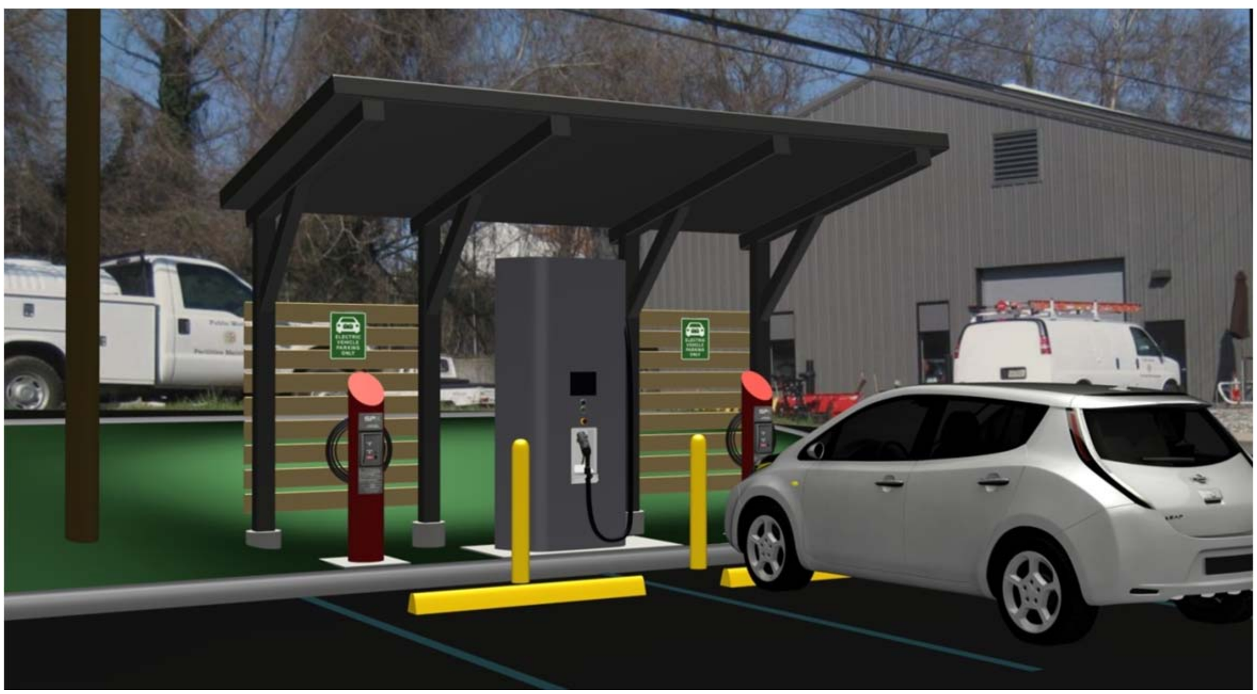
Final Scientific/Technical Report

DOE Award Number: DE-EE0003663

Award Recipient: City of Charlottesville, Virginia

Project Title: Fast Charging Electric Vehicle Research & Development Project

Principal Investigator: Michael Heny



Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number(s) DE-EE0003663."

This project was conducted with the support of Aker Wade Power Technologies which has given permission to the City of Charlottesville to include their Engineering Report as an attachment to this Final Technical Report.

Executive Summary

The research and development project supported the engineering, design and implementation of on-road Electric Vehicle ("*EV*") charging technologies. It included development of potential solutions for DC fast chargers ("*DCFC*") capable of converting high voltage AC power to the DC power required by EVs. Additional development evaluated solutions related to the packaging of power electronic components and enclosure design, as well as for the design and evaluation of EV charging stations. Research compared different charging technologies to identify optimum applications in a municipal fleet.

This project collected EV usage data and generated a report demonstrating that EVs, when supported by adequate charging infrastructure, are capable of replacing traditional internal combustion vehicles in many municipal applications.

The project's period of performance has demonstrated various methods of incorporating EVs into a municipal environment, and has identified three general categories for EV applications:

- **Short Commute:** Defined as EVs performing in limited duration, routine commutes.
- **Long Commute**: Defined as tasks that require EVs to operate in longer daily mileage patterns.
- **Critical Needs**: Defined as the need for EVs to be ready at every moment for indefinite periods.

Together, the City of Charlottesville, VA (the "*City*") and Aker Wade Power Technologies, LLC ("*Aker Wade*") concluded that the EV has a viable position in many municipal fleets but with limited recommendation for use in Critical Needs applications such as Police fleets.

The report also documented that, compared to internal combustion vehicles, BEVs have lower vehicle-related greenhouse gas ("*GHG*") emissions and contribute to a reduction of air pollution in urban areas. The enhanced integration of EVs in a municipal fleet can result in reduced demand for imported oil and reduced municipal operating costs.

The conclusions indicated in the project's Engineering Report (see Attachment A) are intended to assist future implementation of electric vehicle technology. They are based on the cited research and on the empirical data collected and presented. The report is not expected to represent the entire operating conditions of any of the equipment under consideration within this project, and tested equipment may operate differently under other conditions.

Comparison of Accomplishments

Per the Statement of Project Objectives (Amendment 006, dated Aug 19, 2013), this project provided funding for:

- Engineering, design and implementation of Electric Vehicle (EV) charging technologies
- Three electric vehicles (EVs)
- Design and construction of charging infrastructure

The project period of performance was 09/14/2010 through 03/13/14. During that time, the following accomplishments were realized:

- Overall project engineering and planning
- Development of a design concept for a EV DCFC
- Procurement of three commercially available EVs
- Design and construction of two EV charging stations that included both Level II AC Chargers and DCFCs
    - Level II AC Chargers are compatible with the SAE J1772 standard
    - DC Fast Chargers are compatible with the CHAdeMO V0.9 fast charging protocol
- Completion of an Engineering Report (see Attachment A) that details the findings of data, studies, and analyses such as:
    - Charging data to study usage patterns
    - Charging versus peak load conflicts
    - Suitability of fast charge vehicles for various applications
    - Design and performance of the charger and station

Summary of Project Activities

Overview

This research and development project (the "*Project*") was intended to demonstrate zero emissions vehicle technology to local governments and illustrate applications in urban environments. The Project originally involved the engineering, design and implementation of advanced DC fast charge ("*DCFC*") technology to support three electric vehicles ("*EVs"*). As the Project progressed, it was amended to include Level II AC chargers and DCFCs with alternate outputs, and provided additional data collection and technology evaluation opportunities.

Funding for this congressionally-directed project was awarded to the City of Charlottesville, Virginia ("*City*") on September 14, 2010 through the U.S. Department of Energy / National Energy Technology Laboratory ("*DOE/NETL*") as award number DE-EE0003663. The total Project cost was estimated as $634, 041; $500,000 (78.86%) was to be provided by the DOE and $134,041 (21.14%) was to be provided by the Recipient. The Recipient's technical partner was Aker Wade Power Technologies, a local manufacturer of DCFCs used to power off-road industrial forklift fleets.

The primary risk anticipated with the Project was the rapid evolution of key technical specifications and commercial requirements for DCFCs combined with international market forces at play in the demand and production of EVs. Significant changes to these specifications, requirements and market forces during the Project resulted in two schedule modifications and necessitated amending the Project scope.

The original period of performance was one year. In order to adapt to the technical, commercial and market forces, no-cost extensions were granted and the performance period was extended to 3.5 years.

Original Project

Beginning with the award of the Project in September 2010, Aker Wade began development of a DCFC capable of charging on-road EVs. In parallel, Aker Wade monitored competitive activity and market demand for EV DCFC technology. This latter task was essential if the Project was to result in a design for a commercially viable product.

Engineering activities began with the conversion of Aker Wade's existing Integrated Gate Bipolar Transistor ("*IGBT*") industrial forklift fast charger design to meet the unique needs of EVs. This included upgrading the components to operate in outdoor conditions, modifying the power electronics to meet the requirements of EVs and developing software and firmware that would allow the charger to communicate with the most widely available charging protocol at the time, the Japanese "CHAdeMO" standard. Within the first year, three Nissan Leafs were acquired by the City and a prototype DCFC had been designed and power delivery, vehicle compatibility and environmental tests had begun.

During this time, Aker Wade was tracking developments in the EV DCFC market, using three metrics to track competitive activity and end customer preference: Price, Power and Protocol:

- **Price:** Refers to the average list price of a DCFC. In 2010, DCFCs typically cost $50,000 – a result of low volume and limited availability in the U.S.
- **Power:** The output level of the DCFC. Early EV DCFCs most often were configured as 50kW units. The 50kW rating originated during feasibility studies performed during the late 1990's.
- **Protocol:** The means by which the DCFC communicated with the EV. In 2010, the only protocol

offered by a global auto manufacturer was CHAdeMO. CHAdeMO was developed in Japan, and most widely available on the Nissan Leaf EV.

Market Activities

Within months of the Project's start, the metrics that Aker Wade used to track the market for DCFCs were showing significant changes.

In October of 2011, Nissan, the manufacturer of the Leaf, announced a DCFC with a starting price as low as $13,000. In early 2012, two manufacturers – Fuji and ABB – announced DCFCs with power output ratings between 20-30kW. These were offered to help reduce installation and operating costs of DCFCs.

Concurrently, the Society of Automotive Engineers ("*SAE*") announced development of a new global standard for an EV fast charge communication protocol. This announcement provoked an industry rivalry between supporters of the existing CHAdeMO standard and supporters of the SAE protocol. Unsure of which protocol would become the standard, many EV DCFC infrastructure projects were placed on hold, further constraining demand for DCFCs.

Extension One

Based on these disruptions in price, power and protocol, Aker Wade concluded that the IGBT design it had started developing in 2010 would not yield a commercially viable product.

- At a price of ~$50,000, it would not be able to compete with the Nissan offering
- Although output could be de-rated to 20-30kW, there would be no attendant reduction in material cost or installation cost.
- Because the SAE had not completed the specification for their charge protocol, there was no way to know if the design intended for the City could be adapted to a different protocol.

On March 23rd, 2012, Aker Wade informed the City of the commercial challenges facing the IGBT design. In order to achieve the Project goals of demonstrating and evaluating local government use of EVs, Aker Wade proposed a project modification that would allow the City to begin using its three Nissan Leafs while taking advantage of an opportunity that had recently presented itself to Aker Wade.

In the fall of 2011, Aker Wade was approached by an automotive supplier regarding the development of a DCFC designed specifically to meet the needs of auto dealer service teams. After completing a feasibility study with Aker Wade, this supplier was prepared to fund the conversion of Aker Wade's then-new high frequency ("*HF*") industrial forklift DCFC to a design suitable for on-road EVs.

Aker Wade's HF industrial DCFC architecture differed significantly from the IGBT design. Announced at a material handling industry trade show in early 2011 and launched in the summer of 2012, the HF industrial forklift DCFC featured new power conversion electronics and full digital controls. This allowed the unit to be significantly smaller and lighter, reducing material costs and tooling expenses.

The unit required by the auto supplier was consistent with the market trends for EV DCFCs that Aker Wade had been tracking. It called for a maximum power output of 30kW, a price point that would enable it to compete with the Nissan model and an enclosure that would reduce installation cost. It would also be engineered to incorporate the new SAE protocol.

As a means of successfully completing DE-0003663, Aker Wade proposed the Project be extended to allow Aker Wade to complete the HF DCFC for the auto supplier and use a version to satisfy the Project.

As part of the extension proposal, and to allow the City to begin use of the Nissan Leaf EVs, Aker Wade was prepared to acquire and install three readily available Level II AC chargers. This would enable a direct comparison between DCFC, which is inherently more expensive to purchase, install and operate, and Level II AC, which costs significantly less to purchase, install and use but charges EVs at much slower rates than DCFC.

In October of 2012, Aker Wade was informed that the extension was approved. Aker Wade immediately sourced three Level II AC chargers and worked with a contractor to modify the charge stations into which they would be installed.

During this time, the Aker Wade engineering team was expanded to include a specialist in high frequency power electronics. With the supplier's engineering team, a detailed Statement of Work ("*SOW*") was created that included a timeline of the steps required to design the power electronics, receive prototype components and assemble and test the first prototypes.

Extension Two

On November 27th, 2012, the auto supplier informed Aker Wade that it was cancelling the HF DCFC design. This was due to lower than expected EV sales, delayed EV launches and the loss of a project with an auto manufacturer.

With the loss of project funding for the HF DCFC design and the need to provide the City with a DCFC, Aker Wade considered completing the original IGBT design. To determine the cost of completing the unit, Aker Wade hired Underwriters Laboratory ("*UL*") to evaluate the design, allowing Aker Wade to create a budget and timeline. After analyzing the expense required for UL certification combined with further deterioration in the EV market in general and in the market for DCFC in particular, Aker Wade concluded that completing the IGBT design would result in a commercially non-viable product and negatively impact Aker Wade's ongoing industrial forklift fast charger business.

On March 29th, 2013, Aker Wade informed the City that it could not justify the expenses associated with completing the IGBT design. After reviewing the forces that led to this conclusion, Aker Wade presented a proposal for an extension that would allow the Project to be successful and add another level of data. In the proposal, Aker Wade would acquire two commercially available DCFCs, installing one at each City location. Additionally, Aker Wade recommended that one of the DCFCs be de-rated to a lower output power level, adding another dimension to the Project's data collection and final report.

On Sept 19th, The City informed Aker Wade that the proposal was accepted. Aker Wade ordered the DCFCs and began designing modifications to concrete pads poured for the charge stations.

On Dec 29th, 2013, Aker Wade installed the first DCFC and charged one of the City's Nissan Leafs. In early January, the second site was completed and all Leaf EVs were successfully fast charged.

Project Conclusion

In January, 2014, Aker Wade began the final Phase of the project, tracking the City EV usage and energy consumption. This included the detailed analysis of three EVs in different applications. The results are documented in the report "*Fast Charging Electric Vehicle Research and Development Project"* which is provided as Attachment A.

Summary and Results
This Project successfully demonstrated that zero emission vehicle technology has a place in local government fleets.

The Project demonstrated various methods of incorporating EVs into a municipal environment, and has identified three general categories for municipal EV applications and the required charging strategy:

- **Short Commute:** Defined as EVs performing in limited duration, routine commutes.
- **Long Commute**: Defined as tasks that require EVs to operate in longer daily mileage patterns.
- **Critical Needs**: Defined as the need for EVs to be ready at every moment for indefinite periods.

Together, the City and Aker Wade concluded that the EV has a viable position in municipal fleets but may not be ideal for use in critical need applications such as police fleets.

Additionally, due to the approved amendments to the Project, the team was able to deliver on three of the key success criteria outlined in Section 6 of "*Grant Administration Procedures Revised PMP*":

- "The reliability of the battery electric vehicles and the effectiveness, appropriateness, and reliability of the charging technology, specifically the DC fast charge technology."
- "The ability to rely on EVs as a substitute to traditional combustion or hybrid vehicle technologies along with low maintenance requirements of the charging systems will be important elements for a municipality to understand."
- "The data related to fossil fuel saving and associate greenhouse gas emission reduction are also important criteria to determine this fleet strategy as part of a local climate protection program."

As it relates to the fourth success criteria ("*The project aims to produce a commercially viable fast charger that will contribute to the progress of this rapidly developing technology area for the United States*."), the Project produced value in that it was able to unambiguously identify the requirements for a commercially viable fast charger.

Perhaps more impotantly, the expansion of charging options created additional data collection opportunities for the Project, and allowed the Project to identify a range of charging technology that shows compatibility with the municipal EV applications identified above:

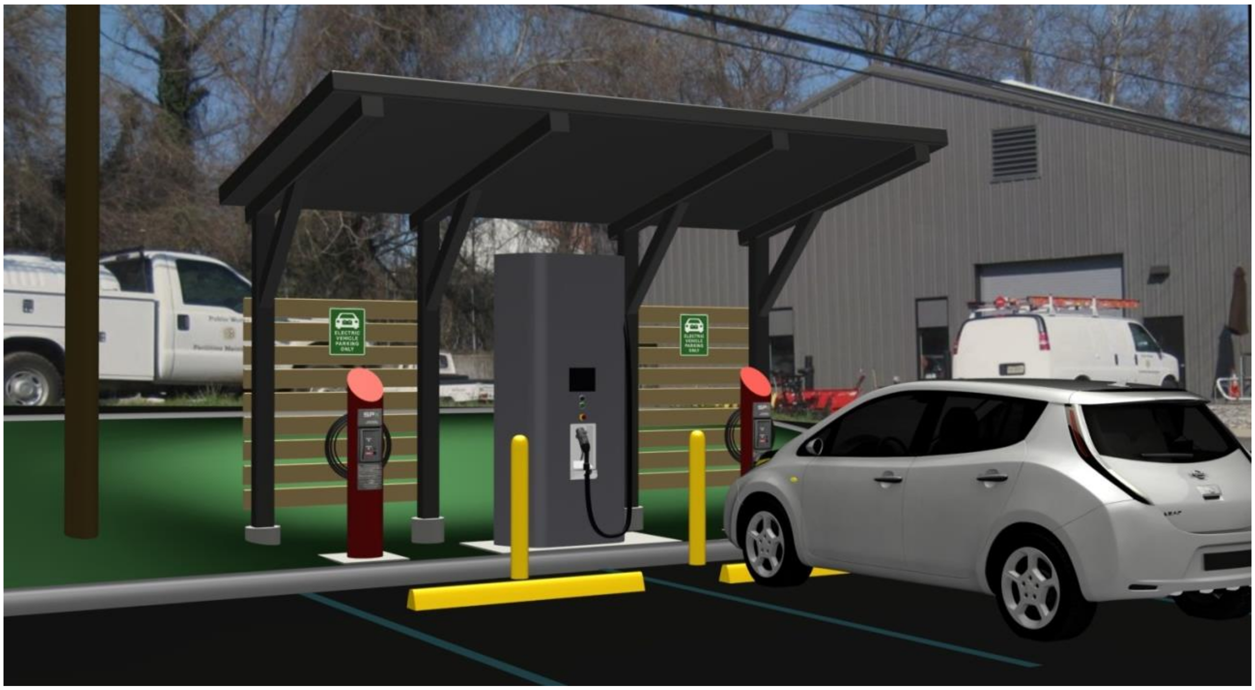
- **Short Commute**
  - AC chargers with high amperage capacity
- **Long Commute**
  - AC chargers with medium to large amperage capacity
  - DCFC with 25kW power
- **Critical Needs**
  - AC chargers with large amperage capacity
  - DCFC with 44kW, 50kW or higher power

In the event that other muncipalities are considering the addition of EVs to their fleet operations, the results of DE 003663, specifically the Engineering Report, provide valuable reference material, data and insights for future project planners and fleet operators to consider.

Products and Technology Transfer Activities

This project did not result in the development of products and did not involve technology transfer activities.

Attachment A – Engineering Report



Engineering Report

For the City of Charlottesville, Virginia

Fast Charging Electric Vehicle Research and Development Project

DOE Award Number: DE-EE0003663

Prepared by

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May 2014

Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number(s) DE-EE0003663."

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Glossary

Absorption	The period of top-off battery recharge at constant voltage with declining current, yielding declining battery recharge per unit of time
AC	Acronym for **A**lternating **C**urrent This type of electric charge flow changes direction periodically, usually sinusoidal. It also defines the *voltage* type, such as that used in the Electric Power Distribution Network, which varies with time as a periodic sinusoidal voltage.
Bulk	The period of battery recharge allowing maximum constant current with rising voltage, accomplishing steady and large battery recharge per unit of time
CAN	Acronym for **C**ontroller **A**rea **N**etwork data communications link
City	Abbreviated form for the City of Charlottesville, Virginia
Company	Abbreviated form for the company Aker Wade Power Technologies, LLC
DC	Acronym for **D**irect **C**urrent This type of electric charge flow is in one direction. It also defines the type of *voltage* that is constant, such as from the terminals of a battery, and used inside most equipment as the power source for the circuitry.
DCFC	Acronym for **DC** **F**ast **C**harger (e.g. the Nissan NSQC442)
ENV	Acronym for **Env**ironmental Sustainability Division project vehicle
EV	Acronym for **E**lectric **V**ehicle
EVSE	Acronym for **E**lectric **V**ehicle **S**ervice **E**quipment (EV Charger)
FM	Acronym for **F**acilities **M**aintenance Division project vehicle
Leaf	2012 Nissan Leaf Electric Vehicle
Level I AC	Electric Vehicle Industry term for a 120 Volt AC charger
Level II AC	Electric Vehicle Industry term for a 240 Volt AC charger
Li-ion	Abbreviation for **Li**thium **ion** battery
MTE	Acronym for **M**iles **t**o **E**mpty
OBD	Acronym for **O**n **B**oard **D**iagnostics vehicle data port
PD	Acronym for **P**olice **D**epartment Traffic Unit project vehicle
SOC	Acronym for **S**tate **o**f **C**harge, an EV term for percentage of full battery capacity

Executive Summary

Project Overview

This Project, the Department of Energy's grant number DE-EE0003663, provided the opportunity for the City of Charlottesville, Virginia ("City") to evaluate an additional strategy for reducing fuel consumption and associated emissions of a municipal fleet in an urban environment. Among the Project's objectives:

"…This project will collect BEV usage data and provide reports capable of demonstrating that BEVs, when supported by adequate charging infrastructure, are capable of supporting municipal fleets in urban environments. It will show that BEVs are capable of replacing traditional internal combustion (IC) vehicles in many municipal applications. Converting IC vehicles to BEVs will decrease vehicle-related greenhouse gas emissions, contribute to a reduction of air pollution in urban areas, reduce demand for imported oil, and reduce the costs associated with operating a municipal fleet."

During this project, the City acquired three EVs. Aker Wade Power Technologies, LLC ("Aker Wade") provided services allowing the City to install and operate EV charging infrastructure. Additionally, Aker Wade recorded Project milestones and data in this engineering report. Per the Statement of Project Objectives (SOPO), this report details the findings of data, studies, and analyses such as:

- Charging data to study usage patterns
- Charging versus peak load conflicts
- Suitability of fast charge vehicles for various applications
- Design and performance of the charger and station

The project's period of performance has demonstrated various methods of incorporating EVs into a municipal environment, and has identified three general categories for EV applications:

- **Short Commute:** Defined as EVs performing in limited duration, routine commutes.
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Together, the City and Aker Wade concluded that the EV has a viable position in many municipal fleets but with limited recommendation for use in critical demand fleets such as Police fleets.

The conclusions indicated in this report are intended to assist future implementation of electric vehicle technology. They are based on the cited research and on the empirical data collected and presented.

This report is not expected to represent the entire operating conditions of any of the equipment under consideration within this project, and tested equipment may operate differently under other conditions.

Infrastructure Planning

The vehicle charging infrastructure was designed to support the fleet efficiently with considerations for energy efficiency, availability, and convenience.

The City electric vehicles were purposed in three separate divisions which offered diverse and broad municipality use cases.

Business Considerations

The City of Charlottesville has three 2012 Nissan Leaf EVs in its fleet. The vehicles were assigned to the following divisions and integrated into their regular rotation and use cases:

DEPARTMENT	DIVISION
City Police Department	Traffic Unit
Department of Public Works	Facilities Maintenance Division
Department of Public Works	Environmental Sustainability Division

The vehicle charging infrastructure was designed to evaluate the following issues for each division's operational model:

- What power level of charger is appropriate for a public fleet of this size?
- What frequency of charging is needed?
- How do different use cases affect the charger selection?
- Based on this evaluation, what number of and type of chargers are needed?

Police Department's Traffic Unit

The Police Department's Traffic Unit uses its vehicles to patrol the roads to enforce parking and driving regulations, to service unique traffic control situations such as special events or road closures, and to provide backup to other officers as needed.

Facilities Maintenance Division

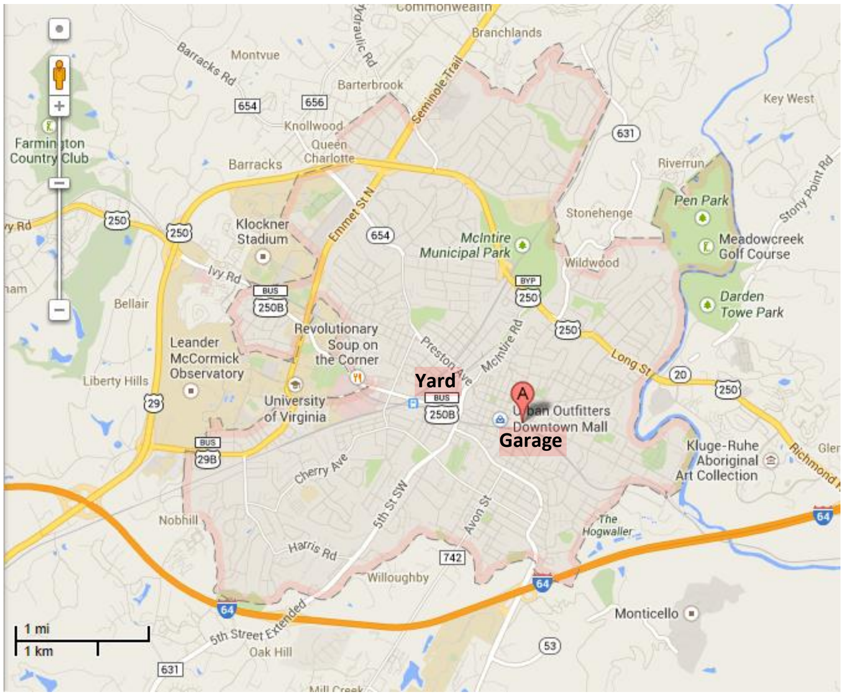
The Facilities Maintenance Division uses its vehicles for site visits to City-maintained properties, to meet with contractors, and to visit various supply shops and vendors in the area. The Leaf was used daily by three drivers for these short trips around the City.

Environmental Sustainability Division

The Environmental Sustainability Division uses its vehicles for site visits and off-site meetings. The Leaf was used at least four times per week for these short trips by four drivers.

Locality Considerations

The geographical locations of the chargers are shown on this map view with the City boundaries encompassing 10.3 square miles.



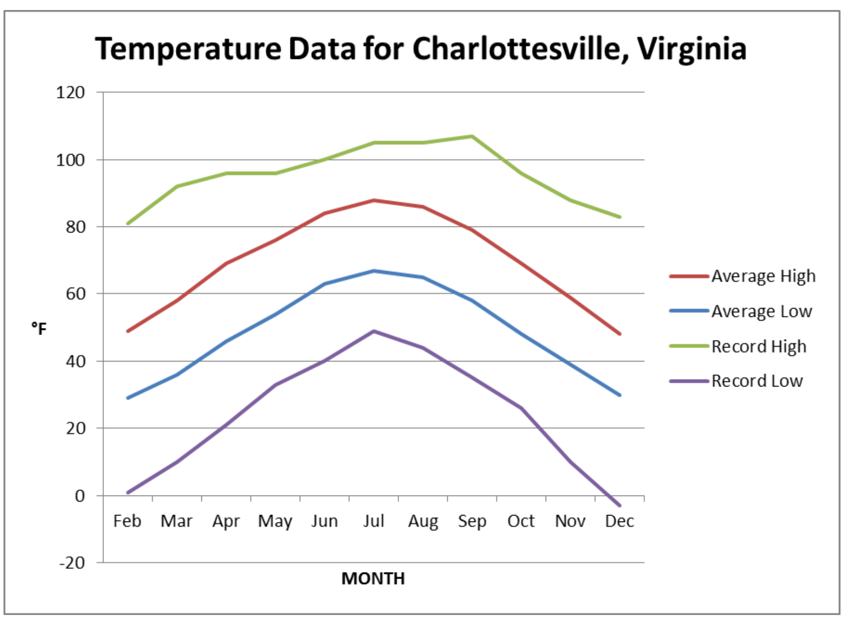
The City Public Works Yard and Police Garage do not have public access.

The Public Works Yard is gated, but is accessible for all project personnel during operating hours.

The Police Garage is accessible 24/7 for all project personnel.

Both of the sites had 480 Volts three phase AC power available.

As shown[1] below, the locality's climate is mostly suitable for the operation of the vehicles and chargers.



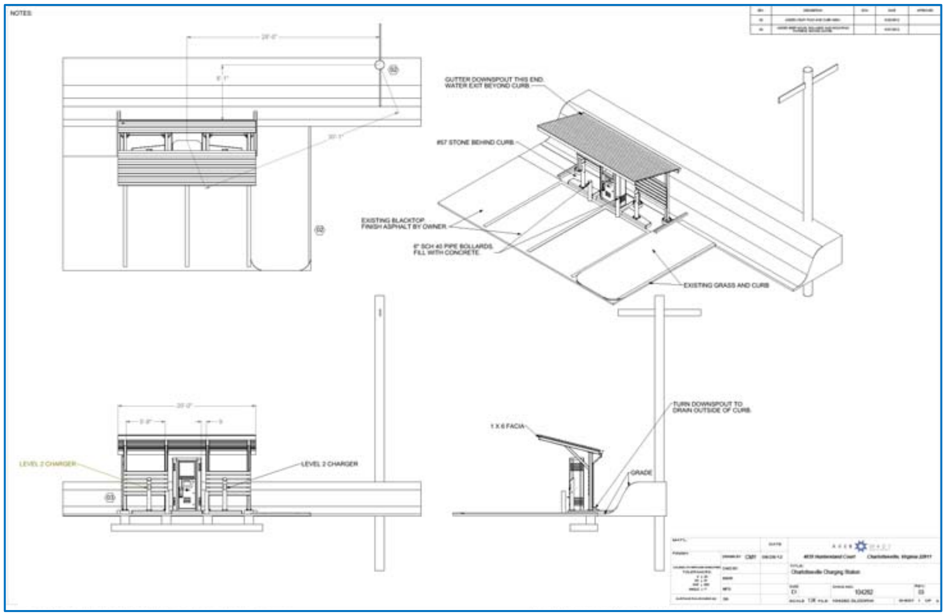
However, there have been recent exceptions with temperatures falling toward 0°F, in line with record lows.

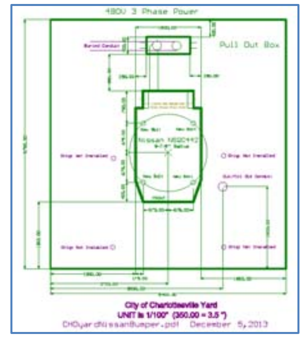
In critical use cases where a DC Fast Charger ("*DCFC*") must keep a fleet charged at all times, then the choice of equipment must consider record low temperatures.

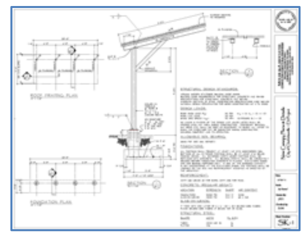
Maintenance personnel were instructed to turn off a DCFC when the ambient temperature fell below +14°F.

[1] See http://www.weather.com/weather/wxclimatology/monthly/graph/22903

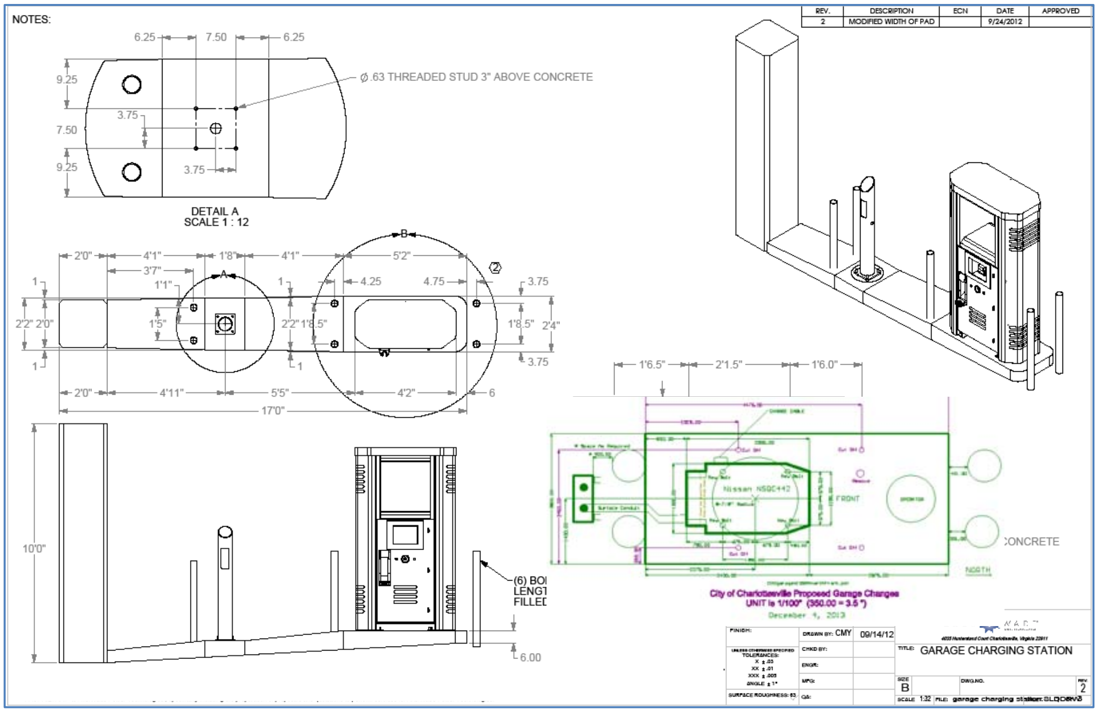
The City Yard charger station site is shown below starting with the design drawings followed by the installation photograph. This design provided a weather protective awning, a curb, protective bollards, two Level II AC chargers, and one DCFC.







The City Police Garage installation site involved the pouring of a curb, installation of bollards, and provisioning one Level II AC charger and one DCFC.



Battery Charger Considerations

The vehicle charging infrastructure provided off peak, near term, and immediate charging needs for fleet readiness with a combination of 3.84kW AC chargers and 44kW DCFCs.

DC Fast Charger

Two Nissan DCFCs (model NSQC442) were installed in December 2013, and project personnel were fully trained in January 2014. These chargers were installed to provide the following needs:

PROBLEM	BENEFIT FROM RESOLUTION
Exhausted battery, fast recovery charge	Deep depletion readiness
En Route and pro-re-nata fast recharge	Minimize down time
Unexpected near term journey	Quick response readiness

The units were capable of delivering 44kW to the vehicle, at limits of 120 Amperes and 500 Volts DC from 480 Volts three phase AC power, at about 90% efficiency, using the Leaf compatible CHAdeMO protocol.

The City Yard DCFC was operated at 25kW reduced power to study the effects of this lower power on the small and mid-sized fleets.

The Police Garage DCFC was operated at 44kW full power to keep the vehicle in a state of readiness.

Regardless of the capabilities of the DCFC and its power settings, the Leaf vehicle controls the charge process through data communications over a Controller Area Network (CAN)[2] data link with the DCFC. The DCFC reports its capabilities and then follows the voltage and charge current targets sent by the vehicle, allowing the attached Leaf (or other vehicle) to charge its battery per its own set of rules and circumstances.

With these capabilities, the units were estimated to bulk charge a Leaf 24kWh battery from 20% to 80% State of Charge (SOC) as follows:

- **Bulk** cycle time estimate
  Conditions: **44kW Charger Power**
  Calculation: (24kWh * 60%) / 44kW
  20 minutes
- **Bulk** cycle time estimate
  Conditions: **25kW Charger Power**
  Calculation: (24kWh * 60%) / 25kW
  35 minutes

The Level II AC charger would be used to charge beyond 80%.

In general, a DCFC is not intended to be left plugged into the vehicle for maintenance charging or off hour, peak load demand scheduling such as by a timer setting, or like events. The user is present to start a charge cycle, and there are no automatic starts.

[2] Exhibits B and C provide background information for those unfamiliar with the following CAN and battery charging subjects

AC Level II Charger

Three Level II SPX[3] AC bollard chargers were installed and operational on October 12, 2012. They fulfilled the Leaf's "normal charging" recommendations, and were installed to provide the following needs:

PROBLEM	BENEFIT FROM RESOLUTION
Energy budgeting	Off peak charging, cost control
Extended non-use (holidays)	Maintenance charging
Non-immediate missions	Future mission fill up
Immediate top off charge > 80%	Range extension, absorption phase charging

The install required a transformer to convert the primary 480 Volts three phase AC power to 240 Volts AC, single phase. The Leaf's onboard AC charger maximum current is 18 Amperes (2012 Leaf owner's manual). Each 32 Amperes capable Level II AC charger was set to deliver 16 Amperes maximum (3.84 kW Leaf *input* power) into an attached Leaf. The infrastructure was sized for that power.

The AC charger informs any attached vehicle of the available maximum current by setting the width of the SAE J1772 Control Pilot Pulse to 27% on time for a 16 Amperes limit. The Leaf controls its battery charge curve while limiting the *input* current to 16 Amperes. It can therefore deliver at most 3.3kW *output* power to its battery:

- **Bulk** cycle time estimate
  Conditions: **3.3kW, 20% - 80% SOC**
  Calculation: (24kW hour * 60%) / 3.3kW

  4.36 hours

An estimate of the additional time to charge from 80% to 100% in the constant voltage absorption mode follows, using the charger capability of 240V and 16A at 86% on board efficiency (3.3kW):

- **Absorption** cycle time estimate
  Conditions: **3.3kW, 80% -100% SOC**
  Calculation: (24kW hour * 20%) / 3.3kW.

  1.45 hours

AC Level I Charger

Nissan equipped each Leaf vehicle with a Level I (110 Volts AC) "trickle" charger for emergency or casual use which is stowed in the rear of the vehicle.

2012 Nissan Leaf Vehicle Considerations

During initial phases of the project in 2012, the Leafs were procured through a competitive bid process. Other fleet planners may have updated, newer releases, or other alternative choices.

Infrastructure planning considerations were given to the Leaf vehicle issues in *Exhibit A: Nissan Instructions for Leaf Charging* to help determine the fleet charger utilization plans.

The Leaf's owner's manual prefers charging to 80% using a Level II AC charger to maximize battery life.

[3] SPX was acquired by Bosch and is now called "Bosch Automotive Service Solutions LLC"

Infrastructure Planning Challenges

The following difficulties were encountered and investigated to refine the fleet charging solutions.

Battery Cell Balancing

An introduction to cell balancing for Lithium Ion battery cells is presented in ***Exhibit B: Typical Charge Profiles and Cell Balancing***. Some cell balancing algorithms operate when individual cells approach 100% SOC. For battery longevity, the Leaf owner's manual advises regular charging to 80% SOC yet makes no mention of any 100% SOC requirements.

Barring further information, the project provisioned for potential cell balancing needs by using a once a week timer programmed to charge to 100% SOC from an attached Level II AC charger.

The timer for the other six days was set for off peak timer charging at 80% SOC. However, the Police Department's Traffic Unit Leaf timer was subsequently disabled as explained later for 100% SOC (this modifies the decision tree presented later at *Charging Instructions*).

80% Charge Limiting

The Leaf's owner's manual does not make it apparent on how to enforce an 80% charge limit of all charge sessions for battery longevity. Per our reading of the owner's manual, the Leaf can limit to 80% charge only from within a timer function.

The Web forums[4] have resolved this difficulty for AC charging by creating an "anytime timer" process. The method sets a timer's start time the same as its stop time. This method was initially tried but abandoned because there were only two timers which have already been used as described earlier.

Per our tests, the DCFC is always limited to 80% by the Leaf, and was available for daily charge needs. AC charge at 100% was available daily with the Immediate Charge process.

DC Fast Charging Profile

The Leaf's owner's manual did not reveal how the Leaf would control a DCFC port. The team was left puzzled by some of the apparent differences in the DCFC port and the AC port regarding time limits, percent of charge limits, and disregard for vehicle timer settings.

Per tests, the DCFC sessions did not adhere to the Leaf timer settings, including the 'anytime timer'. The team interprets that pressing start on a DCFC was indicative and equivalent to a user pressing the immediate charge button to circumvent an active timer for an AC charge.

Upon installation, the DCFC administrator could limit every charge session:

- To stop at a specified percent of charge OR
- To stop after a specified time limit OR
- To have no limit

[4] See: http://sfbayleafs.org/ev-resources/leaf-tips-tricks/charge-to-80-percent/

Initially, the DCFC was set to limit each session to 80% charge per Nissan's "80% long life mode" recommendations. This led to less than the expected 80% SOC charge capacity. Additionally, sessions with only a small charge took considerably longer than expected.

As detailed in *Exhibit C: CAN Data and Definitions*, Controller Area Network (CAN) bus data was taken to observe the Leaf charge control messages. The reverse engineering explained the operational anomalies and helped the team adopt the best use plan. These anomalies were found to cause wide spread notoriety within Web forums[5].

As shown in the data section of the exhibit, the charge current requests sent by the Leaf often followed an exponential decay ($A + Be^{-t/C}$) where A is an asymptote constant current, B is a peak start current added above that, and C is the time required for decay to 37%. Plots would often show a change in these coefficients within a session.

When the depth of discharge was 30 miles to empty or less, the Leaf commanded a bulk constant current charge characteristic. Cold climate resulted in an observed small reduction in this characteristic.

This bulk characteristic of a lot of charge up front is important for a fleet vehicle like the Traffic Unit Leaf with the need for intraday, *pro re nata* refills.

Analysis of the CAN and other test data indicated the following basis for the project's DCFC planning:

- The DCFC was set with no timer and no percent charge limit
- The Leaf controls the DCFC parameters to yield an 80% SOC target (at 100% session charge)
- Do not use the DCFC when the battery still has a high SOC; like most DC charge sessions witnessed, the Leaf spreads these small kWh refills over a one hour period
- The Leaf enforces a reduced DC charge capacity when its battery is below 50% at the start of the charge. It stops the DC charge at 90% of the normal 80% DC limit, for a net charge of 72% of full capacity. This is often quoted as 80% in the forums[6], but is stated as 90% in the owner's manual which agrees with the findings here.

[5] See http://green.autoblog.com/2012/09/09/ignore-the-quick-charge-meter-in-the-nissan-leaf-ev-advocate/
See http://www.mynissanleaf.com/viewtopic.php?f=31&t=9902

[6] See: http://green.autoblog.com/2012/09/09/ignore-the-quick-charge-meter-in-the-nissan-leaf-ev-advocate/

The following table summarizes the empirical causes of the DC Fast Charge anomalies.

ANOMALY	CAUSE
Leaf Timers	• **The Leaf Timers have no effect on the DC Charger Port**
Charger "SOC" Display	• **The Leaf reports SOC relative to 80% and normally ends a DC session at 80%** Leaf data is displayed on the charger as 100% charge when the actual SOC is 80%. The Leaf reports maximum capacity as 19.2kWh (not 24kWh) with CAN message 0x100. The Leaf sends instantaneous capacity in CAN message 0x102. These well-defined CHAdeMO protocol messages are the source for the charger to display real time percent of charge. This displays 100% at 19.2kWh (only 80% SOC[7]).
Charge Current	• **The Leaf sent an exponential charge curve - not a large constant bulk current** Using CAN message 0x102, the Leaf provided discrete time samples to command an exponentially decaying charge current for all tests observed - except when the charger was limited in power capacity or the battery was well under 30 miles to empty. This removed the expected bulk charge curve and may have caused a longer session.
"Slow" Charge	• **The Leaf "adjusted" the current to spread even small energy across 1 hour** The initial current and exponential decay time constants were adjusted to take one hour to deliver either 1kWh or 14kWh.
72% SOC Limit	• **The Leaf stops the charge at 90% of the target maximum (which was already 80%) if the battery was under 50% SOC initially**
Times Out	• **The Leaf limits the charge time because it dictated a 1 hour timer limit using CAN message 0x101 and the charger stopped when that timer ran out**
Leaf Display	• **The Leaf may delay updates of the User Display information** The Level II Time to Charge following a DC Fast Charge may be delayed.

Police Cruiser Conversion

The Leaf has limited speed of about 90mph and would not be considered viable for any Police pursuit applications. Yet, its quiet operation can benefit applications requiring stealthy Police operation. The quiet operation and reduced air pollution provide benefit for a highly concentrated pedestrian city environment.

The Leaf uses an automotive standard, 12-Volt battery for powering many accessory electrical subsystems. This accessory battery is charged from the higher voltage Lithium Ion propulsion battery system. The Leaf accessory battery has a smaller capacity than a typical Ford Crown Victoria Police Cruiser 12–Volt battery, not having to perform gasoline engine cranking duties. The alternator charging system in a standard gasoline engine is quite familiar to secondary systems suppliers and can easily be upgraded to support more electrical load. The smaller Leaf 12-Volt battery and charging system

[7] The data is not exact and varies with time, temperature, and other unknown factors

presently complicates the provisioning of Police light bars, radio systems, and computer tracking systems.

These ancillary devices ultimately draw power from the propulsion battery system, and the useful operating time or range of the Leaf may be slightly shortened as these electrical loads are utilized.

Research[8] indicated that Portugal has outfitted several Leaf vehicles also for light duty Police operations as shown article at the left from the Web article.

The following is an excerpt from the Portugal article:

> "… [Though the Leaf's range] might be acceptable for patrolling in the city, *[Policia de Seguranca Publica]* plans to mostly use the electric vehicles in its Safe School Program. However, Nissan notes that the cars' functional blue police flashers and siren, along with the bold "Policia" markings, allow them to perform other police duties at any time.
>
> "Last year, New York City made a similar green decision when it purchased 50 Chevrolet Volt models. Many of those range-extended electric cars were sent to police departments, but rather than chasing bad guys as pursuit vehicles, most were destined for traffic enforcement duty."

The following two photographs show the City's equipped Traffic Leaf.

Front Blue Flashing Light and Police Markings

Rear Flashing Blue Tail Lights, Rear and Side Markings

[8] See: http://evworld.com/news.cfm?newsid=28331

The project's traffic unit was provisioned as follows:

- One flashing police blue light at the rear view mirror
- Rear flashing blue tail lights
- "POLICE" and "EMERGENCY 911" markings on the two sides
- "POLICE" markings on the front and rear of the vehicle

The traffic unit's officers indicated that these modifications were not sufficient for all of their normal duties, and they can use the cars only for parking and ticketing enforcement. Some additional modifications are required to perform the traffic unit's full set of duties, as follows:

- A top mounted Police light-bar, Blue and Amber
- Vehicle markings significantly more visible
- Provisioned with the Police Department's mobile data system - this would eliminate a seat
- Provisioned with the Police Department's radio system

For this study, the Leaf was used for ticketing and as a take home vehicle for an officer on light duty.

Level II AC Charger Restart Issue

The Level II AC charger did not initially operate as desired with the Leaf timers. The charger and Leaf could perform an exchange at initial plug-in, but afterwards if the Leaf needed to start a charge, the Level II charger did not charge. Several times the Leaf ran down its 12-Volt battery potentially while trying to get the connected charger to operate. Research on the Web[9] uncovered the following confirmation:

> "This [SPX Power Xpress] cord set will also only provide charging once per plug-in sequence. Hence, it may not work well with the certain vehicle charge timers (e.g. a Nissan LEAF end-timer). This issue may have been resolved in more recent firmware."

Through SPX acquirer Bosch, the SPX Xpress firmware was upgraded to Revision 4 and the issue was resolved on or about January 28, 2014.

It is noted that there appear to be other instances of this situation listed on the Web[10], and it is upon the vehicle owner or fleet administrator to make sure the charger will suit their needs for any restart.

> "Some EVSEs are designed to not allow a second charging session to start until they sense being unplugged from the car (getting + 12v on the Control Pilot)."

The Leaf's owner's manual (cited in Exhibit A) and Web forum[11] research indicates that for extended stowage, the 12-Volt system may still drain if left plugged into a charger.

[9] See: http://www.pluginamerica.org/accessories/spx-power-xpress
[10] See http://www.mynissanleaf.com/viewtopic.php?f=26&t=11100
[11] See http://www.torquenews.com/1075/how-avoid-dead-nissan-leaf-after-taking-long-trip

Vehicle and Charger Usage Plans

Usage Plan Overview

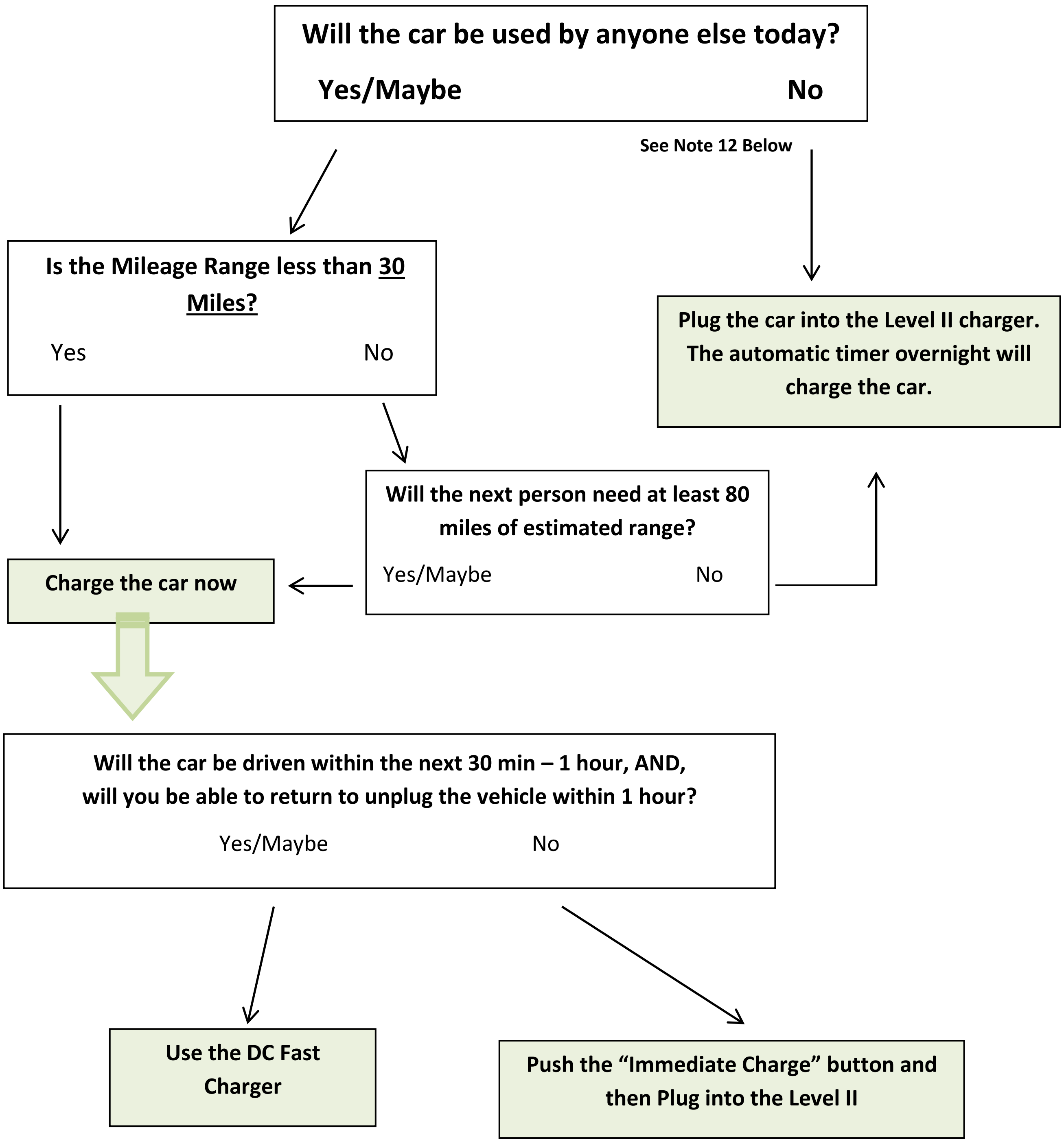
The following usage plan was put in place based on the investigations.

DSICIPLINE	POLICY
Authorization	Personnel operating the EV or the Charger(s) were authorized and trained.
Rest & Short Term Stowage	The EV may rest either not plugged in to a charger or plugged in to the Level II AC Charger depending on other instructions
DC Fast Charge	DCFC was monitored for a successful start; the operators returned within 1 hour to confirm success and drive or rest the vehicle. The Leaf controls the session for 80% SOC limit, 1 hour time limit, and 90% of 80% SOC limit if the battery was below 50% initially.
Normal Daily Off Peak Timer	Daily Off Peak Level II AC Charge End timers were set to end at 5am, 80% SOC.
Cell Balancing Off Peak Timer	Once weekly Off Peak Level II AC Charge timers were set to end at 5am and 100% SOC for potential cell balancing
Daily Charging	Charges during work hours used a DCFC at 80% SOC or a Level II AC Charger at 100% SOC immediate charge. An 'anytime 80% timer' was not available because the two Leaf charge timers controlled off-peak charging.
Immediate Charge	The Immediate Charge process was used to reach 100% SOC for long range needs or to force a Level II charger session outside the timer window.
Temperature Extremes	The DCFC was powered off when the outside temperature fell below +14°F for a period of time. The vehicle was not to be charged if the Li-Ion Temperature Gauge was in the RED or BLUE range.
Extended Stowage	The DCFC were powered off as appropriate to conserve energy. Leaf EV Batteries could be maintained from either of the following: • Off peak timers schedule maintenance charges from Level II AC Chargers • Per Nissan, prepare the vehicle with an 80% SOC and the Leaf may then be left unplugged for 3 months – depending on climate needs and supplementary Solar Panel 12-Volt battery maintenance
Vehicle Use	The vehicles were used for City business purposes and were driven home only as authorized and logged. Certain personnel used the vehicles to test Charger or vehicle operation, which often required a drive session to run the battery down.

Charging Instructions

See *Exhibit D: Quick Reference Instruction Sheet* for the provided charger operating instructions. The following two sheets of instructions were also given to the users and placed in the vehicles.

When done using the car:



[12] The 'NO' route for mission critical fleets should indicate a DC fast charge or 100% SOC AC charge session

The **DC Fast Charge** should be used when:

- Immediate Use
    - The vehicle will be used again within the next 30 min - 1 hour and needs more charge
    - Example: At the beginning of a shift if the vehicle has less than the desired charge
    - Example: In the middle of a shift if the driver wishes to "fill up"
- The vehicle should be unplugged from the DC Fast Charger within 1 hour to ensure that the charge was successful and to reduce the potential for accidental damage to the charging cord.

The **Level II Immediate Charge** should be used when:

- The vehicle will be unattended for more than one hour and cannot wait for overnight charging
    - Turn off the vehicle, push the 'immediate charge to 100%' button, and plug into the Level II charger. Vehicle will begin charging.

The **Level II Charge with Timer** should be used when:

- The vehicle will be unused until the next day
- The remaining mileage range is acceptable and the vehicle may or may not be used until the next morning
- The vehicle will be unused for up to 5 days

No Chargers should be used when:

- The vehicle will be unused for more than 5 days and less than 3 months. Make sure that vehicle is charged to 80% (not 100%) before leaving it unplugged for more than 5 days.

Car Charging Timers

The Leafs come with two timers that can be set as desired and will affect the Level II charging. Most timer based charging is set for the Long Life Mode at 80%, with a cell balancing timer at 100% set for once per week.

Recommended settings:

City Police Leaf

Timer 1: Charge to 80%; Sun-Fri; end time of 5 am, Long Life Mode [13]
Timer 2: Charge to 100%; Sat; end time of 5 am, Cell Balancing
Climate Timer: Start at 7am, Mon-Fri

City Yard Leafs

Timer 1: Charge to 80%; Tues-Fri; end time of 5 am, Long Life Mode
Timer 2: Charge to 100%; Mon; end time of 5 am, Cell Balancing

How to Reach 100% Charge Immediately?

- If well under 80%, Plug into and charge using the DC FC (will stop at 80%)
- Remove the DC FC plug and connect to the Level II charger
- Push the 'charge to 100% button'

Charge to 100% Button – *left of the steering wheel*

How to Reach 80% Charge Immediately?

The only ways to begin charging to 80% immediately is to use the DC Fast Charge or to adjust the car charging timers.

[13] This timer at 80% was contradictory to the Traffic needs, and was set to 100% later on by turning off this timer

Data Acquisition Plan

User Log and Leaf Data

The Leaf will provide user log data for the vehicle miles traveled and the estimated miles to empty ("*MTE*") that will determine the end of route charger operations. The operators will fill in a trip log, as shown in *Exhibit E: City of Charlottesville Log Journal*, during the data acquisition period.

DC Fast Charger Data

The DCFC total kilo-Watt-hour log can be used to estimate the amount of energy used for DC and AC charging when compared with the Utility billing data.

The power usage data for the Level II AC chargers will be extrapolated as the remainder left when the logged DCFC kilo-Watt-hour usage, after adding loss from its efficiency, is subtracted from the Utility total kilo-Watt-hour usage that was metered and billed for each charge station site.

The driver logs may assist in adjusting the assumptions in efficiency and meter reading times.

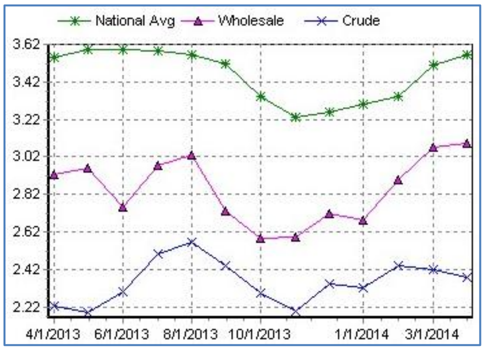
Utility Data

The monthly Utility bills for each charge station site will be used to extract the aggregate energy usage data for each site.

Data Presentations

Gasoline Prices

The following data From the AAA Web site[14] indicates the average United States price for wholesale and retail regular self-serve gasoline. The Average National Retail will be used in the analysis.



Estimated From the Graphs:

Average National Retail: $3.42

Average Wholesale: $2.82

Driver Logs

The project vehicle users filled in a trip log for each vehicle as indicated earlier in the section *User Log and Leaf Data*. The data from those log entries was entered into a spreadsheet and converted to plots that indicate miles traveled and charger usage.

Those resulting data plots are shown in the following subsections.

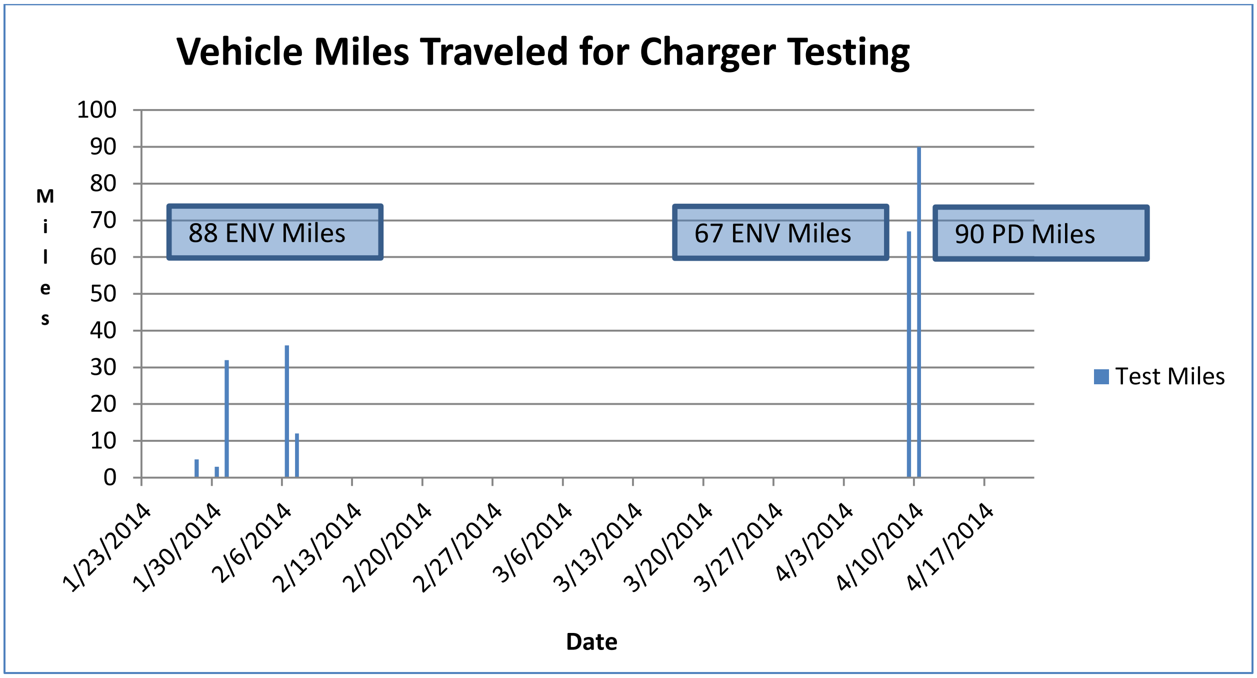
The following abbreviations are used for the vehicles:

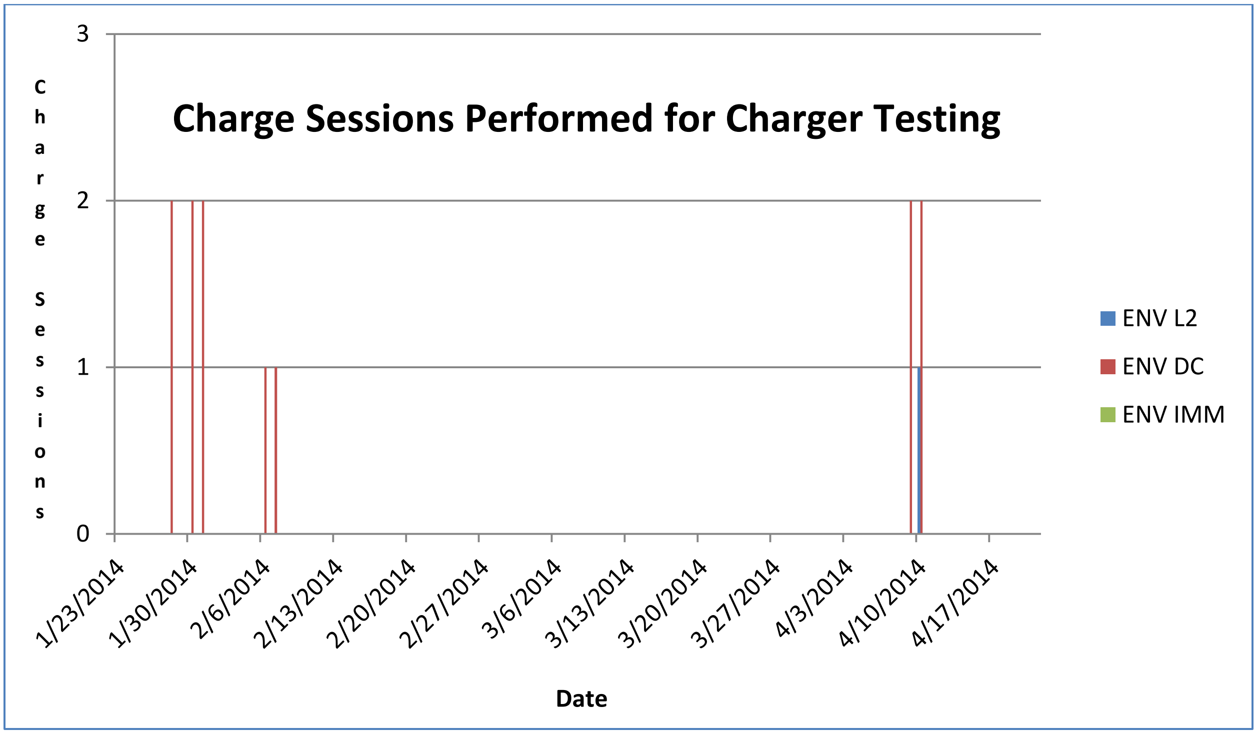
VEHICLE	ABBREVIATION
Facilities Maintenance Division	FM
Environmental Sustainability Division	ENV
Police Department Traffic Unit	PD

[14] See http://fuelgaugereport.aaa.com/?redirectto=http://fuelgaugereport.opisnet.com/index.asp

DC Fast Charger Testing

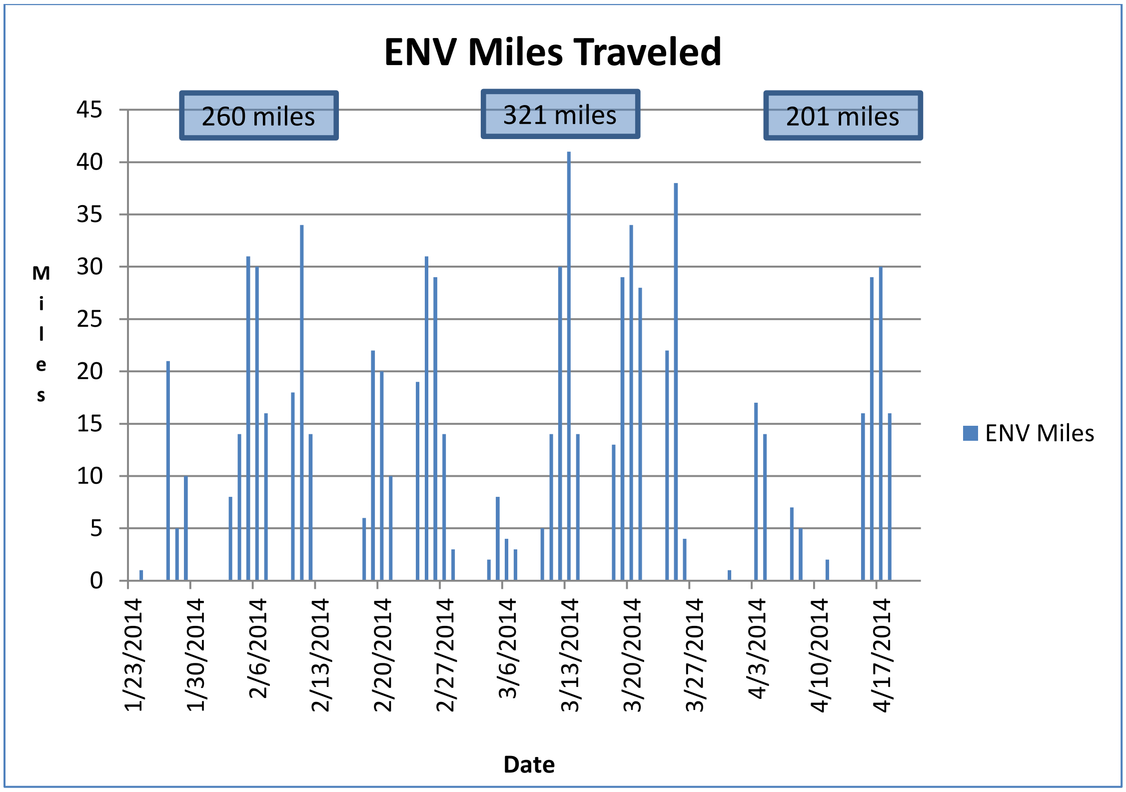
The following data represents DCFC testing using the ENV and PD vehicles. The ENV vehicle saw normal use between some of the January test sessions.

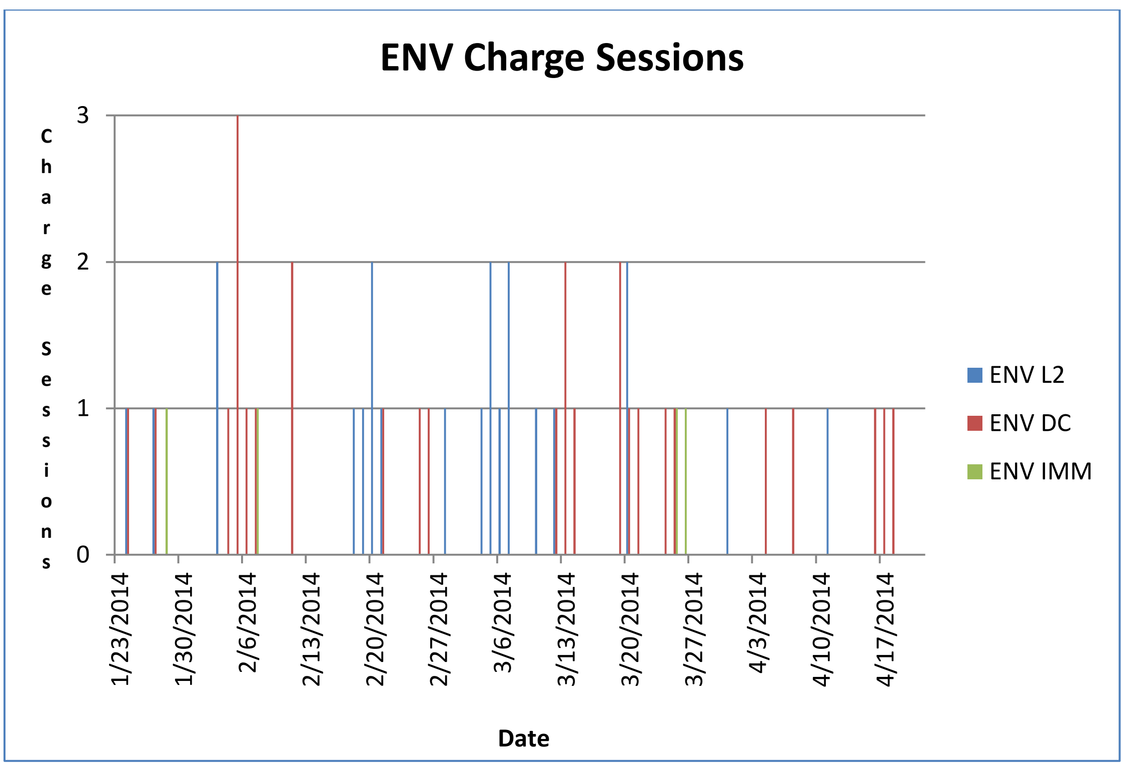




Environmental Sustainability Division (ENV)

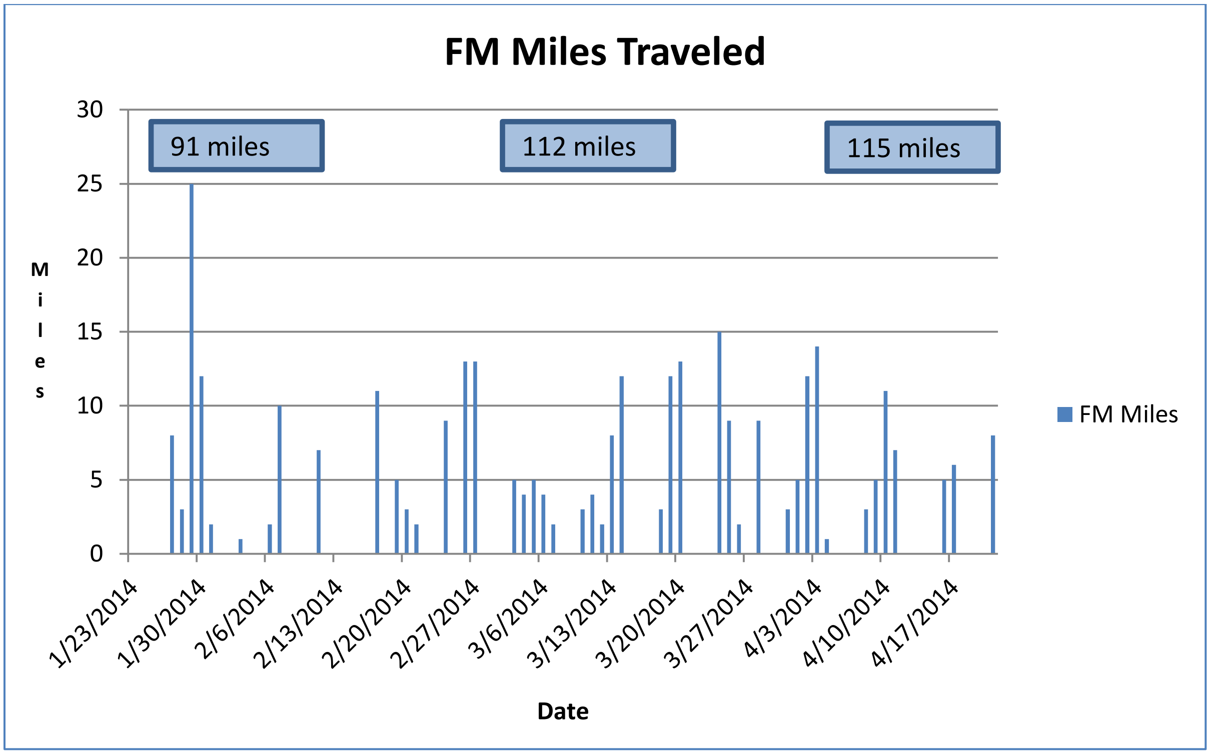
The following data represents ENV vehicle usage.

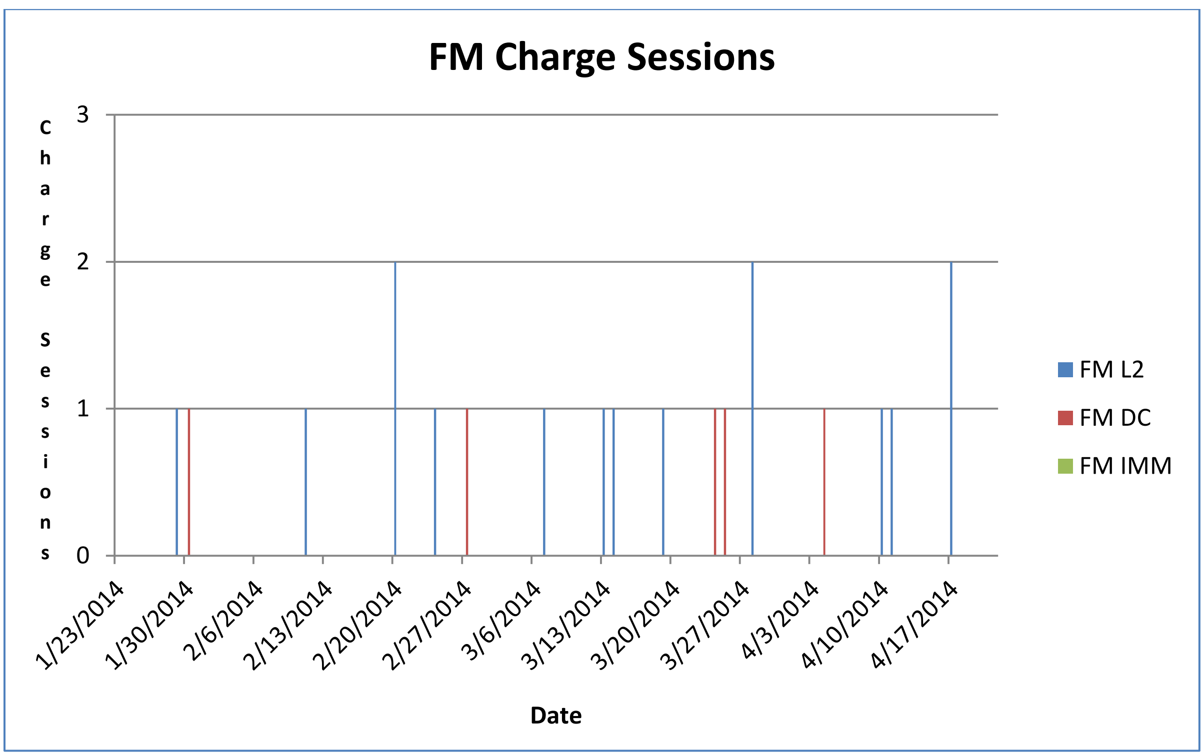




Facilities Maintenance Division (FM)

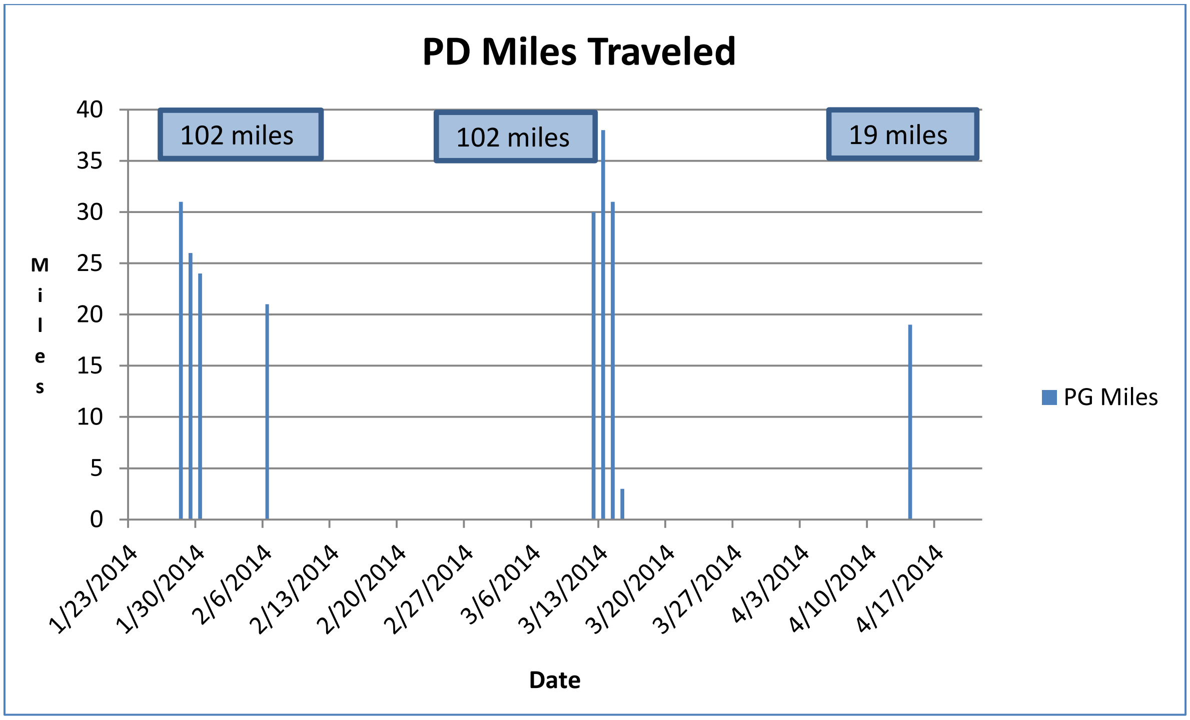
The following data represents the FM vehicle usage.

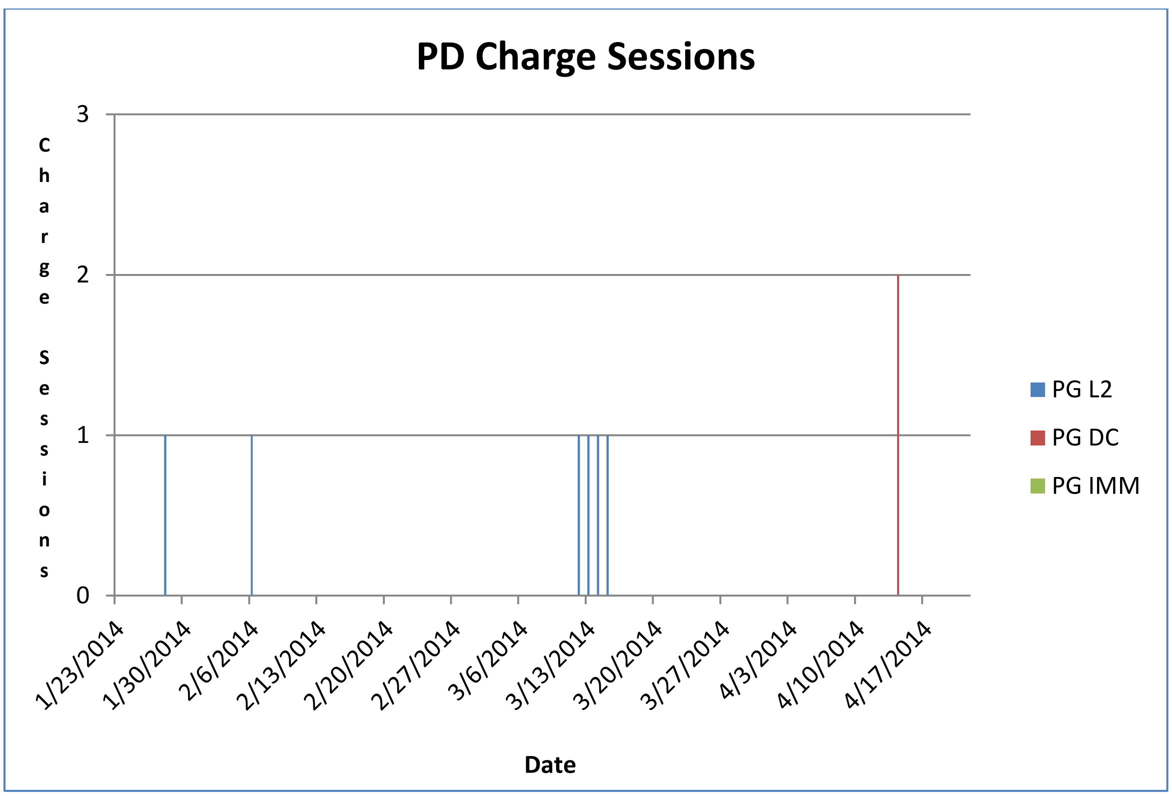




Police Department Traffic Unit (PD)

The following data represents the Police Department Traffic Unit vehicle usage.





Odometer Tallies

The following chart confirms the trip log entries are complete.

MONTH	LOG VERIFICATION WITH ODOMETER MILEAGE				
	Leaf Unit	Ending Odometer	Beginning Odometer	Miles Traveled	Plot Tallies
February	ENV	2373	2025	348	348
	FM	2323	2232	91	91
	PD	3239	3137	102	102
March	ENV	2694	2373	321	321
	FM	2435	2323	112	112
	PD	3341	3239	102	102
April	ENV	2962	2694	268	268
	FM	2550	2435	115	115
	PD	3450	3341	109	109

Power Usage

The following subsections represent power usage derived from the Utility power bill and mileage logs.

ENV and FM Power Usage

The FM and ENV usage is combined since they share a Charge Station:

MONTH	ENV and FM Power Usage		
	Total Miles	**Total kWh**	**Miles Per kWh**
February	439	280	1.57
March	433	340	1.27
April	473[A]	340	1.39

[A] The PD Traffic unit April test miles appear in this April data since the ENV charger was used for the tests.

PD Power Usage

The traffic personnel set a Leaf climate timer in an attempt to extend the vehicle mileage range. It was set to have the climate adjusted by 7am for the work days, Monday to Friday. This was done in concert with the Leaf's owner's manual recommendations (Page 4-7) that it would increase mileage range of a battery charge since the initial climate power would come from the AC Charger and not the Lithium Ion propulsion battery. This, however, may provide some insight into the very low miles per kWh.

PD POWER USAGE			
MONTH	Total Miles	Total kWh	Miles Per kWh
February	102	220	0.46
March	102	260	0.39
April	19[B]	200	0.095

Note: The PD unit had low usage and had a climate timer set to warm the vehicle each weekday.

[B] The PD unit April test miles appear on the City Yard charger since that charger was used for the tests.

Charger Usage

The following tables indicate AC or DC charger type usage for each installation site. First, the Utility kWh data is reduced to 90% for delivered power. Second, the DCFC log for delivered kWh usage is subtracted from to arrive at the AC charger kWh usage. The data shown includes test mileage unless otherwise indicated.

The session tallies are only indicative of what the user intended to happen by picking the charger type that they connected to the Leaf. DCFC and Immediate charges were logged as such and are assumed to have been performed. However, an AC Charger log is dependent on the Leaf Charge timer and could result in no charge or multiple charges, such as by climate control timers across several days of nonuse.

ENV and FM Charger Usage

ENV AND FM CHARGER USAGE								
MONTH	Utility kWh	Load kWh	DCFC kWh	DC % kWh	DC Sessions	AC kWh	AC % kWh	AC Sessions
February	280	252	127	50 %	12	125	50 %	13
March	340	306	109	36 %	11	197	64 %	16
April	340	306	133	43 %	14	173	57 %	18

PD Charger Usage

PD CHARGER USAGE								
MONTH	Utility kWh	Load kWh	DCFC kWh	DC % kWh	DC Sessions	AC kWh	AC % kWh	AC Sessions
February	220	198	0	0 %	0	198	100 %	2
March	260	234	0	0 %	0	234	100 %	4
April	200	180	11	6 %	2	169	94 %	0 [A]

[A] The climate timers may have attributed to this power; however, timer based charge sessions were not logged.

Project Summary

The Project integrated EVs and charging infrastructure within the City of Charlottesville, providing the opportunity to evaluate an additional strategy for reducing fuel consumption and associated emissions while meeting the needs of a municipal fleet in an urban environment.

The Project team concludes that EVs have a viable position in many municipal environments but with limited recommendation for use in critical demand fleets such as Police fleets.

The project's period of performance has demonstrated various methods of incorporating EVs and charging infrastructure, and identified three general categories for municipal EV applications:

- **Short Commute**
  The Facilities Maintenance and Environmental Divisions demonstrated the most success and concluded that the Level II AC charger is sufficient to maintain a fleet performing only short commutes.
- **Long Commute**
  The Environmental Division and Traffic Unit applications demonstrated the limits and needs of longer daily mileage environments by using commuter applications. It pointed out the need for en route Level II or DCFC infrastructure, as well as the impact of extreme winter weather on useful EV range.
- **Critical Needs**
  The project highlighted the weaknesses – both dimensional and perceptual – of the EV in terms of the ability to be ready at every moment for indefinite periods of use for even the smallest of traffic duties, even while being very lightly fitted with otherwise mandatory gear and electronic systems that will absorb minimal EV battery power.

Any particular municipality's choice of vehicle and charger infrastructure, however, may vary widely based on various criteria including programmatic needs, travel patterns, shift schedules, peak charging rates and temperature extremes.

As detailed in the Summary section of this report, the Project has provided a seed for the municipal learning curve, enabling others to avoid the many subtle yet very important setup and use pitfalls and prepare the infrastructure and policies before incorporation into daily routines.

The suitability of an electric vehicle, type of electric vehicle, and the charging infrastructure chosen, should be carefully decided and optimized with considerations for the guidelines learned with this project.

Emissions data Analysis

The following table compares the average nationwide emissions for a conventional internal combustion engine and an All Electric Vehicle and was obtained[15] from the Web on May 2, 2014:

EMISSIONS FOR A 100-MILE TRIP	
ENGINE TYPE	GREENHOUSE GAS EMISSIONS
conventional	87 lb. CO_2
all-electric	54 lb. CO_2

This Greenhouse data is incorporated in the charts for each fleet analyzed in the following sections.

Short Commute Fleet

The FM vehicle data demonstrates a small fleet size with short commutes. With a small fleet, there are fewer vehicles contending for charger use. The vehicle can make several short-route trips on a single charge, and does not need a full charge at the beginning of each trip. The battery can be allowed to go to a low charge over several trips before recharging. These less stringent needs allow for a lower power charger that can take more time to charge.

For DC fast charging needs, given a 24kWh battery and the Leaf vehicle DCFC profile spread across 1 hour, then a 25kW DCFC was the optimum quick charge choice in the smaller fleet.

Using this lower power DCFC could minimize the installation infrastructure costs and reduce the peak load demand.

For AC charging needs, the Leaf was restricted to 18 Amperes in its AC Charger interface and proved sufficient for the fleet.

However, as an alternative, the Nissan 2013 Leaf model indicates capability for 18 or 32 Amperes at 240 Volts, “if so equipped”. Using the 32 Amperes AC charger option, smaller fleets with shorter route requirements could potentially work without a DCFC, with a full AC bulk charge estimated at:

240V X 32A = 7.68kW sourced, 24kWh *60% / 6.6kW = **2.2 Hours**

(Assumes 86% on board efficiency, 20% to 80% charge)

[15] See http://www.afdc.energy.gov/vehicles/electric_emissions.php

Facilities Maintenance Fleet Power Cost and CO_2 Analysis

The Facilities Maintenance EV usage is shown in the following chart. Since it shared the same charging station as the Environmental EV and the EV charger test exercises, this chart represents the pro-rata share of each vehicle based on its mileage. As such, any actual miles per kWh results are not indicated. Note that the Leaf's miles per kWh are not useful to split these accounts since that calculation does not represent the data recovered in this project.

FM POWER USAGE (EXTRAPOLATED)										
MONTH	Total Miles	Total kWh	Miles Per kWh	Cost kWh	Retail Gas 30mpg	Retail Gas 20mpg	Save @ 30mpg	Save @ 20mpg	CO_2 Gas	CO_2 Electric
February	91	58	1.57	$6.80	$10.37	$15.56	**$3.57**	**$8.76**	79 lb.	**49 lb.**
March	112	88	1.27	$10.00	$12.77	$19.15	**$2.77**	**$9.15**	97 lb.	**60 lb.**
April	115	83	1.39	$9.43	$13.11	$19.67	**$3.68**	**$10.24**	100 lb.	**62 lb.**

Larger Fleet

The project simulated more rigorous needs with the ENV vehicle. There, in addition to normal daily short commutes, long distance commutes were simulated with "drive home" assignments.

Larger fleets would receive benefit by using vehicles that allowed the more powerful fast chargers, such as 44kW and 100kW, to actually deliver their full capacity continuously and charge to Bulk quickly. We are unsure why the Leaf appears to spread every charge, large or small, across a one hour window, but respect their need to control battery charge characteristics. However, the Leaf was observed to provide a rapid bulk type charge when the battery is down below a 30 mile range.

Vehicles such as the GM Spark and BMW i3 are being introduced with published[16] charge times of 20 minutes to obtain 80% Bulk SOC. Tests would need to confirm whether or not the charge times are an improvement from what the project witnessed.

AC Charging would still be made available for maintenance and off peak choice for the large fleet.

[16] See http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2013/Jun/0611-fast-charge.html

Environmental Sustainability Fleet Power Cost and CO_2 Analysis

The ENV vehicle usage is shown in the following chart. Since it shared the same charging station as the FM vehicle for the EV charger test exercises, this chart represents the pro-rata share of each vehicle based on it mileage. As such, any actual miles per kWh results are not indicated. Note that the Leaf's miles per kWh are not useful to split these accounts since that calculation does not represent the data recovered in this project.

ENV POWER USAGE (EXTRAPOLATED)										
MONTH	Total Miles	Total kWh	Miles Per kWh	Cost kWh	Retail Gas 30mpg	Retail Gas 20mpg	Save @ 30mpg	Save @ 20mpg	CO_2 Gas	CO_2 Electric
February	260	166	1.57	$19.43	$29.64	$44.46	**$10.21**	**$25.03**	226 lb.	**140 lb.**
March	321	252	1.27	$28.63	$36.59	$54.89	**$7.96**	**$26.26**	279 lb.	**173 lb.**
April	201	144	1.39	$16.36	$22.91	$34.37	**$6.55**	**$18.01**	175 lb.	**109 lb.**

Critical Fleet

The Project simulated the most strenuous demands on an EV application through the Police Department's Traffic Unit EV. The main hurdle here was the requirement to provision an EV that can properly serve public protection and safety interests, where shortcomings will not be forgiven. The project discovered and adapted some plans around these difficult and special needs, and continues to address the unique problems.

The Traffic Unit Leaf's 12-Volt accessory system was not outfitted with the normal Police Cruiser light bar, radio, and computer equipment.

The drivers were initially exposed to the Leaf with only Level II AC chargers available. There were no Leaf timers set, and they could receive 100% SOC.

Without benefit of an intraday (*pro-re-nata)* DCFC session, the vehicle was tested on a normal shift using a single overnight charge. This resulted in performance and EV suitability reputations that were hard to erase with the arrival of the DCFC.

Several anecdotal comments summarize the Police experience in trying the vehicle in different use cases as follows.

Ancillary Power Limitation (Jan 2014, based on full day's use with no DCFC intraday recharge):

> "This morning we worked a wreck at [removed]. We were there for a little over an hour. I honestly do not think the car would have made it with lights running the full time. I think the car is great for a short commuter but not for a functioning police vehicle."
>
> "… [It] limits the amount of traffic crashes or hazards I can assist on, including assisting with funeral escorts. This creates a back and forth situation to switch out proper vehicles better equipped for these types of occurrences or events…"

Lack of Range (Jul 2013 without a DCFC available):

> "…I have to conserve the amount of patrols I conduct throughout my day in order for the battery charge to uphold. If I were to enforce 30 minute loading zones, 1 hour parking, and 2 hour parking on the dot and continue to patrol my beat looking for other parking violations I would lose power to the vehicle…"

Silent Operation Benefits (Feb 2014):

> "The vehicle has liquid-smooth handling and is virtually silent, allowing for easy ambushes on parking violations."

Police Fleet Power Cost and CO_2 Analysis

The Project data plan was to use Nissan's recommended 80% SOC as possible, and this was done using AC off peak charge timers set at 80% SOC. The drivers were expected to manually perform an AC charge using the immediate procedure to get 100% SOC if required for the next cycle. The DCFC was not being used for intraday refills.

The PD DCFC was set at its 80% limit during initial experiments, and was inadvertently not reset to remove that limit as planned. That experiment had proven the Leaf already reported 80% maximum to the DCFC as the vehicle's full battery capacity, limiting any DCFC to no more than 80%. With the charger also set at 80%, then the traffic DCFC stopped at 80% of the Leaf 80%, for less than desired DC charge. This resulted in less than desired intraday fill capacity.

In addition, the use of climate timers may have resulted in less than optimal cost of operation.

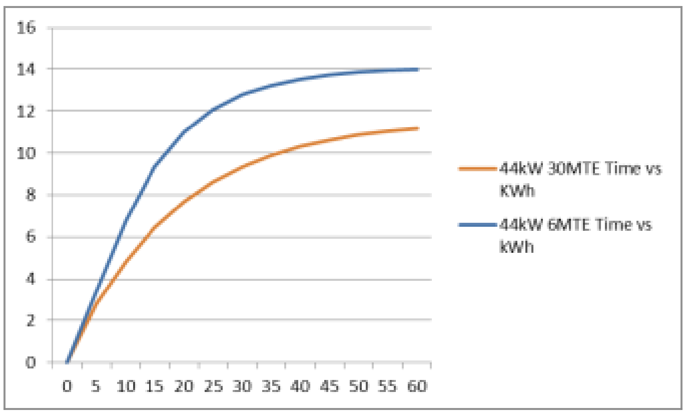
PD POWER USAGE										
MONTH	Total Miles	Total kWh	Miles Per kWh	Cost kWh	Retail Gas 30mpg	Retail Gas 20mpg	Save @ 30mpg	Save @ 20mpg	CO_2 Gas	CO_2 Electric
February	102	220	0.46	$26.97	$11.63	$17.44	-$15.34	-$9.53	89 lb.	55 lb.
March	102	260	0.39	$30.87	$11.63	$17.44	-$19.24	-$13.43	89 lb.	55 lb.
April	19[B]	200	0.095	$25.06	$2.17	$3.25	-$22.89	-$21.81	17 lb.	10 lb.

After review of the application and confirmation of the equipment setups, the following changes and corrections were made to benefit the traffic application in the third month data period:

- The PD Leaf's work day timers were set off
  - This allows AC charging to 100% SOC for initial morning readiness
- The PD DCFC was set to no limit as initially intended
  - This improves the net Leaf and DCFC SOC limit from about 64% to 80%

Realizing the DCFC was incorporated to enhance performance by providing quick intraday refills during daily traffic rounds, and from empirical Leaf data, the following was re-emphasized to the team:

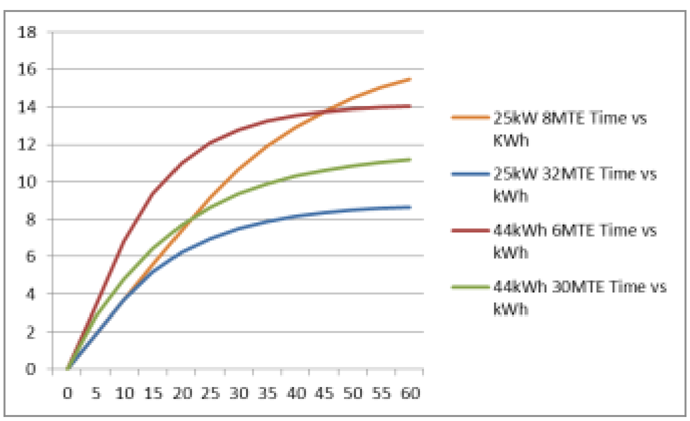
- Perform DCFC during breaks, rest periods, or lunch (whenever 10-20 minutes is available). Manually stop the DCFC after 10-20 minutes.
- The DCFC pushes more power per second into the car at the beginning of a charge than at the end (e.g. it charges faster during the 5 minute period from 0-5 minutes than it does from 20-25 minutes). As such, multiple short ‘fill-ups’ during the day at break times may increase the usefulness of the car battery without reducing the officers’ abilities to perform their duties.
- A lower battery gets more charge during the 0-5 minute interval than a full battery will. Running the battery down to about 20 - 30 miles remaining before doing a DCFC may be a sweet point for charging quickly.
- The officers can try using the DCFC at different mileage points and charging for different lengths of time to find what gives them the best results… whatever works for them is the best way to use the technology.



The curves at the left show delivered energy in kWh (Y) versus time (X) as commanded by the Leaf and delivered by the 44kW DCFC at two different Miles to Empty indications.

This shows that the Leaf targets to spread the 80% SOC energy across a 1 hour time for all of the data taken on multiple tests.

These curves represent the data for CAN curves in Figures 9 and 11 of the CAN Exhibit.



The curves shown at the left are the same charge conditions from above but add graphs for the derated 25kW charger.

This confirms that the 25kW charger delivered the 8 MTE recharge of 13kWh in 41 minutes whereas the 44kW charger delivered 12.8kWh in 28 minutes, only a slight improvement. That also indicates the Leaf spreads each charge across an targeted one hour period.

These curves also indicate the advantage of the 44kW charger during the beginning of the charge where it is clear that more recharge energy is delivered per unit of time on the red and green 44kW curves than on the orange and blue 25kW charge curves.

The red curve represents the best recharge per unit time where the car battery is very low and the charger capacity is 44kW.

For a fleet of this type, the vehicle should receive 100% SOC when possible, with a DCFC available for intraday refills but at 80% SOC maximum. Battery life may suffer as a consequence, but fleets of this nature are expected to be more robustly utilized.

The Traffic Unit Leaf had a climate timer set to warm the vehicle each work day morning, and did not use the vehicle very often. The logs were not sufficient to determine when the climate system would have actually operated.

With the vehicle fitted only as a light duty traffic unit, the performance of the electric vehicle with full Police systems installed was not measurable.

Even with the less than normal Police loads on the Traffic Unit Leaf's electrical systems, the vehicle was not a favorite of the fleet. General shortcomings were as follows:

- Not readily identifiable as a Police Enforcement unit (size, marking, lighting)
    - This may be addressable beyond this report's time window
    - The project witnessed the lack of authority and respect while riding in the Traffic Leaf on an interstate highway, at the posted speed limit, while almost every driver passed the vehicle without any concern.
- Not able to stand up to lengthy route operations required by fleet routines [on one daily charge]
    - Re-evaluate after changes for AC 100% and DCFC refills
- Operating ancillary systems for extended incident support drains charge [on one daily charge]
    - Re-evaluate after changes for AC 100% and DCFC refills
- Insufficient project planning window to evaluate how the DCFC can improve performance after experiencing the weakness with only an AC charger at hand

Ancillary Police Equipment

The Traffic Unit Leaf was fitted with a Whelen[17] Single Avenger Blue LED Dash Light. It operates on 12-Volt DC accessory or cigarette lighter receptacle and recommends a 3-5A fuse depending on application.

Barring installation of specific equipment, the Web [18] indicates LED Light Bar technologies can operate within the following estimated power requirements:

- Dimensions: 22" L x 4.9" W x 1.8" high
- Input Voltage: 12 Volts DC
- Average current draw: 7A @12.8 VDC

[17] See http://www.whelen.com/auto/product.php?head_id=8&cat_id=64&prod_id=412
[18] See http://www.emergencycity.com/Police_Lightz_Linear_Slim_Po_Mini_Bar_p/pl-splb4xx.htm

- 13' cable from light bar to cigarette plug
- [Four] – 60-lb magnets
- Front – [Four] OX warning modules - each contain [six] 1-watt LEDs
- End caps – [Three] 1-watt LEDs
- Rear – [Four] OX warning modules - each contain [six] 1-watt LEDs

The power consumption during operation would be:

12.8 Volts x 7 Amperes, or 90 Watts

With this as the only load, the 24kWh battery (19.2kWh to maximum allowed discharge) could at best power the light bar alone as follows:

19,200Wh / 90W = 213 Hours of continuous use (almost 8 days)

This is a minimal load compared to the propulsion battery capacity. It is probable that radio and computer loads would also degrade mileage minimally.

The Leaf provides a 12-Volt accessory port, whose lid carries a specification of 12 Volts DC and 120 Watt capability.

This is within the mentioned bar light's requirements, but the Whelen front window unit is also powered from the port.

With the Whelen unit at 3-5 Amperes, and 7 Amperes for the bar, then they capacity is near the limit.

Implementation of this type of Bar Light is under consideration for future possibilities.

"The light bar comes with a 12-volt DC cigarette plug that has an on/off switch and pattern changing switch for a quick setup!"

In the worst case scenario, power shedding might be practical. Engaging the Light Bar could switch off other devices (seat and steering warmers, headlights) and prevent any major overload concerns.

Notwithstanding the Leaf's owner's manual cautions, the Leaf can be exited, and the key removed, while leaving the engine running and the vehicle in park with the park brake on. Time limits allowed for this type of operation were not measured.

Other Considerations

General Climate Issues

Experience with this project indicates that charging and mileage are both affected by very low temperatures. The following excerpt summarizes published AAA research[19]:

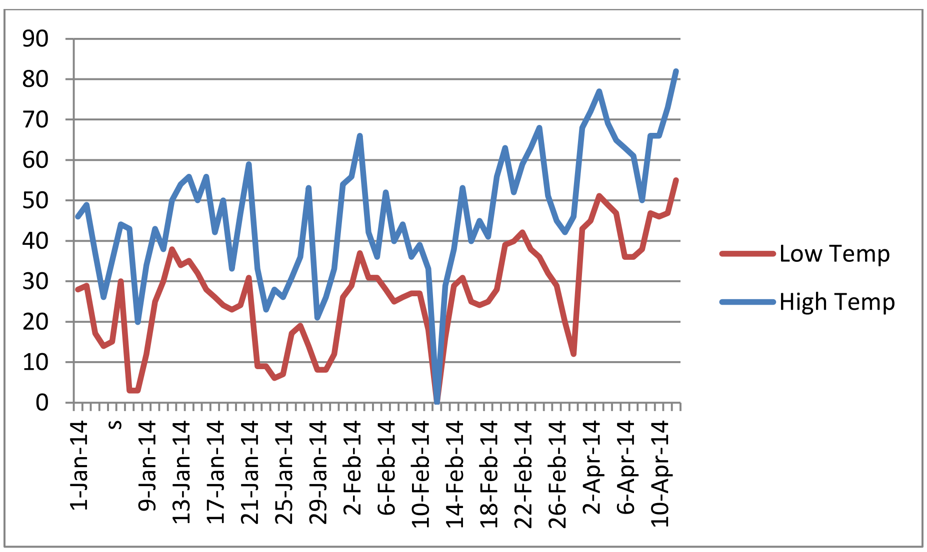
> "The average electric vehicle battery range for each full charge in AAA's test was 105 miles at 75 degrees Fahrenheit. That dropped 57% to 43 miles when the temperature was held steady at 20 degrees [Fahrenheit]. Warm temperatures were not as stressful but still delivered a lower average of 69 miles per full charge at 95 degrees [Fahrenheit], AAA said."

The Project did demonstrate range limitations during cold weather (Jan 2014, Level II AC at 80% SOC):

> "I started out with a full charge … showing 71 … miles and when I [ended the 26 mile trip] there was only 14 miles showing. I then had to plug [in the 110V Level I charger] … just so I could get back … Very disappointed. The vehicle rides great. But imagine riding 26 miles in 5 degree weather with no heat just so I would have enough energy to get back…"

Note that this result of 52 miles at 5°F is close to the project planning distances, from the EPA[20] which indicate 62 miles in stop-and-go winter traffic at 14°F and 47 miles in heavy stop and go traffic.

Temperature data[21] for this report period is shown in this plot.



Climate Timer Issues

The Traffic Unit Leaf used a climate timer to adjust the Leaf temperature by 7am for Monday to Friday shift operations. Per the Leaf's owner's manual page 4-7, this should extend mileage slightly since the

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[19] See http://www.usatoday.com/story/money/business/2014/03/20/cold-sharply-cuts-range-of-electric-vehicles/6622979/
[20] See http://en.wikipedia.org/wiki/Nissan_Leaf
[21] From http://www.usclimatedata.com/climate/charlottesville/virginia/united-states/usva0143/2014/4

initial climate control would use Utility power through a connected charger as opposed to driving off in the vehicle and then warming the vehicle from the Lithium propulsion battery power.

However, using this timer may have adversely affected miles per kWh cost of operating the vehicle. The vehicle did not have significant use but did use considerably more power than the Environmental Leaf and Facilities Maintenance Leaf counterparts that did not utilize this feature.

The use of climate timers will affect the net operating cost the vehicle, with potentially high costs if the vehicle is warmed or cooled but not driven.

Demand and Smart Energy

Rate profiles for the City are in the VEPGA contract with Dominion Virginia Power ("Dominion") listed in the references.

The installation of a DCFC will determine the peak demand requirements, so its maximum power rating (25kW, 44kW, 50kW) should be chosen as small as practical for the fleet readiness needs.

Dominion peak times from the reference material indicated the following schedule:

June 1 through September 20:	10 am to 10 pm
October 1 to May 31:	7 am to 10 pm

Although the project was not based on demand billing, the timers for off peak charging were set to avoid the peak load hours of 7am to 10pm.

As provided by Alison M. Kaufman[22], Dominion smart meter plans and capabilities at this time are as follows:

- Dominion currently has EV time based rates[23] which offer a lower price for charging electric vehicles during the overnight, off peak periods
- At this time, the Company does not offer the ability to bill a customer's account when charging from a community location.
- Long term, Dominion is looking at all available options
- The present smart meters in use and installed at the sites do not allow drawing power from the cars or controlling load demand
- If a customer had a smart meter, they would have to voluntarily enroll in a Dominion program that would allow Dominion to use the smart meter in such manners

[22] Information provided, reviewed and approved by Alison M. Kaufman
Program Manager, Dominion Resources Smart Meter Program
[23] See https://www.dom.com/about/environment/electric-vehicles.jsp

Conclusions

The electric vehicle industry is expanding and evolving. At the beginning of the Project, the Nissan Leaf was the vehicle most appropriate for the analysis. At the time of this report there has been a move toward an SAE standard for DC Fast charging, and other manufacturers have begun building electric vehicles. A BMW i3 and GM Spark press release emphasized that 80% Bulk charge can be accomplished in 20 minutes; as demonstrated, the charge profile from the Leaf often spanned across one hour.

The SAE standard J2847-2 defines that the vehicle shall determine its particular bulk SOC that is optimum for DCFC and shall also calculate the time remaining. This may lead to different battery charge state displays between different vehicle manufacturers. It may be difficult to do comparison shopping for the best charger performance for the chosen vehicle.

The EV 12-Volt accessory battery system is unfamiliar to the aftermarket upgrades. For the gasoline engine industry, there is highly integrated and general familiarity with 12-Volt battery systems, including alternators and regulators. The EV 12-Volt battery charging systems, using system solar cell and propulsion battery sources, are unfamiliar niche products not yet in the mainstream market place, representing challenges in provisioning aftermarket electrical system products.

With the challenges presented, it has been shown that consumer forums are robust in documenting and reverse engineering some of the issues. That being said, it is clear that a means should be sought to better regulate or document the confusing data, potentially through standards compliance or changes.

With the potential cost savings and reductions of greenhouse gas emissions, the EV is sure to be incorporated into many venues.

Adopters of the EV technology must be aware of, face, and resolve the challenges presented in this report, and others that must be found and resolved.

Summary for Municipal Planners

This Project faced typical technology challenges. Future municipal fleet planners should prepare for and resolve the following challenges up front. The list offers a quick synopsis for the casual reader and offers an outline for the detailed investigator or project manager facing an installation.

Define the application

- How many miles need to be covered during a typical shift?
- How much time is available to charge?
- How many charging opportunities are there during and between shifts?
- What impact will the region's terrain and climate have on the vehicle choice?
    - Will a backup alternative fuel vehicle or charger be necessary?

Define the vehicle needs

- What kind of cargo and/or how many occupants will a vehicle need to carry?
- What kind of accessory loads does the vehicle need to provide?
    - Will it require after-market electrical add on capabilities, such as Police light bars?
- What kind of duties will the vehicle need to perform?
- Which vehicle offers charge timers to provide the best benefit of readiness and cost?

With a defined application, it is possible to use the Project's recommendations for charger selection:

- Small fleet, minimum users, small commutes
    - AC chargers with high amperage capacity
- Mid-size fleet, multiple users, medium trips
    - AC chargers with medium to large amperage capacity
    - DCFC with 25kW power
- Critical Mission Fleet
    - AC chargers with large amperage capacity
    - DCFC with 44kW, 50kW or higher power

In addition, the following environmental considerations must be included in the decision process:

- What are the locality's historical high and low temperatures?
- If you need DCFC, what is the lowest kWh required to meet vehicle needs?
- Which available charge protocol allows the car to quickly charge the battery and minimize spreading a charge session across a long time period? This may help drive vehicle selection.

Finally, it is critical to provide extensive and immersive driver training prior to driving

- Determine, plan, and engage employees about the policies for recharge needs which will differ from gasoline vehicle policies, especially for critical mission fleets
- Provide a simplified decision tree for choosing which type of charger to use under differing circumstances, such as time before next use, planned trip distance, timer settings, and cost
- Provide mileage expectations to the operators
    - Reductions in mileage from driving style
    - Battery Mileage variations resulting from temperature considerations
    - Reductions in mileage when using climate control
- Determine policies on how to schedule climate timers
    - Beware of the cost of climate control timers when the vehicle may not be driven
- Monitor vehicle usage and driver satisfaction closely for the first 30, 60 and 90 days.

Check results against upfront assumptions and be prepared to re-evaluate the effectiveness of an EV in a role formerly occupied by an internal combustion vehicle.

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*** END ***

Exhibit A: Nissan Instructions for Leaf Charging

The following paraphrases represent information in the Leaf's owner's manual.

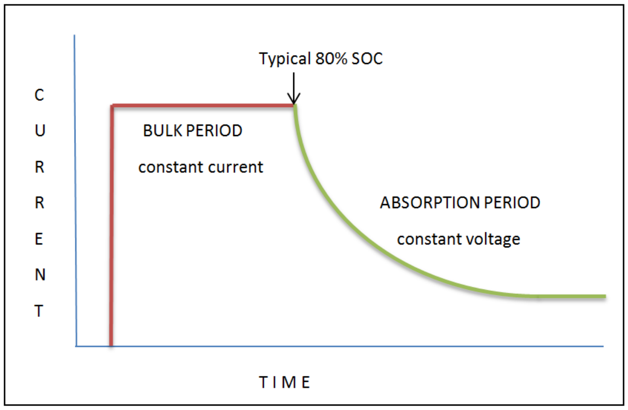
- Use normal charging for usual charging of the vehicle.
- Minimize Quick Charges to prolong battery life.
- Quick charging is possible several times a day unless the battery temperature reaches the red zone, where quick charging is not allowed and the power limitation mode will be triggered to protect the battery.
- Set up an 80% SOC timer to engage long life charging mode for maximum battery life.
- The 12-volt battery can become discharged if the charging timer is operated repeatedly for an extended period of time.

  "NISSAN recommends you use the following driving and charging habits, where possible, to help maximize the battery's useful life:"

- Avoid ambient temperatures above 120°F (49°C) for over 24 hours.
- Avoid temperatures below −13°F (−25°C) for over 7 days.
- Avoid leaving your vehicle for over 14 days where the battery reaches near zero state of charge.
- Allow the vehicle cool down before charging.
- Park/store your vehicle away from direct sunlight and heat sources.
- Avoid sustained high battery temperatures
- Avoid frequently charging to 100% state of charge or leaving the battery above 80% state of charge for long periods of time
- Discharge the battery to less than 80% before recharging
- Drive moderately and use the ECO mode
- Unless driving a long distance, use 80% Long Life charging
- Stow the vehicle over an extended period of time by charging the battery with long life mode once every 3 months. Do not operate the charging timer repeatedly which may discharge the 12V battery.

Exhibit B: Typical Charge Profiles and Cell Balancing

A typical charge curve for lithium-ion batteries is shown below[24]. The large "bulk" constant current can flow until the battery voltage reaches nominal. Then, the "absorption" period reduces the current to avoid over voltage.



For rapid up front refills, the DCFC should operate in the Bulk period at a high constant current. The Leaf often follows the absorption exponential decay when the battery charge is not very low or the temperature is low. The Leaf did exhibit a Bulk period at warmer climates with deeper discharges. To get the most DCFC fill up in a short period of time, the Leaf's battery charge remaining should be relatively low.

General information on the technology of Lithium Ion Cell Balancing is available from the Web[25]. Batteries are composed of individual cells which may not charge the same as other cells in the battery. The total capacity is set by the weakest cell. The cell balancing process equalizes the energy in each individual cell either actively or passively, by discharging or transferring energy from the strong cells to balance the energy in the weaker cells. The process continues charging and balancing until all cells are fully and equally charged for maximum capacity.

Specific Leaf information was not available from Nissan in the literature. However, here is information from one user Web forum[26].

> "When I charge [my 2013 Leaf] to 100%, the charger runs at full power up to 98% and then goes to a very low power setting which may take an additional 40 to 60 minutes to reach 100%. I assume the battery is balancing at this point, however it seems like it taking a long time to do this.
>
> "While I cannot answer your questions, I will say that this sounds like a much better algorithm than what is included in the 2011/2012s. This should be capable of fully balancing the cells with a single charge to 100%, which is something the older Leafs did not seem able to do with the exception of L1 charging. The benefit here is that you can be assured that you are leaving with a full and balance pack, something I am never quite confident of unless I charge our 2011 at L1."

[24] "Electric Vehicle Battery Technologies", Kwo Young, Caisheng Wang, Le Yi Wang, and Kai Strunz
[25] See http://www.digikey.com/us/en/techzone/energy-harvesting/resources/articles/battery-cell-balancing.html
[26] See http://www.mynissanleaf.com/viewtopic.php?f=9&t=13912

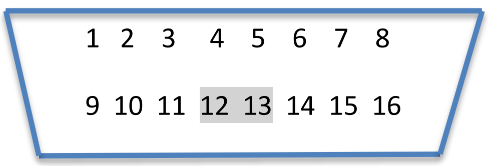
Exhibit C: CAN Data and Definitions

Vehicle to DCFC Data Messages (CHAdeMO Protocol[27])

Type 0x100: - Total capacity of vehicle battery (Used by charger to display charge rate)
Type 0x102: - Remaining capacity of vehicle battery (Used by charger to display charge rate)
- Instantaneous Charging Current requested by vehicle
- Value of battery end of charging voltage
Type 0x101: - Maximum charging time permitted to charger by vehicle

Per a WEB forum[28], there are three CAN buses on the Leaf's On-Board Diagnostic Port. Observation of the vehicle primary CAN data link could be considered but the database is not available and would be difficult to determine what the data means. The present equipment can only monitor two Data links and they are best used for the EV CAN data link in the vehicle and the CHAdeMO data link to the DCFC.

Leaf On-Board Diagnostic Port Pin Connections for the EV CAN bus follow:



Pin 12 = EV CAN-L

Pin 13 = EV CAN-H

Per the Web, the following vehicle EV CAN parameters may be worth recording for analysis, validation, and correlation to the web forums:

Vehicle EV-CAN data:

Type 0x55B State of Charge
Type 0x1DB Battery Voltage and Battery Current
Type 0x5B9 Available Charge BARS
Type 0x5BC Available Charge, 0-281 GIDS Reference: Gary Giddings, Ph.D.

The CAN data plots provide a visual graphical representation of the DCFC session as shown in the following figures. The time (x axis) is in seconds with multiple data files each starting at zero seconds. The deep red color trace, BCS, is the reported Leaf battery charge current.

These curves illustrate issues discussed in multiple places in this document including:

- Cold and Warm temperature data under similar battery SOC conditions
- 25kW and 44kW Charger operation under the similar battery SOC conditions
- Battery conditions of very high SOC, 30 MTE SOC, and 6 MTE SOC
- The exponential charge current characteristic
- The spread of all charge sessions toward a 1 hour time frame

[27] CHAdeMO Protocol "Technical Specifications of Quick Charger for the Electric Vehicle", Rev. 0.9, April 9, 2010
[28] See: http://www.mynissanleaf.com/viewtopic.php?f=37&t=4131

Winter Climate Data

Environmental 2012 Leaf, City Yard Nissan NSQC442E Standard Model DCFC, and cold climate

Figure 1: Test C-1, 44kW charger, 45 MTE SOC, 1 hour Car Limit time out occurred, 35°F, 5.6kWh delivered, 60min 0sec

The above represents a medium depletion of the battery with the recharge spread over one hour that terminated because of the Car enforced a time limit of 1 hour.

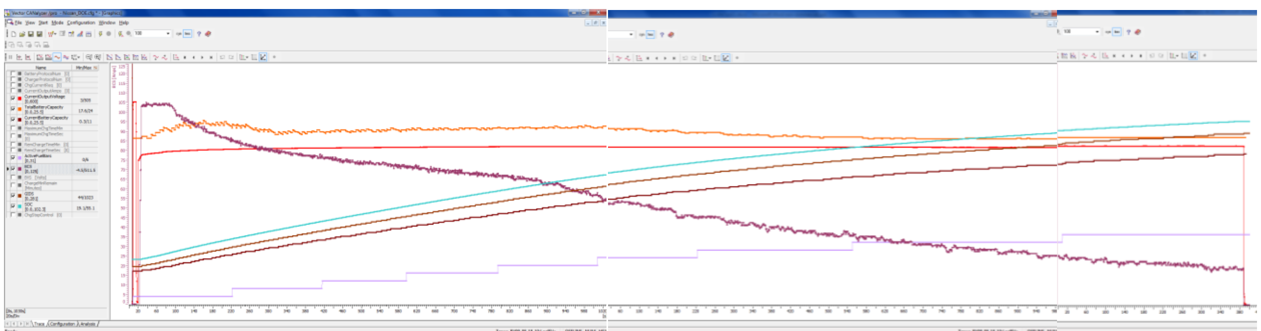


Figure 2: Test D-2, 44kW charger, 6 MTE SOC, 90% of 80% Session Car Limit, Initial SOC <50%, 40°F, 13.6kWh delivered, 40min 05sec

The above represents a very deep depleted battery that stopped at the car limit of 90% of the DC 80% recharge limit (72% SOC)

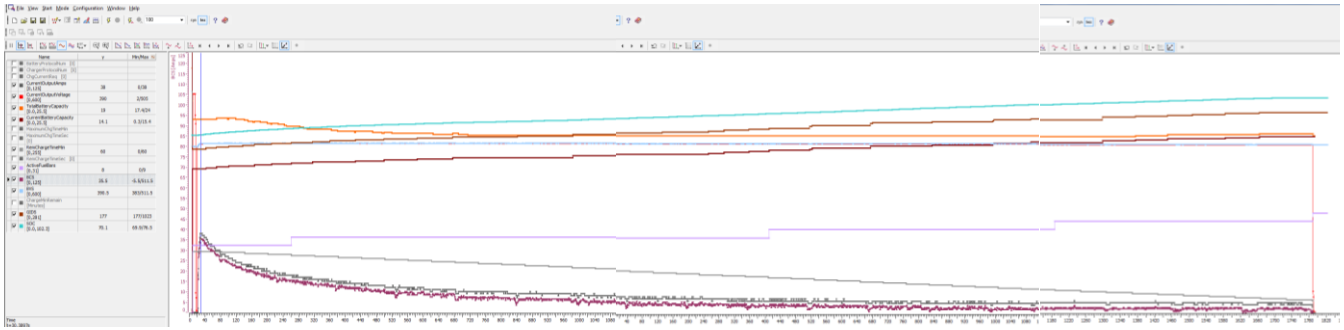


Figure 3: Test 11, 44kW, 61 MTE, 100% DC SOC, 17°F, 2.6kWh, 47min 58sec

This curve represents a very small charge requirement spread over 1hr, representing a very good reason to restrict DC charging cases when the battery has this high initial SOC. This small amount of power took a long period of time due to the charge control profile.

)

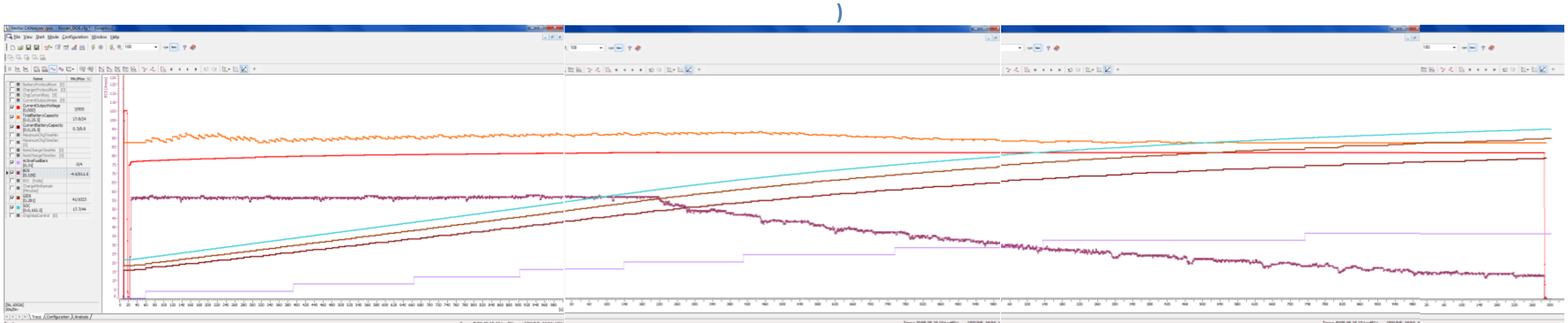


Figure 4: Test E-2, 25kW, 6 MTE, 90% of 80% Car Limit (charges to 72% SOC), Initial SOC < 50%, 29°F, 14.2kWh, 54min 39sec

This curve exhibits a Bulk appearance because the charger is limited at 25kW and the Leaf battery is almost completely discharged.

Spring Climate

2012 Leaf vehicles as designated, City Yard Nissan NSQC442E Standard Model DCFC, mixed power levels, warm climate
Some gaps occur in the graphs due to PC anomalies during the intermediate file save procedures done to minimize file sizes.

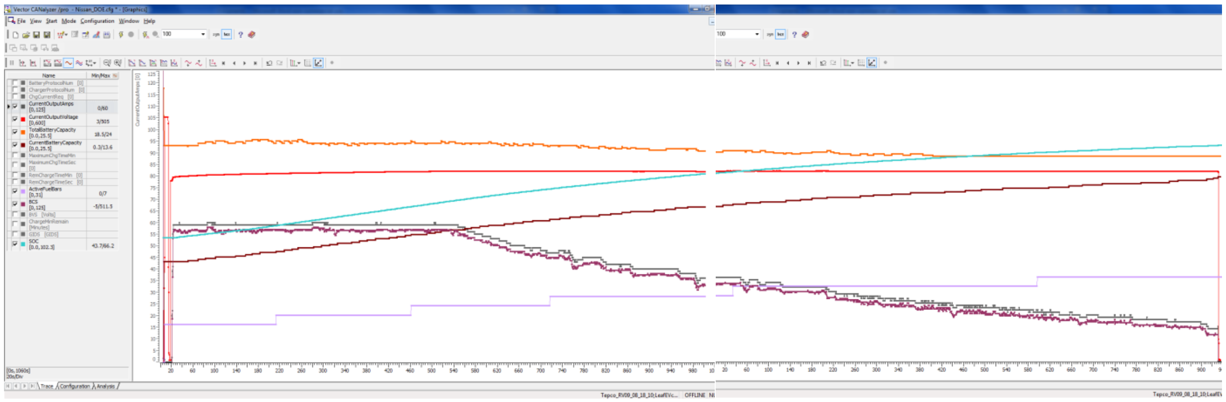


Figure 5: 25kW Environmental Leaf, 60°F, 32 MTE, Leaf Stopped Charger at Leaf Reported 90% on Charger Display at 8kWh

The above represents 90% car charge limit of the 80% DC charge (charges to 72% SOC) on a 25kW power charger at warmer climate.

(~1930 s = 32min 10sec, Charger = 31min 55sec)

APPROXIMATION: **Let Factor = (390V*57A)/ 1000 / 3600**

Plateau kWh = $\{Factor * t\}_{\text{for } 0 < t \text{ \& limit at } 540}$ **PLUS** **Exponential kWh =** $\{Factor * (890 - 890 * e^{-(t-540)/890})\}_{\text{for } t > 540}$

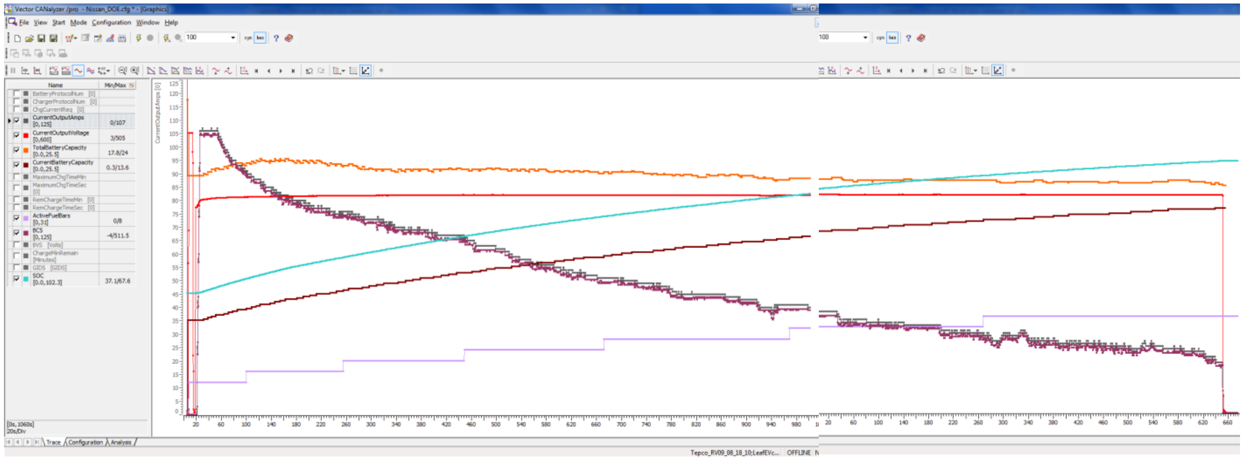


Figure 6: 44kW Traffic Leaf, 60°F, 26 MTE, Leaf Stopped Charger at Leaf Reported 90% on Charger Display at 8.9kWh

The above represents 90% car charge limit of the 80% DC charge (charges to 72% SOC) on a 44kW power charger at warmer climate.

(~1670s = 27min 50sec, Charger 28min 35sec)

APPROXIMATION:

Plateau kWh = {390V*105A*t/1000/3600} $_{\text{for } 0 < t \text{ \& limit at } 40}$ **PLUS**

Exponential 1 kWh = {60A*290V*(t-40) + (45A*390V*(180 – 180*e $^{-(t-40)/180}$**)}/1000/3600** $_{\text{for } 40 < t < 460}$ **PLUS**

Exponential 2 kWh = {65A*390V*(1100 – 1100*e $^{-(t-460)/1100}$**)}/1000/3600** $_{\text{for } 460 < t}$

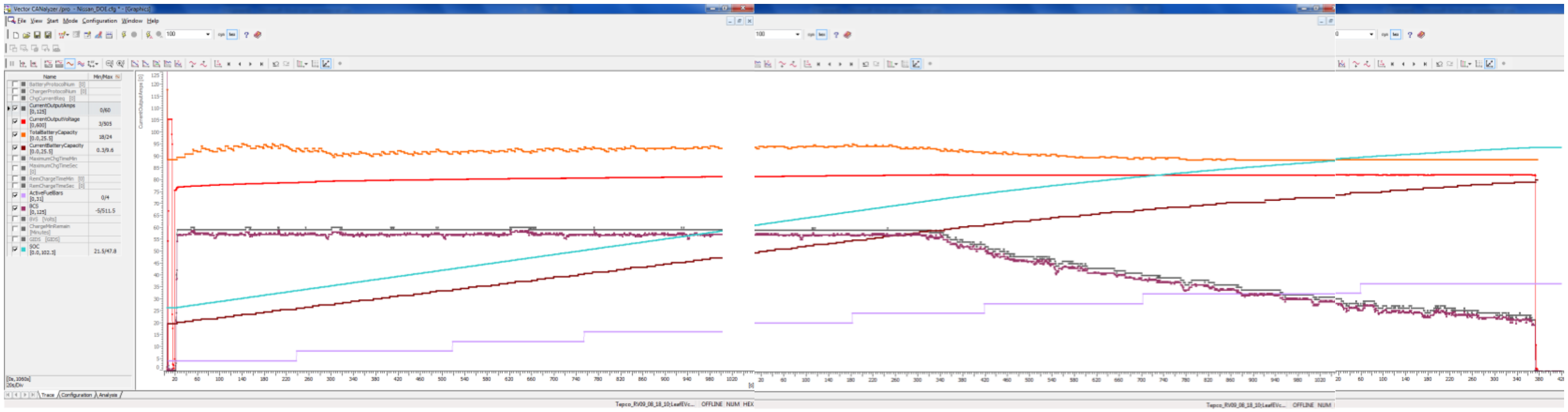


Figure 7: 25kW Environmental Leaf, 58°F, 8 MTE, Leaf Stopped Charger at Leaf Reported 90% on Charger Display at 13kWh (~2470s = 41min 10sec, Charger 41min 35sec)

This shows about the same up front plateau energy compared to the Cold Climate data in Figure 4, 14.2kWh, 54min 39sec. Hence, the temperature range tested did not significantly affect the results.

APPROXIMATION: **Let Factor = (390V*57A)/ 1000 / 3600**

Plateau kWh = {Factor * t} $_{\text{for } 0 < t \text{ \& limit at } 1300}$ **PLUS** **Exponential kWh = {Factor * (1570 – 1570 * e** $^{-(t-1300)/1570}$**)}** $_{\text{for } t > 1300}$

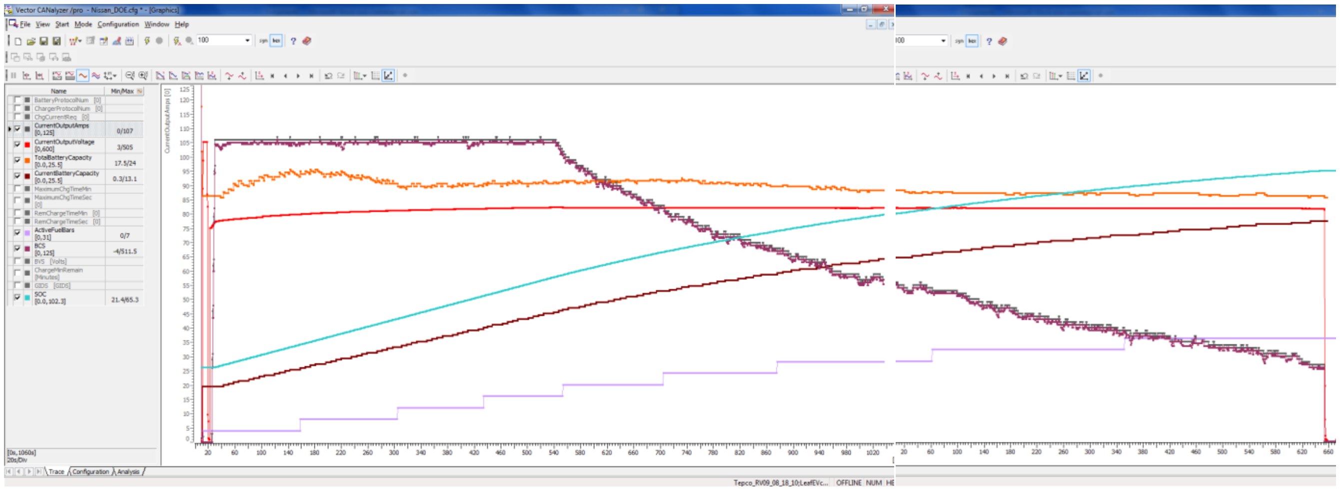


Figure 8: 44kW Traffic Leaf, 72°F, 6 MTE, Leaf Stopped Charger at Leaf Reported 90% on Charger Display at 12.8kWh (~1690s = 28min 10sec, Charger 27min 47sec)

This curve shows more up front plateau energy compared to the Cold Climate data in Figure 2, 40min 05sec at 13.6kWh.
This curve also shows more up front plateau energy than the 26MTE curve on the same vehicle and charger at the same temperature in Figure 9.

APPROXIMATION: **Let Factor = (390V*105A)/ 1000 / 3600**

Plateau kWh = $\{Factor * t\}_{\text{for } 0 < t \text{ \& limit at } 540}$ **PLUS** **Exponential kWh =** $\{Factor * (700 - 700 * e^{-(t-540)/700})\}_{\text{for } t > 540}$

Exhibit D: Quick Reference Instruction Sheet

DO NOT OPERATE DURING THUNDER, WHEN HANDS OR CONNECTORS ARE WET, EXTREME TEMPERATURE OR IF DAMAGED

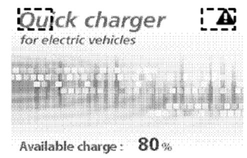
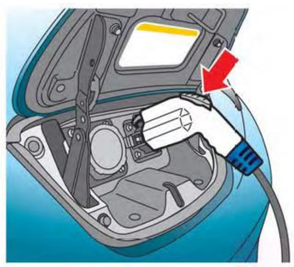
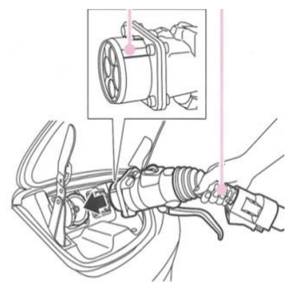
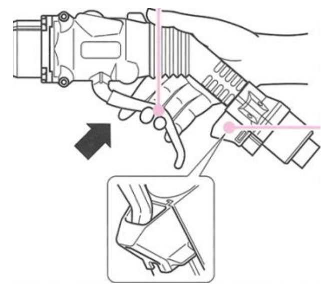
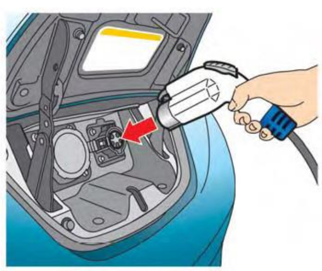
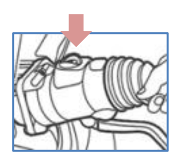
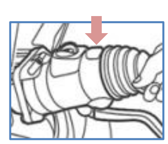
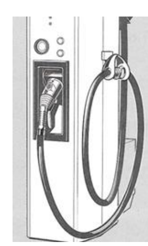
INSTRUCTIONS	AC CHARGER	DC FAST CHARGER
Vehicle OFF Park Gear Park Brake Doors Closed	---	 Ready
Only For AC Immediate Charge	For Immediate Charge  Set Car Timer Off	Not Applicable
Insert and Lock The Charge Plug Into the Correct Car Inlet Port	 Insert to AC Inlet on RIGHT	 Insert to DC Inlet on LEFT  Pull Lever and LOCK into Slide
START	The Charge will start Automatically or when the Timer is set to Start	 Press START Button  Charging Screen after Tests  Locked LED Lights
STOP	 Press PROXIMITY Button	 Press STOP Button  Locked LED Off
Disconnect Cable	 Stow Cable and Plug	 Press RELEASE Button  Move Slide to Release Lever Remove Plug  Stow Cable and Plug

Exhibit E: City of Charlottesville Log Journal

Leaf Driving Log – Data Collection for US DOE Grant Reporting – January 20 to April 30, 2014

Day / Date (ex. Mon / 1-19)	Time Start	Start Odometer (Miles)	Time Returned	End Odometer (Miles)	Est. Remaining Mile Range	Charger Level (DC / L2 / L2 - Immediate)

Leaf Driving Log – Data Collection for US DOE Grant Reporting – January 20 to April 20, 2014

Day / Date (ex. Mon / 1-19)	**Feedback / Comments** Pleas share your experiences with the car and charger performance and use; concerns about the car and charging in general. How challenging or easy was it to utilize the vehicle sufficiently to use the Fast Charge option?