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Electric Vehicle Deployment Potential in the Yukon Territory

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Summary

The deployment of plug-in electric vehicles has the potential to help communities realize significant benefits. However, in cold weather climates, there are significant barriers to electric vehicle adoption. This paper conducts a market assessment in the Yukon Territory of Canada, including a review of the unique characteristics of the Yukon that may facilitate electric vehicle adoption, while also recognizing the challenges in the region. We find modest potential for electric vehicles in the Yukon, with comparably modest GHG reduction potential.

Keywords: EV, deployment, Canada, utility, range

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. The objective of this report is to determine to what extent an active engagement in PEV deployment will facilitate and/or accelerate adoption in the Yukon Territory, and to determine what the associated impacts or opportunities might be in the long term for electrical sales and peak and base loads. This potential is characterized against the backdrop of significant challenges and obstacles that PEVs face in the Yukon, namely the impacts of cold weather on electric vehicle operation. Plug-in electric vehicles currently make up less than 1% of vehicle sales in Canada, with only seven models currently available [1]. For this report, we use the term PEV to include battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). A recent survey in Canada however has shown that there is a demand for PHEVs, with more than a third of participants wanting to buy a PEV, mostly PHEVs [1]. 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.[1]

[1] 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.

2 Electric Vehicle and Charging Impacts in Cold Weather

2.1 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.

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 [2]. Another report by researchers at Carnegie Mellon University found similar results, which increased the emissions associated with PEVs because of the additional electricity requirements [3]. This is less of an issue for Yukon Energy customers where 99.6% of power generation is from clean hydropower, unless backup power is required from Yukon's fleet of diesel or natural gas generators. FleetCarma, a vehicle monitoring service for major auto manufacturers, aggregated data from Chevrolet Volt and Nissan Leaf drivers, and found that driving range was reduced by about half in colder temperatures (-25°C) [4]. 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. 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 [5]. PEVs can be adapted to winter road conditions as the battery cells create a lower center of gravity to help vehicles gain traction.

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 Vehicles [6]. 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 collected data on 30 Mitsubishi i-MiEV BEVs in both Europe and near Montreal for 3 years from 2010–2013 [7]. They report 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 i-MiEV has a range of 120 km). 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 [8] Manitoba Hydro then monitored the vehicle for 3 years in the Winnipeg area. 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. The

Province of Manitoba signed an MOU with Mitsubishi in 2011 to test two Mitsubishi i-MiEV BEVs for two years [9]. 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.

2.1.1 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 [10]. 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. The Arctic Energy Alliance began testing a Chevrolet Volt in January 2015 [11]. 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 only 35 km [12]. 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.

The first PEVs deployed in the Yukon Territory were conversions, as opposed to vehicles that come directly from the manufacturer [13]. 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. In March 2014, Quantum Machine Works of Whitehorse purchased a Ford Focus PEV for the company use [14]. 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.

2.2 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. 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 (tubes under the pavement circulating heated water and anti-freeze) and electric radiant heating (low-voltage mats under the pavement heated by electricity) [15].

Between 2010 and 2013, Hydro-Québec operated an electric vehicle pilot project to understand a number of issues, including how the ambient temperature impacted PEV charging [16]. 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. 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 [17]. 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 [19]. Researchers in Gothenburg, Sweden evaluated a pilot project with CHAdeMO fast chargers located around the city [20]. In an environment that frequently reaches extreme low temperatures, users reported a variety of charging impacts. If the battery 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.

2.2.1 Engine Block Heater Outlets as Electric Vehicle Chargers

The widespread availability of Level 1 charging in the Yukon will help offset the loss of charge from cold weather. Engine block heaters require similar electricity load and connections as Level 1 PEV charging (including a weatherized 120V outlet); we 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, they never would have considered them for PEV use before they researched PEV charging [13,14]. 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.

2.2.2 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 [20]. 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) [21].

2.3 Summary of Findings

Our 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 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 Whitehorse area and 15.7 minutes for the entire Yukon Territory [22] or 4.1 km for Whitehorse and 3.9 km for the entire Yukon Territory [23]. 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 abundance of Level 1

charging at homes and businesses, due to the readily available charging for engine block heaters. Awareness campaigns (e.g., via the Government of Yukon) to educate the public and businesses that these can be used as chargers may increase the demand for electric vehicles.

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. 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. 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.

3 Plug-in Electric Vehicle Market Assessment

3.1 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 [24]. Furthermore, consumers expect PEVs to be cost-competitive with similar internal combustion engine (ICE) vehicle models, with a majority desiring a sticker price under US$30,000 [24]. 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 [25]. 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, we considered the following parameters

Income and Demographics. 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 [1,26, 27,28]. 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.

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 [29]

Population and Commuting Patterns. 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 [29]. Of these residents, there are a significant number of daily commuters, with 75% of Whitehorse residents driving a vehicle to work. 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 [30]. The City of Whitehorse's Transportation Demand Management Plan Employee Survey [31], 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.

Access to Charging Stations. 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[2] (75.9%) versus apartments (23.9%) (compared to 65.8% and 34.3% of Canadians, respectively) [29]. 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 [30], 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. Vehicle registration in the territory has steadily increased annually at an average rate of 3% since 2001 [32]. Most vehicles registered are classified as *vehicles up to 4.5 tonnes* (passenger vehicles and light-duty trucks). Gasoline and diesel prices also play a significant role in adoption rates of electric vehicles [1]. Conventional fuel prices are high in the Yukon, with the price of diesel and gasoline steadily increasing from 1999–2012 [32].The higher fuel cost savings for PEV consumers in the Yukon results in increased adoption potential within the territory.

3.1.1 PEV Forecasts for Yukon Territory

We estimate 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. 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. 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. To estimate sales growth moving forward, we used a combination of forecasted demand for vehicle kilometres traveled, population growth, and economic growth. We assumed a year-over-year increase in new vehicle sales of 1.0% for 2015-2035. For vehicle-kilometres traveled (VKT), we 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 [33]. However, in Canada's Energy Future 2013, the National Energy Board reports an assumed growth of 1.0% in VKT. We developed low, medium, and high PEV deployment scenarios out to 2035, as outlined below.

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. Assumed no availability of light-duty trucks

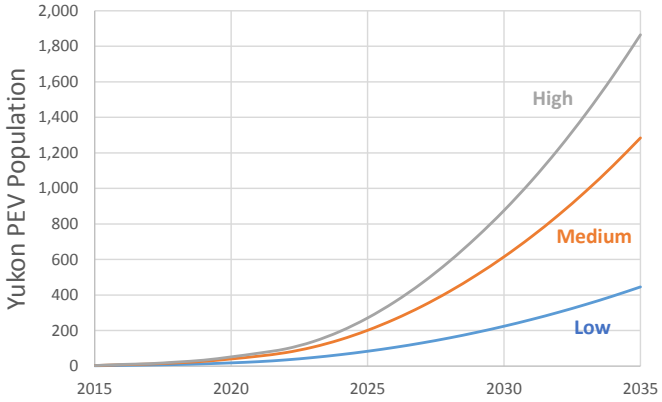
Medium: Assumed modest levels of PHEVs deployed in passenger vehicles with low levels of adoption in light-duty trucks. PEVs represent about 7% of new passenger car sales in 2025 and 18% in 2035. PEVs represent about 2.7% of new light truck sales in 2025 and 6.7% in 2035.

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

High: Assumed more aggressive levels of PHEVs deployed in passenger vehicles; some penetration in light-duty trucks. In this scenario, we assumed 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.

We assumed a 50-50 split of PHEVs between the PHEV32 and PHEV64 vehicle categories in each deployment scenario. Figure 1 below show the cumulative PEVs in each scenario.

Figure 1. PEV Forecasts for Yukon Territory in Low, Medium, and High Scenarios, 2015-2035



3.2 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 or g/MJ)–also referred to as carbon intensity. ICF used emission factors from GHGenius of 8.24 g/MJ and 87.29 g/MJ for electricity and gasoline, respectively. The carbon intensity of electricity assumes 3% of powere generated is from diesel generators. The GHG emission reductions are estimated 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 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. The equations below show 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.

$$GHG_{gasoline} = PEVs * \left(\frac{VMT}{mpg}\right) * \delta_{gasoline} * CI_{gasoline}, \quad (1)$$

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

$$GHG_{PHEV} = PHEVs * \left[\left(\frac{(1-eVMT)}{mpg}\right) * \delta_{gasoline} * \frac{CI_{gasoline}}{EER_{Fuel}} + \frac{eVMT}{mpg} * \delta_{gasoline} * CI_{electricity}/EER_{electricity}\right] \quad (2)$$

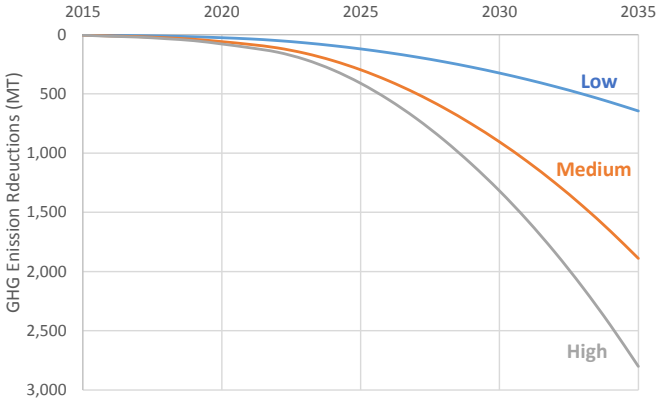
$$GHG_{BEV} = BEVs * \left(\frac{VMT}{mpg}\right) * \delta_{gasoline} * CI_{electricity}/EER_{electricity} \quad (3)$$

$$GHG\ Emission\ Reductions = \Delta\left(GHG_{gasoline}, GHG_{PHEV} + GHG_{BEV}\right), \text{ where} \quad (4)$$

$$PEVs = PHEVs + BEVs \quad (5)$$

Figure 2 below shows annual reductions as metric tons for each of the PEV deployment scenarios.

Figure 2. 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, 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) [34].

4 Grid Impacts of PEVs in Yukon Territory

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.

4.1 Energy Consumption and Loadshapes

Absent a profile of PEV energy consumption in the Yukon Territory, we relied on energy consumption profiles and loadshapes developed by our team elsewhere [35]. Based on the research outlined previously, we assumed a 50% reduction in the range of plug-in electric vehicles. We did not include any additional load during winter months for pre-heating the vehicle, because we assume pre-heating for PEVs would be the same or similar to the demand generated by engine block pre-heaters. We 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.

Table 1. Estimated Daily PEV Energy Consumption (in units of kWh) in the Yukon for Summer and Winter[3]

PEV Type	Passenger Car		Light Truck	
	Summer	Winter	Summer	Winter
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

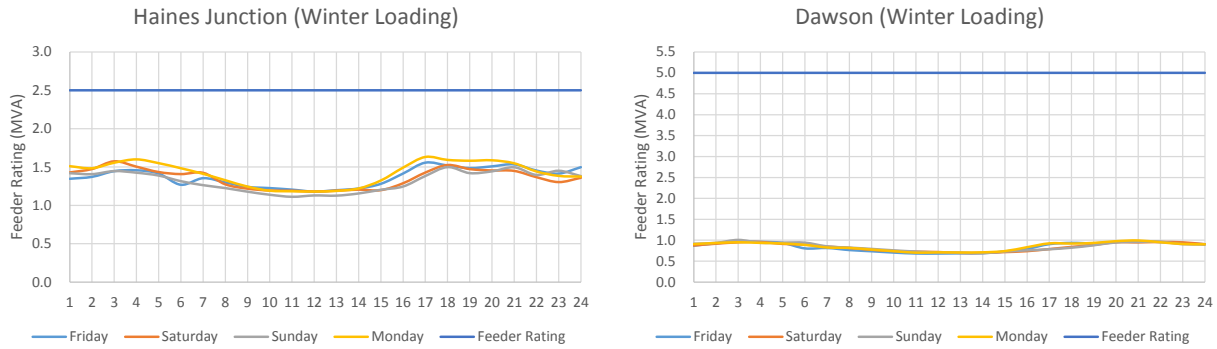
[3] These values do not include line losses.

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.

4.2 Feeder Impacts for Yukon Energy

The peak demand for summer (April 1 to September 30) and winter months (October 1 to March 31) range from 0.5–7.0 MW and 0.6–9.4 MW by 2035, respectively, for the PEV deployment scenarios, and charging scenarios. Yukon Energy provided maximum ratings for several assets owned by Yukon Energy. For illustrative purposes, we 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 Fig. 3 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). The Dawson 2 feeder 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 3. Winter Loadings on the Haines Junction and Dawson Feeder



One of the factors that our forecasts lacks is geographic distribution of PEVs. We present two ways to consider PEV adoption in Yukon Energy's territory: 1) 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; and 2) we assume that PEVs are clustered on certain feeders to determine the potential impacts. ICF reviewed distributed load on 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. 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.[4] 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

[4] 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).

become stressed and trigger an upgrade. Table 2 below highlights the maximum number of vehicles that can charge on each of the distribution assets before triggering an upgrade.

Table 2. Electric Vehicle Deployment and Stressed Assets

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

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. 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: a) Technological improvements to PEVs will likely yield larger batteries in the future, thereby increasing the daily load from PEV charging; b) charging behavior can change depending on factors such as price signals (e.g., via utility intervention) and charging availability; and c) 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. 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.

4.3 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 we anticipate 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. 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 25 kv conversion project. 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. 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.

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