NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Telematics and Data Science: Informing Energy-Efficient Mobility

October 25, 2016 — October 31, 2017

Ryan Daley and Matthew Helm
Sawatch Group

NREL Technical Monitor: Ted Sears

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Subcontract Report
NREL/SR-5400-69018
April 2018

Contract No. DE-AC36-08GO28308

Telematics and Data Science: Informing Energy-Efficient Mobility

October 25, 2016 — October 31, 2017

Ryan Daley and Matthew Helm
Sawatch Group

NREL Technical Monitor: Ted Sears

Prepared under Subcontract No. LGZ-7-70005-01

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Subcontract Report
NREL/SR-5400-69018
April 2018

Contract No. DE-AC36-08GO28308

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at SciTech Connect http:/www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
OSTI http://www.osti.gov
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
NTIS http://www.ntis.gov
Phone: 800.553.6847 or 703.605.6000
Fax: 703.605.6900
Email: orders@ntis.gov

Cover Photos by Dennis Schroeder: (left to right) NREL 26173, NREL 18302, NREL 19758, NREL 29642, NREL 19795.

NREL prints on paper that contains recycled content.

Acknowledgements

This work was supported by the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308 with Alliance for Sustainable Energy, LLC, the Manager and Operator of the National Renewable Energy Laboratory (NREL). Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office's Alternative Fuel Transportation Program. The Program, also referred to as the State and Alternative Fuel Provider Fleet Program, offers compliance assistance to covered fleets as they work to achieve compliance with their requirements under the Energy Policy Act (EPAct), as implemented via the Program. The Program, as with other EPAct transportation-related programs at DOE, aims to increase alternative fuel use by supporting alternative fuel vehicle availability and related infrastructure. This work was completed under a contract between NREL and Sawatch Group. The authors would like to thank fleet-management personnel at the University of Connecticut—including Nicole Tomassetti, Mary Sohon, and Charles Grab—as well as NREL expert Ted Sears. All judgments in the final analytic methodologies and interpretations were developed by and are the responsibility of the Sawatch Group and not of the persons acknowledged above.

List of Acronyms

BDL	Bradley International Airport
BEV	battery electric vehicle
CO_2e	carbon dioxide equivalent
DC	direct current
DOE	U.S. Department of Energy
ECU	engine control unit
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
EV	electric vehicle
EVSE	electric vehicle supply equipment
GHG	greenhouse gas
GPS	Global Positioning System
ICE	internal combustion engine
mi/kWh	miles per kilowatt-hour
MPG	miles per gallon
MPH	miles per hour
MTCO2e	metric tons of carbon dioxide equivalent
NREL	National Renewable Energy Laboratory
PHEV	plug-in hybrid electric vehicle
ROI	return on investment
TCO	total cost of ownership
UCONN	University of Connecticut
VMT	vehicle miles traveled

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Executive Summary and Recommendations

The University of Connecticut (UCONN) is exploring the possibility of adding electric vehicles (EVs)—battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), or both—to its vehicle fleet. This report presents results of the UCONN fleet EV Suitability pilot program and offers recommendations for transitioning fleet vehicles to EVs as well as implementing adequate charging infrastructure.

The pilot program required collection of telematics data from UCONN's participating vehicles via Sawatch Group's "ezEV-Fleet" software. The data set collected with ezEV-Fleet included data for five Dodge Caravan minivans assigned to the Parking and Transportation Services Department. Data were collected over a 77-day period from March 7–May 23, 2017. This period represents real-world driving conditions and is assumed to reflect normal operational characteristics such that these data are assumed to be typical of annual duty cycles and fleet driving needs of UCONN personnel.

The drive cycles of the UCONN study vehicles present opportunities to replace all five with an EV technology. Three study vehicles operated exclusively on the UCONN campus during the data-collection period, and all three are excellent candidates for replacement with a BEV like the Ford Focus. In addition, all three should be able to operate exclusively on electricity if replaced with a Chrysler Pacifica PHEV minivan.

Two study vehicles had consistent off-campus travel. When they traveled exclusively on campus during a day, they exhibited nearly identical behavior, travel patterns, and metrics as the three on-campus-only vehicles discussed above. Transition to electric miles is recommended for that portion of their driving needs. However, the longer-distance trips that occurred on about one fourth of all travel days will have a noticeable impact on the ability to transition all miles to electricity. Particularly challenging is the roundtrip drive to Bradley International Airport, which is about 72–78 miles and will require approximately 18–22 kWh of energy in an EV. The distance, estimated energy consumption, and frequency of this route are the only significant hurdles to UCONN transitioning all the miles on these vehicles to electricity. If BEVs are placed into the UCONN fleet, then BEV routes should be scheduled to avoid multiple daily airport trips by any single BEV. Another solution is to have at least one PHEV to cover days with multiple long-distance trips, so the internal combustion engine can enable completion of the drive cycles.

All five study vehicles regularly ended their days in the lots surrounding the Parking Services building at UCONN, which already has one Level 2 electric vehicle supply equipment (EVSE) port. Given the frequency of trips and days that end at this location, UCONN should consider adding at least one more Level 2 EVSE unit to the existing charging station in that lot. In the longer term, UCONN could benefit from adding at least two Level 2 EVSE units on the southwest corner of the Parking Services building. Finally, any EVs deployed into the UCONN fleet should have access to the Level 2 EVSE at the North and South Garages on campus when necessary, especially prior to the deployment of any additional EVSE.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table of Contents

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

List of Figures

List of Tables

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

1 Introduction

Certain state agency fleets are mandated under the Energy Policy Act (EPAct) to acquire alternative fuel vehicles or otherwise implement strategies to increase alternative fuel use in covered fleet vehicles. The U.S. Department of Energy's Vehicle Technologies Office implements the Alternative Fuel Transportation Program, also known as the State and Alternative Fuel Provider Fleet Program, with the assistance of the National Renewable Energy Laboratory (NREL). NREL works with covered fleets to help them meet their EPAct requirements. The University of Connecticut (UCONN) is a covered EPAct fleet.

In late 2016, the State and Alternative Fuel Provider Fleet Program began working with Sawatch Group to analyze fleet vehicle suitability for transition to electric vehicles (EVs) and pilot the use of ezEV smartphone-based telematics to collect the data necessary to perform the analyses. In early 2017, UCONN engaged with NREL about the opportunity to analyze vehicles in its fleet for transition to EVs. UCONN can obtain telematics data across many of its fleet vehicles using Sawatch Group's ezEV.

The analysis described in this report uses vehicle performance, routing, and location data from ezEV to: (1) determine the suitability of each vehicle for transition to an EV; (2) identify the electric vehicle supply equipment (EVSE, also known as charging infrastructure) needed to match the driving needs of these vehicles should they be transitioned to EVs; and (3) provide guidance on EV total cost of ownership (TCO), return on investment (ROI), and potential cost savings. Five vehicles have ezEV data for the analysis period, March 7 through May 23, 2017.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

2 Methodology

This section describes the methods used in the study.

2.1 Sawatch Group Telematics Solution

The UCONN fleet EV Suitability pilot program required that telemetry be captured from UCONN's participating vehicles. In industry parlance, this is referred to as "telematics," the technology to track location, movement, and behavior of a vehicle. In the UCONN pilot, telematics data gathering was performed through Sawatch Group's "ezEV-Fleet" software.

Sawatch Group's PTRTelematics framework is used by ezEV-Fleet to capture vehicle telemetry. PTRTelematics serves as the framework for all Sawatch Group's driving telemetry software applications, including the consumer-facing version of ezEV and the "Petrolr" consumer brand telematics product. Rather than gather telemetry data in the traditional way—plugging hardware into the onboard diagnostic port to communicate with the vehicle's computer, the engine control unit (ECU)—PTRTelematics uses a smartphone's internal sensors to derive vehicle activity and performance.

Much of the functionality incorporated in a traditional telematics hardware component is duplicated in today's smartphones. The sensors most often used in traditional telematics include a Global Positioning System (GPS) to track location data, an accelerometer for hard braking/hard acceleration and accident detection, a data/cellular connection for data transmission, and a hardwired connection to the vehicle's ECU for vehicle performance capture. Of these functions, the GPS, accelerometer, and data connectivity functions of an Android or iOS smartphone are in many cases superior to what is available in the hardware on the telematics market.

Where PTRTelematics cannot match traditional installations is the hardwired connection to the vehicle's electronics. For this, PTRTelematics models vehicle performance[1] through a variety of stochastic methods and through use of low-energy Bluetooth radio beacons, which are placed in the vehicle and powered through the vehicle's direct current (DC) outlet. The radio beacon indicates that the vehicle's engine is running and—through use of an identifier on the radio signal—identifies in which vehicle the data-collecting smartphone is located.

2.2 Individual Vehicle Compatibility

The ezEV fleet assessment analyzes telemetry data from the mobile device, translating a vehicle's drive cycles and driving behavior for individual fleet vehicles into an EV Suitability score for each vehicle assessed. This methodology explains vehicle use and driving style in the context of impact on vehicle performance as if the vehicle operator were driving an EV, doing so across four metrics contributing to an overall EV Suitability score. Each metric is based on a score of 1–100, but lower scores do not necessarily indicate that an EV could not work in a particular application or duty cycle. Instead, lower scores suggest that modifying driving habits and/or identifying where midday charging could occur to complete each day's driving needs may be necessary.

[1] Because PTRTelematics is not connected to a vehicle's on-board diagnostics (OBD) port and Engine Control Unit (ECU), other engine performance data points—RPM, maintenance diagnostics codes, and transmission performance—that are seen in more traditional, hardware-based telematics, are not accessible.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

- **Overall Score:** Considering a combination of the categories below, how well each vehicle is suited for transition to an EV. Whenever a vehicle is mentioned for the first time, the overall EV Suitability score in this report is noted in parentheses directly after it, for example, **9-527 (98)**.
- **Confidence:** The degree to which an available data set constitutes a representative sample of driving.
- **Energy Use:** How often a vehicle could rely on a single daily charge—eliminating the need for midday charging and assuming that each day the vehicle would start with a fully charged battery.
- **Speed:** The amount of time driven at lower speeds—frequent travel at highway speeds can reduce the range of a battery electric vehicle (BEV) or the all-electric range of a plug-in hybrid electric vehicle (PHEV).
- **Efficiency:** The impact of driving style on a vehicle's efficiency—how aggressively an EV is driven affects the vehicle's actual miles per kilowatt hour (mi/kWh) in the same way that driving style affects miles per gallon (MPG) in an internal combustion engine (ICE) vehicle.

The scores can then be used to provide a degree of certainty in a fleet manager's decision to replace a conventional vehicle with an electric drive vehicle. Electric drive vehicles effectively come in two varieties, BEVs and PHEVs. They differ primarily in the form of fuel or energy they store on board and can access when they are driving, and as a result differ in the distance they can travel when fully fueled. BEVs have energy in the form of electricity, stored on board the vehicle, and the vehicle is limited as to the range it can travel on a single charge depending on the size or capacity of the battery in which the fuel, as electricity, is stored. Limited range can lead to "range anxiety," or driver concern about running out of energy/fuel before returning to the vehicle's garage location. PHEVs have both a battery, typically smaller than a BEV's battery, and a conventional ICE that runs on liquid gasoline fuel. As a result, PHEVs have a considerably longer range, and PHEV drivers are not subject to "range anxiety."

The base ezEV analytics use a generic BEV, which is assumed to have a 27-kWh battery with 23 kWh of usable battery capacity.[2] All ezEV suitability scores are based on this generic BEV unless otherwise noted (e.g., in Table 6, where the suitability scores are applied to specific makes and models). UCONN has indicated interest in the following makes and models of EVs: Ford Focus BEV, Ford Fusion Energi (PHEV), Ford C-Max Energi (PHEV), and Chrysler Pacifica PHEV. Accordingly, this ezEV analysis employs operational metrics specific to these vehicles as well as the generic BEV throughout the analysis (Table 1). All vehicles are assumed to charge at a rate of 4.15 kW using Level 2 EVSE.[3]

[2] Electric vehicle batteries are rated in terms of "battery capacity" or the total amount of energy the battery can store. The amount of energy a vehicle can use in real-world driving conditions is generally 80%–90% of the battery's total capacity. The usable energy is averaged across the 2017 Nissan Leaf, Ford Focus EV, BMW i3, and Kia Soul EV.
[3] Level 2 EVSE refers to equipment that will charge a vehicle through a 240-volt (V) electrical service, Level 1 charging refers to a 120-V service or outlet, and DC fast charging requires 480-V service. Additional information on EVSE definitions is available at https://www.afdc.energy.gov/fuels/electricity_infrastructure.html.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table 1. Study Vehicle Characteristics

2017 Vehicle	Manufacturer's Suggested Retail Price	Total Battery Capacity	All-Electric Range (miles)
Ford C-Max Energi PHEV	$27,120	7.6 kWh	20
Ford Fusion Energi PHEV	$31,120	7.6 kWh	20
Chrysler Pacifica PHEV	$41,995	16 kWh	33
Ford Focus BEV[4]	$29,170	23 kWh	76
Generic BEV	$33,806	27 kWh	102

2.3 Electric Vehicle Supply Equipment

An inherent benefit of telematics is the collection of location data. These data are not only useful to understand where a vehicle travels, but also to understand where vehicles regularly park, especially overnight, when opportunities for charging can be maximized. The data will allow UCONN to make an informed decision about fleet vehicle use of existing EVSE on campus and the number of additional Level 2 EVSE units that must be installed to support new EVs. By optimizing the number of Level 2 chargers installed, it is possible to reduce the amount of infrastructure needed and, as a result, reduce infrastructure and overall project costs.

To evaluate infrastructure needs, ezEV characterizes each trip by duration, estimated electricity use, and starting and ending location. The same metrics are calculated and compiled for each individual day that a vehicle operates. Overnight parking locations and durations are a focus, to estimate the time that would be needed to fully recharge each vehicle after a day's worth of driving. Using the list of possible EVSE locations in Table 2, the amount of time between trips and the locations at which there is an opportunity for midday charging are also calculated.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Table 2. Possible EVSE Locations on and around the UCONN Campus

Facility	Location
UCONN Parking Services	9 Discovery Drive Storrs, CT 06269
UCONN North Parking Garage	103 N Eagleville Rd Storrs, CT 06269
UCONN South Parking Garage	505 Jim Calhoun Way Storrs, CT 06269
Town of Mansfield Community Center	10 S Eagleville Rd Mansfield, CT 06268
Storrs Center Parking Garage	33 Royce Cir Storrs, CT 06268
Mansfield Parking Garage	9 Dog Lane Storrs, CT 06268
Price Chopper	1220 Storrs Rd Mansfield, CT 06269

2.4 Total Cost of Ownership

Although this analysis offers the opportunity to examine TCO, UCONN did not provide fleet-specific cost data that would have enabled a complete TCO analysis. To support decision making that helps ensure EVs are deployed where they offer an economic benefit, a generalized comparison of TCO among different vehicle makes and models is included in Appendix A. This analysis uses mileage averages for five ICE Dodge Grand Caravans in the UCONN fleet examined in this study—which average 15,289 annual miles—and compares them to four possible 2017 electric drive vehicles: the one BEV and three PHEVs listed in Table 1. These cost estimates should be used for comparative purposes only. Vehicle procurement decisions should be based on the actual fleet cost data for the UCONN vehicles. TCO calculations do not currently account for any additional social benefits of incorporating EVs into the fleet (e.g., reducing air pollution or exposing the public to new vehicle technologies).

Because the economic benefits of EVs derive from lower operating (fuel and maintenance) costs, vehicles that drive many miles annually tend to realize greater savings from the use of electricity and simplified maintenance. In many cases, such high-use vehicles are necessary to compensate for the higher upfront cost of acquiring EVs, so the fleet can earn a large enough ROI and do so more rapidly. On the other hand, the need to make long-distance trips can favor PHEV use over BEV use. To achieve the highest ROI, fleets must find the "sweet spot" between vehicle type and requirements for high-use versus long-distance travel.

To further reduce the TCO of EVs, UCONN should consider leasing new EVs through a third-party, private-sector financier. As a tax-exempt entity, UCONN cannot take advantage of federal (up to $7,500) or state tax credits for purchasing EVs. In an increasingly common scenario, public-sector fleets can finance an EV for a set period (e.g., 36 months) and establish a predetermined residual value for the vehicle such that the fleet can easily buy out the vehicle at the end of the lease term. The financier captures the tax credit and passes the savings along to the

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

public-sector fleet. This option can bring the acquisition costs of an EV near cost-parity with a new ICE vehicle, allowing the fleet to capitalize on lower operating costs immediately and reducing potential ROI timeframes to less than 5 years. A comparison of EV costs with and without tax credits is available in Appendix A.

2.5 Greenhouse Gas Emissions

Greenhouse gas (GHG) emissions savings are estimated based on the grid mix of electricity production in Connecticut.[5] This level of granularity provides more accurate estimates of GHG emission savings due to EV use. It is common to use regional averages for such estimates, which aggregate grid mix averages across eight regional entities that constitute the North American Electrical Reliability Corporation. Connecticut is part of the Northeast Power Coordinating Council New England. Electricity production data at a more granular level than the state level (e.g., at the county or municipal level) are not available.

The GHG emissions rate—on a grams per kilowatt-hour basis—from Connecticut's grid mix is among the nation's lowest. With a mix dominated by nuclear power (48%) and natural gas (46.5%), Connecticut is one of the top 10 "cleanest" states for using electricity as a transportation fuel. As such, the transition to EVs in Connecticut can have a greater impact on reducing carbon emissions compared with such a transition in many other states.

2.6 Impacts of Driver Behavior

The driving style and behavior of individual fleet vehicle drivers can have a noticeable impact on fuel consumption and vehicle efficiency. As with an ICE vehicle, the efficiency of an EV—and therefore the overall range of a battery charge—is affected by how drivers operate the vehicle. Aggressive starts and stops, as well as excessive speeding, reduce efficiency. Studies by NREL estimate that improving driver behavior could reduce fuel consumption by 10%, and up to 20% for the most aggressive drivers.[6] Translated to an EV, these same improvements would extend the range of a battery charge significantly. The analysis in this report accounts for these behaviors using an Efficiency score factored into the overall EV Suitability score.[7]

[5] Source: U.S. Environmental Protection Agency (EPA) eGRID 2012 data (https://www.epa.gov/sites/production/files/2015-10/documents/egrid2012_summarytables_0.pdf).

[6] Source: Alternative Fuels Data Center (http://www.afdc.energy.gov/conserve/driving_behavior.html).

[7] The value of this score is heavily influenced by the granularity of telematics data, because aggressive driving behaviors are easier to detect with more granular data. For example, Sawatch Group's ezEV application detects rapid changes in movement using a smartphone's accelerometer in milliseconds, logging and transmitting those instances every 4 seconds. Traditional telematics typically collect and transmit data over longer intervals, usually 1 to 2 minutes, and therefore miss these more rapid changes in movement.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

3 Baseline Fleet Evaluation

This section describes the baseline fleet evaluation.

3.1 UCONN Technical Summary

UCONN purchased its own iPhones—Apple SE models—with minimal data plans to leave in each vehicle and collect data. The phones were attached to the DC outlets for charging purposes and then placed inside the glove box with the charging cord tucked out of the way. In future installations, the smartphones may remain with the driver to evaluate driver behavior in addition to vehicle performance. The ezEV-Fleet mobile app was installed on each phone, and Bluetooth radio beacons were place inside each vehicle. When a vehicle was started, the radio beacon activated, and the software on the phone became active and monitored the vehicle's activity.

From March 7 through May 23, 2017, PTRTelematics captured more than 500 hours of driving activity, 1,500 trips, and 5,600 miles of vehicle telemetry in the monitored UCONN vehicles. During the same period, it detected 422 hard-braking events and 448 hard-acceleration events. During the period of telemetry collection, Sawatch Group monitored the internal consistency of the captured data. End points for each trip were compared to determine if and when any trips were missed by a software or hardware failure. These figures are summarized in Table 3.

Table 3. Sawatch Data Capture Rates for UCONN

Vehicles	Trips	Missed Trips	Miles	Missed Miles	Captured Miles (%)	Captured Trips (%)
5	1,507	42	5,647	183	96.87%	97.04%

The software performed very well in terms of data capture. About 97% of all trips and miles were captured. The most consistent point of data-capture failure was a recurring drive cycle from campus to the airport. On these cycles, the trip to the airport was consistently recorded, but the corresponding return trip of approximately 23 miles was missed. Most missed miles identified in this analysis are explained by the return trip from the airport. Because there were numerous instances in which the return trip from the airport was recorded, and hence the impact that travel has on estimated energy use is known, these miles were not added back into the analysis.[8] During these failure events, the vehicle either idled or sat with the ignition turned to the accessory-on position; possibly the driver was listening to the radio while waiting for passengers to arrive from their incoming flights. After 6 minutes of idling, or accessory use without significant movement, the ezEV software turned itself off. Because the software went into an off state, but the vehicle was running or at least powering the Bluetooth beacon, the software did not recognize the return to campus from the airport as a new trip—instead staying in the off state for the entire return trip. A recent update to the software has corrected this issue for future use. Documenting this issue also served as an opportunity to educate drivers about the negative issues associated with excessive idling while awaiting ride-pickups at the airport.

[8] Roundtrip travel from UCONN to the airport is roughly 70 miles depending on route taken. These missed trips were not added back into the analysis because the impact of this frequent trip is known; the full roundtrip drive could be completed with the generic BEV but would exhaust the battery of a PHEV in every instance.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Overall the PTRTelematics software performed better than expected. A 90% accuracy rate in telemetry capture had been anticipated owing to concerns about cold temperatures causing low phone battery levels and hardware failures. Instead, a 0% hardware failure rate and a software failure rate of about 3% were observed. With the software issue addressed, a software capture rate of about 98% is anticipated in the future, which is on par with traditional hardware-based telematics deployments. This performance suggests that, on a technical level, the PTRTelematics "hardware free" solution can be implemented on a more far-reaching, cost-effective basis and may be a good option to replace traditional telematics deployments for such analytical purposes.

3.2 General Fleet Characteristics

UCONN installed the ezEV smartphone application in five fleet vehicles assigned to the Parking and Transportation Services Department from March 7–May 23, 2017. This period represents real-world driving conditions and is assumed to reflect normal operating characteristics such that these data are typical of annual duty cycles and fleet driving needs of UCONN personnel.

Table 4 shows the use summary for each vehicle covered in this analysis. These vehicles averaged 1,129 miles during the 77-day study data period, which projects to just under 3,400 miles per vehicle annually, accounting for use in an academic campus environment and subject to school vacations and periods of less activity. These vehicles drive relatively few miles compared with vehicles in other public-sector fleets, presenting opportunities and challenges for a transition to EVs. Further, the vehicle miles traveled (VMT) are not evenly distributed across vehicles, ranging from 673 to 2,067 miles during this period. Trips per vehicle ranged from 198 to 533.

Table 4. Individual Vehicle Use, March 7–May 23, 2017

Vehicle ID	Year, Make, Model	Trips	Days in Operation	VMT	Fuel Used (gal)	Avg. MPG	GHGs (lb CO_2e)
9-095	2012 Dodge Grand Caravan	198	30	673	72	6.3	1,411
9-153	2013 Dodge Grand Caravan	228	43	1,181	82	7.1	1,604
9-154	2012 Dodge Grand Caravan	202	28	792	99	7.7	1,931
9-527	2015 Dodge Grand Caravan	346	46	933	121	7.0	2,373
9-528	2015 Dodge Grand Caravan	533	52	2,067	251	7.6	4,925
Totals		**1,507**	**199**	**5,647**	**625**	**9.7**	**12,244**

CO_2e = carbon dioxide equivalent.

This use pattern (high number of trips relative to low total mileage) reflects vehicles that operate frequently within the small geographic extent of the UCONN campus. Three of the five vehicles traveled exclusively on campus during the data-collection period (9-527, 9-528, 9-154), while the other two had multiple days of off-campus travel: 9-095 (9 days off campus) and 9-153 (11 days off campus). In total, 90% of all data collected on the five vehicles were from activity

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

occurring within 1.5 miles of the campus center, reflecting geographically centralized operations. When traveling on campus, the vehicles averaged just 9 miles per hour (MPH), with speeds rarely exceeding 35 MPH. In contrast, the long-distance trips off campus averaged 40 MPH, with large portions spent at highway speeds of 55–75 MPH. Average trip lengths were about 3 miles on campus and 40 miles off campus.

These operational characteristics have a significant impact on EV suitability. Because the economic benefits of EVs are realized in lower operating costs, a fleet commonly would only realize a return on higher upfront EV costs by maximizing lifetime miles driven. Thus, a fleet analysis that only considered operational data aggregated across months or years would not identify these UCONN vehicles as good candidates for replacement with EVs, because the oldest, least-efficient, and highest-VMT vehicles are typically identified as most suitable for replacement. However, this telematics analysis examines more granular data on each vehicle to determine which vehicles are best suited for a transition to EV technology based on the individual vehicle duty-cycles as opposed to vehicle age and the other aforementioned general characteristics.

4 Electric Vehicle Suitability Analysis

This section describes the EV suitability analysis.

4.1 Overview of Electric Vehicle Compatibility

The five study vehicles are Dodge Caravan minivans, largely used to transport students around campus and to/from a few locations throughout the state, such as Bradley International Airport (BDL) and downtown Hartford. Owing to the frequency of local, low-mileage travel, these vehicles' drive cycles fit very well with EV capabilities. However, given the need to carry multiple passengers and sometimes travel longer distances, UCONN requested that comparisons be made with several specific PHEVs: the Ford C-Max Energi, Ford Fusion Energi, and Chrysler Pacifica. In addition, the Ford Focus BEV is included in the analysis (Table 5).

The EV suitability analysis was based on generic BEV operational metrics averaged across four of the BEVs most commonly deployed in government fleets. This generic BEV is assumed to have 23 kWh of usable[9] battery and a charge rate of 4.15 kW using Level 2 EVSE. The analytics focused on the specific vehicles listed in Table 5, which will have a noticeable impact on electric range and thus the potential to transition miles on these vehicles from gasoline to electricity as well as the associated impacts on costs, fuel use, and emissions. Across all vehicles, the most material impact on the ability to transition miles to electricity is the step down to the 7.6 kWh battery in both Ford Energi PHEV models, which reduces electric range. Regardless, based on the EV vehicle battery and charging specifications and the duty cycles of the vehicles examined in this study, all five of the UCONN vehicles analyzed are exceptional candidates for replacement with EVs, even accounting for the long-distance off-campus trips.

Table 5. Model Year 2017 Makes/Models Analyzed for Potential as Replacement Vehicles

Make and Model	Vehicle Type	Base Price[10]	Battery Size (kWh)	Electric Range (mi)	Gasoline Engine Size	Gasoline Range (mi)
Generic BEV	BEV	$33,806	27	102	n/a	n/a
Ford Focus	BEV	$29,170	23	76	n/a	n/a
Ford Fusion Energi	PHEV	$33,120	7.6	20	2.0L I-4 Hybrid	500+
Ford C-Max Energi	PHEV	$27,120	7.6	20	2.0L I-4 Hybrid	500+
Chrysler Pacifica	PHEV	$41,995	16	33	3.6L V6	500+

4.2 Vehicles 9-154, 9-527, and 9-528

Three UCONN vehicles, 9-154, 9-527, and 9-528, traveled exclusively on campus during the data-collection period; 95% of their travel occurred within 1 mile of the campus center, and 100% of their travel occurred within 2.5 miles of the campus center. A summary of each vehicle's EV Suitability scores is presented in Figure 1, Figure 2, and Figure 3.[11] Despite significant differences in terms of the number of trips and miles recorded per vehicle, all three of

[9] See footnote 2.
[10] Base price before tax incentives.
[11] In these and all similar figures, MTCO2e = metric tons of carbon dioxide equivalent.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

these vehicles exhibit remarkably similar EV suitability profiles. The only noticeable negative impact on their overall score is the efficiency ratings in the low 90s.

The Dodge Caravan has an EPA rating of 17 MPG city and 25 MPG highway, but the actual MPG recorded by ezEV-Fleet over the course of this project averaged 8.1 MPG for the three vehicles that traveled exclusively on campus. This is due in large part to a significant amount of low-speed travel with numerous starts, stops, and idling events. These driving patterns suit EVs well, but they are inefficient for ICE vehicles because, for example, an ICE vehicle's MPG is zero when idling. The MPG of these vehicles is 9.7 when they are not idling. The vehicles that travel off campus regularly exhibit a similar pattern, with an average MPG of 6.3 on campus, 7.8 when not idling on campus, and 24.9 when traveling off campus.

The on-campus driving pattern bodes well for the transition to EVs. Idling in UCONN vehicles while on campus consumed more than 100 gallons of gasoline in the 77-day data collection—almost 17% of total fuel use. Operating on electricity would eliminate this fuel consumption almost entirely, because EVs use a negligible amount of battery power when idling.[12] Eliminating idling fuel use would provide UCONN with immediate tangible benefits from transitioning to EVs, producing fuel savings of about $1,000 per year across the five vehicles combined (at a gasoline price of $2.15 per gallon).

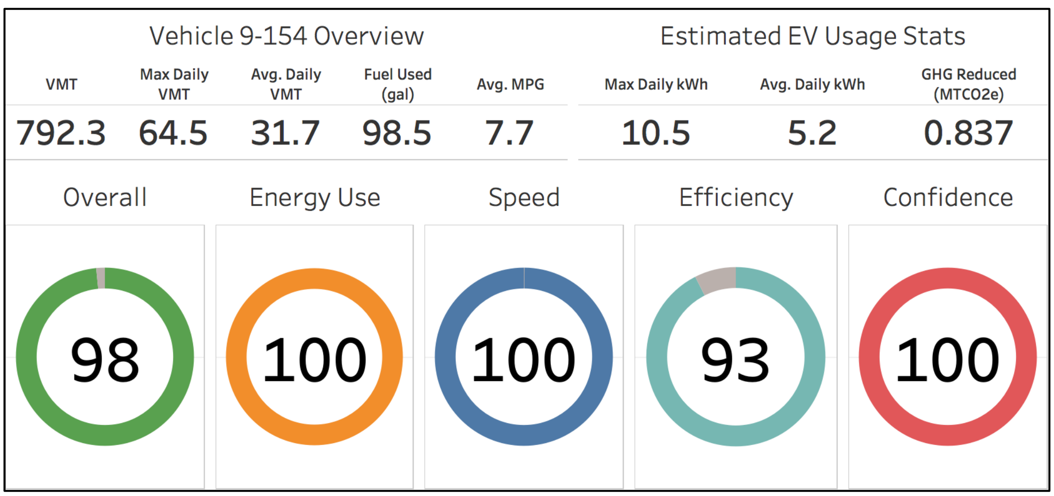

Figure 1. Overview and EV Suitability scores for vehicle 9-154

[12] The electricity used while idling will increase if auxiliary systems—such as the audio/stereo, heater, and air conditioning—are used.

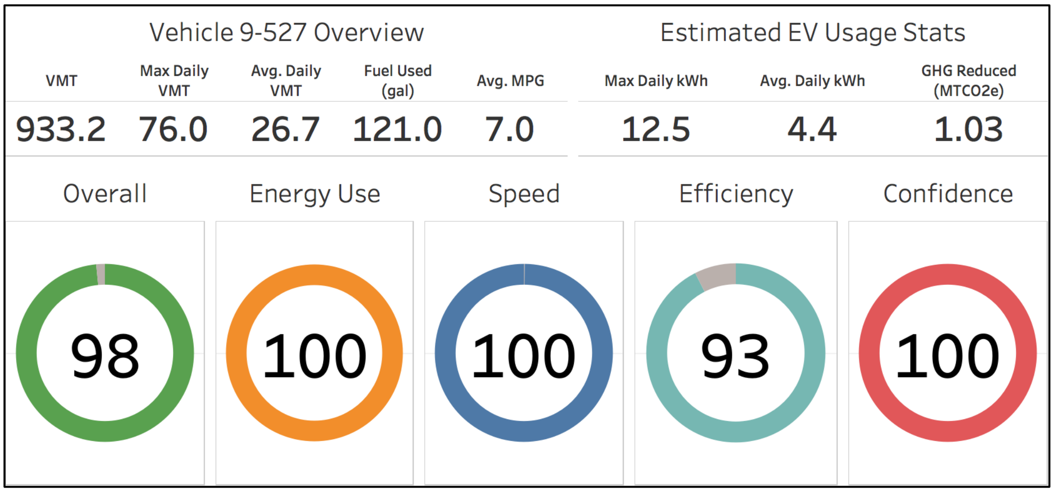

Figure 2. Overview and EV Suitability scores for vehicle 9-527

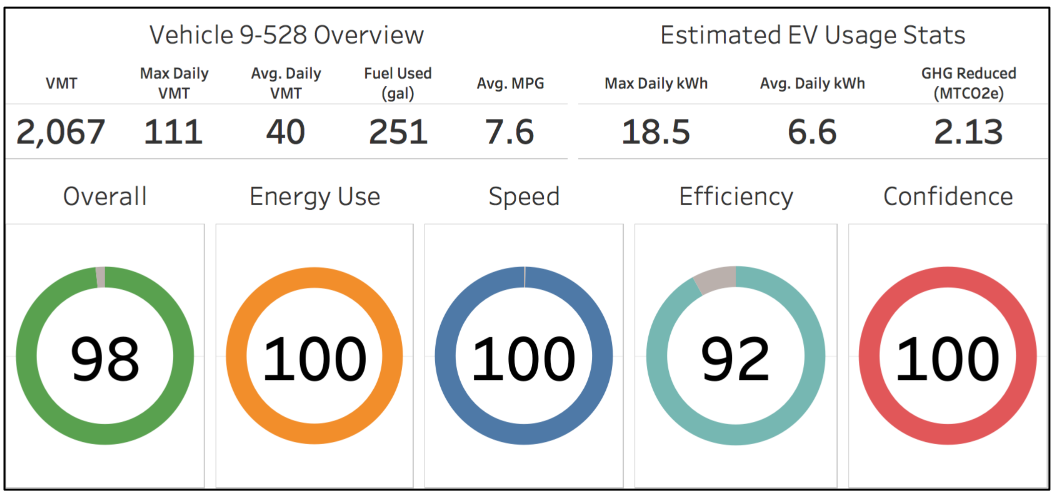

Figure 3. Overview and EV Suitability scores for vehicle 9-528

Vehicle **9-154 (98)** was the least-used vehicle during the data-collection period, with 28 days of use and 202 trips. This vehicle did not capture data during the week of UCONN's spring break, nor during the week after the bulk of its data was collected from March 28 to April 24.

Vehicle **9-527 (98)** exhibited behavior and driving patterns very similar to those of 9-154, although it drove on more days (46) and had many more trips (346). This vehicle operated twice during spring break, but data collection was interrupted from April 6 to May 1, resuming on May 2 and continuing through May 22.

Vehicle **9-528 (98)** showed similar behavior and driving patterns, but also had significantly more activity than the two vehicles noted above, with 52 days of driving and 533 trips. The 2,000 miles recorded were the most of any vehicle in this study. This vehicle also operated during spring break. Data collection for this vehicle ceased on May 5.

Simulated as EVs, these three vehicles averaged an estimated 5.5 kWh per day of driving; even on their most heavily driven days (50+ miles), they rarely exceeded the 16-kWh battery capacity

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

available in the Chrysler Pacifica PHEV. In fact, this only occurred once, on April 25, when 9-528 consumed an estimated 18.5 kWh over 111 miles of driving from 8:30 AM until just after midnight. Still, 9-528 had multiple trips end at Parking Services throughout the day, giving it multiple opportunities to recharge and have adequate battery capacity to meet the 111 miles of driving needs.

Each of these three vehicles is an excellent candidate for replacement with an EV. Even in the Chrysler Pacifica PHEV, each vehicle could operate exclusively on electricity. However, if the vehicles were transitioned to one of the Ford Energi PHEVs, the Energy Use scores drop into the low 60s to the mid 80s, and all three vehicles would need regular access to midday charging to run on electricity all the time. This does not seem problematic given the nearly constant proximity to EVSE on campus; however, the current number of chargers on campus may not be sufficient to ensure these vehicles are fully charged each day. The differences in Energy Use and overall EV Suitability scores are listed in Table 6.

4.3 Vehicles 9-095 and 9-153

The two UCONN vehicles with consistent off-campus travel show different EV Suitability scores overall, especially for the PHEV models of interest to UCONN (Figure 4, Figure 5, and Table 6). When they travel exclusively on campus over the course of a day, they exhibit nearly identical behavior, travel patterns, and metrics to the three vehicles discussed above. Accordingly, transition to electric miles is recommended for that portion of their driving needs. However, the longer-distance trips that occur on about 27% of all travel days will have a noticeable impact on the ability to transition all miles to electricity.

Vehicle **9-095 (96)** recorded 30 days of travel and just short of 200 trips; off-campus travel accounted for 57% of all miles recorded and occurred on 9 of the 30 days of travel. Data collection for this vehicle started on March 7 and ended on April 24; it did not record any miles during spring break. Vehicle **9-153 (92)** recorded 43 days of travel and 228 trips; off-campus travel accounted for 69% of all miles recorded and occurred on 11 of the 43 days of travel. Data collection for this vehicle started on March 11 and ended on May 22; it traveled a small number of miles (5) during spring break and experienced data-collection gaps[13] in April and early May.

[13] These data-collection gaps are believed to be due to either of the following two scenarios: (1) a phone and/or a beacon, which triggers the start of data collection, were physically removed from the vehicle; or (2) the vehicle was inactive for several days. Inactivity could lead the phone, which was installed and remained with the vehicle throughout the study, to lose battery power. However, once the vehicle became operational, the phone would regain power. Despite such issues, the ezEV technology had a 97% data capture rate (see Table 3).

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

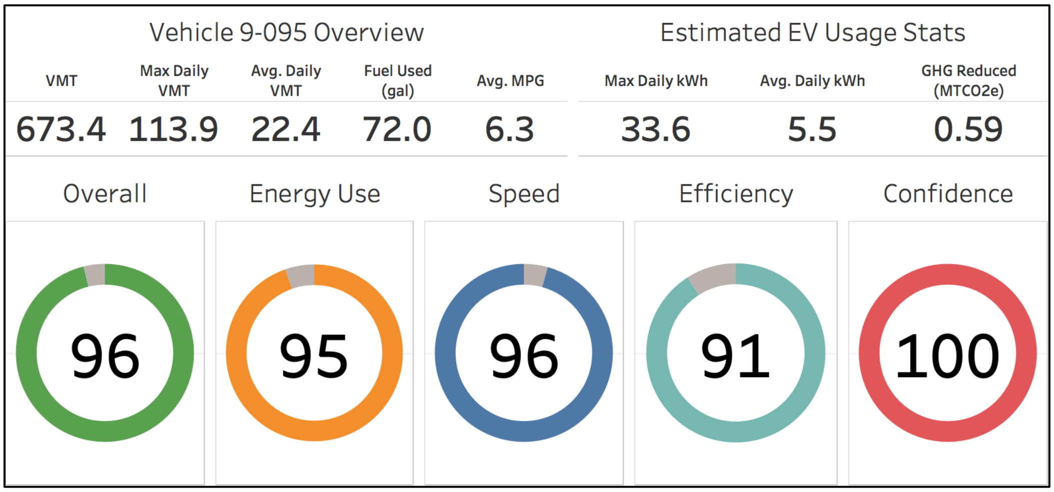

Figure 4. Overview and EV Suitability scores for vehicle 9-095

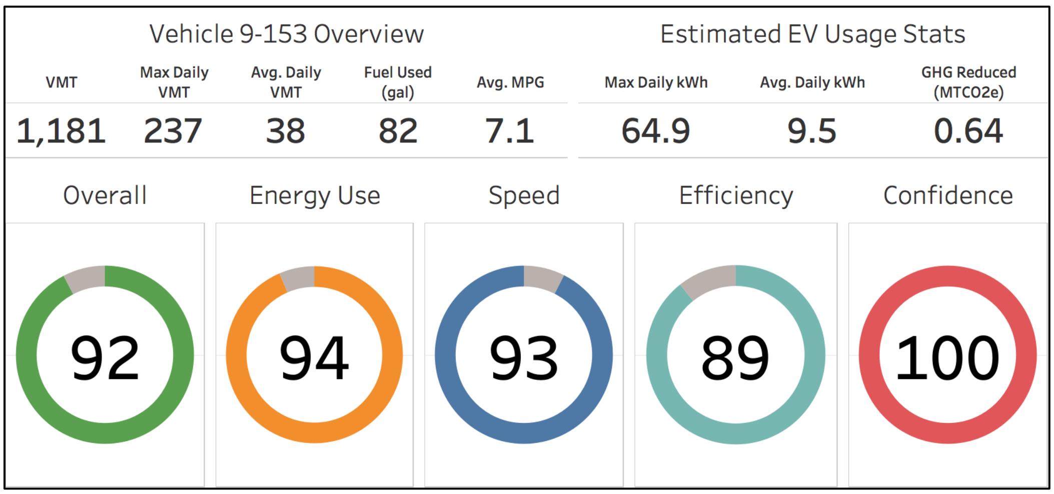

Figure 5. Overview and EV Suitability scores for vehicle 9-153

There are three locations to which vehicles 9-095 and 9-153 traveled regularly on long-distance trips away from the UCONN campus: Willimantic, Hartford, and BDL north of Hartford. The trips to Willimantic by vehicle 9-095 do not have an impact on EV Suitability scores, because they are only about 16 miles roundtrip. There were 2 days on which a trip to Hartford was driven, one each by 9-095 and 9-153. This is a little over 50 miles roundtrip and showed an estimated energy consumption of 15.7 kWh on March 11 in vehicle 9-153. The other trip was on April 5 by vehicle 9-095, but it appears the data capture missed the final 15 miles of the return trip.

Trips to BDL were common; ezEV recorded 20 total trips to the airport and 13 total return trips back to UCONN. Depending on the exact route taken, the roundtrip drive to BDL is about 72–78 miles and requires approximately 18–22 kWh of energy in an EV. The distance, estimated energy consumption, and frequency of this route are the only significant hurdles to UCONN transitioning all the miles on these vehicles to electricity. All of these trips could likely be served by the Ford Focus BEV, assuming sufficient passenger capacity, but they would stress the capacity of the estimated 19.5 kWh of usable energy in that vehicle; drivers would be well served

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

to seek quick charging opportunities (30–60 minutes) at BDL before returning to campus. The Chrysler Pacifica and the Ford Energi PHEVs would need to recharge before returning to UCONN from BDL or use the ICE available in those vehicles.

There is publicly available EVSE at BDL, but the ability of UCONN vehicles to use that charging infrastructure would be subject to (1) its availability on any given day, (2) an acceptable method of payment for UCONN drivers to use it, and (3) the amount of time the vehicles are at BDL. Based on the data collected during this analysis, these vehicles apparently would not have sufficient time at the airport to charge, because they either continue running and drive directly back to campus or spend less than 10 minutes at BDL before returning. Missing data preclude confirming what happened for return trips from BDL on seven instances.

Making an airport trip twice or more in a single day or driving multiple short on-campus trips directly before or after trips to the airport would further constrain the transition to EVs for these vehicles. Such a pattern occurred four times during the study period, once for 9-095 on April 11, twice for 9-153 on March 31, and then again on May 19 when 9-153 made the airport trip three times. On April 11, 9-095 had a little over 1 hour of downtime between trips to BDL. On March 31, 9-153 had almost 3 hours between airport trips. On May 19, 9-153 made its first trip to BDL shortly before 9 AM and returned at 10:40 AM. The next airport trip did not begin until 12:44 PM, but the vehicle made three other short trips, totaling 4.8 miles, around campus in the interim and was back from the second airport trip at 2:40 PM. The final BDL trip was preceded by two short campus trips, totaling 1.4 miles, and left campus at 3:48 PM. It would have been very difficult for this vehicle to have received any meaningful charging between airport trips.

Although such high-use days are rare, occurring on only 3 out of 199 total days of travel recorded during this project, they highlight a scenario that could evoke range anxiety: based on data collected, 3% of travel days required more energy than the base, generic EV referenced in this study can provide in a single charge and had insufficient time for midday charging. One potential solution for UCONN is to schedule BEV routes to avoid multiple daily airport trips by any single BEV. Another solution is to have at least one PHEV to cover days with multiple long-distance trips, so the ICE can enable completion of the drive cycles.

Table 6. Differences in Energy Use and Overall EV Suitability Scores across EVs

Make and Model	Score	9-095	9-153	9-154	9-527	9-528
Generic BEV	Energy Use	94.7	93.5	100	100	100
	Overall	96.1	92.3	98.4	98.4	98.3
Ford Focus BEV	Energy Use	90.0	90.4	100	100	100
	Overall	93.8	91.4	98.4	98.4	98.3
Chrysler Pacifica PHEV	Energy Use	90.0	76.4	100	100	98.1
	Overall	93.1	87.5	98.4	98.4	97.5
Ford Fusion Energi PHEV	Energy Use	76.7	64.5	78.8	84.4	60.6
	Overall	88.1	81.4	90.9	93.7	82.6
Ford C-Max Energi PHEV	Energy Use	76.7	64.5	78.8	84.4	60.6
	Overall	88.1	81.4	90.9	93.7	82.6

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

5 Electric Vehicle Supply Equipment Analysis

All five of the vehicles tracked in this analysis regularly ended their days in the parking lots surrounding the Parking Services building at UCONN, at which there already is one Level 2 EVSE port. Although they did not often stop at the North Garage or South Garage on campus, each of those buildings also has two Level 2 EVSE units that UCONN fleet vehicles could use. Figure 6 shows trip ending locations on campus for each study vehicle.

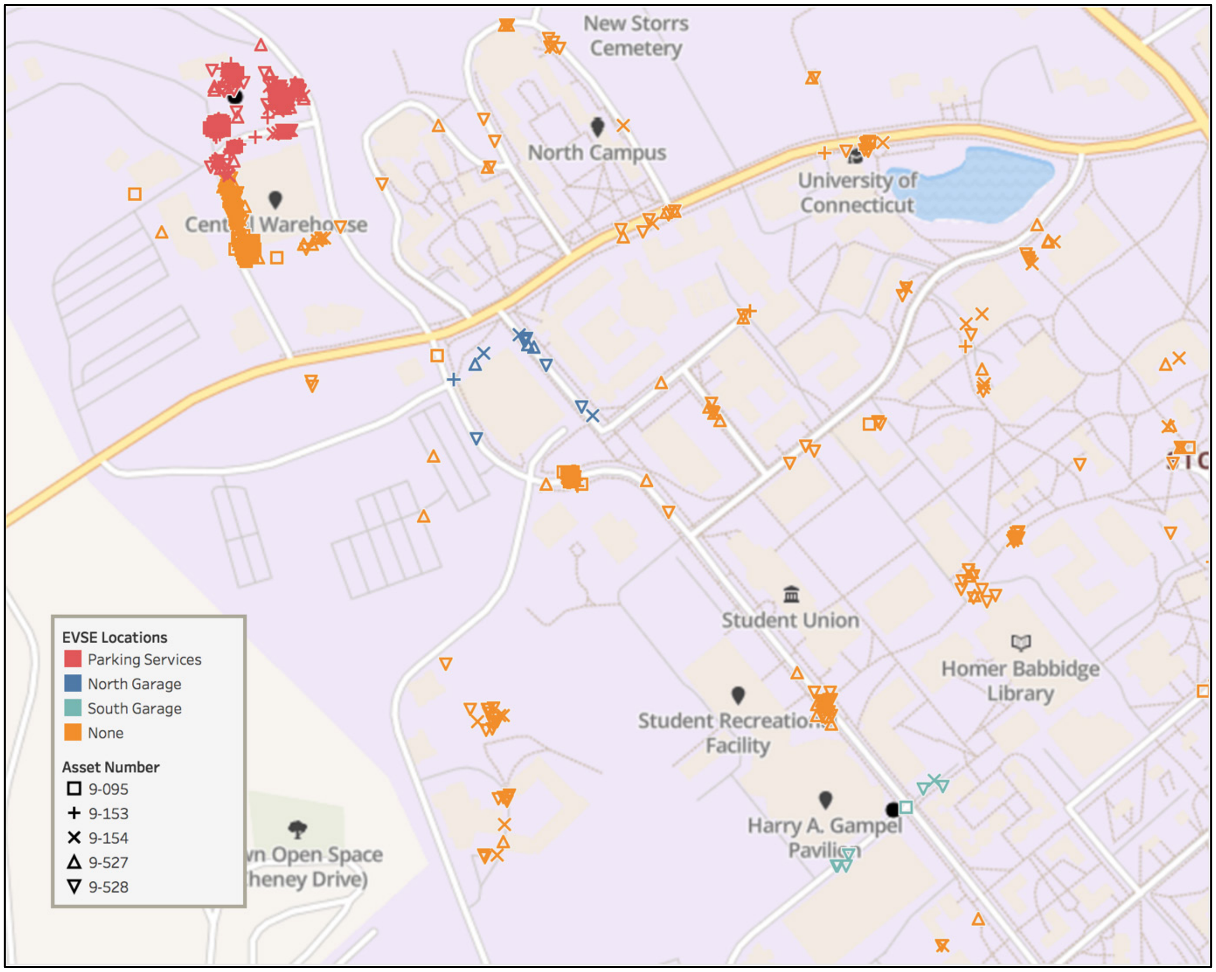

Figure 6. Vehicle trip ending locations relative to existing EVSE on campus

Given the frequency of trips and days that end with a vehicle parking in the lot just northwest of the Parking Services building, UCONN should consider adding at least one more Level 2 EVSE unit to the charging station in that lot. This unit would help support the charging needs of the three vehicles that operated exclusively on campus during this study if those vehicles were EVs. Figure 7 shows the distribution of trips by starting and ending parking location for these three vehicles. Each bar represents an individual trip: the color of the left side of the bar indicates the parking location where the trip began, and the color of the right side of the bar indicates the parking location where the trip ended. The width of each bar corresponds to the length of the trip. The blank spaces represent time parked. Most driving occurred between 8 AM and 10 PM, with the typical day ending at 10 PM for all three vehicles. On most days, these vehicles had about 10 hours to charge overnight, which is sufficient to fully charge all four EV models

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

included in this analysis, even with a Level 1 charger. Although all three vehicles had trips between 10 PM and 1:30 AM, these accounted for less than 1% of all trips, and they should not affect the ability to charge these vehicles fully overnight.

The two vehicles with frequent off-campus travel, 9-095 and 9-153, had slightly different parking patterns than those that traveled exclusively on campus. Both of these vehicles ended most days parking on the southwest corner of the Parking Services building; this is reflected in the cluster of orange in Figure 6. In the more detailed picture of these vehicles' parking habits in Figure 8, this is reflected in the frequency of trips that start and stop at the "other" location. These two vehicles rarely traveled after 10 PM and rarely started driving before 8 AM. In fact, the average start times were close to 10 AM for 9-095 and 12 PM for 9-153; the average ending times for these vehicles each day were 7:45 PM and 4:50 PM, respectively. In the short term, if the vehicles were EVs, both could achieve a complete overnight charge using Level 1 EVSE. In the longer term, UCONN could benefit from adding at least two Level 2 EVSE units on the southwest corner of the Parking Services building. This additional infrastructure could support transitioning the study vehicles to EVs as well as preparing for other EVs UCONN might add.

Although the Parking Services building offers the most frequent and immediate opportunities to use and expand EVSE on the UCONN campus, the five study vehicles also had sporadic trips that stopped or started near the North and South Garages, which each have two Level 2 EVSE units. Any EVs deployed into the UCONN fleet should have access to this infrastructure when necessary, especially prior to the deployment of any additional EVSE.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

6 Conclusion

Fleet operation teams interested in deploying alternative fuel vehicles into their fleets may face obstacles in economics and operational practicality (such as charging and routing) when selecting vehicle technology that can work well for their fleet. Consequently, it is important to fully understand how to overcome these obstacles, and ensure that any changes in technology will meet mission and duty cycle requirements. Telematics data can provide the required certainty, but the telematics hardware and analytics associated with such data can be expensive.

This pilot project sought to demonstrate the efficacy and efficiency of an inexpensive, smartphone-based telematics system and associated approach to analytics that both collects and assesses the data necessary to afford a fleet the certainty needed to convert whole portions of its fleet from conventional vehicles to electric drive vehicles. Specifically, the UCONN fleet used the smartphone-based ezEV-Fleet to assess five vehicles and their duty cycles to determine their suitability for conversion to electric drive vehicles, and any need for additional associated EVSE. This study determined that three of the five UCONN vehicles operating exclusively on campus are very well suited for replacement with an EV given their nearly constant proximity to EVSE and small geographic footprint. The two other vehicles included frequent long-distance trips and highway driving, which can tax the state of charge in a vehicle’s battery, thus requiring some midday charging away from campus.

Across all five vehicles, an important factor for UCONN to consider is the use of a minivan-sized vehicle (comparable to the vehicles analyzed) for its passenger-carrying capacity versus small, sedan-sized EVs. Only one minivan option is available—the Chrysler Pacifica PHEV—but multiple options are available for smaller vehicles. These vehicles would be well served by the existing EVSE available on campus, although inserting more than five EVs into the fleet may require additional investments in EVSE.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Figure 7. Distribution of parking locations by trip for vehicles with on-campus travel only

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

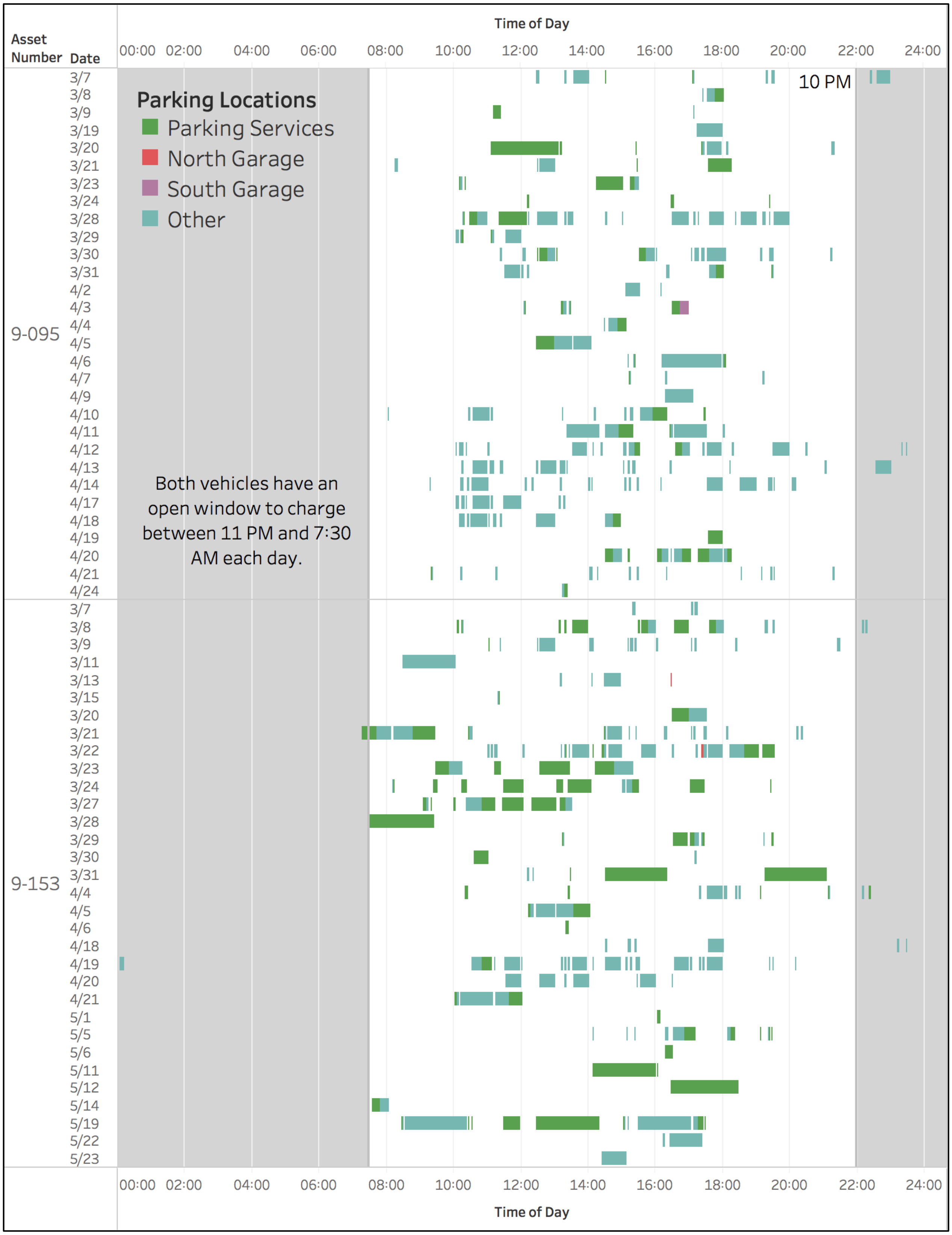

Figure 8. Distribution of parking locations by trip for vehicles with off-campus travel

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Appendix A: General Cost Comparison of Electric Vehicle Options Available to the University of Connecticut[a]

	Make/Model	Ford Focus	Ford Fusion Energi	Ford C-Max Energi	Chrysler Pacifica
	Model Year	**2017**	**2017**	**2017**	**2107**
	Category	BEV	PHEV	PHEV	PHEV
	Battery Size	23 kWh	7.6 kWh	7.6 kWh	16 kWh
	Manufacturer's Suggested Retail Price	$29,170	$33,120	$27,120	$41,995
	Price After Tax Federal Credit[b]	$21,670	$29,120	$23,120	$34,495
	All-Electric Range	76 miles	20 miles	20 miles	33 miles
	Efficiency Ratings (city/hwy)	3.1/3.4 mi/kWh	43/41 MPG 3.3/3.7 mi/kWh	43/41 MPG 3.3/3.7 mi/kWh	32/33 MPG 3.8/4.3 mi/kWh
	Charge Time (Level 2 – 240 V)	4 hours	2.5 hours	2.5 hours	3.5 hours
Gas Price: $2.20/gal	**Est. Annual Operating Cost[c, d]**	$3,117	$3,750	$3,750	$4,711
	Cost per mile	$0.40	$0.46	$0.44	$0.58
	Cost per mile w/tax credit[e]	$0.35	$0.44	$0.42	$0.54
Gas Price: $3.50/gal	**Est. Annual Operating Cost**	$3,117	$4,270	$4,270	$5,211
	Cost per mile	$0.40	$0.50	$0.48	$0.62
	Cost per mile w/tax credit	$0.35	$0.47	$0.45	$0.57

[a] Source: http://www.afdc.energy.gov/calc/

[b] In 2017, federal tax credits are available for EV purchases and are calculated based on the size of the electric engine. For the PHEVs with smaller battery capacities, the available credit is about $4,000, whereas the available credit for the largest batteries is $7,500. For UCONN to access these savings, it would need to lease the vehicles through a private financier, who would then pass the saving on to the state.

[c] Operating costs include fuel, tires, maintenance, registration, and insurance.

[d] PHEV cost estimates assume an approximate split of 50% miles driven on electricity and 50% driven on gasoline. They would trend upward with increased use of gasoline and downward with greater number of miles driven on electricity.

[e] This scenario assumes that the state could monetize the full value of the available tax credit through a financier.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.