Plug In America's LEAF Battery Survey

by Tom Saxton

Updated: December 27, 2012

Introduction

The Nissan LEAF comes with an 8-year or 100,000 mile warranty on the battery pack. That's a whole lot of electric driving, and a lot of money saved over burning gas.

LEAF owners have been told to expect some loss of capacity over time and miles. In January, 2010, Mark Perry, Nissan's Director of Product Planning for the United States, set the expectation of having 70% to 80% capacity after 10 years and that the LEAF's battery pack would meet that without active thermal management in the US[1]. In October, 2012, Andy Palmer, executive vice president of Nissan stated that the battery degradation norm was set using the LA4 driving cycle and 12,500 miles per year, yielding an average battery capacity level of 80% at 5 years and 70% at 10 years.[2]

At least a few LEAF owners in hot climates have experienced more capacity loss than expected, but many others are not seeing any noticeable loss. Owners, and potential owners, are understandably curious to know what the typical experience is like and what factors influence battery health.

Plug In America is conducting a survey to better understand these issues. Early results are presented here.

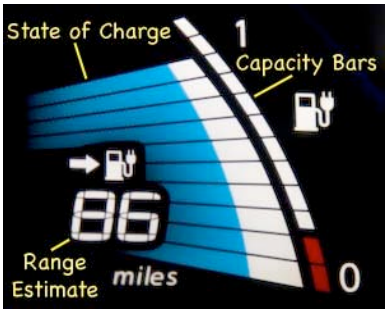
Survey Data Collected

Nissan LEAF owners were invited to contribute to the survey by answering a series of questions about their location, car, driving, and charging behavior, as well as both objective quantitative and subjective qualitative questions about how their battery capacity has changed.

Sample Distribution

The survey was promoted through various social media services including the My Nissan LEAF owners forum (MNL), various Facebook LEAF owner groups, and Plug In America's newsletter. One of the first places it was posted was on an MNL thread discussing the battery capacity loss issue, so early data was probably oversampling owners who have lost battery capacity at a higher rate than the average owner. It's difficult to know how balanced the survey data is without more information from Nissan, but the data is broad enough to establish some apparent patterns to the data even if it is not certain how common battery degradation issues are among the full LEAF population.

Measuring Battery Capacity



The Nissan LEAF has a 12-segment battery capacity display. A new battery pack begins with 12 capacity bars. According to Nissan's service manual, when a battery pack's capacity has dropped 15%, the top capacity bar will disappear. Each subsequent bar represents another 6.25% capacity loss.

Battery capacity can be measured in higher resolution with an aftermarket meter which reports the current state of charge in energy units called Gids[3] by the LEAF owner community. A Gid represents 80 Wh, although that may vary with temperature[4]. A new battery will show about 281 Gids after a full Level 2 charge in moderate weather. Of the LEAFs reported on the survey, 30 out of 240 (12.5%) reported Gid readings for a 100% charge.

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[1] http://www.wired.com/autopia/2010/01/nissan-leaf-2/
[2] http://green.autoblog.com/2012/10/10/nissan-andy-palmer-leaf-battery-degradation-crisis-video/
[3] http://www.mynissanleaf.com/wiki/index.php?title=Glossary
[4] http://www.mynissanleaf.com/viewtopic.php?f=44&t=9689&start=9

Nissan LEAF Annual Battery Report

At each annual service for the LEAF, Nissan performs a battery check and gives a "report card" to the owner. This reports shows the battery's capacity as a 12-bar rating, identical to the 12 capacity bars shown on the LEAF's dashboard. It also grades the owner's pattern of use in driving and charging the LEAF as feedback for how well the owner is treating the battery.

Each of the four patterns of use receive a star rating from 5 stars (minimizing impact on battery health) to 1 star (not so good), for a potential high score of 20 points. The categories are:

- Frequent use of quick charging
- Frequent charging when battery state of charge is already high
- Too much electric consumption while driving
- Long term parking with high state of charge

A sample battery report is included on page 12.

Results

Some results from the survey are shown below as a series of graphs designed to answer questions about what factors are most influential in determining the rate of battery capacity loss in the Nissan LEAF.

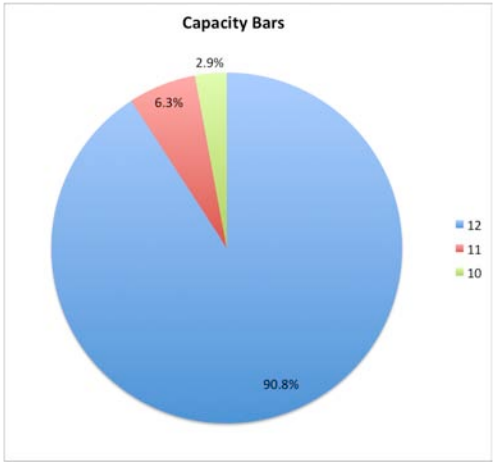
Data Collected

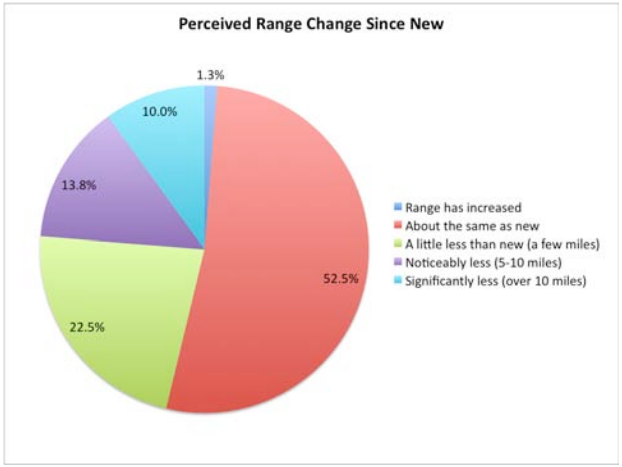
The survey has so far collected detailed data on 240 vehicles, with contributions from over 25 states, 2 Canadian provinces, and the UK, representing over 3 million miles driven.

Number of LEAFs surveyed	240
Average miles driven	13,152
Median miles driven	11,600
Most miles driven	57,600
Total miles reported	3,198,764
Vehicles with all 12 capacity bars	218 (90.8%)

Current Battery Capacity Reported

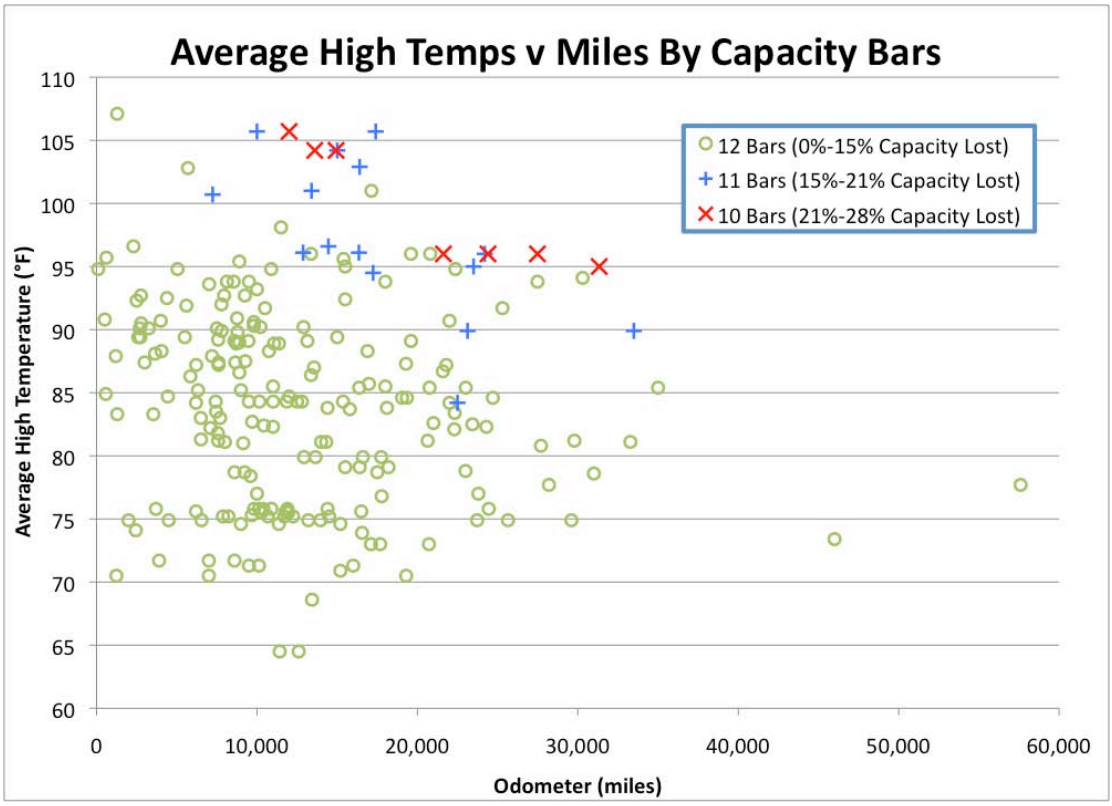
Survey participants were asked to describe their car's current range both objectively, by number of capacity bars, and subjectively by perceived change in range since acquiring the car. The chart below on the left shows that 90.8% of the vehicles are still showing all 12 capacity bars, meaning they are within 15% of nominal full capacity. The chart on the right shows that 76.3% of owners believe they have lost no more than a few miles of range.





Does Climate Affect Battery Longevity?

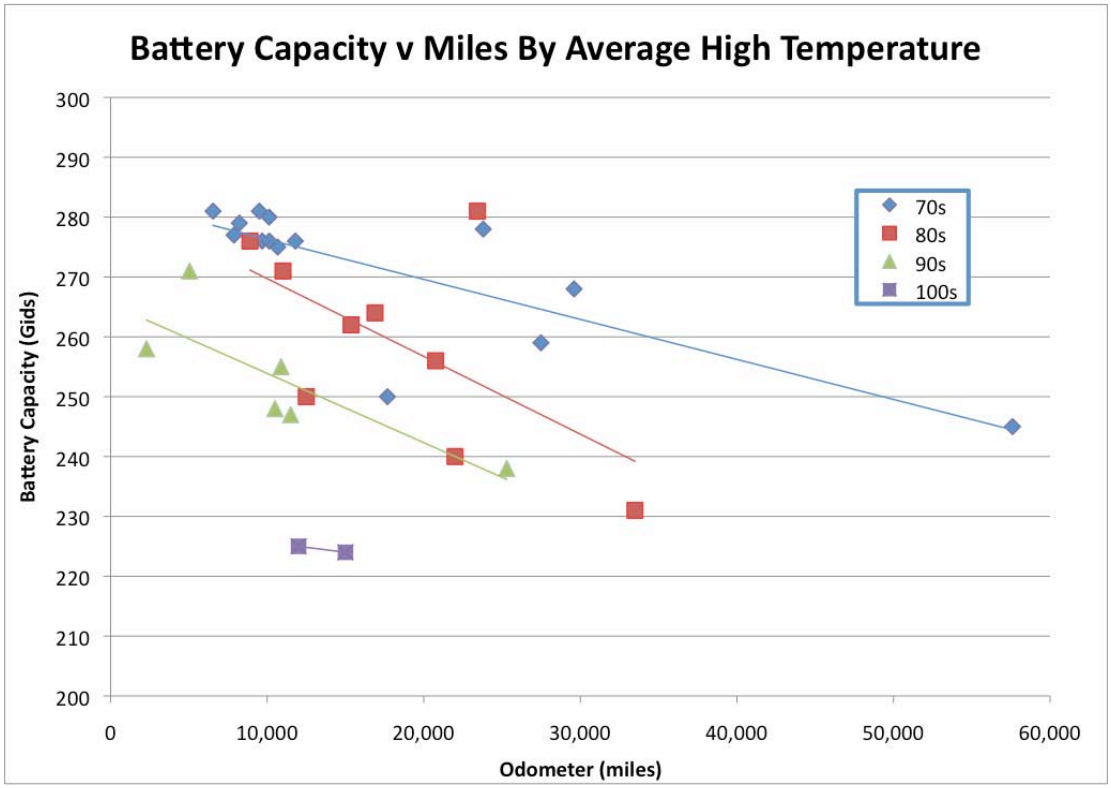
To measure the effect of climate, specifically hot weather temperatures, on battery capacity, the web tool http://www.melissadata.com/lookups/ZipWeather.asp was used to look at the average daily highs for each US zip code reported to the survey and assigned the highest value reported to each zip code. In the graph below, high temperature is plotted against odometer for each vehicle in the survey. These data points are drawn in three groups by the number of capacity bars reported.



The graph shows a clear correlation between high temperature areas and lost capacity. All but one of the cars showing lost capacity bars are in hot climates (summer days hit 90° F or higher on average). Note that not every car in the hot climate portion of the graph reports having lost capacity. Note also that the greatest lost capacity, red x markers, are in the hottest climates.

This data indicates that hot climates accelerate the loss of battery capacity and the hotter the climate, the faster the rate of capacity loss in cars affected by this issue. Some cars in hot climates are not losing capacity, but there is not yet enough data to understand the proportion of cars affected or what determines which cars have the issue.

The capacity bars are pretty coarse. Someone reporting 12 capacity bars might still have full nominal capacity, or they could be very close to losing the first capacity bar. We can get better resolution from the those owners who have reported full charge Gid readings. The graph below shows Gid readings for fully charged battery packs versus miles driven, with the data points drawn in groups by the average high summer daily temperature.

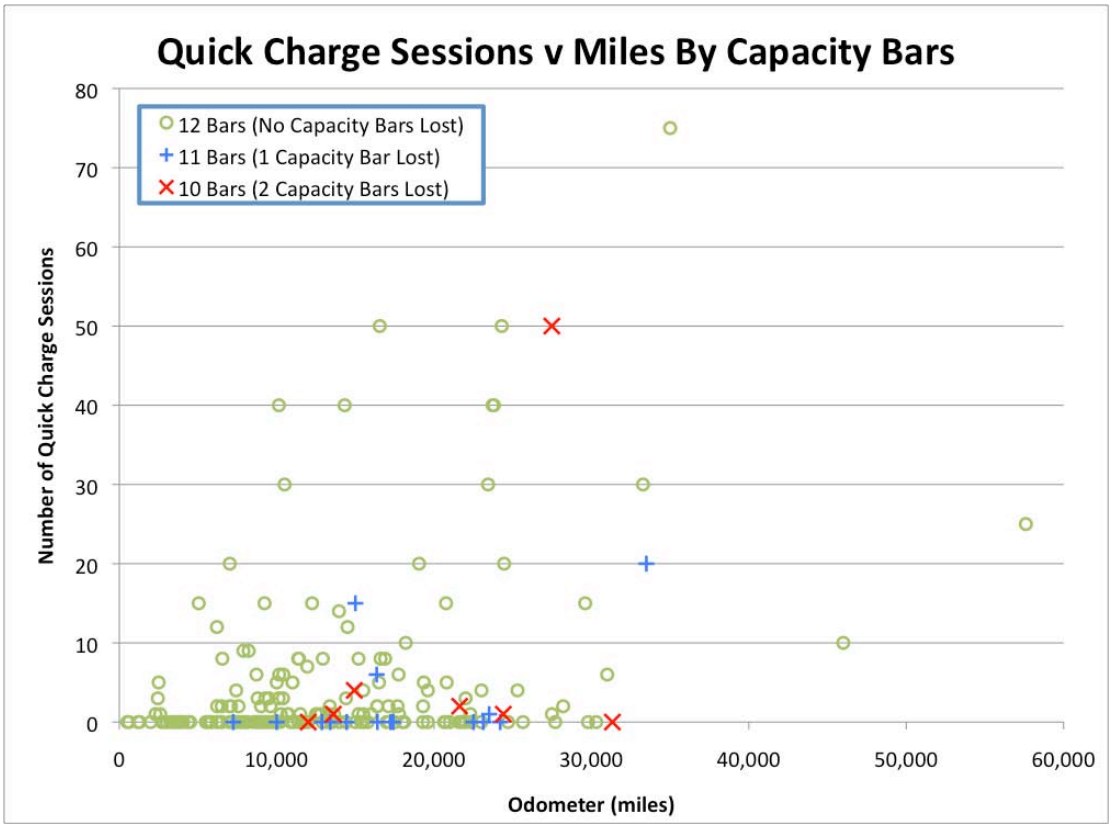


The blue diamonds represent the vehicles in moderate climates, with average high summer temperatures in the 70s. These cars consistently have the highest Gid readings for miles driven. The red squares represent vehicles in climates that get average high temperatures in the 80s and fare somewhat worse than the first group. The vehicles which see summer temperatures in the 90s (green triangles) are showing significantly lower battery capacity as compared to cars with similar mileage, beginning with as little as a few thousand miles driven. The two cars in the hottest climates reported, with summer high temperatures average 100° or higher, are showing even more lost capacity despite their relatively low mileage of 12,000 to 15,000 miles. These two hot-weather cars have lower battery capacity than the two highest mileage cars reported at 33,488 and 57,600 miles in more moderate climates.

What Does Nissan's Battery Report Tell Drivers?

To explore the effect of the behaviors graded in the Nissan battery report, the survey asks drivers to describe their charging routine in the three charging categories in the battery report.

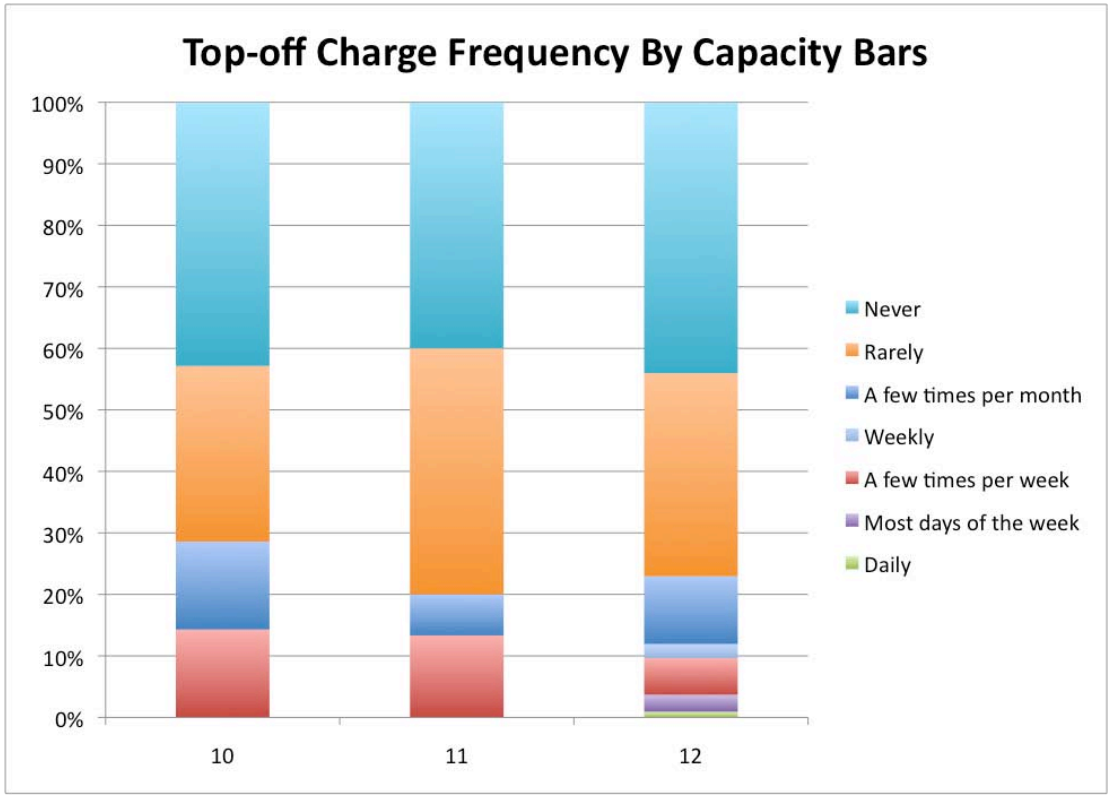
The graph below shows the odometer and number of quick charge sessions reported for each vehicle, with vehicles grouped according to their capacity bars. The graph shows that many of the cars that have lost capacity reported no use of quick charging, and a broad scattering of significant use of quick charging in cars with significant miles driven without losing any capacity bars.



Nissan originally recommended no more than one quick charge per day, but in later revisions to the LEAF Owners Manual, removed that statement.

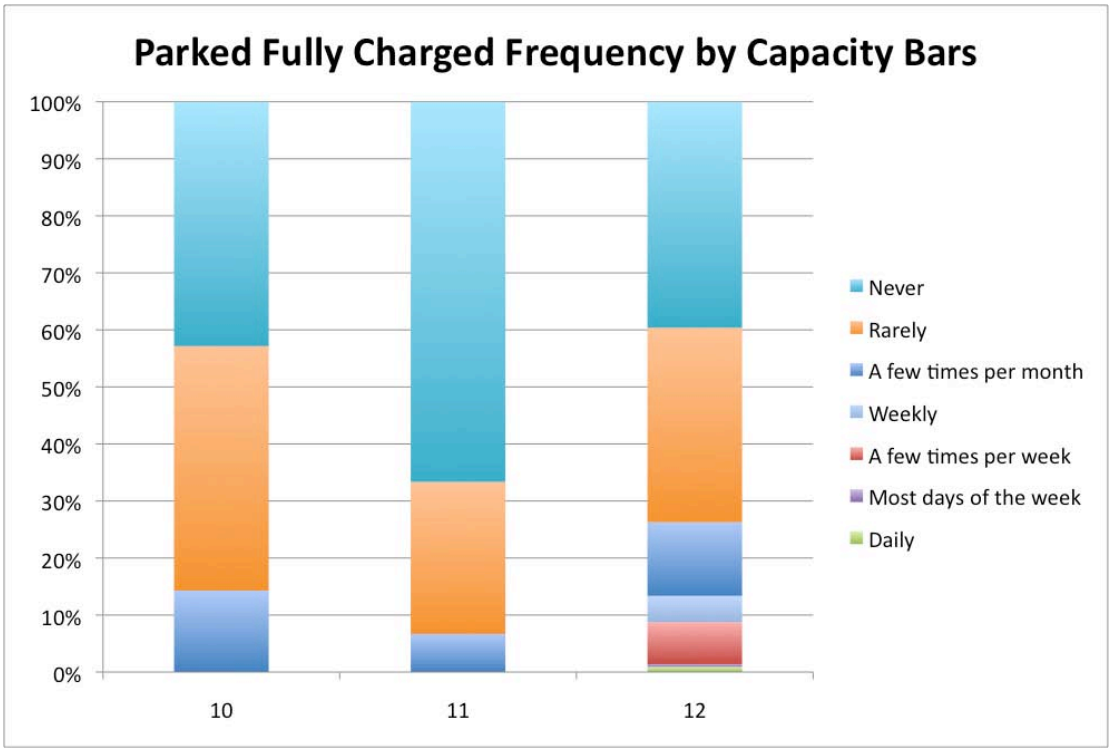
The author had occasion to do two back-to-back quick charge sessions on June 5th, 2012, for a 160-mile trip, and then participated in the inaugural EV rally along the US 2 highway from the Seattle area up over Stevens Pass (elevation 4,065 ft) to Wenatchee on June 16th. This 267-mile trip required 6 quick charge sessions in one day. A local LEAF technician requested that the car be brought in for a battery test after the intense use of quick charging. The result of the test was a full 20-point score, including a 5-star rating on "frequent use of quick charging." Nine quick charge sessions in less than two weeks was not enough to lose a star on the quick charge category.

The graph below shows how often drivers report that they top-off a charge (the second item on Nissan's report card), grouped by capacity bars. The top three graph segments represent the least frequent top-off charging "never" (top), "rarely", and "a few times per month." Only a few drivers in each category, less than 15%, report doing top-off charging one or more times per week.



The third item, "too much electric consumption while driving," is difficult to access due to a lack of reliable instrumentation for measuring energy use. Although the LEAF has the capability to report energy use to drivers through the CARWINGS service, the most common comment from survey participants is describing problems with the statistics reported: long periods of missing data and/or figures reported that differ widely from the owner's expectation based on observing the car's on-board instrumentation. The only reliable way to measure energy use is to record odometry and meter all energy transferred to the car during charging. Few owners have the equipment, or desire, to perform these measurements.

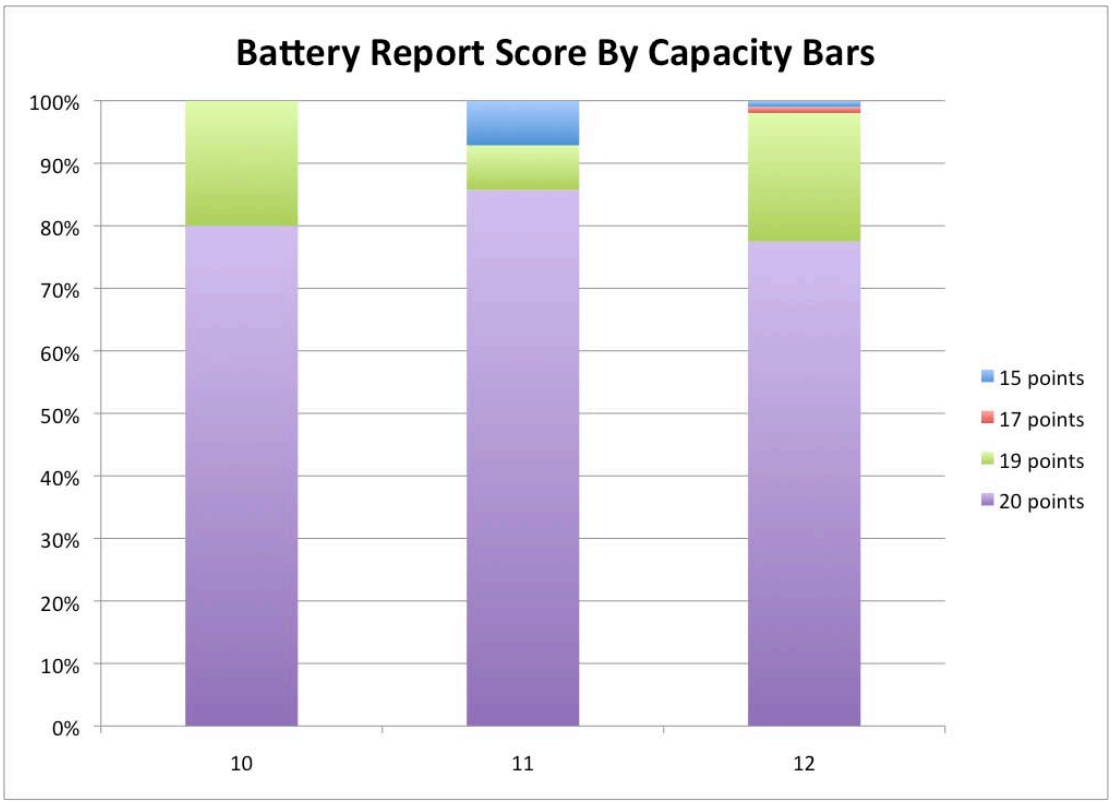
The graph below shows the frequency that owners report leaving their car parked for 12 hours or more with a high state of charge. A large portion of the drivers who have lost capacity report doing this "never" or "rarely." In contrast, a relatively larger portion of drivers reporting no energy loss park fully charged at least a few times per month.



These three graphs show no strong correlation between the behaviors assessed in Nissan battery test report and battery capacity loss. The majority of drivers do these potentially detrimental charging actions infrequently, including those hot-climate owners who have lost capacity bars faster than their moderate-weather peers.

The three previous graphs look at how drivers report their charging behavior in categories similar to the items that appear on the battery report card, but those reports are somewhat subjective and we don't know exactly what is measured by Nissan to generate the scores.

About half of the survey participants (121 out of 240) included battery report scores in their survey data. The graph below shows how the report scores are distributed among owners grouped by capacity bars.



The graph shows that 77.5% of owners with full capacity bars got a perfect score of 20 on the battery report. An even greater portion of the owners who have lost capacity got perfect scores. If we combine the 10 and 11 bar groups, we find 16 of 19, or 84.2%, got perfect scores. This suggests no strong correlation between the battery report score and battery capacity loss.

High Mileage LEAFs

The top three high-mileage vehicles in the survey report having driven 35,000, 46,000, and 57,600 without losing a capacity bar. The following table presents survey data for those vehicles. All three vehicles are being charged to 100% on a daily basis, with the top two being full charged multiple times per day. The three vehicles have received a significant number of quick charges. The two that reported battery test results received full 20-point assessments.

By the Gid measurement, vehicle #240 is at 87.2% of nominal full capacity after 57,600 miles. The owner has a typical trip distance of 130 miles, does two 100% chargers per day, and is now driving down to the low battery warning twice per day. Despite this heavy use regimen, this nearly-60,000-mile car has more battery capacity than some hot-weather cars with as little as 7,000 miles. Linear extrapolation suggests this vehicle will lose its first capacity bar at approximately 80,000 miles, although the author expects that capacity loss will be faster than a linear model would suggest if the current use level is continued due to the increased depth of battery discharge required.

It would be very helpful to get Gid readings from more high-mileage vehicles to establish an expected battery loss rate for LEAFs and compare how that rate varies with climate.

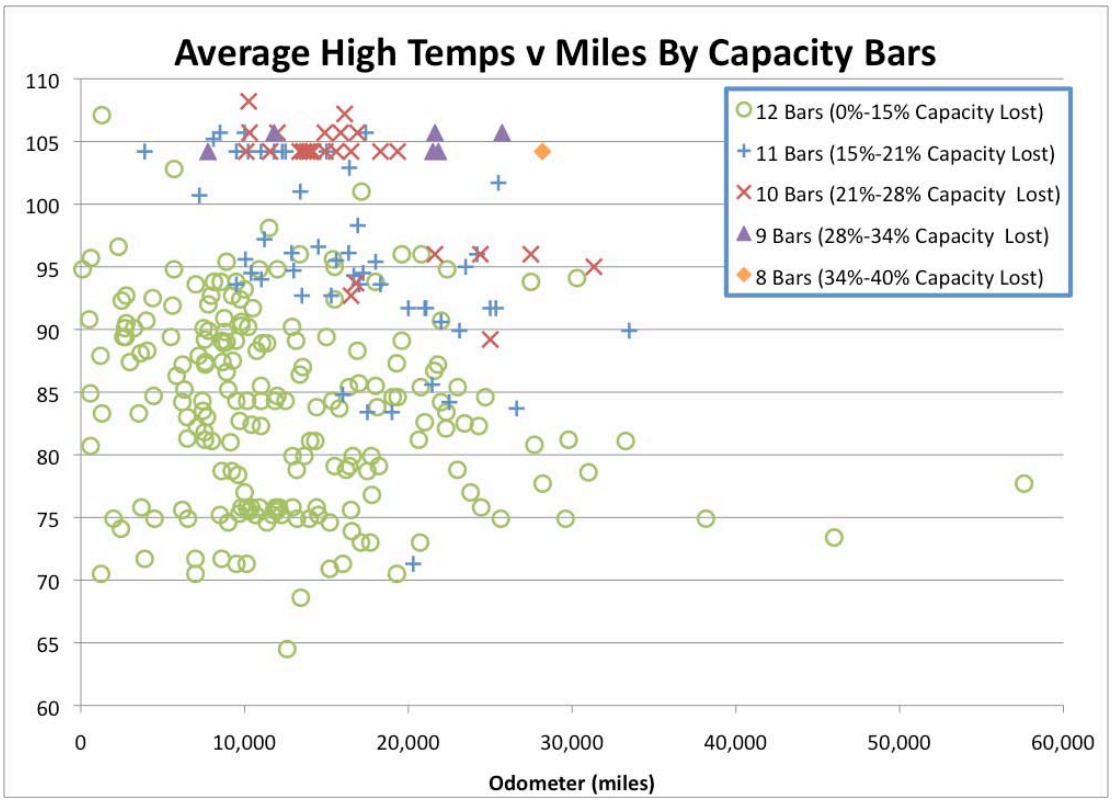
Survey Data From Highest Mileage Vehicles

PIA LEAF Survey Vehicle Number	240	232	6
Report Date	11/16/12	11/12/12	10/29/12
Model Year	2011	2011	2011
Country	United States	United States	United States
Location	Kent, WA 98030	Burlingame, CA 94010	San Jose, CA 95139
Zip Code Average High Temp (°F)	77.7	73.4	85.4
Built Date	03/01/11	02/01/11	03/01/11
Date Acquired	05/01/11	04/01/11	04/01/11
Quick Charge Port	yes	yes	yes
Odometer (miles)	57,600	46,000	35,000
Capacity Bars	12	12	12
Perceived Range Change	Noticeably less (5-10 mi)	About the same as new	About the same as new
Full Charge (Gids)	245	n/a	n/a
Days Owned	565	591	577
Average Miles/Day	102	78	61
Most Common Charging Method	Level 2	Level 2	Level 2
100% Charging Frequency	More than once per day	More than once per day	Daily
80% Charging Frequency	Never	Never	Never
Top-Off Charge Frequency	Never	A few times per month	A few times per week
Parked Fully Charged Frequency	Rarely	Rarely	A few times per week
Number of Quick Charges	25	10	75
Driving Frequency	Daily	Daily	Daily
Typical Trip Distance (miles)	130	60	40
Portion of Driving on Highways	95	80	60
Typical Highway Speed (mph)	60	65	65
Number of Low Battery Warnings	50	30	50
Number of "turtle" Warnings	1	1	0
Number of Battery Drains	1	1	0
Ownership Status	Own	Own	n/a
Battery Check Date	Oct-2012	n/a	May-2012
Report Card Total Score	20		20

Adding Data Collected on the My Nissan LEAF Forum

Prior to the Plug In America study, several LEAF owners who participate in the MyNissanLEAF.com owners forum (MNL) collected data from owners whose vehicles had lost capacity. They collected data on when each vehicle lost capacity bars with the odometer reading at the time of loss. Cars that lost multiple bars may appear in the data set multiple times. Not all cars were reported directly by the owners, some are secondhand, so not all reports have all data fields filled in. Looking at the reports that have VIN sequence numbers, there are 82 vehicles with reported capacity loss in the MNL data set, compared to 22 in the PIA survey data set. The MNL reports don't have systematic information about other potential factors for battery capacity loss, such as driving and charging behavior, so it can't be analyzed in as much detail as the PIA survey, but it is interesting to merge them into the survey data using the reported VIN sequence numbers to identify and merge data into a single comprehensive data set.

The graph below shows the combined data set of 288 vehicles with VIN, location, and odometer data.



The MNL data did not collect zip codes, only city and state, so representative zip codes were chosen for each city in order to look up climate data. Of course even in the PIA survey data, the owner's home zip code may not tell the whole story as an owner could, for example, live in cooler suburban foothills but do most driving in the hotter urban climate.

We do see the same general pattern as in the graph on page 3, although the combined graph shows cars losing a capacity bar at lower temperatures beginning around 16,000 miles. The 11-bar car shown at 71° (in the San Francisco, CA, area) and 20,300 miles is an outlier worthy of further investigation.

It would be helpful to get full survey data for the vehicles in the MNL set that haven't yet participated in the PIA survey.

Conclusions

Of 240 LEAFs reported in the survey, with a median of 11,600 miles driven, 90.8% are still showing all 12 capacity bars, meaning they are within 15% of nominal full capacity. Subjectively, 76.3% of owners believe they have lost no more than a few miles of range.

Of the data collected and analyzed thus far in the Plug In America LEAF Battery Survey, by far the strongest indicator of premature battery capacity loss is the owner's local climate conditions, specifically cars that have lost enough capacity to be visible on the car's dashboard capacity display are nearly all in hot-weather climates.

Not every car in a hot climate is seeing battery capacity degradation, and this study does not yet have enough information to determine what fraction of cars are affected. Data collected on the MNL forums suggest that at least 11.8% of the LEAFs in Arizona are affected[5]. Perhaps most hot-climate cars are losing capacity at a higher rate than cars in more moderate climates, or perhaps only a small portion of the cars are susceptible to hot weather-related capacity loss. If it's the later case, it could be differences in driver habits or conditions, or it could be a manufacturing issue. The root cause cannot be determined without more data, either from more owners participating in the survey and using aftermarket state-of-charge meters, or from Nissan providing more data to the user community.

The high mileage vehicles in the survey thus far show that the Nissan LEAF is capable of considerable driving before losing enough capacity to drop the first capacity bar. This would seem to bode well for LEAFs that are not having the problems seen in some hot-climate vehicles.

The Battery Information Sheet that LEAF owners are supposed to receive when they have their annual service done has potentially significant educational potential. If presented and explained by a knowledgeable technician, this report can serve as a method to educate owners on best practices for maintaining the health and capacity of their battery pack. Although the effect of doing well on the report is apparently too small to be measured by this survey, Plug In America recommends that LEAF owners be aware of the issues and follow them as much as is convenient in their use of the vehicle by avoiding habits that have little benefit to the owner and potentially contribute to battery pack degradation.

Survey Data Availability

The raw survey data is available for third party analysis on Plug In America's web site.

http://www.pluginamerica.org/surveys/batteries/leaf/

About Plug In America

Plug In America is the preeminent nonprofit organization for the promotion and support of plug-in electric vehicles for the many economic, national security, and environmental benefits they bring. We are focused on increasing the number of electric miles displacing fossil fuel miles through advocacy with industry and government and outreach to consumers. Plug In America has over a million electric miles of experience on the board of directors and uses that to advocate for the interests of current and potential future plug-in vehicle owners.

If you find the information in this study helpful, please consider donating to Plug In America so that we can continue our critical work supporting plug-in vehicles and the consumers who drive them.

http://www.pluginamerica.com/donate

[5] http://www.mynissanleaf.com/wiki/index.php?title=Battery_Capacity_Loss

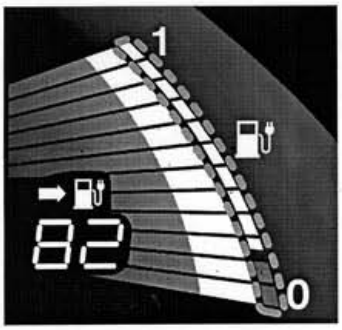
Sample Nissan LEAF Battery Report

Battery Information Sheet

11/15/2012

VIN or Chassis #	JN1AZ0CP9BT008847

<Battery Capacity Status>



The battery capacity retrieved from your LEAF is as follows.

Current battery status

Gradual loss of capacity is a normal battery characteristic as experienced with cell phones and laptops. The degree of capacity loss will vary based on driving, charging habits, and environmental conditions. This status is also shown on the high voltage battery status meter in instrument cluster. (Surrounded by dotted line at the left illustration)

<Advice for your usage>

The recommendations below can help to minimize the ongoing impact on your LEAF Li-ion battery, which can affect your batteryfs total capacity over its lifetime.

Item	Cause of gradual loss of capacity	Recommendation	Your score
Charging	Frequent use of Quick charging	Your score is very high and good for your battery.	★★★★★
	Frequent charging when battery state of charge is already high.	Your score is very high and good for your battery.	★★★★★
Driving	Too much electric consumption while driving.	Your score is very high and good for your battery.	★★★★★
Storage	Long term parking with high state of charge.	Your score is very high and good for your battery.	★★★★★

<Comment>