3
Bus										2		2
Total	6	15		2	13	10	6	30	21	2	3	108

5.2 Survey Results

Ten vehicles were included in the study at GRC. Seven vehicles have pool missions and three are law enforcement. One law enforcement vehicle did not report data. Table 10 presents a summary of these vehicles and Table 11 provides details of the monitored vehicles. Specific vehicle references may be made to the vehicle ID or logger ID in this report.

Appendix B provides the analysis of each individual vehicle included in this study. Grouping the vehicles by mission creates an aggregated view of mission requirements to provide observations related to PEV replacement. The missions of these three categories vary considerably; therefore, these missions are evaluated separately. Two of the pool vehicles are assigned to PBS and are evaluated separately from GRC.

Table 10. Vehicle study summary.

Mission	Sedan Compact	Sedan Midsize	Minivan	SUV	Cargo Van	Pickup Truck	Truck HD	Total
Pool		4				3		7
Law Enforcement		2		1				3
Total		6		1		3		10

Table 11. Detailed GRC vehicle index.

Vehicle Index						
Log	Fleet Vehicle Id	Make	Model	Year	EPA Class	Mission
23	***9340	Chevrolet	Malibu	2010	Sedan – Midsize	Pool – GRC
24	***4364	Chevrolet	Malibu	2010	Sedan – Midsize	Pool – GRC
25	***2148	Chevrolet	Malibu	2011	Sedan – Midsize	Law Enforcement
26	***5846	Dodge	Dakota	2007	Pickup Truck	Pool – GRC
27	***5847	Dodge	Dakota	2007	Pickup Truck	Pool – GRC
28	***9021	Chevrolet	Malibu	2010	Sedan –Midsize	Law Enforcement
29	***5845	Dodge	Dakota	2007	Pickup Truck	Pool – GRC
30	***0432	Chevrolet	Malibu	2011	Sedan – Midsize	Pool – PBS
31	***3544	Chevrolet	Malibu	2011	Sedan – Midsize	Pool – PBS
32	***2944	Jeep	Gr Cherokee	2011	SUV	Law Enforcement

Note: The Fleet Vehicle Id is the last four digits of the VIN.

5.3 Data Validity

GRC data collection took place from October 5 through December 20, 2011. Vehicle data sheets (presented in Appendix B) detail the collected data for each vehicle, including specific dates the logger provided data.

Of the data collected, validation occurred for 98.5%, while null values exist for the balance. Table 12 shows this information by mission type.

Table 12. Vehicle data logger reporting summary.

Vehicle Data Logger Reporting Summary			
Mission	% Collected	% Null Values	Total
Pool	98.3	1.7	100%
Law Enforcement	97.2	2.8	100%
All Vehicles	98.5	1.5	100%

5.4 Glenn Research Center Pool Vehicles Evaluation

5.4.1 Survey and Site Information

Pool vehicles are typically light-duty motor vehicles for use in passenger transportation, with not more than 10 passengers. Pool missions can vary by agency, location, and jurisdiction; however, they typically utilize sedans, minivans, sport utility vehicles (SUVs), vans, or small pickup trucks and typically do not carry specific cargo or equipment. Table 9 identifies the five vehicles (i.e., three pickup trucks and two midsize sedans).

Incorporation of BEVs and/or PHEVs into the pool mission is a definite possibility. Pool vehicles used for shorter trips or outings qualify for BEV or PHEV replacement, while other pool vehicle activities that are associated with longer trips may require PHEV capabilities.

5.4.2 Summary for Pool Vehicles

Appendix B provides the vehicle data sheets for each of the pool vehicles monitored. This section aggregates the data for all pool vehicles for GRC. Table 13 summarizes pool travel during the study period for those days in which the vehicle was driven. Vehicle use occurred primarily between 0300 and

1300 hours daily. The vehicles were driven 4,196 miles and logged 167 hours during the 75-day study period. As shown in the Appendix B data sheets, idle time was not significant.

Table 13. GRC pool vehicles travel summary.

Pool Vehicles Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	21.4/206.9	9.8/411.8	3.7/204.9	4,196
Travel Time (Minutes)	51.0/228.0	23.4/403.0	8.8/199.0	10,003

5.4.3 Pool Vehicles Daily Summary

Figure 13 identifies daily travel distance and time for all the pool vehicles. The green line and bars indicate typical electric range on a single charge for a PHEV, while the blue line and bars (including the green bars) indicate the same for a BEV. Figures 14 and 15 show the composite history in distance and time traveled for the pool vehicles. In the stacked bar charts of Figures 14 and 15, the contribution of each vehicle is indicated by a different color.

When driven, the average travel distance per day for pool vehicles was 21.4 miles. On 86% of these vehicle days, the daily travel was less than the 70 miles considered to be within the BEV safe range (i.e., while BEV range can vary based on several factors, most BEVs provide at least 70 miles of vehicle range on a single battery charge), and 14% percent of pool daily travel was greater than 70 miles. Further, 85% of vehicle travel days were less than the 40 miles considered to be within the CD range of a PHEV.

Figures 14 and 15 show that the vehicles are not used every day, although there are many days when many of the vehicles are in use. Vehicles ***5846 and ***9340 had the highest number of travel days, while vehicles ***5847 and ***4364 had the least. Figure 16 displays the summary of use by time of day for all pool vehicles. Figure 17 shows the outing distances traveled, including data for all pool vehicles.

Appendix B provides the details of each of the pool vehicle's outing travel. The average travel outing for pool vehicles was 9.7 miles. On 95% of these vehicle outings, the distance traveled was less than the 70 miles considered to be within the BEV safe range. Only 5% percent of pool outing travel was greater than 70 miles. Further, 94% of vehicle travel outings were less than 40 miles considered to be within the CD range of a PHEV. In summary, these vehicles can be characterized by fairly low daily travel and outing distances (the average numbers are quite low), with a few days of travel that exceed the typical BEV range.

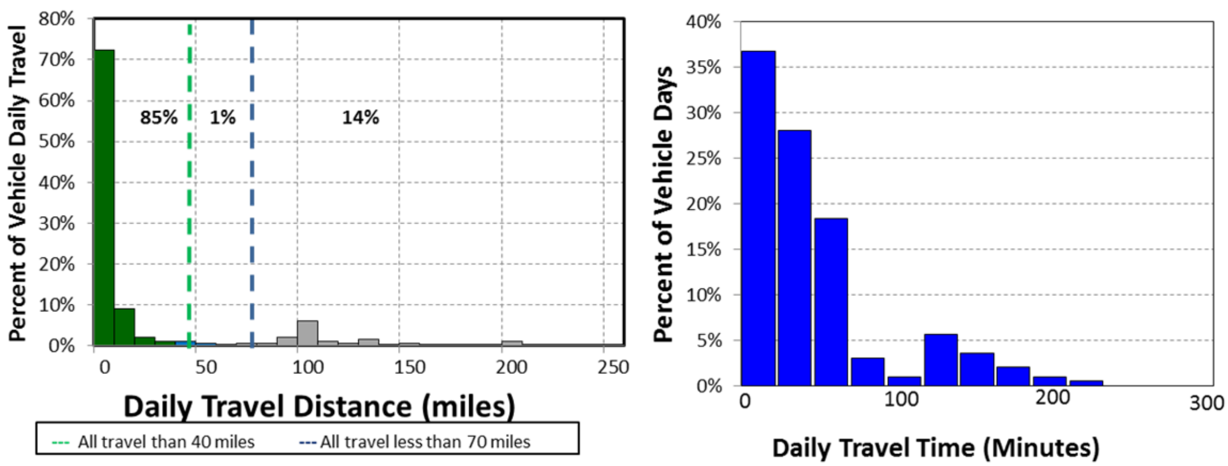


Figure 13. GRC pool vehicle daily travel miles and time (all vehicles).

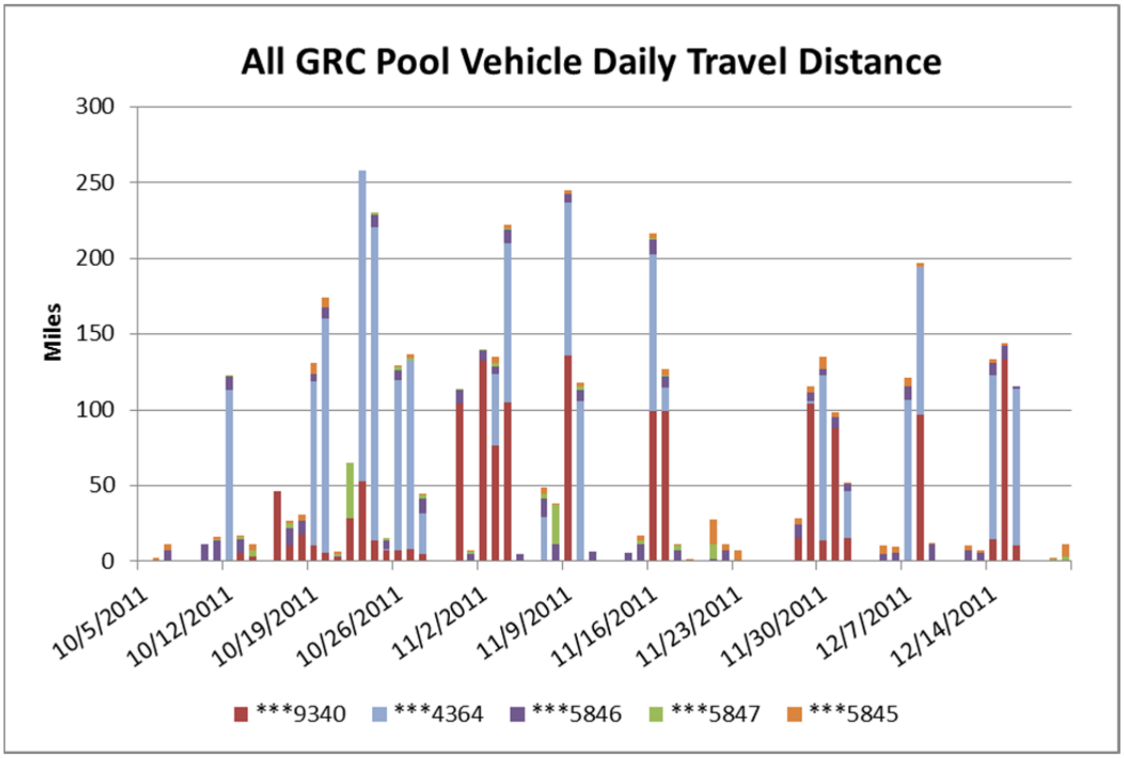


Figure 14. GRC pool vehicle daily travel history (all vehicles).

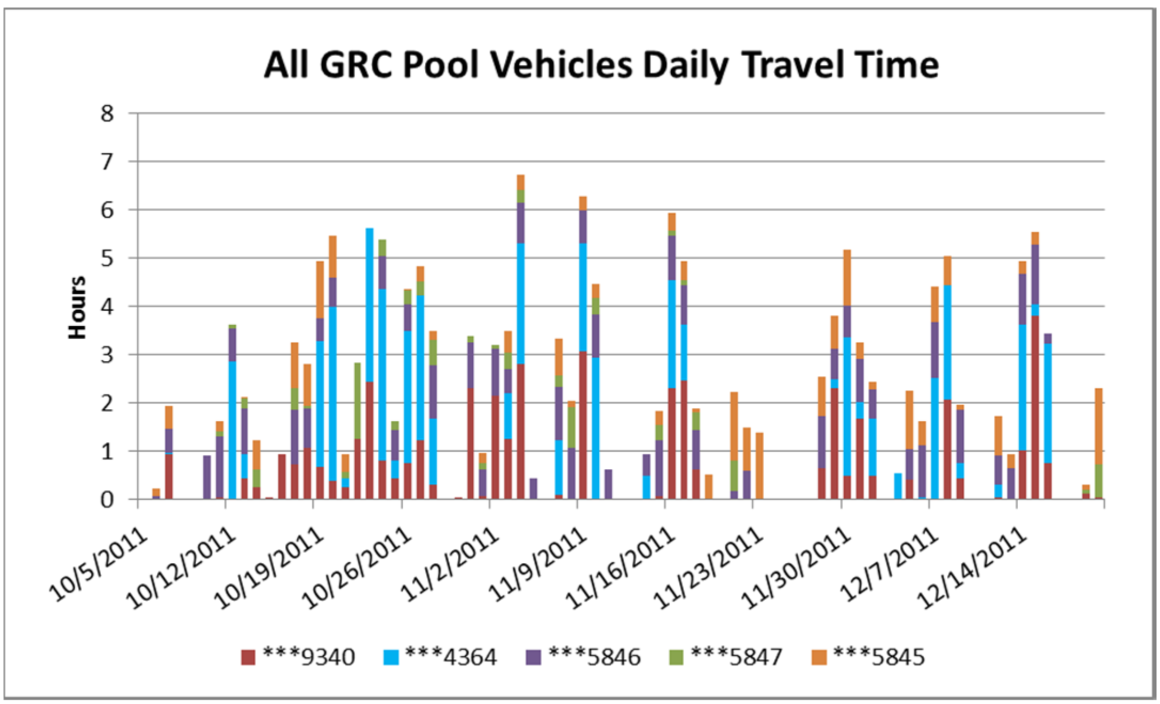


Figure 15. GRC pool vehicles travel time (all vehicles).

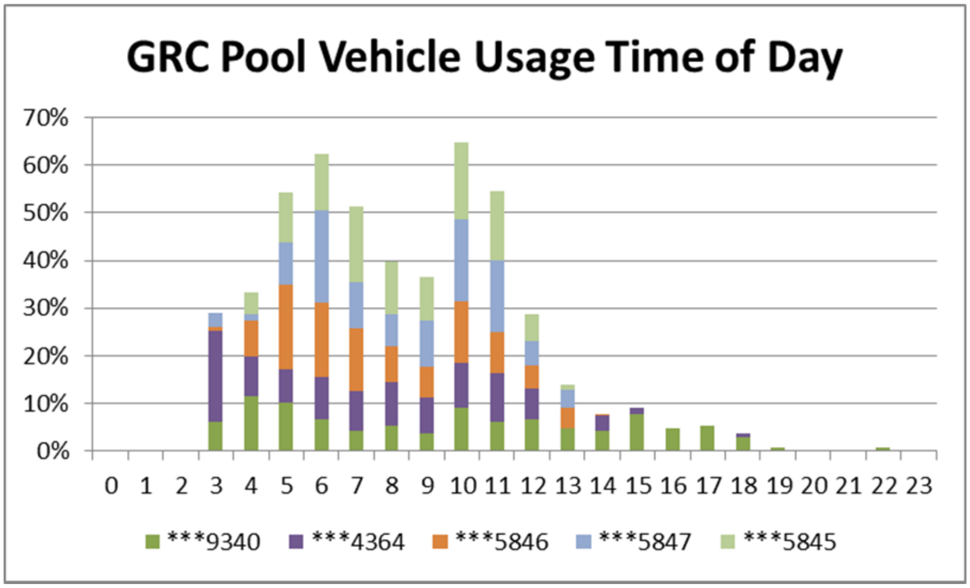


Figure 16. GRC pool vehicles hourly usage.

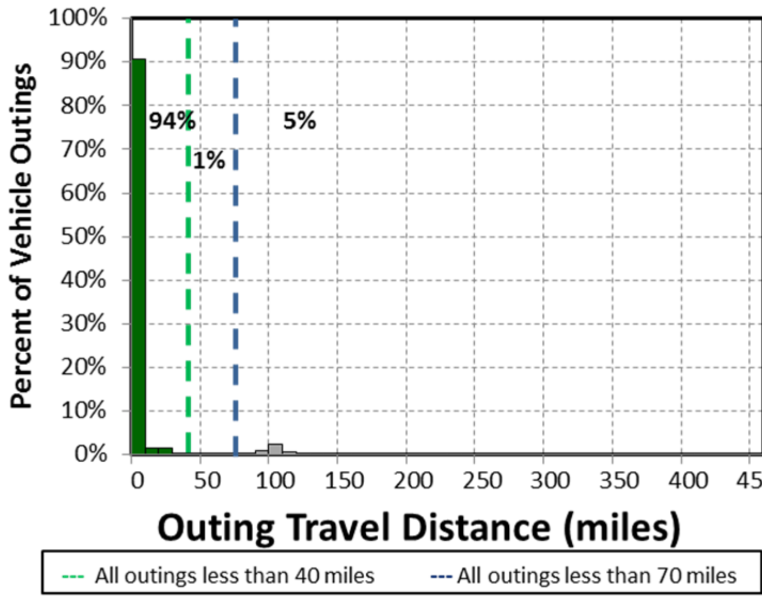


Figure 17. GRC pool vehicle outings. Note: the one outing of 411.8 miles is not visible on this graphic due to scale size.

5.4.4 Glenn Research Center Pool Vehicle Observations/Summary

There appears to be three choices for GRC in implementing PEVs into the pool fleet at GRC. It should be noted that the objective would be to incorporate as many BEVs as possible to realize the advantages of reduced petroleum usage and reduced emissions of GHGs.

1. **All BEV fleet:** While some BEV manufacturers report vehicle range exceeding 70 miles, Intertek recommends careful evaluation of experienced range to ensure vehicle missions are accomplished. Nevertheless, assuming the 70-mile safe range for a BEV, an all-BEV fleet does not appear to be possible due to the length of some of the daily travel.

2. **Mixed BEV/PHEV fleet:** Certainly, PHEVs can accomplish the same mission as the current fleet when only considering travel times and distances because the PHEV's gasoline engine can provide motive power when the battery has been depleted. Figure 13 shows that on 85% of all vehicle travel days, the total daily travel is less than 40 miles, which typically is the maximum distance a PHEV will travel in CD mode. This represents a significant operating cost savings opportunity while retaining the ability to go longer distances when needed. In addition, 94% of the outings are less than 40 miles and could be completed in CD mode for certain PHEVs if the battery is fully charged prior to the outing.

   Meanwhile, 95% of the outings are within the typical capability of a BEV and EVSE at the home base could provide recharge energy for another outing. A mixed fleet requires fleet manager attention to assign vehicles appropriately for the anticipated use on that day.

   Figure 13 also shows 86% of daily travel was within the typical range of a BEV. This would suggest that 14% of the fleet could be PHEVs to handle the travel greater than 70 miles per day without requiring additional opportunity charging during daytime stops and 86% of the fleet could be BEVs. However, this does not allow for use of several vehicles at the same time and would require a greater level of fleet management, with daily assignment of vehicles based on anticipated driving distance. Allowing more conservatism in assigning vehicles, two PHEVs and three BEVs could conservatively meet the demand for these five pool vehicles. All monitored pool vehicles are pickup trucks or midsize sedan and replacement PEVs are currently available for these vehicle types.

3. **All PHEV fleet:** As noted above, PHEVs can accomplish the same mission as the current fleet when only considering travel times and distances. Replacing all current vehicles with PHEVs only requires an evaluation of the individual vehicle capabilities of currently available PHEVs to meet current pool requirements. These five pool vehicles have replacement PEVs available. Data show that for a significant number of days, the PHEV will operate in CD mode. The first 40 miles of longer travel days would also be powered by (at least mostly) electricity; therefore, 85% of all pool vehicle travel would be (again, at least mostly) battery powered with only one charge per day. As above, this represents an opportunity for significant operating cost savings, while retaining the ability to go longer distances when needed. Intermediate charging opportunities provide additional benefit, enhancing CD mode. Data show significant charging opportunities throughout the day during stop times.

The vehicle summary shows sufficient time for charging at the base location during the course of the day and additional opportunities at intermediate charging stations are not required. These stations also provide charging opportunities for the visiting public, whose fees may assist in offsetting operating costs. Given the availability of daytime changing, with experience, GRC may find that a greater fraction of BEVs within the pool vehicle fleet may meet their needs.

Considering a full complement of 17 pool vehicles in the total fleet, Intertek suggests that a mixed fleet may be possible. While the remaining vehicles were not monitored, using the same ratio as above suggests a fleet of 10 BEVs and seven PHEVs would conservatively meet vehicle travel requirements. Typically, additional EVSE at frequently visited locations provide recharging for both BEVs and PHEVs that may be of benefit.

5.4.5 Glenn Research Center Pool Vehicle Charging Needs

Upon review of these data, Intertek suggests replacement of the studied pool fleet with three BEVs and two PHEVs. No available PHEVs at this writing provide for DCFC nor do the data suggest that this would be a significant benefit for PHEVs in the pool fleet. A DCFC at the home base will provide a more rapid recharge for BEVs, but appears to be unnecessary, given that the data show that 95% of outings are less than a typical BEV's driving range.

As noted above, AC Level 2 overnight charging of BEVs is typical, whereas overnight charging of PHEVs can usually be accomplished with AC Level 1 charging.

Intertek's experience suggests that each vehicle should have an assigned charging parking space at its home base. Assigned stations require less management attention to ensure completion of overnight charging. BEVs and PHEVs not assigned to these stations also benefit during visits to the location as part of their normal operation. For the entire fleet of pool vehicles, the 10 BEVs require 10 AC Level 2 EVSE units for overnight charging and the seven PHEVs require seven AC Level 1 outlets at each vehicles overnight parking location. Intertek recommends a minimum of two EVSE at each location to maximize charge capability without a significant increase in installation costs. The PHEVs can utilize the AC Level 2 EVSE at the home base during the day to increase the amount of vehicle miles traveled in CD mode.

At times, fleet vehicles obtain benefit from using public charging infrastructure. Figure 18 displays the availability of public charging for the GRC area at the time of this writing. All the indicated stations provide AC Level 2 EVSE. Some of these are located along the traffic route from GRC to PBS.

Figure 18. Public EVSE in GRC region.[26]

5.5 Plum Brook Station Pool Vehicles Evaluation

5.5.1 Survey and Site Information

PBS identified two midsize sedans in its pool fleet for monitoring.

Incorporation of BEVs and/or PHEVs into the pool mission at PBS is a definite possibility. Pool vehicles used for shorter trips or outings qualify for BEV or PHEV replacement, while other pool vehicle activities that are associated with longer trips may require PHEV capabilities.

5.5.2 Summary for PBS Pool Vehicles

Appendix B provides the vehicle data sheets for each of the pool vehicles monitored. This section aggregates data for all pool vehicles. Table 14 summarizes pool travel during the study period for those days in which the vehicle was driven. Vehicle use occurred primarily during typical day shift times. The vehicles were driven 5,431 miles and logged122 hours during the 75-day study period.

[26] http://www.plugshare.com/ [accessed August 30, 2014].

Table 14. PBS pool vehicles travel summary.

Pool Vehicles Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	77.6/682.9	48.6/1,368.7	16.7/268.8	5,431
Travel Time (Minutes)	105.0/713.0	65.8/1,423	22.7/251.0	7,349

5.5.3 Plum Brook Station Pool Vehicles Daily Summary

Figure 19 identifies daily travel distance and time for all pool vehicles. The green line and bars indicate typical electric range on a single charge for a PHEV, while the blue line and bars (including the green bars) indicate the same for a BEV. Figures 20 and 21 show the composite history in distance and time traveled for the pool vehicles. In the stacked bar charts of Figures 20 and 21, the contribution of each vehicle is indicated by a different color.

When driven, the average travel distance per day for PBS pool vehicles was 77.6 miles. On 63% of these vehicle days, the daily travel was less than the 70 miles considered to be within the BEV safe range (i.e., while BEV range can vary based on several factors, most BEVs provide at least 70 miles of vehicle range on a single battery charge), and 37% percent of pool daily travel was greater than 70 miles. Further, 63% of vehicle travel days were less than 40 miles considered to be within the CD range of a PHEV.

Figures 20 and 21 show that the vehicles were not used every day, although there were many days when both vehicles were in use. Vehicles ***3544 was used for the longer trips, while ***0432 had consistently shorter trips. Figure 22 displays the summary of use by time of day for all pool vehicles. Figure 23 shows the outing distances traveled, including data for all pool vehicles.

Appendix B provides the details of each of the pool vehicle's outing travel. Both vehicles exceeded 70 miles of travel on at least one outing. The average travel outing for pool vehicles was 48.6 miles. On 81% of these vehicle outings, the distance traveled was less than the 70 miles considered to be within the BEV safe range and 19% percent of pool outing travel was greater than 70 miles. Further, 81% of vehicle travel outings ere less than 40 miles considered to be within the CD range of a PHEV. In summary, one vehicle was used for the longest trips, while the other was used for shorter trips.

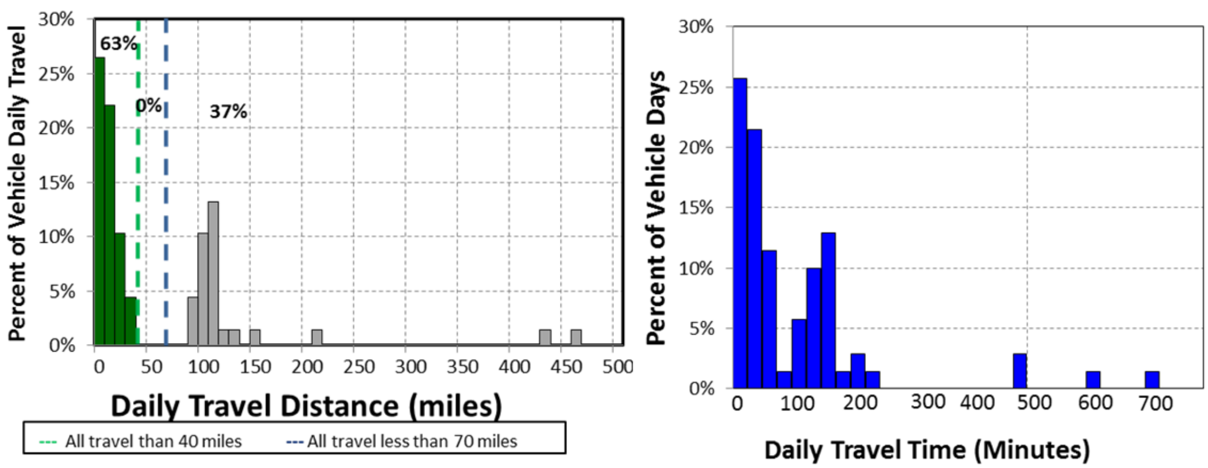


Figure 19. PBS pool vehicle daily travel miles and time (all vehicles). Note: two daily travel points of 563.8 and 682.9 miles are not shown for clarity.

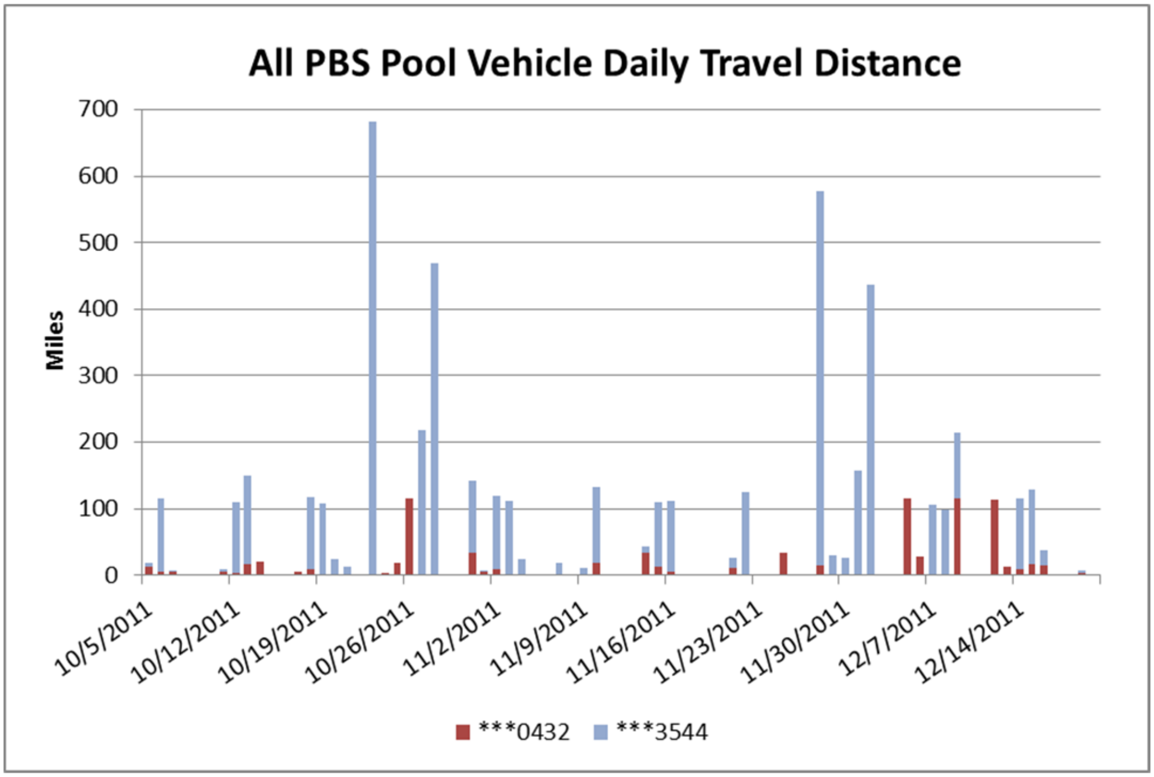


Figure 20. PBS pool vehicle daily travel history (all vehicles).

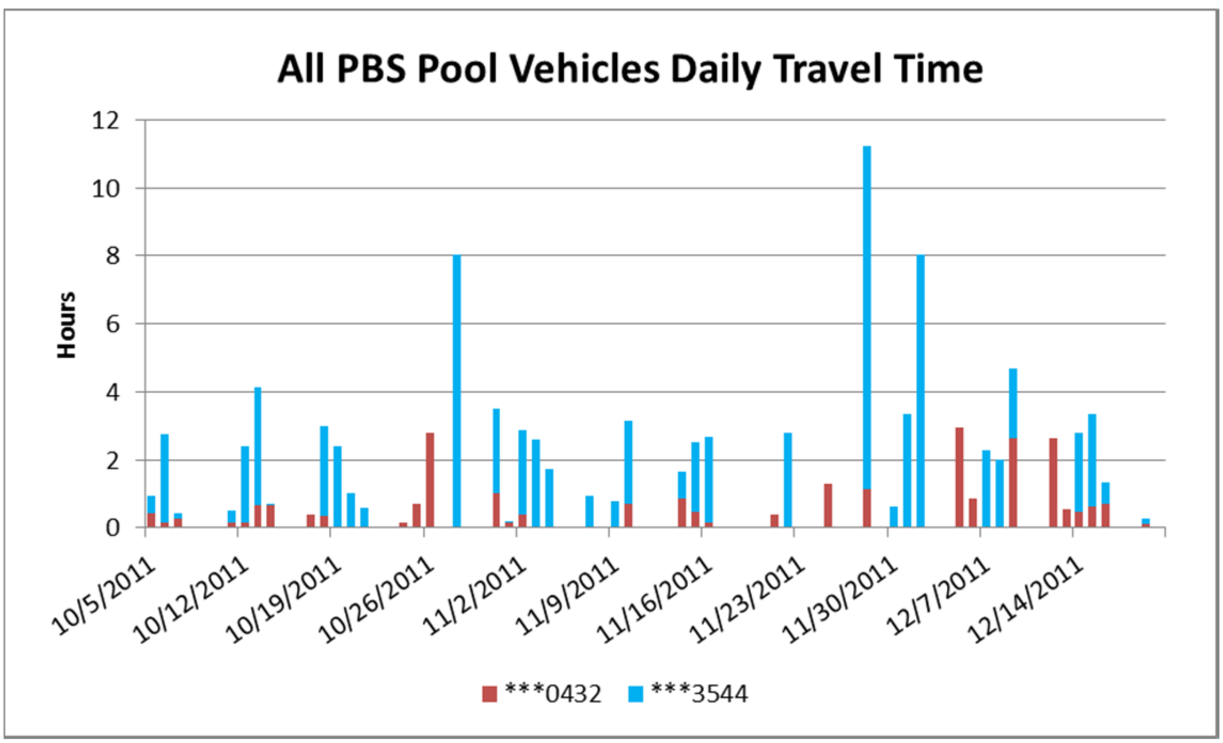


Figure 21. PBS pool vehicles travel time (all vehicles).

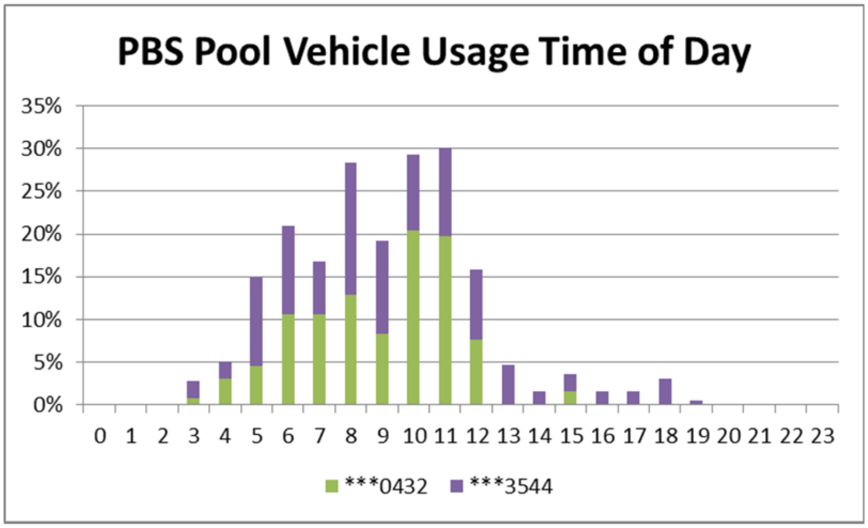


Figure 22. PBS pool vehicles hourly usage.

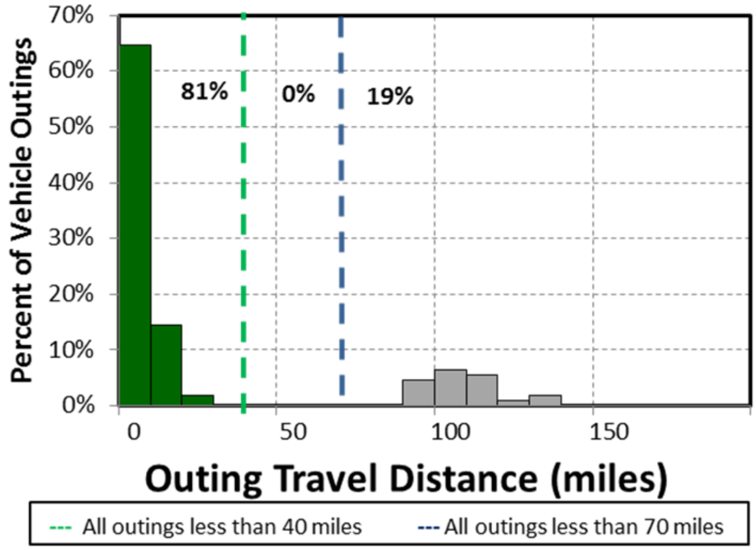


Figure 23. PBS pool vehicle outings. Note: the graphic omits the two largest outings of 1,368.7 and 1,212.9 miles for clarity.

5.5.4 Plum Brook Station Pool Vehicle Observations/Summary

There appears to be three choices for PBS in implementing PEVs into the pool fleet. It is noted that the objective would be to incorporate as many BEVs as possible to realize the advantages of reduced petroleum usage and reduced emissions of GHGs.

1. **All BEV fleet:** While some BEV manufacturers report vehicle range exceeding 70 miles, Intertek recommends careful evaluation of experienced range to ensure vehicle missions are accomplished. Nevertheless, assuming the 70-mile safe range for a BEV, an all-BEV fleet does not appear to be possible due to the length of some of the daily travel.
2. **Mixed BEV/PHEV fleet:** Certainly, PHEVs can accomplish the same mission as the current fleet when only considering travel times and distances because the PHEV’s gasoline engine can provide motive power when the battery has been depleted. Figure 19 shows that on 63% of all vehicle travel

days, the total daily travel was less than 40 miles, which typically is the maximum distance a PHEV will travel in CD mode. This represents a significant operating cost savings opportunity, while retaining the ability to go longer distances when needed. In addition, 81% of the outings were less than 40 miles and could be completed in CD mode for certain PHEVs if the battery was fully charged prior to the outing.

Meanwhile, 81% of the outings were within the typical capability of a BEV and EVSE at the home base could provide recharge energy for another outing. A mixed fleet requires fleet manager attention to assign vehicles appropriately for the anticipated use on that day.

This would suggest that 63% of the fleet could be BEVs and 37% of the fleet could be PHEVs to handle the travel greater than 70 miles per day without requiring additional opportunity charging during daytime stops. However, this does not allow for use of several vehicles at the same time and would require a greater level of fleet management, with the daily assignment of vehicles based on anticipated driving distance. Allowing more conservatism in assigning vehicles, one PHEV and one BEV could conservatively meet the demand for these two pool vehicles, especially if there were additional pool vehicles available. Both the monitored pool vehicles are midsize sedans for which replacement PEVs are currently available.

3. **All PHEV fleet:** As noted above, PHEVs can accomplish the same mission as the current fleet when only considering travel times and distances. Replacing all current vehicles with PHEVs only requires an evaluation of the individual vehicle capabilities of currently available PHEVs to meet current pool requirements. These two pool vehicles have replacement PEVs available. Data show that for a significant number of days, the PHEV will operate in a CD mode. The first 40 miles of longer travel days would also be powered (at least mostly) by electricity, so that 81% of all pool vehicle travel would be (again, at least mostly) battery powered with only one charge per day. As above, this represents an opportunity for significant operating cost savings, while retaining the ability to go longer distances when needed. Intermediate charging opportunities provide additional benefit, enhancing CD mode. Data show significant charging opportunities throughout the day during stop times.

The vehicle summary shows sufficient time for charging at the base location during the course of the day and additional opportunities at intermediate charging stations are not required. These stations also provide charging opportunities for the visiting public, whose fees may assist in offsetting operating costs. Given the availability of daytime changing, with experience, PBS may find that a greater fraction of BEVs within the pool vehicle fleet may meet their needs.

The total inventory of vehicles at PBS was not identified separately from the GRC inventory. These pool vehicles operated in a manner similar to those at GRC and the same ratio of BEVs to PHEVs would seem to apply.

5.5.5 Pool Vehicle Charging Needs

Upon review of these data, Intertek suggests replacement of the studied pool fleet with one BEV and one PHEV. No available PHEVs at this writing provide for DCFC nor do the data suggest that this would be a significant benefit for PHEVs in the pool fleet. A DCFC at the home base will provide a more rapid recharge for BEVs, but it appears to be unnecessary, given that the data show that 81% of outings were less than a typical BEV's driving range.

As noted above, AC Level 2 overnight charging of BEVs is typical, whereas overnight charging of PHEVs can usually be accomplished with AC Level 1 charging.

Intertek's experience suggests that each vehicle should have an assigned charging parking space at its home base. Assigned stations require less management attention to ensure completion of overnight charging. BEVs and PHEVs not assigned to these stations also benefit during visits to the location as part of their normal operation.

As noted above, Figure 18 displays the availability of public charging at the time of this writing for the GRC area. Some of these stations are within the BEV range of PBS and may be of benefit for extending BEV and PHEV CD mode range.

5.6 Law Enforcement Vehicles Evaluation

Enforcement vehicles typically are light-duty motor vehicles specifically approved in an agency's appropriation act for use in apprehension, surveillance, police, or other law enforcement work. Enforcement missions can vary by agency, location, and jurisdiction; however, they typically utilize sedans, minivans, vans, or small pickup trucks and typically do not carry specific cargo or equipment.

Incorporation of BEVs and PHEVs into the enforcement mission is a definite possibility. Enforcement vehicles used to patrol small areas and for parking enforcement activities qualify for BEV or PHEV replacement, while other law enforcement vehicle activities that are associated with longer trips may require PHEV capabilities.

5.6.1 Summary for Enforcement Vehicles

Appendix B provides the vehicle data sheets for the enforcement vehicles monitored. Note that no data were transmitted for vehicle ***2944 for unknown reasons.

Table 15 summarizes enforcement vehicles travel during the study period. Vehicle use occurred primarily during typical day shift hours. Enforcement vehicles traveled 691 miles and logged 23 hours during the 75-day study period. Vehicle idle time is not significant for these vehicles.

Table 15. Enforcement vehicle travel summary.

Enforcement Vehicle Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	13.3/110.7	6.1/109.7	4.2/58.9	691
Travel Time (Minutes)	26.4/161.0	14.4/161.0	8.4/66.0	1,373

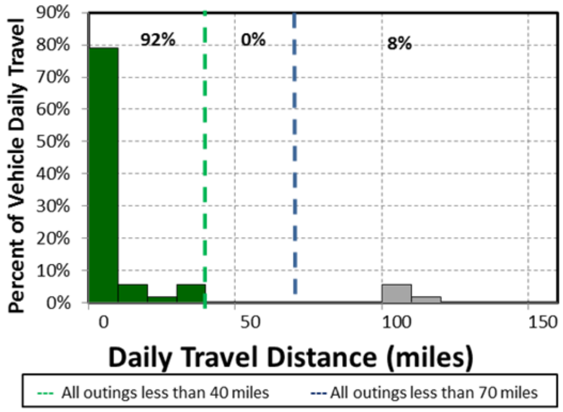
5.6.2 Enforcement Vehicle Daily Summary

Figure 24 identifies the daily travel distance and time for the enforcement vehicles. The green line and bars indicate typical electric range on a single charge for a PHEV, while the blue line and bars indicate the same for a BEV. Figures 25 and 26 show the composite history in distance and time traveled for the enforcement vehicles.

During the study period, the average travel distance per day, when driven, by the enforcement vehicles was 13.3 miles. On 92% of these vehicle days, the daily travel was less than the 70 miles considered to be within the BEV safe range and 8% percent of enforcement vehicle daily travel was greater than 70 miles. Further, 92% of vehicle travel days were less than 40 miles considered to be within the CD mode range of a PHEV.

Figures 25 and 26 show that the vehicles were not used every day, although frequent usage was indicated. Figure 27 displays the summary of use by time of day for the enforcement vehicles combined. Figure 28 shows the outing distances for the enforcement vehicles.

Appendix B provides the details of the enforcement vehicles' daily travel. The average travel outing for the enforcement vehicles was 6.1 miles, and 97% of vehicle travel outings were less than 40 miles and considered to be within the CD mode range of a PHEV. In summary, these vehicles can be characterized by rather consistent low daily travel with short daily usage.



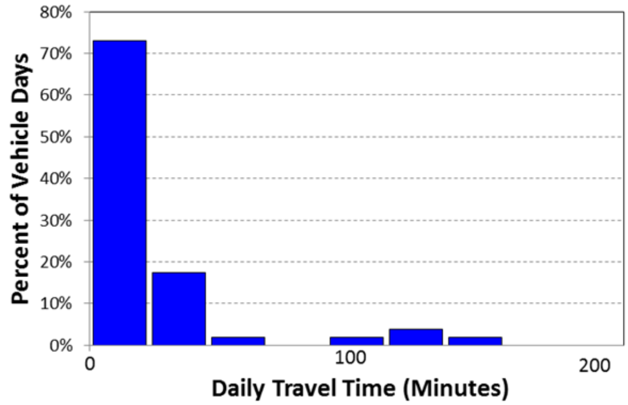


Figure 24. Enforcement vehicle percentage of daily use versus daily travel miles and time (all vehicles).

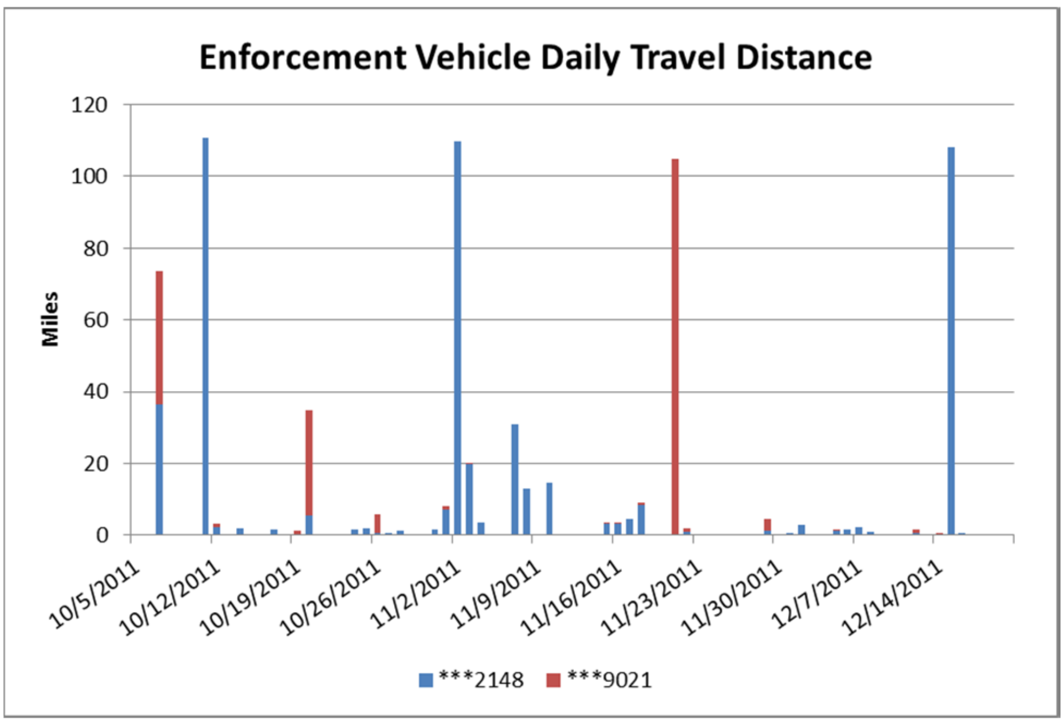


Figure 25. Enforcement vehicle daily travel miles (all vehicles).

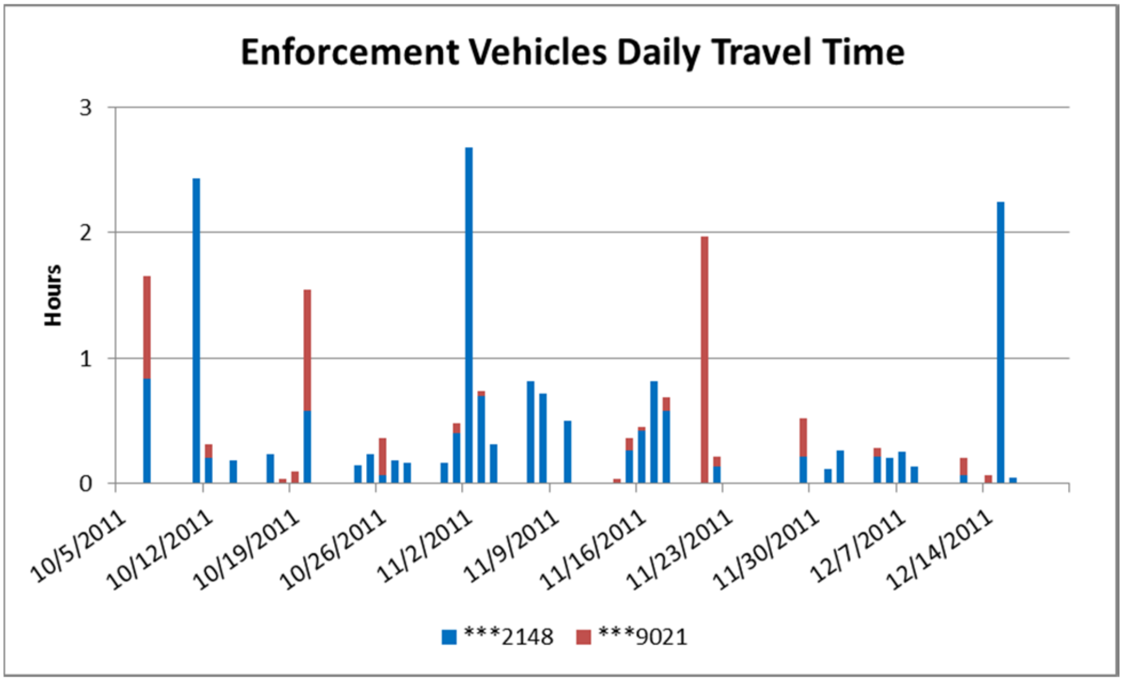


Figure 26. Enforcement Vehicle daily travel time (all vehicles).

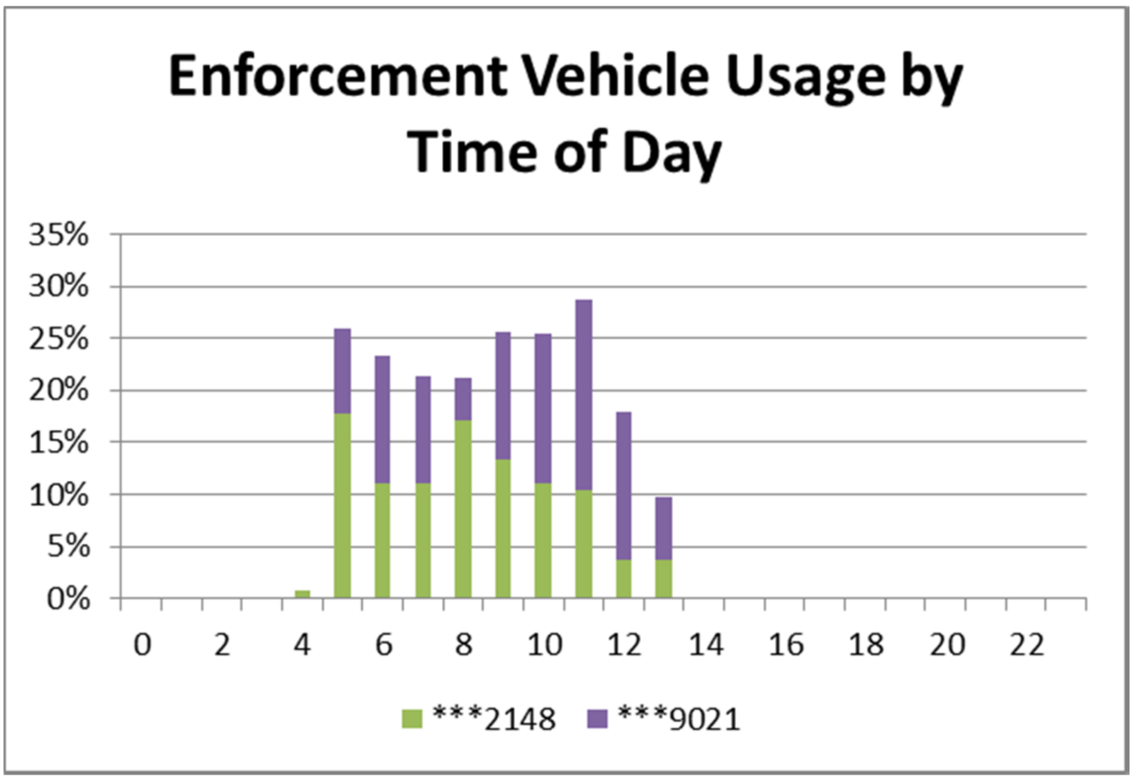


Figure 27. Enforcement vehicle hourly usage.

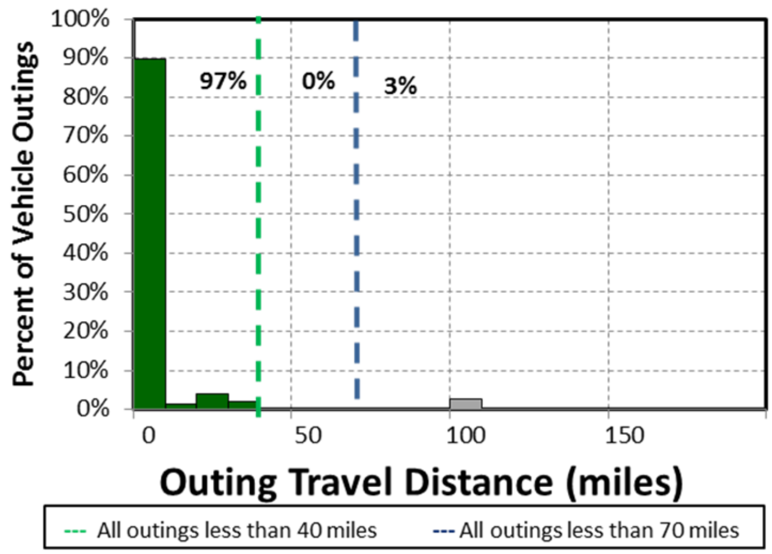


Figure 28. Enforcement vehicle outings.

5.6.3 Enforcement Vehicle Observations/Summary

The enforcement vehicles are two midsize sedans and one SUV. While the SUV failed to report data, it is assumed it operates in a manner similar to those monitored. These are a popular choice for enforcement vehicles because they are versatile to support the various types of enforcement activities needed.

As before, there appear to be three possible options for GRC in implementing PEVs into the enforcement vehicle fleet. It should be noted that the objective would be to incorporate as many BEVs as possible to realize the advantages of reduced petroleum usage and reduced emissions of GHGs.

1. **All BEV fleet:** While some BEV manufacturers report vehicle ranges exceeding 70 miles, Intertek recommends careful evaluation of experienced range to ensure vehicle missions are accomplished. Nevertheless, assuming the 70-mile safe range for a BEV, an all-BEV fleet is not possible for enforcement vehicles due to the occasional long distances experienced by the vehicles. In addition, the mission of enforcement vehicles does not typically lend itself to range limitations.

2. **Mixed BEV/PHEV fleet:** Certainly, PHEVs can accomplish the same mission as the current fleet when only considering travel times and distances because the PEV's gasoline engine can provide motive power when the battery has been depleted. Figure 24 shows that on 92% of all vehicle travel days, the total daily travel was less than 40 miles, which typically is the maximum distance a PHEV will travel in CD mode. This represents a significant operating cost savings opportunity, while retaining the ability to go longer distances when needed. In addition, 97% of the outings were less than 40 miles and could be completed in CD mode for certain PHEVs if the battery was fully charged prior to the outing.

   Fully 97% of the outings were within the typical capability of a BEV; therefore, EVSE at the home base could provide recharge energy for another outing. A mixed fleet requires fleet manager attention to assign vehicles appropriately for the anticipated use on that day.

   The data suggests that 92% of the fleet could be BEVs and 8% of the fleet could be PHEVs to handle the travel greater than 70 miles per day, without requiring additional opportunity charging during daytime stops. A more conservative approach for enforcement vehicles, for which range limitations may not be desirable, is to replace these three vehicles with two PHEVs and one BEV.

3. **All PHEV fleet:** As noted above, PHEVs can accomplish the same mission as the current fleet when only considering travel times and distances. Replacing all current vehicles with PHEVs only requires an evaluation of the individual vehicle capabilities of currently available PHEVs to meet current support vehicle requirements.

The vehicle summary shows sufficient time for charging at the base location during the course of the day. These stations also provide charging opportunities for the visiting public, whose fees may assist in offsetting operating costs.

The current fleet contains these three enforcement vehicles. Thus, Intertek suggests that two PHEVs and one BEV could replace these vehicles and continue to carry out the same mission.

5.6.4 Enforcement Vehicle Charging Needs

As noted above, overnight charging of PHEVs can usually be accomplished with AC Level 1 charging. Opportunity charging at intermediate stops obtains greater benefits from AC Level 2 EVSE. However, remote intermediate stop locations were not identified in the data.

For the fleet of enforcement vehicles, two PHEVs require two AC Level 1 outlets for home base charging. Intertek recommends a minimum of two EVSE at each location to maximize charge capability without a significant increase in installation costs. As noted above, there are no publicly accessible EVSE in the vicinity to provide significant backup charging resources.

This analysis does assume a fully recharged battery at the start of each day. GRC will gain experience in this management as the PEV fleet grows.

5.7 Balance of Fleet Vehicles

The balance of the GRC fleet consists of buses, support vehicles, specialty vehicles, heavy-duty trucks, and passenger vans. Certain select PEVs are being demonstrated for various specialty applications but none is listed in the GSA schedule.

6. GREENHOUSE GAS EMISSIONS AVOIDED AND FUEL COST REDUCTION ANALYSIS

PEV substitution for an existing conventional vehicles avoids GHG emissions and reduces fuel costs. The GHG emissions avoided occur due to the difference in emissions associated with power plant electricity generation versus fuel combustion that occurs in the engine of a conventional vehicle. This analysis does not account for life-cycle emissions that occur outside of electricity generation and the fuel combustion phases (i.e., materials and resource extraction, production supply-chains, and decommissioning are not accounted for). These phases are beyond the scope of this report due to the significant effort required to conduct an accurate environmental life-cycle assessment for a transportation system in a very specific setting. The analysis used is known as a “tank-to-wheel” analysis rather than a “well-to-wheel” analysis that would include the aforementioned phases. Cost reduction also occurs because the cost of electricity is comparable to the cost of gasoline on a unit of energy basis; however, PEVs are more efficient than conventional ICE vehicles. Because fuel logs were not kept, the mileage accumulated by each vehicle and the extrapolation to annual miles provide one source of annual miles estimates. GRC also provided information related to anticipated annual miles. These are compared to those calculated during the study to identify the source of fuel consumption estimates for the study vehicles. In order to perform the analysis, EPA fuel economy ratings are used. [27] Tables 16 and 17 provide these ratings. Ratings for the PHEVs in Table 17 include CD operation. Because these data are estimates, assumptions include the following:

[27] http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=33558 [accessed August 27, 2014]

1. PHEVs operate in CD mode only for the percentage of travel less than 40 miles per day. This is reasonable for most daily operations, as described in Section 5. This is conservative because there exists additional charge time between most outings. It is also conservative in that the replacement PEV typically will have greater fuel economy when operating in CS mode. BEVs operate in electric mode for 100% of travel.
2. The energy consumption for the Mitsubishi Outlander is assigned the same value as the RAV4 EV and the Via Motors VTRUX PU is estimated because EPA has not yet created ratings for these vehicles.
3. Table 17 suggests the PEVs to replace existing monitored vehicles. See Section 4.4 for vehicle availability.
4. Annual miles are calculated from the actual miles identified in the study and extrapolated to a full 365-day year. This is compared to the annual miles as reported by GRC for information. The GRC annual miles are used for the reduction calculations, if available. Miles in CD mode are the GRC annual miles times percent of daily travel less than 40 miles for the PHEV replacement and full annual miles for the BEV replacement.

Table 16. U.S. EPA fuel economy ratings of current fleet vehicles.

Vehicle	Logger	Mission	Make & Model	Model Year	Fuel Economy-Combined (miles/gallon)
9340	23	Pool	Chevrolet Malibu	2010	26
4364	24	Pool	Chevrolet Malibu	2010	26
2148	25	Enforcement	Chevrolet Malibu	2011	26
5846	26	Pool	Dodge Dakota	2007	17
5847	27	Pool	Dodge Dakota	2007	17
9021	28	Enforcement	Chevrolet Malibu	2010	26
5845	29	Pool	Dodge Dakota	2007	17
432	30	Pool	Chevrolet Malibu	2011	26
3544	31	Pool	Chevrolet Malibu	2011	26
2944	32	Enforcement	Jeep Gr Cherokee	2011	18

Table 17. U.S. EPA PEV energy consumption assumptions.

Mission	Replacement PEV	Wh/mile
Pool	Fusion	370
Pool	Fusion	370
Enforcement	Fusion	370
Pool	eNV200	400
Pool	Rav4	440
Enforcement	Leaf	300
Pool	Rav4	440
Pool	Leaf	300
Pool	Fusion	370
Enforcement	Outlander	440

Table 18 provides a pictorial view of potential replacement PEVs.

Table 18. PEV substitutions for current vehicles.

Vehicle Class	Current Vehicle Example	Replacement PHEV	Replacement BEV
Sedan – Midsize	 Chevrolet Malibu	 Ford Fusion 370 wh/mi	 Nissan Leaf 300 wh/mi
SUV	 Jeep Grand Cherokee	 Mitsubishi Outlander 440 wh/mi	 Toyota RAV4 440 wh/mi
Pickup Truck	 Dodge Dakota	 Via Motors VTRUX 475 wh/mi	 Nissan eNV200 400 wh/mi
Pickup Truck (alternate)	 Dodge Dakota	 Mitsubishi Outlander 440 wh/mi	 Toyota RAV4 440 wh/mi

Calculations provided for GHG emissions and fuel savings include both a total U.S. perspective and for the local area. The electricity generation mix of power plants for the total United States is different from the local mix of generation in the GRC area. Likewise, the national average cost for petroleum fuel is different from the local cost for fuel. This analysis includes both approaches in order to allow for local evaluation and to provide the potential benefit for fleet vehicles in other locations of the United States that may be of interest. The final report summarizing results from all sites studied across the United States from Intertek to Idaho National Laboratory primarily will consider the national figures. For clarity, only the local figures are shown here. The national figures are included in Appendix C.

For the GHG emissions avoided portion of the analysis, the GHG emissions (in pounds of carbon dioxide equivalent (which also accounts for other GHGs such as methane and nitrous oxide) (lb-CO_2e) from combustion of gasoline is 20.1 lb-CO_2e/gallon.[28] The United States averages for GHG emissions for the production of electricity is 1.53 lb-CO_2e/kWh.[29]

[28] http://www.theevproject.com/cms-assets/documents/106077-891082.ghg.pdf [accessed 19 July 2013].

[29] http://www.theevproject.com/cms-assets/documents/106077-891082.ghg.pdf [accessed July 19, 2013].

Cleveland Public Power provides the electric power to GRC. Cleveland Public Power reports receiving power from American Municipal Power.[30] American Municipal Power reports generation from several power plants, including coal, gas, oil, hydro, and wind generation.[31] American Municipal Power provided Sustainability Performance “At a Glance” performance metrics in 2012 that reports the CO_2 emission rate at 144 lb/MM Btu[32] or 0.491 lb-CO_2/kWh. This emission rate is considerably lower than the national average and reflects high emphasis on generation by natural gas and renewables. PBS receives power from Ohio Edison. For clarity, it is assumed that the GRC vehicles home-based at PBS receive power like GRC.

GHG emissions avoided are the GHG emitted by the current vehicle (total annual gallons gasoline × GHG emissions/gallon) minus the annual GHG emitted by the replacement PEV (total annual kWh × GHG emissions/kWh). For the PHEVs, the percentages of outings less than 40 miles are counted for the annual miles saved in CD mode, with the balance of the miles accounted as fueled with gasoline.

Table 19 shows the calculation of annual miles based on the recorded and extrapolated miles in this study. The GRC reported annual miles are also shown for comparison. The replacement vehicle is identified for each vehicle. It is important to note that the analysis conducted above suggests replacement vehicles for the fleet of vehicles rather than necessarily replacing the exact vehicle monitored. The percent of miles in CD mode is 100% for BEVs because all travel is battery powered. The percent of miles in CD mode for PHEVs is obtained from the daily travel shown in Appendix B. Miles in CD mode is the percentage of GRC reported annual miles.

Table 19. CD mode miles calculations.

Vehicle	Replacement Vehicle	Study Calculated Annual Miles	GRC Reported Annual Miles	Percent of Miles CD Mode	CD Mode Miles
Chevrolet Malibu	Fusion	7,258	24,000	71%	17,040
Chevrolet Malibu	Fusion	11,056	22,000	51%	11,220
Chevrolet Malibu	Fusion	2,628	4,700	91%	4,277
Dodge Dakota	eNV200	1,708	2,200	100%	2,200
Dodge Dakota	Rav4	627	2,000	100%	2,000
Chevrolet Malibu	Leaf	1,005	2,000	100%	2,000
Dodge Dakota	Rav4	736	2,000	100%	2,000
Chevrolet Malibu	Leaf	4,036	4,000	100%	4,000
Chevrolet Malibu	Fusion	21,029	11,000	43%	4,730
Jeep Gr Cherokee	Outlander	-	4,000	92%	3,680

For the cost-avoided piece of the analysis, fuel cost assumptions are $3.454/gallon of regular gasoline for the United States and $3.416/gallon in Ohio.[33] Electrical cost are 0.0984 $/kWh for the United States and 0.0912$/kWh in Ohio.[34] Therefore, fuel costs savings are the current vehicle’s calculated annual gasoline cost (total annual gallons gasoline × cost/gallon) minus the electricity cost (total annual kWh × cost/kWh) of the replacement PEV traveling the same distance.

[30] http://www.cpp.org/bitsabout/CPP11AR.pdf [accessed August 31, 2014].

[31] http://amppartners.org/consumers/conservation-sustainability/ [accessed September 1, 2014].

[32] Ibid.

[33] http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sco_w.htm [accessed September 1, 2014].

[34] http://www.eia.gov/electricity/state/ [accessed September 1, 2014].

The miles calculated above for CD Mode yields estimates for yearly GHG emissions avoided and fuel cost reductions. The results of this analysis (shown in Table 20) demonstrate that the substitution of a conventional ICE vehicle with a PEV can reduce the GHG emissions and fuel costs dramatically. The table also shows the percentage reduction in GHG emissions and fuel costs for ease of comparison. For example, if the Mitsubishi Outlander replaces law enforcement vehicle ***2944, an 81% reduction in GHG emissions in Ohio occurs. The Jeep Grand Cherokee produces 4,109 lb-CO_2e/year for the distance traveled, whereas the Outlander produces 795 lb-CO_2e/year for that same distance for a reduction of 3,314 lb-CO_2e/year.

Table 20. Greenhouse gas emissions avoidance and fuel cost reduction analysis summary.

	Mission	Replacement Model	Extrapolated Local Yearly CO_2e Avoided (lb-CO_2e/year)	% reduction	Extrapolated Local Yearly Fuel Cost Reduction	% reduction
	Pool	Fusion	10,078	77%	$1,664	74%
	Pool	Fusion	6,636	77%	$1,096	74%
	Enforcement	Fusion	2,529	77%	$418	74%
	Pool	eNV200	2,169	83%	$362	82%
	Pool	Rav4	1,933	82%	$322	80%
	Enforcement	Leaf	1,252	81%	$208	79%
	Pool	Rav4	1,933	82%	$322	80%
	Pool	Leaf	2,503	81%	$416	79%
	Pool	Fusion	2,797	77%	$462	74%
	Enforcement	Outlander	3,314	81%	$551	79%
Total			**35,143**	**78%**	**$5,818**	**75%**
Total Pool			28,048	78%	$4,642	74%
Total Enforcement			7,095	79%	$1,176	76%

Table 21 shows the high potential benefit in the reduction of GHG emissions in the local GRC area. In addition, the fuel cost reduction potential benefit is also significant due to the low cost of power.

As presented in Section 5, 10 BEVs and seven PHEVs could replace the pool fleet of 17 vehicles and one BEV and two PHEVs are assumed to replace the enforcement fleet of three vehicles. Using an average savings per vehicle, Table 21 provides the avoided GHG and fuel cost savings should these replacements occur. The table also shows the percentage reduction in GHG emissions and fuel costs for ease of comparison. Only local Ohio savings are projected in this table, while national figures are presented in Appendix C.

Table 21. Extrapolated GHG emissions avoided and fuel cost savings for the entire fleet.

Mission	Extrapolated Local Yearly CO2e Avoided (lb-CO2e/year)	% reduction	Extrapolated Local Yearly Fuel Cost Reduction ($/year	% reduction
Pool	67,088	79%	$11,120	77%
Enforcement	7,776	80%	$1,290	78%
Total	74,864	79%	$12,410	77%

7. OBSERVATIONS

Intertek appreciates the opportunity to present the results of this evaluation. Observations for possible follow-up action include the following:

Observation #1:

Implementation: GRC can move forward in the near future with the replacement of pool and enforcement vehicles with PEVs as current budget and vehicle replacement schedules allow. Certainly, most of the vehicle types studied in this report are candidates for immediate replacement.

Observation #2:

Fleet Inventory: A more thorough examination of the quantities and types of fleet vehicles within each usage category may be beneficial to quantify the potential for replacement by PEVs. While Intertek suggests a mix of BEVs and PHEVs, a more refined look may be possible. In addition, this study did not look at the other fleet vehicle categories such as support or specialty vehicles.

Observation #3:

Vehicle Replacement Plan: The development of a detailed vehicle replacement plan could be beneficial. This plan would include cost and schedule for vehicle replacement. A more detailed survey and calculation of the use of the fleet vehicles (such as vehicle parking locations, age of vehicle, expected replacement time, expected replacement costs, GSA vehicle costs, EVSE cost, total life costs, and EVSE installation costs) provide support to this replacement plan. A more refined estimate for reduced GHG emissions, petroleum usage reduction, and fuel cost savings flow from this detailed plan.

Observation #4:

Infrastructure Planning: In conjunction with the replacement plan, evaluation of the GRC sites for the placement of PEV charging infrastructure could be beneficial. Intertek has significant experience in this area and such plans will consider not only fleet vehicle charging needs, but also the convenience that charging infrastructure provides employees and visitors. This planning also considers the existing facility’s electrical distribution system. Vehicle home base considerations factor into the ratio of PEVs to EVSE units to maintain all vehicles at operational readiness.

Charging stations located at various destination points may provide additional infrastructure for PEV charging of the GRC fleet. Charging stations at GRC may also provide an opportunity for charging by the public. GRC can benefit through collection of charging fees during times when these stations are not required for the overnight charging of fleet vehicles. The fees avoid the questions associated with a federal agency providing fuel for privately owned vehicles and support the costs for installation and operation of the EVSE.

Appendix A
Definitions

Alternative fuel	An alternative fuel means any fuel other than gasoline and diesel fuels, such as methanol, ethanol, and gaseous fuels (40 CFR 86.1803-01). A fuel type other than petroleum-based gasoline or diesel as defined by the Energy Policy Act (examples include ethanol, methanol, compressed natural gas, propane, and electrical energy).
City fuel economy (MPG)	City fuel economy means the city fuel economy determined by operating a vehicle (or vehicles) over the driving schedule in the federal emission test procedure or determined according to the vehicle-specific 5-cycle or derived 5-cycle procedures (40 CFR 600.001).
Conventional fuel	A petroleum-based fuel (examples include gasoline and diesel fuel).
Daily travel	The sum of daily trips and stops in one day.
Diesel fuel	Diesel means a type of engine with operating characteristics significantly similar to the theoretical diesel combustion cycle. The non-use of a throttle during normal operation is indicative of a diesel engine (49 CFR 86-1803).
E85	Ethanol fuel blend of up to 85% denatured ethanol fuel and gasoline or other hydrocarbons by volume.
Electric vehicle	Electric vehicle means a motor vehicle that is powered solely by an electric motor drawing current from a rechargeable energy storage system, such as from storage batteries or other portable electrical energy storage devices, including hydrogen fuel cells, provided that (1) The vehicle is capable of drawing recharge energy from a source off the vehicle, such as residential electric service (2) The vehicle must be certified to the emission standards of Bin #1 of Table S04-1 in § 86.1811-09(c)(6) (3) The vehicle does not have an onboard combustion engine/generator system as a means of providing electrical energy (40 CFR 86-1803).
Ethanol-fueled vehicle	Ethanol-fueled vehicle-means any motor vehicle or motor vehicle engine that is engineered and designed to be operated using ethanol fuel (i.e., a fuel that contains at least 50% ethanol (C_2H_5OH) by volume) as fuel (40 CFR 86.1803-01).
Federal vehicle standards	The document that establishes classifications for various types and sizes of vehicles, general requirements, and equipment options. It is issued annually by the GSA Vehicle Acquisition and Leasing Service's Automotive Division.
Government motor vehicle	Any motor vehicle that the government owns or leases. This includes motor vehicles obtained through purchase, excess, forfeiture, commercial lease, or GSA fleet lease.
Gross vehicle weight rating	Gross vehicle weight rating (GVWR) means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle (e.g., vocational vehicle) (US Government Printing Office 2009)
GSA fleet	GSA fleet lease means obtaining a motor vehicle from the General Services Administration fleet (GSA fleet) (41 CFR 102-34).

Heavy light-duty truck	Heavy light-duty truck means any light-duty truck rated greater than 6,000 lb GVWR. The light-duty truck 3 (LDT3) and LDT4 classifications comprise the heavy light-duty truck category (40 CFR 86.1803-01).
Highway fuel economy (Hwy MPG)	Highway fuel economy means the highway fuel economy determined either by operating a vehicle (or vehicles) over the driving schedule in the federal highway fuel economy test procedure or determined according to either the vehicle-specific, 5-cycle equation, or the derived 5-cycle equation for highway fuel economy (40 CFR 600.001).
Hybrid electric vehicle	Hybrid electric vehicle means a motor vehicle that draws propulsion energy from onboard sources of stored energy that are both an internal combustion engine or heat engine using consumable fuel and a rechargeable energy storage system (such as a battery, capacitor, hydraulic accumulator, or flywheel), where recharge energy for the energy storage system comes solely from sources on board the vehicle.
Idle time	Idle time is logged whenever a vehicle idles with the engine running for 3 minutes or longer.
Law enforcement	Law enforcement motor vehicle means a light-duty motor vehicle that is specifically approved in an agency-s appropriation act for use in apprehension, surveillance, police, or other law enforcement work or specifically designed for use in law enforcement. If not identified in an agency's appropriation language, a motor vehicle qualifies as a law enforcement motor vehicle only in the following cases: (1) A passenger automobile having heavy-duty components for electrical, cooling, and suspension systems and at least the next higher cubic inch displacement or more powerful engine than is standard for the automobile concerned (2) A light truck having emergency warning lights and identified with markings such as "police" (3) An unmarked motor vehicle certified by the agency head as essential for the safe and efficient performance of intelligence, counterintelligence, protective, or other law enforcement duties (4) A forfeited motor vehicle seized by a federal agency that subsequently is used for performing law enforcement activities (41 CFR Part 102-34.35).
Light-duty motor vehicle	Any motor vehicle with a GVWR of 8,500 pounds or less (41 CFR 102-34).
Light-duty truck	Light-duty truck means any motor vehicle rated at 8,500 pounds GVWR or less, which has a curb weight of 6,000 pounds or less and, which has a basic vehicle frontal area of 45 square feet or less, which is as follows: (1) Designed primarily for purposes of transportation of property or is a derivation of such a vehicle (2) Designed primarily for transportation of persons and has a capacity of more than 12 persons (3) Available with special features, enabling off-street or off-highway operation and use. LDT1 means any light light-duty truck up through 3,750-lb loaded vehicle weight. LDT2 means any light light-duty truck greater than 3,750-lb loaded vehicle weight.

	LDT3 means any heavy light-duty truck up through 5,750-lb adjusted loaded vehicle weight. LDT4 means any heavy light-duty truck greater than 5,750-lb adjusted loaded vehicle weight (US Government Printing Office 2009)
Light-duty vehicle	Light-duty vehicle means a passenger car or passenger car derivative capable of seating 12 passengers or less.
Low-speed vehicle	Low-speed vehicle means a motor vehicle (1) That is 4-wheeled (2) Whose speed attainable in 1.6 km (1 mile) is more than 32 kilometers per hour (20 miles per hour) and not more than 40 kilometers per hour (25 miles per hour) on a paved level surface (3) Whose GVWR is less than 1,361 kilograms (3,000 pounds) (49 CFR 571.3 – Definitions).
Medium-duty passenger vehicle	Medium-duty passenger vehicle means any heavy-duty vehicle (as defined in this subpart) with a GVWR of less than 10,000 pounds that is designed primarily for transportation of persons. The medium-duty passenger vehicle definition does not include any vehicle which (1) Is an “incomplete truck” as defined in this subpart (2) Has a seating capacity of more than 12 persons (3) Is designed for more than 9 persons in seating rearward of the driver's seat (4) Is equipped with an open cargo area (for example, a pick-up truck box or bed) of 72.0 inches in interior length or more. A covered box not readily accessible from the passenger compartment will be considered an open cargo area for purposes of this definition (US Government Printing Office 2009)
Model year	Model year means the manufacturer's annual production period (as determined by the administrator), which includes January 1 of such calendar year; provided that if the manufacturer has no annual production period, the term “model year” shall mean the calendar year (40 CFR 86-1803.01).
MPG	“MPG” or “mpg” means miles per gallon. This generally may be used to describe fuel economy as a quantity or it may be used as the units associated with a particular value.
MPGe	MPGe means miles per gallon equivalent. This generally is used to quantify a fuel economy value for vehicles that use a fuel other than gasoline. The value represents miles the vehicle can drive with the energy equivalent of one gallon of gasoline: (c) SCF means standard cubic feet (d) SUV means sport utility vehicle (e) CREE means carbon-related exhaust emissions [76 FR 39527, July 6, 2011].
Non-passenger automobile	A non-passenger automobile means an automobile that is not a passenger automobile or a work truck and includes vehicles described in paragraphs (a) and (b) of 49 CFR 523.5.

Owning agency	Owning agency means the executive agency that holds the vehicle title, manufacturer's Certificate of Origin or is the lessee of a commercial lease. This term does not apply to agencies that lease motor vehicles from the GSA fleet (41 CFR Part 102-34.35).
Passenger automobile	A passenger automobile is any automobile (other than an automobile capable of off-highway operation) manufactured primarily for use in the transportation of not more than 10 individuals (49 CFR 523.4 – Passenger automobile). A sedan or station wagon designed primarily to transport people (41 CFR 102-34).
Pickup truck	Pickup truck means a non-passenger automobile, which has a passenger compartment and an open cargo bed (49 CFR 523.2).
Plug-in hybrid electric vehicle	PHEV means a hybrid electric vehicle that has the capability to charge the battery from an off-vehicle electric source, such that the off-vehicle source cannot be connected to the vehicle while the vehicle is in motion (40 CFR 86.1803).
Vehicle class	The designation of motor vehicle types that include sedans, station wagons, ambulances, buses, and trucks, or different categories of vehicles according to Federal vehicle standards and further defined in 49 CFR 600.315-82.
Vehicle configuration	Vehicle configuration means a unique combination of basic engine, engine code, inertia weight class, transmission configuration, and axle ratio.
Vehicle days	The number of days a vehicle was driven or utilized during the (vehicle) study period.
Vehicle home base	The primary assigned outing beginning and ending parking location for the vehicle.
Vehicle study period	The time period the vehicle, within the study, has been equipped with a data logger.

Appendix B
GRC Vehicle Data Sheets

Table B-1. GRC vehicle index.

Vehicle Index						
Log	Fleet Vehicle Id	Make	Model	Year	EPA Class	Mission
23	***9340	Chevrolet	Malibu	2010	Sedan – Midsize	Pool
24	***4364	Chevrolet	Malibu	2010	Sedan – Midsize	Pool
25	***2148	Chevrolet	Malibu	2011	Sedan - Midsize	Law Enforcement
26	***5846	Dodge	Dakota	2007	Pickup Truck	Pool
27	***5847	Dodge	Dakota	2007	Pickup Truck	Pool
28	***9021	Chevrolet	Malibu	2010	Sedan - Midsize	Law Enforcement
29	***5845	Dodge	Dakota	2007	Pickup Truck	Pool
30	***0432	Chevrolet	Malibu	2011	Sedan - Midsize	Pool
31	***3544	Chevrolet	Malibu	2011	Sedan - Midsize	Pool
32	***2944	Jeep	Gr Cherokee	2011	SUV	Law Enforcement

Fleet Vehicle ID is last four digits of VIN.

Vehicle ***9340

Make/Model/Year	Chevrolet Malibu LS/2010
EPA Class Size	Sedan – Midsize
Mission	Pool
VIN	1G1ZA5E00AF279340
Parking Location	Emerald Ct, Brook Park
Fleet Vehicle ID	***9340
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy/Combined)	22/33/26 15/23/18
EPA GHG Emissions (Grams CO_2/Mi)	342/350
Study Logger ID	23
Total Vehicle Days/Total Study Days	45/74

Vehicle ***9340 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	32.7/136.2	17.9/235.3	8.8/132.5	1,472
Travel Time (Minutes)	60.0/228.0	32.7/337.0	16.1/129.0	2,684
Idle Time (Minutes)	6.2/NA	3.4/NA	1.7/NA	280

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	133	83.0%	Less than 2	90
10 to 20	4	2.5%	2 to 4	13
20 to 40	2	1.3%	4 to 8	10
Greater than 40	21	13.2%	Greater than 8	46

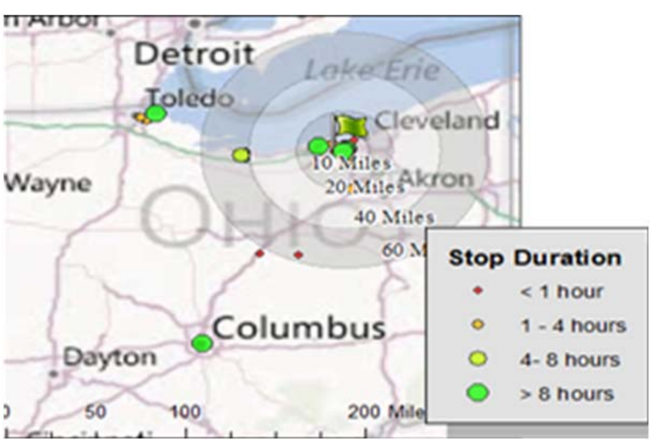


Figure B-1. Vehicle ***9340 stops.

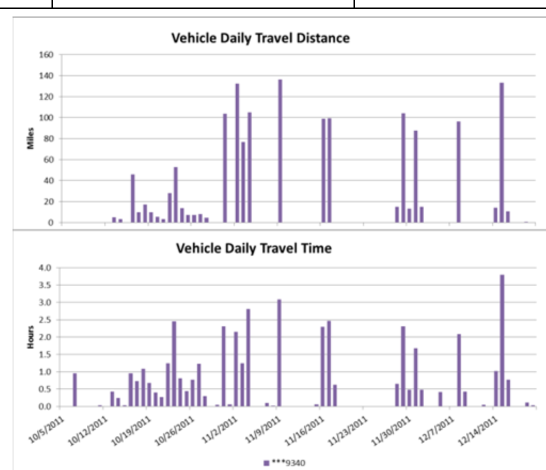


Figure B-2. Vehicle ***9340 history.

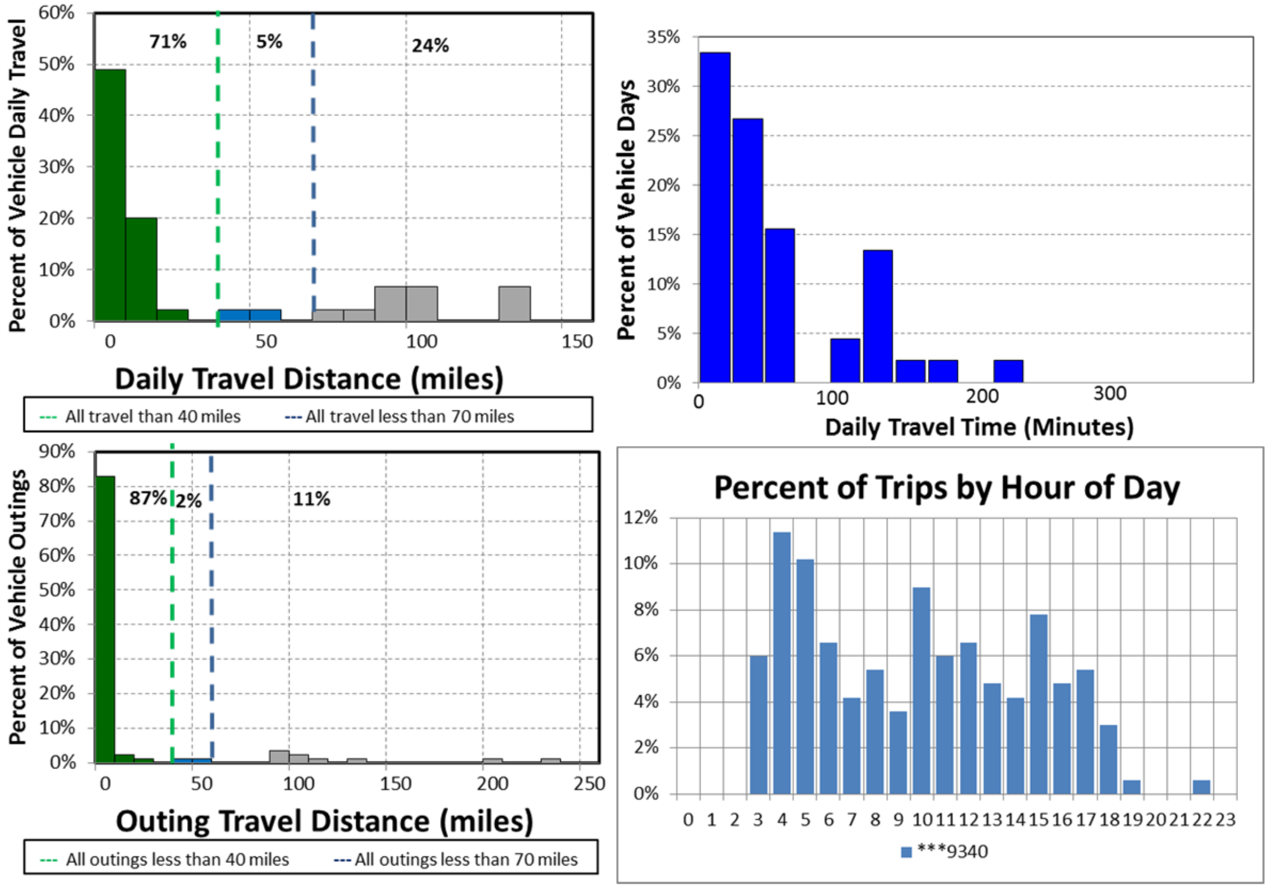


Figure B-3. Vehicle ***9340 travel graphs.

Vehicle ***9340 Observations

Logger 23 collected data on this vehicle for a period of 45 days of the 74-day study period. Validation occurred on 90.8% of the input data. GRC reports that this is a pool vehicle. Data recorded for this vehicle indicated that it typically parks on Emerald Court in Cleveland. During this study, it spent several evenings parked nearby at the Cleveland Hopkins International Airport on Grayton Road or W. Hanger Road. The identified outings consider all of these areas as a home base for analysis purposes.

NASA reports that the vehicle odometer indicated 32,531 miles during the study and it travels approximately 24,000 miles per year. The vehicle was used on 61% of the available days, with an average daily usage of 1.0 hours and a peak daily usage of 3.6 hours on the days it was used. The vehicle was used during extended day shift hours.

Figure B-1 shows all stops exceeding a 2-hour duration, with most occurring at the home base.

Figure B-3 shows 76% of daily travel and 89% of all outings were within the typically advertised range of a BEV of approximately 70 miles and 24% of daily travel exceeded this range. Further, 71% of daily travel and 87% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet 76% of daily travel without additional charging opportunities. However, sufficient time exists daily for additional charging that could then meet additional outing usage. A fleet of BEVs and PHEVs is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***4364

Make/Model/Year	Chevrolet Malibu LS/2010
EPA Class Size	Sedan – Midsize
Mission	Pool
VIN	1G1ZA5E06AF284364
Parking Location	W Hanger Rd, Brook Park
Fleet Vehicle ID	***4364
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy/Combined)	22/33/26 15/23/18
EPA GHG Emissions (Grams CO_2/Mi)	342/350
Study Logger ID	24
Total Vehicle Days/Total Study Days	33/70

Vehicle ***4364 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	64.3/206.9	42.4/411.8	13.9/204.9	2,120
Travel Time (Minutes)	97/215.0	64.2/403.0	21.5/199.0	3,208
Idle Time (Minutes)	11.6/NA	7.7/NA	2.5/NA	384

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	94	67.6%	Less than 2	90
10 to 20	10	7.2%	2 to 4	14
20 to 40	5	3.6%	4 to 8	3
Greater than 40	30	21.6%	Greater than 8	32

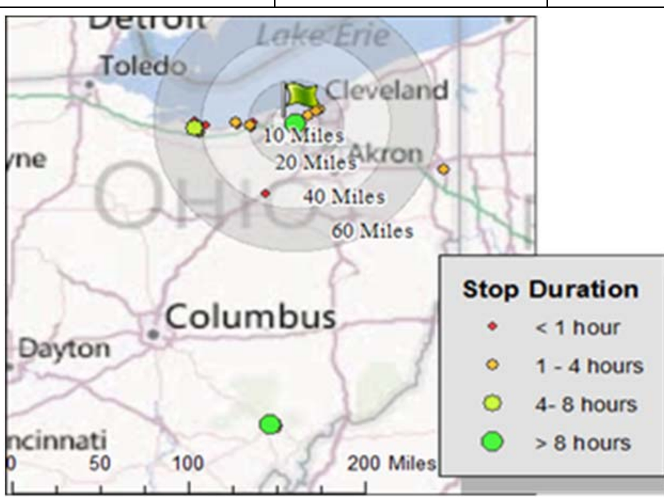


Figure B-4. Vehicle ***4364 stops.

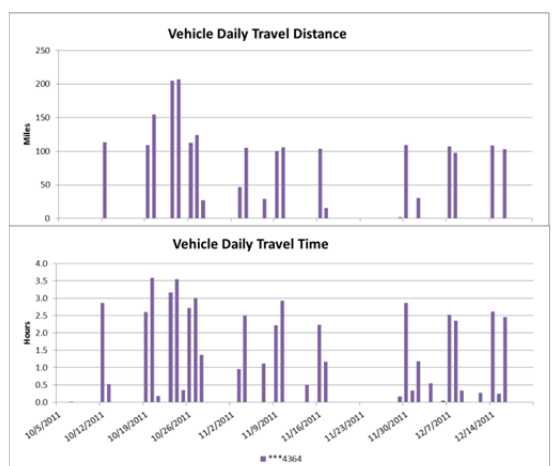


Figure B-5. Vehicle ***4364 history.

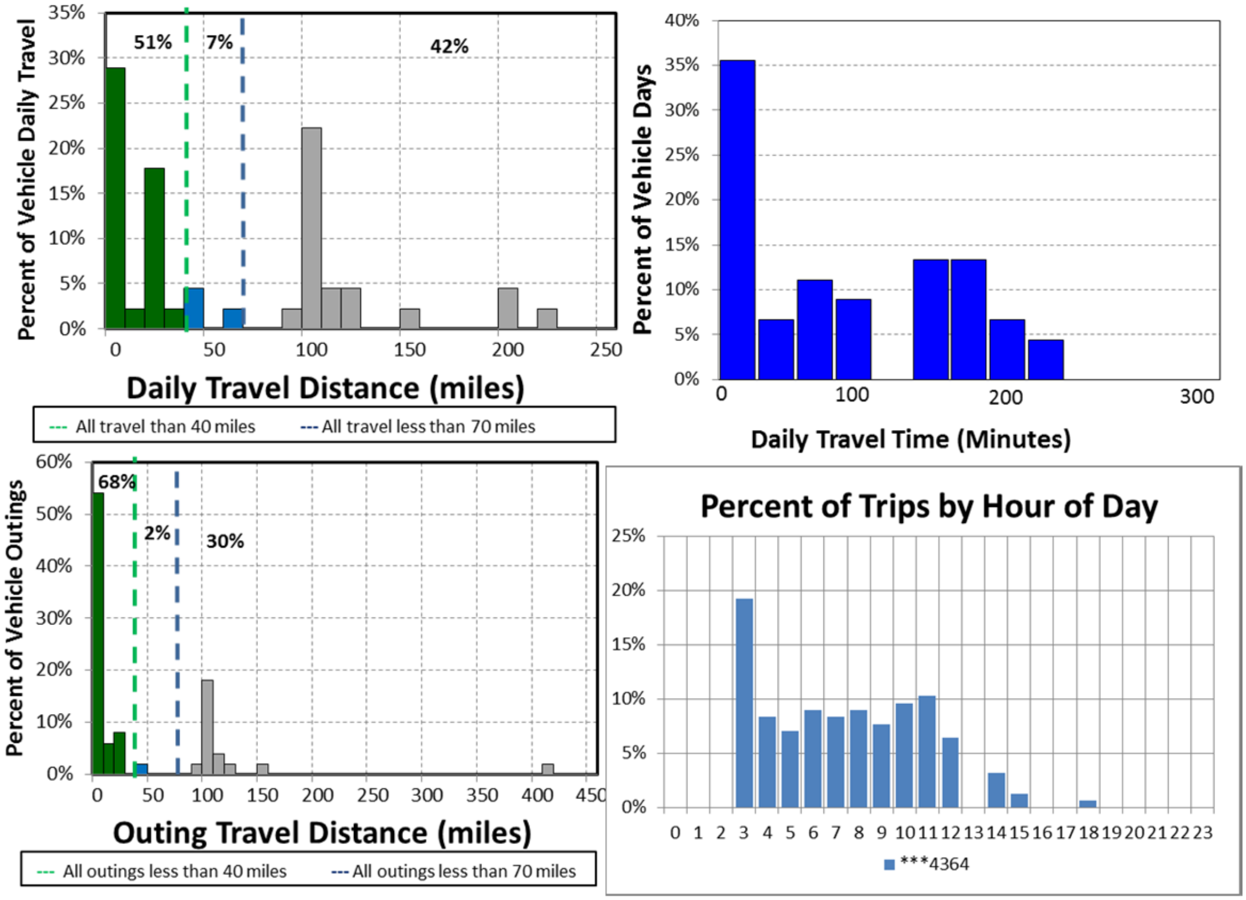


Figure B-6. Vehicle ***4364 travel graphs.

Vehicle ***4364 Observations

Logger 24 collected data on this vehicle for a period of 33 days of the 70-day study period. Validation occurred on 97.7% of the input data. GRC reports that this is a pool vehicle. Data recorded for this vehicle indicated that it typically parks on Hanger Road in Brook Park. The vehicle spent the night of October 23rd in Athens, Ohio and returned the following day.

NASA reports that the vehicle odometer indicated 31,099 miles during the study and it travels approximately 22,000 miles per year. The vehicle was used on 47% of the available days, with an average daily usage of 1.6 hours and a peak daily usage of 3.6 hours on the days it was used. The vehicle was used during extended day shift hours.

Figure B-4 shows all stops exceeding a 2-hour duration, with most occurring at the home base.

Figure B-6 shows 58% of daily travel and 70% of all outings were within the typically advertised range of a BEV of approximately 70 miles and 42% of daily travel exceeded this range. Further, 51% of daily travel and 68% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet 58% of daily travel without additional charging opportunities. However, sufficient time exists daily for additional charging that could then meet additional outing usage. A fleet of BEVs and PHEVs is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***2148

Make/Model/Year	Chevrolet Malibu LS/2011
EPA Class Size	Sedan – Midsize
Mission	Law Enforcement
VIN	1G1ZA5EU5BF332148
Parking Location	W Hanger Rd, Brook Park
Fleet Vehicle ID	***2148
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy/Combined)	22/33/26 15/23/18
EPA GHG Emissions (Grams CO_2/Mi)	342/350
Study Logger ID	25
Total Vehicle Days/Total Study Days	34/70

Vehicle ***2148 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	14.8/110.7	9.5/109.7	4.2/58.9	504
Travel Time (Minutes)	31.0/161	19.9/161.0	8.8/66.0	1,053
Idle Time (Minutes)	1.1/NA	0.7/NA	0.3/NA	38

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	106	86.0%	Less than 2	77
10 to 20	6	4.5%	2 to 4	8
20 to 40	0	0%	4 to 8	4
40 to 60	12	9.5%	Greater than 8	34

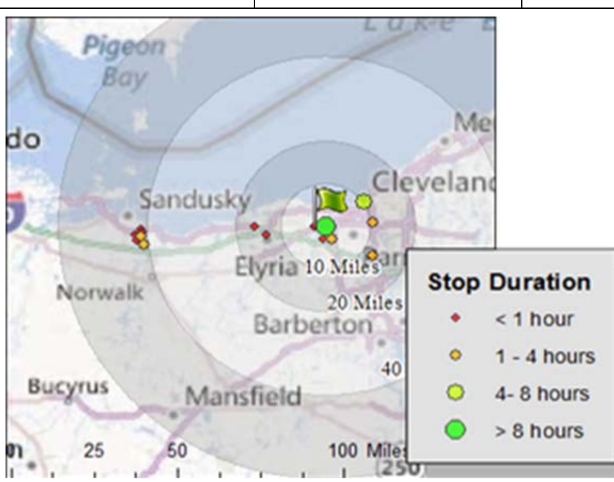


Figure B-7. Vehicle ***2148 stops.

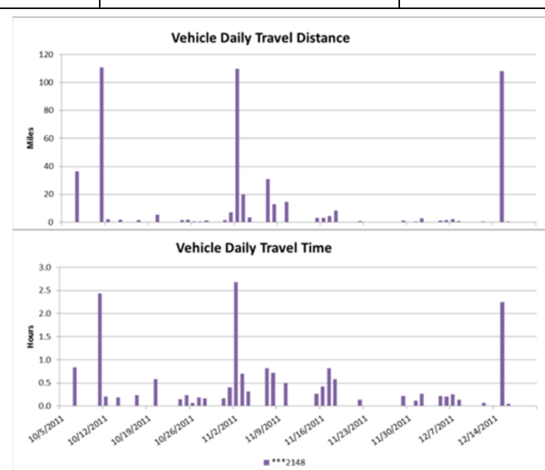


Figure B-8. Vehicle ***2148 history.

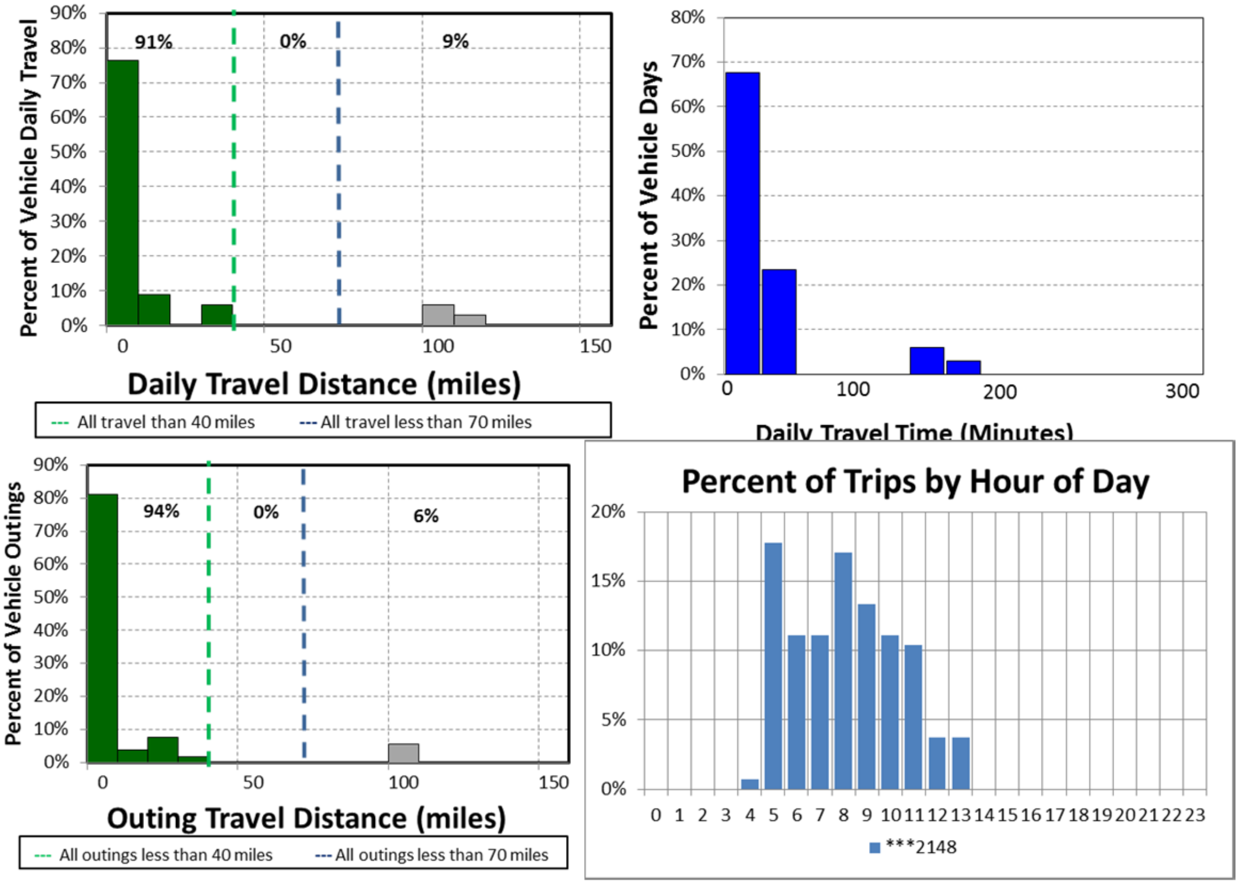


Figure B-9. Vehicle ***2148 travel graphs.

Vehicle ***2148 Observations

Logger 25 collected data on this vehicle for a period of 34 days of the 70-day study period. Validation occurred on 98.5% of the input data. GRC reports that this is a law enforcement vehicle. Data recorded for this vehicle indicated that it typically parks on W. Hanger Road in Brook Park.

NASA reports that the vehicle odometer indicated 1,980 miles during the study and it travels approximately 4,700 miles per year. The vehicle was used on 49% of the available days, with an average daily usage of 0.5 hours and a peak daily usage of 2.5 hours on the days it was used. The vehicle was used during typical day shift hours.

Figure B-7 shows all stops exceeding a 2-hour duration, with most occurring at the home base.

Figure B-9 shows 91% of daily travel and 94% of all outings were within the typically advertised range of a BEV of approximately 70 miles and 9% of daily travel exceeded this range. Further, 91% of daily travel and 94% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet 91% of daily travel without additional charging opportunities. However, sufficient time exists daily for additional charging that could then meet additional outing usage. A fleet of BEVs and PHEVs is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for law enforcement activities. Typically, vehicles without range limitations are desired for law enforcement vehicles.

Vehicle ***5846

Make/Model/Year	Dodge Dakota ST/2007
EPA Class Size	Pickup Truck
Mission	Pool
VIN	1D7HE22P77S205846
Parking Location	Near 20886 State Rte 17, Fairview Park
Fleet Vehicle ID	***5846
Fuel Type	Gas
EPA Label/MPG (City/Hwy/Combined)	15/20/17
EPA GHG Emissions (Grams CO_2/Mi)	523
Study Logger ID	26
Total Vehicle Days/Total Study Days	46/71

Vehicle ***5846 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	7.2/12.8	3.3/10.3	0.8/2.5	332
Travel Time (Minutes)	46.0/76.0	20.9/70.0	4.8/40.0	2,129
Idle Time (Minutes)	6.9/NA	3.1/NA	0.7/NA	317

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	413	100%	Less than 2	342
10 to 20	0	0%	2 to 4	25
20 to 40	0	0%	4 to 8	3
40 to 60	0	0%	Greater than 8	43

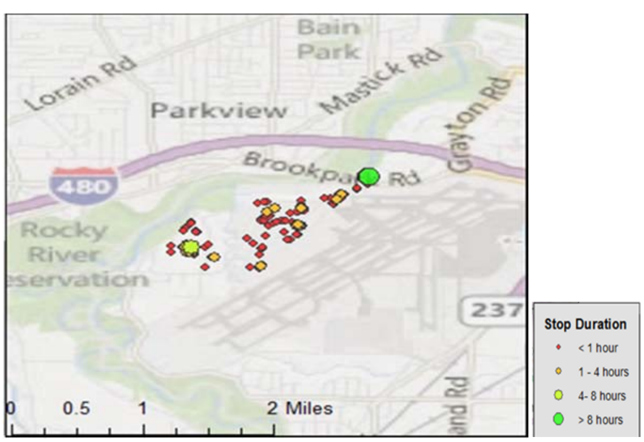


Figure B-10. Vehicle ***5846 stops.

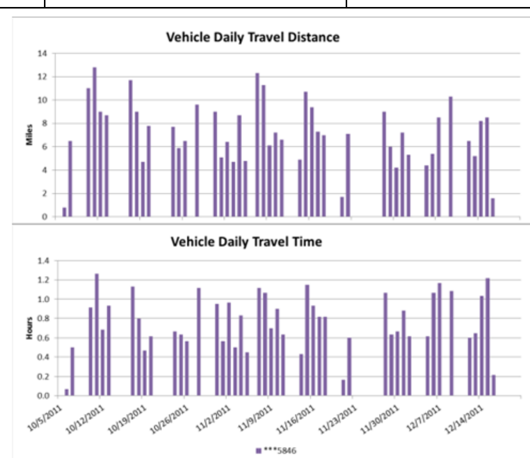


Figure B-11. Vehicle ***5846 history.

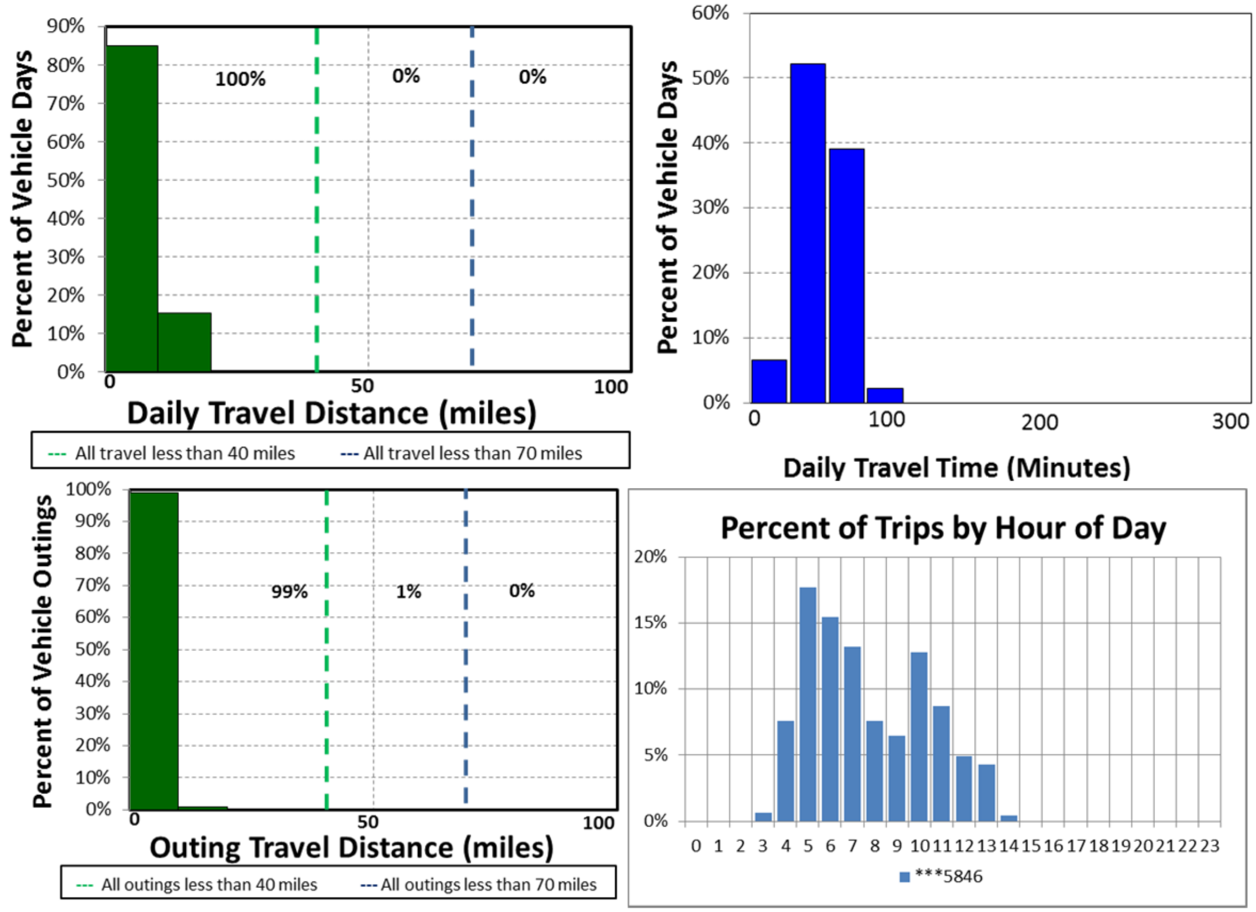


Figure B-12. Vehicle ***5846 travel graphs.

Vehicle ***5846 Observations

Logger 26 collected data on this vehicle for a period of 46 days of the 71-day study period. Validation occurred on 100% of the input data. GRC reports that this is a pool vehicle. Data recorded for this vehicle indicated that it typically parks on State Rt 17 (Brookpark Road) in Fairview Park. During this study, it spent several evenings parked nearby on Grayton Road, Hanger Road, and W. Area Road. From identified outings, only Brookpark Road is considered as a home base for analysis purposes.

NASA reports that the vehicle odometer indicated 8,783 miles during the study and it travels approximately 2,200 miles per year. The vehicle was used on 65% of the available days, with an average daily usage of 0.8 hours and a peak daily usage of 1.3 hours on the days it was used. The vehicle was used during typical day shift hours.

Figure B-10 shows all stops exceeding a 2-hour duration, with most occurring at the home base.

Figure B-12 shows 100% of daily travel and 100% of all outings were within the typically advertised range of a BEV of approximately 70 miles. No daily travel exceeded this range. Further, 100% of daily travel and 100% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet all daily travel without additional charging opportunities. A fleet of BEVs and PHEVs in the fleet is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***5847

		
	Make/Model/Year	Dodge Dakota ST/2007
	EPA Class Size	Pickup Truck
	Mission	Pool
	VIN	1D7HE22P97S205847
	Parking Location	W. Area Rd, Brook Park
	Fleet Vehicle ID	***5847
	Fuel Type	Gas
	EPA Label/MPG (City/Hwy)	15/20/17
	EPA GHG Emissions (Grams CO_2/Mi)	523
	Study Logger ID	27
	Total Vehicle Days/Total Study Days	28/70

Vehicle ***5847 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	4.3/37.2	1.7/36.1	0.9/19.2	120
Travel Time (Minutes)	20/95.0	8.0/89.0	4.1/33.0	554
Idle Time (Minutes)	3.8/NA	1.5/NA	0.8/NA	105

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	113	98.3%	Less than 2	80
10 to 20	2	1.7%	2 to 4	4
20 to 40	0	0%	4 to 8	6
40 to 60	0	0%	Greater than 8	25

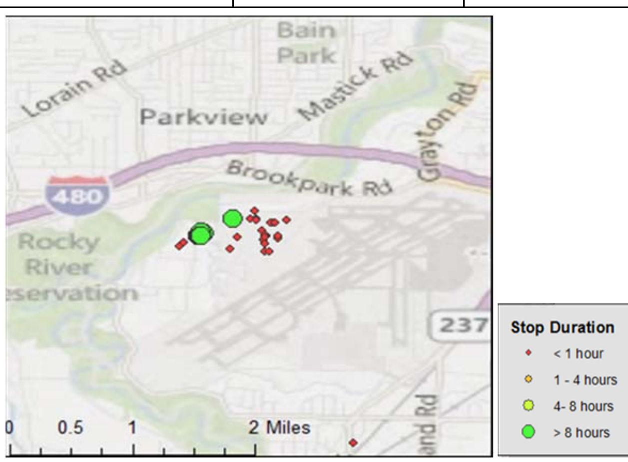


Figure B-13. Vehicle ***5847 stops.

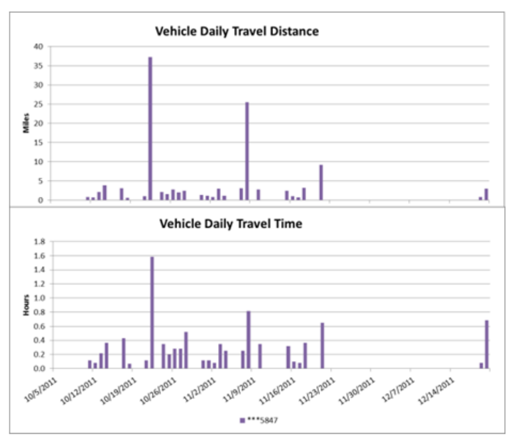


Figure B-14. Vehicle ***5847 history.

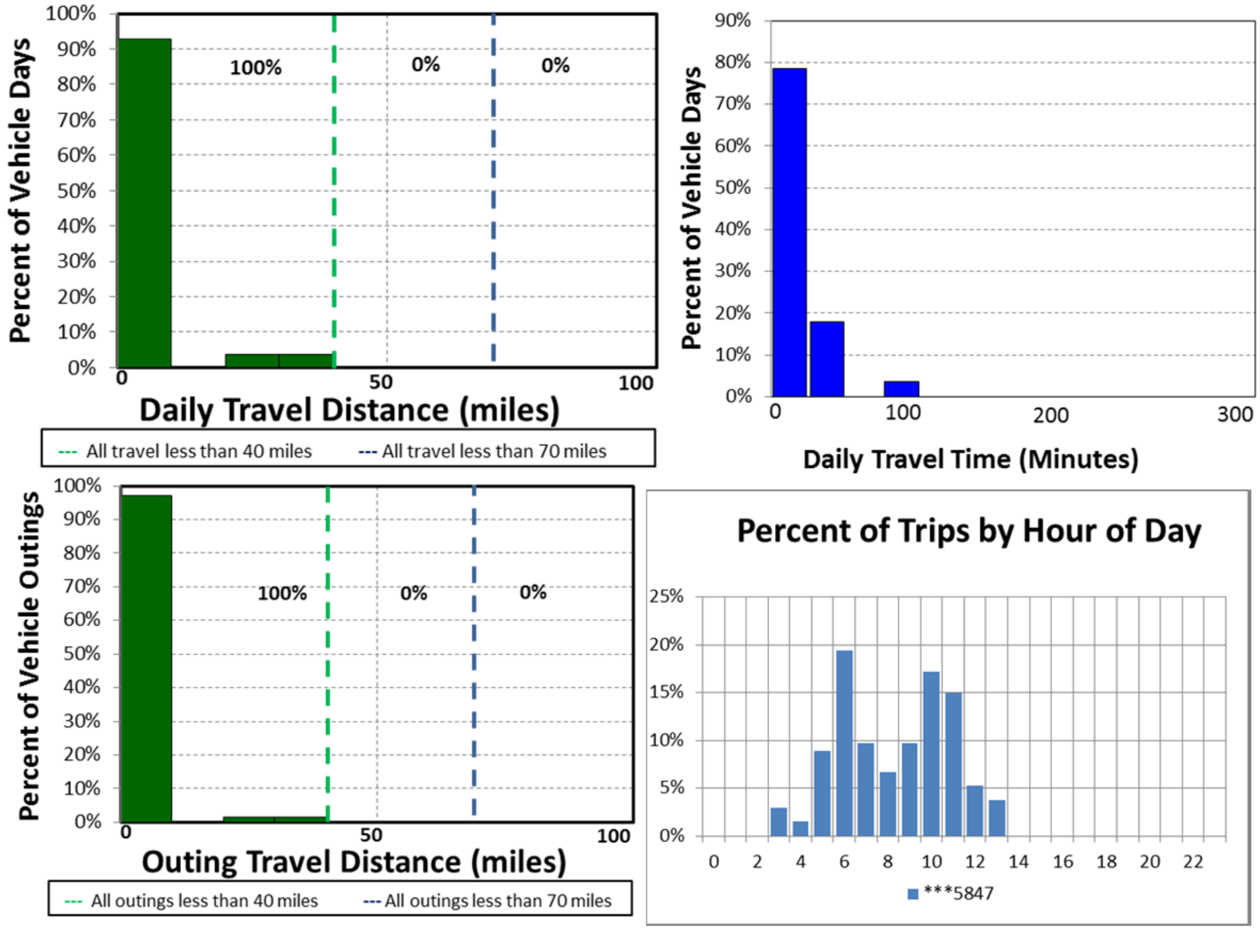


Figure B-15. Vehicle ***5847 travel graphs.

Vehicle ***5847 Observations

Logger 27 collected data on this vehicle for a period of 28 days of the 70-day study period. Validation occurred on 100% of the input data. GRC reports that this is a pool vehicle. Data recorded for this vehicle indicated that it typically parks on W. Area Road in Brookpark.

NASA reports that the vehicle odometer indicated 8,789 miles during the study and it travels approximately 2,000 miles per year. The vehicle was used on 65% of the available days, with an average daily usage of 0.3 hours and a peak daily usage of 1.6 hours on the days it was used. The vehicle was used during typical day shift hours.

Figure B-13 shows all stops exceeding a 2-hour duration and shows most occurred at the home base.

Figure B-15 shows 100% of daily travel and 100% of all outings were within the typically advertised range of a BEV of approximately 70 miles. No daily travel exceeded this range. Further, 100% of daily travel and 100% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet all daily travel without additional charging opportunities. A fleet of BEVs and PHEVs in the fleet is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***9021

Make/Model/Year	Chevrolet Malibu LS/2010
EPA Class Size	Sedan – Midsize
Mission	Law Enforcement
VIN	1G1ZA5E06AF279021
Parking Location	W. Hanger Rd, Brook Park
Fleet Vehicle ID	***9021
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy/Combined)	22/33/26 15/23/18
EPA GHG Emissions (Grams CO_2/Mi)	342/350
Study Logger ID	28
Total Vehicle Days/Total Study Days	18/68

Vehicle ***9021 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	10.4/104.8	7.8/104.8	4.0/52.3	187
Travel Time (Minutes)	18.0/118.0	13.3/118.0	7.3/60.0	320
Idle Time (Minutes)	0/NA	0/NA	0/NA	0

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	39	88.6%	Less than 2	23
10 to 20	3	6.8%	2 to 4	2
20 to 40	0	0%	4 to 8	1
Greater than 40	2	4.5%	Greater than 8	18

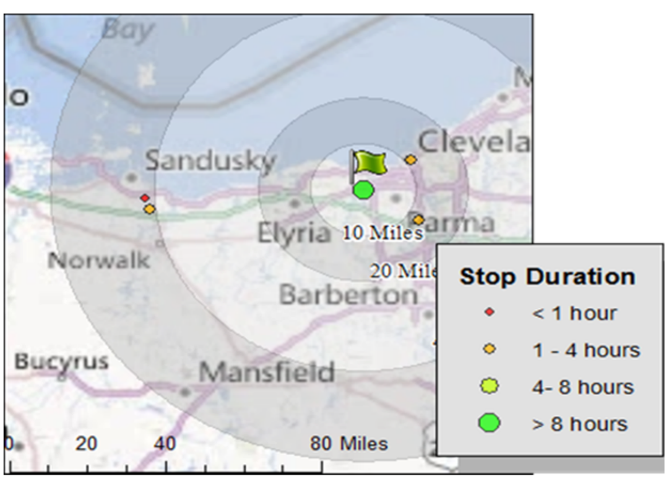


Figure B-16. Vehicle ***9021 stops.

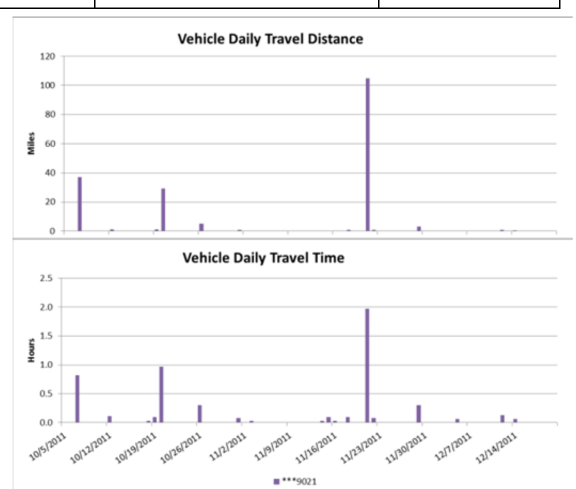


Figure B-17. Vehicle ***9021 history.

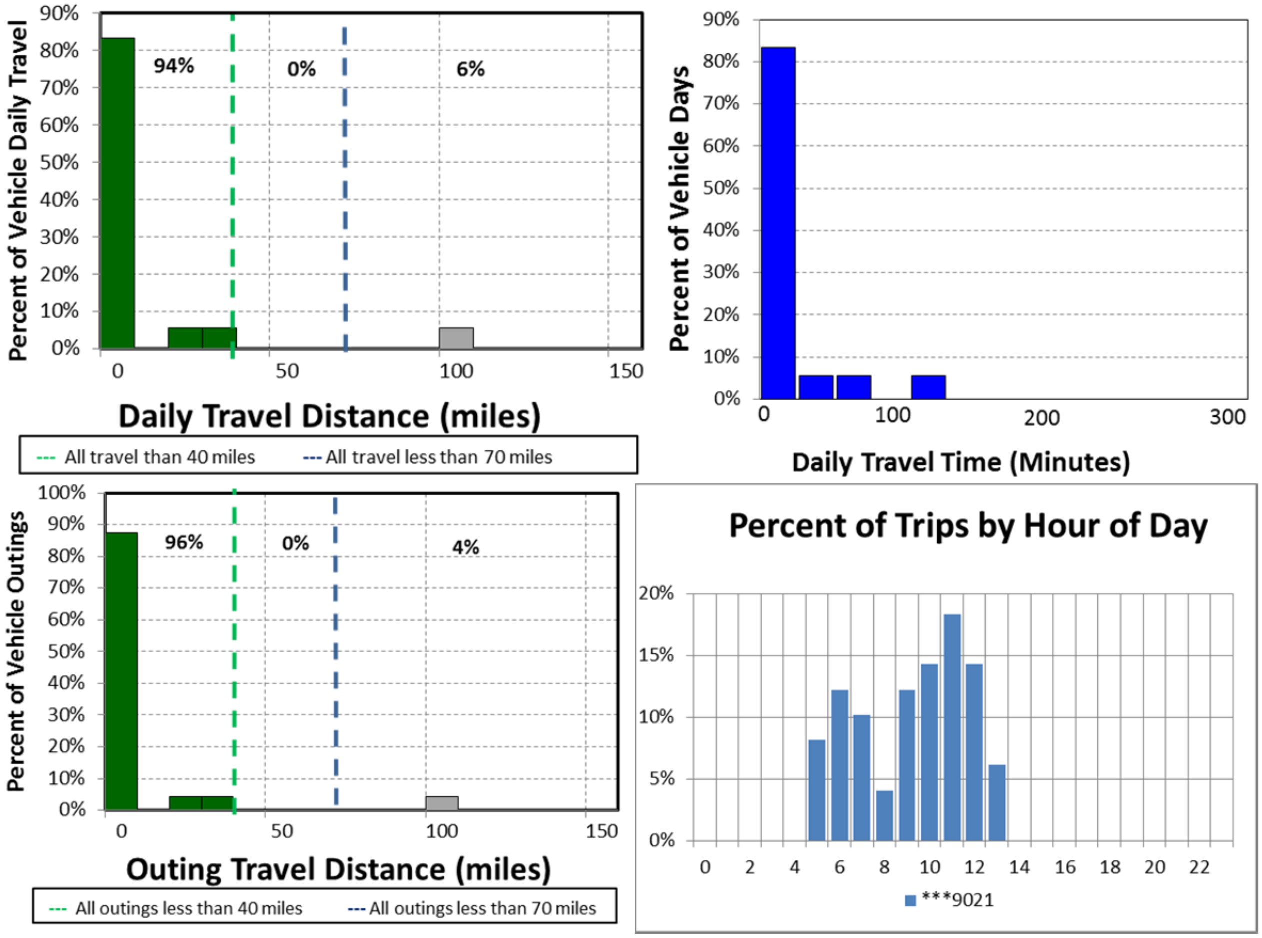


Figure B-18. Vehicle ***9021 travel graphs.

Vehicle ***9021 Observations

Logger 28 collected data on this vehicle for a period of 18 days of the 68-day study period. Validation occurred on 95.9% of the input data. NASA reports that this is a law enforcement vehicle. Data recorded on the vehicle indicated that it typically parks on W. Hanger Rd in Brook Park.

NASA reports that the vehicle odometer indicated 2,741 miles during the study and it travels approximately 2,000 miles per year. The vehicle was used on 26% of the available days, with an average daily usage of 0.3 hours and a peak daily usage of 2.0 hours on the days it was used. The vehicle was used during typical day shift hours.

Figure B-16 shows stops exceeding a 2-hour duration and shows that most occurred at the home base.

Figure B-18 shows that 94% of daily travel and 96% of all outings were within the typically advertised range of a BEV of approximately 70 miles and 6% of daily travel exceeded this range. Further, 94% of daily travel and 96% of outings were within the typically advertised CD mode for PHEVs of 40 miles.

A BEV could meet 94% of daily travel without additional charging opportunities. However, sufficient time exists daily for additional charging that could then meet additional outing usage. A fleet of BEVs and PHEVs is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for law enforcement activities. Typically, vehicles without range limitations are desired for law enforcement vehicles.

Vehicle ***5845

Make/Model/Year	Dodge Dakota ST / 2007
EPA Class Size	Pickup Truck
Mission	Pool
VIN	1D7HE22P575205845
Parking Location	Grayton Rd, Brook Park
Fleet Vehicle ID	***5845
Fuel Type	Gas
EPA Label/MPG (City/Hwy)	15/20/17
EPA GHG Emissions (Grams CO_2/Mi)	523
Study Logger ID	29
Total Vehicle Days/Total Study Days	44/75

Vehicle ***5845 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	3.4/16.8	1.1/10.9	0.6/6.8	151
Travel Time (Minutes)	32.0/96.0	10.7/81.0	5.7/69.0	1,428
Idle Time (Minutes)	3.2/NA	1.1/NA	0.6/NA	140

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	228	100%	Less than 2	169
10 to 20	0	0%	2 to 4	11
20 to 40	0	0%	4 to 8	2
Greater than 40	0	0%	Greater than 8	46

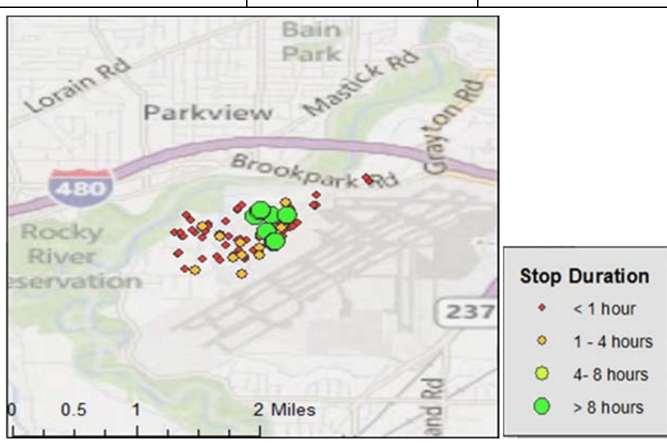


Figure B-19. Vehicle ***5845 stops.

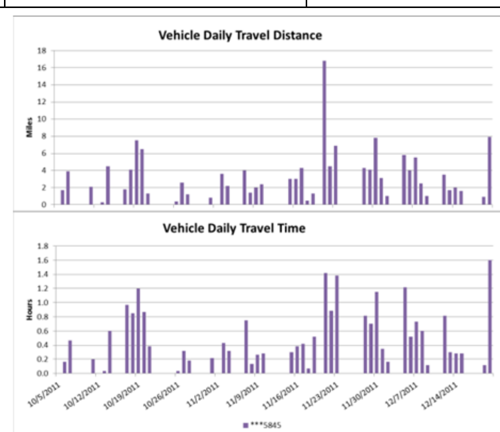


Figure B-20. Vehicle ***5845 history.

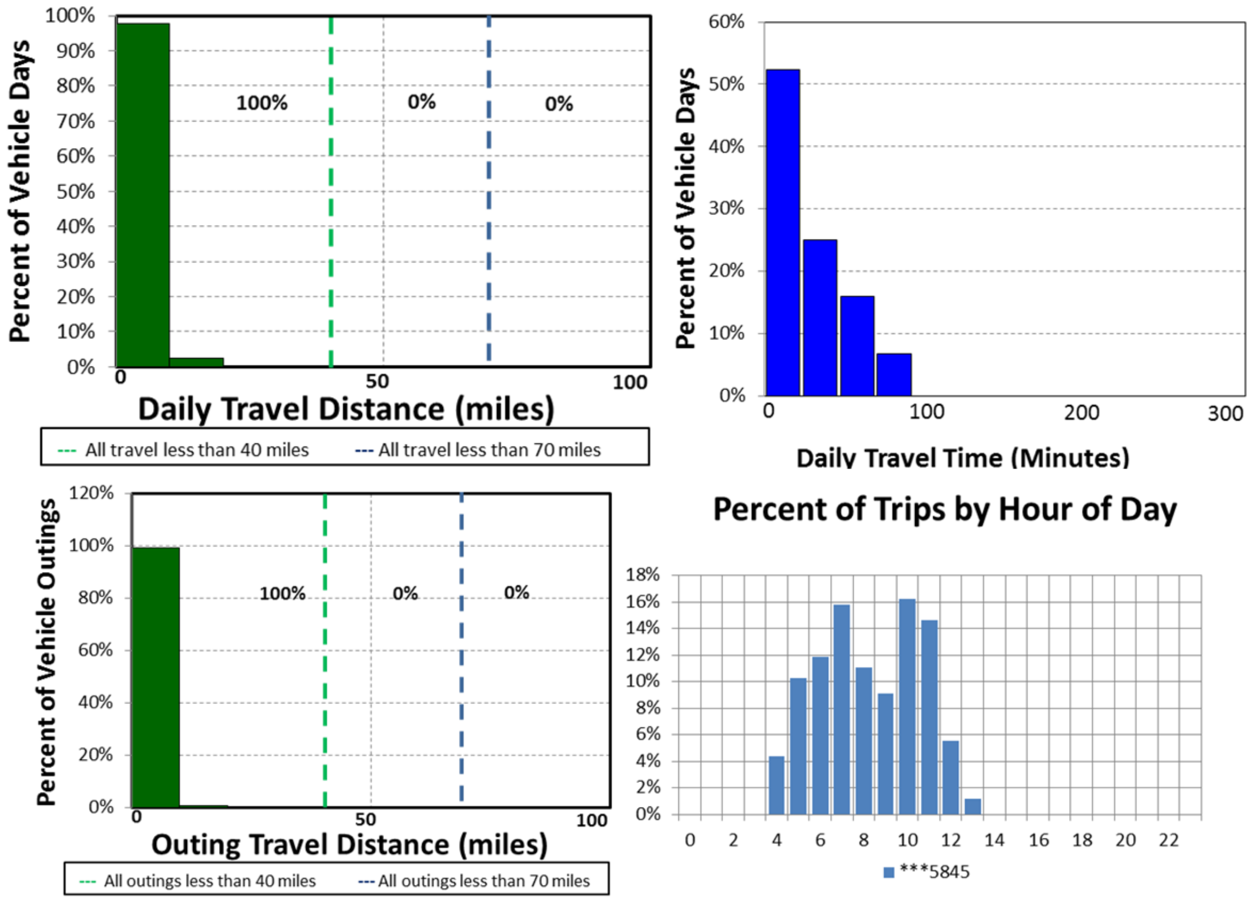


Figure B-21. Vehicle ***5845 travel graphs.

Vehicle ***5845 Observations

Logger 29 collected data on this vehicle for a period of 44 days of the 75-day study period. Validation occurred on 100% of the input data. NASA reports that this is a pool vehicle. Data recorded on the vehicle survey indicated that it typically parks on Grayton Road in Brook Park.

NASA reports that the vehicle odometer indicated 18,850 miles during the study and it travels approximately 2,000 miles per year. The vehicle was used on 59% of the available days, with an average daily usage of 0.5 hours and a peak daily usage of 1.6 hours on the days it was used. The vehicle was used during typical day shift hours.

Figure B-19 shows all stops exceeding a 2-hour duration and shows most occurred at the home base.

Figure B-21 shows 100% of daily travel and 100% of all outings were within the typically advertised range of a BEV of approximately 70 miles. No daily travel exceeded this range. Further, 100% of daily travel and 100% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet all daily travel without additional charging opportunities. A fleet of BEVs and PHEVs in the fleet is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***0432

Make/Model/Year	Chevrolet Malibu LS/2011
EPA Class Size	Sedan – Midsize
Mission	Pool
VIN	1G1ZA5EU88F320432
Parking Location	S Magazine Rd, Oxford OH
Fleet Vehicle ID	***0432
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy)	22/33/26 15/23/18
EPA GHG Emissions (Grams CO_2/Mi)	342/350
Study Logger ID	30
Total Vehicle Days/Total Study Days	31/75

Vehicle ***0432 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	26.8/116.4	15.9/131.1	6.4/57.5	829
Travel Time (Minutes)	48.0/178.0	28.7/199.0	11.5/85.0	1,493
Idle Time (Minutes)	1.6/NA	0.9/NA	0.4/NA	49

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	103	85.8%	Less than 2	81
10 to 20	1	0.8%	2 to 4	6
20 to 40	8	6.7%	4 to 8	3
40 to 60	8	6.7%	Greater than 8	30

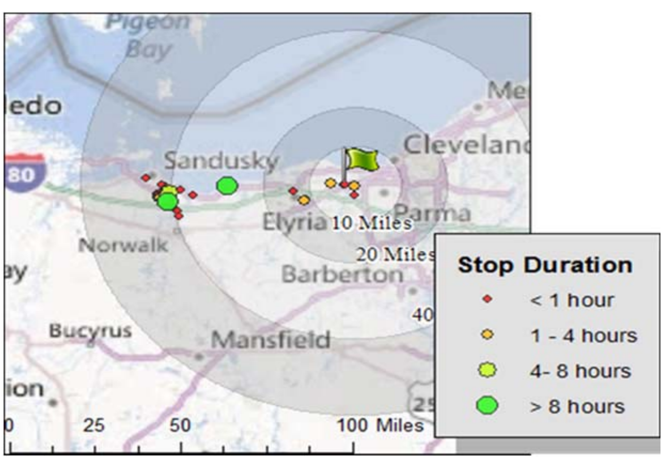


Figure B-22. Vehicle ***0432 stops.

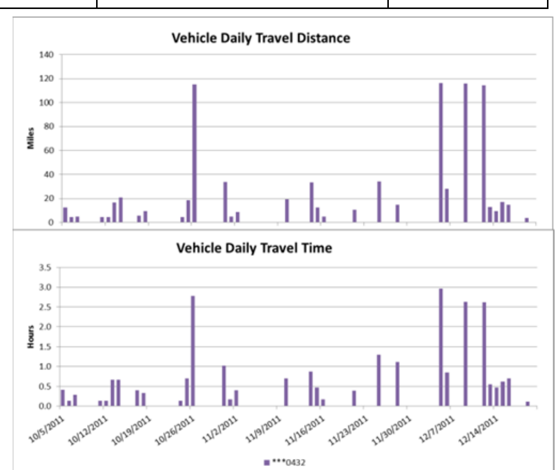


Figure B-23. Vehicle ***0432 history.

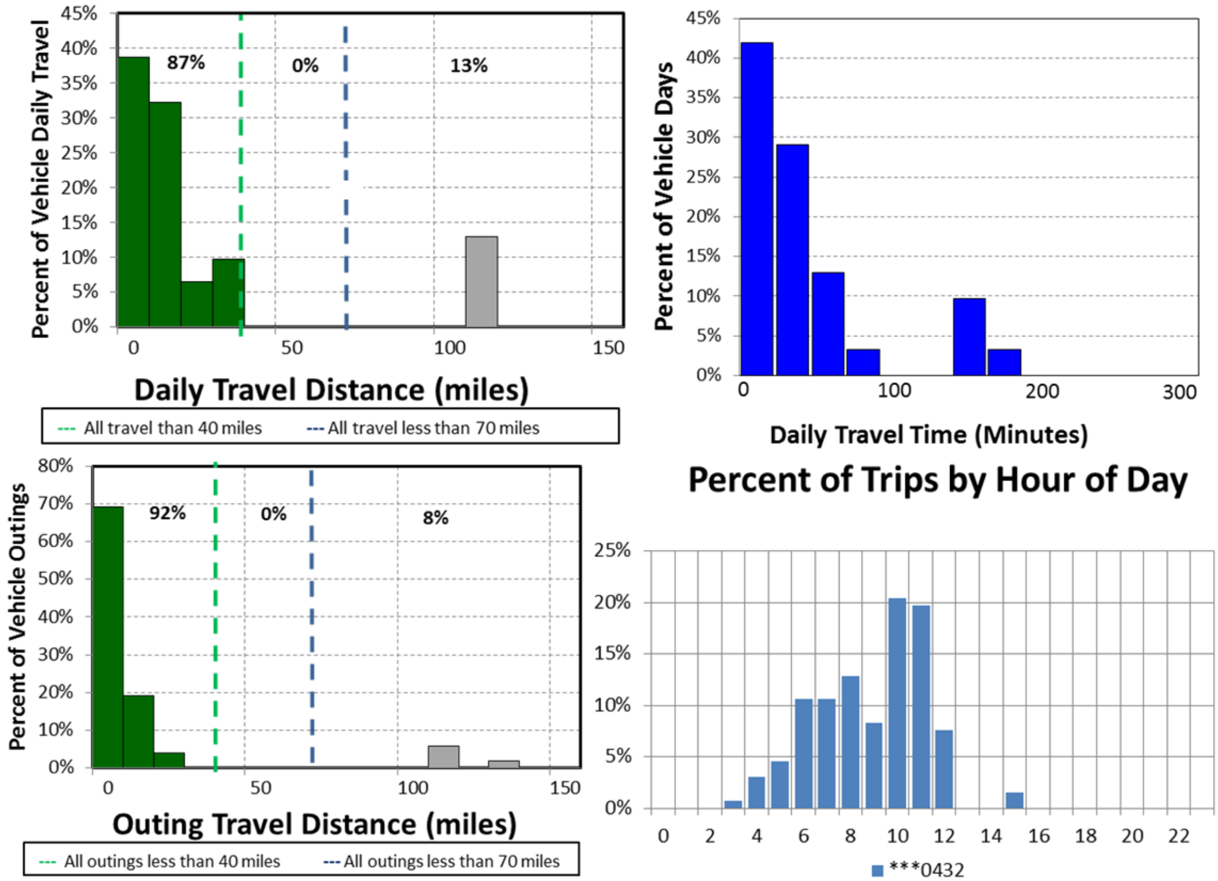


Figure B-24. Vehicle ***0432 travel graphs.

Vehicle ***0432 Observations

Logger 30 collected data on this vehicle for a period of 31 days of the 75-day study period. Validation occurred on 99.6% of the input data. NASA reports that this is a pool vehicle assigned to PBS. Data recorded on this vehicle indicate it normally parks on S. Magazine Road in Oxford, OH.

NASA reports that the vehicle odometer indicated 2,433 miles during the study and it travels approximately 4,000 miles per year. The vehicle was used on 41% of the available days, with an average daily usage of 0.8 hours and a peak daily usage of 3.0 hours on the days it was used. The vehicle was used during typical day shift hours.

Figure B-22 shows all vehicle stop locations and shows that most stops of greater than 2 hours occurred at the home base.

Figure B-24 shows that 87% of daily travel and 92% of all outings were within the typically advertised range of a BEV of approximately 70 miles and 13% of daily travel exceeded this range. Further, 87% of daily travel and 92% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet 87% of daily travel without additional charging opportunities. However, sufficient time exists daily for additional charging that could then meet additional outing usage. A fleet of BEVs and PHEVs is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***3544

Make/Model/Year	Chevrolet Malibu LS/2011
EPA Class Size	Sedan – Midsize
Mission	Pool
VIN	1G1ZA5EU1BF323544
Parking Location	Maintenance Rd, Perkins OH
Fleet Vehicle ID	***3544
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy)	22/33/26 15/23/18
EPA GHG Emissions (Grams CO_2/Mi)	342/350
Study Logger ID	31
Total Vehicle Days/Total Study Days	39/75

Vehicle ***3544 Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/Peak	Total
Travel Distance (Miles)	118.0/682.9	76.7/1,368.7	23.8/268.8	4,602
Travel Time (Minutes)	150.0/713.0	97.6/1,423.0	30.3/251.0	5,856
Idle Time (Minutes)	3.7/NA	2.4/NA	0.7/NA	143

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	97	53.0%	Less than 2	131
10 to 20	1	0.5%	2 to 4	14
20 to 40	12	6.6%	4 to 8	2
Greater than 40	73	39.9%	Greater than 8	36

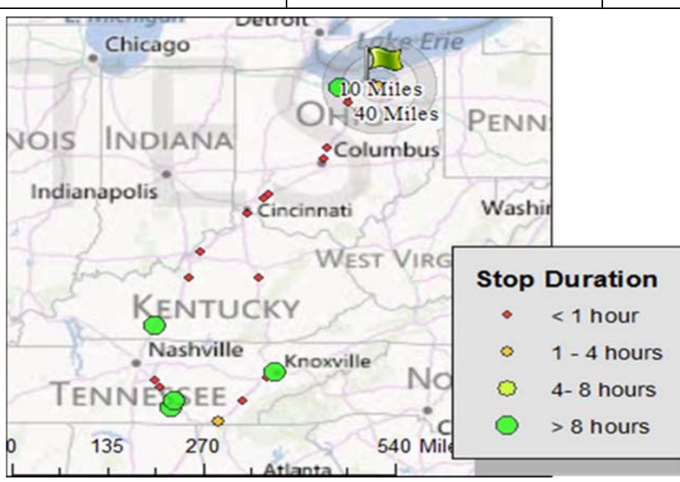


Figure B-25. Vehicle ***3544 stops.

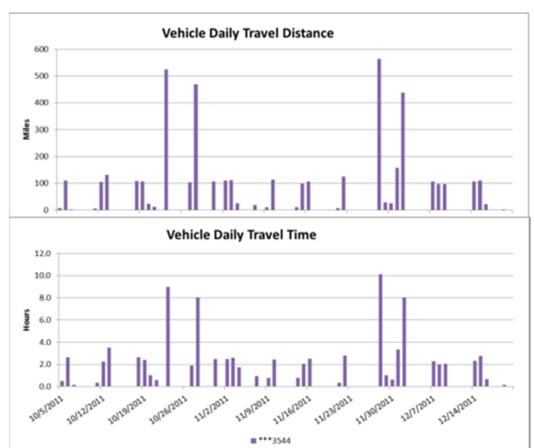
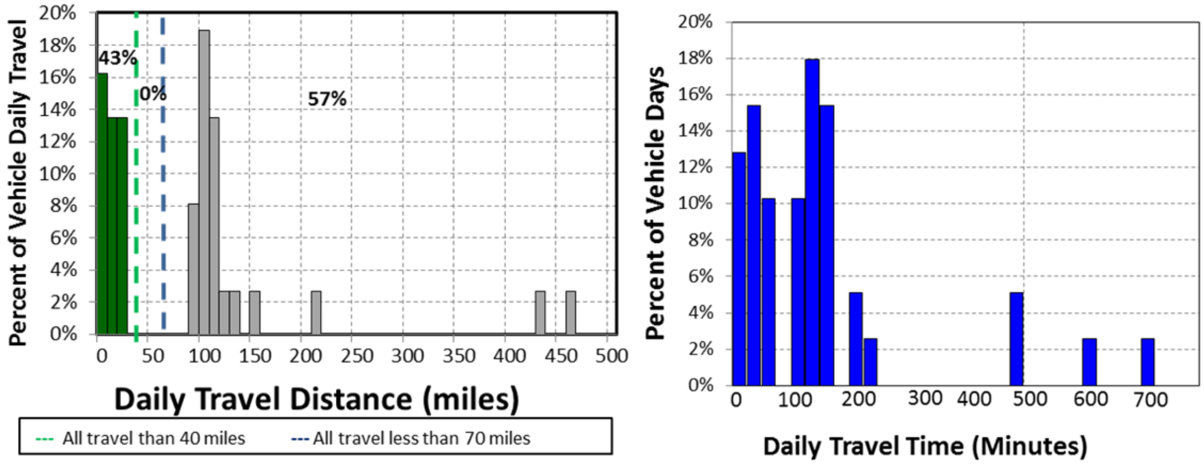
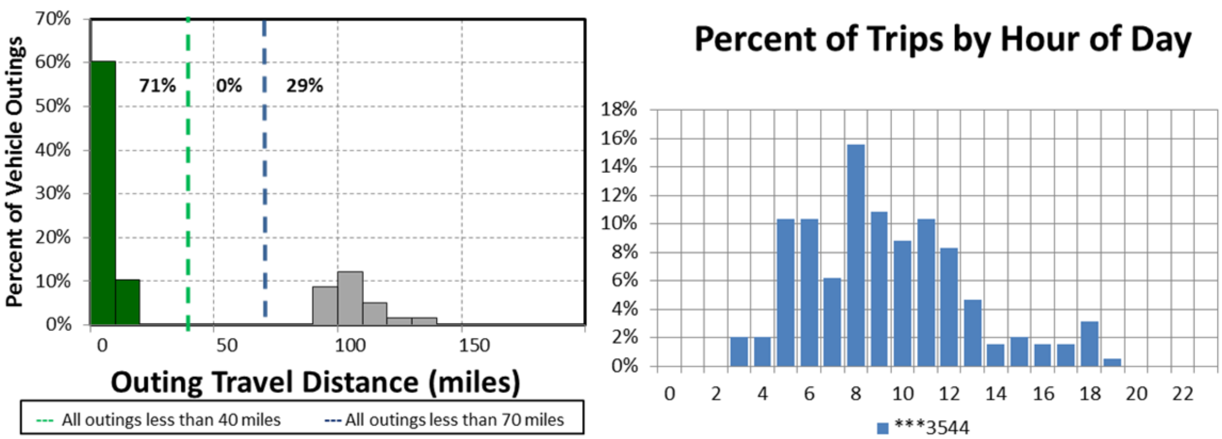


Figure B-26. Vehicle ***3544 history.



Note: Two days of travel of 682.9 and 563.8 miles not shown for clarity



Note: Two outings of 1212.9 and 1368.7 miles are not shown for clarity

Figure B-27. Vehicle ***3544 travel graphs.

Vehicle ***3544 Observations

Logger 31 collected data on this vehicle for a period of 39 days of the 75-day study period. Validation occurred on 99.7% of the input data. NASA reports that this is a pool vehicle assigned to PBS. Data recorded on this vehicle indicate it normally parks on Maintenance Road in Perkins, OH. NASA reports the vehicle odometer indicated 6,040 miles during the study and it travels approximately 11,000 miles per year. The vehicle was used on 52% of the available days, with an average daily usage of 2.4 hours and a peak daily usage of 10.1 hours on the days it was used. The vehicle was used during the extended day shift hours.

Figure B-25 shows all vehicle stop locations. While in the PBS area, most stops occurred at the home base. During the study period, two extended outings occurred from October 23 to 28 and November 28 to December 2, both involving trips to Kentucky and Tennessee. These accounted for the longest daily travel and outings. These are excluded from the graphs above for clarity of scale.

Figure B-27 shows 43% of daily travel and 71% of all outings were within the typically advertised range of a BEV of approximately 70 miles and 57% of daily travel exceeded this range. Further, 43% of daily travel and 71% of outings were within the typically advertised CD mode of 40 miles for PHEVs.

A BEV could meet 43% of daily travel without additional charging opportunities. A fleet of BEVs and PHEVs is more likely to allow daily travel without requiring additional charge times, providing the PEV meets other mission requirements. The survey information suggests no other special requirements exist for pool activities.

Vehicle ***2944

Make/Model/Year	Jeep Grand Cherokee/2011
EPA Class Size	SUV
Mission	Law Enforcement
VIN	1J4RRGG5BC712944
Parking Location	
Fleet Vehicle ID	***2944
Fuel Type	Gas/E85
EPA Label/MPG (City/Hwy)	16/23/18 13/17/14
EPA GHG Emissions (Grams CO_2/Mi)	494/450
Study Logger ID	32
Total Vehicle Days/Total Study Days	No data

Vehicle ***2944Travel Summary				
	Per Day Average/Peak	Per Outing Average/Peak	Per Trip Average/10.0/Peak	Total
Travel Distance (Miles)	No data	No data	No data	No data
Travel Time (Minutes)	No data	No data	No data	No data
Idle Time (Minutes)	No data	No data	No data	No data

Total Stops			Stop Duration	
Distance From Home Base (Miles)	Stops	Percentages	Stop Duration (Hours)	Stops
Less than 10	No data	No data	Less than 2	No data
10 to 20	No data	No data	2 to 4	No data
20 to 40	No data	No data	4 to 8	No data
Greater than 40	No data	No data	Greater than 8	No data

Vehicle ***2944 Observations

No data were transmitted during the study period. The logger never checked in, indicating it was not installed.

NASA reported that this vehicle is a law enforcement vehicle assigned to GRC.

The reported odometer reading was 1,164 during the study period, with an estimated annual usage of 4,000 miles.

Appendix C
National Fuel Cost and GHG Savings

Section 5 notes that fuel cost and GHG savings are calculated on a local and a national basis. Local savings are of higher interest to the facility, while national figures are of higher interest in evaluating all sites. Section 5 provides the savings on the local level. Table C-1 presents these savings on a national basis for the PEV replacement of monitored vehicles.

Table C-1. Fuel cost and GHG savings on a national basis.

	Mission	Replacement Model	Extrapolated U.S. Yearly CO_2e Avoided (lb-CO_2e/year)	% reduction	Extrapolated U.S. Yearly Fuel Cost Reduction	% reduction
	Pool	Fusion	3,527	27%	$1,643	73%
	Pool	Fusion	2,322	27%	$1,082	73%
	Enforcement	Fusion	885	27%	$412	73%
	Pool	eNV200	1,255	48%	$360	81%
	Pool	Rav4	1,018	43%	$320	79%
	Enforcement	Leaf	628	41%	$207	78%
	Pool	Rav4	1,018	43%	$320	79%
	Pool	Leaf	1,256	41%	$413	78%
	Pool	Fusion	979	27%	$456	73%
	Enforcement	Outlander	1,632	40%	$547	77%
Total			**14,521**	**32%**	**$5,761**	**75%**
Total Pool			11,376	32%	$4,595	74%
Total Enforcement			3,145	35%	$1,166	76%

As presented in Section 5, 11 BEVs and nine PHEVs could replace the pool and law enforcement vehicles in the fleet of 20 vehicles with these missions. Using an average savings per vehicle, Table C-2 provides the avoided GHG and fuel cost savings should these replacements occur.

Table C-2. Extrapolated greenhouse gas emissions avoided and fuel cost savings for the entire fleet.

Mission	Extrapolated U.S. Yearly CO_2e Avoided (lb-CO_2e/year)	% reduction	Extrapolated U.S. Yearly Fuel Cost Reduction ($/year	% reduction
Pool	29,345	35%	$11,019	76%
Enforcement	3,536	36%	$1,279	76%
Total	32,881	35%	$12,298	76%