Final Report

Electric Vehicle Investigation

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Executive Summary

The deployment of plug-in electric vehicles has the potential to reduce petroleum consumption and greenhouse gas emissions dramatically, and increase energy independence through the utilization of locally produced energy. However, the success of long-term transportation electrification will depend in part on the near-term deployment of vehicles and charging infrastructure. Yukon Energy stands to play a significant role in the transition towards higher rates of plug-in electric vehicle adoption and the deployment of charging infrastructure. The objective of this report is to provide Yukon Energy Corporation and partners an assessment of the technical feasibility of plug-in electric vehicles (PEVs) in the Yukon Territory and their potential opportunities and impact to the current grid. The goal of this project is to determine to what extent an active engagement in PEV and charging station deployment is a wise investment in the Yukon. Additionally this project determines the potential long-term associated impacts or opportunities for electrical sales and peak and base loads.

ICF's investigation of the potential for electric vehicles in the Yukon Territory is focused on 1) a review of cold weather impacts on plug-in electric vehicles and charging infrastructure, 2) a market assessment for the Yukon Territory, including vehicle forecasts, and associated greenhouse gas impacts of electric vehicle deployment, and 3) a grid impact assessment regarding the amount of energy that Yukon will need in the future, and the potential stress on some distribution assets. ICF's key findings are summarized here:

- ICF's literature review indicates that residents in the Yukon Territory will have difficulty maintaining normal functionality of electric vehicles during the coldest months of the year; however, electric vehicles, particularly plug-in hybrid electric vehicles (PHEVs), are still a viable transportation option. The main hurdle for electric vehicle adoption in the Yukon Territory will be vehicle performance in below freezing temperatures. The range of an electric vehicles can be more than halved in below freezing temperatures, requiring double the electricity to charge these vehicles for daily use (or relying more significantly on plug-in hybridization). Notably, even a halving of the range of many PHEVs on the market today will keep the electric range of the vehicle within the scope of the average Yukon commute. One factor bolstering the potential for electric vehicles in the Yukon Territory is the ubiquitous availability of vehicle charging at homes and business, which is tied to the availability of plug-in engine block heaters.
- ICF developed three electric vehicle penetration scenarios–low, medium, and high–with varying assumptions regarding the growth in total vehicle sales, electric vehicles sales, vehicle offerings (e.g., light trucks), vehicle pricing, and fuel pricing. Generally, ICF finds that there is low to modest potential for electric vehicle adoption in the Yukon Territory, with percent of new sales ranging from 2.6–11.7% by 2035. Limited electric vehicle offerings, notably limited availability of plug-in electric light-duty trucks, is a major hindrance to electric vehicle adoption in the Yukon Territory. About 60% of new vehicle registrations in the Yukon Territory are light-duty trucks; if this pattern of vehicle ownership persists over time, then it will be challenging for the Yukon Territory to increase electric vehicle adoption moving forward.

- On-road gasoline and on-road diesel use accounts for about 50 percent of total Yukon greenhouse gas emissions. Even at low adoption levels, electric vehicles can have a substantive impact on greenhouse gas emissions. ICF estimates that PEVs could reduce greenhouse emissions by about 120–410 MT by 2025 and 650–2,800 MT by 2035. For the sake of comparison, the Government of Yukon reports a total of 638,000 MT of GHG emissions in the territory.
- The forecasted levels of electric vehicles will have only minor grid impacts in the Yukon. ICF's grid impact assessment is based on assumptions regarding vehicle charging levels, vehicle energy consumption, and the rate schedules that consumers might use. ICF assessed the impacts of electric vehicle adoption on peak load assuming that vehicles (PHEVs and battery electric vehicles) charge on a time-of-use (TOU) rate at Level 1 (110 V) or Level 2 (220 V), or on a standard household rate (i.e., non TOU[1]). We find that the maximum peak demand occurs at Level 2 charging on a TOU rate, with a range of 0.1–1.4 MW and 0.6–9.4 MW in 2025 and 2035, respectively, across the three electric vehicle adoption scenarios (low, medium, and high). ICF notes that the peak demand has the same values as peak energy values, simply with units of MWh–our current understanding of how electric vehicles charge does not allow us to make estimates at less than one hour intervals. As a result, we simply assume that the demand (MW) is constant over a one-hour period (yielding energy demand in units of MWh).
- ICF also assessed the potential for impacts on Yukon Energy's distribution assets, by reviewing the potential increased load on Yukon Energy feeders. We looked at the Haines Junction and Dawson 2 feeders, which distribute about 1.8% and 1.3% of the electricity that Yukon generates. Using a fair share assumption (i.e., that electric vehicles are adopted proportionally to electricity consumption), and considering the load associated with the high electric vehicle deployment scenario in 2035 (when there are nearly 1,900 PEVs assumed to be on the road in the Yukon), ICF finds that the additional load from PEVs may have an impact on Yukon's distribution assets assuming that no upgrades occur over the study time period. This is particularly true in the winter months when charging demands are likely to increase.
- ICF also considered the potential for electric vehicle clustering. This is important because more than 75% of the Yukon Territory population is located in Whitehorse. However, most of the distribution assets in Whitehorse are owned and operated by ATCO. In other words, the only way that clustering would have an impact on Yukon Energy's assets is if electric vehicle deployment were concentrated outside of Whitehorse and consistently charged at higher-than-expected levels, which ICF believes is unlikely. ICF and Yukon Energy did reach out to ATCO regarding this study, and were informed that breakers are not the weak points in their distribution system; rather they highlighted that there are a variety of issues associated with managing load and assets in the downtown core (of Whitehorse), with a focus on a planned 25 kv conversion project. ATCO noted that ICF's forecasts for increased load from electric vehicle adoption would change ATCO's annual load increase from about 2.2% per year to 2.24% per year and 2.39% per year in the low and high cases, respectively. ATCO has agreed that the

[1] ICF does not assume an explicit blend of Level 1 and Level 2 charging for the non TOU rate; rather the rate is reflective of the time that vehicles would charge. The power draw associated with this rate implies that it is about a 50-50 blend of Level 1 and Level 2 charging.

magnitude of this potential load increase should be included in their incremental load growth forecasts moving forward.

- Finally, despite the modest potential for electric vehicles in the Yukon, Yukon Energy has the opportunity to establish a leadership position in the market with only minor investment. More specifically, targeted outreach and education to consumers in the near-term future, as interest for electric vehicles increases over the next several years, will be critical. Furthermore, strategic partnerships and engagement with other stakeholders, including ATCO, automobile manufacturers, and local automobile dealerships, can help establish a leadership position in the market. ICF is not seeking to over-state the potential in the Yukon for electric vehicles, but low-investment engagement such as keeping updated on market developments and consumer interest over the next several years could have significant implications in the mid- to long-term future for resource planning.

1 Introduction

The deployment of plug-in electric vehicles (PEVs) has the potential to reduce petroleum consumption and greenhouse gas (GHG) emissions dramatically, and increase energy independence through the utilization of locally produced energy. However, the success of long-term transportation electrification will depend in part on the near-term deployment of vehicles and charging infrastructure. The transition towards higher rates of PEV adoption and the corresponding charging infrastructure requires a broad range of stakeholders to prepare and plan for deployment. Yukon Energy is understandably keen on engaging in this space given the opportunity; however, there are challenges and obstacles, namely the impacts of cold weather on electric vehicle operation that must be considered.

Objective

The objective of this report is to provide Yukon Energy Corporation and partners an assessment of the technical feasibility of PEVs in the Yukon and their potential opportunities and impact to the current grid. The goal of this project is to determine to what extent an active engagement in PEV deployment is a wise investment in the Yukon, and to determine what the associated impacts or opportunities might be in the long term for electrical sales and peak and base loads.

Background on Plug-in Electric Vehicles and Charging Infrastructure

Vehicles

Electricity is used as transportation fuel in three types of vehicles: hybrid electric vehicles (HEV), which are powered by both an internal combustion engine (ICE) and an electric motor; plug-in hybrid electric vehicles (PHEV), which have an ICE and larger battery packs than HEVs and are designed to plug into the electrical grid to charge the vehicle; and battery electric vehicles (BEV), which plug into the electrical grid and are then powered solely by energy from the battery. In the context of this report, vehicles that use electricity from the grid are referred to as plug-in electric vehicles (PEV), a term that includes both PHEVs and BEVs.

The battery technology used in PEVs has been in development for over a decade; however, limitations on stability, energy capacity, energy storage capacity, and the cost of producing the battery have been barriers to widespread deployment in vehicles. Despite the latest advances in rechargeable battery technology, most recently using lithium-ion technology, the energy densities of batteries are still about two orders of magnitude less when compared to common liquid fuels used in ICEs. Prior to 2012, PEVs were limited to niche markets, introduced in demonstration programs, converted by aftermarket companies, or legacy PEVs from the deployment in the 1990s. More recently, the number of vehicle offerings is steadily increasing. For instance, both the Nissan LEAF (a BEV) and the Chevrolet Volt (a PHEV) have been available since early 2011; today, there are more than twenty (20) PEV offerings in the marketplace. However, these vehicles are not available everywhere.

Most PHEVs are designed to provide an all-electric driving range of 16 to 65 km. However, when the battery state of charge falls to a predetermined limit, the system automatically switches to the ICE.

Battery-related costs tend to be lower for PHEVs as compared to BEVs because of the smaller battery size, but this is partially offset by the additional expense of outfitting a vehicle with two powertrains (electric and ICE). PHEVs can have two types of drivetrain architectures, characterized as series or parallel configurations. The series PHEV is designed for electric motor propulsion only, with the ICE acting as a backup generator. Currently, the only series PHEV on the market is the Chevrolet Volt. The parallel PHEV is based on a conventional HEV architecture and has two powertrains, one with the electric motor and one with the ICE. The parallel PHEV is equipped with additional battery capacity and a higher power electric system to extend the electric motor propulsion system range. Parallel PHEV models based on aftermarket conversions of the Prius have been available in the past, but in the near future most original equipment manufacturers (OEM) models are expected to produce parallel PHEVs as well.

BEVs operate solely on an electric powertrain and therefore are equipped with more batteries to extend the operating range. This is a very simple architecture where the battery drives the electric motor to propel the vehicle. This simplified architecture may make BEVs less expensive than the comparable PHEVs in some cases, but given the greater need for electricity, BEVs also typically have a heavier reliance on infrastructure with faster charging times.

PEV Charging

Electric vehicle charging infrastructure (often referred to as electric vehicle supply equipment, EVSE) is typically differentiated by the maximum amount of power provided to a PEV battery. Two primary types of EVSE provide either alternating current (AC) or direct current (DC) electricity to PEVs. Current SAE standards are as follows:

- **Level 1 AC** – These chargers use standard 120 volt (V), single phase service with a three prong electrical outlet at 15-20 amperage (A). Local codes may apply to limit cord and plug connection length. Level 1 charging outlets should have ground fault interrupters installed and a 15 A minimum branch circuit protection. Level 1 charging requires no new electrical service for a building operating on an existing circuit. The main drawback of Level 1 charging is the time required to recharge the PEV. At 15 A and 85% electrical transfer efficiency, the power delivered is 1.4 kW.[2] This leads to longer charging times (ranging from about 4–20 hours, depending on the size of the battery).
- **Level 2 AC** – These chargers are used specifically for PEV charging and are rated at less than or equal to 240 V AC, and less than or equal to 80 A. Level 2 EVSE requires additional grounding, personal protection system features, a no-load make/break interlock connection, and a safety breakaway for the cable and connector. If 240 V service is not already installed at the charging site, a new service drop will be required from the utility. With a 40 A, 240 V service power can be delivered at 7.5 kW which shortens charging time considerably for PEV. These chargers use a standard SAE approved J1772 connector
- **Level 1 & 2 DC** – Level 1 & 2 DC chargers, also known as DC fast chargers, provide power much faster than the AC counterparts. However, DC fast chargers are more expensive to build and operate

[2] For the sake of comparison, most engine block heaters use between 0.4-1.5 kW of power.

due to the equipment and electrical upgrades necessary to operate them. Thus, they are less common than Level 2 AC chargers, and will not likely be used for residential applications. Few PEVs are currently equipped with compatible hardware for DC charging, but certain models such as the Nissan LEAF, Mitsubishi iMiEV, Kia Soul, BMW i3, Volkswagen eGolf, and Tesla do come with "fast charging" as an option. SAE approved (in 2013) the DC charging standard for the Level 1 and 2 DC coupler and connector as part of the J1772 standard.[3] The central component of the standard is the Combo Connector, which maintains the functionality of the previous J1772 connector and introduces two new pins that provide the option of charging via DC. DC charging typically requires a dedicated circuit of 20–100 A, with a 480 V service connection. Power is typically delivered in the range of 50–150 kW.

Charging Times

One of the common questions asked about PEVs is: How long do they take to charge? The simple answer is: It depends. One of the key aspects to understand about PEVs is the battery pack: The battery capacity is the amount of electrical charge a battery can store. Maximum capacity can only be reached; however, under optimal discharge conditions that account for the magnitude of the current, the allowable terminal voltage of the battery, and other external conditions such as temperature. PEV manufacturers have optimized battery packs to provide maximum capacity through devices such as battery thermal management systems. Thermal management systems maintain a constant temperature around the battery pack to prevent potential impacts from extreme hot or cold temperatures.

In addition to temperature, vehicle charging time is heavily dependent on the current type (AC or DC), electric potential difference (V), current (A), maximum power (kW), and the on-board charging capabilities of the vehicle. The most important determination of charging time is generally the charging capabilities of the vehicle. For example, the Chevy Volt and original Nissan LEAF both included a 3.3 kW on-board charger; Nissan has since upgraded to 6.6 kW on-board chargers. The Tesla charging system has a capacity of 10 to 20 kW. Battery capacities vary amongst vehicles, therefore electric vehicle range also varies.

The times needed to replenish a battery halfway and fully for the Toyota Prius Plug-in, Chevy Volt, and Nissan LEAF are shown in Table 1 below. Charging times on Level 1 infrastructure are primarily suitable for small battery vehicles, such as the Volt, which require over 7 hours to fully charge. Estimated charge times using DC fast charging for the Prius Plug-in, Volt and LEAF are included.[4] For DC fast charging, calculations assume the battery is charged to only 80% and the remaining 20% is completed by charging at a slower rate. If left connected at high power, the time to fully charge the battery will increase above an hour due to the nature of direct DC fast charging. Furthermore, some industry observers have voiced

[3] EVs get boost from new SAE standard for dc fast charging, SAE Vehicle Engineering Online. Available online at: http://www.sae.org/mags/sve/11484/

[4] ICF notes that neither the Prius Plug-in nor Chevrolet Volt is equipped with the appropriate charging couplers to charge using a DC fast charger; these values are shown for illustrative purposes only.

concerns about the effects of fast charging on battery life due to potential over-heating and over-voltage; however, Nissan reports that proper cooling and voltage can allay these effects.[5]

Table 1. Estimated charging times using various EVSE (hours:minutes)

Charger Type	Charge	Vehicle		
		Prius	Volt	LEAF
		4.4 kWh (3.5 kWh usable)	16 kWh (12.8 kWh) useable)	24 kWh (21.6 kWh useable)
Level 1 1.4 kW	Half	1:34	3:42	7:42
	Full	3:08	7:25	15:25
Level 2 7.5 kW	Half	0:40	1:34	3:16
	Full	1:20	3:09	6:32
DC Fast 50 kW	Half	0:02	0:06	0:12
	Full	0:05	0:47	1:39
DC Fast 150 kW	Half	0:01	0:02	0:04
	Full	0:02	0:41	1:25

Structure of Report

The remainder of this report includes the following:

- Section 2 provides an overview of how cold weather impacts PEV performance and charging.
- Section 3 includes ICF’s market assessment, with a focus on the potential for PEV adoption in the Yukon Territory, as well as our low, medium, and high forecasts for the region out to 2035.
- Section 4 reviews the potential grid impacts of the PEV deployment scenarios, with a focus on Yukon Energy distribution assets.
- Section 5 concludes with recommendations.

2 Electric Vehicle and Charging Impacts in Cold Weather

Plug-in electric vehicles currently make up less than 1% of vehicle sales in Canada, with only seven models currently available.[6] As a reminder, this report uses the term PEV to include BEVs and plug-in PHEVs. A recent survey in Canada however has shown that there is a demand for PHEVs, with more than

[5] Mark Perry, Nissan, EVS26, May 6-9, 2012. Los Angeles, CA.

[6] Axsen, J., S. Goldberg, J. Bailey, G. Kamiya, B. Langman, J. Cairns, M. Wolinetz, and A. Miele (2015). Electrifying Vehicles: Insights from the Canadian Plug-in Electric Vehicle Study. Simon Fraser University, Vancouver, Canada. http://rem-main.rem.sfu.ca/papers/jaxsen/Electrifying_Vehicles_(FINAL)_V2.8_(July10).pdf, (last accessed July 23, 2015)

a third of participants wanting to buy a PEV, mostly PHEVs.[7] In the Yukon Territory however, cold weather performance will be a critical issue to the viability of PEVs.

Limited studies are available for PEVs in the coldest regions of the world, but it is clear that cold temperatures primarily impact the time it takes to use all of the battery energy or recharge a PEV battery. This report outlines specific issues related to impacts on vehicle range, including the impact of auxiliary power consumption and reduced efficiency from cold weather conditions on battery life. Additionally, this report outlines the impact on charging infrastructure (namely, EVSE) to transfer electricity to the vehicle in cold weather conditions.[8]

Cold Weather Impacts on Vehicle Range

Two things happen when a vehicle system is cold: 1) it will lead to an increase in auxiliary power consumption as drivers increase energy demand to heat the passenger cabin and to operate the defogger, and 2) vehicle components will become less efficient from increases in internal friction as an engine or battery gets colder. The greatest impact on range in cold weather usually comes from auxiliary loads, such as cabin heaters and fans and component heaters (i.e., battery heaters). Conventional vehicles use waste heat to help warm the cabin, but because all-electric vehicles do not generate sufficient waste heat, an electric heater must be used. Cabin heating therefore reduces the battery charge and potential range of a PEV. For some PEVs, a pre-heating setting is available to allow the battery and cabin heaters to run while still plugged in, preventing any initial loss in range to heat the vehicle. PHEVs are able to heat the cabin from engine rather than battery thereby minimizing battery efficiency loses at the expense of gasoline. However, like other gasoline engines, these PHEVs will need engine block heater to operate properly in extremely cold climates.

A cold battery also reduces regenerative braking which is used by most PEVs to increase driving range. Vehicles are typically outfitted with an electric heater to warm up the battery, which can draw as much as 6 kW of electricity. Some vehicle manufacturers are beginning to offer more efficient heaters and researchers are looking at methods to improve the insulation and special window coatings to reduce heating demand, but it is unlikely these solutions will be available in the near-term future.

Based on findings of the AAA Automotive Research Center, PEV battery range on a limited number of sample vehicles was reduced by nearly 60% at -7°C (20°F), largely due to the vehicles auxiliary loads.[9] Another report by researchers at Carnegie Mellon University found similar results, which increased the emissions associated with PEVs because of the additional electricity requirements.[10] This may be less of an issue for Yukon Energy customers where 99.6% of power generation in 2014 was from clean

7 Ibid.

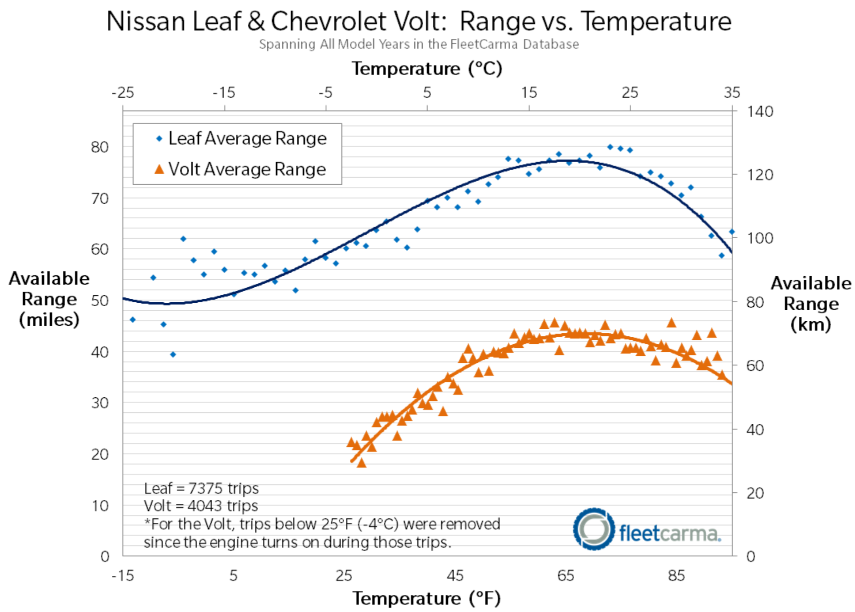
8 ICF notes that we did not consider the power requirements associated with pre-heating the interior of the vehicle, as we assume that this load is comparable to the load of an engine block heater for conventional vehicles using an internal combustion engine.

9 AAA Automotive Research Center, 2014, http://newsroom.aaa.com/2014/03/extreme-temperatures-affect-electric-vehicle-driving-range-aaa-says/.

10 Yuksel, T. and Michalek, J., 2015, Effects of Regional Temperature on Electric Vehicle Efficiency, Range, and Emissions in the United States, http://pubs.acs.org/doi/pdf/10.1021/es505621s.

hydropower, unless backup power is required from Yukon's fleet of diesel or natural gas generators (which is discussed in more detail in Section 3). FleetCarma, a vehicle monitoring service for major auto manufacturers, aggregated data from Chevrolet Volt and Nissan Leaf drivers to assess the range impact at temperatures between -25°C (-15°F) and 35°C (100°F).[11]

Figure 1. Electric Vehicle Range vs Temperature



Source: *FleetCarma*

Based on over 11,000 logged trips, driving range was reduced by about half in colder temperatures. At extreme cold temperatures, PHEVs automatically switch back to operating on the internal combustion engine, as noted in the graph that Volts switched to the engine at -4°C. Vehicle range was reduced by driver habits, such as using seat heaters to reduce the need for cabin heat.

PEVs require good battery thermal management to operate in the coldest months. Allowing the battery to be plugged in continuously to Level 1 chargers may help keep the battery warm and will be critical to normal function.[12] PEVs can be adapted to winter road conditions as the battery cells create a lower center of gravity to help vehicles gain traction.

Fleet Case Studies

Calstart: Calstart studied electric trucks in Chicago, with testimony from three fleets and input from custom electric vehicle suppliers: AMP Electric Vehicles, Motiv Power Systems, and Smith Electric

[11] FleetCarma, 2013, 'Electric Vehicle Range for the Nissan Leaf and Chevrolet Volt in Cold Weather,' http://www.fleetcarma.com/nissan-leaf-chevrolet-volt-cold-weather-range-loss-electric-vehicle/. The Chevrolet Volt turns on the gasoline engine intermittently at temperatures below 25°F (-4°C), so trips with ambient temperatures below that threshold were excluded.

[12] Arctic Energy Alliance, 2013, 2013 Electric Vehicle Update http://www.aea.nt.ca/files/download/5500e4297ef91bf,

Vehicles.[13] The average minimum temperature for the study was -21°C, going as low as -27°C, with -12°C the observed threshold that fleets began to notice a difference in vehicle operations. Lithium ion battery vehicles were observed to have a loss of 10-20% charge at temperatures between -10 to 0°C, and a loss of up to 40% charge at temperatures below -20°C. Cabin heating was found to be an additional drain on battery life, lowering the charge another 20-40%. Overall it was found that these specific electric trucks with a 130 km range were reduced to a range of 32 km on days with temperatures below -10°C.

Hydro Québec: Hydro Québec collected data on 30 Mitsubishi i-MiEV BEVs in both Europe and near Montreal for 3 years from 2010–2013.[14] Twenty-seven companies and organizations took part in the initiative, which involved 31 users for a total of 650 vehicle-months and 740,000 km driven. A compact four-seater, the i-MiEV has a range of 120 km, with a 16 kWh lithium-ion battery. It takes about six hours to charge at Level 2 (240 V) or 12 to 21 hours at Level 1 (120 V). Every car in the project was equipped with on-board instruments to register energy consumption (charging pattern) and the effect of temperature on charging and users' charging habits. An observed loss of range of 13 km when temperatures were between 0°C and 10°C due to heating the interior of the vehicle. The range of the BEV used depends heavily on the ambient temperature and loss of range increased to 40% in below freezing conditions. Car heating has more of an effect (13 km less when the temperature is between 10°C and 20°C) than air-conditioning (5 km less when the temperature is above 20°C).

Manitoba Hydro: Manitoba Hydro added Hymotion lithium ion battery packs to 10 existing Toyota Prius Hybrids in 2008, allowing the vehicles to plug-in to charge, converting the traditional hybrid vehicles to PHEVs[15] Manitoba Hydro then monitored the vehicle for 3 years in the Winnipeg area. Driving 233,000 km over the course of the study, noting on average an additional 10% savings to fuel economy over the traditional Prius. Electricity use in the winter was not closely monitored, however vehicles were noted to have a significant range drop and required some modifications to the vehicles to enhance performance. The original 12V Prius batteries had to be replaced with newer and more efficient 12V battery and then were trickle charged whenever the vehicles were plugged in. Tests were run with engine blankets and electric in-car warmers, which both proved effective at reducing range issues associated with heating the interior.

Manitoba Hydro, in collaboration with the Province of Manitoba, Mitsubishi Heavy Industries, New Flyer Industries, Winnipeg Transit and Red River College, operate an all-electric bus on a daily, 20 km route[16]. The route runs a loop from the Winnipeg Richardson International Airport where it charges whiles waiting at the stop. Chargers are roof mounted and replace two operational hours of charge in approximately 10 minutes. The electric bus was originally a demonstration project used as a shuttle for

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13 CALSTART, E-Truck Performance in Cold Weather, June 2014 - http://www.calstart.org/Libraries/Publications/E-Truck_Performance_in_Cold_Weather.sflb.ashx

14 Hydro-Quebec, November 2013, Mitsubishi Electric Vehicle Pilot Project, http://www.hydroquebec.com/transportation-electrification/pdf/mitsubishi-pilot-project-report.pdf (last accessed July 10, 2015).

15 Center for Emerging Renewable Energy Inc., October 2011, Manitoba PHEV Demonstration Final Summary Report, http://www.gov.mb.ca/ia/energy/transportation/images/phev_summary_report.pdf (last accessed July 10, 2015).

16 New Flyer, November 2014, New Flyer Battery-Electric Buses Enter Into Service With Winnipeg Transit, http://www.newflyer.com/index/112714-battery-electric-bus-winnipeg-transit (last accessed August 12, 2015).

Manitoba Hydro beginning in March 2014[17], and was so successful that the airport route was added in November 2014. Manitoba Transit has installed additional chargers in their fleet yard in anticipation of future electric vehicle additions.

Province of Manitoba: The Province of Manitoba signed an MOU with Mitsubishi in 2011 to test two Mitsubishi i-MiEV BEVs for two years[18]. Winter testing included driving in temperatures as low as -29°C, the lowest (public) recorded driving temperature of an electric vehicle within Manitoba. Tests included driving vehicles to battery depletion in temperatures ranging from -15°C to -29°C, where it was discovered that all interior heating had to be redirected to the defogger to maintain an unfrozen windshield. When operating in these negative temperatures, the average ranges of the iMiEVs was discovered to drop to 40-50 km, less than half of the average range of 110-120 km.

Lessons Learned from Vehicle Testing

Electric vehicle manufacturers have been unable to share externally many of their cold weather testing results. This is due in a large part to the current research and development happening to improve cold weather vehicle operations and increase vehicle efficiencies. Current research for many manufacturers revolves around thermal management systems, specifically whether air-cooled or liquid-cooled batteries can produce the best performance in weather extremes. Improvements for alternative heating packages are being explored as well, such as Tesla's "cold weather package" which provides additional seat warmers, windshield fluid heaters, and modified intake grills.

Kia added new heating technologies to the 2015 all-electric Kia Soul, including a new heat pump, air intake controller, driver-side only heating options, and technology to pre-heat the vehicle while charging[19]. Kia tested these PEVs in the Arctic Circle, successfully operating the Soul in -40°C temperatures, including letting the PEVs become cold soaked by sitting in sub-zero temperatures for over 8 hours.

Battery testing is a major component to ongoing research and development of electric vehicles, as this is a constantly evolving technology. New battery materials and configurations are being tested, in efforts to find a longer-lasting battery that can handle cold weather and still be affordable.

Arctic Energy Alliance: The Arctic Energy Alliance began testing a Chevrolet Volt in January 2015.[20] Housed primarily in Yellowknife, the PHEV is being used throughout the Northwest Territories. To date, the electric range has been more than sufficient to accommodate the Yellowknife daily commute of 6.3 km, however while the average summer range has been approximately 67 km, the winter range was

[17] Manitoba Hydro, Electric Vehicles, https://www.hydro.mb.ca/environment/electric_vehicles.shtml (last accessed August 12, 2015)

[18] Electric Vehicle Technology & Education Centre, December 2013, All-Electric Mitsubishi i-MiEV in Manitoba, http://www.meetar.com/mitsubishi-imiev-in-manitoba-blogs-red-river-college/

[19] Kia, February 2014, The world's toughest boot camp – Kia weathers the extremes, http://kia-buzz.com/ps_ev_winter_test/

[20] Arctic Energy Alliance, 2015, Electric Vehicle, http://aea.nt.ca/research/electric-vehicle

only 35 km.[21] This information is not entirely accurate for temperatures at or below -10°C, for at this temperature the internal combustion engine automatically turns on.

Arctic Energy Alliance has also noted a handful of traditional hybrid vehicles (non-plugins) in the Northwest Territories. A Hay River resident will soon have what they believe is the first Tesla in the Territory.

Home conversions: The first PEVs deployed in the Yukon Territory were conversions, as opposed to vehicles that come directly from the manufacturer[22]. The Government of Yukon has sponsored a course at Yukon College and at a local high school to convert vehicles to run off electricity. Currently there are at least three home-conversions in the Dawson area, and at least two in Whitehorse. Home conversions however do not have many of the auxiliary heating options that factory ready PEVs have, so typically are not able to be driven during the winter months.

Quantum Machine Works: In March 2014, Quantum Machine Works of Whitehorse purchased a Ford Focus PEV for the company use[23]. Purchased from a dealership in Vancouver, the PEV has worked great for the company in temperatures as low as -28°C. While the average warm weather vehicle range has been 100 km, in the winter the range drops to approximately 60 km. The PEV typically used for short trips by several employees, and is constantly connected to a charger when not in use. Quantum has had several other companies ask about the vehicle and has offered to loan it out for test drives.

Cold Weather Impacts on Vehicle Charging Time

Most electric vehicle chargers manufactured for residential and commercial use are suitable for outdoor use, although some perform better in extreme cold weather conditions. The operation of all equipment can be impacted when covered in snow or ice, particularly the charging cable, which could be encased if lying on the ground or coiled. If equipment must be outside, retractable charging cables or protecting the equipment with some form of shelter is preferable. Further, when siting charging equipment outside, considerations should be made for snow plow operations. Installing bollards, curbs, or wheel stops could help minimize equipment damage. Sub-surface heating of the charging space is another option, including hydronic (small tubes under the pavement circulating heated water and anti-freeze) and electric radiant (low-voltage mats under the pavement heated by electricity) heating.[24]

Chargers, also known as electric vehicle supply equipment, are available in a variety of charging levels. As noted previously, chargers are currently divided into Level 1, Level 2 and DC Fast Charging categories.[25]

21 Email interview with Nick Walker, Arctic Energy Alliance, August 18, 2015.
22 Interview with Shane Andre, Government of Yukon, August 6, 2015.
23 Interview with Lee Johnson, Quantum Machine Works, August 5, 2015.
24 Chittenden County RPC, June 2014, Electric Vehicle Charging Station Guidebook, http://www.driveelectricvt.com/docs/default-source/default-document-library/electric-vehicle-charging-station-guidebook-.pdf?sfvrsn=0
25 U.S. Department of Energy Alternative Fuels Data Center, April 2015, Developing Infrastructure to Charge Plug-In Electric Vehicles, http://www.afdc.energy.gov/fuels/electricity_infrastructure.html

Table 2. Electric Vehicle Supply Equipment Categories

	Level 1 Charging	Level 2 Charging	DC Fast Charging
Electrical Circuit	120V AC	208V or 240V AC	480V AC
Equipment Needed	None- Standard Outlet used for Block Heaters	Home or public charging equipment	Designated DC Fast chargers and charge receptacles on vehicles.
Charging Rate (Kilometres Per Charging Hour) [26]	3-8 km	16-32 km	80-113 km in 20 minutes

In addition to the physical impacts of extreme cold weather, some types of electric vehicle chargers have difficulty transferring electricity to the vehicle. As discussed below, case studies and lessons learned from charging equipment manufacturers may mitigate potential impacts.

Charging Case Studies

Hydro-Quebec: Between 2010 and 2013, Hydro-Quebec operated an electric vehicle pilot project to understand a number of issues, including how the ambient temperature impacted PEV charging.[27] The initiative included nine Level 1 workplace chargers, 47 Level 2 chargers (27 residential and 20 workplace), and one DC fast charger. The researchers found that the Level 2 charging time was not affected by the ambient temperature and was the same year-round. However, researchers noted the DC fast charger took considerably longer than the standard 30 minutes to charge a vehicle to 80% capacity in colder conditions. The extended charge length is related to the battery pack's internal resistance (in addition to temperature, calculated based on battery size, chemical properties, age, and discharge current), which will be higher during extreme cold conditions.[28] Numerous batteries are being tested and developed to determine which batteries are best for PEVs and PHEVs for the life of the vehicle.

Airport Cooperative Research Program (ACRP): According to researchers contracted by ACRP, PEV charging stations are not typically affected by extreme cold. Researchers advised that cold weather airports consider installing Level 1 charging stations in long-term facilities so that batteries could charge slowly and be kept warm, replacing any parasitic loss that would occur while the batteries are not in use.[29]

North Sea Region Electric Mobility Network: Researchers in Gothenburg, Sweden evaluated a pilot project with CHAdeMO fast chargers located around the city.[30] In an environment that frequently reaches extreme low temperatures, users reported a variety of charging impacts. If the battery

[26] Average charging capabilities under optimal temperatures, not Yukon winter temperatures.
[27] Hydro-Quebec, November 2013, Mitsubishi Electric Vehicle Pilot Project, http://www.hydroquebec.com/transportation-electrification/pdf/mitsubishi-pilot-project-report.pdf
[28] Transport Evolved, November 2014, Electric Car Rapid Charging, https://transportevolved.com/2014/11/06/electric-car-rapid-charging-need-know/
[29] Airport Cooperative Research Program, ACRP Synthesis 54, Electric Vehicle Charging Stations at Airport Parking Facilities, http://onlinepubs.trb.org/onlinepubs/acrp/acrp_syn_054.pdf
[30] North Sea Region Electric Mobility Network, November 2012, Experiences from the Gothenburg fast charging project for electric vehicles, http://archive.northsearegion.eu/files/repository/20130716113751_FastCharge_Pilot_GOTHENBURG.pdf

temperature was less than 10°C (50°F), it was difficult to charge beyond 20% capacity with the fast charger. Further, the charging cables felt ‘like a pipe’ in cold temperatures and there was often a problem returning the plug to the base after charging. Finally, the display was difficult to read in cold weather. These charging issues apply only to the fast chargers used in this study.

Engine Block Heater Outlets as Electric Vehicle Chargers

Helping to offset the loss of charge from cold weather is the widespread availability of Level 1 charging in the Yukon. Engine block heaters require similar electricity load and connections as Level 1 PEV charging (including a weatherized 120V outlet); ICF reviewed several block heater specifications available from retailers online and found a power draw in the range of 0.4-1.5 kW. As these connections are pre-existing across businesses and home in the Yukon, Level 1 charging is possible for almost all drivers.

Awareness of using these outlets as PEV chargers however is not widespread. Current PEV drivers in the Yukon indicated that they utilize these outlets daily, however never would have considered them for PEV use before they researched PEV charging.[31,32] Business owners currently offer these outlets as a necessity in winter, not expecting to have the same electricity demand the remainder of the year, so year round usage may require corporate policy changes.

Lessons learned from EVSE Manufacturer Testing

Certain types of DC fast charging equipment are unable to function properly in extreme cold. For example, Eaton DC fast charger screens were switched out to prevent fade-out in cold weather and some ChargePoint networking capabilities have reportedly gone down in extreme cold weather and need to be rebooted.[33] Some DC fast charger manufacturers, such as AeroVironment, have created a cold weather package option that testing has shown can accommodate temperatures as low as -30°C (-22°F).[34]

Summary of Findings

ICF’s literature review indicates that residents in the Yukon Territory will have difficulty maintaining normal functionality of electric vehicles during the coldest months of the year; however, electric vehicles, particularly PHEVs, are still a viable transportation option. The hurdle for market penetration will be that the PEV range in below freezing temperatures will be less than half of the average vehicle range. This may require more electricity to charge these vehicles, consumers making sure that there vehicle has sufficient range (including the battery and a combustion engine, as with the PHEV), or behavioral change. For daily use in cold winter months, however, the reduced electric vehicle range may still be within the scope of the average Yukon commute, an average of 15 minutes for the

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31 Interview with Lee Johnson, Quantum Machine Works, August 5, 2015.

32 Interview with Shane Andre, Government of Yukon, August 6, 2015.

33 Interview with Michelle McCutcheon-Schour, Vermont Clean Cities, November 21, 2014

34 AeroVironment, http://www.chargepoint.com/files/Nissan_DC_Quick_Charger_datasheet.pdf

Whitehorse area and 15.7 minutes for the entire Yukon Territory (based on 2011 Census data)[35] or 4.1 km for Whitehorse and 3.9 km for the entire Yukon Territory (based on the 2006 Census data).[36] Dealerships in Yukon are not currently selling PEVs, requiring vehicles to be ordered online or from southern provinces. Training is needed for Yukon dealerships and mechanics on how to service these vehicles.

Unique to the Yukon market however is the vast abundance of Level 1 charging at homes and businesses, due to the readily available charging for engine block heaters. Awareness campaigns to educate the public and businesses that these can be used as chargers may increase the demand for electric vehicles. The Government of Yukon has indicated that they could easily promote electric vehicle charging, particularly as this additional electricity demand in warmer months would help even out the demand cycle.

Like conventional vehicles, precautions will need to be taken to allow the vehicles to start and function normally, including keeping the vehicles in garages and using good battery thermal management systems. Allowing the battery to remain plugged in to even a Level 1 charger will keep the battery warm and will be critical to normal function.[37] Further, drivers may want to consider alternative options to increase the cabin temperature, such as the use of seat heaters. By pre-starting these vehicles while attached to a charger, drivers can allow the vehicle cabin to warm and the windshield to defog before operating the vehicle on a reduced range; ICF estimates that this pre-heating will have the same or similar energy consumption as engine block heaters currently in use.

Additional precautions will also need to be exercised when installing and maintaining charging infrastructure, including public and workplace chargers that may be exposed to the elements.

[35] Statistics Canada, 2011 National Household Survey, Statistics Canada Catalogue no. 99-012-X2011031.

[36] Statistics Canada, 2006 Census of Population, Statistics Canada Catalogue no. 97-561-XCB2006010.

3 Plug-in Electric Vehicle Market Assessment

Plug-in Electric Vehicle Forecasting in Yukon Territory

Consumers' willingness to pay for new technology, as well as the extent to which they value their convenience will play a large role in PEV deployment. Consumer surveys in the US indicate the manufacturer's suggested retail price (MSRP) of a PEV is a critical factor, with nearly 70% of survey respondents claiming it is the most important factor in deciding their purchase.[38] Furthermore, consumers expect PEVs to be cost-competitive with similar internal combustion engine (ICE) vehicle models, with a majority desiring a sticker price under $30,000.[39] While consumers do acknowledge the higher cost of PEVs and are willing to pay more, the price differential between a PEV and a conventional vehicle or even an HEV remains too high to induce larger volumes of vehicle sales.

Consumers' expectations regarding price, range, and charging time are in many cases not met by PEVs available today.[40] These barriers make converting potential consumers into actual purchasers a significant challenge. As discussed previously, vehicle price is the primary barrier to widespread PEV adoption in the near-term. Even with incentives, the initial costs of PEVs generally remain higher than HEVs and ICE vehicles.

To develop forecasts for Yukon Territory, ICF considered the parameters identified in the table below. The subsequent subsections discuss these parameters in more detail. ICF notes that we typically rely on hybrid electric vehicle (HEV) ownership data as a good indicator of the potential for PEV adoption. The premise of the relationship between HEV ownership and PEV adoption is that households that value non-economic benefits are more likely to purchase PEVs, and HEV owners show a willingness to pay to reduce gasoline use that goes beyond the economic benefits of using an HEV. While we were able to obtain vehicle registration counts from the Government of Yukon, they did not include HEV registration data. Despite this limitation in our forecasts, the parameters in the table below do provide good indicators for PEV adoption.

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[38] Deloitte Touche Tohmatsu Ltd, "Gaining Traction: A Customer View of Electric Vehicle Mass Adoption in the U.S. Automotive Market," 2010, http://www.deloitte.com.br/publicacoes/2007/MFG.Gaining_Traction_customer_view_of_electric_vehicle_mass_adoption.pdf.

[39] Ibid.

[40] Deloitte, "Gaining Traction: Will Consumers ride the electric vehicle wave?" Deloitte Global Services Ltd., 2011.

Table 3. Parameters Influencing PEV Adoption

Parameter	Description
Income	Studies have found that consumers of electric vehicles typically earn more than the average household
Commuting Patterns	Drivers consider many factors when purchasing vehicles; their daily work commuting is a significant factor. Interestingly, Yukon residents on average have a significantly shorter commuting distance than other parts of Canada
Access to Charging	Households that own their property are more likely to adopt a PEV than those who rent, according to market research by various analysts. Further, access to charging at workplaces can be a significant driver for growth.
Vehicles & Fuel Pricing	Vehicle population, population and economic growth, and vehicle turnover provide boundary conditions for the volume of and the rate at which PEVs can be deployed. Whereas fuel prices (gasoline and diesel) can impact consumer decision-making,

Income and Demographics

Key takeaways for Yukon Territory:

- The annual median income is relatively high compared to other provinces
- A large proportion of Yukon residents are within the age range of typical PEV consumers

Studies have found that consumers of electric vehicles typically earn more than the average household, with current PEV owners in Canada earning an annual income greater than $90,000.[41,42,43,44] Yukon residents may demonstrate greater rates of PEV adoption compared to other regions due to their higher than average median income. For the past five years, for instance, the annual median family income for a Yukon family is relatively high compared to other provinces and territories in Canada, with a median income of $95,360 per family in 2013, the third highest in the country (see Figure 2).

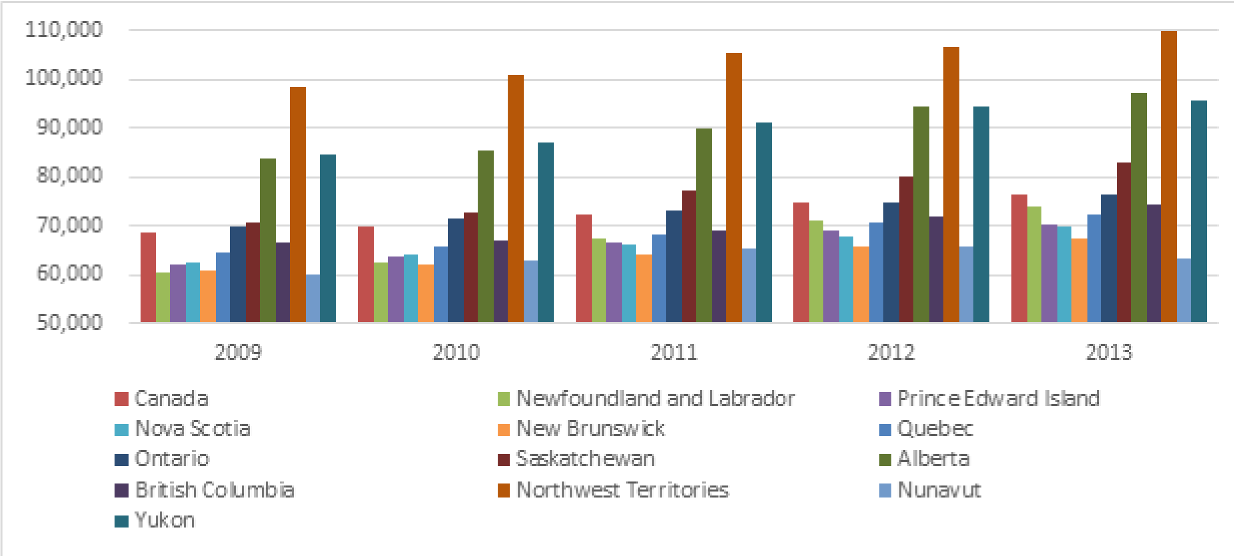
[41] Axsen, J., J. Bailey, and M.A. Castro (2015). Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. Energy Economics 50, 190-201.

[42] Axsen, J., S. Goldberg, J. Bailey, G. Kamiya, B. Langman, J. Cairns, M. Wolinetz, and A. Miele (2015). Electrifying Vehicles: Insights from the Canadian Plug-in Electric Vehicle Study. Simon Fraser University, Vancouver, Canada. Available online at http://rem-main.rem.sfu.ca/papers/jaxsen/Electrifying_Vehicles_(FINAL)_V2.8_(July10).pdf

[43] The International Council on Clean Transportation (2012). Consumer Acceptance of Electric Vehicles in the US. Available at: http://www2.epa.gov/sites/production/files/2014-09/documents/kodjak121312.pdf .

[44] Oceanus – Electric Vehicle Information Exchange (2012). Electric Vehicle Survey Panel. Available online at: www.evix.com.

Figure 2. Annual Income Estimates for Census Families and Individuals, By Province, 2009-2014.

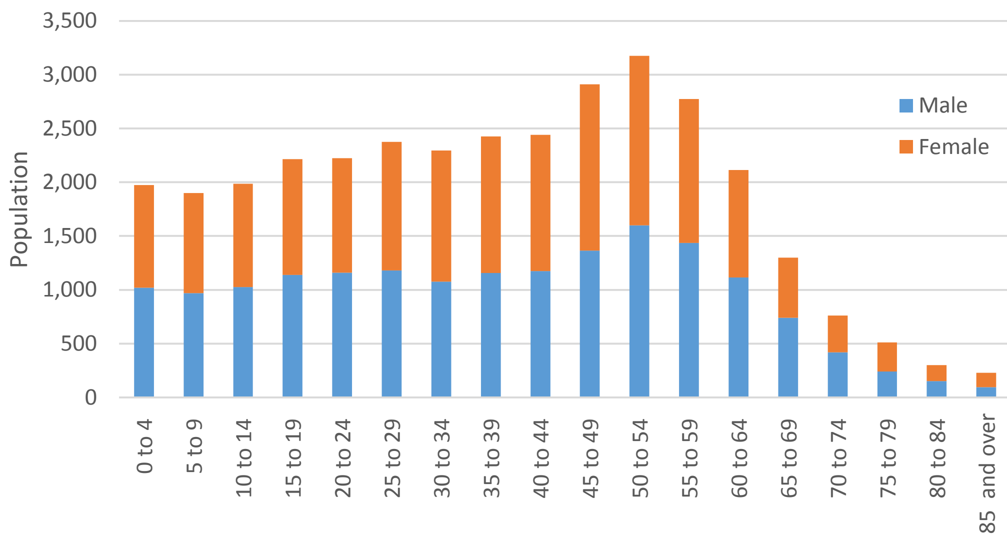


Source: StatsCanada

The previously referenced studies also found the majority of PEV consumers to be between the ages of between 35 and 54, with an average age of 46 years old. The demographics of Yukon residents support increased PEV adoption potential due to the high number of residents within the age category of PEV consumers[45], as shown in Figure 3.

[45] Statistics Canada, (2011). Focus on Geography Series, 2011 Census. Available at: http://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-pr-eng.cfm?Lang=Eng&GC=60.

Figure 3. Yukon - Population by five-year age groups and sex.



Source: 2011 Census Data, StatsCanada

Population and Commuting Patterns

Key takeaways for Yukon Territory:

- The majority of residents live in urban areas
- There are a significant number of daily commuters
- Commuter trip length is less than the range of PEVs in cold climates

Several factors related to commuting patterns of residents result in the potential for increased adoption rates of PEVs in the Yukon. While the population density overall is very low, at 0.1 persons per square kilometre, the majority of residents in the Yukon live in metropolitan or agglomeration areas (CMA/CA) (77%; 26,028 persons), with 69% of the population within the capital city of Whitehorse itself.[46] Of these residents, there are a significant number of daily commuters, with 75% of Whitehorse residents driving a vehicle to work (see Table 4).

[46] Statistics Canada (2011). Focus on Geography Series, 2011 Census. Available at: http://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-pr-eng.cfm?Lang=Eng&GC=60.

Table 4. Yukon mode of transportation to work

Commute Mode	Percent
Car, truck, van as driver	75%
Car, truck, van as passenger	8%
Public transit	5%
Walk to work	7%
Bicycle	3%
Other (motorcycles, taxi, etc.)	2%
Source: Government of Yukon (2011 Canadian Census)	

As discussed previously in Section 2, the Yukon's cold climate impacts charging abilities and driving range of PEVs, reducing the range of PEVs up to approximately 60%. Considering this reduced driving range, the average commuter trip length is still comparable to the expected PEV range. For instance, a survey conducted by the City of Whitehorse in 2000 indicated that most commuters drive less than 10 km one-way to work (Table 5).[47] The City of Whitehorse's Transportation Demand Management Plan Employee Survey,[48] which surveyed 207 employees from Yukon Government, Yukon Energy and City of Whitehorse, validates the 2000 report numbers referenced above. Compared to Canadians, Yukon residents on average have a significantly shorter commuting distance, with a median distance of 3.9 km for Yukon residents versus 7.6 km for Canadians (Figure 4).

[47] Public Service Commission, City of Whitehorse (2000). "How Do You Get to Work" A Transportation Survey of Whitehorse Area Employees: Technical Report. Available at: http://www.whitehorse.ca/home/showdocument?id=1602.

[48] Whitehorse Transportation Demand Management Plan, City of Whitehorse, YT, March 2015. Available online at http://www.whitehorse.ca/home/showdocument?id=4250

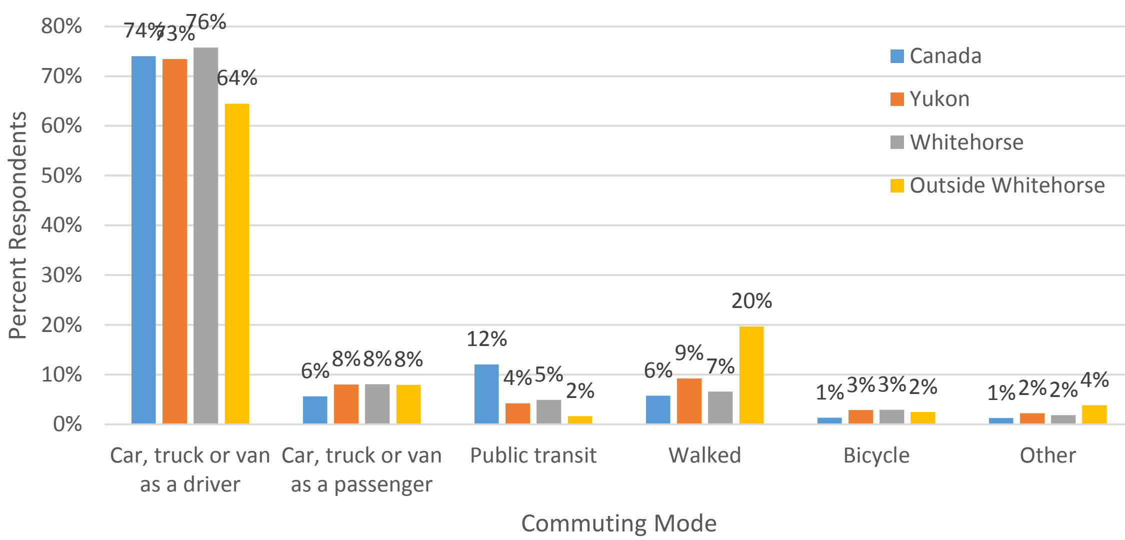
Taking into consideration the fact that many people (43%) use their vehicle at lunch time, increasing the daily range requirements, the daily commute of most residents remains below the typical range of PEVs in cold climates.

Table 5. Home to Work Commuting in Whitehorse, 2002

Responses to transport survey question: "Approximately how many kilometres is it from your home directly to work (one-way)?"		
Distance	No. of Responses	Percent of Responses
< 5 km	639	29.5%
5–10 km	618	28.5%
10–25 km	672	31.0%
> 25 km	239	11.1%
Total	**2,168**	**100%**

Source: Public Service Commission, 2000

Figure 4. Commuting Modes in Canada, Yukon, Whitehorse, and Outside Whitehorse



Source: 2011 Canadian Census

Access to Charging Stations

Key takeaway for Yukon Territory:

- Access to suitable areas for home charging
- Access to suitable charging infrastructure at work

As colder temperatures increase the time needed to charge PEV batteries, access to charging infrastructure is an important factor to consider. The majority of Yukon residents live in houses[49] (75.9%) versus apartments (23.9%) (compared to 65.8% and 34.3% of Canadians, respectively).[50] These dwelling types are more likely to have access to a garage, providing an area protected from the elements, thereby reducing the charging time required.

Access to suitable charging infrastructure is also available to residents at work. According to the City of Whitehorse survey[51], 72.3% of commuters have plug-ins available at work parking areas and for those that do not have access to plug-ins, 20.1% already start their car periodically throughout the day. The remaining portion either do not bring their vehicles to work on very cold days, have a command start or have access to parking in a heated garage.

Vehicles and Fuel Prices

Key takeaways for Yukon Territory:

- Vehicle registration in the Yukon is steadily increasing annually; however, vehicle purchasing patterns indicate a preference for light-duty trucks, for which there are few PEV offerings today.
- Gas and diesel prices are on average higher in Yukon Territory (although prices in Whitehorse are sometimes comparable to lower mainland prices), resulting in higher fuel cost savings with the purchase of a PEV.

Increased forecast adoption of electric vehicles can also be supported by evidence of increasing vehicle registration in the Yukon, as electric vehicles are a portion of these increasing registrations. Vehicle registration in the territory has steadily increased annually at an average rate of 3% since 2001 (see Figure 5).[52] Most vehicles registered are classified as *vehicles up to 4.5 tonnes* (passenger vehicles and light-duty trucks).

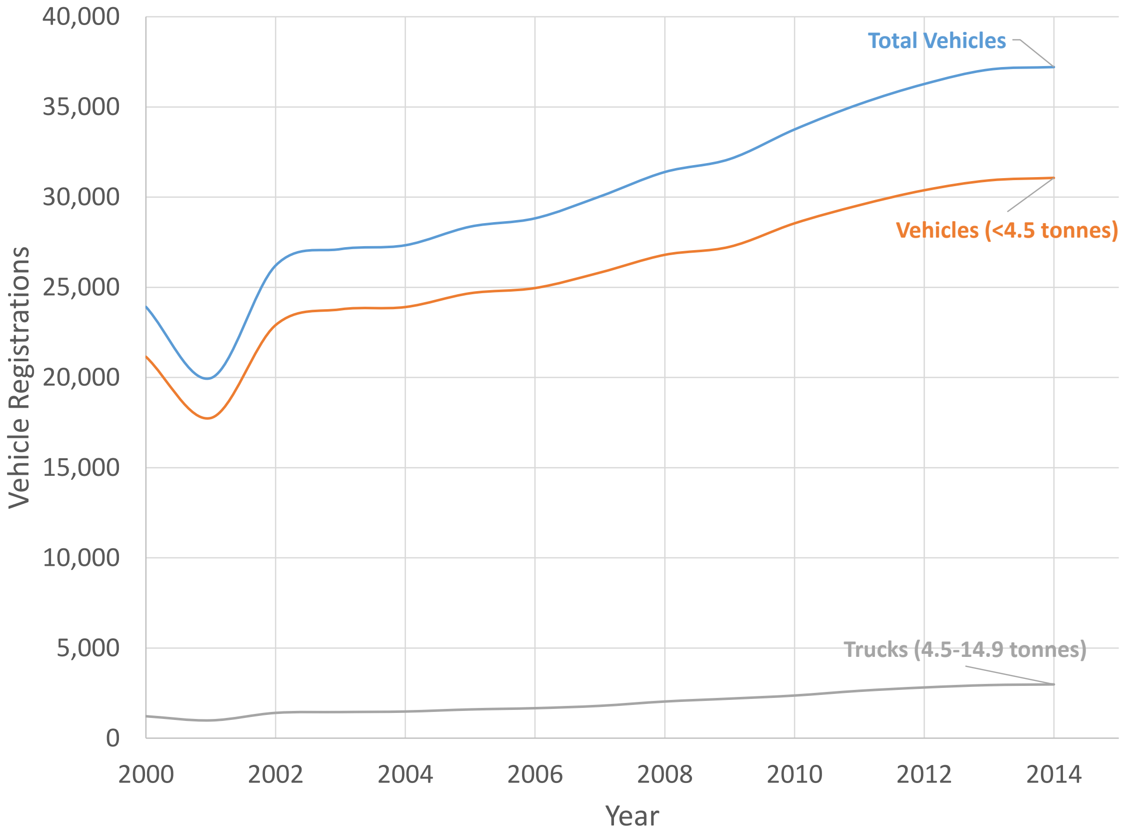
49 Houses include single-detached houses, semi-detached houses and row houses. Apartments include apartment buildings, duplexes and other movable dwellings.

50 Statistics Canada (2011). Focus on Geography Series, 2011 Census. Available at: http://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-pr-eng.cfm?Lang=Eng&GC=60.

51 Public Service Commission, City of Whitehorse (2000). “How Do You Get to Work” A Transportation Survey of Whitehorse Area Employees: Technical Report. Available at: http://www.whitehorse.ca/home/showdocument?id=1602.

52 Government of Yukon, Energy, Mines and Resources (2012), An Energy Strategy for Yukon Priority Action: Yukon Transportation Sector Information Paper. Available at: http://www.energy.gov.yk.ca/pdf/yt_sector_info_paper.pdf

Figure 5. Vehicles registered in the Yukon, 2000–2014[53]



Source: Statistics Canada (2015)

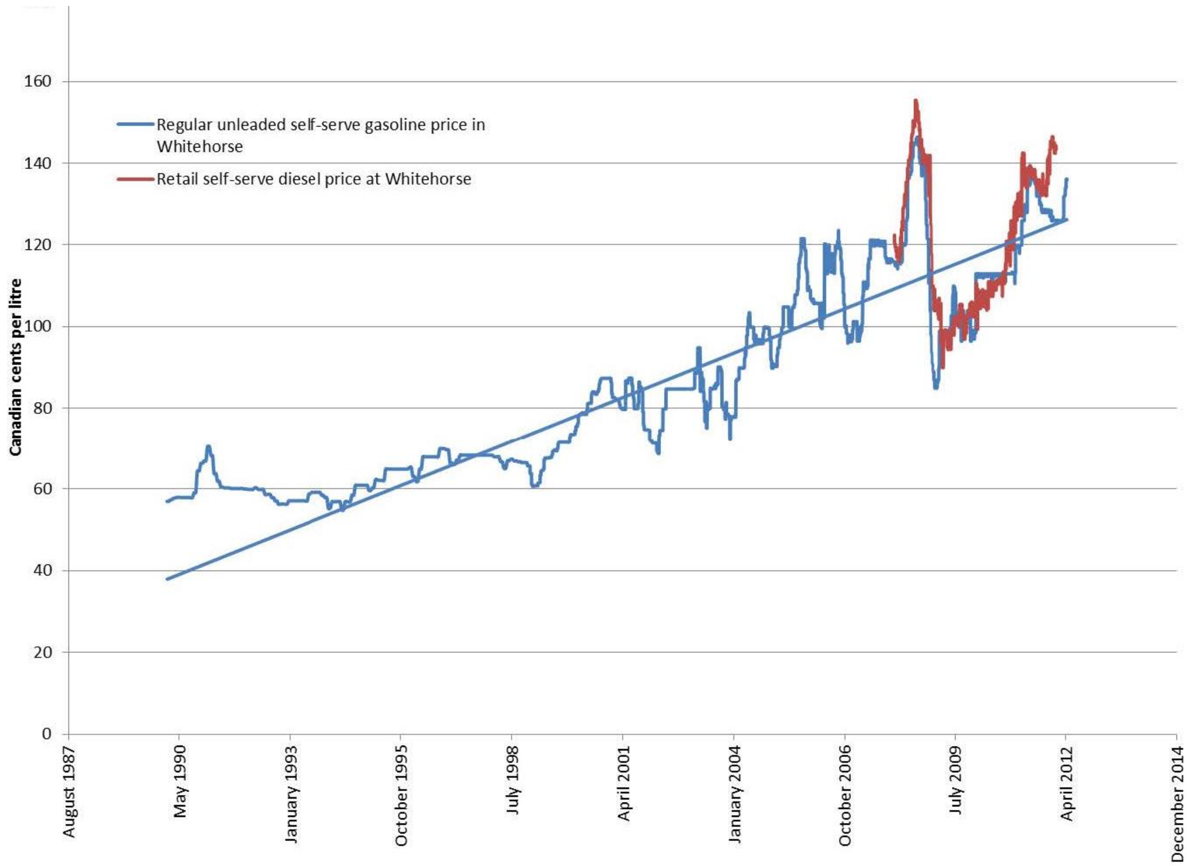
Gasoline and diesel prices also play a significant role in adoption rates of electric vehicles.[54] Conventional fuel prices are high in the Yukon, with the price of diesel and gasoline steadily increasing from 1999–2012 (Figure 6).[55] The higher fuel cost savings for PEV consumers in the Yukon results in increased adoption potential within the territory.

[53] Statistics Canada, CANSIM, table 405-0004

[54] Axsen, J., S. Goldberg, J. Bailey, G. Kamiya, B. Langman, J. Cairns, M. Wolinetz, and A. Miele (2015). Electrifying Vehicles: Insights from the Canadian Plug-in Electric Vehicle Study. Simon Fraser University, Vancouver, Canada. http://rem-main.rem.sfu.ca/papers/jaxsen/Electrifying_Vehicles_(FINAL)_V2.8_(July10).pdf, (last accessed August 18, 2015)

[55] Government of Yukon, Energy, Mines and Resources (2012), An Energy Strategy for Yukon Priority Action: Yukon Transportation Sector Information Paper. Available at: http://www.energy.gov.yk.ca/pdf/yt_sector_info_paper.pdf

Figure 6. Whitehorse Transportation Fuel Costs, 1999 - 2012



Source: Yukon Bureau of Statistics

PEV Forecasts for Yukon Territory

ICF estimates about 3,000 vehicles sold in Yukon Territory in 2014; showing average increase of about 5-6% (year-over-year) for the last 7 years.[56] Data from the Motor Vehicles Section of the Government of Yukon indicate that about 39% of registered light-duty vehicles since 2009 are passenger cars.[57] Statistics Canada only reports data for "British Columbia and the Territories", and does not report new vehicle sales for the Yukon Territory; however, the aggregated data for British Columbia and the Territories indicate that over the same time period for which we have total vehicle registration data (2009-2014), 41% of new light-duty vehicle sales were passenger cars. Further, for comparative purposes, we note that the country-wide average is about 43% of new light-duty vehicle purchases are passenger cars and 57% are light trucks. This vehicle split limits the potential of PEVs in the near-term future because there are limited offerings available today in the cross-over segments and light trucks.

56 Based on ICF analysis of vehicle sales, registered vehicle data, and population (via Statistics Canada).

57 Vehicle registration data also includes heavy-duty trucks, buses, and other vehicles; however, for the purposes of this analysis, we only considered vehicles less than 4,500 kg.

To estimate sales growth moving forward, ICF used a combination of forecasted demand for vehicle kilometres traveled, population growth, and economic growth. ICF assumes a year-over-year increase in new vehicle sales of 1.0% for 2015-2035.[58] For vehicle-kilometres traveled (VKT), ICF reviewed the most recently available data from the Canadian Vehicle Survey, which reports average VKT growth for all of Canada at 2.5% for the period from 2000-2009.[59] However, in Canada's Energy Future 2013, the National Energy Board reports an assumed growth of 1.0% in VKT. ICF notes that VKT is a good proxy for forecasting, and more reliable than fuel consumption, for instance, because it is largely unaffected by vehicle efficiency/fuel economy.

Growth rates for electric vehicles are derived from hybrid electric vehicle adoption in multiple jurisdictions, modified for local factors such as income and demographics, and commuting patterns. Generally we forecast exponential growth in the first 5-9 years of electric vehicle adoption, with that growth tailing off into a linear function by year 10. That linear growth is not a constant over time; rather, it increases with vehicle price reductions in the years 10-15, and decreases thereafter.

ICF developed three penetration scenarios out to 2035:

- **Low**: Assumed low levels of PHEVs deployed in light-duty passenger vehicles; no penetration in light-duty trucks. PEVs represent about 3% of new passenger car sales in 2025 in this scenario, increasing to 6.7% of new passenger car sales in 2035. ICF opted not to include light-duty trucks because there is significant uncertainty around automobile manufacturers' willingness to transition their electrification plans to their light trucks. Generally, ICF assumes that OEMs will meet fuel economy and GHG standards by focusing on a combination of fuel efficiency improvements and electrification for conventional light-duty passenger cars; whereas, OEMs will focus almost exclusively on fuel efficiency improvements (e.g., via light weighting and powertrain improvements) for light-duty trucks.[60]
- **Medium**: Assumed modest levels of PHEVs deployed in passenger vehicles with low levels of adoption in light-duty trucks. PEVs represent about 7% of new passenger car sales in 2025 and 18% in 2035. PEVs represent about 2.7% of new light truck sales in 2025 and 6.7% in 2035.
- **High**: Assumed more aggressive levels of PHEVs deployed in passenger vehicles; some penetration in light-duty trucks. In this scenario, ICF assumes that OEMs take a more aggressive approach towards meeting existing regulations via the deployment of plug-in hybrid and battery electric trucks. PEVs represent about 7.8% of new passenger car sales and 5.5% of new light-truck sales in 2025, increasing to 23.2% and 13.4% in 2035.

[58] ICF notes that the variations in our forecasts are all linked to the same VKT and sales growth forecasts, which are linked to other forecasts of population and economic growth. This growth is held constant across each EV deployment scenario developed; the variation arises from parameters such as vehicle availability and vehicle pricing.

[59] Natural Resources Canada, Canadian Vehicle Survey, 2009. Available online at http://oee.nrcan.gc.ca/publications/statistics/cvs09/pdf/cvs09.pdf

[60] The U.S. Energy Information Administration's Reference Case in the Annual Energy Outlook 2015, for instance, forecasts an average ratio of nearly 60-to-1 for electrified powertrains (including PHEVs and BEVs) in cars versus trucks through 2040. Over the same time period, the fuel efficiency of light trucks is forecasted to improve at a comparable rate to passenger vehicles.

ICF assumed a 50-50 split of PHEVs between the PHEV32 and PHEV64 vehicle categories in each deployment scenario. Figure 7 below show the cumulative PEVs in each scenario and Table 6 below includes the total number of EV passenger cars and light-trucks deployed in each scenario, as well as the share of electric vehicles of the total on-road vehicle fleet in the Yukon from 2015–2035.

Figure 7. PEV Forecasts for Yukon Territory in Low, Medium, and High Scenarios, 2015-2035

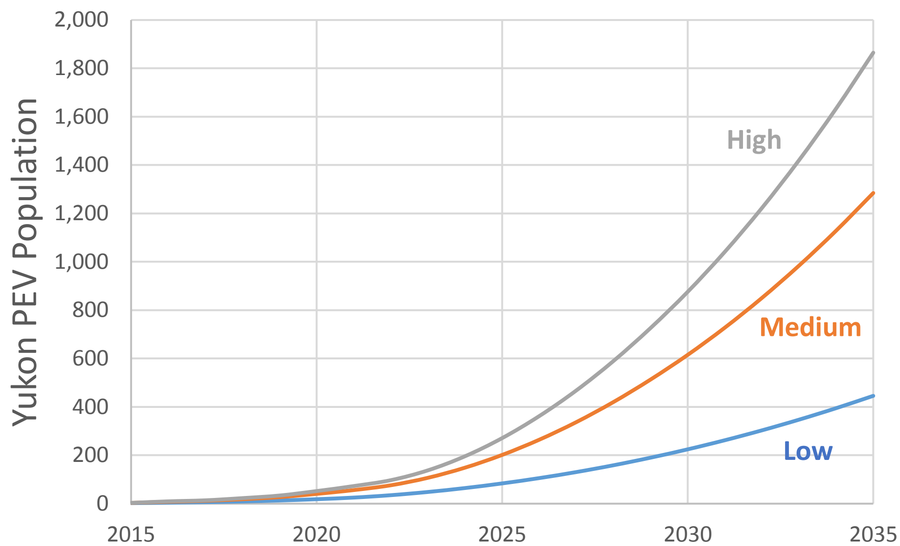


Table 6. PEV Deployment in Yukon Territory (Percent of Total On-Road Vehicles)

Deployment Scenario	Vehicle Type	2015	2020	2025	2030	2035
Low	Passenger Cars	2	18	83	224	445
	%Total Vehicles	0.0%	0.0%	0.2%	0.5%	1.1%
Medium	Passenger Cars	2	34	175	544	1,144
	Light Trucks	1	6	26	71	140
	%Total Vehicles	0.0%	0.1%	0.5%	1.5%	3.0%
High	Passenger Cars	1	33	183	640	1,397
	Light Trucks	2	19	87	235	467
	%Total Vehicles	0.0%	0.1%	0.7%	2.1%	4.4%
	Total Vehicles	37,736	38,556	39,602	40,833	42,214

Greenhouse Gas Impacts of Plug-in Electric Vehicles

PEV have zero tailpipe GHG emissions; however, there are upstream emissions attributable to electricity generation that must be accounted for to conduct a proper GHG reduction analysis. In the case of the Yukon Territory, even the upstream emission factors are small because such a large share of the generation profile comes from renewable resources, predominately hydropower. The emission factors for transportation fuels are reported on a lifecycle or well-to-wheels basis and are reported as grams of carbon dioxide equivalents per unit of energy (g CO_2eq/MJ) – also referred to as carbon intensity. ICF used emission factors from GHGenius, as shown in Table 7 below.

Table 7. GHG Emissions for Electricity and Gasoline

Fuel	Carbon intensity (gCO_2eq/MJ)
Electricity*	8.24 g/MJ
Gasoline	87.29 g/MJ
*Assumes 3% of power generated is from diesel generators	

The GHG emission reductions are reported as the difference between a light-duty internal combustion engine vehicle using gasoline and a PEV using electricity (and gasoline for PHEVs). The carbon intensity of electricity reported in the table above does not account for the fact that electricity used to power a motor is more energy efficient than gasoline. As a result, one must apply a factor referred to as the energy economy ratio (EER). For electricity, the value is 3.4; in other words, after accounting for the EER of electric vehicles, the effective carbon intensity of electricity is 2.42 gCO_2eq/MJ.

GHG Emission Reductions

The equations below shows how the various parameters outlined previously are combined into calculations to yield the GHG emission reductions attributable to vehicles using gasoline and electricity, or a combination thereof.

$$GHG_{gasoline} = PEVs * \left(\frac{VMT}{mpg}\right) * \delta_{gasoline} * CI_{gasoline},$$

where $\delta_{gasoline}$ is the energy density of gasoline, 34.69 MJ/L, and $CI_{gasoline}$ is the carbon intensity of gasoline.

$$GHG_{PHEV} = PHEVs * \left[\left(\frac{(1-eVMT)}{mpg}\right) * \delta_{gasoline} * \frac{CI_{gasoline}}{EER_{Fuel}} + \frac{eVMT}{mpg} * \delta_{gasoline} * CI_{electricity}/ EER_{electricity}\right]$$

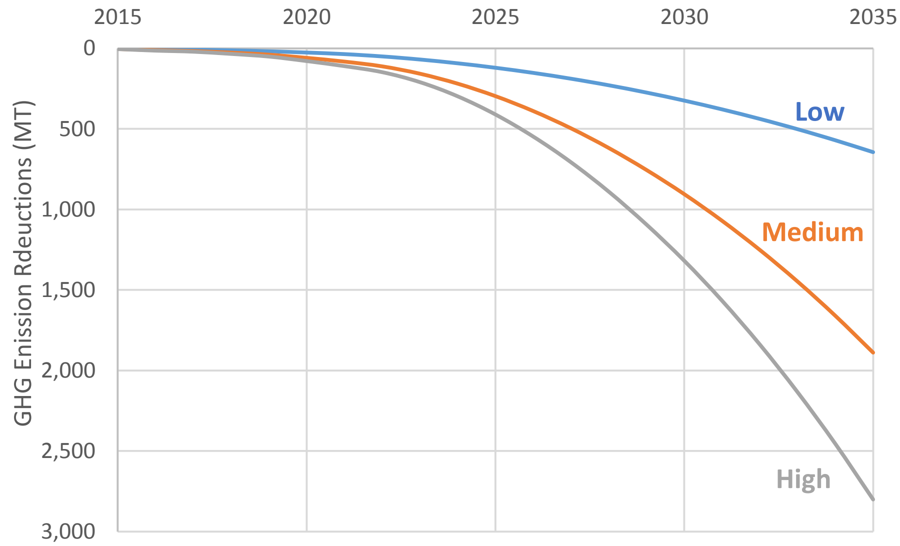
$$GHG_{BEV} = BEVs * \left(\frac{VMT}{mpg}\right) * \delta_{gasoline} * CI_{electricity}/EER_{electricity}$$

$$GHG\ Emission\ Reductions = \Delta\left(GHG_{gasoline}, GHG_{PHEV} + GHG_{BEV}\right),$$ where

$$PEVs = PHEVs + BEVs.$$

Figure 8 below shows annual reductions as metric tons for each of the PEV deployment scenarios developed previously.

Figure 8. GHG Emission Reductions from PEV Forecasts



ICF estimates that PEVs could reduce GHG emissions by about 120–410 MT by 2025 and 650–2,800 MT by 2035. For the sake of reference, the Yukon Transportation Sector GHG emissions report[61] on-road diesel and on-road gasoline accounted for 274,000 MT CO2e in 2012, representing about 50% of total GHG emissions for the Yukon Territory (638,000 MT CO2e). These GHG reduction estimates account for the cold weather performance of plug-in electric vehicles and assume that the range of PHEVs is halved in the winter months (e.g., from 64 km to 32 km) and that there is twice as much electricity consumed in battery electric vehicles–in other words, we do not assume that drivers travel fewer kilometres, rather that they need to charge their vehicles more. Table 8 below shows the estimated emissions performance of conventional vehicles running on gasoline compared to PHEVs and BEVs in standard operating (or summer) conditions and in cold weather (or winter). The values are shown for new vehicles purchased in the year indicated, and do not represent the fleet average vehicle performance.

61 Yukon Greenhouse Gas Emissions: The transportation sector, Updated Report 2015. Available online at http://www.env.gov.yk.ca/publications-maps/documents/Yukon_Transportation_Sector_GHG_Emissions_Final_Updated_Report_March_2015.pdf

Table 8. GHG Emissions Rates (gCO2e/km) for various vehicle types and different operating conditions

Conditions	Year	Conventional ICE		PHEV32		PHEV64		BEV	
		Car	Light Truck	Car	Light Truck	Car	Light Truck	Car	Light Truck
Standard Operation / Summer	2015	218	277	118	161	19	35	6	9
	2020	166	239	91	139	16	28	6	9
	2025	127	182	70	107	13	22	6	9
	2030	127	182	70	107	13	22	6	9
	2035	127	182	70	107	13	22	6	9
Cold Weather Operation / Winter	2015	240-273	305-346	186-211	243-275	130-147	139-157	13	18
	2020	183-208	263-299	143-162	210-238	100-113	106-121	13	18
	2025	140-159	200-227	110-125	161-182	77-87	82-93	13	18
	2030	140-159	200-227	110-125	161-182	77-87	82-93	13	18
	2035	140-159	200-228	110-125	161-182	77-87	82-93	13	18

The emissions rates for cold weather are reported as a range to account for impacts to both conventional vehicles and electric vehicles. For instance, the Natural Resources Canada reports a 12–28% increase in fuel consumption (per US EPA estimates) in urban commutes, increased highway fuel consumption as a result of increased aerodynamic resistance, increased resistance from poor road conditions, and the energy density of winter gasoline formulations.[62] For illustrative purposes, we use an estimated increase in emissions linked to increased fuel consumption of 10–25% for conventional vehicles. The GHG emission rates for PHEVs are linked to the share of kilometres traveled using electricity or gasoline, and the range of estimates for cold weather operation reflects the range of estimates for when the vehicle is operating using its combustion engine. ICF also notes that the emission rates plateau in improvement in 2025 and are constant thereafter, reflecting Environment Canada's regulations related to vehicular GHG emissions, proposed in 2012 and adopted in 2014.[63]

4 Grid Impacts of PEVs

One of the key concerns about PEVs is the potential impact to the electric grid. If vehicle charging occurs coincident with peak demands, increased loads will drive a need for new investment in generation, transmission and distribution capacity. If charging can be managed to occur primarily in off-peak periods, much of the load will potentially be served with existing infrastructure such that impacts on the electric grid will be significantly reduced and there will be a potential for significant grid benefits, such as deferred or avoided investments in generation, transmission, and distribution capacity. Furthermore, PEVs have the potential to help level load and support higher penetration of renewable generation on the grid by using the vehicles' batteries for storage.

In the following subsections, ICF outlines our approach to analyzing the potential grid impacts of PEVs in the Yukon Territory, namely by reviewing the potential energy consumption of PEVs and the corresponding load profiles of those vehicles.

Energy Consumption and Loadshapes of PEVs

Given that there is not a profile of PEV energy consumption in the Yukon Territory, ICF relied on energy consumption profiles developed elsewhere. In a recent report for the California Electric Transportation Coalition, ICF developed energy consumption profiles shown in the table below.

62 Natural Resources Canada, Learn the facts: Cold weather effects on fuel efficiency, Available online at http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/16748.

63 Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations (SOR/2014-207)

Table 9. Energy Consumption of Plug-in Electric Vehicles

Vehicle Type (battery size)	Vehicle Kilometres Traveled		eVKT		Energy Consumption (kWh)	
	Daily	Annual	Daily	Annual	Daily	Annual
PHEV16 (4 kWh)	66	24,090	16	5,840	3.5	1,278
PHEV32 (8 kWh)			32	11,680	7.0	2,555
PHEV64 (16 kWh)			49	17,885	10.7	3,909
BEV (24-80 kWh)	48	17,370	48	17,374	10.3	3,770

These data are developed largely based on information from the EV Project.[64] The plug-in hybrid electric vehicles (PHEVs) are distinguished by their so-called all electric range or the estimated distance that each vehicle can travel using only battery power. These are listed as PHEV16, PHEV32, and PHEV64, capable of traveling an estimated 16, 32, and 64 km using only battery power before engaging the internal combustion engine.

ICF developed the values in the table above for PHEVs assuming that they would drive similar distances as the Chevrolet Volt (a PHEV64) and that they will exceed their all-electric range. For the purposes of this analysis, we excluded the consideration of PHEV16s, with the underlying assumption that the negative impacts on vehicle range would preclude them from deployment in the Yukon Territory. ICF held these values constant over time, considering the following: On one hand, battery technology will likely improve by 2035 to enable PEVs to travel longer distances. On the other hand, the lifetime of batteries for use in automotive applications is not well understood today. ICF recognizes that the constant VKT for PEVs is a simplifying assumption; however, given the uncertainty regarding battery technology today and into the future, we recommend a conservative simplifying assumption whereby VKT is held constant over the course of the analysis.

The all-electric range of these vehicles is likely to be reduced significantly in the winter months in the Yukon. Based on the research outlined previously in Section 2, ICF assumed a 50% reduction in the range of plug-in electric vehicles. We did not however, include any additional load during winter months for pre-heating the vehicle. Based on our research, pre-heating for plug-in electric vehicles would be the same or similar to the demand generated by engine block pre-heaters. ICF developed the daily energy consumption profiles shown in the table below for the Yukon Territory in summer (April to September) and winter (October to March) months.

64 See for instance, The EV Project, Q2 2013 Quarterly Report

Table 10. Estimated Daily PEV Energy Consumption (in units of kWh) in the Yukon for Summer and Winter[65]

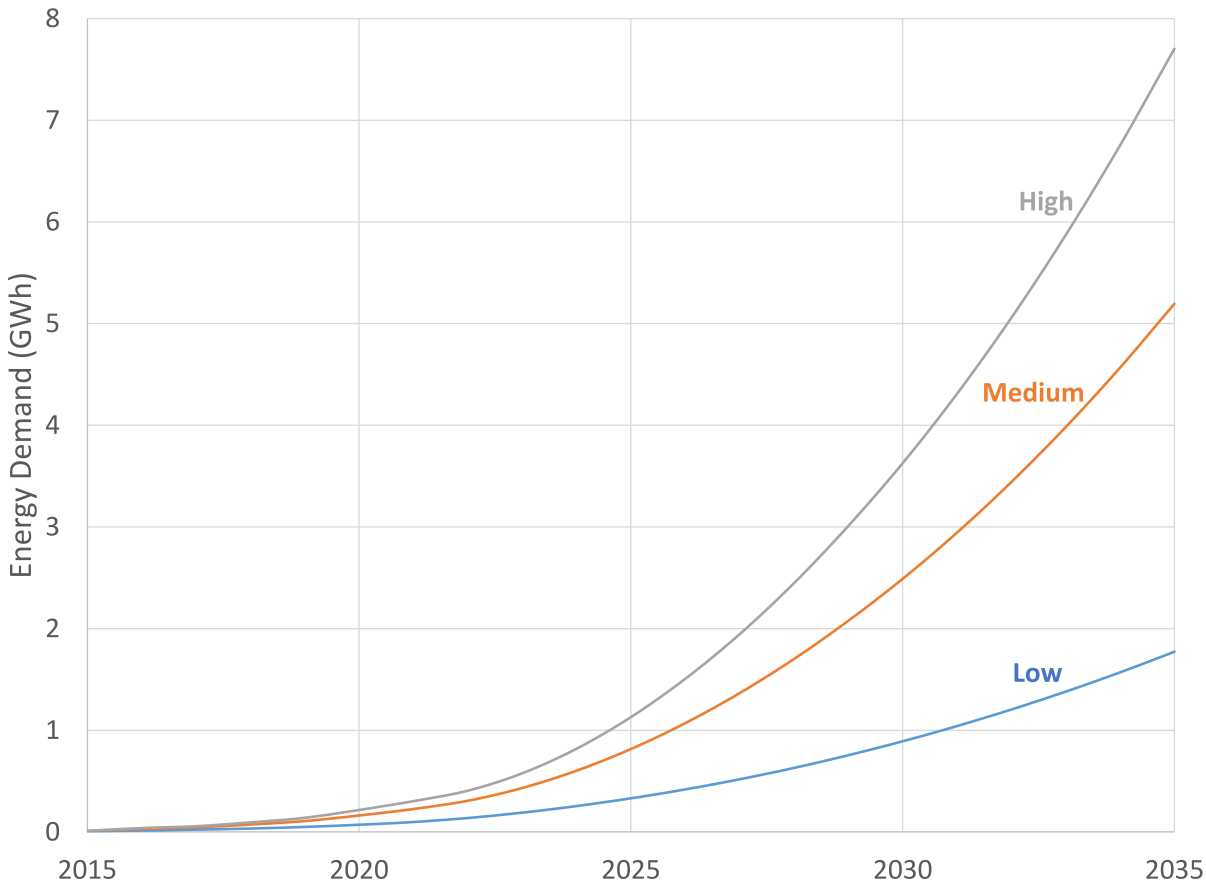
PEV Type	Passenger Car		Light Truck	
	Summer (Apr–Sept)	Winter (Oct–Mar)	Summer (Apr–Sept)	Winter (Oct–Mar)
PHEV32	7.0	7.0	10.0	10.0
PHEV64	10.7	14.0	15.3	15.3
BEV	10.3	20.6	14.8	29.5

We assume that passenger car and light truck PHEV32s deplete the full range of their battery in both summer and winter months; and in the winter months, they simply consume more gasoline to account for the additional reduced range using the battery. We assume that passenger car PHEV64s will consume the additional 24% of energy that the battery is capable of delivering in winter months. In the case of light truck PHEV64s, we assume that they consume the entirety of their battery power in both winter and summer months. For BEVs, we assumed that the vehicle would use its full range based on estimated battery sizing.

The figure below shows the forecasted energy demand (in MWh) of EVs in the low, medium, and high deployment scenarios.

65 These values do not include line losses.

Figure 9. Forecasted Energy Demand (GWh) for EV Deployment Scenarios



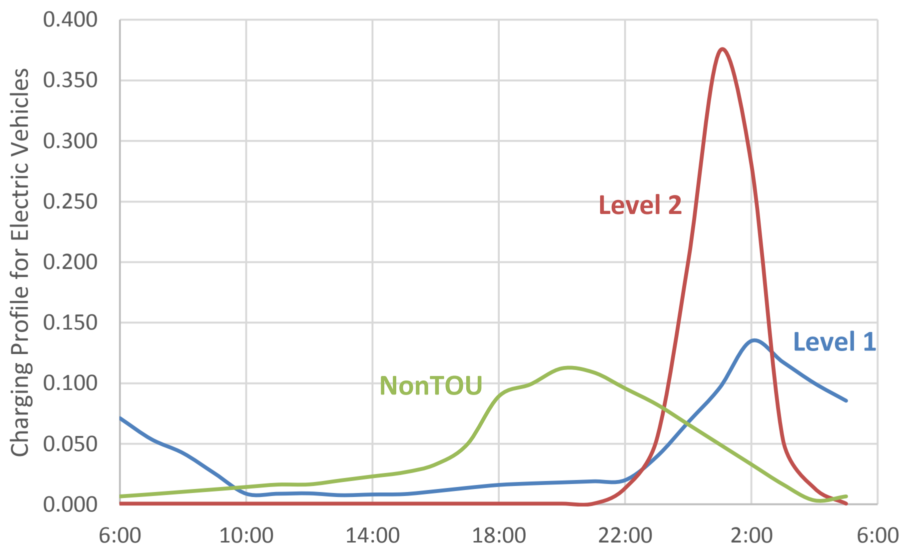
ICF also developed loadshapes for various charging scenarios, considering various charging levels and rate profiles. ICF considered both Level 1 and Level 2 charging; as noted previously, Level 1 charging is at 110 V and peaks around 1.4 kW. Level 2 charging is at 240 V and peaks around 7.5 kW. Note that many electric vehicles available today, particularly PHEVs, are power-limited by the on-board charger. For instance, the charging hardware on the Toyota Prius Plug-in and Ford Energi series of vehicles limit the charging rate to 3.3 kW. Nissan, on the other hand, quickly changed over to providing consumers with a 6.6 kW on-board charging rate within two generations of the LEAF. Given the long-term outlook of the illustrative analysis shown here, we assume a peak power demand of 7.5 kW at Level 2 charging.

For both Level 1 and Level 2 charging, we assume that there are time-of-use rates in place that incentivize charging at certain times of day. Ultimately, the structure of the TOU rate is up to the utility or load-serving entity. For the purposes of this analysis, we simply assumed that charging would be pushed off-peak.

The following bullets describe briefly the various charging scenarios considered, including charging level and rate assumptions:

- **L1 residential charging, TOU rate**: Level 1 charging at home is a proxy for charging of PHEVs with smaller batteries, like the PHEV16 or PHEV32. The normalized profile is based on a similar start time as L2 charging; however, it is stretched out over a longer period.
- **L2 residential charging, TOU rate**: Level 2 charging at home is a proxy for BEV or PHEV64 charging.
- **Residential charging, Non-TOU rate**: Residential charging in the non-TOU case is a modified version of what is reported in the EV Project for Nashville, Tennessee in the US–a region without a TOU rate.[66]

Figure 10. Daily Loadshapes for Electric Vehicles in Various Charging Scenarios



Note that the area under the curve of the daily load profiles shown in the figure above is normalized to 1.0. The daily charging profile has been normalized to 1.0 for illustrative purposes. In other words, the integrated area under the curve is equal to 1.0; and that value is adjusted in the analysis depending on the vehicle type and battery size. We did not modify the daily loadshapes over the analysis period; the loadshapes shown in the figure above were held constant over time.

ICF combined the energy consumption, load profiles, and PEV deployment scenarios to develop multiple load scenarios for analysis.

Feeder Impacts for Yukon Energy

The tables below include the peak demand (in units of MW) for summer (Table 11; April 1 to September 30) and winter months (October 1 to March 31), for each of the PEV deployment scenarios, and each charging scenario. The numbers shown are for weekday charging, with the note that weekend charging has lower demand.

[66] ICF does not assume an explicit blend of Level 1 and Level 2 charging for the non TOU rate; rather the rate is reflective of the time that vehicles would charge. The power draw associated with this rate implies that it is about a 50-50 blend of Level 1 and Level 2 charging.

ICF notes that peak energy values (in MWh) are not shown, but that they are equivalent to peak demand, simply in different units (MW). The reason these values are equivalent is that our current understanding of how vehicles charge does not allow us to make estimates at less than one hour intervals. As a result, we simply assume that the demand (MW) is constant over a one-hour period (yielding energy demand in units of MWh). In other words, the peak demand values listed in the tables below also represent our best estimate of peak load (in MWh). We effectively assume that charging events are staggered to some extent over each hour interval. In order for these values to not be representative of peak demand, one would have to assume that a large percentage of electric vehicles initiated charging events simultaneously (on the minute scale, not hourly scale).

Table 11. Peak Demand (in MW) during Summer (Apr 1–Sept 30), by Year for PEV Deployment Scenarios

Charging Scenario	Summer Peak Demand, Weekday, by Year (MW)				
	2015	2020	2025	2030	2035
Low PEV Deployment Scenario					
Level 1 TOU	0.0	0.0	0.1	0.3	0.6
Level 2 TOU	0.0	0.1	0.3	0.8	1.7
NonTOU	0.0	0.0	0.1	0.3	0.5
Medium PEV Deployment Scenario					
Level 1 TOU	0.0	0.1	0.3	0.8	1.7
Level 2 TOU	0.0	0.1	0.8	2.3	4.8
NonTOU	0.0	0.0	0.2	0.7	1.5
High PEV Deployment Scenario					
Level 1 TOU	0.0	0.1	0.3	1.1	2.4
Level 2 TOU	0.0	0.2	1.0	3.3	7.0
NonTOU	0.0	0.1	0.3	1.0	2.1

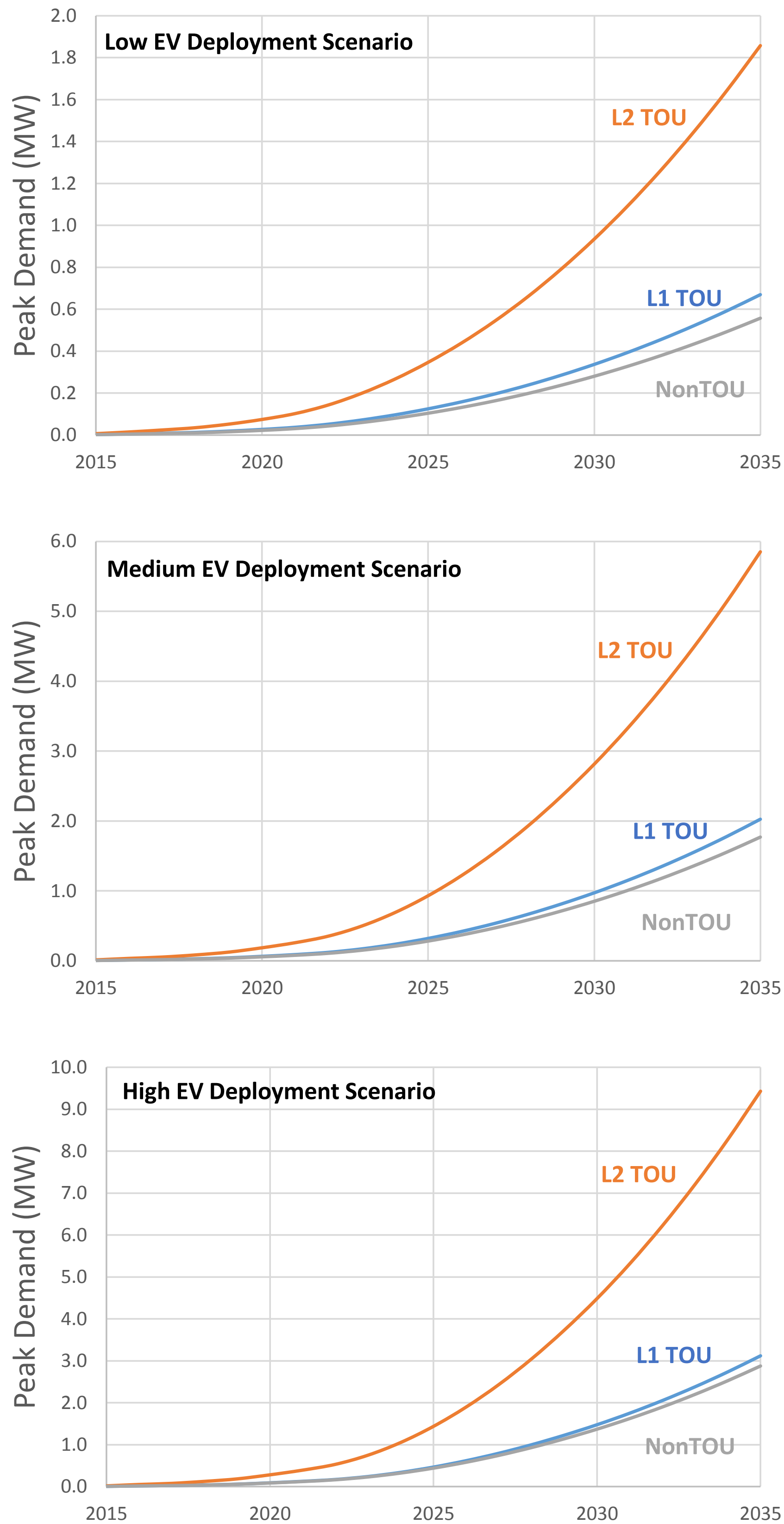
Table 12. Peak Demand (in MW) during Winter (Oct 1–Mar 31), by Year for PEV Deployment Scenarios

Charging Scenario	Winter Peak Demand, Weekday, by Year (MW)				
	2015	2020	2025	2030	2035
Low PEV Deployment Scenario					
Level 1 TOU	0.0	0.0	0.1	0.3	0.7
Level 2 TOU	0.0	0.1	0.3	0.9	1.9
NonTOU	0.0	0.0	0.1	0.3	0.6
Medium PEV Deployment Scenario					
Level 1 TOU	0.0	0.1	0.3	1.0	2.0
Level 2 TOU	0.0	0.2	0.9	2.8	5.9
NonTOU	0.0	0.1	0.3	0.9	1.8
High PEV Deployment Scenario					
Level 1 TOU	0.0	0.1	0.5	1.5	3.1
Level 2 TOU	0.0	0.3	1.4	4.5	9.4
NonTOU	0.0	0.1	0.4	1.4	2.9

The L2 TOU scenario has the highest peak (in MW) for each deployment scenario because of the way the load profile is developed (see Figure 10). The L2 TOU load profile assumes that drivers are provided with a price signal or incentive to encourage shifting at “off-peak” periods (i.e., at night). Similarly, the rate at which power is drawn during a charging event is higher. As a result the peak demand is predictably higher than the other charging scenarios. Also note that the values shown are for weekday peak demand, and that weekend peak demand is not shown simply because the values are consistently lower than for weekday charging events. ICF notes that the actual peak demand for the Yukon Territory is likely to be a mix of the various charging scenarios, with any near-term deployment likely to resemble the non-TOU charging scenario, simply because there is not an electric vehicle specific TOU rate.

The graphs in Figure 11 below show the peak demand (in MW) for the low, medium, and high EV deployment scenarios under different charging assumptions (L1, L2, and non-TOU).

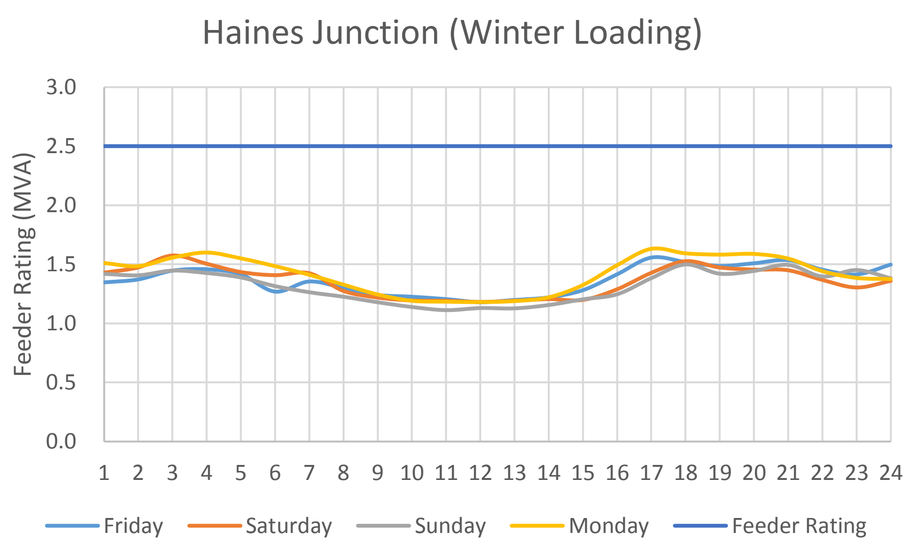
Figure 11. Forecasted Pea k Demand (MW) for EV Deployment in Different Charging Scenarios

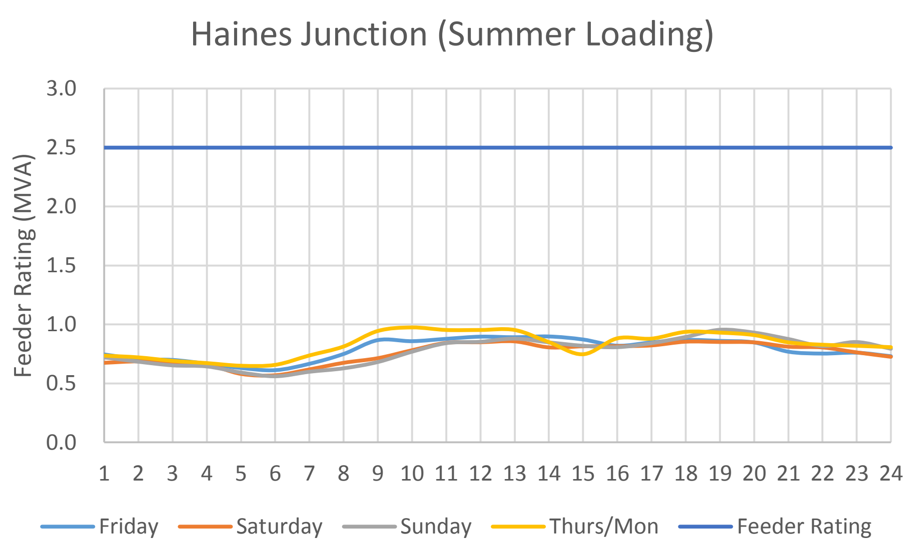


Yukon Energy provided maximum ratings for several assets owned by Yukon Energy. For illustrative purposes, ICF selected two feeders to conduct our feeder impact analysis, focusing on feeders that are most likely to be overloaded based on data provided:

- The Haines Junction feeder (see figure below) is considered relatively high loading and is rated at 2.5 MW with a peak load of 1.6 MW (in the winter months).

Figure 12. Winter and Summer Loadings on the Haines Junction Feeder

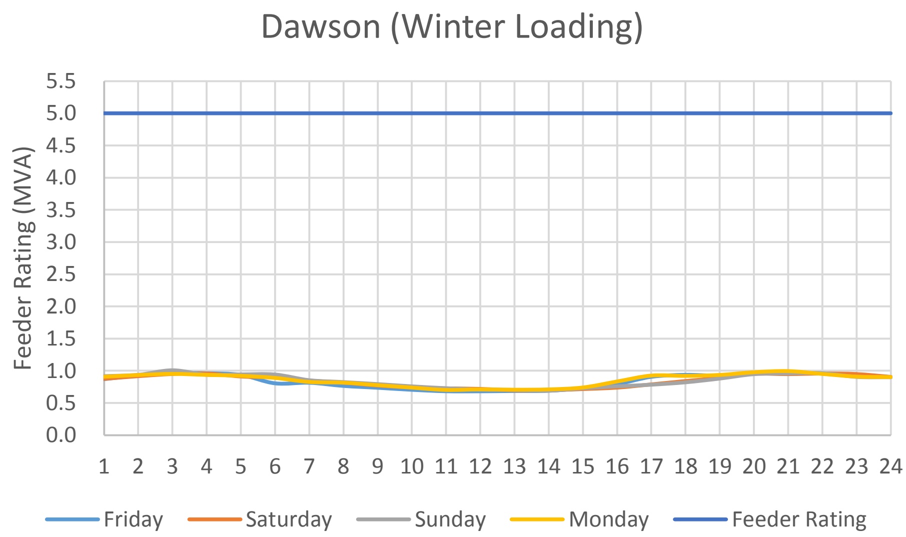


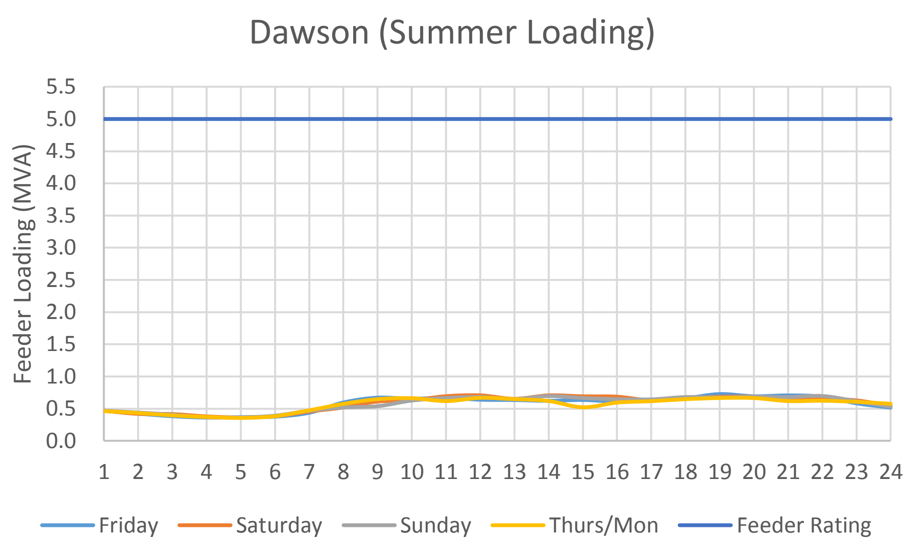


*Note: The summer "Monday" profile is a combination of half of Thursday and half of Monday

- The Dawson 2 feeder (see figure below) is low loading and is rated at 5.0 MW with a peak load of about 1.0 MW (also in the winter months).

Figure 13. Winter and Summer Loadings on the Dawson Feeder





*Note: The summer "Monday" profile is a combination of half of Thursday and half of Monday

One of the factors that our forecasts lacks is geographic distribution of PEVs. In other work, we have simply assumed that PEVs will be deployed in regions similar to the way that HEVs have been purchased. These data usually comes via vehicle registrations; however, as noted previously, we did not have this information available.

We present two ways to consider PEV adoption in Yukon Energy's territory:

- We assume that PEVs will be charged in a similar pattern in which electricity is currently distributed in Yukon Energy's service territory. This is a "fair-share" assumption i.e., that PEVs will be distributed across feeders according to their share of the distribution load.

- We assume that PEVs are clustered on certain feeders to determine the potential impacts.

ICF was provided distributed load on all Yukon Energy feeders and four ATCO feeders from 2013-2015 (year to date). Based on these data sets, the Haines Junction and Dawson 2 feeders distribute about 1.8% and 1.3% of the electricity. If we do a fair share distribution of the load associated with the high PEV deployment scenario in 2035 (when vehicle penetration is at its highest and there are nearly 1,900 PEVs assumed to be on the road), then this yields the equivalent of 34 and 24 PEVs on the Haines Junction and Dawson 2 circuits, representing a peak daily demand of about 0.23–0.99 MW and 0.17–0.71 MW, respectively, in the winter months.[67] Given the rating on both of these circuits and the current load, the additional load from PEVs may have an impact on Yukon's distribution assets in the winter months, depending on a) vehicle clustering, b) the timing of vehicle charging, and c) the types of electric vehicles) charging at the same time.

In the second part of the analysis, ICF considered the potential for PEV clustering. With more than 75% of the Yukon Territory population located in Whitehorse, it is unlikely that Yukon Energy's distribution assets will experience any severe clustering of PEVs. However, for the purposes of this analysis, we calculated the maximum number of PEVs that could charge on both the Haines Junction and Dawson 2 feeders before the assets would become stressed and trigger an upgrade. We performed this calculation using the three different charging profiles (L1-TOU, L2-TOU, and NonTOU) and for PHEVs and BEVs. Table 13 below highlights the maximum number of vehicles that can charge on each of the distribution assets before triggering an upgrade.

Table 13. Electric Vehicle Deployment and Stressed Assets

Feeder	Charging Profile	Maximum No. of Vehicles	
		PHEV	BEV
Haines Junction	L1-TOU	672	235
	L2-TOU	221	118
	NonTOU	822	398
Dawson 2	L1-TOU	2,827	1,035
	L2-TOU	974	522
	NonTOU	3,437	1,662

*ICF notes that we did not have a rating for ATCO feeders, and could not conduct the same analysis for Whitehorse

The population of PEVs in the year 2035 for the three scenarios ranges from about 500–1,900. As the table above shows, you would need significant PEV clustering, representing 12–50% of the PEVs forecasted to be on the road charging at the same time on the Haines Junction feeder at Level 2 to trigger an upgrade.

67 The daily load is presented as a range, with the minimum representing a passenger car PHEV32 (7 kWh/day) and the maximum representing a light-truck BEV (29.5 kWh/day).

Based on our analysis, it is unlikely that PEV charging will trigger upgrades to Yukon Energy's distribution assets, and will have minimal grid impacts absent more rapid adoption of PEVs than expected. That said, there are several variables that can change which would modify our conclusion:

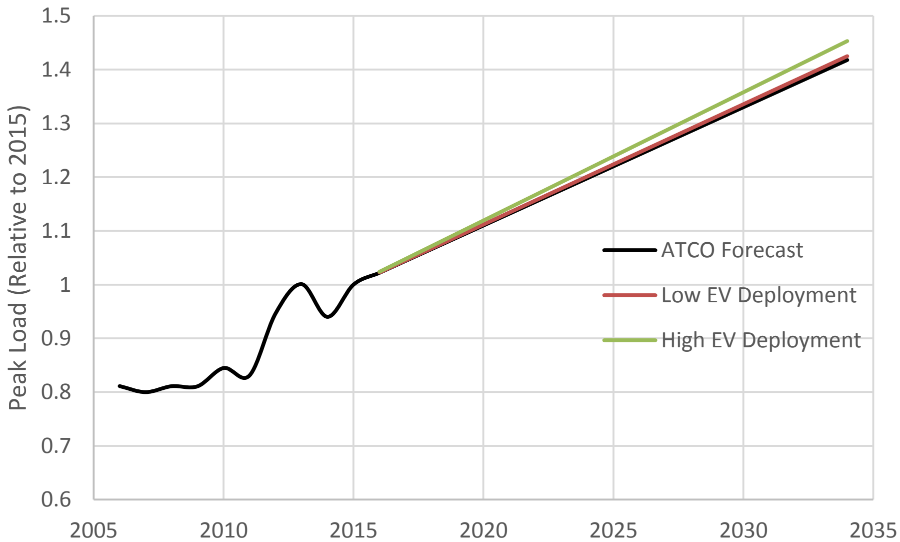
- Technological improvements to PEVs will likely yield larger batteries in the future, thereby increasing the daily load from PEV charging.
- Charging behavior can change depending on factors such as price signals (e.g., via utility intervention) and charging availability.
- Consumer purchasing preference could change over time, yielding a shift from light truck purchasing to passenger cars. One of the limiting factors for PEV deployment in our analysis is the assumed new truck sales as a percentage of new vehicle sales. If this changes over time, and the percentage of light duty passenger cars increases accordingly, then the electrification potential will increase accordingly.
- Policy changes could shift consumer purchasing as well. Incentives could induce a more significant deployment of PEVs in the near- to mid-term future. Furthermore, regulations that require reduced GHG emissions, perhaps with a focus on the transportation sector, can act as a strong incentive for electrification.

Impact on ATCO Assets

The feeders considered in the impact analysis in the previous subsection are a long distance from the City of Whitehorse, where 75% of the Yukon Territory's population resides and where ICF anticipates most electric vehicles will be deployed. Haines Junction, for instance, is a 90-minute drive from the City of Whitehorse and has a population under 1,000, whereas Dawson City is 6 hours north, does not have paved roads in the city, and has a population of 2,000. The distribution assets for the City of Whitehorse are primarily controlled by ATCO Electric, thereby limiting our ability to assess analytically the impact to their assets. ICF and Yukon Energy reached out to ATCO to help characterize the potential impacts on their system. The following information is a summary provided by ATCO and edited by ICF.

When contacted regarding the study, ATCO engineers noted that breakers are not the weak points in their distribution system; rather they highlighted that there are a variety of issues associated with managing load and assets in the downtown core, with a focus on a 25kv conversion project. ATCO expressed some reservations about modeling the increased load from the deployment of EVs and attributing the additional upgrades to EVs. For the sake of reference, ATCO noted that the low and high deployment scenarios would increase their load from about 2.2% per year to 2.24% per year and 2.39% per year, respectively. The figure below shows the forecasted peak load on ATCO's S150 and S170 feeders in Whitehorse (black line), with the impact of the electric vehicles in the low (red line) and high (green line) EV deployment scenarios. ATCO has agreed that the magnitude of this potential load and peak demand increases should be included in their incremental load growth forecasts. However, they also concluded that while it does not alleviate any existing loading issues, it further supports foreseeable upgrades that have already been identified as high priorities.

Figure 14. Peak Load Impact of EV Deployment on ATCO's Assets (S150 and S170)



5 Conclusions and Recommendations

ICF's finds modest potential for electric vehicles in the Yukon, with comparably modest GHG reduction potential. In a high forecasted electric vehicle deployment scenario at high charging, ICF's analysis indicates that it is conceivable that Yukon's distribution assets are stressed in the long-term future (e.g., around 2030–2035) absent any upgrades. However, this stress is dependent on a higher level of charging (Level 2 vs Level 1) and can be mitigated by shifting charging throughout the day (e.g., via workplace charging). Given the ubiquitous presence of engine block-heaters, it seems more likely to ICF that Level 1 charging will be more common than Level 2 charging at residences and workplaces.

The market potential for electric vehicles is constrained to some extent because of the cold weather in the Yukon, especially in the coldest months of the year. Most notably, vehicles may lose more than 50% of their advertised electric-powered range in cold weather. There are also near-term limitations on the electric vehicle market in the Yukon, namely the lack of dealerships selling electric vehicles and the limited vehicle offerings available more broadly to consumers. For instance, more than 60 percent of new vehicles sales are light trucks in the Yukon, likely because of weather and driving conditions, and other factors (e.g., consumer preference). As of 2015, electric vehicle manufacturers do not offer many models that can compete in this class.

Despite the limitations, electric vehicles, particularly PHEVs, are still a viable transportation option in the Yukon. Despite the potential loss of electric range, PHEVs also have the ability to run on petrol. Even after losing a portion of electric range due to cold weather, many electric vehicles will still provide sufficient range within the scope of the average Yukon commute. Furthermore, ICF may be under-estimating the potential for technological change and improvements in battery technology, thereby mitigating some of the concerns about diminished range.

The prevalence of engine block heaters also gives the potential electric vehicle market a boost in Yukon. These block heaters are effectively an ubiquitous electric vehicle charging network, currently available at homes and businesses. Public education and outreach could help new vehicle buyers understand the potential for vehicle electrification, and how the existing infrastructure can support that potential.

ICF generally recommends utility engagement in the electric vehicle market that keeps the utility slightly ahead of consumer preference and interest. There are a handful of electric vehicles in the Yukon, and interest is likely to improve moving forward. In that regard, Yukon Energy has an opportunity to support the deployment of electric vehicles through education and outreach to interested consumers, particularly in the role of trusted advisor that is common for a utility. ICF also recommends a more substantive engagement with ATCO, given their role as utility provider to the majority of residents in Whitehorse, where ICF anticipates the most significant electric vehicle deployment. To date, ATCO is justifiably focused on more pressing issues impacting their assets; however, moving forward, Yukon can work with ATCO to incorporate electric vehicle deployment into mid- and long-term resource planning. Outside of working with ATCO, Yukon Energy has an opportunity to maintain engagement with consumers and other stakeholders (e.g., automobile manufacturers and dealership) in the electric vehicle market space in the Yukon, thereby establishing a leadership position.