



2013 ***Electric Vehicle (EV) UPDATE***



Photo: Tesla Roadster, electric vehicle, in Norway

Prepared for



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Any mistakes remain the sole responsibility of the author.

Summary – Conclusions & Recommendations

This study is an update on a study titled “Electric Car Research” that was done by Dillon Consulting. Most of the research for that report was done in 2011 and, at that time, there were no plug-in electric vehicles available that could be serviced in the NWT.

Now, in 2013, there are two models of Plug-In Hybrid Electric Vehicles (PHEVs) available that can be serviced in the NWT. There is also data showing that Battery Electric Vehicles (BEVs) have been operating through Canadian winters at temperatures down to minus 30 degrees. The literature review done for this report could not find any data on the fuel consumption of any type of vehicle, electric, gasoline or diesel, at temperatures below minus 30°C. But this does not mean that these vehicles do not work below minus 30. Northerners have figured out how to plug in electric engine and battery warmers and, if they can't be plugged in, to start their vehicles every few hours during the coldest weather. The same techniques should allow northerners to use BEVs as short distance commuter vehicles and PHEVs to replace a standard vehicle.

This report looks at three cold weather issues: cold starting, fuel efficiency/range, and cold interior/windshield frosting that are common to all vehicles, regardless of fuel. It also looks at cold weather charging of electric vehicles.

Although none are currently available in the NWT, a properly equipped BEV could function as a short distance commuter vehicle throughout the year. To maintain enough battery capacity, a northern BEV would need to have the ability to warm the main battery using grid power and it would need to be plugged in at home and at work. The range could be reduced by about 60% (i.e. from 100 km to 40 km) in cold temperatures, but NWT commuting distances are generally so short that this could still be adequate. To be comfortable at cold temperatures, a northern BEV would need to pre-warm the seats and the cabin using grid power and at the coldest temperatures, a northern BEV driver should dress warmly as the cabin heater will probably not keep up.

Currently, the Toyota Prius Plug-In and the Chevrolet Volt (both PHEVs) are the only plug-in vehicles that are serviceable in the NWT (only in Yellowknife). Range is not an issue for these vehicles because they have gasoline engines that can power them when the batteries are depleted. Like all vehicles, they will eventually be unable to start if they are not plugged in during extreme cold temperatures. Both vehicles use their engines as heaters so they should be warmer than pure BEVs.

Even with escalating electricity prices, the Prius Plug-In and the Volt in EV mode will be cheaper to operate than comparable gasoline or diesel vehicles. At current prices, a 10 km in town trip would cost 3 to 4 times less than a comparable gasoline and diesel vehicles and 5 times less than a typical pickup truck. On the highway the Prius Plug-In is 25% cheaper to drive than a similar car while the Volt uses about the same amount of fuel as a similar car. And for trips within NWT hydro powered communities, they offer the unique experience of commuting using a local and green energy resource without producing any Green House Gas GHG emissions.

As many automotive reviewers have pointed out, it is not easy to figure out whether the Volt or the Prius Plug-In is the better PHEV. The Prius Plug-In is more efficient over shorter commutes and on long drives, which makes it ideal for short trip commuters who still want to take a 1,700 km trip to Edmonton once in a while. But the battery warming system in the Prius Plug-In uses cabin air (taken from vents around the rear seats) to warm the battery and it cannot be pre-heated using grid power. The Volt has a more confidence inspiring liquid heating system for the battery that can be powered from the grid and the Volt's larger battery makes it the most efficient vehicle for people who drive 50 to 70 km per day.

It is difficult to compare NWT winter fuel efficiency of electric vehicles to gasoline and diesel vehicles because we do not have data on how efficient any of these vehicles are during NWT winters. In order to make a fair comparison, one would also need information on how much power vehicle block heaters, battery warmers and cabin heaters use, as well as how much fuel is used in idling to warm up the cabin of a gasoline or diesel powered vehicle. Keeping fuel log records on a fleet of existing vehicles and comparing them to outdoor temperature records would be a good start. Minute by minute monitoring of a Prius Plug-In and a Volt compared to a few other standard vehicles using on-board data loggers such as those used by FleetCarma¹ would be ideal.

The opportunity to use local NWT hydroelectricity to power vehicles in the NWT is real. If the Arctic Energy Alliance or its funding partners wished to pursue this further the next steps would be:

1. Conduct market research to determine the potential size of the market, both in terms of electricity sales and greenhouse gas reductions. The market research should also identify the key barriers and benefits of owning an electric vehicle from the perspective of a northern driver.
2. If the market study shows sufficient potential, create a program of incentives designed to reduce the barriers and enhance the benefits of driving an electric vehicle in the NWT.
3. Partner with Toyota and/or GM to conduct a study comparing the performance and fuel efficiency of either a Prius Plug-In and/or a Volt with a similar gasoline powered car through an NWT winter. As driver behaviour is a key factor, several vehicles should be tested.

1. www.fleetcarma.com

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Introduction

The purpose of this study is to update a report titled “Electric Car Research” that was done by Dillon Consulting for the Arctic Energy Alliance. The focus is on answering questions about the cold weather performance of 2013 model year vehicles that are currently available and serviceable in the Northwest Territories (NWT). The scope of the study was limited to 1 week of reviewing existing research and literature.

Background – Vehicle Efficiency 101

This report compares the cold weather performance of electric vehicles to vehicles that are powered with an Internal Combustion Engine (ICE) that run on gasoline or diesel. To understand what happens when it gets cold, it is useful to know a bit about vehicle efficiency at “normal” temperatures.

Internal Combustion Engines vs. Electric Motors

Vehicles with gasoline and diesel engines are surprisingly inefficient. As shown in the figure, only about 20% of the energy contained in the fuel put into a typical car is converted into motion while about 70% is given off as heat from the engine and exhaust.

Electric motors are much more efficient and can convert 90% or more of the electricity they receive into motion. Tests done by Transport Canada reported overall efficiencies of 80% to 90%, at 20°C, including losses during the recharging process.²

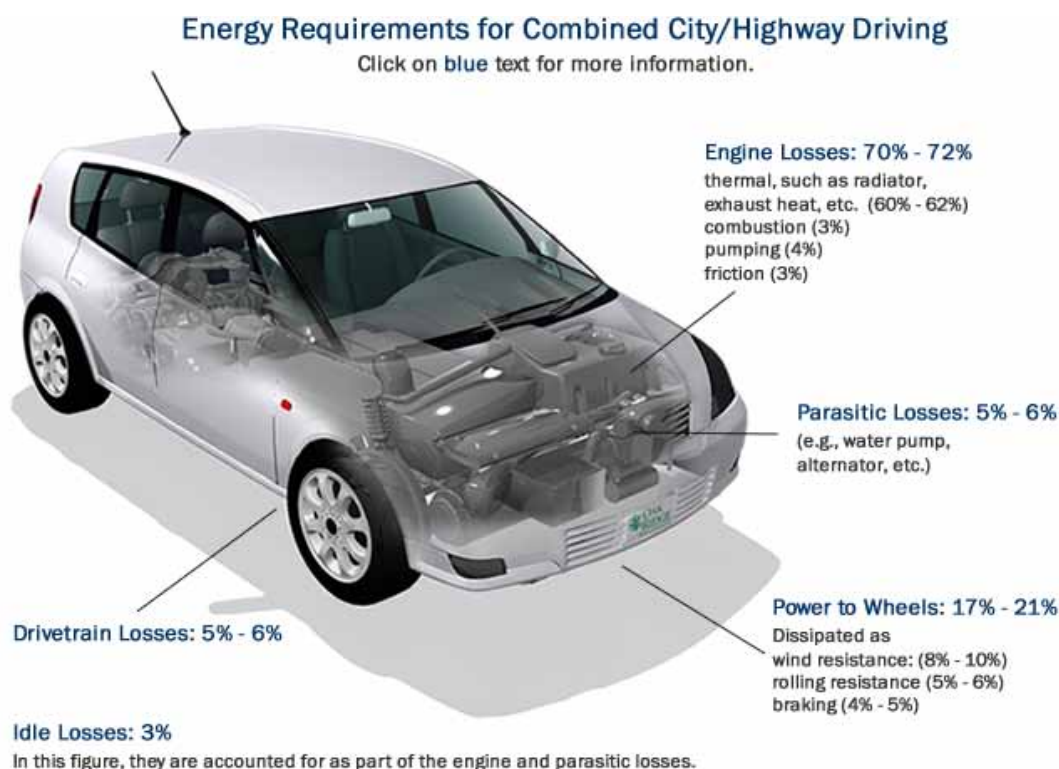


Image from EPA website <http://www.fueleconomy.gov/feg/atv.shtml> Accessed: April 10, 2013

2. Meyer, N. et al., 2012, *The Impact of Driving Cycle and Climate on Electrical Consumption & Range of Fully Electric Passenger Vehicles*

Gas Tanks vs. Batteries

In spite of being so inefficient, current vehicles are able to drive hundreds of kilometers on a single tank of fuel because gasoline and diesel contain an impressive amount of energy. For example, a cup of gasoline contains roughly the same amount of energy as 2 of the lead-acid batteries that would be used to start the car.³

Newer battery technologies such as nickel metal hydride (NiMH) and lithium ion (Li-ion) can hold more energy than lead-acid, but a typical gas tank still holds a lot more energy than even the best batteries.

Types of Electric Vehicles

In the last ten years, vehicle manufacturers have started producing several types of electric vehicles – each type uses a different strategy to take advantage of the efficiency of electric motors without being too limited by the lower energy capacity of batteries. The following definitions are taken directly from Natural Resources Canada's (NRCan) 2013 Fuel Consumption Guide.⁴

Hybrid-electric vehicles (HEV)⁵



Hybrid-electric vehicles (HEVs) combine a battery-powered electric motor with a conventional internal combustion engine. Thus they offer the driving range and rapid refueling of conventional vehicles, together with features of electric vehicles. Hybrids cannot be charged using external electricity – they use the gasoline engine, regenerative braking, and the energy produced from coasting to recharge their batteries. Through increased fuel efficiency and reduced fuel use, hybrids can reduce GHG emissions.

Plug-in hybrid electric vehicles (PHEV)



Plug-in hybrid-electric vehicles (PHEVs) are hybrids with high-capacity batteries that can be charged by plugging them in. Although PHEVs don't have to be plugged in to be driven, they will not achieve optimal fuel consumption or maximum driving range without charging.

There are two basic types of PHEVs available:

Series PHEVs – an internal combustion engine is used to generate electricity only; an electric motor is used to propel the vehicle. They can run in electric-only mode until the battery needs to be recharged. The engine will then generate the electricity needed to power the electric motor. When operating in electric-only mode, series PHEVs produce no tailpipe emissions.

Blended PHEVs – an internal combustion engine and an electric motor are connected to the wheels, and both propel the vehicle under most driving conditions. Electric-only operation may occur at lower speeds.

3. 125 ml of Gasoline @ 33.7 MJ/L = 4.2 MJ; 100 Ah @ 12V = 1.2 kWh = 4.3 MJ

4. NRCan, 2013, Fuel Consumption Guide

5. Images are from Electric Power Research Institute, 2011, *Plugging In: A Consumer's Guide to the Electric Vehicle*

Battery-electric vehicles (BEV)



Battery-Electric Vehicles (BEVs) are propelled by an electric motor (or motors) that draw electricity from on-board rechargeable batteries. When the batteries run low, they must be plugged in to recharge. Electric vehicles produce no tailpipe emissions.

Technically, all of the above can be called electric vehicles (EVs) but sometimes companies and websites shorten "Battery-Electric Vehicles" to just "Electric Vehicles". This report focuses on Battery-Electric Vehicles (BEVs) and Plug-In Hybrid-Electric Vehicles (PHEVs); those vehicles that can be charged from the power grid.

Gas Stations vs. Charging Stations

Batteries need to be recharged with electricity instead of being refilled with a liquid fuel like gasoline. Manitoba Hydro's website describes the two main types of chargers in North America:

Level 1 AC – These charging systems are compatible with standard 120 Volt outlets commonly found in garages and exteriors of homes and businesses. The 120 Volt outlets can also be found in parking lots that power your vehicle's block heater. Using a Level 1 AC charging system, a full charge for a battery-electric vehicle ranges between 12-18 hours and 6-8 hours for a plug-in hybrid-electric vehicle.



A level 1 charger. (image: GM)

Level 2 AC – These chargers can be used in a wide range of residential, commercial, and public settings. Using a Level 2 AC charging system, a full charge for a battery-electric vehicle ranges between 4-6 hours and 3-4 hours for a plug-in hybrid-electric vehicle. They require a 240-Volt outlet, similar to what is required by an electric clothes dryer.⁶

Manitoba Hydro's website also recommends checking to make sure the circuit used to charge the vehicle is appropriate:

Manitobans' experience with cold weather and plugging in their vehicles will help ease the transition to adopting EVs. In some circumstances, the existing infrastructure used to power vehicle block heaters in the winter can also be used to provide limited charging for EVs.

However, some existing electrical outlets may not be suitable for EV charging. Residential outlets can be part of a circuit used to power multiple lights and other electrical devices, and could become overloaded if used to charge an EV. A dedicated circuit for EV charging may need to be installed by a licensed electrician in these situations.

Also, some commercial parking lot outlets operate in a load restricted or cycled manner and using them may result in your EV receiving a lower charge than expected or no charge at all. If a parking stall is not specifically designated for EV use, we recommend that you consult with the parking lot or building manager to ensure it can provide adequate power to your vehicle.⁷

Most electric vehicles come with a built-in Level 1, 120-Volt charger, but most owners will want to install a Level 2, 240-Volt charger because the charge times are about half as long. Consumer Reports magazine states that a 240-Volt, Level 2 home charger sells for between \$700 and \$1,200, and installation can run an additional \$300 to \$500.⁸

6. http://www.hydro.mb.ca/environment/electric_vehicles.shtml Accessed April 15, 2013

7. http://www.hydro.mb.ca/environment/electric_vehicles.shtml Accessed: April 15, 2013

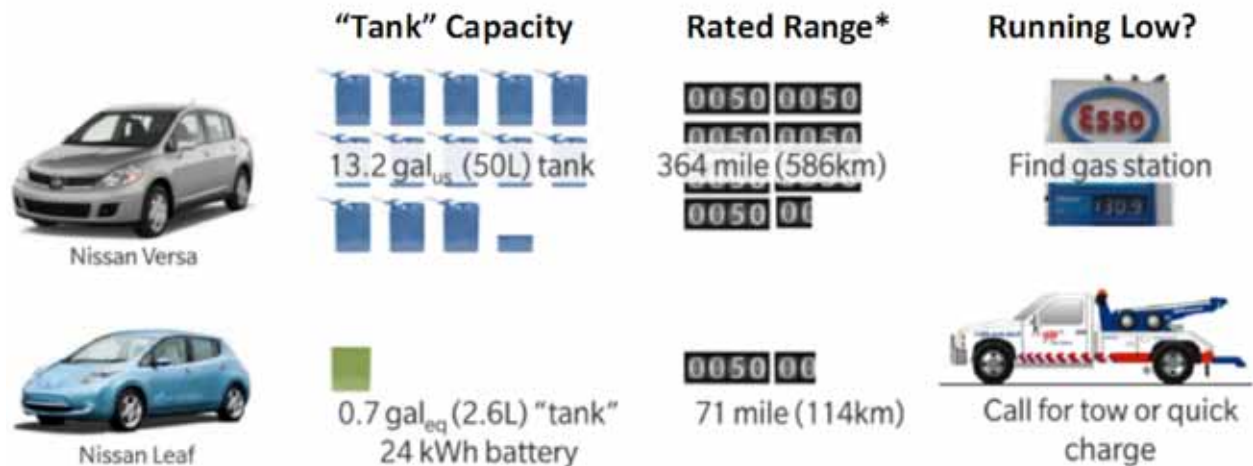
8. Consumer Reports, 2013 Electric Cars 101 Accessed: April 6, 2013

Partial charging

It is possible to partially recharge a vehicle and, while each car and charger combination is a little different, charging with a standard household outlet will give about 6.5 km of driving for every hour of charging (and twice that on a dedicated 240-Volt charger).⁹ Partial charging may impact battery life because the batteries are designed for a limited number of charge-discharge cycles. Manufacturers also recommend that lithium ion batteries be stored in a discharged state.¹⁰ However, this should not be a major concern for a vehicle owner because all batteries come with extended warranties and the manufacturers take partial charging into account when they calculate the length of the warranty.

Range – How far do you need to go today?

Electric vehicles are much more efficient than gasoline or diesel powered vehicles, but their range is shorter. The following image from a study on cold weather performance by Fleetcarma.com compares the range of two Nissan vehicles.



Fleetcarma.com compares the range of two Nissan vehicles. ¹¹

Image: www.fleetcarma.com

9. Consumer Reports, 2013 Electric Cars 101 Accessed: April 6, 2013

10. The Chevrolet Volt owner manual recommends that the remaining electric range should be "zero" when the vehicle is to be stored for long periods.

11. <http://www.fleetcarma.com/en/Resources/the-truth-about-electric-vehicles-in-cold-weather-webinar> Accessed April 15, 2013

Vehicles and Cold Weather

Cold temperature affects both gasoline and diesel powered vehicles and electric vehicles, but in different ways. This section discusses the general effects of cold weather on vehicles and a later section discusses electric vehicles available in the NWT (the Volt and Prius Plug-In) in more detail.



*Converted Toyota Prius near Winnipeg
Image: Red River College*



Cold weather and gasoline /diesel vehicles

The main issues with gasoline and diesel vehicles in cold weather are:

- **Cold starting.** They become more difficult to start because the internal friction in the engine increases and the power available in the 12 V lead-acid starter battery goes down. This is solved by adding plug-in electric heaters to the engine and battery. If electricity is not available, they can be manually or automatically started every few hours or a smaller fuel-fired heater¹² can be installed to heat the engine coolant. If a vehicle cannot start on its own, it can be "jump-started", using 12-Volt electricity from another vehicle or a charger pack that is plugged in to the grid.
- **Fuel consumption and range.** They lose efficiency because internal friction in the drive-train and the rolling resistance of the tires increases. This reduces the range of the vehicles significantly, but usually not to the point that vehicles are stranded after running out of fuel – they just fill up more often.
- **Cold interior and frost on windows.** They take longer to warm up to a comfortable level and frost on windows can block visibility. This is usually solved by allowing the vehicle to warm up before driving or by installing an electric cabin heater, plugged in to the grid.

12. <http://www.webasto.com/int/markets-products/car/retrofit-parking-heater/> Accessed April 18, 2013

Cold weather and electric vehicles

The literature review conducted for this study did not find studies on the performance of electric (or any other) vehicles in temperatures below minus 30°C, but five studies were reviewed that reported on minimum temperatures between minus 20 and minus 30°C.

- Manitoba Hydro added Hymotion lithium ion battery packs to 10 existing Toyota Prius Hybrids starting in 2008 and monitored them for 3 years in the Winnipeg area.¹³
- FleetCarma collected data from a fleet of Mitsubishi i-MiEV, Nissan Leaf and Ford Transit BEVs, and Chevrolet Volt PHEVs in Ontario. They recorded temperatures as low as minus 25°C.¹⁴
- Transport Canada did road and laboratory based testing of a Tesla Roadster and a Mitsubishi i-Miev at their laboratory in Ottawa at temperatures of minus 20°C.¹⁵
- Hydro-Québec collected data on 30 Mitsubishi i-MiEV BEVs in both Europe and near Montreal for 3 years from 2010 – 2013. They recorded temperatures as low as minus 30°C.
- Red Deer College in Manitoba collected data on two Mitsubishi i-MiEV BEVs, recording temperatures as low as minus 27°C.

Electric motors do not have a problem starting in the cold, but BEVs and PHEVs do have cold temperature issues. Colder temperatures decrease the capacity of the lithium ion batteries while, at the same time, there is a need for extra heating energy to keep the driver, passengers and the battery itself warm. Excess heat can also decrease battery performance, which causes problems in hotter parts of the United States.

Different manufacturers are using different approaches to battery temperature management. Some are using air from the passenger cabin to heat and cool the batteries, while others use specially designed liquid heating and cooling systems. PHEVs take advantage of their on-board engines to generate heat and/or additional electricity to power electric heaters or air conditioners. Other vehicles use grid power while they are plugged in to “pre-heat” and “pre-cool” the cabin and batteries before departing on a trip.

The cold weather issues reported on in the five studies can be discussed under the same temperature headings as for gasoline and diesel powered vehicles.

13. Red River College, 2011, *Plug-In Hybrid Electric Vehicle Demonstration*

14. <http://news.fleetcarma.com/2013/01/31/electric-car-range-in-bitter-cold/#.UWBSxDd49TO> Accessed April 16, 2013.

15. Hydro Québec, 2012, Presentation at EV 2012, *Le projet pilot de VÉ à Boucherville : un projet d'avenir Parsons, Presentation to EV 2011, Manitoba PHEV*

Cold starting

Most of the studies did not report inability to start in the cold as an issue, but early in the Manitoba tests of converted Prius Hybrids, two of the vehicles would not start after a period of cold weather. The problem was traced back to the small 12-Volt lead-acid battery that is used to activate the larger lithium ion battery when the vehicle is started. The 12 V battery was upgraded to a battery with more capacity and a trickle charger was added, which solved the problem. It is possible that the extra power needed for the monitoring equipment was draining the 12 V battery (which is already much smaller than a standard 12 V car battery).¹⁶ It is also important to note that these vehicles were modified versions of the standard Prius Hybrid and not the current factory produced Prius Plug-In.

Lithium ion batteries do lose capacity as temperatures decline and the gasoline powered engines in PHEVs get harder to start in cold weather. A vehicle with a large battery in an insulated enclosure with an integrated battery heating system would survive longer in cold temperatures.

Charging in cold temperatures

While none of the studies reported cold charging issues, some sources state that charging efficiency could decrease in cold temperatures and that, at extremely cold temperatures, it could become impossible for a lithium ion battery to be charged at all.¹⁷ The "Electropaedia", a website maintained by a battery consultancy based in Chester, UK stated that "as temperatures decrease, charging time will increase while acceptance of charge will decrease".¹⁸ They also state that the life cycle of lithium ion batteries decrease with charging temperature due to lithium plating of the anode.¹⁹ Different manufacturers handle this in different ways – either by heating the battery during charging or by suggesting that the vehicle not be charged below a certain temperature.

16. Parsons, Presentation to EV 2011, Manitoba PHEV Demonstration: Experience from a 3 year collaboration

17. Behr 2009, Thermal Mangement for Hybrid Vehicles p.7 [http://www.behr.de/internet/behrrmm.nsf/lupgraphics/Behr_Thermomanagement_TPT09_E.pdf/\\$file/Behr_Thermomanagement_TPT09_E.pdf](http://www.behr.de/internet/behrrmm.nsf/lupgraphics/Behr_Thermomanagement_TPT09_E.pdf/$file/Behr_Thermomanagement_TPT09_E.pdf) Accessed: April 10, 2013

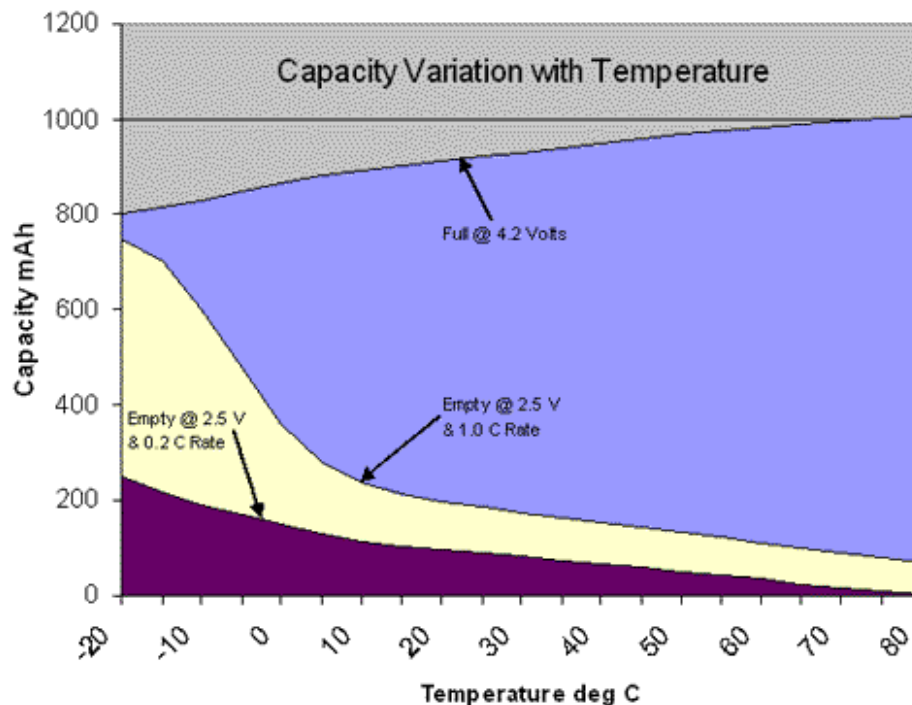
18. <http://www.mpoweruk.com/chargers.htm#rates> Accessed April 17, 2013

19. http://www.mpoweruk.com/lithium_failures.htm#lifetime Accessed April 17, 2013

Fuel Consumption and Range

Battery-Electric Vehicles

Battery capacity can be expected to “deteriorate dramatically” with temperature according to the lithium ion battery theory explained in the following graph. This information is from the previously mentioned “Electropaedia”.²⁰



The graph shows a lithium cell working between its specified upper and lower voltage cut-off limits of 4.2 Volts and 2.5 Volts respectively. These are considered the fully charged and the empty conditions of the cell. The “Full” line is the point at which the cell reaches full charge using the constant current – constant voltage charging method at the corresponding temperature. Two “Empty” lines are shown corresponding to two different discharge rates 0.2 C and 1.0 C.

The capacity of the cell at a given rate and temperature is the difference from the “Full” line and the corresponding “Empty” line.

In actual practice, the cell may be charged at one temperature and discharged at a different temperature and this must be taken into account when calculating the effective capacity of the cell. Note that the cell is very inefficient at giving up its charge at high discharge rates and low temperatures. In other words, its coulombic efficiency deteriorates dramatically at low temperatures.

Source: *Electropaedia*

20. <http://www.mpoweruk.com/soc.htm#algorithms> Accessed April 17, 2013

All the studies on BEVs reported that the electric efficiency of the vehicles decreased with colder weather as shown in the graphs in an appendix to this report. However, the reductions were not as severe as the previous graph which shows that a battery at minus 20 would have very little usable capacity. This suggests that the battery thermal management systems in the vehicles were able to keep the battery temperature from reaching outside temperatures.

FleetCarma recorded a decrease in fuel efficiency of about 1% per °C decrease in temperature, starting at around 20°C for the Nissan Leaf BEV. Transport Canada tests showed an average “on road” decrease in fuel efficiency of 0.8% per °C in one BEV and 0.7% per °C in another.²² Hydro Québec’s data from 30 Mitsubishi i-MiEV BEVs showed that fuel efficiency decreased by 2% per degree C.²³ If a BEV loses 1% of range per degree C below plus 20°C, it would lose 60% of its capacity at minus 40°C.

The actual reduction depended very much on the habits and preferences of the driver – particularly on how aggressively they accelerated and braked as well as how much they used the heaters. For example, FleetCarma reported that a driver, with a “heavy foot” and high heat used 134% more electrical energy than a “gentle driver” using a low heat setting. Both were driving Chevrolet Volts at minus 4°C on the same day.

Meyer et al. (Transport Canada) also reported that using the heater on high reduced the range of the BEVs that they tested by about 25% at minus 7°C,²⁴ and Hydro Québec stated that heating was the principle cause of increased energy use during the winter.

Natural Resources Canada states that driver behaviour can affect the efficiency of gasoline – or diesel-powered vehicles by up to 25%.²⁵ Turning up the heat in a gasoline – or diesel-powered vehicle has virtually no effect on efficiency because there is plenty of heat available for “free” from the engine. So, while heating and aggressive driving could reduce the range of a gasoline – or diesel-powered vehicle, these effects are relatively small in comparison with the overall scale of energy used. As the overall energy budget of battery-electric vehicles is much smaller, these effects become much more important.

Battery thermal management will be very important if a BEV is to operate successfully in the coldest months of an NWT winter. The ability to use grid power to keep the battery warm while it was plugged in would be essential and a partly heated garage would be ideal for the coldest days.

Plug-In Hybrid-Electric Vehicles

Manitoba Hydro reported that the modified Prius PHEV used less electricity during the winter.²⁶ PHEVs are able to use their on-board gasoline engines as heaters so cold temperatures cause the engine to start even if the battery is not depleted. This reduces the need for the battery to provide heat to the cabin and the engine also provides power to the wheels. The extra help from the engine explains why a PHEV might use less electricity while still operating in “EV” mode.

21. <http://news.fleetcarma.com/2013/01/31/electric-car-range-in-bitter-cold/#.UWBSxDd49T0> Accessed: April 16, 2013

22. Transport Canada, 2012 *Comparison of on-road vs dynamometer range and energy consumption of fully electric passenger vehicles*, presentation at EV 2012, Montreal Quebec

23. Hydro Quebec, 2012 presentation at EV 2012 *“Le projet pilote de VÉ à Boucherville : un projet d’avenir”*

24. Meyer et al., 2012 *The Impact of Driving Cycle and Climate on Electrical Consumption & Range of Fully Electric Passenger Vehicles*

25. <http://oee.nrcan.gc.ca/cars-light-trucks/driving/fuel-efficient-driving-techniques/17823> Accessed: April 10, 2013

26. Parsons, R., Presentation to EV 2011, *Manitoba PHEV Demonstration: Experience from a 3 year collaboration*

Cold interior & frost on windows

The studies by Manitoba Hydro,²⁷ Transport Canada,²⁸ as well as a study on two Mitsubishi i-MiEV BEVs done by Red Deer College in Manitoba²⁹ all reported that drivers felt that the BEVs and PHEVs did not warm up fast enough and that window fogging could be an issue. This was improved in the Manitoba Hydro study by adding electric heaters to the vehicles that were able to pre-heat the cabin using grid electricity (using a separate circuit from the charger).³⁰ Many of the vehicles tested also had electrically heated seats, which drivers found very effective for reducing the need to heat the entire cabin.



Electric cabin pre-heater used in Manitoba

Photo: Parsons

27. Gregor, C., Presentation to IEEE EPEC11 Conference, *Cold Weather Modifications of Plug-in Hybrid Electric Vehicles for Manitoba Operation*

28. Transport Canada, presentation to EV 2011, *Overview of Transport Canada's Laboratory and on-road evaluations of several battery electric vehicles in Canadian climate conditions.*

29. Red Deer College, 2012, *All electric Mitsubishi i-MiEV in Manitoba: Summary of Operational Experience: First Year Report*

30. The wattage and power consumption was not mentioned, but similar 900 W heaters are available from Canadian Tire. They are typically used with a timer to pre-heat regular vehicles in the morning.
<http://www.canadiantire.ca/AST/browse/4/Auto/VehicleAccessories/CarHeaters/PRD~0303409P/Pyroil+Interior+Heater.jsp?locale=en>

2013 Model Year – What is available in the NWT?

In 2013, there are 8 BEVs and PHEVs listed in NRCan's fuel consumption guide.³¹ Together, they won the ecoENERGY for Vehicles Award for most efficient vehicle in 6 categories for cars ranging from Two-seater to Station Wagon.

All the manufacturers listed in the Dillon report were contacted as well as new manufacturers listed in the NRCan guide. Of those that responded, most did not have an authorized service centre in the NWT and stated that if the vehicle broke down, the owner would be responsible for getting the vehicle to the nearest service centre, usually in Edmonton. The manufacturers of battery-electric vehicles such as the Nissan Leaf and the Mitsubishi i-MiEV emphasized that the maintenance required was much lower than a typical vehicle – limited to checking the brakes once every two years. Tesla Motors claims that it will provide "service at your home", anywhere in Canada, but has not confirmed that this includes the NWT.³²

Two electric vehicles are available for purchase and can be serviced under warranty in the NWT. Both are plug-in hybrids: the Toyota Prius Plug-In and the Chevrolet Volt and both can only be serviced in Yellowknife.

The NWT Climate

If you are going to buy and operate a BEV or a PHEV in the NWT, you will want to know what your average cost savings would be and what you could expect the minimum range to be. Cost savings depend on the average efficiency which depends on the average temperature (as well as driver habits). Minimum range depends on the lowest temperature on a particular day that you want to drive somewhere.

The studies reviewed from the rest of Canada showed an average reduction in efficiency and range of roughly 1% per °C for temperatures below plus 20°C. Since no data was reported for temperatures below minus 30°C, the vehicles would be operating in unknown territory at those temperatures.

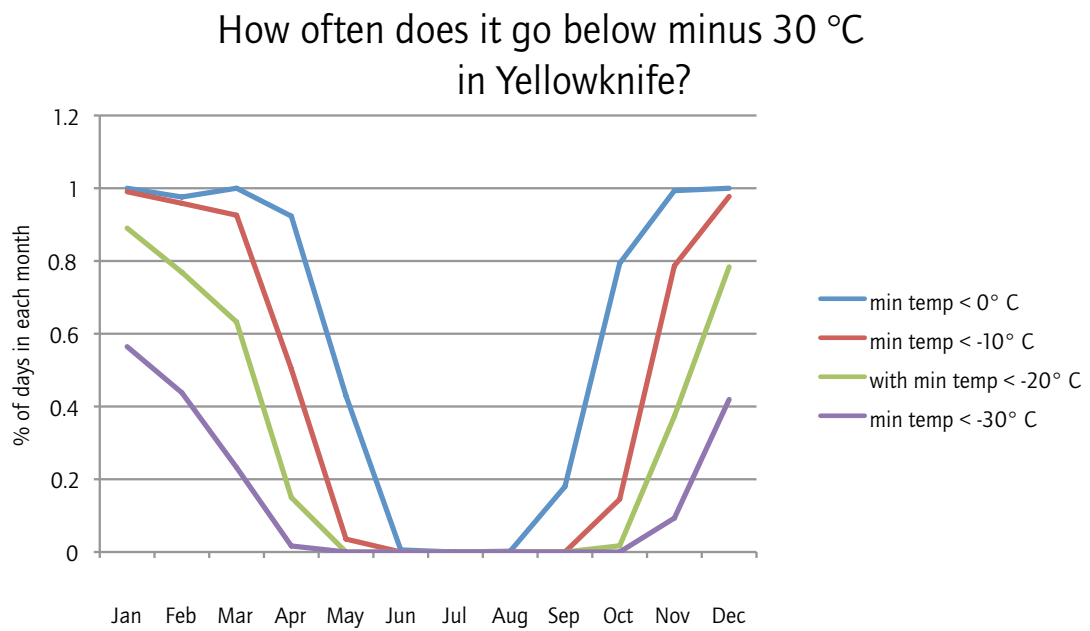
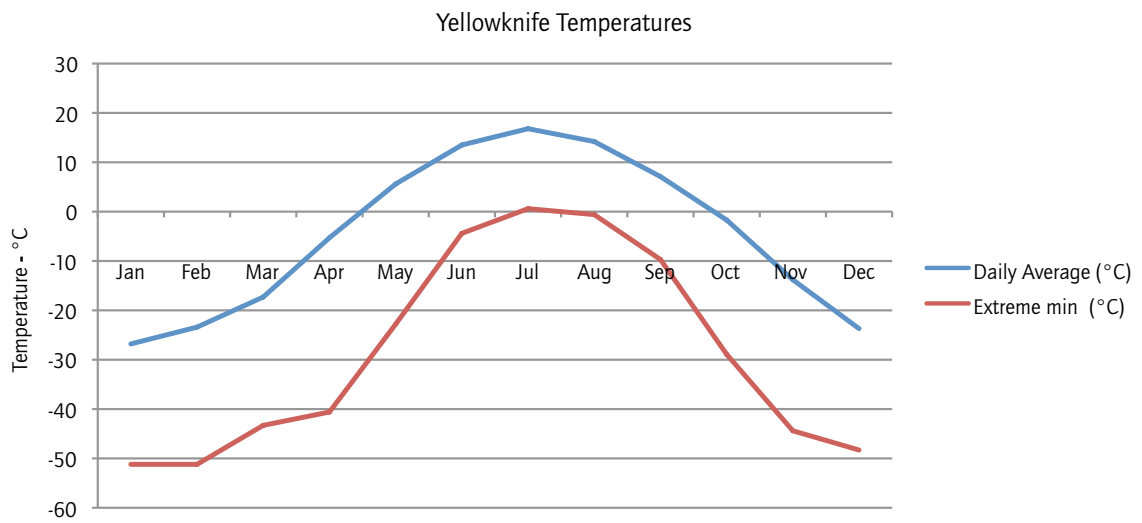
The daily average temperature in Yellowknife ranges from minus 27°C in January to plus 17°C in July and is shown in the following graph.³³

The extreme minimums are also shown, but these are the extreme lows for each month recorded over a 30 year period. They are very low, but not very useful for figuring out what an electric vehicle is likely to encounter. The following graph shows the percentage of days in each month that the lowest temperature was lower than minus 30°C, minus 20°C, etc. On average, fifty-four days or 15% of the entire year experience a minimum temperature below minus 30°C. Other communities that have access to hydroelectricity like Fort Smith and Hay River have slightly warmer climates than Yellowknife.

31. NRCan, 2013, *Fuel Consumption Guide*

32. Conversations and e-mails with Kingland Ford, Lacombe Ford, Southside Mitsubishi Edmonton, Sherwood Nissan, Tesla Canada, Smith Electric, Western International, March 27 & 28, 2013

33. Source: Environment Canada Yellowknife Climate Normals from 1971 to 2000 http://climate.weatheroffice.gc.ca/climate_normals/index_e.html



BEVs in the NWT

Pure battery only electric vehicles are not currently available in the NWT, but in spite of the cold climate, they could be a viable commuter vehicle in the NWT. Their range would likely be reduced by up to 60% on the coldest days, but NWT communities are smaller than typical Canadian cities so the average commute is also shorter. For example, the average commute in Yellowknife was reported to be 6.3 km return.³⁴ The BEVs listed in NRCan's fuel consumption guide have ranges from 100 km (Mitsubishi i-MiEV) to 426 km (Tesla Model S).

For the majority of the time, the vehicles would operate in conditions similar to the rest of Canada. For the remaining, extremely cold days (roughly below minus 30) the following should be considered:

- The vehicle should be plugged in both at home and at work.
- The vehicle needs to have the ability to use grid electricity to pre-heat the cabin and battery. If not already part of the vehicle's temperature management system, an after-market electric cabin heater, battery heating pad or coolant heater could be installed. If the vehicle cannot pre-heat itself using grid power, it should be kept in a garage during the coldest temperatures.
- There is no data, but it is likely that the vehicle cabin will be cold and have windshield frost issues as the heating systems will probably not keep up during very cold weather. This is similar to what is experienced with some gasoline and (particularly) diesel vehicles in the NWT. Electrically heated seats and grid powered pre-heaters would be helpful, as would a good parka and well insulated mitts and boots.
- A gasoline- or diesel-fired coolant heater such as those manufactured by Webasto³⁵ could be an option to improve electric range and occupant comfort. These heaters use less fuel than running a full-sized engine and are used to warm gasoline- and diesel-powered vehicles that cannot be plugged in during cold temperatures.

34. City of Yellowknife, 2006, *Community Energy Plan Action Area 2 – Transportation – Final Report*

35. <http://www.webasto.com/int/markets-products/car/retrofit-parking-heater/> Accessed April 18, 2013

PHEVs in the NWT

The remainder of this report focuses on the two vehicles that are available and serviceable in the NWT (Yellowknife) – the Prius Plug-In and the Volt. Both vehicles have their own gasoline-powered engines in addition to battery packs, which mean that concerns about battery range in cold temperatures are not as important. PHEVs are not just commuter vehicles; they are capable of completely replacing a gasoline or diesel powered car. The cold temperature issues remaining are cold starting, fuel efficiency and cabin heating/windshield defrosting.

The Prius Plug-In is what NRCan classifies as a “blended PHEV” while the Chevrolet Volt is classified as a “series PHEV”. They are quite different vehicles. The following table outlines some of the differences with a focus on how they handle cold temperatures. The information is from the 2013 owner manual of each vehicle or NRCan’s 2013 fuel consumption guide unless otherwise noted:

	Prius Plug-In	Volt
Type	“Blended PHEV” - Hybrid with a larger battery to extend range of electric mode. The engine can drive the wheels directly.	“Series PHEV” - Electric Vehicle with a gasoline engine to extend range of battery. The engine generates electricity to power motors that drive the wheels.
Size	Mid-Size	Compact
EV Mode Electric Efficiency	14.4 kWh/100 km plus 0.4 L/100 km of gasoline ³⁶	21.4 kWh/100 km ³⁷
EV Mode Electric Efficiency (l/100km _{EQ}) ³⁸	2.0 L/100km _{EQ}	2.4 L/100km _{EQ}
Battery Capacity	4.4 kWh lithium ion	16 kWh lithium ion ³⁹
Electric Range	22 km	61 km
ICE Engine Size	1.8 L	1.4 L
Gasoline Required	Regular	Premium
HV Mode City Efficiency	3.7 L/100 km	6.7 L/100 km
HV Mode Hwy Efficiency	4.0 L/100 km	5.9 L/100 km
Gas Tank	40 L	35.2 L
Total Range	1,039 km	550 km
Charging Times	Level 1 – 120 V, 3 hours Level 2 – 240 V, 1.5 hours Charging is slowed by cold temperatures.	Level 1 – 120 V, 12 Amps – 10 hours Level 1 – 120 V, 8 Amps – 16 hours Level 2 – 240 V, 20 Amps – 4 hours Charging is slowed by cold temperatures.

36. NRCan, 2013, *Fuel Consumption Guide*, The Prius Plug-In can operate for extended periods without using the gasoline engine, but the engine is needed for higher speeds and sometimes during warm-up.

37. NRCan, 2013, *Fuel Consumption Guide* NOTE THAT THE PRIUS WAS TESTED USING 2-CYCLE TESTING WHILE THE VOLT WAS TESTED USING 5-CYCLE TESTING. 5-CYCLE TESTING RESULTS IN FUEL CONSUMPTION FIGURES THAT ARE ~15% HIGHER THAN 2-CYCLE TESTING.

38. This is a measure of energy efficiency that allows comparison of EVs with gasoline powered vehicles. One litre of gasoline is equivalent to 8.9 kWh of electricity.

39. Brochure: *Chevrolet Volt Battery*

	Prius Plug-In	Volt
Battery Thermal Management	Uses air from passenger cabin to heat /cool battery. No ability to heat battery directly. Coolant loop from engine heats cabin, which then heats the battery. ⁴⁰	Liquid cooled/heated battery in a separate, insulated compartment. Liquid is heated by an electric heater; no direct connection from engine coolant loop to battery. ⁴¹
Ability to use grid power for "pre-heating"	No.	Yes – both cabin & battery can be heated with grid power.
Cabin Heating	Uses engine coolant with a supplementary electric heater. ⁴²	Uses engine coolant with a supplementary electric heater.
Temperature When Engine Comes on to Provide Heat	0°C if vehicle has been left for a long time. Minus 10°C while driving.	Minus 12°C at lowest settings.
12-Volt Battery Required to Start	Yes – recharged from main battery when running. Can be depleted if left unplugged for long periods. Can be boosted.	Yes – recharged from main battery. Can be boosted.
"Remote Start"	Yes – but only to power the air conditioning unit. Pre-heating is not possible.	Yes – can be remote started to pre-heat but only twice between before having to fully turn on vehicle by starting with a key inside the vehicle. If plugged in, this uses grid power, if not, it can start the engine to provide power.
Cold Temperature Limits	• Vehicle should be plugged in when not used for extended periods – to prevent 12 V battery from draining. • "Do not leave the vehicle or the charging cable in areas where the outside temperature is lower than minus 40°C. The vehicle or charging cable will probably be damaged". • "Do not charge below minus 30°C".	• "Plug in below 0°C – even when charged." • If "battery too cold to start", requires plugging in to warm up before starting.
Electric Seats	Yes	Yes
MSRP – FOB Yellowknife	\$41 K ⁴⁴	\$44 K ⁴⁵
Warranty ⁴⁶	Basic 3 yrs, Engine 5 yrs; Battery 8 yrs	Basic 3 yrs, Engine 5 yrs; Battery 8 yrs

40. <http://voltowner.blogspot.ca/2013/01/battle-of-plug-in-hybrids-volt-versus.html> Accessed April 18, 2013. There is no mention of a battery heater in the owner manual, Toyota has not responded to inquiries by e-mail on this question.

41. <http://www.mychevroletvolt.com/chevy-volt-battery-cooling-systems-algorithms> Accessed April 10, 2013

42. <http://pressroom.toyota.com/releases/toyota+introduces+2012+prius+plug-in+hybrid.htm> Accessed April 18, 2013

43. <http://www.driving.ca/Electric+cars+plug+hybrids+Which+gets+better+economy/8228380/story.html>

44. Toyota website

45. GM Website plus \$990 additional shipping quoted by Autotec

46. http://www.motortrend.com/roadtests/alternative/1302_2012_chevrolet_volt_vs_toyota_prius_plug_in/viewall.html Accessed April 19, 2013

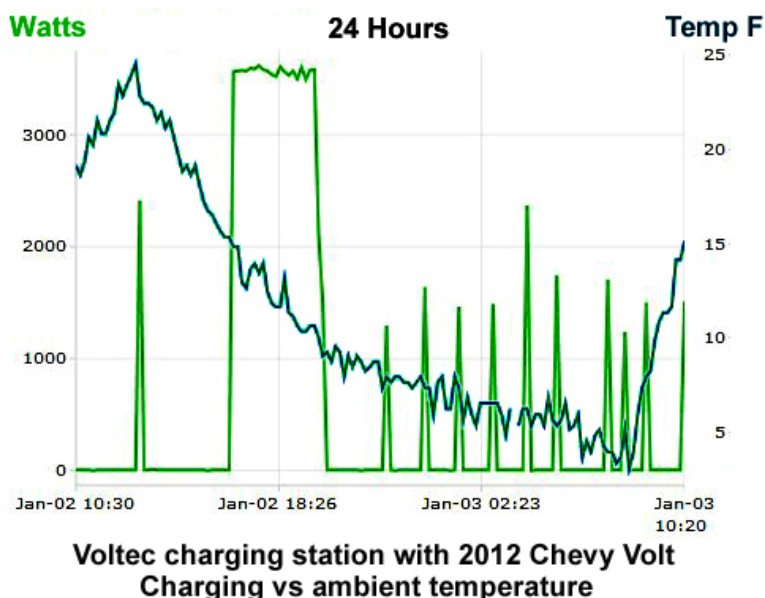
Cold starting

The 12 V battery, main battery and gasoline powered engines in the Prius Plug-In and Volt will not work if they get too cold. As with regular gasoline- and diesel-powered vehicles, a method of keeping them warm is required.

Plugged in

The Prius Plug-In owner manual states that the vehicle should not be charged below minus 30°C and should not be left at temperatures below minus 40°C. Toyota Canada stated in e-mails that “the Prius Plug-In will operate in colder climates” but that “approaching these extreme temperatures ... charge time can increase indefinitely”⁴⁷. The Volt owner manual states that the vehicle should be plugged in below 0°C, even if it is fully charged.

A key difference between the Prius Plug-In and the Volt is the Volt’s ability to use grid electricity to maintain the temperature of the battery and/or the cabin if it is plugged in. The following graph shows the power used by a Volt user in Maine (note that 5°F is minus 15°C).⁴⁸



“That first spike of 2500 Watts was when we pre-warmed the vehicle remotely for 10 minutes prior to driving it. The sustained energy draw represents a full battery charge after that trip and the small spikes represent power drawn for up to 10 minutes at between 1200 and 2400 Watts for thermal management.”

A Prius Plug-In could probably be modified with an after-market electric cabin heater and/or a battery heating pad on a separate 120 V AC circuit if no garage was available. The Manitoba Hydro study of 10 upgraded Prius Hybrids found that grid powered electric cabin heaters (similar to the 900 W model available from Canadian Tire⁴⁹) were very much appreciated.⁵⁰

A Prius Plug-In could probably be modified with an after-market electric cabin heater and/or a battery heating pad on a separate 120 V AC circuit if no garage was available. The Manitoba Hydro study of 10 upgraded Prius Hybrids found that grid powered electric cabin heaters (similar to the 900 W model available from Canadian Tire) were very much appreciated.

47. E-mails, April 12th and 15th, 2013, John-Paul Farag, B.EngSci, MBA Manager, Advanced Technology & Powertrain, External AffairsToyota Canada Inc

48. http://www.arttec.net/Chevy_Volt/index.htm Accessed: April 10, 2013

49. <http://www.canadiantire.ca/AST/browse/4/Auto/VehicleAccessories/CarHeaters/PRD~0303409P/Pyroil+Interior+Heater.jsp?locale=en>

50. Gregor C., Presentation at IEEE EPEC 11, Cold Weather Modifications of PHEVs for Manitoba Operation

Using grid power for heating the battery and cabin will use more power, but gasoline and diesel vehicles also use electric heaters during cold temperatures. A study by the Arctic Energy Alliance estimated that these heaters draw an average of 700 W – or about 6 Amps at 120 V.⁵¹

Not plugged in

Any vehicle left at extremely cold temperatures without a source of heat will eventually refuse to start. On a minus 30 day, a typical Yellowknifer would not expect a vehicle to start if it had been left unplugged for more than four hours.⁵²

The typical procedure for re-starting a “frozen” gasoline– or diesel-powered vehicle would be:

1. Attempt to “boost” the 12-Volt battery from another vehicle or a charger,
2. Warm up the vehicle for a few hours by plugging in the block heater and battery warmer,
3. Push or tow the vehicle to a heated garage and warm it up overnight.

Based on information in the owner manuals, re-starting a frozen Prius Plug-In or a Volt would be a little more complicated:

1. “Boosting” the 12-Volt battery is possible with both cars and may be successful in re-starting the car. But the 12-Volt battery is only used to “unlock” the main battery, not to start the gasoline engine. The main battery is needed to start the gasoline engine, so the engine cannot be used to heat up the vehicle/battery if the main battery does not have enough power to start it.
2. Warming up the vehicle by plugging it in should work for the Volt, but the charger must be able to reach an outlet directly - extension cords are not advised. Plugging in the Prius might help to recharge the main battery, but recharging below minus 35°C is not advised and the Prius does not have a grid powered heater.
3. Towing the vehicle to a heated garage would work, but the front wheels might be locked so they would need to be lifted for the tow (no pushing or dragging with a tow rope).

Neither vehicle can be “roll started”.

The battery pack in the Volt is insulated, temperature regulated with its own liquid cooling/heating circuit and weighs 180 kg – all factors that should help it stay warm enough to start over a longer period than the Prius Plug-In.

Leaving the vehicle “running”

In extreme cold weather, some people leave their gasoline– or diesel-powered vehicles running if there is no possibility of plugging them in. Additionally some “command start” systems can be programmed to start the engine and warm it up below a certain temperature.⁵³

The Volt can be “remote started” up to two times before it requires being fully powered up by starting it with a key inside the vehicle. The remote start function uses the main battery and, if needed, the gasoline engine to pre-heat the battery and cabin. The Prius Plug-In can only remote start the air conditioning, which will not be helpful in cold weather.

It is not clearly stated in the owner manuals, but it appears that both the Volt and the Prius Plug-In would automatically re-start their engines as needed if they were left in the “ON” position. Although not directly related to cold weather, Toyota has released a kit that allows the Prius to be used as a back-up generator⁵⁴ and Volts have also been used as back-up generators.⁵⁵ Operation as a generator would require that the vehicle be able to re-start the engine when the battery was depleted, even if the driver was not present, so it should be safe to assume that this would also be possible in cold weather.

51. AEA, 2008, Basic Household Electricity Needs

52. John Carr, life-long Yellowknifer, conversation, April 2013

53. <http://www.tune-town.com/Alarms/autostart.htm> Accessed April 18, 2013

54. http://techon.nikkeibp.co.jp/english/NEWS_EN/20121025/247531/ Accessed April 18, 2013

55. <http://gm-volt.com/2012/11/01/a-chevy-volt-as-an-emergency-electricity-generator/> Accessed April 18, 2013

Fuel efficiency and range

The Volt and Prius Plug-In have different strengths and weakness depending on the type of journey they are being used for. The following scenarios evaluate different journeys that are common in the NWT:

- A 10 km, round-trip inside municipal boundaries (which PHEVs could complete in EV mode)
- A 200 km, round-trip on the highway
- A full year of driving at 20,000 km 55% City; 45% Highway

Not enough data could be found to reasonably estimate the change in PHEV performance in an NWT climate compared to the national figures provided by NRCan. PHEVs are particularly complicated because their gasoline powered engines are used as heaters and it is not clear how much power they would also provide to the wheels while they were operating. For example, in the modified Prius study by Manitoba Hydro, electrical consumption, in terms of kWh/km, was found to decrease in the winter while all BEV studies, including one on the Volt, showed electricity consumption increasing at low temperatures.

The following graphs show the scenarios based on NRCan's 2013 average fuel consumption figures⁵⁶ adapted to the 2012 fuel and residential electricity prices in Fort Smith, Hay River and Yellowknife.⁵⁷

	Yellowknife	Fort Smith	Hay River
2012 Premium Gasoline Cost (\$/L)	\$ 1.489	\$ 1.369	\$ 1.349
2012 Regular Gasoline Cost (\$/L)	\$ 1.389	\$ 1.269	\$ 1.249
2012 Diesel Cost (\$/L)	\$ 1.349	\$ 1.290	\$ 1.289
2012 Residential Electricity Cost (\$/kWh)	\$ 0.24	\$ 0.16	\$ 0.24

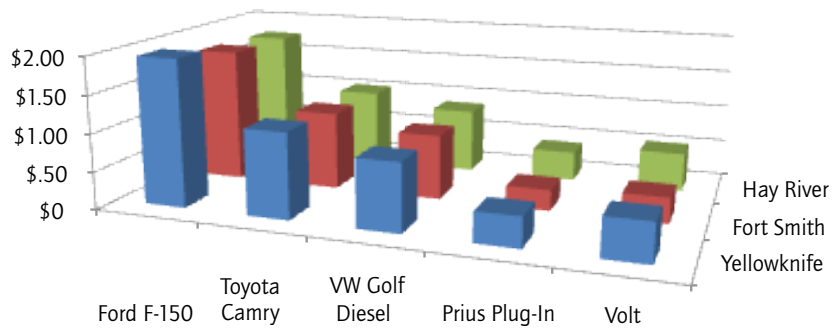
Commercial power rates are up to 1/3 lower than residential rates and wholesale power rates are even lower so savings for commercial and wholesale customers would be greater than shown here.

Electricity rates are expected to rise in the NWT by 17 to 30 percent over the next 4 years, but electric vehicles will still be cheaper to operate than gasoline- or diesel-powered vehicles. Power prices would have to increase by 100 – 200 percent before operating gasoline- or diesel-powered vehicles at current fuel prices would be cheaper than electric vehicles.

56. NRCan, 2013, *Fuel Consumption Guide* NOTE THAT THE PRIUS WAS TESTED USING 2-CYCLE TESTING WHILE THE VOLT WAS TESTED USING 5-CYCLE TESTING. 5-CYCLE TESTING RESULTS IN FUEL CONSUMPTION FIGURES THAT ARE ~15% HIGHER THAN 2-CYCLE TESTING.

57. Arctic Energy Alliance – energy cost estimates for 2012

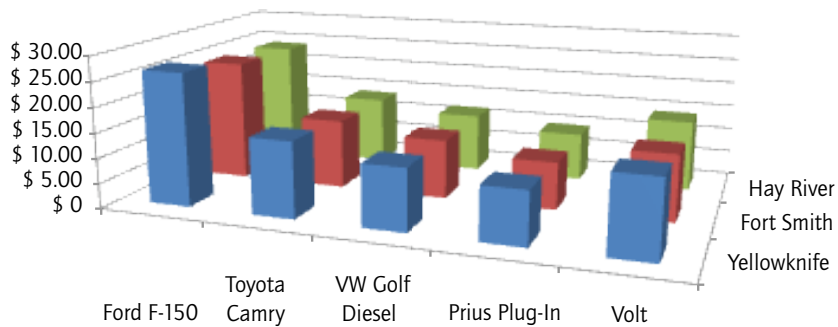
Cost of 10 km trip in town



	Ford F-150	Toyota Camry	VW Golf Diesel	Prius Plug-In	Volt
Yellowknife	\$ 1.96	\$ 1.14	\$ 0.90	\$ 0.40	\$ 0.51
Fort Smith	\$ 1.80	\$ 1.04	\$ 0.86	\$ 0.28	\$ 0.34
Hay River	\$ 1.76	\$ 1.02	\$ 0.86	\$ 0.40	\$ 0.51

In this scenario, the gasoline and diesel powered vehicles drive at their city rated fuel consumption rate, while the Prius Plug-In and Volt operate in electric vehicle (EV) mode. The Prius Plug-In uses a small amount of fuel because, even in EV mode, the engine is sometimes used. Even so, the Prius Plug-In costs the least to operate.

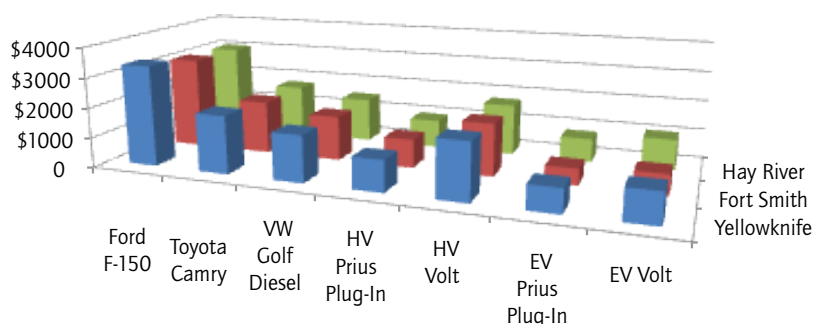
Cost of 200 km trip on highway



	Ford F-150	Toyota Camry	VW Golf Diesel	Prius Plug-In	Volt
Yellowknife	\$ 26.67	\$ 15.28	\$ 12.41	\$ 10.65	\$ 15.34
Fort Smith	\$ 24.36	\$ 13.96	\$ 11.87	\$ 9.54	\$ 13.32
Hay River	\$ 23.98	\$ 13.74	\$ 11.86	\$ 9.65	\$ 14.20

In this scenario, the gasoline- and diesel-powered vehicles drive at their highway rated fuel consumption rate, while the Prius Plug-In and Volt operate in electric vehicle (EV) mode until they drain their batteries and they then switch to hybrid (HV) mode. For the first 20 km or so, the Prius Plug-In is more efficient, but then it has to switch to HV mode, while the Volt can continue in EV mode. The Volt wins the efficiency battle between 20 and 60 km, but after that it switches to HV mode and becomes less efficient than the Prius. Over the entire 200 km trip, the Prius Plug-In costs the least. The Volt also requires premium gasoline which ends up making it even more expensive than the VW Golf TDI, which runs on diesel.

Cost of 20,000 km of mixed highway and in town trips

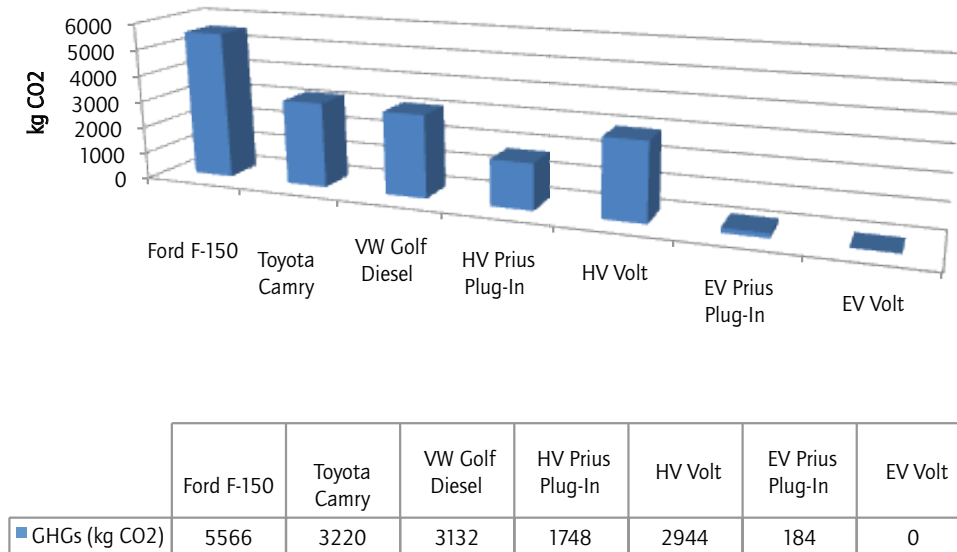


	Ford F-150	Toyota Camry	VW Golf Diesel	HV Prius Plug-In	HV Volt	EV Prius Plug-In	EV Volt
■ Yellowknife	\$3361.38	\$1944.60	\$1564.84	\$1055.64	\$1905.92	\$802.32	\$1027.20
■ Fort Smith	\$3070.98	\$1776.60	\$1496.40	\$964.44	\$1752.32	\$562.32	\$684.80
■ Hay River	\$3022.58	\$1748.60	\$1495.24	\$949.24	\$1726.72	\$791.12	\$1027.20

In this scenario, the gasoline- and diesel-powered vehicles drive 20,000 km at a 45% / 55% mix of their highway and city rated fuel consumption rates. The Prius Plug-In and Volt are shown operating both in electric vehicle (EV) mode and hybrid (HV) mode over the same distance. In this case, HV mode assumes that the vehicles are never charged from the grid and EV mode assumes the vehicles are always recharged before they drain their batteries completely. The Prius Plug-In is the most efficient vehicle in both modes.

All these scenarios roughly represent what would happen in the warmer half of the year in the NWT. For the remaining, colder six months, all the vehicles would use more fuel than shown here. The Prius Plug-In and the Volt would spend a lot of time in "EV with engine as heater" mode which would be somewhere between EV and HV mode in terms of fuel and electricity use.

GHGs from 20,000 km of mixed highway and in town trips



The GHG emissions shown in this graph are based on the same 20,000 km scenario shown in the previous graph. This is where the Prius Plug-In and Volt in EV mode really clobber the competition. Yellowknife, Hay River and Fort Smith are all powered by hydroelectricity, so when the graph shows "zero" greenhouse gas emissions, this includes the emissions from the power system.

It is also clear that the Volt in HV mode uses almost as much fuel as similar gasoline and diesel powered vehicles. The Volt was tested using the new 5-cycle protocol, which can result in fuel consumption ratings that are 15% higher than 2-cycle tests.

NRCAN is switching from the current 2-cycle vehicle testing protocol to a 5-cycle protocol that is already being used by the EPA in the United States. The 5-cycle protocol includes a test at minus 7°C, which would be helpful in figuring out how vehicles respond to lower temperatures.

Cold interiors and windows fostering

Both the Prius Plug-In and the Volt have had complaints of weak heating in warmer parts of Canada and the US.⁵⁸ The Volt can be pre-heated using grid electricity and has electric seats, but it cannot access heat directly from the engine to warm the cabin so cabin heating is probably limited by the capacity of the electric cabin heater. The Prius Plug-In uses heat from the engine plus a supplementary electric heater to warm the cabin, but it cannot be pre-heated using grid electricity. An after-market, grid powered cabin pre-heater could be added to the Prius Plug-In as was done in Manitoba or it could be kept in a heated garage. Both have electrically heated seats, which should be considered an essential efficiency measure rather than a luxury.

58. Consumer Reports, <http://www.consumerreports.org/cro/magazine-archive/2011/april/cars/chevrolet-volt/overview/index.htm>
Accessed: April 6, 2013 & Gregor C., Presentation at IEEE EPEC 11, *Cold Weather Modifications of PHEVs for Manitoba Operation*

Conclusions & Recommendations

This study is an update on a study titled “Electric Car Research” that was done by Dillon Consulting. Most of the research for that report was done in 2011 and, at that time, there were no plug-in electric vehicles available that could be serviced in the NWT.

Now, in 2013, there are two models of Plug-In Hybrid Electric Vehicles (PHEVs) available that can be serviced in the NWT. There is also data showing that Battery-Electric Vehicles (BEVs) have been operating through Canadian winters at temperatures down to minus 30 degrees. The literature review done for this report could not find any data on the fuel consumption of any type of vehicle, electric, gasoline or diesel, at temperatures below minus 30°C. But this does not mean that these vehicles do not work below minus 30. Northerners have figured out how to plug in electric engine and battery warmers and, if they can't be plugged in, to start their vehicles every few hours during the coldest weather. The same techniques should allow northerners to use BEVs as short distance commuter vehicles and PHEVs to replace a standard vehicle.

This report looks at three cold weather issues: cold starting, fuel efficiency/range, and cold interior/windshield frosting that are common to all vehicles, regardless of fuel. It also looks at cold weather charging of electric vehicles.

Although none are currently available in the NWT, a properly equipped BEV could function as a short distance commuter vehicle throughout the year. To maintain enough battery capacity, a northern BEV would need to have the ability to warm the main battery using grid power and it would need to be plugged in at home and at work. The range could be reduced by about 60% (i.e. from 100 km to 40 km) in cold temperatures, but NWT commuting distances are generally so short that this could still be adequate. To be comfortable at cold temperatures, a northern BEV would need to pre-warm the seats and the cabin using grid power and at the coldest temperatures, a northern BEV driver should dress warmly as the cabin heater will probably not keep up.

Currently, the Toyota Prius Plug-In and the Chevrolet Volt (both PHEVs) are the only plug-in vehicles that are serviceable in the NWT (only in Yellowknife). Range is not an issue for these vehicles because they have gasoline engines that can power them when the batteries are depleted. Like all vehicles, they will eventually be unable to start if they are not plugged in during extreme cold temperatures. Both vehicles use their engines as heaters so they should be warmer than pure BEVs.

Even with escalating electricity prices, the Prius Plug-In and the Volt in EV mode will be cheaper to operate than comparable gasoline or diesel vehicles. At current prices, a 10 km in-town trip would cost 3 to 4 times less than a comparable gasoline and diesel vehicles and 5 times less than a typical pickup truck. On the highway the Prius Plug-In is 25% cheaper to drive than a similar car while the Volt uses the about the same amount of fuel as a similar car. And for trips within NWT hydro-powered communities, they offer the unique experience of commuting using a local and green energy resource without producing any GHG emissions.

As many automotive reviewers have pointed out, it is not easy to figure out whether the Volt or the Prius Plug-In is the better PHEV. The Prius Plug-In is more efficient over shorter commutes and on long drives, which makes it ideal for short trip commuters who still want to take a 1,700 km trip to Edmonton once in a while. But the battery warming system in the Prius Plug-In uses cabin air (taken from vents around the rear seats) to warm the battery and it cannot be pre-heated using grid power. The Volt has a more confidence-inspiring liquid heating system for the battery that can be powered from the grid and the Volt's larger battery makes it the most efficient vehicle for people who drive 50 to 70 km per day.

It is difficult to compare NWT winter fuel efficiency of electric vehicles to gasoline and diesel vehicles because we do not have data on how efficient any of these vehicles are during NWT winters. In order to make a fair comparison, one would also need information on how much power vehicle block heaters, battery warmers and cabin heaters use, as well as how much fuel is used in idling to warm up the cabin of a gasoline or diesel powered vehicle. Keeping fuel log records on a fleet of existing vehicles and comparing them to outdoor temperature records would be a good start. Minute by minute monitoring of a Prius Plug-In and a Volt compared to a few other standard vehicles using on-board data loggers such as those used by FleetCarma⁵⁹ would be ideal.

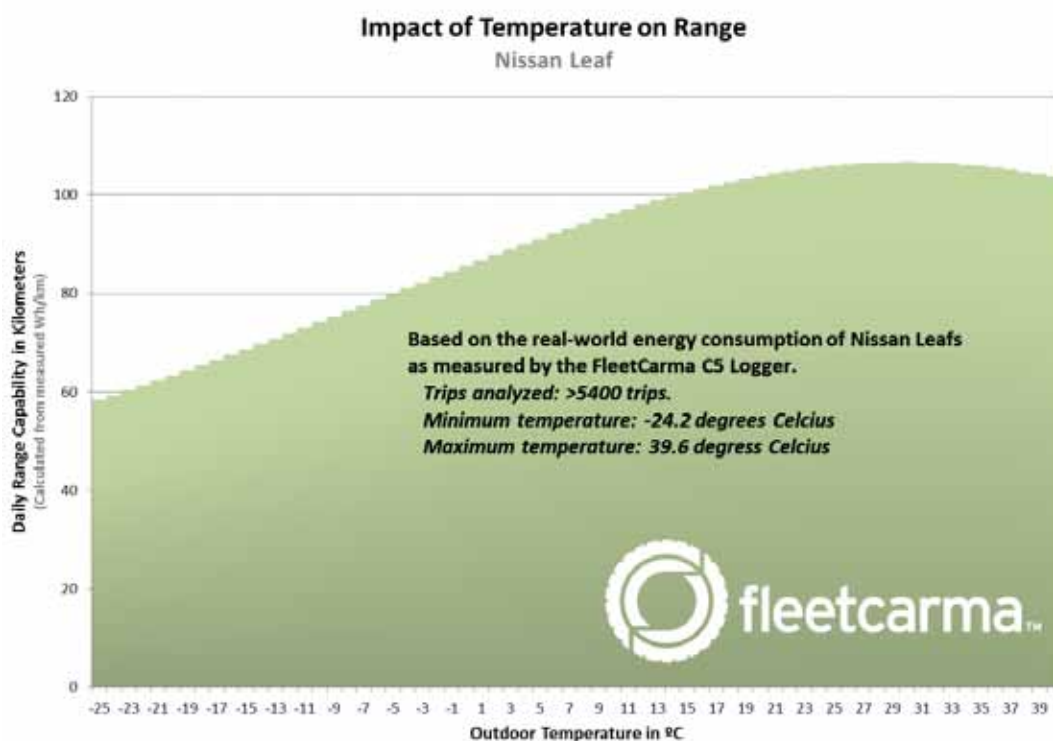
The opportunity to use local NWT hydroelectricity to power vehicles in the NWT is real. If the Arctic Energy Alliance or its funding partners wished to pursue this further the next steps would be:

1. Conduct market research to determine the potential size of the market, both in terms of electricity sales and greenhouse gas reductions. The market research should also identify the key barriers and benefits of owning an electric vehicle from the perspective of a northern driver.
2. If the market study shows sufficient potential, create a program of incentives designed to reduce the barriers and enhance the benefits of driving an electric vehicle in the NWT.
3. Partner with Toyota and/or GM to conduct a study comparing the performance and fuel efficiency of either a Prius Plug-In and/or a Volt with a similar gasoline powered car through an NWT winter. As driver behaviour is a key factor, several vehicles should be tested.

59. www.fleetcarma.com

Appendix – Fuel Consumption and Temperature Graphs

All the studies on BEVs reported that the electric efficiency of the vehicles decreased with colder weather as shown in the graphs.

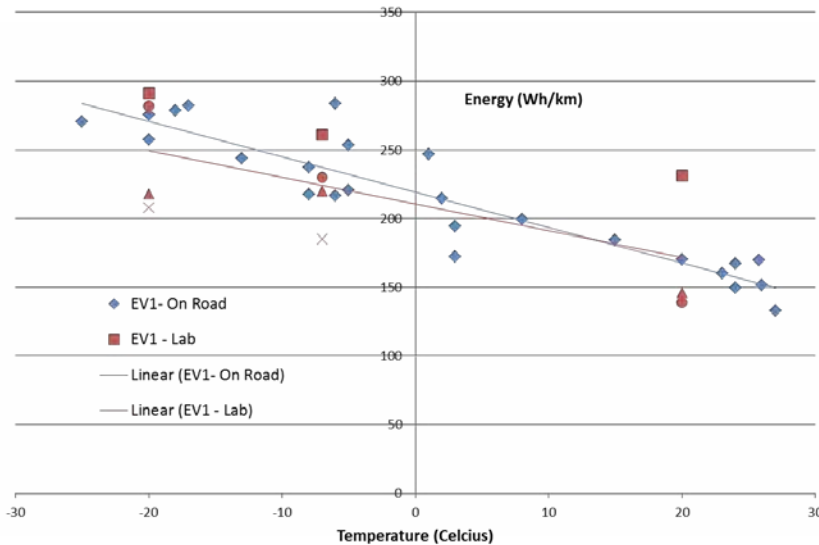


Source: Fleetcarma.com

FleetCarma recorded a decrease in fuel efficiency of about 1% per °C decrease in temperature, starting at around 20°C for the Nissan Leaf BEV.⁶⁰

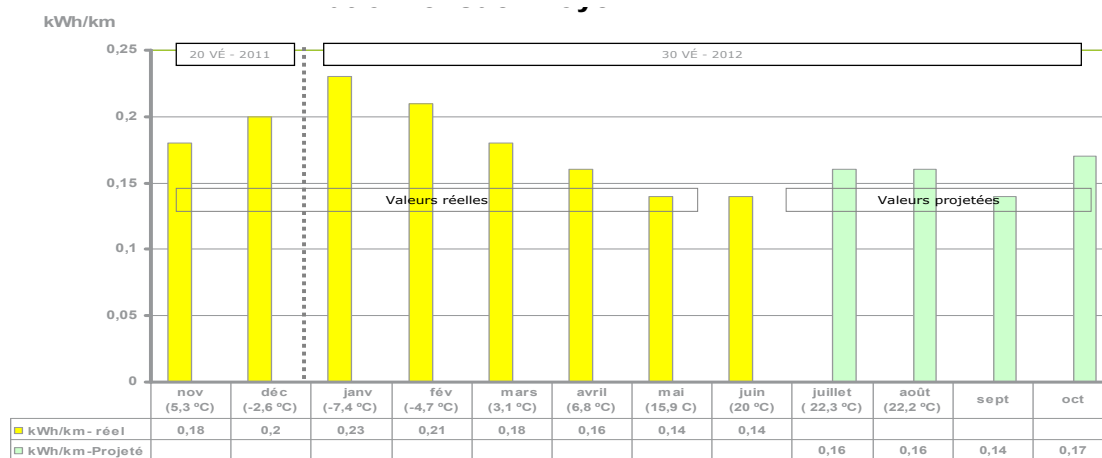
60. <http://news.fleetcarma.com/2013/01/31/electric-car-range-in-bitter-cold/#.UWBSxDd49T0> Accessed: April 16, 2013

EV1 - On Road and Lab Energy Consumption



Source: Transport Canada

Transport Canada tests showed an average "On Road" decrease in fuel efficiency of 0.8% per °C in one BEV and 0.7% per °C in another.

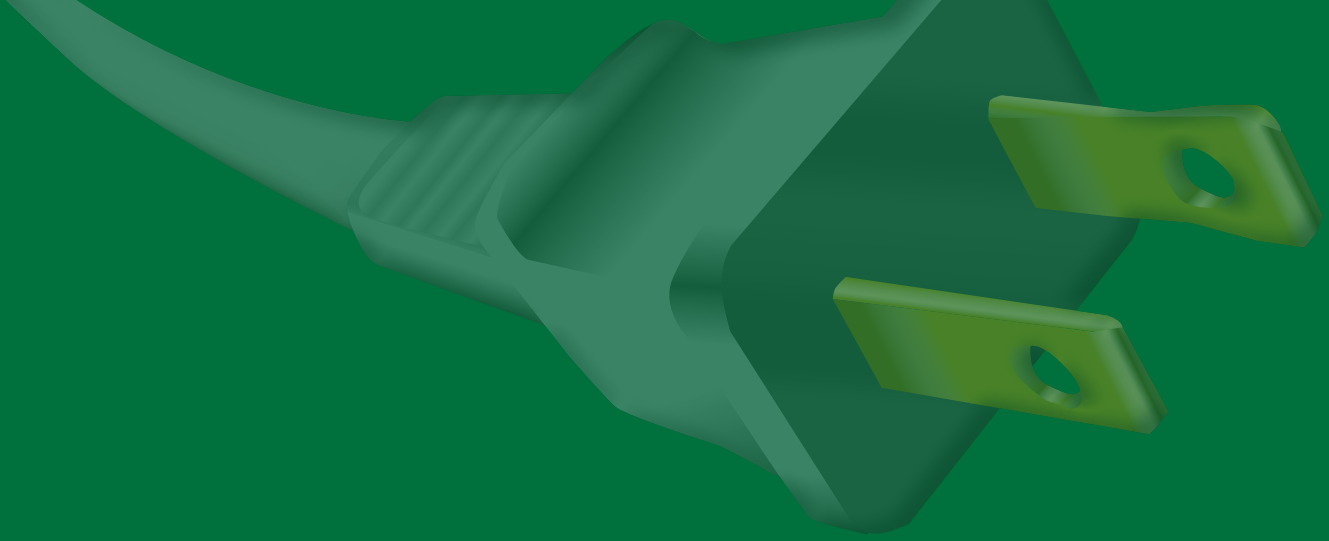


Source: Hydro Québec

Hydro Québec's data from 30 Mitsubishi i-MiEV BEVs showed that fuel efficiency decreased by 2% per degree C.⁶²

61. Transport Canada, 2012 *Comparison of on-road vs dynamometer range and energy consumption of fully electric passenger vehicles*, presentation at EV 2012, Montreal Quebec

62. Hydro Quebec, 2012 presentation at EV 2012 "Le projet pilote de VÉ à Boucherville : un projet d'avenir"



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