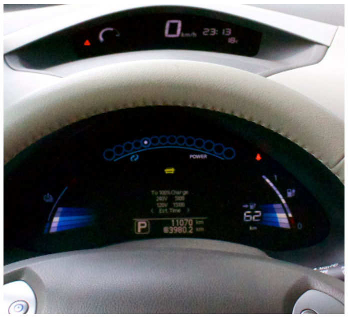
All-Electric

Nissan Leaf in Manitoba


Summary of Operational Experience: First Year Report

Prepared by the Electric Vehicle Technology & Education Centre,
Red River College, in cooperation with the Energy Division, Manitoba
Department of Municipal Government

November 2013

EVTEC
ELECTRIC VEHICLE TECHNOLOGY & EDUCATION CENTRE

RED RIVER COLLEGE
OF APPLIED ARTS, SCIENCE AND TECHNOLOGY

Table of Contents

Objectives and Reporting

In 2011 the Government of Manitoba began the testing of commercially-available electric vehicles.[1] The overall objectives for testing have been to understand the practicality and public perception of using electric vehicles in our climate conditions, and to publicize and demonstrate the benefits of these vehicles. The primary intent of this and other reports prepared on electric vehicles is to be able to address a variety of practical questions that potential users may have in considering the purchase of such vehicles. As such, this report is deliberately organized according to a series of questions clustered into four areas, regarding: operation; maintenance; economics; and overall suitability. Information in this and other reports is also being shared with respective automobile manufacturers to hopefully help them make their vehicles better in the future.

Introduction

MOU on Electric Vehicles

The Government of Manitoba, together with Manitoba Hydro, signed a Memorandum of Understanding (MOU) with Nissan Canada in May 2011 to work jointly on advancing the use of plug-in electric vehicles in Manitoba. A key aspect of this collaboration has been the testing and evaluation of vehicles. Nissan's first commercial electric vehicle model, the Leaf, became publicly available within Canada in late 2011. The Government of Manitoba through its Vehicle and Equipment Management Agency (VEMA) purchased a Leaf in March of 2012. This vehicle is being used within the Energy Division, Department of Municipal Government for a three-year period, up to March of 2015. Annual reports of experience with this vehicle are being prepared for each individual year. This first report covers a somewhat longer period of 16 months from March 2012 through July 2013.

Leaf Vehicle Specifications

The Leaf is a first of a kind vehicle in the modern era. It has been the first modern, commercially available vehicle deliberately designed and manufactured to be all-electric, not a conversion or adaptation from a conventional internal combustion engine vehicle platform. The Leaf is intended as a family vehicle, able to seat up to five passengers, and able to drive both within urban environments and on highway. Key technical specifications for the Leaf are provided in the table on page 1, with photographs throughout.

2012 Nissan Leaf Technical Specifications	
Dimensions	4.4 m long x 1.8 m wide x 1.6 m high
Curb Weight	1.5 tonnes (3,400 lb)
Motor	Synchronous AC; 80 kW max output; 280 Nm torque
Battery	Lithium ion chemistry; capacity of 24 kWh; 360 V (direct current)
On-Board Charger	3.3 kW capacity
Speed	150 km per hour maximum
Range	160 km under normal operating conditions

Licensing and Insurance

The Leaf was registered for operation in Manitoba with Manitoba Public Insurance (MPI) and covered under a standard automobile insurance policy. Registration was undertaken by VEMA, as the formal owner of the vehicle, and as one of their regular vehicle-related functions. There were no concerns identified or special requirements for registration or insurance as compared to a conventional vehicle.

Data-Logging Devices

No on-board data-logging device was installed on the Leaf during its first year. At the same time, owners of the Leaf vehicle are eligible to access Nissan's internet-based telematics service, called "CARWINGS." Although this system is significantly oriented to remote operations (i.e., via smart-phones) and navigation, it also maintains vehicle information

---

[1] http://news.gov.mb.ca/news/?item=11605

IPLC-PM2 device

relating to energy performance.

A separate meter, the IPLC-PM2 manufactured by Manitoba-based Vantera Inc., was used for interactive monitoring of electricity consumption of the vehicle when plugged into the grid for Level 1 (i.e., 110 V, 15 A) charging. This device, which is illustrated in the photograph on page 2, was carried with the vehicle and externally installed between the vehicle cord-set and a Level 1 plug-point during recharging. Data was recorded and stored on a memory stick.

Although vehicle range is ultimately most important for drivers to understand in the operation of an electric vehicle, range estimates can sometimes be vague. In order to objectively address vehicle range, precise measurements of vehicle electricity consumption were taken at the wall plug under different conditions using the IPLC-PM2 device. The range of any all-electric vehicle depends directly on the available battery capacity, and on electricity consumption under the conditions of operation. As such, expected range is inversely related to any change in energy consumption, i.e., higher energy consumption means lower expected range.

Operation

What is it like to drive this vehicle?

The Leaf is a sophisticated vehicle designed to act and feel exactly like a conventional car, and, based on driver-feedback, this goal was largely achieved. During the first year of operation, the Leaf primarily was driven by four people, all management and technical staff from the Government of Manitoba. All drivers consistently indicated the Leaf was "great to drive". In at least one case, driving was described as serendipitous (i.e., pleasant unexpected surprise), given the completely novel nature of the car.

The Leaf features two forward drive settings: D-mode, or "drive" mode, which is intended for optimum driving performance; and Eco-mode, which enhances regenerative braking and is intended to extend driving range. Qualitatively, drivers indicated that in Eco-mode, the Leaf reacted like a typical economy-car, in particular with reduced acceleration. On the other hand, in D-mode, the Leaf reacted, deceptively, like a high-performance car. The operation and performance of the Leaf in D-mode typically was a surprise for drivers. The impacts of D-mode versus Eco-mode on energy consumption and driving range will be investigated quantitatively during the second year of operation.

The overwhelming concern of drivers during the first year was regarding winter driving range. This is outlined in more detail in subsequent sections. A variety of issues were identified, also discussed later.

How is this vehicle typically used?

No specific data were collected on vehicle-use characteristics during the first year of operation. Other vehicles that have been tested in the past were monitored in terms of two primary parameters: trips per day; and daily travel distance.

By the end of the first full year of operation, the Leaf had travelled approximately 7,500 km. An average passenger car within Manitoba travels approximately 16,000 km annually, based on data from Statistics Canada's Canadian Vehicle Survey. Compared to an average vehicle, the travel distance covered by the Leaf corresponds roughly to the distance travelled involving daily commutes (i.e., 150 km per week x 50 weeks), but not the smaller number of longer distance trips that would be typical of an average vehicle. This makes sense given the Leaf's orientation primarily for commuting in an urban environment.

For testing purposes Leaf, the was driven on a highway trip once, this in early March 2013 traveling to Otterburne, roughly 60 km south of Winnipeg. The vehicle operated well on the highway, at speeds ranging from 90 to 100 km per hour. Given late-winter operation with associated heating requirements, the battery was depleted by more than half driving out. Given that only a Level 1 charge-point was available, sufficient top-up of energy would have required roughly a nine-hour stay, versus an available meeting timeframe of only seven hours in this case. As such, the vehicle was left overnight to fully charge and retrieved the next day. This activity showed that some highway travel was certainly possible with the Leaf, but would need to be planned to incorporate sufficient recharging time.

How does recharging work on this vehicle, how long does it take, and how frequently do I need to charge?

The charging-point access for the Leaf is unique among electric vehicles, being directly at the front. The latched cover is released at the driver's position using a lever on the lower left. Within the front panel the Leaf has a SAE J1772-compliant port for charging at Level 1 (i.e., 110 V AC; 15 A), or at Level 2 (i.e., 220 V AC; 20 A). The Leaf also includes one cord-set for recharging, this suitable for Level 1, i.e., it plugs into standard 110 V electrical receptacles, which are broadly available within Manitoba and not different from receptacles already used for plugging-in conventional vehicle block heaters or in-car warmers.

For Level 2 charging, Nissan, like other electric vehicle manufacturers, recommends that owners purchase a dedicated home-based Level 2 charger. Although Nissan works closely with the electric supply equipment manufacturer Aerovironment, the vehicle can be charged using any Level 2 station that has a SAE J1772 compliant plug, and is installed in compliance with the Canadian Electrical Code. Over the reporting period, the Leaf was recharged almost exclusively using Level 1, but was charged on a few occasions using Level 2, this at a suitable station located at Red River College.

In the owner manual, Nissan refers to Level 1 as "trickle" charging, and indicates the vehicle requires about 21 hours to recharge from full-depletion. Nissan refers to Level 2 as "normal" charging, and indicates the vehicle requires about 7 hours to recharge from full-depletion at this level. Selected tests operating the Leaf to full-depletion showed recharging of the battery using only Level 1 was completed in 18.8 ± 0.6 hours (n = 3), about 10% faster than suggested by Nissan. At the same time, it was rare for the Leaf to be extensively depleted by the end of a given day of operation. As such, Level 1 charging was adequate. It was found, based on experience, that as long as the Leaf was not more than about 65% depleted, i.e., still had 35% or more state of charge (SOC) remaining, the vehicle could be fully charged overnight using Level 1, i.e. over 12 hour period from 6:00 PM to 6:00 AM. During warm months the Leaf certainly did not need to be recharged every day. On one occasion during the summer, the Leaf was used for commuting a full week prior to recharging, but such extended time between recharging events depends on travel distance. During colder months it was found to be prudent to recharge the vehicle every night, this to ensure that maximum possible charge was available if required.

First Stage Low Battery Warning on

A dedicated home-based Level 2 charger represents an additional cost for the owner, likely in the range of $1,000 to $2,000 depending on circumstances. Although Level 2 certainly allows faster recharging, the decision of an owner to implement Level 2 is not a matter of necessary, but rather convenience. Also important for Level 2 is that the on-board charging system of the 2012 model Leaf is limited to 3.3 kW (see specifications on page 1). This is satisfied by a Level 2 charger on a 20 A rated circuit (i.e., 16 A delivered). The Leaf certainly can be plugged into a Level 2 charger having higher rated amperage, i.e. 30 A or more, but the vehicle will not charge any faster.

The Leaf can, as an option, also be purchased with an additional charging port at the front panel for Level 3 (i.e., direct DC) rapid charging, this compliant with the Japanese-based CHAdeMO protocol. On the vehicle purchased, this optional port was not included. Unlike Level 1 and Level 2 charging, there is no universal standard yet in place for Level 3 charging. Level 3 charging stations based on CHAdeMO protocol are still relatively rare, with none currently within Manitoba, and are extremely expensive to implement.

What happens if the vehicle runs out of battery energy while driving?

As battery energy nears full depletion, the vehicle display of the Leaf proceeds through two progressive warning stages. The first occurs when the SOC bar meter (see photograph on page 3), drops to a single bar. There is both an audio enunciation and visual indicator that the battery level is low. The vehicle at the same time still continues to show some remaining projected travel distance. This is also illustrated in the photograph on page 3. Once the last bar disappears, a second audio enunciation indicates that the battery is very low, and the range remaining indictor goes blank (i.e., showing "- -").

At the second stage warning, the on-board navigation system also asks to search for the nearest charging station. On one occasion during a drive to full-depletion near Red River College, the on-board system was authorized to do so, illustrating a potential issue. The on-board system identified a Level 2 charging station at a local Nissan dealership, but at a travel distance of almost 10 km. The on-board system did not identify a closer, publicly available Level 2 station less than 3 km away that was already listed on the interactive charging station map for Canada prepared by CAA and Electric Mobility Canada.[2] This was a potential concern, and Nissan will need to ensure that on-board navigation systems are up-to-date in this regard.

Even after the second stage warning, the vehicle continued to travel at least 3 to 4 km, albeit at restricted speed, ensuring that drivers would not be stranded. Importantly, at the zero bar warning, the Leaf does not automatically turn off either cabin air conditioning (AC) or heating. This is left to the driver to do, which may be important depending on how far away a suitable charging point is located.

How much electricity does this vehicle use?

Electricity use was measured for the Leaf using the IPLC-PM2 meter for Level 1 charging, as described earlier. Combined with odometer changes over logged periods, this permitted calculating vehicle energy consumption in units of kWh per 100 km. This calculation method is consistent with that employed by Transport Canada as part of the ecoTechnology for Vehicles (ETV) program in evaluation of electric vehicle performance.[3]

Three different types of commercially available electric vehicles have been evaluated for energy consumption in the same way during summer operation in the vicinity of Winnipeg, with no AC or heating employed. In addition to the Leaf, these include the Mitsubishi iMiEV and the Chevrolet Volt. Baseline energy consumption data for all three vehicles are provided in the table on page 4, with mean and standard deviation shown, based on actual monitor data with five replicate tests for each vehicle (n = 5).

Official baseline energy consumption results for these same three vehicles have also been determined by Natural Resources Canada under conditions for city-based driving with no AC or heating employed, albeit in this case based on specific dynamometer cycle operation. These results are also included in this table.

Baseline Energy Consumption for Electric Vehicles in Summer Operation with No Heating or Air Conditioning Involved

Vehicle Model	**Vehicle Energy Consumption (kWh per 100 km)**	
	Winnipeg Test Results (n = 5 Replicates)	Natural Resources Canada 2012 City-based Official Result*
2012 Nissan Leaf	20.2 ± 1.6 (Test in June 2013)	19.6
2011 Mitsubishi iMiEV (European Version)	16.3 ± 0.8 (Test in August 2011)	16.9 **
2012 Chevrolet Volt (Electric-only Operation)	19.9 ± 2.1 (Test in July 2012)	22.3

* Natural Resources Canada. Fuel Consumption Guide 2012. Available at: http://oee.nrcan.gc.ca/transportation/tools/fuelratings/fuel-consumption-guide-2012.pdf

** Value for 2012 model North American version of iMiEV.

Baseline summer energy consumption for the Leaf was found to be 20.2 ± 1.6 kWh per 100 km (n = 5). This was higher than the Mitsubishi iMiEV by roughly 24%, but not practically different from the Chevrolet Volt. These results make sense given that the Leaf and Volt have relatively similar curb weights, and both are heavier than the iMiEV.

---

[2] http://www.caa.ca/evstations/

[3] http://www.tc.gc.ca/media/documents/programs/i-MiEV_testplan_ENG.pdf

2012 Model Nissan Leaf Effect of Air Conditioning on Energy Consumption, with mean and standard deviation presented based on five replicates, and with tests based on roughly 40 km travel, same driver, similar route, and duty cycle in all cases.

Test Condition	Energy Consumption	Testing Timeframe
AC Off/Low	20.2 ± 1.6 kWh per 100 km	June 2013
AC On Fully	25.1 ± 3.0 kWh per 100 km	July 2013

Testing with electric vehicles has shown that overall energy consumption is strongly affected by the use of climate controls, whether cabin AC during the summer, or cabin heating during the winter. Respective impacts of summer-based AC and winter-based heating were evaluated.

Summer-based testing of energy consumption was undertaken using comparative trials with AC set to fully on versus AC off (i.e., baseline consumption described above). Results are presented in the table on page 5, again based on five replicate tests for each condition. Energy consumption with AC-on increased by approximately 25%, which would correspond to a range reduction of about 25%. This finding of a 25% increase in energy consumption due to AC being fully on was also highly consistent with experience for a number of other electric vehicles tested in the past within Manitoba. These included the Mitsubishi iMiEV, factory-built Toyota Prius Plug-in Hybrid Vehicle, and converted Prius PHEV.

Importantly, the AC being turned fully on was done for testing purposes, and this ended up on occasions causing the vehicle to become excessively cold. Given ample cooling capacity for the Leaf, drivers need only turn AC up to a sufficient level, rather than fully on, in order to save energy and extend range. Only on relatively infrequent occasions would full AC capacity actually be required. Effects of cabin heating on energy consumption (and range) are discussed in the next section.

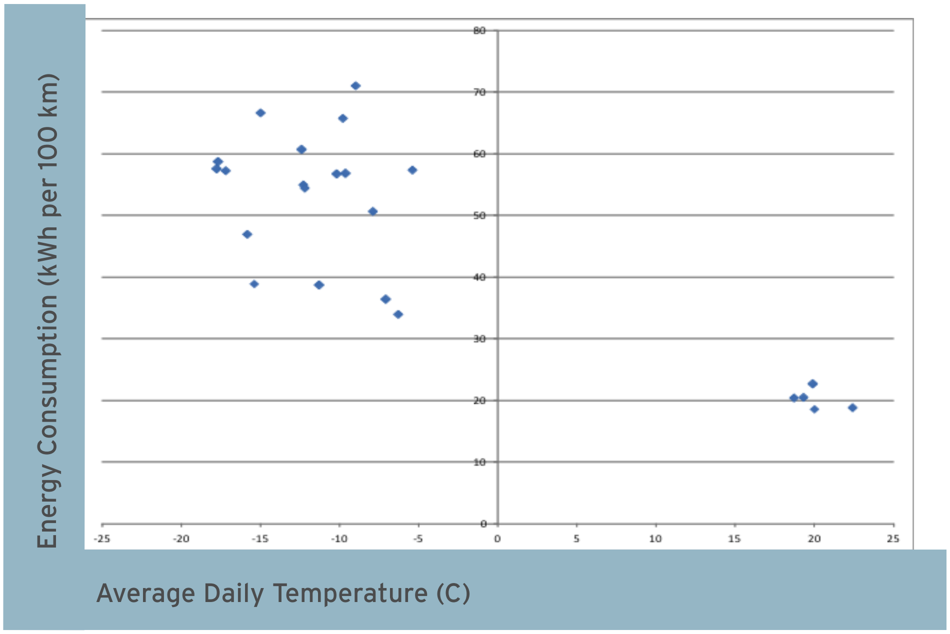
How well does this vehicle operate in the winter?

Operation in Manitoba's winter conditions is a challenge for all vehicles, including those that are electric. In some regards the Leaf performed extremely well, notably in keeping passengers warm. On the other hand, winter operation and associated vehicle range impacts were the overwhelming concerns of drivers.

The Leaf's cabin heating systems performed well in the winter, being able to keep windshields clear and all passengers warm, even over relatively extended periods. The heated seats and, in particular, the heated steering wheel, were excellent features that enhanced passenger comfort during winter. No drivers had any complaints about cabin warmth.

The apparent priority in the vehicle's operating system on passenger comfort, however, did have consequences. During monitored periods in the winter, energy consumption was very high, with significant associated range reduction, and also was relatively erratic. Rapidly diminishing travel range was specifically noted by a number of drivers, leading to a "winter range anxiety" effect. Part of this heightened concern likely had to do with problems with the vehicle's range remaining indicator, which are discussed later.

Detailed energy consumption monitoring was only undertaken for the Leaf starting in the late-winter to early-spring period of 2013, which was not the coldest portion of the season. Quantitative validation of concerns regarding high energy consumption became evident at that time. For the period covering the last week of February through to the end of the third week of March, average energy consumption for the Leaf was 53 kWh per 100 km, or



roughly 2.6x higher than baseline energy consumption of around 20 kWh per 100 km in the summer. This translates to a range reduction from about 160 km during summer operation to only about 60 km. Over the short period monitored, four energy-use spikes were recorded, these in the range of 61 to 71 kWh per 100 km, or roughly 3.1x to 3.6x baseline. Given that data-logging did not cover the coldest part of the winter, energy consumption at the coldest portion of winter would be likely higher.

It was also found for the Leaf over the monitored period that energy consumption on individual days did not appear to correlate at all to average daily temperature. This was a surprising result, with data illustrated in the figure on page 5. Data for the colder period from late-February through mid-March are illustrated on the left of the plot, and are highly erratic. For comparison, on the right of the plot are data for the five days used for baseline energy consumption monitoring during the following summer. There is obviously a general monotone relationship, whereby energy consumption increases generally as temperature drops, however, there is no clear-cut correlation evident during colder conditions. More rigorous winter testing of energy consumption and maximum driving range will be undertaken in subsequent winter periods.

Lastly in terms of winter operations, specialized winter tires were installed on the Leaf. This is not an issue specific to electric vehicles, but rather part of a more recent general trend with vehicles toward the use of winter tires. These tires generally appeared to improved winter handling of the Leaf, however the opinion was not universal, with one driver saying handling did not seem to be improved. The use of specialized winter tires will continue through the remainder of testing.

How far will this vehicle travel (on a single charge), particularly in the winter (i.e., range by season)?

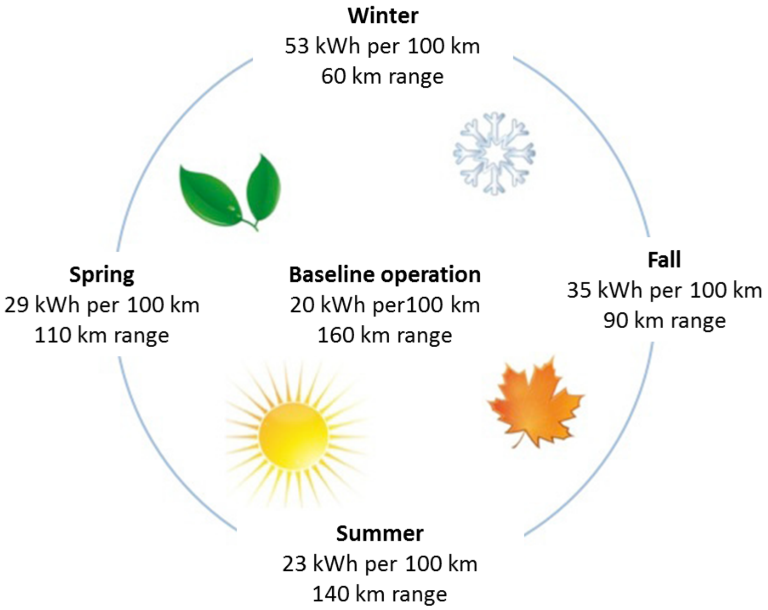
Electricity consumption and travel range are directly linked, as described earlier. In order to establish base-line expectations for range, the Leaf was driven to full battery depletion during summer conditions without use of AC. This was undertaken in July 2013 travelling for a period of roughly 4.5 hours. Ambient temperature conditions were consistent at around 25°C. The Leaf was driven in urban conditions within Winnipeg, including speed zones of 50 to 80 km per hour, but with actual average distance per total time over the period consistently close to 40 km per hour. The Leaf achieved 161.1 km travel distance, consistent with Nissan's suggested normal travel distance of around 160 km during such urban driving conditions.

The electricity consumption and resulting range of the Leaf depended significantly on the season. Any combination of heating and/or cooling would have an impact. Based on experience with the vehicle so far, rough estimates of seasonal energy consumption and associated travel ranges were determined, as presented in the figure on page 6. These values provide preliminary guidelines on what could be expected for the Leaf. These data will be updated in future reports as more experience is obtained.

Are there any important issues to be aware of in the operation of this vehicle?

A variety of issues were noted during operation. In some cases these merely require driver adaptation. In other cases more investigation will be undertaken during further years of operation to gain a better understanding.

The Leaf is very quiet, and at low speeds does incorporate warning sounds for reverse operation and low-speed forward driving. Despite this, a concern specifically noted by one driver was a potential blind spot on the driver's side near the front wheel-well, in one case almost resulting in a low-speed pedestrian



Travel Range Remaining Indicator

collision. Given the very quiet nature of the vehicle, diligent caution is definitely required of Leaf drivers.

The display of the Leaf presents a great deal of data to a driver, all at one time. There are, for example, 30 different warning or indicator lights that may come on under different circumstances. This situation led to a perception of clutter and distraction for some drivers. Of particular note in this regard is the Leaf's prominent travel range remaining indicator at the lower right of the display, in conjunction with the battery SOC meter. This is illustrated in the photograph (left).

Very quickly it became obvious to Leaf drivers that this indicator is not reliable. One driver specifically noted that the vehicle, "definitely has a faulty energy meter." Systematic tracking of this issue was undertaken, comparing changes in the range remaining indicator to changes in odometer as the vehicle travelled. Four example tracks of operation through the course of different days are provided in Appendix A. For comparison, two of these were during the winter and two were during the summer. The results showed the range remaining indicator to change erratically compared to the corresponding change in odometer.

These observations are not intended to single out Nissan in a bad light. The prediction of electric travel range remaining for all-electric vehicles and PHEVs is highly problematic across models available today. The concern is just more obvious on the Leaf, given the prominence of the indicator. A key recommendation by EVTEC is the need to provide better tools to consumers to be able to quickly and accurately evaluate travel range remaining, particularly under unique climate conditions such as in Manitoba. In the case of the Leaf, more-useful information than estimated travel range remaining would be a numerical percentage read-out of the battery's SOC, rather than just a series of bars. Indeed, Nissan had since implemented this display option change in the 2013 model Leaf.

Erratic energy use by the Leaf during winter was noted earlier. This issue and associated range impacts will require further evaluation. Higher energy use certainly would result in higher electrical energy cost for operation, which may or may not be critical, but may also impact range. Some additional observations were made that may be related to the same issue. These involve two inconsistent characteristics in charging curves for the Leaf, discussed in more detail in Appendix B. It is uncertain at this time whether these observations may be important or not.

Maintenance

What maintenance is required for this vehicle?

The extent of maintenance required for electric vehicles tends to be much lower than for conventional internal combustion engine (ICE) vehicles, but appropriate maintenance is still required, i.e., they are not completely maintenance free. This represents a saving both in terms of convenience and economics. This situation was borne out with the Leaf during its initial operating year.

During the entire 16-month period covered by this report, the Leaf visited a dealership or maintenance facility only four times. Two of these events involved the changing of tires, undertaken at VEMA's facilities. Winter tires were installed for the winter period of 2012-2013 and then in the spring changed back to summer tires.

One small warranty repair issue needed to be addressed at the dealership, but this only involved a few hours and no cost. This situation is little different from conventional vehicles. The only unique maintenance activity was a one-year based battery diagnostic review undertaken in the early spring of 2013. The main battery of the Leaf was found to be in good shape with no perceived deterioration in capacity. The cost of this review was less than $100.

Although several drivers noted a distinct pleasure in being able to drive past gasoline refueling stations, the Leaf was still occasionally taken to such stations, notably for windshield washer fluid purchase and car-washes.

Comparative Current Operating Costs per 100 km			
Vehicle	**Fuel Consumption**	**Operating Cost**	**Annual Operating Cost**
Leaf (all-electric)	35 kWh/100 km annual	$2.50 per 100 km	$300
Average conventional car	15 Litres/100 km annual	$19.50 per 100 km	$2,160
Efficient conventional car	8 Litres/100 km annual	$10.50 per 100 km	$1,150
Assumptions: gasoline price of $1.20 per Litre; electricity price of 7¢ per kWh; and annual travel of 12,000 km			

What battery degradation would be expected, both seasonal and long-term?

Over the first year of operation, there was no degradation of the main battery on the Leaf, as noted earlier. Battery performance, including seasonal based impacts will continue to be evaluated over future years.

How long will the batteries last, and will replacement be required?

The practical longevity of batteries is key aspect for electric vehicle operation that still remains uncertain. Insufficient long-term experience exists yet to be able to predict battery life. This uncertainty has been reflected in the economic evaluation (next section) by including differences in the assumed resale value of an electric versus conventional vehicle.

Economics

What does it cost to purchase an electric vehicle?

From earlier economic assessment of electric vehicles it is known that their economics depend most sensitively on the purchase price.[4] Up until the recent past, the Leaf has been a relatively expensive vehicle. Initially, the purchase price was around $42,000. Recently, however, in June 2013, Nissan announced the introduction of a new, more-basic version of the Leaf, called the S, which has a significantly reduced purchase price, around $33,000.[5] This reflects a general trend of reducing purchase prices for electric vehicles, primarily associated with decreasing battery costs and increasing battery performance.

What does it cost to operate an electric vehicle?

The use of electricity as the "fuel" for the Leaf results in a dramatically lower operating cost compared to a conventional vehicle. Representative operating costs are presented in the table above, comparing the Leaf to both an average conventional vehicle and an efficient vehicle, like a conventional hybrid. Values are presented both in term of "per 100 km" basis and "annual" basis, the latter assuming 12,000 km travel per year (noting that an average Manitoba vehicle travels roughly 16,000 km, which includes a portion of longer distance trips).

The electricity consumption value of 35 kWh per 100 km was calculated as the average of assumed seasonal values based on actual experience so far. The current cost of electricity is about 7¢ per kWh, versus about $1.20 per Litre of liquid fuel used in conventional vehicles. Even with relatively high annual electricity consumption, the Leaf's operating cost is only roughly 1/8th that of an average Manitoba vehicle, and roughly 1/4th that of an efficient vehicle. Recharging the Leaf from a fully-depleted condition to completely full works out to cost less than $2.00. In contrast, one individual visit to a gasoline refuelling station today for a conventional vehicle typically costs more than $25.00. These price advantages make a compelling case for electric vehicles within Manitoba.

What is the payback compared to a conventional vehicle?

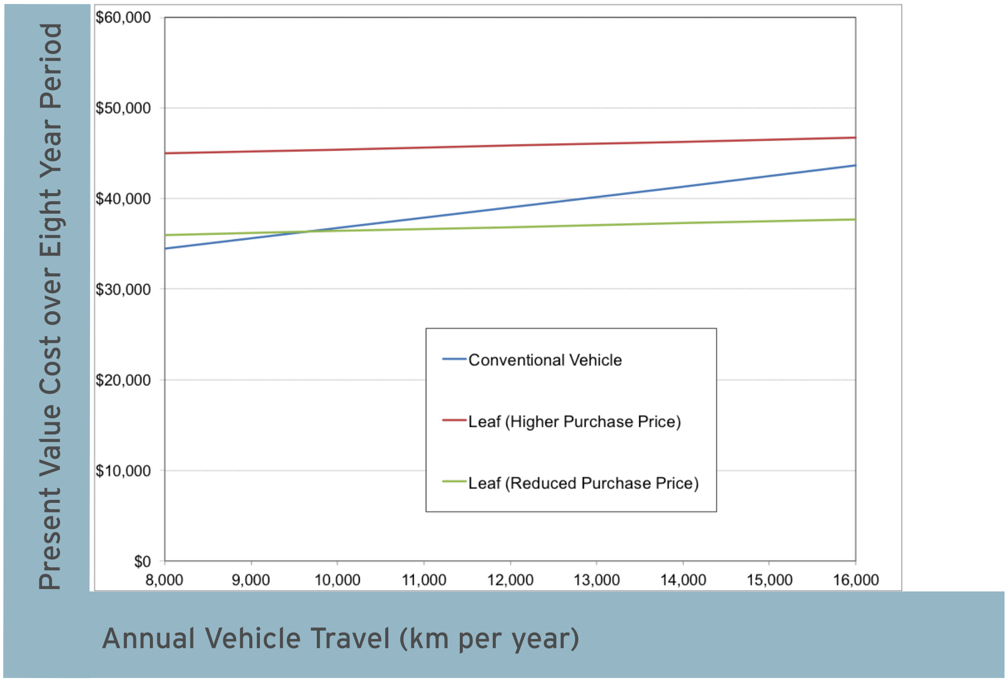
The overall economic feasibility of the Leaf was considered based on a series of assumptions. These are summarized in the table on page 9. The results are presented in the figure on page 9, in terms of the present value of total vehicle costs (i.e., purchase and capital) over an eight-year period. The Leaf could be expected to operate much longer, but eight years was selected for analysis given it corresponds to the typical battery warranty period, including that provided by Nissan. There is still some uncertainty as to the life and costs of batteries for electric vehicles, so for this analysis, the conventional car was assumed to be worth $5,000 more than the Leaf at the end of life. This is a highly conservative assumption.

It is also known that the economic feasibility of electric vehicles is most sensitive to purchase price. Two cases were included: "higher purchase price" of $42,000, which reflects the cost of the Leaf in early 2012; and "reduced purchase price" of $33,000, which reflects the recent price reduction announced by Nissan in 2013.

---

[4] http://www.rrc.mb.ca/files/file/appliedresearch/preliminaryeconomicreport.pdf

[5] http://nissannews.com/en-CA/nissan/canada/releases/nissan-announces-canadian-price-reduction-and-faster-charging-time-for-2013-nissan-leafpdf



In earlier economic analysis on electric vehicles, the price of gasoline was used as the major independent variable. Although the economics of electric vehicles are known to be much more sensitive to changes in gasoline price versus electricity price, gasoline price has continued to increase more or less steadily, and a single average future price of $1.60 per Litre was assumed in this case covering the eight year period. The corresponding future average price of electricity was assumed as 10¢ per kWh. For analysis of the Leaf, the major independent variable was assumed as the annual travel distance by the vehicle, ranging from 8,000 km annually, reflecting basic commuting only, to 16,000 km annually, which is the average travel distance for all cars within Manitoba.

As illustrated in the figure on page 8, if the older, higher purchase price is used, the Leaf is overall much more costly than the conventional vehicle. Using the reduced purchase price, however, changes the economics dramatically, with the Leaf having lower overall cost if annual travel is greater than about 10,000 km per year. This is even after including a significant end of life price penalty for the Leaf to take account of battery uncertainties. For many prospective vehicle purchasers today, the Leaf represents the best choice economically, not even considering any of its environmental benefits.

Economic Feasibility Assessment Assumptions

Leaf	**Conventional Car**
Higher purchase price of $42,000 for Leaf, and Reduced purchase price of $33,000 for Leaf	Purchase price of $26,000 for average conventional vehicle
Annual maintenance cost of $200 for Leaf	Annual maintenance cost of $400 for conventional car
Energy consumption of 35 kWh per 100 km annually for Leaf	Fuel consumption of 11.5 Litres per 100 km annual for conventional car (Half way between efficient and average conventional cars on page
Longer term price of 10¢ per kWh for electricity km annually for Leaf	Longer term price of $1.60 per Litre for liquid fuel
Cost of money of 6%, and assumed vehicle life of 8 years. Higher residual value for conventional car of $5,000 versus Leaf at end of eight-year life. Annual travel treated as independent variable as presented.	

Overall Suitability

What are the most suitable users for this type of vehicle?

The Leaf is primarily an urban commuting vehicle, with some capability for highway travel, as long as well planned and not too far on a single trip. As such, the suitable annual travel distance likely would be in the range of 10,000 km to 14,000 km annually, in order to be economically attractive, but not push the limits of the vehicle too much.

How does one determine if a particular operation or style of use is suitable for an electric vehicle?

In order to help evaluate suitability of the Leaf, a series of relevant user characteristics are provided as a guideline in the table on page 10.

Suitable User Characteristics for the Leaf All-Electric
Need to carry up to only five passengers at a time.
Drive roughly 200 km per week on a regular basis throughout year, including daily commuting and additional use.
Potential one-way highway travel distances within summer of no more than about 80 km, further if well planned (i.e., summer travel from Winnipeg as far as Portage la Prairie,
Limited very-long distance travel by car, or consider air or rental.
Available dedicated driveway, garage, carport or parking spot with at least Level 1 charge point available.

Electric Vehicle Technology & Education Centre (EVTEC)

EVTEC at Red River College is responsible for applied research and innovation projects concerning ground transportation electric and hybrid vehicles that utilize renewable fuels, including bio-diesel (used for auxiliary systems, such as on-board heating, ventilation and air conditioning). EVTEC has a mission to: support electric vehicle (EV) innovation amongst Manitoba's transportation sector; enhance electric vehicle education at the College and in the region; and increase public awareness of electric vehicle technology.

Contacts

Jose Delos Reyes, Adv Dipl (Tech Mgmt)
EVTEC Manager | Research Coordinator
Electric Vehicle Technology and Education Centre
Red River College
(204) 631-3301
jdelosreyes@rrc.ca

Robert Parsons, MBA PhD
Advanced Energy Projects, Energy Division
Manitoba Department of Municipal
Government
(204) 945-6077

Appendix A: Travel Range Remaining Data for Four Example Days

Travel Range Remaining Data for four example days*

Example Winter Operation 1 - March 10, 2013

Travel Leg	Odometer Change	Range Remaining Change	Ratio
First	+ 11 km	- 54 km	4.9
Second	+ 11 km	+ 7 km	- 0.6
Third	+ 9 km	- 8 km	0.9
Overall	+ 31 km	- 55 km	1.8

Example Winter Operation 2 - March 5, 2013

Travel Leg	Odometer Change	Range Remaining Change	Ratio
First	+ 5 km	- 13 km	2.6
Second	+ 9 km	- 13 km	1.4
Third	+ 9 km	- 14 km	1.6
Fourth	+ 7 km	- 21 km	3.0
Fifth	+ 7 km	- 18 km	2.6
Overall	+ 37 km	- 78 km	2.1

Example Summer Operation 1 - June 29, 2013

Travel Leg	Odometer Change	Range Remaining Change	Ratio
First	+ 5 km	- 24 km	4.8
Second	+ 6 km	- 12 km	2.0
Third	+ 4 km	+ 4 km	- 1.0
Fourth	+ 12 km	- 22 km	1.8
Fifth	+ 1 km	+ 2 km	2.0
Sixth	+ 12 km	+ 3 km	0.3
Overall	+ 40 km	- 59 km	1.5

Example Summer Operation 2 - June 30, 2013

Travel Leg	Odometer Change	Range Remaining Change	Ratio
First	+ 16 km	- 36 km	2.3
Second	+ 8 km	- 18 km	2.3
Third	+ 9 km	+ 3 km	- 0.3
Fourth	+ 9 km	- 20 km	2.2
Fifth	+ 0.5 km	- 1 km	2.0
Overall	+ 42 km	- 72 km	1.7

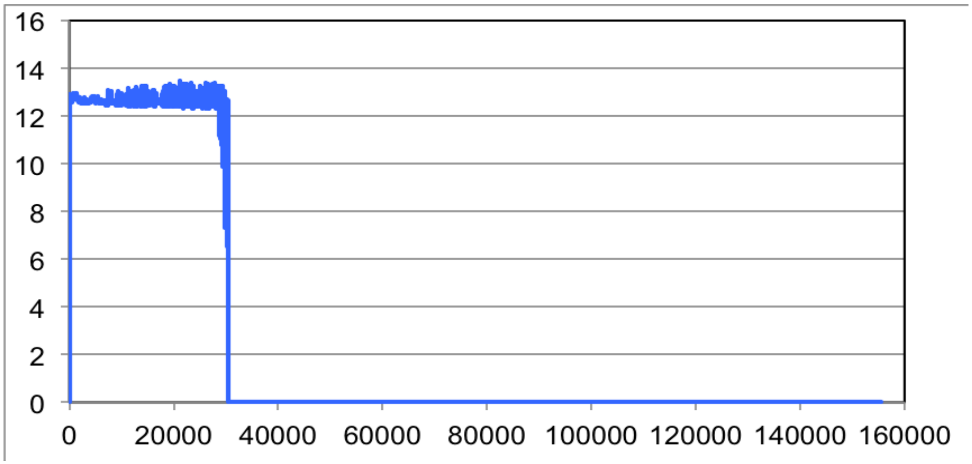
*Ratio = (Range Remaining Change) x -1 / (Odometer Change). Ideally this ratio should be close to 1, or at least have a consistent value. As observed from data, neither is the case. The ratio is rarely close to 1, and varies significantly, from high positive values, to values less than 1, to even negative values.

Appendix B: Example Leaf Charging Curves Showing Inconsistencies

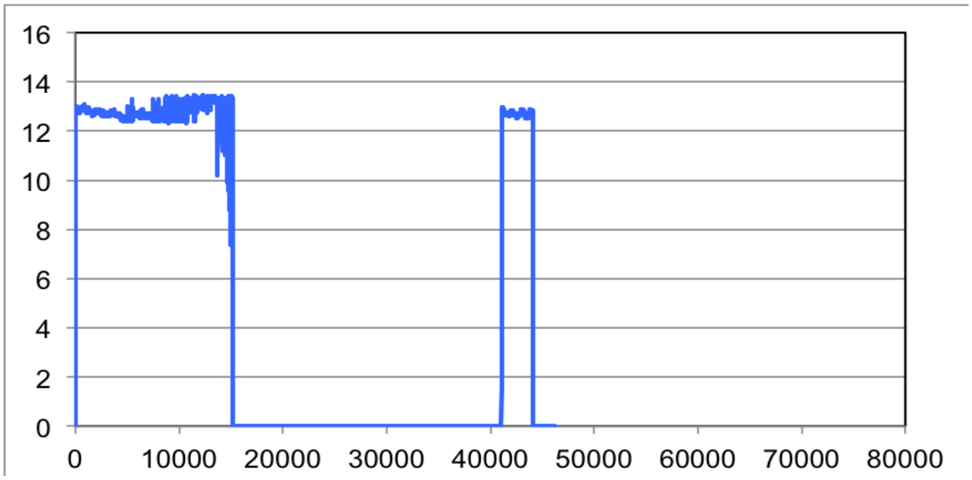
The IPLC-PM2 meter was used to log electricity (i.e., voltage, amperage and power) at one-second intervals over the course of individual charging events when plugged-in at Level 1. Previous experience with other electric vehicles had shown different models to exhibit consistent and distinct charging curve profiles, largely reflecting the overall battery management system (BMS) for the particular manufacturer. Such unique profiles essentially provide a consistent signature that can literally identify what type of vehicle is being charged. But in the case of the Leaf, the charging curves showed significant inconsistencies.

Four example curves of current as a function of time for charging events are presented to illustrate two identified inconsistencies.

Firstly, with most electric vehicles, once a charging event is completed, the charger either would not come back on again or might come back on again based on a consistent pattern. In the case of the Leaf, the charger might or might not come back on again, but unpredictably. The first two curves show this, with, in both cases, logging continued for more than 40 hours after the start of the initial charging event. One obvious explanation might be heating of the battery for proper conditioning. This, however, appears unlikely. The first example curve, which shows the charger remaining off at the end of the initial charging event, was for March 15, 2013, with a recorded low that evening of -22°C and then -26°C on the following evening. The second example curve, which shows the charger subsequently turning back on, was for March 11, 2013, with a recorded low that evening of -18°C and then -17°C on the following evening. If battery heating was involved, it was not directly related to the ambient temperature. From charging data that was actually logged, 8 charging events were recorded where the charger turned back on, versus 17 charging events where it remained off once initial charging was complete, this at least for as long as monitored. There was no reasonable explanation for the observed differences.



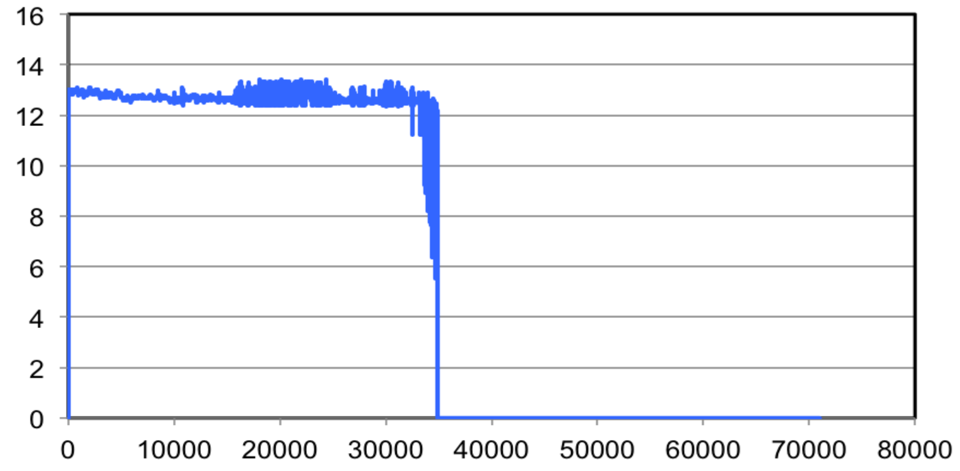
Charging curve for Leaf with no additional current uptake even after 40 hours 1_0100 (March 15, 2013)



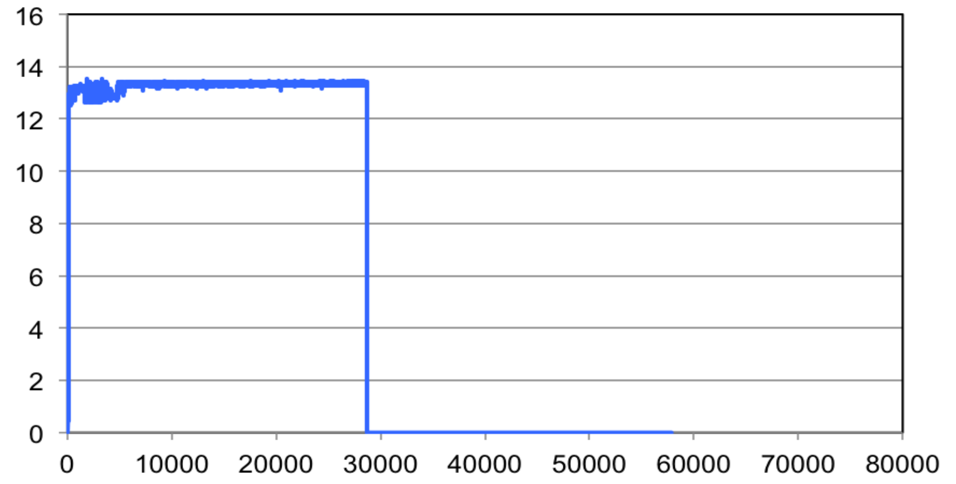
Charging curve for Leaf with additional current uptake roughly 8 hours after initial charging event 1_0096 (March 11, 2013)

Appendix B: Example Leaf Charging Curves Showing Inconsistencies

Secondly, the shape of the current charging curve was not consistent for the Leaf, as illustrated by the third and fourth curves. In some cases, current would be relatively steady at the beginning, but fluctuate significantly at the end of a charge cycle. This is illustrated in the third example curve for a charging event on February 15, 2013. In other cases, current would fluctuate significantly at the beginning of the charge cycle, but become relatively stable toward the end. This is illustrated in the fourth example curve for a charging event on July 12, 2013. There was further no apparent connection between this fluctuation behaviour and whether or not the charger might turn back on again. As such, although observed current fluctuation likely is associated with the BMS operation for the vehicle, there was no obvious explanation for observed differences.



Charging curve for Leaf showing current fluctuation at end of charging cycle 1_0076 (February 15, 2013)



Charging curve for Leaf showing current fluctuation at beginning of charging cycle 1_0128 (July 12, 2013)

*X-axis for all curves is time from initial plug-in (seconds), and Y-axis for all curves is measured current (A_{rms})