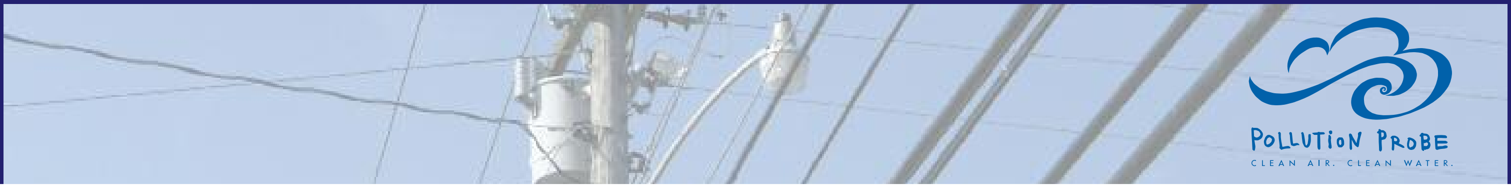

POLLUTION PROBE
CLEAN AIR. CLEAN WATER.

EMAP
TORONTO

ELECTRIC MOBILITY ADOPTION AND PREDICTION

Informing the development of an electric vehicle deployment strategy for the City of Toronto

ABOUT POLLUTION PROBE

Pollution Probe is a national, not-for-profit, charitable organization that exists to improve the health and well-being of Canadians by advancing policy that achieves positive, tangible environmental change. Pollution Probe has a proven track record of working in successful partnership with industry and government to develop practical solutions for shared environmental challenges.

ABOUT THE CENTRE FOR URBAN ENERGY (CUE)

The Centre for Urban Energy (CUE) at Ryerson University is a unique research and technology demonstration centre devoted to the discovery and commercialization of innovative, practical solutions to urban energy issues.

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Pollution Probe is solely liable and responsible for the contents of this report. Inclusion of the names of individuals is for acknowledgement purposes only and does not constitute an endorsement of the material.

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About This Report

In October 2010, Pollution Probe released its study, *Moving Toward an Electric Mobility Master Plan for the City of Toronto (EMMP)*, which demonstrated a need to focus on how the electricity distribution system (or "grid") responds to the power demand from electric vehicle (EV) charging at the neighbourhood level. The report was the result of in-depth research, analysis and consultation with stakeholders, culminating in a comprehensive set of recommendations for advancing the deployment of EV technology in Canada's largest urban centre. Pollution Probe collaborated with Toronto Hydro-Electric System Limited (THESL) on the development of more than 150 scenarios representing different levels of EV use across the City of Toronto and simulated the response of the grid to the resulting demand for power.

The EMMP analysis showed that the capacity of the grid to accommodate substantial levels of EV charging varies across neighbourhoods, with some areas notably constrained. The study recognized that this potential shortfall would be an important issue to understand and manage effectively in order to support the uptake of EV technology and that further work was called for to determine if EV early adopter neighbourhoods would coincide with potentially grid-constrained areas. The Electric Mobility Adoption and Prediction (EMAP) project emerged as a means of addressing this need. The EMAP methodology is a tool of predictive analysis, capable of improving the efficiency of capital investments in electricity distribution system assets and EV charging infrastructure by ensuring that they align with the needs of early adopter markets.

Using the EMAP methodology as a guiding framework, Pollution Probe and the Centre for Urban Energy (CUE) at Ryerson University reached out to stakeholder organizations playing an integral role in the future of electrified transportation in the City of Toronto. These stakeholders met regularly as an advisory group, contributing to the overall project scope, sharing technical expertise and providing guidance for all milestones and deliverables. The participation of these expert advisory group members helped to ensure that a local perspective informed the project, thus providing further credibility and enhancing the value and relevance of the outputs. The meetings of the advisory group fostered opportunities for important collaborations and provided a space for stakeholders to work together in developing options to support the growing demand for EVs and address key barriers to their adoption.

This report summarizes the process, findings and implications emerging from the application of the EMAP methodology to the City of Toronto.

While a number of stakeholders have been involved in important work on EVs over the past several years, the Toronto EMAP study involved a significant process of discovery, of equal importance to the findings themselves. The methodology provides a means for furthering shared investigation, and the process and findings support the need for ongoing collaborative management of EV deployment and constitute a foundation upon which those with a direct stake in that deployment can base their actions. This study led to the production of a number of complementary reports, including an in-depth investigation undertaken by THESL of the electricity distribution system at the systems level (see Appendix A of this report, provided by THESL) and full-length reports on the EMAP market research and the electricity distribution system assessment produced by Environics Research Group and CUE, respectively. Taken together, these resources provide a comprehensive look at the implications of EV technology uptake for the City of Toronto and served as the basis for this report.

This report summarizes the process, findings and implications emerging from the application of the EMAP methodology to the City of Toronto. It includes maps of the city with details of the likely locations for deployment based on the market research and local electricity distribution assessment, as well as information that addresses the communications needs of residents and stakeholders. The report also identifies opportunities for ongoing capacity-building to manage and support the use of EVs in the city.

Why You Should Read This Report

In anticipation of the increasing uptake of electrified transportation, many jurisdictions are analyzing the degree to which EVs will penetrate the market in their region and are working to determine the most effective approach for introducing and managing EV infrastructure to meet the anticipated needs of the user and of power suppliers and distributors. EVs require infrastructure to support battery charging, a fact that necessitates strategic planning to successfully support and enable their deployment. However, appropriate investments in infrastructure are not possible without further clarity about when, where and how EVs will be used.

Early successes with EVs can lead to patterns of successful market introductions, supported by government policy, appropriate investment in technology and infrastructure, and innovative business models. By contributing to a successful deployment strategy for the City of Toronto, the EMAP findings can accelerate the uptake of EVs among early adopters and, in turn, help to realize the potential for measurable reductions in emissions of greenhouse gases (GHGs) and criteria air contaminants from personal transportation. The findings summarized in this report also provide a solid and objective foundation upon which to build a successful EV deployment strategy for the City of Toronto, capable of aligning with the needs of the local market, supporting local grid asset management planning and increasing the efficiency of capital investments in local infrastructure.

> ***The findings summarized in this report also provide a solid and objective foundation upon which to build a successful EV deployment strategy for the City of Toronto.***

The EMAP research and findings presented in this report provide the basis for better understanding how to support EV uptake in a strategic, cost-effective and collaborative manner. The findings can contribute to the optimization of the economic and environmental benefits of grid asset management planning and capital investments made on behalf of the public and the local distribution companies (LDCs) in the context of accommodating and encouraging EV ownership and use. As such, this report will be of value principally to LDCs and municipalities; however, the results of the market research will also be of use to automakers, policy decision makers and other relevant stakeholders.

In addition to providing insight into the specific challenges and opportunities facing the City of Toronto, this report lends itself to use as a process template, constituting the basis of an analytical and empirical tool capable of supporting and informing the ongoing development of EV system strategies as the market continues to expand and evolve. The methodology employed provides broad latitude to craft research objectives specifically tailored to the particular characteristics and challenges facing any municipality or LDC preparing for the uptake of EVs. As such, the EMAP methodology can contribute to developing a consistent capacity across municipalities, their LDCs and other stakeholders for evaluating the needs of the evolving EV market from a grid capacity and consumer demand perspective and for formulating comprehensive strategies to unlock the potential of EV technology in their regions.

Report Outline

This report is divided into three sections describing the process, findings and implications of the EMAP study and exploring options for a strategic path forward.

Section One provides a broad overview of the EMAP study, including key findings from the market research and the electricity distribution system assessment. This forms the basis for an investigation of the potential implications of these findings as they relate to a three-point strategy for supporting the deployment of EVs in the City of Toronto.

Section Two describes the specific process, outputs and assumptions made in the development and application of the market research. This section builds a detailed picture of the characteristics of potential early adopters, including a broad demographic profile, typical personal mobility patterns, and the barriers to and opportunities for the uptake of EVs.

Section Three of this report describes the methodology and results of simulation work conducted by CUE using data provided by THESL. The simulations address the capacity of the electrical distribution system at the neighourhood level to support additional loading resulting from EV charging under a number of conditions.

SECTION ONE:
Transformation to an Electric Vehicle Society

Introduction

EV technology does not need to evolve as urgently as does our thinking and approach to EV deployment. Transformation to an electric vehicle society requires a transformation in perspective.

EMAP is an investigative tool designed to be used to understand how to support the uptake of EVs among early adopters in urban regions. A primary output of the EMAP research methodology is a body of evidence that identifies and characterizes potential early adopter communities in the context of both the consumer market and electricity distribution system asset planning and management. This evidence provides a solid and objective foundation upon which to build a successful EV deployment strategy for an urban region, comprehensively addressing the consumer, the technology and the infrastructure dimensions of the challenge.

The THESL service area was investigated, and the implications of the findings are significant, demanding a fresh approach to EV technology and the infrastructure that supports it in the City of Toronto.

The interest of the potential early adopter in EV technology is tied to environmental performance, not to fuel savings.

The value proposition of EV technology to the crucial early adopter consumer group is founded on the promise of social benefits, as opposed to personal gain. But, notwithstanding this altruistic motivation, potential early adopters are also very concerned about the risks and limitations that EV technology may impose on their mobility – a personal freedom they dearly value. Thus, EV charging solutions that are *fast* and *convenient* are a must. Currently, limited public infrastructure necessitates the use of home-based charging to accommodate early adopter preferences. This presents fundamental challenges and opportunities for LDCs.

Powering transportation becomes a key function of the local electricity distribution grid in urban regions.

Accommodating transfers of energy from the local electricity distribution grid to EV batteries at the rate required to satisfy market demand will shift the principal demand profile for the grid in urban regions from serving home comfort, safety and convenience to serving the demand for mobility. This is because the power needed to charge an EV is considerably greater than a typical household's electrical load – in some cases as much as three to four times greater. Whereas electricity distribution planning currently focuses on accommodating a household load, in future the demand for mobility may be the primary impetus for asset planning. As the number of EVs on the road increases and drivers employ fast charging to meet their minimum expectations, even greater challenges will confront the electricity distribution system.

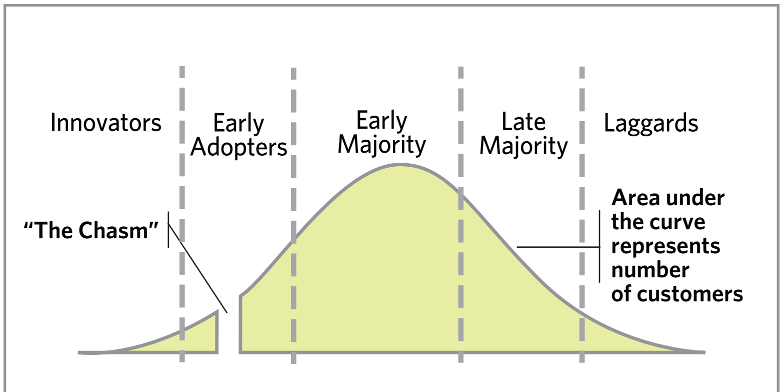
Based on the EMAP research, potential early adopters tend to concentrate in specific communities that can be characterized by sets of values the residents share as consumers and as citizens.

Based on the EMAP research, potential early adopters tend to concentrate in specific communities that can be characterized by sets of values the residents share as consumers and as citizens. This means that streets in certain early adopter neighbourhoods could have multiple EVs charging simultaneously. While this additional demand may not overload the local transformers serving these streets in the near term, in areas such as the downtown core of the City of Toronto, which is primarily serviced by a network system, it can erode the spare capacity of the transformers to take on emergency loading when lines are down or when nearby transformers fail in the course of routine service. Thus, if the scale of the EV demand for power is not recognized and addressed pre-emptively, the introduction of EVs could compromise the capacity of the local grid to reliably meet the basic demands of Toronto residents.

These findings point to the need to reconsider the role of the LDC. In terms of the deployment of EVs, this role is usually viewed as incidental – nothing more than a supplier of household electricity, delivered reliably at low cost. But the EMAP findings indicate that the LDC has the potential to play a more significant role. The benefits of EV use principally accrue to society via cleaner air to breathe and fewer GHG emissions. As a trusted institution with a public mandate, the LDC is capable of addressing many consumer concerns about and perceived barriers to EV technology. How the role of the LDC may evolve to meet these challenges will require rethinking on the part of a wide range of stakeholders, including automakers, regulators and policymakers. A flexible EV strategy capable of addressing the rate of EV uptake is essential sooner rather than later.

The Electric Vehicle as an Emerging Technology

If EVs are to become part of a successful sustainable transportation option in the City of Toronto, the social, environmental and financial needs of the user must be met. If early users of the technology are unable to experience and appreciate its full value, a broader market will not emerge. These early users will play a key role in expanding and developing the EV market and, for this reason, it is important to better understand exactly how to address their needs and incorporate the technology into their lives.



Technology Adoption Life Cycle

While the results of the EMAP study identify barriers and opportunities specific to EVs, the technology's adoption cycle also shares a number of characteristics with other emerging technologies. Over time, the process of technology adoption tends to follow a classical bell curve. The first users are known as innovators, followed closely by an early adopter group. Innovators are generally a very small number of risk takers who thrive on the challenge of a new technology and are willing to buy into a product even though the technology may ultimately fail. Early adopters, on the other hand, are generally more cautious in their adoption of a new technology and are not as willing to form new routines or behaviours to incorporate it into their lives. This observation is supported by the early adopter profile generated through the EMAP market research, which suggests that, in the City of Toronto, this group is unaccustomed to inconvenience and perhaps less willing to make the perceived sacrifices necessary to transition to an EV, given current market and technological considerations.

Support or endorsement of a technology from the early adopter group is one of the most important factors contributing to its adoption by a broader market. Whereas innovators may be perceived as extravagant or in a better position to take risks than the general public, early adopters demonstrate a high degree of opinion leadership capable of generating confidence in the usefulness of a technology among the broader public.

The early majority of the mass market tends to take its cues and base its decisions on the experiences and feedback of early adopters because their choices are perceived to be more discerning. It is for this reason that the EMAP study focuses on this influential consumer group.

While the traditional bell curve has long been the typical visual representation of market development for an emerging technology, more recently, Geoffrey Moore* has introduced the notion of a "chasm." Moore argues that there is a gap (or chasm) between the early adopter group and the early majority because the latter not only wants a useful product but also a well-established infrastructure to support it. Moore believes that, during the chasm phase, an emerging technology experiences a pause in market development. The length of this pause depends entirely on how disruptive the technology is to "business as usual."

**Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers.* HarperCollins, 1991.

There have been many attempts to forecast the rate at which adoption of EVs will occur – whether it will move quickly, like the Internet or the radio, or whether it will resemble the slower adoption curve of the washing machine, considered a luxury item for many years. Radically new or different technologies may have a difficult time breaking through, not because of the merits of the technology itself, but because regulations, infrastructure, maintenance networks and user practices are aligned to an existing technology. This is certainly a major consideration in the case of EVs. The current automotive marketplace revolves primarily around gasoline-powered vehicles. In addition to automakers themselves, there is an entire aftermarket involved in manufacturing, distributing, retailing and installing vehicle parts, equipment and accessories for gasoline-powered vehicles. This is not to say, however, that emerging technologies are unable to overcome these challenges.

While technological advances will go a long way to overcoming barriers to EV adoption, these alone may not be enough to appeal to the broader market.

While technological advances will go a long way to overcoming barriers to EV adoption, these alone may not be enough to appeal to the broader market. Even if EVs become technologically more attractive than they currently are, they will not succeed if perceptions about their usefulness are not positive. For example, Consumer Reports, an independent organization that tests consumer products and services, awarded the Tesla Model S a rating of 99 out of 100. This matches the best score earned by any vehicle, not just an EV, in the history of Consumer Reports. Yet many were quick to point out that, because of the lack of infrastructure to support its use, particularly infrastructure for fast charging, the vehicle is hardly just one point shy of perfect.

Better understanding the needs and perceptions of the early adopter community is important for developing effective and targeted information and awareness campaigns, incentives, bylaws and local policy implementation capable of supporting the market and infrastructure for EVs. By documenting the needs of early adopters (for example, if they require slow or fast charging or charging solutions at home or at work), the EMAP study can enhance the value proposition of EV use among end-users, establishing a solid foundation for the growth of the EV industry.

The following section briefly summarizes key findings from the market research and electricity distribution system assessment. For a more comprehensive description of the market research methodology, process and outcomes, refer to Section Two of this report. A more in-depth investigation of the electricity distribution system assessment is provided in Section Three.

Market Research

The results of the market research provide a detailed picture of the demographic characteristics and social values shared by potential early adopters, their typical personal mobility patterns, their expectations of the technology, and the barriers and opportunities they associate with the uptake of EVs.

Profile of the Potential Early Adopter: Shared Characteristics and Personal Mobility Patterns

Potential early adopters are more affluent, better educated and older (i.e., likely to be over the age of 45) than the general population of the City of Toronto. The majority of this group lives in detached, single-family homes with on-property parking, which is important for home vehicle-charging purposes. The EV early adopter community values the integration of environmental concerns with their purchasing decisions and has an enthusiasm for technology and for purchasing products and services in an area of particular interest (e.g., music, electronics) about which they make an effort to stay informed.

The majority of potential early adopters are considered vehicle commuters, characterized as those who drive on a regular basis and make little use of public transit. Vehicle commuters drive to a specific location at least twice a week, where most park in an employer-provided lot, many for at least eight hours. As previously noted, this profile suggests that EV early adopters are unaccustomed to inconvenience, which may limit their willingness to make the sacrifices perceived to be necessary to transition to an EV, given current market and technological considerations. For example, few in this group would likely be open to charging an EV at a centralized location any distance from their accustomed parking.

Early adopters who have personally owned or driven a hybrid vehicle were twice as likely as those who have not to say that they would definitely consider owning an EV in the next couple of years. This could have to do with the fact that hybrid owners or drivers have experience with a technology alternative to the gasoline-powered vehicle. As a result, they may be more comfortable with the possibilities offered by driving an EV or, at the very least, not as easily put off by the potential need to alter their behaviour to integrate the technology into their lives.

Barriers and Opportunities to EV Adoption: Environmental Benefits and "Range Anxiety"

A majority of potential early adopters feel that the main advantages of EVs are the environmental benefits and the opportunity to reduce vehicle emissions; a much smaller number mentioned fuel efficiency or cost savings. The environmental impacts of EVs were also the most familiar aspect of the vehicles, as opposed to how they work, how they compare to conventional gasoline-powered vehicles or awareness of existing government purchase incentives. The market research findings suggest that a lack of knowledge about EVs may underlie much of the resistance to the technology. While potential early adopters feel that they are at least somewhat familiar with EVs, few claim to be very familiar with them or are able to name a specific make or model.

Despite the perceived advantages, purchasing an EV may not be imminent even among potential early adopters because they also identify a number of significant barriers to the uptake of the technology. The current lack of public charging infrastructure and the length of time required to charge EVs, as well as the potentially limiting range of the vehicles, are seen as major obstacles to their adoption. Early adopters indicated that these "range anxiety" issues are the most important consideration in deciding whether or not to purchase an EV. The initial upfront cost of the vehicle was also identified as important but less so than range and charging concerns.

The market research findings also identified important opportunities for the further promotion of EV uptake. For example, the majority of early adopters felt that access to faster home charging would be very important; they believe that it should take under four hours to fully charge an EV (similar to the length of time required to charge a cell phone or an iPod). The market research also showed the LDC to be the most trusted proponent and facilitator of EV adoption among the early adopter group. The LDC already has a clear stake in preparing for EV deployment because of the need to meet the demand for additional electricity. The findings of the market research indicate that there is also an opportunity for the LDC to play a vital role in the promotion and success of EV deployment.

Electricity Distribution System Assessment

The majority of scenarios investigated during the electricity distribution system assessment showed that, in general, the system would be able to support the anticipated EV-related load. However, the capacity of the grid to do so could be constrained under certain conditions. A number of factors are capable of significantly affecting the LDC's ability to accommodate additional loading as a result of EV charging, including the size of the on-board charger, the time of charging, the ambient temperature and the number of vehicles charging.

Key Variables Influencing How EV Charging Affects the Distribution System at the Neighbourhood Level

One of the key factors affecting the ability of the electricity distribution system at the neighbourhood level to accommodate EV-related loading is the capacity of the vehicle's on-board charger. The charging process for an EV involves components both on and off the vehicle. Electricity delivered through an external device such as a household outlet or an EV charging station is converted to battery power by a small charger on board the vehicle. The charging level determines the rate at which electrical energy is drawn when an EV battery is being charged. The majority of the first wave of mass-produced EVs on the market contain an on-board battery charger rated at 3.3 kW or 6.6 kW when charging at 240 V – similar to the power delivered through a clothes dryer receptacle. This is known as Level 2 charging. Most EVs can also be charged using a standard 120 V household outlet; this is known as Level 1 charging. If a vehicle is charging at Level 1, power flows through the on-board charger at a lower rate, between 1.4 kW and 1.9 kW – similar to a typical hair dryer. Newer EV models are expected to have significantly more powerful on-board chargers, rated at 10 kW, 16 kW or 20 kW depending on the vehicle.

Under most of the conditions investigated, all houses serviced by a single pole-top transformer could simultaneously charge an EV with an on-board charger rated at 3.3 kW or less with little effect on the electricity distribution system. However, some newer EVs contain a 6.6 kW charger or greater (10 kW, 16 kW or 20 kW). These chargers are capable of dramatically reducing the length of time required to charge the vehicle, but they also increase the demand for power from the electricity distribution system. If just two-thirds of the households serviced by the transformer charge a vehicle simultaneously with a 6.6 kW charger, the transformer could be overloaded, depending on the time of charge and the ambient temperature. As the size of the on-board charger increases, the number of vehicles that can be charged simultaneously decreases.

The results of the electricity distribution system assessment also showed that EV charging during periods of peak electricity demand would pose an increased risk of system overload and potential power outages, compared to charging during off-peak times. As the majority of early adopters fit a typical vehicle commuter pattern (i.e., leaving home between 7 a.m. and 9 a.m. and returning home between 5 p.m. and 7 p.m.), there is the potential for them to return home and begin charging their vehicles simultaneously during periods of peak demand.

Ambient temperature was a surprisingly significant factor affecting the grid's capacity to accommodate EV charging.

Ambient temperature was a surprisingly significant factor affecting the grid's capacity to accommodate EV charging. On the warmest day in summer or the coldest day in winter, the number of EVs able to charge simultaneously without putting stress on the grid was significantly lower than on a day with average temperatures. On days with extreme temperatures, as few as three vehicles with a 20 kW on-board charger could cause overloading of the transformer. The assessment also showed that in winter, in neighbourhoods with high concentrations of electrically heated households, the transformer could exceed its rated capacity with significantly fewer numbers of EVs charging simultaneously. Under certain conditions, just one EV charging could cause transformer overloads where less than one-third of the total number of houses serviced by the transformer use electric heating.

Additional Considerations

The potential for EV charging to reduce the lifetime of distribution equipment is an important consideration not investigated in depth in the electricity distribution system assessment. For example, if EVs are plugged in overnight, they will be drawing continuous power, even at Level 1, at a time when the transformer would typically be cooling down. Continuous operation, particularly at or near full load, could contribute to accelerated degradation of the transformer and secondary cables.

While there is overhead built into the system, it was not intended to be used to accommodate EV charging. For example, the standard operating procedure of some LDCs is not to predict when transformers are about to fail, but rather to "run to failure" and then replace them. If one transformer fails in an area serviced by a network system, an adjacent one takes over and keeps the power flowing to customers' homes in the interim. At this point, the backup transformer is potentially carrying twice its usual load and is drawing on the overhead built into the system to accommodate this. If even a few EVs are charging when this happens, it could eat into this overhead and cause the transformer to overload as a result.

THESL also undertook an examination of the distribution system in the City of Toronto to complement the EMAP research. The system-wide analysis indicated that distribution transformer stations in certain areas of the city may be operating at low capacity or may be more seriously constrained in their capacity to accommodate the future loads predicted as a result of EV uptake over the next ten years. An overwhelming majority of early adopter neighbourhoods in the City of Toronto happen to be located within areas where the distribution system is predicted to be constrained or where there is little capacity to accommodate additional EV-related loading, highlighting the need to prioritize infrastructure investments in specific geographic areas. For more detailed information related to the findings from the system-wide analysis conducted by THESL, refer to Appendix A.

We Need a Plan: A Coordinated EV Deployment Strategy for the City of Toronto

An EV deployment strategy executed with thought and foresight has the potential to advance EV use, broaden options for sustainable transportation systems and foster thinking about new business models capable of accelerating clean technology uptake. A flexible yet coordinated approach capable of adapting to the evolving needs of the consumer, the LDC, automakers and the market is essential to support and promote EV technology. EV technology will not succeed without a well-thought-out plan capable of addressing current real and perceived barriers to adoption and use while leveraging potential opportunities.

The EMAP findings presented in this report point to a need for a new approach and a transformation in perspective related to EVs. A three-point strategy capable of supporting EV deployment is recommended for the City of Toronto, based on the needs of the early adopter community and the potential challenges facing the electricity distribution system. The strategy consists of the following:

- Develop and implement an EV business model.
- Create a supporting policy framework.
- Engage early adopters *and* the general public.

Develop and Implement a New Business Model

As the findings from the EMAP study demonstrate, the value proposition for EVs differs significantly from the value proposition for their gasoline-powered counterparts. Both present a particular set of challenges and benefits for their users and, for this reason, the current business model used to support and market gasoline-powered vehicles may not be effective for communicating the value proposition of EVs to those outside a small niche market. There is, therefore, a need to develop and implement an innovative business model specific to EVs. What exactly this business model should be, however, requires ongoing dialogue and rethinking on the part of those with a direct stake in the success of EVs.

An EV business model must be capable of mitigating the principal barriers (both real and perceived) to EV use, including range issues. At the same time, it should look to leverage existing opportunities and benefits resulting from increased EV use. For example, early adopter interest in EV technology is clearly linked to environmental performance and the potential for reducing transportation-related emissions, more so than to the potential for fuel or maintenance savings. The social benefits of the technology constitute the value proposition, rather than any perceived personal or financial gains. The importance of this finding must not be underestimated in marketing the technology to both early adopters and the general public.

The EV business model also requires consideration of the role of the LDC. To date, the utility has usually been viewed as incidental in the deployment of EVs. However, the EMAP findings indicate that the LDC has the potential to play a more significant role. As previously noted, public utilities are best positioned to address many of the consumer concerns about EV technology. At the same time, LDCs will be profoundly affected by the uptake of EVs within their service area, requiring planning to manage the implications of EV charging. For these reasons, it is imperative that utilities be empowered to play a more central and proactive role in the future deployment of EVs.

It is clear from the EMAP findings that the successful uptake of EVs requires a business model capable of returning optimal value to all parties involved in their production, use, maintenance and retirement. The development of the elements of an appropriate business model for EVs, based on real and tangible findings, should be an immediate priority for all stakeholders.

Create a Supporting Policy Framework

The development of a new EV business model in turn requires the creation of a supporting policy framework. Governments across Canada have already begun to invest in the installation of public charging infrastructure and to initiate purchase incentive programs aimed at addressing key barriers to EV adoption, including the higher upfront vehicle costs. These initiatives are important components of an overall policy framework. However, the EMAP findings suggest that there are opportunities to expand on these strategies to further leverage the benefits associated with EVs, and it is clear that it will take a comprehensive set of policy tools and measures to incentivize manufacturers, utilities and municipalities to fully commercialize EVs. The right policy framework will not only support EV growth but can even encourage it. Sustaining the focus on policy development, particularly in the near term, will help mitigate substantial uncertainty concerning the evolution of the EV market.

Determining the right policy framework and initiatives to guide, motivate and incentivize the EV market requires continued exploration of that market and a commitment to remaining flexible as it evolves. A policy framework should balance stakeholder interests and, as previously noted, complement effective business models by working to address barriers to their success.

Engage Early Adopters and the General Public

With the number of electrified transportation options on the rise, many consumers are looking for better information about how these technologies work so that they can determine if an EV would be a good fit for them. As previously noted, the EMAP research indicates that uncertainty and gaps in knowledge related to EVs remain perhaps the most significant challenge to their commercialization. Effective awareness campaigns to reinforce and expand the information currently made available about EVs are prerequisites to establishing consumer confidence and promoting support for EVs. The provision of relevant, reliable and easily accessible information is crucial, particularly during the early adopter phase.

As noted previously, a key factor in ensuring the diffusion of an emerging technology is the transfer of knowledge and experience from its early adopter group to the broader market. As such, strategies for engaging the early adopter community and the general public should take into consideration the potential differences between the demographic and psychographic profile and needs of each group. For example, the EMAP findings indicate that the greater upfront capital required to purchase an EV may not be a major consideration for early adopters, but it could be the primary factor influencing the broader market's interest in the technology.

While the provision of clear and concise information aimed at early adopters and the general public is important in promoting their engagement, the flow of information in the opposite direction is also necessary. Only through an understanding of driver experiences and the needs of consumers and the market can stakeholders continue to address the ongoing or emerging barriers and opportunities related to EV adoption. It is here that the findings from the EMAP study can be of particular value, especially in the absence of a large body of substantive data related to actual user experiences.

Summary

The EMAP methodology and findings constitute an important input to a successful EV deployment strategy for the City of Toronto. The outputs of the research can be of use to a wide range of stakeholders concerned with managing and promoting the uptake of EVs. The primary value of this study, however, remains its methodology, which can be easily replicated by other municipalities or LDCs planning for the uptake of EVs.

Continued dialogue and collaboration among the LDC, the regulator, governments, automakers and others with a direct stake in the future of EV technology will be one of the most important factors contributing to the development and implementation of a successful EV deployment strategy for the City of Toronto. Greater clarity about the most appropriate path forward will clear the way for specific measures to mitigate barriers and leverage opportunities for EV deployment.

Section One of the EMAP report has summarized the research findings and discussed some of the implications of them. It has also identified the need for a three-point strategy that will address the uptake of EVs in the City of Toronto through the development of an EV business model, the creation of a supporting policy framework, and the ongoing engagement of both early adopters and the general public. Section Two of the report provides a more detailed description of the market research, including process, methodology and key findings.

SECTION TWO:
Market Research

Purpose of Surveying the City of Toronto

Understanding the perceptions of the early adopter community within the City of Toronto will make it possible to develop effective and targeted information and awareness campaigns as well as to provide a framework to facilitate local policy implementation. This can be accomplished by undertaking market research to better understand the needs and views of potential early adopters, which will in turn ensure a solid foundation for the successful growth of the EV industry. Market research can generate critical information on the early adopter population, using demographic and psychographic analyses to understand the barriers that must be addressed to encourage the uptake of EV technology.

It is important to understand how EVs will be used in order to ensure that their deployment in communities is a successful experience for owners and operators, and that the potential environmental gains are realized. This means that potential negative experiences must be identified and mitigated so that users will accept and value the technology. To accomplish this, it is important to identify where the first successful deployments of EVs could occur.

Methodology

The market research process involved two separate but related sets of investigations:

- secondary research to identify the geographic distribution of potential early adopters of EV technology
- primary research to characterize early adopters and identify potential opportunities and barriers to EV adoption

The specific process, outputs and assumptions made in the development and application of the research are described below.

Secondary Research to Identify the Geographic Distribution of Potential Early Adopters

The secondary research sought to identify the behavioural and attitudinal characteristics of likely early adopters of EV technology and to map the neighbourhoods in which they may tend to cluster. This research was the basis for the primary research that followed, allowing for a more efficient and targeted household survey of the characteristics and preferences of likely early adopters of EV technology.

The secondary research was undertaken in collaboration with Environics Analytics, using its proprietary PRIZM$_{c2}$ segmentation system database. The PRIZM$_{c2}$ system has the capacity to classify every neighbourhood and postal code throughout Canada into one of 66 segments based on the most important drivers of consumer behaviour, including demographics, lifestyles and social values. It assumes that neighbourhoods that are classified similarly have comparable demographic, behavioural and attitudinal characteristics regardless of where they are located. As such, the PRIZM$_{c2}$ segments are an effective means of estimating behaviours and attitudes at a very local level, based on data collected at a very high level.

For the purpose of creating a profile of a potential early adopter of EV technology, data from a number of different surveys as well as national and regional vehicle purchase information were linked to the PRIZM$_{c2}$ segments. These databases included the Environics Analytics Demographic Estimates and Projections (DEP) database, the Environics Research Social Values nationwide survey and R.L. Polk Canada's New Vehicle Registrations (NVR) and Total Vehicles in Operation (TVIO) databases.

Because EVs currently play a limited role in the marketplace, there is little EV purchase data in existing surveys and databases. Therefore, the following key variables were selected as indicators of the propensity to purchase an EV:

- demographic characteristics
- social values
- vehicle purchase data

These variables were developed using analogous products and services, appropriate demographics, relevant social values and a degree of expert judgment. The key variables are described in further detail below.

KEY VARIABLES USED AS INDICATORS OF THE PROPENSITY TO PURCHASE AN ELECTRIC VEHICLE

Demographic Characteristics

Potential early adopters were assumed to be those who met a set of demographic criteria based on an understanding of the current characteristics of the EV market and technology. These demographic criteria are as follows:

- **Average household size of not less than two people:** Because of the potentially limiting vehicle range, it was assumed that early adopters of EV technology would likely use the vehicle as a secondary, rather than the sole, household vehicle. While EVs would easily suit urban transportation needs, longer trips may require a second, conventional gasoline-powered vehicle. If the EV were to be used as a secondary vehicle, it was assumed that the current purchase price of an EV would be prohibitive for such purposes for a single household resident.
- **Average household size of two or three people:** Early EV models tend to be small and, therefore, more suitable for small households than for large families.
- **Average household income of $120,000 or greater:** Based on the high purchase price of EVs at the time the research was done, it was assumed that the household income of early adopters would be high compared to the general population of Toronto.

Social Values

Potential early adopters of EV technology were assumed to be those who exhibit one or more of the following three attitudes:

- **Ecological lifestyle:** This indicator characterizes those individuals who value the integration of environmental concerns with purchasing decisions. Because of the potential environmental benefits and emission reductions promised by EV technology, early adopters were assumed to be environmentally conscious.
- **Enthusiasm for technology:** This indicator reflects a favourable bias towards technology. People with an enthusiasm for technology tend to believe that it is the best tool for adapting and responding to the demands of daily life. Because EVs are not yet part of the mainstream marketplace, early adopters of EVs were assumed to have an enthusiasm for technology.
- **Consumptivity:** This indicator represents an enthusiasm for purchasing products or services in an area of particular interest (e.g., music, electronics) about which consumers make an effort to stay informed. Because information about EVs is not yet widely available in the mainstream media, it was assumed that early adopters of the technology would need to be particularly enthusiastic or have made an effort to become informed about the topic.

Vehicle Purchase Data

For the purposes of the market research, potential early adopters of EV technology were assumed to share psychographic and demographic characteristics with early adopters of hybrid vehicle technology. Hybrid vehicle purchases between 2001 and 2006 were used to help estimate potential EV demand.

Environics PRIZM$_{c2}$ Profiles

The variables identified as indicators of the propensity to purchase an EV were used to create profiles that were compared with the PRIZM$_{c2}$ system to identify a set of seven target segments and the neighbourhoods in which they are located. These initial target segments were then compared to a 2011 Nissan LEAF reservations dataset to further validate and refine the selection. Based on the postal code data for those on the waiting list for the Nissan LEAF in the City of Toronto, additional geographic locations were identified as potential early adopter neighbourhoods. As a result of this process, two segments whose demographic and psychographic characteristics were initially below the selection criteria threshold were added to the list.

SECONDARY RESEARCH RESULTS

This section documents the findings from the secondary research, including a description of the early adopter target segments and the further refinement of this group based on geographic location.

Target Segments

A total of nine psychographic segments of the Toronto population were identified based on the selected demographics, social values and hybrid vehicle purchasing data, as well as indications of interest in purchasing the Nissan LEAF. These segments include the types of individuals and households considered the most likely to be early adopters of EV technology in the City of Toronto, based on available secondary data.

To ensure a more manageable and targeted primary research household survey, six of the original nine segments were selected based on their more concentrated locations and the strength of their alignment with the characteristics of potential early adopters. The following are the six segments selected:

Cosmopolitan Elite: This group represents Canada's wealthiest people, including new-money entrepreneurs and heirs to old-money fortunes. The Cosmopolitan Elite are urban, middle-aged families and older couples. With household incomes five times the national average, this segment remains concentrated in only a handful of established neighbourhoods throughout the country.

Urbane Villagers: Located in Canada's largest urban centres, this segment is a prosperous world of stately homes and high-end cars, charity auctions and golf club memberships. The nation's second wealthiest segment, it is characterized by married couples with university degrees and university-aged children, and includes a significant percentage of European, Asian and Middle Eastern immigrants.

Young Digerati: This segment consists of the nation's tech-savvy singles and couples living in fashionable neighbourhoods in a handful of big cities. Affluent, highly educated and ethnically mixed, Young Digerati communities are typically filled with high-rise apartments and expensive condos located near fitness clubs, clothing boutiques and bars. Because many residents in this segment have yet to start families, they have the time and discretionary income to pursue active social lives.

Asian Affluence: This segment is made up of educated, middle-aged families, 37 per cent of whom speak Chinese as their first language. Most of the people in this group came to Canada in the 1980s and 1990s, settling in a small number of prosperous neighbourhoods in Toronto and Vancouver. Characterized by large families, this group is made up of households with a number of teenage and twenty-something children. Asian Affluence residents enjoy sophisticated lifestyles thanks to their healthy incomes.

Money & Brains: The residents in this segment have high incomes, advanced degrees and sophisticated tastes. Many of them are empty nesters or married couples with university-aged children, who live in older, fashionable homes in both urban and suburban neighbourhoods.

Continental Culture: This segment presents a portrait of old-fashioned diversity with its many first- and second-generation European immigrants, especially those from Italy, Portugal, Greece and Poland. Centred in Toronto, Continental Culture households contain a mix of married and common-law couples and, increasingly, young families. Living in older, urban neighbourhoods in detached or semi-detached houses or low-rise apartments, these relatively young residents tend to have university degrees, white-collar jobs and upscale lifestyles.

Geographic Segmentation

A map was created, indicating the geographic distribution of each of the six target segments within the City of Toronto, based on postal code. Each area identified on the neighbourhood map represents a postal code area of potential early adopters, providing a visual representation of where they may be clustered throughout the city.

To further refine the target group for the purposes of the primary research household survey, five geographic areas were chosen as a point of focus. These areas included the most concentrated selection of all six target segments and were evenly distributed across the City of Toronto to ensure a broad representation of the potential early adopter population.

The selected geographic areas are broadly characterized as follows:

1. Central Toronto
2. Bloor West
3. North York/North East
4. Scarborough Shore
5. Queen East

These areas became the focus of the primary research described below.

Figure 1: Distribution of Target Segments and Neighbourhoods in the City of Toronto

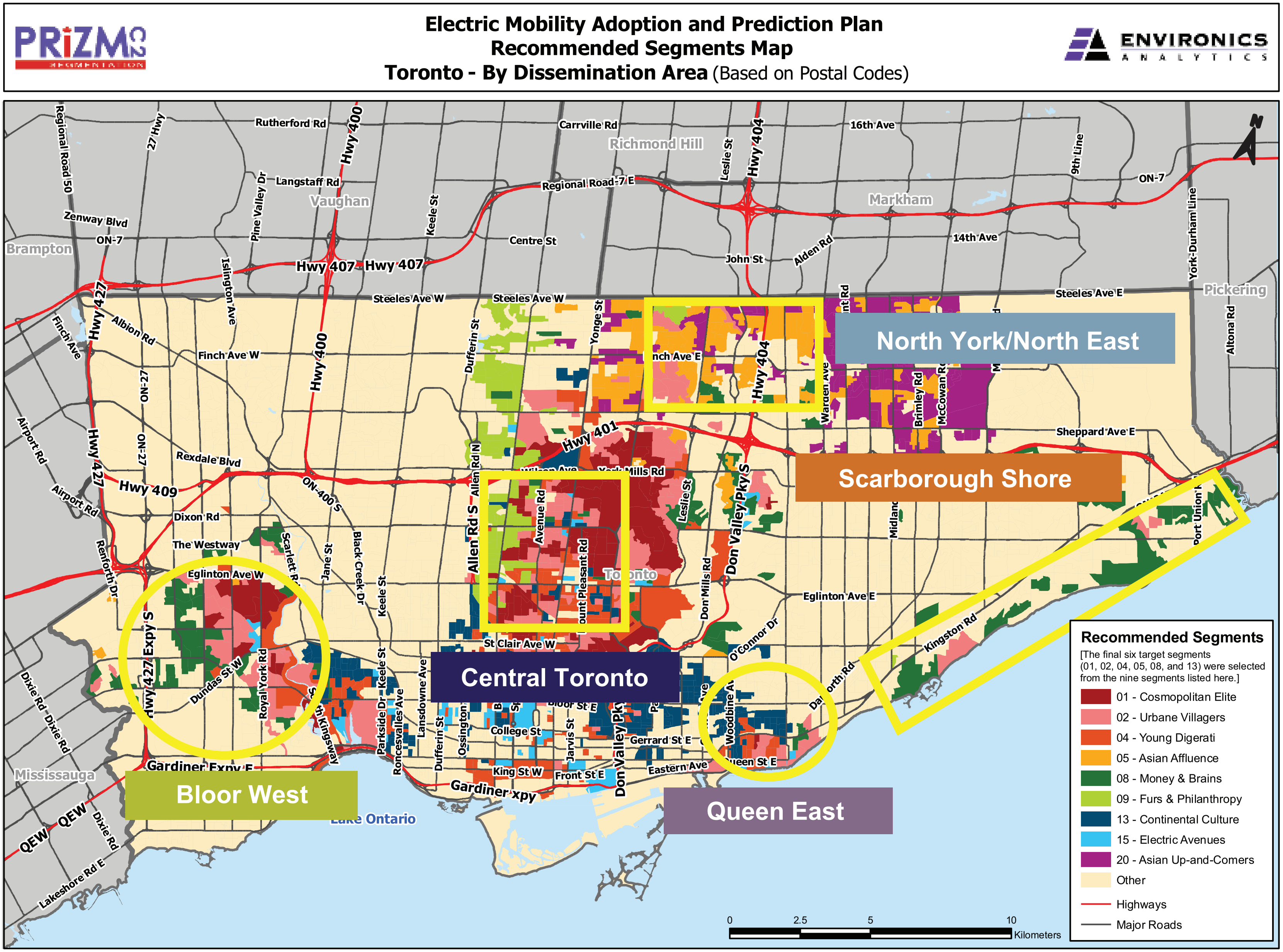


Figure 2: Target Segments Located in Each of the Five Target Areas

Central Toronto	Queen East	Scarborough Shore	Bloor West	North York/North East
Cosmopolitan Elite	Cosmopolitan Elite	Urbane Villagers	Cosmopolitan Elite	Urbane Villagers
Urbane Villagers	Urbane Villagers	Money & Brains	Urbane Villagers	Young Digerati
Young Digerati	Young Digerati		Young Digerati	Asian Affluence
Money & Brains	Money & Brains		Asian Affluence	Money & Brains
Continental Culture	Continental Culture		Money & Brains	
			Continental Culture	

Primary Research to Validate and Characterize Early Adopter Neighbourhoods

In addition to estimating the demand for EVs in the Toronto area using PRIZM$_{c2}$-based tools, the analysis and results of the secondary research informed the design of a questionnaire for use in a household telephone survey conducted by Environics Research Group in the neighbourhoods identified as offering the highest potential for the adoption of EV technology. A total of 751 Toronto residents participated in the survey, which took place between November 16, 2011, and December 11, 2011, and averaged approximately 15 minutes in length. The use of a telephone survey rather than an online survey allowed for a targeted focus on residents in the identified geographic areas, which would have been difficult to screen for online. In addition, the telephone survey allowed for a greater opportunity to test scenarios with survey respondents to build an understanding of how best to position EVs in a deployment strategy.

Respondents were screened to ensure that they were licensed drivers, aged 18 or over, and involved in household vehicle purchase decisions. They also had to have bought or leased a 2009 or newer vehicle within the past two years or be intending to buy or lease a late-model vehicle in the following two years. Respondents who met these criteria were deemed to have an understanding of or experience with the factors contributing to purchasing decisions for a new vehicle.

The household survey was designed to gain insight into motivations for and interest in EV use, the personal mobility patterns of the respondent, the expectations of EV technology, and the barriers to address and opportunities to leverage in relation to EV use. The survey was divided into the following four sections:

- vehicle ownership and use
- awareness and perceptions of electric vehicles
- charging capabilities
- market segmentation and respondent profile

KEY FINDINGS FROM THE PRIMARY RESEARCH

This section presents key findings and insights from the household telephone survey. It begins with a profile of the potential early adopter population and is followed by a discussion of awareness and perceptions of EV technology and expectations for at-home charging.

Profile of the Potential Early Adopter

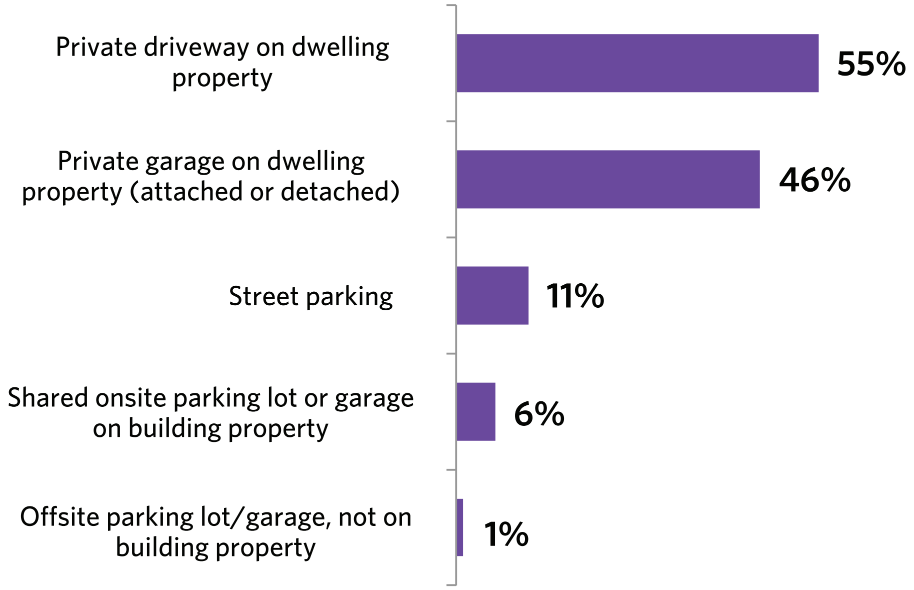
Demographic Profile

Potential early adopters are older, better educated and more affluent than the general population. The majority live in detached, single-family homes with a driveway or a garage or both.

Potential early adopters are considerably more likely to be over the age of 45 than the general adult population in Toronto. They are also better educated, with three-quarters of those surveyed holding a university degree (bachelor or post-secondary), compared to only 34 per cent of the general population. Potential early adopters were also almost eight times as likely as the average city resident to have a household income of $150,000 or more.

A strong majority of early adopters live in detached, single-family homes with on-property parking and with easy access to an electrical outlet for charging purposes. Over half have use of a driveway and close to half report that they have a garage. Those who have street or offsite parking report a short or no walk to get to their dwelling, with few needing more than three minutes to get home from where they typically park their vehicle.

Figure 3: Type of Parking



Note: adds up to more than 100% due to multiple mentions and vehicles

Vehicle Purchasing Preferences

Potential early adopters are almost as likely to purchase a compact or subcompact vehicle as a compact SUV.

Approximately one-third of potential early adopters who had recently purchased or leased a vehicle chose a subcompact or compact vehicle. Smaller car purchases are associated with higher proportions of respondents who live in smaller dwellings (i.e., apartments or condos versus single-family homes), with the proportion who bought a small car decreasing as household income increases. The purchase of a compact SUV was reported by 18 per cent and is higher among those living in semi-detached homes and in one-vehicle households. The top vehicle makes purchased were Toyota, Honda and Ford.

The majority of prospective new vehicle purchasers state that they have a specific vehicle type in mind for their next purchase. Approximately 23 per cent of prospective new vehicle purchasers reported that they would consider a subcompact or compact vehicle, with an equal number preferring a mid-sized vehicle. Prospective buyers are also somewhat more likely than recent purchasers to mention interest in larger vehicles.

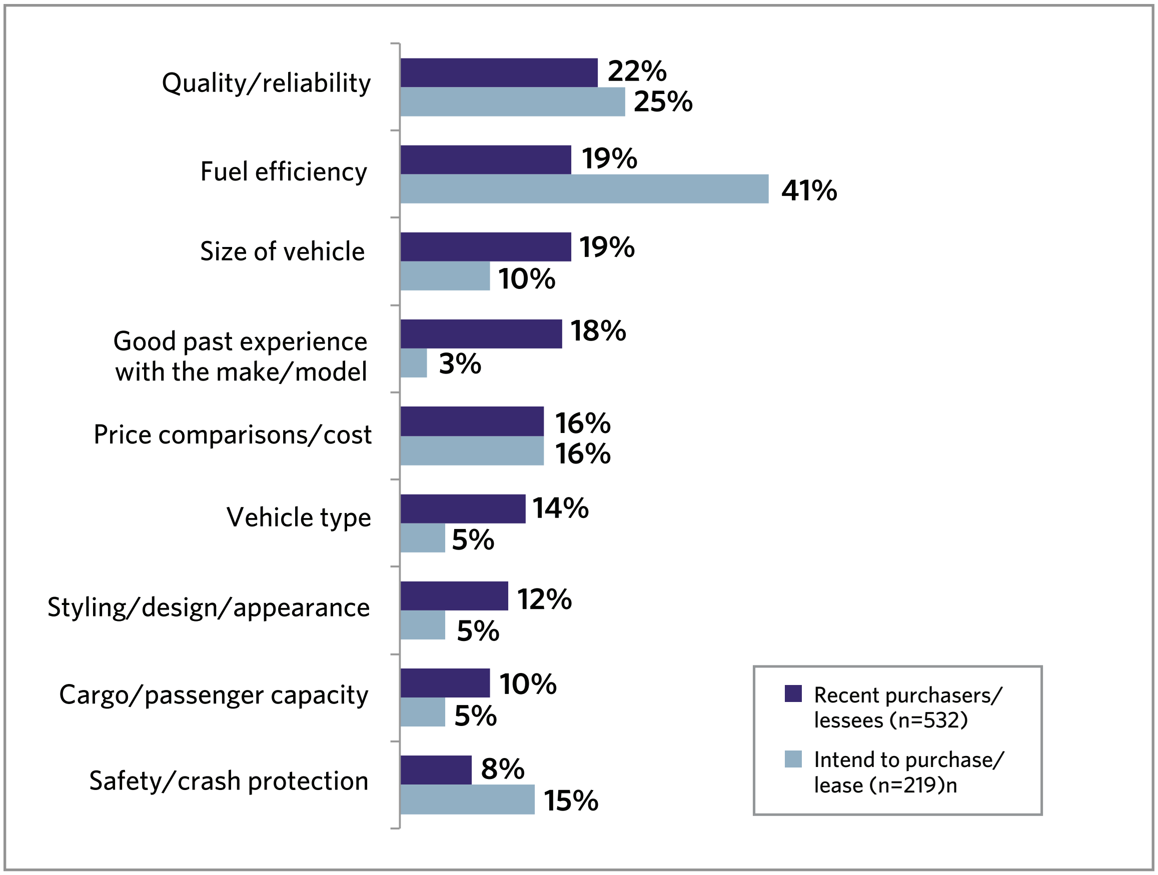
Experience with a hybrid vehicle is linked to greater interest in owning an EV.

Six per cent of recent vehicle purchasers indicated that their household owns a hybrid, while 40 per cent of intending purchasers would be open to considering either a hybrid or an EV in the next couple of years. However, less than half of prospective purchasers could name a specific EV, indicating that this consideration may be more theoretical than actual. Of those who could name a specific model, it was almost always a hybrid, with the Toyota Prius and the Chevrolet Volt the most commonly mentioned models. Potential early adopters who have personally owned or driven a hybrid were also twice as likely as those who have not to say that they would definitely consider owning an EV in the next couple of years.

Reliability and fuel efficiency are the main considerations for potential early adopters when they are purchasing a vehicle.

Reliability and fuel efficiency were the top responses for both recent and prospective buyers when asked why they chose their current vehicle or would choose their next vehicle. Prospective buyers were twice as likely (41 per cent) as recent purchasers (19 per cent) to cite fuel efficiency as the main consideration. Size and type of vehicle (which are related to fuel efficiency) are considerations for recent purchasers but were mentioned less frequently by prospective buyers.

Figure 4: Top Reasons for Vehicle Choice

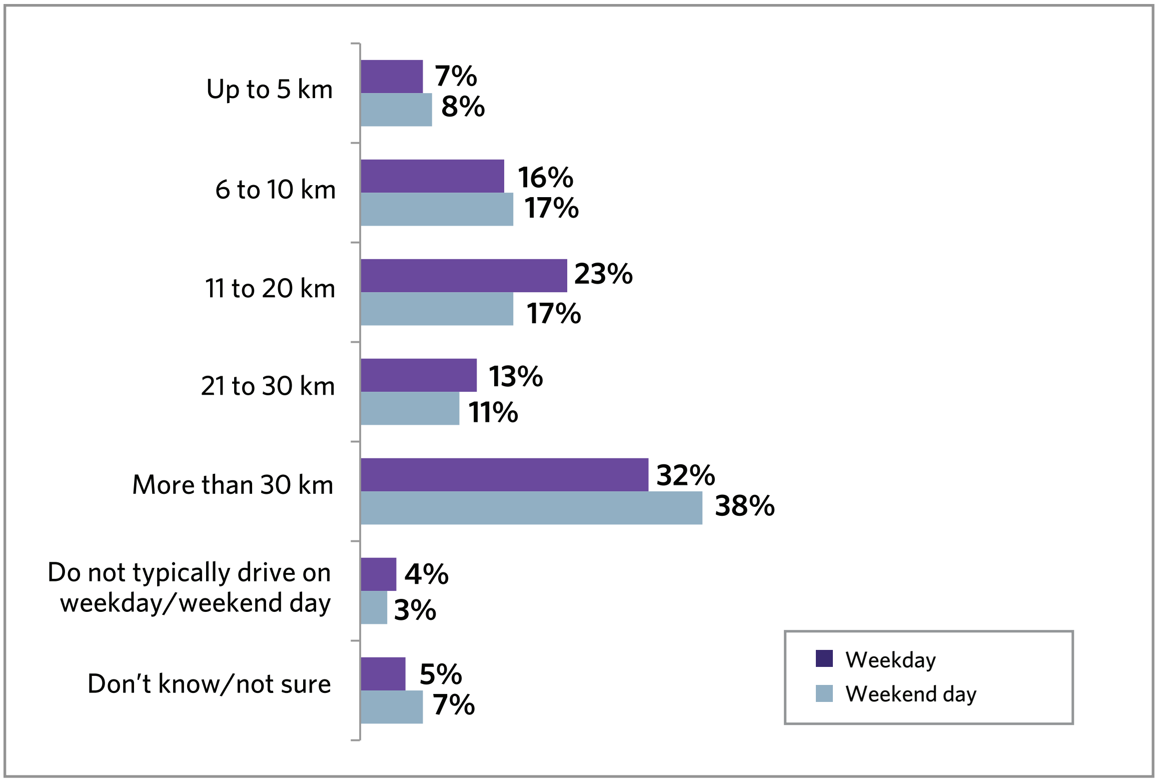


Personal Mobility Patterns

Close to half of all potential early adopters use their vehicles every day.
Approximately 48 per cent of potential early adopters indicated that they use their vehicles seven days a week. While four in ten make some use of the public transit system, only one in ten uses transit five days a week, consistent with a typical transit commuter pattern. Driving every day increases proportionally with an increase in household income, in the number of vehicles per household and in the distance driven on a typical weekday. The number saying that they drive seven days a week also increased as interest in owning an EV declined and was highest among those who said that they would definitely not consider an EV in the next couple of years

Approximately one-third of potential early adopters travel more than 30 kilometres on a typical weekday, while 38 per cent drive the same distance on a typical weekend day. Driving longer distances on the weekends was highest among those who would definitely not consider purchasing an EV.

Figure 5: Kilometres/Day Typically Driven

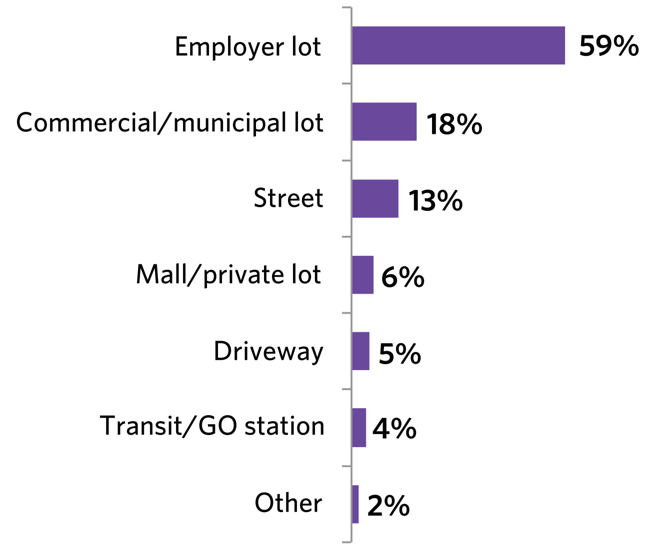


Approximately half of potential early adopters are considered vehicle commuters.
Approximately half of potential early adopters said that there is a specific location which they typically drive to at least two days per week and where they leave their vehicle for three or more hours (the selected proxy for vehicle commuting).

The majority of vehicle commuters leave home between 7 a.m. and 9 a.m. and return home between 5 p.m. and 7 p.m.
Most vehicle commuters described a typical workday as one on which they leave home between 7 a.m. and 9 a.m. (57 per cent) and return home between 5 p.m. and 7 p.m. (49 per cent). Vehicle commuters were also asked to indicate how many hours they park at the location where they typically leave their vehicle. Approximately 29 per cent spend at least nine or more hours, while 41 per cent spend seven or fewer hours. The most common response was eight hours parked away from home (26 per cent).

The majority of vehicle commuters park in an employer-provided lot somewhere in the Greater Toronto Area (GTA).
When asked to indicate which of several options described their typical parking arrangements at the location where they park at least two days per week, the majority of vehicle commuters indicated that they park in an employer-provided lot.

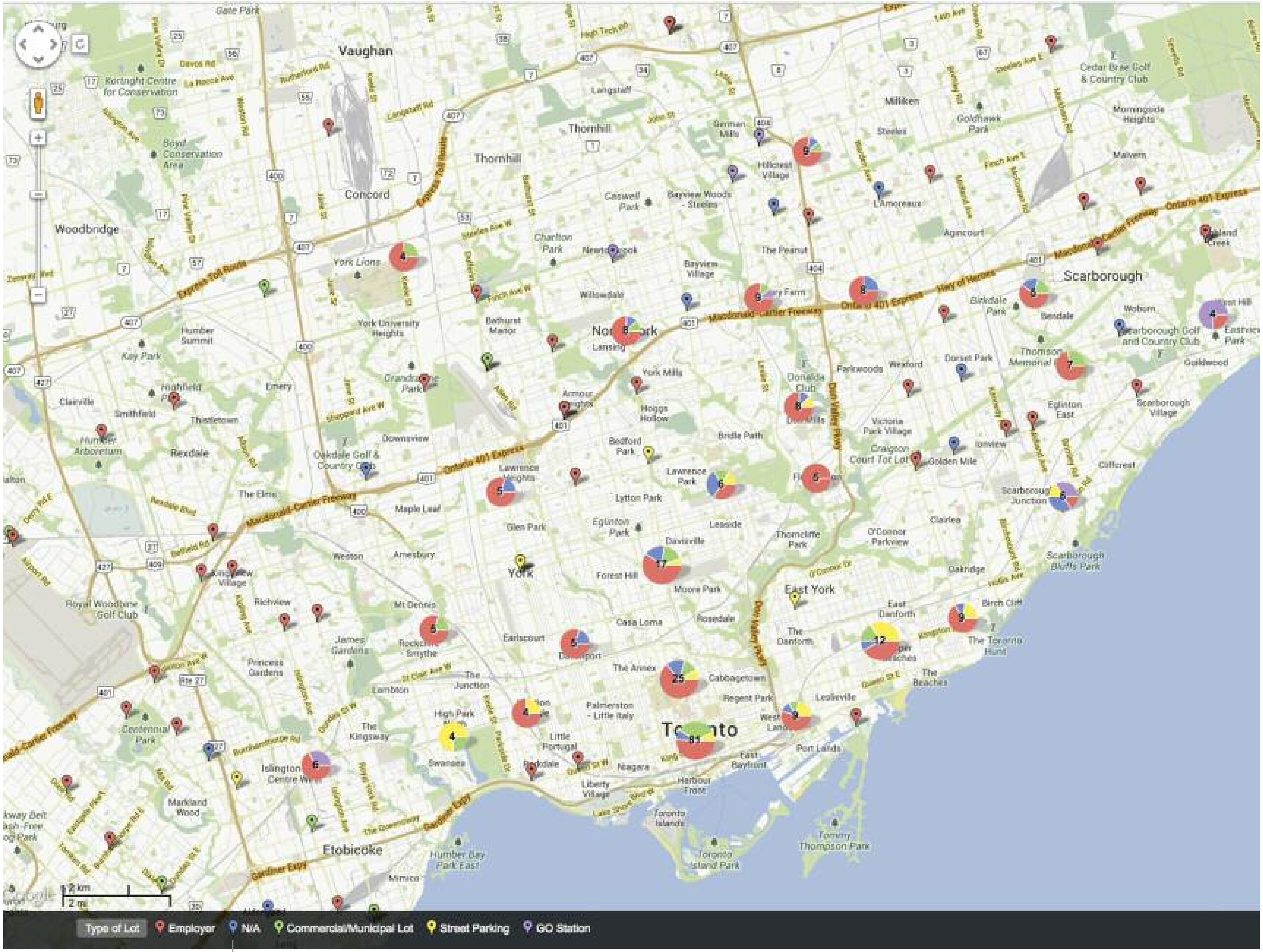
Figure 6: Type of Parking at Specific Location



Subsample: Those who leave their vehicle at a specific location at least two days per week for at least three hours (N=392)

When asked to indicate the nearest major intersection to the location where they typically leave their vehicle, the majority of vehicle commuters reported that they remain in the downtown core or within the GTA. See Figure 7.

Figure 7: Early Adopter Parking Locations in the Downtown Core by Lot Type



The numbers in the circles indicate the number of respondents.

Respondents who identified a location but not the type of parking lot

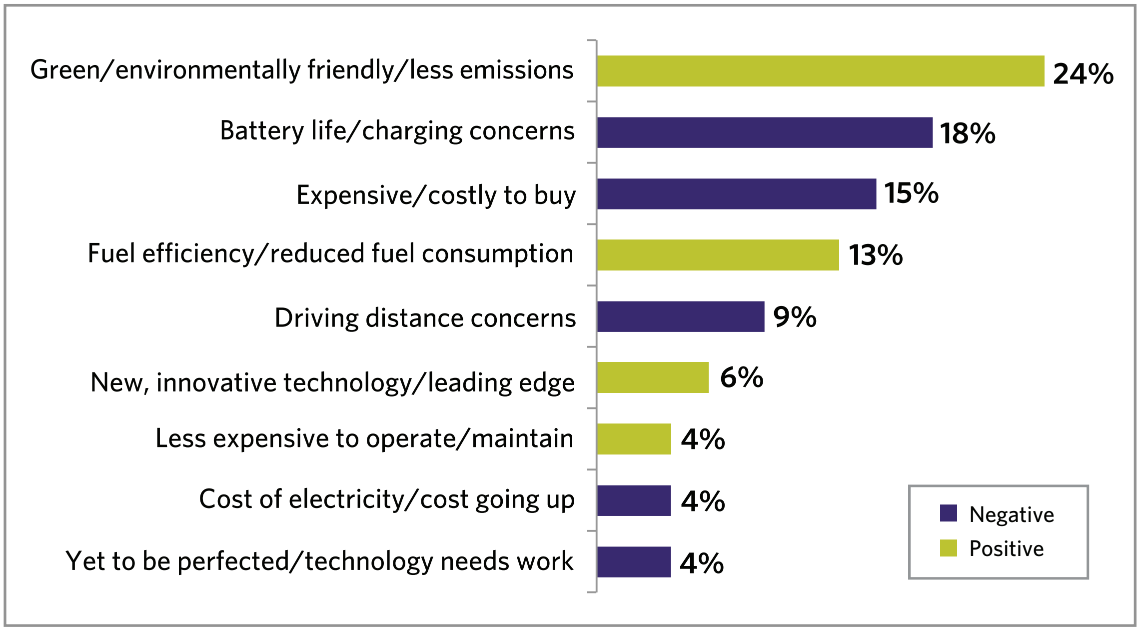
Awareness and Perceptions of Electric Vehicles

Familiarity with Electric Vehicles

Potential early adopter impressions of EVs reflect both barriers and opportunities.

When asked to provide their top-of-mind impressions of EVs, potential early adopters gave a range of responses covering both the advantages and the disadvantages. One-quarter mentioned the green or environmentally friendly potential, but a similar proportion expressed range anxiety related to battery life or the potentially limiting range of the vehicle. These range anxiety concerns were mentioned more by those who said that they would likely not or definitely not consider an EV.

Figure 8: Most Mentioned Top-of-Mind Impressions of EVs



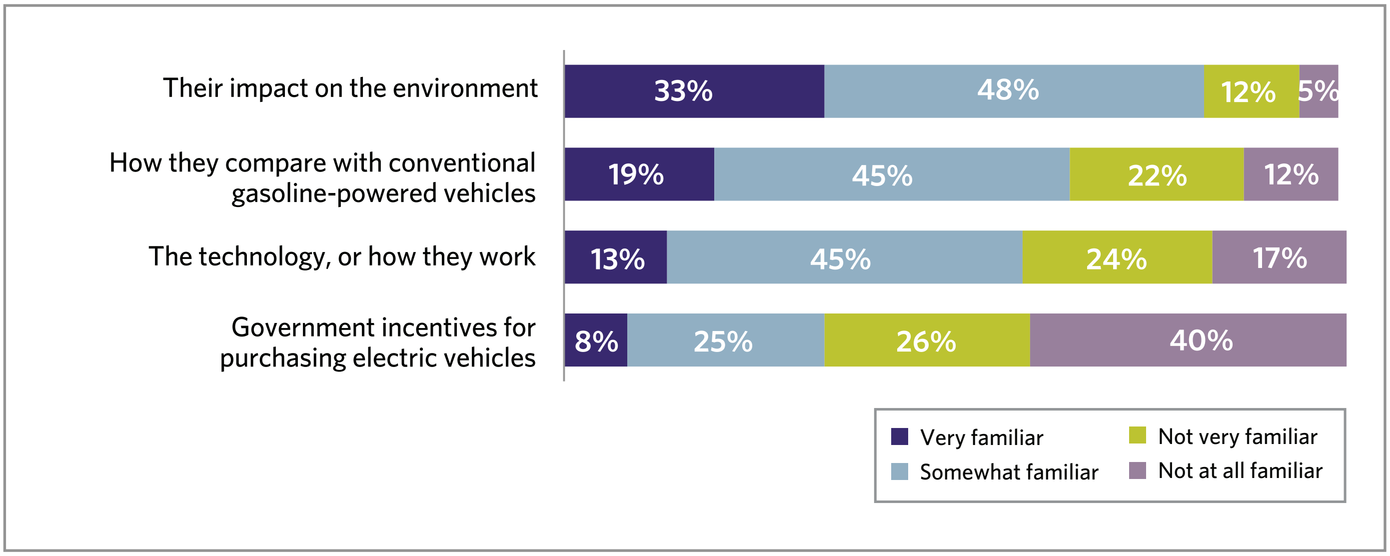
The majority of potential early adopters are most familiar with the environmental impact of EVs.

All respondents were asked to indicate their level of familiarity with four specific aspects of EVs:

- their impact on the environment
- how they compare with conventional gasoline-powered vehicles
- the technology, or how they work
- government incentives for purchasing electric vehicles

A majority of eight in ten said that they are at least somewhat familiar with the environmental impact of EVs. Approximately two-thirds expressed the same level of familiarity with how EVs compare with conventional vehicles and with the technology, or how they work. Awareness of current government incentives was relatively low across the group but was higher among those who said that they would definitely not consider an EV.

Figure 9: Familiarity with Specific Aspects of EVs



Likelihood of Considering an EV

Less than half of potential early adopters would consider purchasing an EV in the next couple of years.

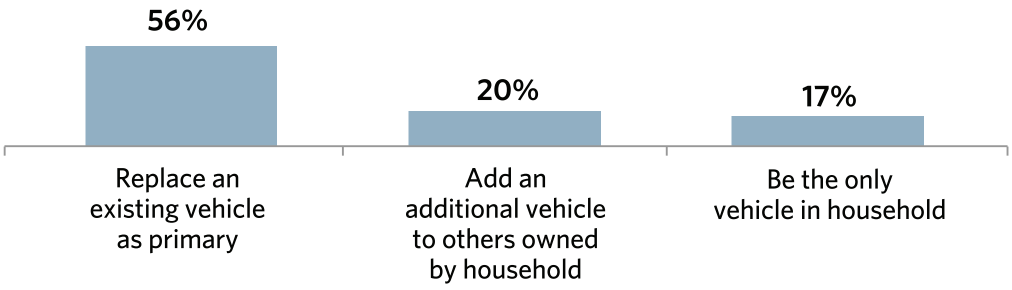
Only 42 per cent of potential early adopters said that they would likely (30 per cent) or definitely (12 per cent) consider an EV if they were purchasing or leasing a vehicle in the next two years. A majority of 55 per cent felt that they would likely not or definitely not consider an EV within the next two years. The major barriers to considering an EV included a lack of charging infrastructure, the length of time required to charge the vehicle, and range limitations.

Those who indicated a familiarity with EVs are somewhat more likely than those who did not to give a definite response, either that they would definitely consider or definitely not consider a purchase in the next two years. However, the end result is the same, with a slim majority having said that they would not consider an EV in that time frame. When the age of the respondents was factored in, it also emerged as an important factor in the potential purchase of an EV, with the likelihood of considering an EV decreasing as age increases. The survey findings also validated the selection of the potential early adopter neighbourhoods, with PRIZM$_{c2}$ segment and geographic location linked to consideration of an EV purchase.

Those early adopters who might consider an EV would use it as a primary vehicle.

The majority of those who would consider an EV indicated that they would use it to replace an existing primary vehicle. The remainder are closely split as to whether it would be an additional, secondary vehicle or the sole household vehicle.

Figure 10: Potential Use of Electric Vehicle in the Household



Subsample: Would definitely/likely/likely not consider an electric vehicle (N=578)

Perceived Barriers and Opportunities

Potential environmental benefits are the most mentioned advantage of EVs. Battery life and charging concerns are the most mentioned barriers.

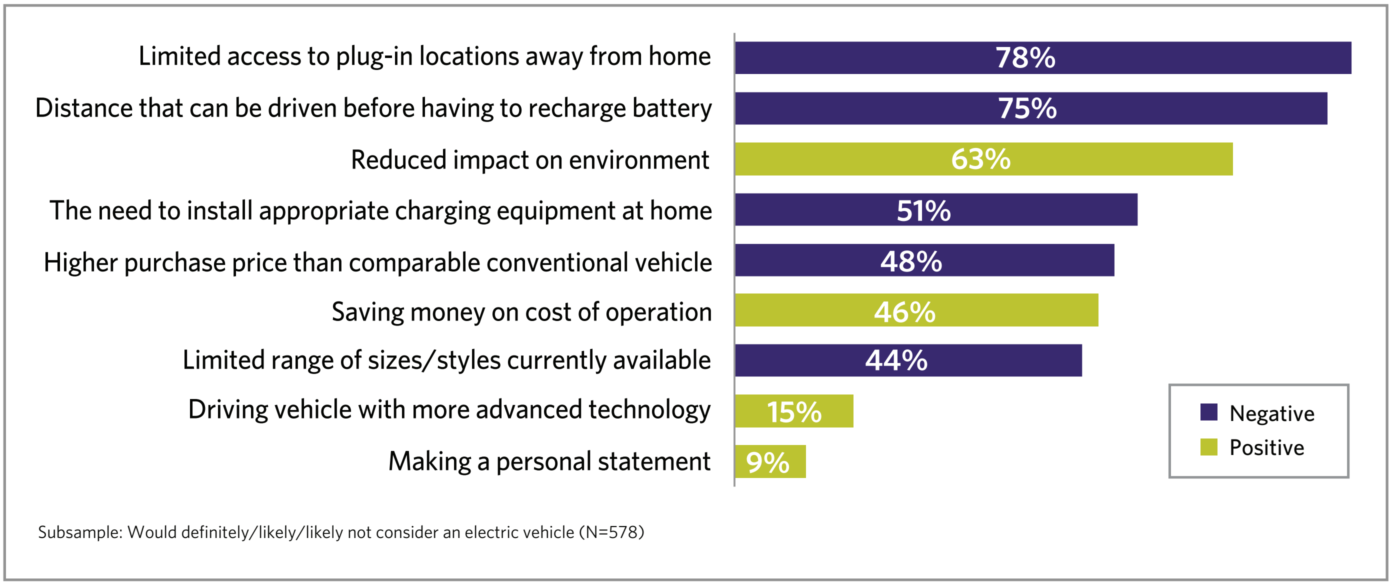
Approximately 60 per cent of those who would likely or definitely consider purchasing an EV mention that the main advantages of the vehicle are the potential environmental benefits and the opportunity to reduce vehicle emissions. Only 21 per cent mention fuel efficiency and 23 per cent the cost savings. A small number report an interest in EVs as an emerging technology and the suitability of the vehicle for city driving.

Close to half of those who indicated that they would definitely not or likely not consider an EV felt that the most important reason for not doing so was battery life or charging concerns. A further 29 per cent felt that the technology was not yet ready, and 17 per cent noted the high purchase price of the vehicle as a barrier. A small number mentioned the potentially limiting vehicle range and the cost of electricity.

Charging concerns are the most important consideration in deciding whether to purchase an EV.

Those potential early adopters who would at least marginally consider purchasing an EV were asked to rank several positive and negative aspects of the vehicles in terms of their importance in the consideration of a future purchase or lease. The aspects rated as the most important once again reflect concerns related to range anxiety, including the currently limited access to public charging stations and the distance that can be driven before the vehicle needs to be charged. The potential for reduced impact on the environment as a result of driving an EV, and cost or status aspects (both negative and positive), are of less importance than these other concerns. It should be noted, however, that the purchase price may end up being a deciding factor when an actual retail scenario is being considered.

Figure 11: Electric Vehicle Aspects Considered *Very Important* in Purchase Decision



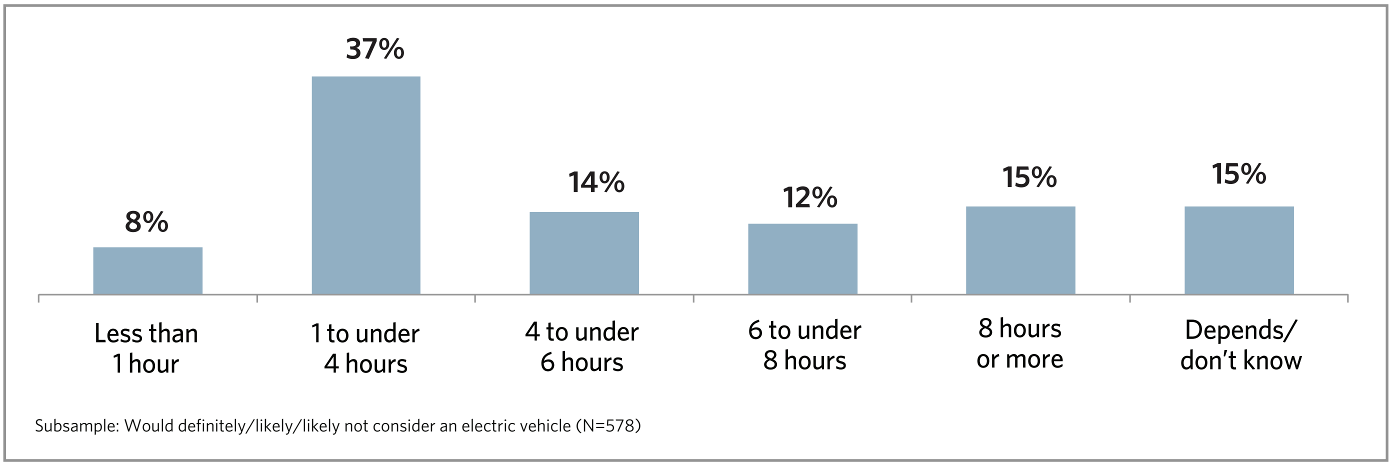
Subsample: Would definitely/likely/likely not consider an electric vehicle (N=578)

Charging Expectations

The majority of those who would consider purchasing an EV think that it should take less than four hours to fully charge.

A range of opinions were expressed when those who are at least marginally likely to consider an EV purchase or lease in the next couple of years were asked what they felt would be an acceptable length of time to fully charge the vehicle. Close to half think that it should take under four hours to charge, with the most common response being between one and four hours.

Figure 12: Acceptable Length of Time to Fully Charge an Electric Vehicle



Subsample: Would definitely/likely/likely not consider an electric vehicle (N=578)

Access to faster home charging is considered very important.

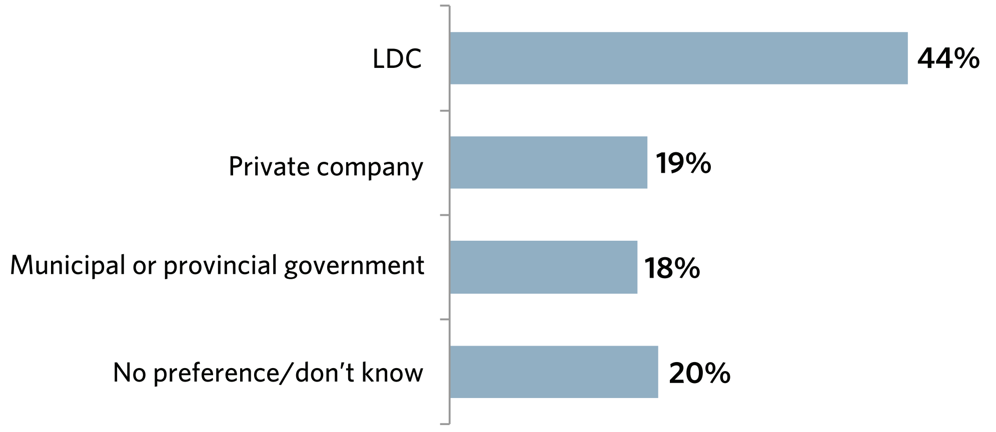
Potential early adopters understand that electric vehicles need time to charge, unlike a gasoline-powered vehicle with a gas tank that can be filled quickly. However, close to half think that it should take less than four hours (similar to the length of time it takes to charge an iPod) to fully charge the vehicle. When told that charging the vehicle could take 12 hours or more using a standard household outlet, an overwhelming majority said it would be very (74 per cent) or somewhat (18 per cent) important to be able to charge faster – for example, with a more powerful Level 2 charger installed at home. This is consistent with close to half the respondents thinking that an acceptable length of time to fully charge an EV would be less than four hours.

Those who said that faster charging would be very important increases proportionally with an increase in the distance driven each weekday and is higher among vehicle commuters. Saying faster charging would be very important also increases as level of consideration for buying an EV decreases and is highest among those who would likely *not* consider this type of vehicle. This is consistent with the charging concerns noted as one of the main barriers to the purchase of an EV.

Most potential early adopters would prefer their LDC to install and maintain a home charging station.

Those who said that it would be at least somewhat important to charge an EV faster were asked which of three potential service providers they would prefer to have install and maintain a Level 2 charging station at their home. Approximately 44 per cent said that they would prefer this to be done by their LDC, while 19 per cent would prefer a private company and 18 per cent would prefer the government to act as the primary service provider.

Figure 13: Preferred Service Provider for Installing and Maintaining an At-Home Charging Station

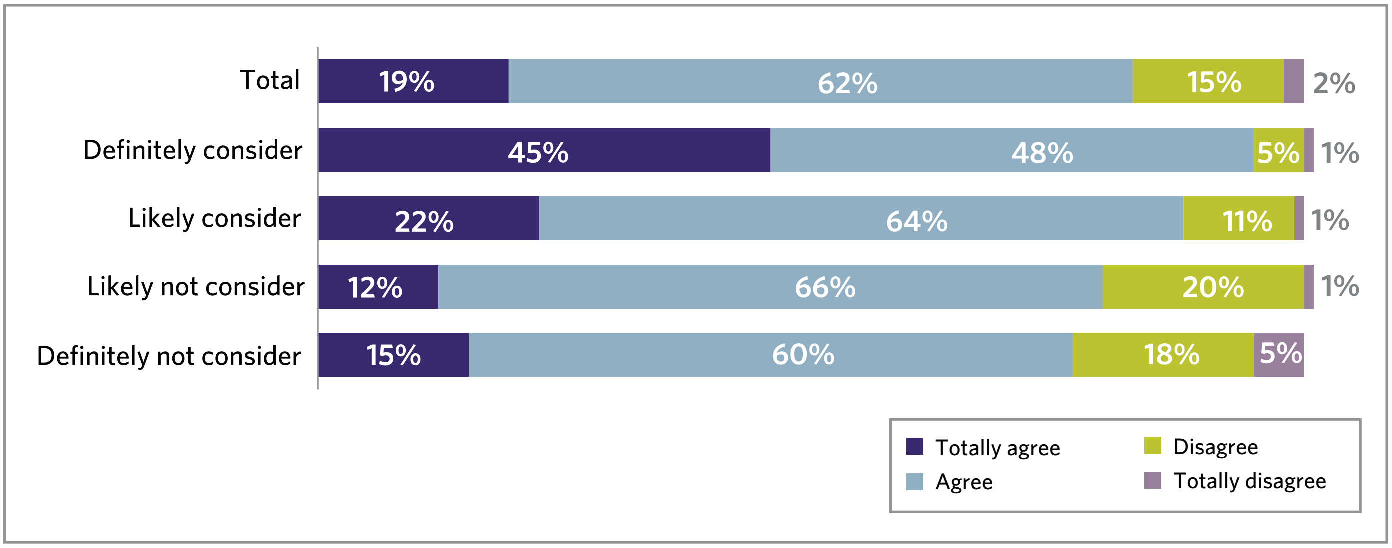


Subsample: Important to charge electric vehicle faster (N=542)

Validation of Preliminary Assumptions

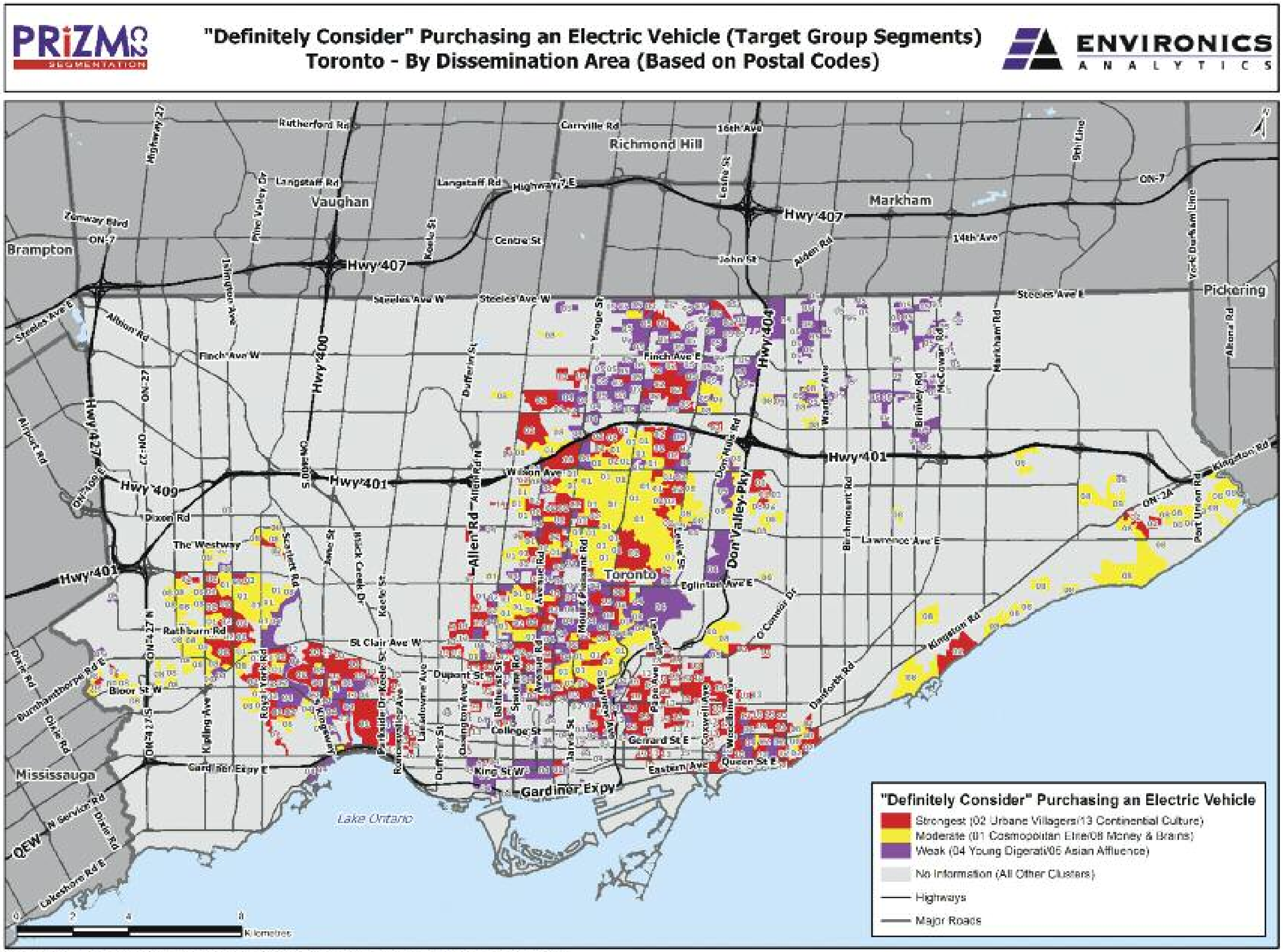
Potential early adopters who said that they would definitely consider an EV expressed greater agreement with statements about ecological consciousness, interest in technology and consumptivity than those less likely to consider an EV. This helps to validate the initial assumptions and criteria for early adopters in the secondary research. In particular, potential early adopters felt strongly about their interest in technology.

Figure 14: Responses to the Statement "I am excited about the possibilities presented by new technologies" by Likelihood of Considering an EV in the Next Two Years



Based on answers to the question about whether a potential early adopter would consider purchasing an EV in the next couple of years, the original segment map was recalibrated to reflect the relative strength of interest in considering an EV in the next couple of years. The six early adopter segments were cross-referenced with their answers and, based on the number of "definitely consider" responses from each segment, were rated according to strong, moderate or weak interest. This map details neighbourhoods characterized by a significant interest in the adoption of EVs and therefore likely to be areas for deployment of them within the City of Toronto.

Figure 15: Strength of Interest in Purchasing an EV by Dissemination Area



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Summary

For the EV market to evolve and expand in the City of Toronto, the early adopter phase must be successful. If early users of the technology are unable to experience and appreciate its value, a broader market may not emerge. It is clearly important to better understand where knowledge gaps exist among the early adopter community and what barriers must be addressed to facilitate the successful uptake and integration of the technology among this important segment of the population.

The results of the market research build a detailed picture of the characteristics of potential early adopters, including a broad demographic profile, typical personal mobility patterns and clearly articulated perceptions of the barriers to and opportunities for the uptake of EVs. Potential early adopters in the City of Toronto are more affluent, better educated and older than the general population, and the majority of this group live in detached, single-family homes with on-property parking and easy access to an electrical outlet. In addition, the majority of this group drive regularly, making little use of public transit, and park in an employer-provided lot while away from home. This profile suggests that the early adopter group is unaccustomed to inconvenience, which may limit their willingness to make the perceived sacrifices necessary to transition to an EV, given current market and technological considerations. In addition, as the majority of the early adopter group drive to a specific location at least twice a week, where many leave their vehicle for at least eight hours, few in this group will likely be open to charging an EV at a centralized location any distance from their accustomed parking.

The survey results suggest that even among potential early adopters, purchasing or leasing an EV does not seem imminent, as a number of significant perceived barriers exist. Concerns about the current lack of infrastructure and the length of time required to charge an EV, as well as the potentially limiting range of the vehicle, are perceived as major barriers to the adoption of EVs. In addition, the findings suggest that a lack of awareness of EVs underlies much of the resistance to the technology. While potential early adopters feel that they are at least somewhat familiar with EVs, few claim to be very familiar or are able to name a specific make or model. Awareness of government purchase incentives is very low, indicating that there are still further opportunities for education. That said, awareness of the environmental opportunities that EVs present is very high, and over half the respondents are familiar with how they compare with conventional vehicles.

The survey findings also identified important opportunities for the promotion of EV uptake. For example, the majority of potential early adopters felt that access to faster home charging would be very important. This points to an opportunity to promote technology that enables faster home charging as a means of overcoming a perceived barrier. The survey also shows that the LDC is the most trusted proponent and facilitator of EV adoption for the early adopter group. The LDC already has a clear stake in preparing for EV deployment because of the need to meet the demand for additional electricity. The survey results indicate that there is also an opportunity for the LDC to play a vital role in the promotion and success of EV deployment.

While there is not yet a large sample of actual early adopters of EV technology in the City of Toronto to compare with these findings, the market research can enhance the value proposition of EV use among end-users, establishing a solid foundation for the growth of the EV industry in the absence of actual comparative data. The results can inform a comprehensive understanding of the knowledge and information required to plan and prepare for the successful deployment of EVs in the City of Toronto. Unless the barriers identified in this report are addressed, scarce and valuable resources may be misallocated or misaligned with the needs of the emerging market for EVs, thus decreasing the efficiency of these investments and increasing the cost of enabling EV use in Toronto.

Section Two of the EMAP report has described the methodology and results of two separate but interrelated market research investigations. Section Three of the report describes the process of assessing the capacity of the electricity distribution system to accommodate the additional loading predicted as a result of the uptake of EVs.

SECTION THREE:
Electricity Distribution System Assessment

Purpose of Assessing the Electricity Distribution System

The electrical power generation and transmission systems serving the City of Toronto are capable of supporting a robust market for EV charging and use. However, the capacity of the local distribution system to deliver power to EV end-users may be constrained under certain conditions. The EMAP market research survey showed that potential early adopters of EV technology may exhibit consumer values that are shared by others in their communities. This could lead to the phenomenon of "clustering" of early EV adopters, which, in turn, could create conditions in which the electricity distribution system might not have sufficient capacity to support EV-related loads.

The EMAP market research survey generated a body of evidence that richly characterizes the market for EVs in the City of Toronto. It also provides a better understanding of the nature of the charging services required to support EV deployment (i.e., when vehicles would be plugged in, for how long, and the importance of fast charging to the end-user). The findings from this market research were the basis for an assessment of the capacity of the electricity distribution system at the neighbourhood level to respond to the expected patterns of demand for power to charge EVs.

Understanding how EVs are likely to change the profile of power demand at the neighbourhood level is critical to making informed, strategic and effective investments in technology and infrastructure to maintain and improve quality of service. This assessment can also contribute to improving the efficiency of capital investment in EV charging infrastructure by ensuring that it aligns with the needs of the early adopter market, defined by geographic location, mobility patterns and the need to address key barriers to EV charging and use.

Terms and Definitions

The following section provides an overview of a number of key terms related to the basic units of electricity as well as power system configurations, with examples drawn from the City of Toronto and the THESL service area. The definitions and descriptions are provided solely for the purpose of supporting the EMAP electricity distribution system assessment discussion and are not intended to reflect the intricacies of either the basic units of electricity or electrical power systems in general.

Basic Units of Electricity

The following basic units of electricity are used throughout this report in relation to potential constraints on the electricity distribution system at the neighbourhood level:

Current (I) is the flow of electric charge through a conductor, such as a copper wire. Current is measured in amperes (A), often referred to as amps. Electrons are induced to move by electromagnetic forces, described as voltage.

Voltage (V) is a measure of electrical energy, or the *work* that an electromagnetic field can impart to a charged particle. Measured in volts (V), it is the energy that induces electrons to move in a conductor. Volts are also used to express the voltage applied to a circuit by an energy source, such as a battery or an electrical generator; in this context, voltage can also be referred to as **electromotive force**.

Resistance (R) is a measure of a material's tendency to oppose the flow of electrical current. Resistance is expressed as the ratio of voltage to current and is measured in ohms (Ω). The greater the resistance, the less electrical current flows through a conductor and the more the voltage (i.e., the electrical energy) applied to the conductor is converted to heat energy that dissipates into the immediate surroundings. Keeping current levels low in an electric wire is one way to minimize the amount of electrical energy that is converted to and lost as heat. Such losses are known as line losses.

This report also makes frequent references to three other terms related to electricity: **power**, **load** and **energy**.

What is the difference between a watt and a volt-ampere?

Both watts and volt-amperes can be used to express power when direct current (DC) circuits are being measured. In alternating current (AC) circuitry, which is a more common design in transmission and distribution systems, volt-amperes are used to accurately express more complex power characteristics.

Power is the time rate at which energy (e.g., the energy of electrons carrying charge to a battery through a conducting wire) is transferred or converted. Power is expressed as the product of voltage and current, and is measured in watts (W). For example, a wire carrying a current of 15 A at 110 V is transferring energy at a rate of 1,650 W. A watt is a per-second measure of energy transfer or conversion. A kilowatt (kW) is equal to 1000 W and is one of the units typically used to express the maximum power characteristics of an electric motor or a transformer. For example, the charging systems built into new EVs (i.e., the on-board chargers) referenced in this report are rated in kilowatts. Power is also measured in kilovolt-amperes (kVA). The power capacities of the transformers investigated in this report are measured in kilovolt-amperes.

A **load** is any device that uses electric energy or changes it into other forms of energy (e.g., heat, light or mechanical energy). An EV plugged in to charge its battery is an example of an electrical load. If the EV is plugged into a socket that supplies electricity at 15 A and 110 V, then power can flow at 1,650 W – not dissimilar to a typical hair dryer.

Energy, measured in kilowatt-hours (kWh), is the product of the power (i.e., the rate at which energy is transferred) and the time period over which it is supplied (Energy = Power x Time). An EV battery charging at 1,650 W for eight hours stores approximately 13 kWh of energy.

The Electrical Power System

The focus of the electricity distribution system assessment is the distribution system at the secondary, or neighbourhood, level. To better understand the implications of EV charging for the distribution system, it is important first to explore the functions of some of the electrical power system components. The following section provides a simplified description of these functions; it is not intended to reflect the intricacies of any particular system.

The purpose of the electrical power system is to connect the centres of demand for electricity (i.e., the end-users) with the sources of supply (i.e., the power plant). Because the capacity to store electricity once it is generated is limited, the balance of supply and demand in Ontario is delicately managed on an instant-by-instant basis by the Independent Electricity System Operator (IESO). If customers generated their own electricity to meet their own individual needs, no system of transmitting or distributing power would be needed. In reality, however, because the centres of demand are usually located far from the sources of supply, transmission and distribution are essential elements of today's power system.

In general, the power system involves electricity being generated at a power plant, where it is converted, or "stepped up," to very high voltages for transmission over long distances and then "stepped down" to lower voltages for distribution to end-users.

GENERATION

At the core of almost all generating stations is a series of turbines that are driven by water, steam or combustion gases. Connected by a driveshaft, the turbines cause an electromagnet inside the generator to rotate. The movement of the magnetic field induces a current in the surrounding coils of wire within the generator, producing a voltage that can feed the transmission system. The voltage levels generated are directly related to how quickly and with how much force the generator spins. Some generating stations in Ontario are privately owned and operated, while some are publicly owned. The largest power generator in the province is a Crown corporation, Ontario Power Generation.

TRANSMISSION

A **transmission substation** is located at or near the generating station. The transmission substation contains a large **step-up transformer**, which increases the voltage produced by the generator to the high levels required for long-distance transmission. Electrical power systems generally use a series of transformers to convert electricity to different voltage levels appropriate for each stage of the system.

A few high-voltage transmission lines can carry more electrical energy, more efficiently, than a larger number of lower voltage lines.

How does a transformer "step down" or "step up" voltage?

Transformers neither produce nor consume power or energy. But, by regulating power to the right levels, they make it possible for devices of all types and purposes to operate on just a few levels of power supply.

Transformers at their most essential level consist of parallel but separate coils of wire wound around a magnetic core. When voltage is applied to one coil (usually called the primary or input), it magnetizes the iron core, which induces a voltage in the other coil (usually called the secondary or output). If the secondary coil has fewer loops than the primary coil, less voltage and more current is induced in the secondary coil. This is the case with a "step-down" transformer. A "step-up" transformer works in the opposite way. With more loops in the secondary coil than in the primary coil, it increases voltage and reduces current. The turns ratio (the ratio of the number of turns on the primary coil of an electrical transformer to the number on the secondary) of the two sets of windings determines the amount of voltage transformation.

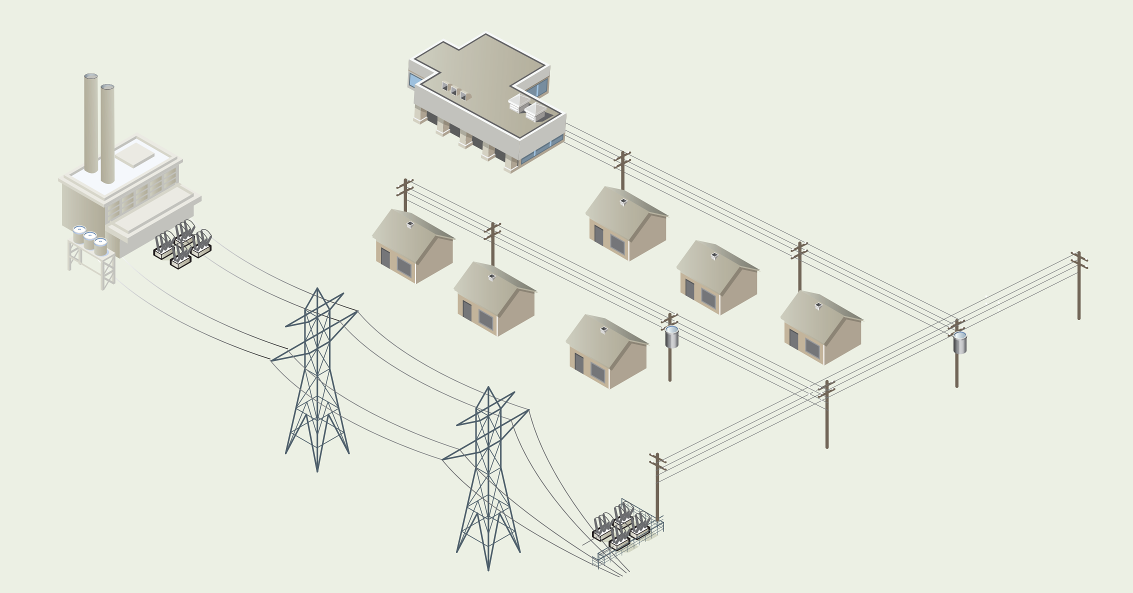
Individual households are usually located far from the generation station. To reach the consumer, the electricity generated must be conducted by wires spanning long distances. High-voltage **transmission lines** are used for this purpose. A few high-voltage transmission lines can carry more electrical energy, more efficiently, than a larger number of lower voltage lines. Also, the transmission of electrical power at high voltage keeps current levels low, and this minimizes resistance and line losses. While for the majority of end-users, these high voltages need to be reduced (stepped down) to a lower level for household or small business use, some industrial facilities with high electrical loads (e.g., high-power motors) may be connected directly to the transmission system. The transmission company responsible for transmitting electricity to the City of Toronto is Hydro One Networks, Inc. The transmission lines servicing the city operate at voltages of 500 kV, 230 kV or 115 kV.

Step-down transformers are found at transmission stations located close to or within the city. These transformers convert the high voltages from the transmission lines to lower voltages for distribution. These transmission stations and lower voltage transmission lines are sometimes referred to as the **subtransmission system**. Currently, the step-down transformers for the City of Toronto are owned by Hydro One, except for one owned by THESL. Power destined for households in the City of Toronto is stepped down at these transmission stations from 500 kV to 230 kV or from 230 kV to 115 kV.

DISTRIBUTION

Electricity distribution is the final step in the delivery of electricity to end-users. The distribution system takes the electricity carried along the high-voltage transmission lines and, through a series of step-down transformers, lowers the voltage to levels appropriate for use by individual households and businesses. The distribution system is owned and operated by LDCs. As previously mentioned, THESL is the LDC for the City of Toronto.

The **distribution transformer station** is the point where the conversion from transmission to distribution occurs. In the THESL service area, these



Electricity Generation, Transmission and Distribution

transformers step down power to one of three voltage levels – 27.6 kV, 13.8 kV or 4.16 kV. **Distribution feeders** are electrical cables or conductors that originate at the distribution transformer station and distribute electric power to one or more secondary transformers. The voltage level of these distribution feeders may vary geographically within a service area. For the THESL service area, there are two broad geographic areas that represent different distribution system configurations: the "horseshoe" (the region surrounding central Toronto) and the downtown core.

Horseshoe: Both 230 kV and 115 kV transmission lines supply electric power to 20 distribution transformer stations that step down the voltage to 27.6 kV and provide electric power to the areas of the city located outside the downtown core. The 27.6 kV distribution feeders from these distribution transformers serve the following:

- A large number of end-users (residential, commercial and industrial).
- Smaller **municipal substations** where step-down transformers convert voltage to 13.8 kV. Feeders running from some of the 13.8 kV municipal substations provide electric power directly to end-users, while others service yet other municipal substations where a transformer steps the voltage down to 4.16 kV.
- Smaller municipal substations where step-down transformers convert voltage to 4.16 kV for end-users

Downtown core: A total of 15 distribution transformer stations located in the downtown core of the City of Toronto convert 115 kV transmission lines to 13.8 kV feeders. The feeders from these 13.8 kV distribution transformer stations serve the following:

- residential, commercial and industrial loads
- municipal substations that convert the voltage from 13.8 kV to 4.16 kV for downtown residential, commercial and industrial end-users.

LOCAL TRANSFORMERS

Pole- or pad-mounted transformers or transformers in underground vaults provide the final voltage transformation in the electrical power system. These transformers step down the voltage from distribution feeders (27.6 kV, 13.8 kV or 4.16 kV) to the level appropriate for use by individual households (typically 120 V or 240 V).

When distribution feeders are located overhead, the transformer is usually mounted on a utility pole and is referred to as pole-mounted. In the THESL service area, pole-mounted transformers are primarily located in the downtown core.

When the distribution feeders run underground, the transformer is mounted on a concrete pad (pad-mounted) or installed in an underground vault. In the THESL service area, pad-mounted transformers are used mainly in the horseshoe area whereas underground vaults are generally used in the downtown core.

SECONDARY CONNECTION SYSTEM – SECONDARY DROP LEAD, SECONDARY BUS AND SERVICE CABLES

The secondary connection system supplies power from the local transformer to the end-user and consists of the following:

- The **secondary drop lead** is a conductor connecting the transformer to a secondary bus. A bus provides a common electrical connection between multiple electrical devices.
- The **secondary bus** is a common connection point for the individual service cables running directly to each household serviced by the transformer.
- **Service cables** connect the secondary bus to the end-user. Service cables are the last stage of the distribution system.

This section of this report, documenting the EMAP electrical distribution system assessment, focuses on residential areas typically serviced by pole-mounted transformers as opposed to areas serviced by pad-mounted transformers or transformers installed in underground vaults. For the purposes of this report, the neighbourhood-level distribution system is defined as the pole-mounted transformer and anything beyond it (i.e., the secondary connection system).

Methodology

To better understand the implications of the anticipated uptake of EVs in the context of electricity demand within the City of Toronto, scenario development and simulation were undertaken by Ryerson University's Centre for Urban Energy (CUE) with data provided by THESL. The assessment of the electricity distribution system's capacity to support additional loading resulting from EV charging involved the investigation of the distribution system at the neighbourhood level, beginning with the pole-mounted transformer and ending with the secondary cables responsible for running electrical power to individual households. A neighbourhood in which the likely adoption of EVs is expected to occur (based on the market research) was modelled, and the impacts were simulated by CUE using relevant feeder and transformer data provided by THESL. Each of the scenarios reflects a steady-state analysis as opposed to real-time dynamic simulations, which were beyond the scope of this study.

The specific process, outputs and assumptions made in the development and application of the assessment are described below.

Assessment of the Electricity Distribution System at the Neighbourhood Level

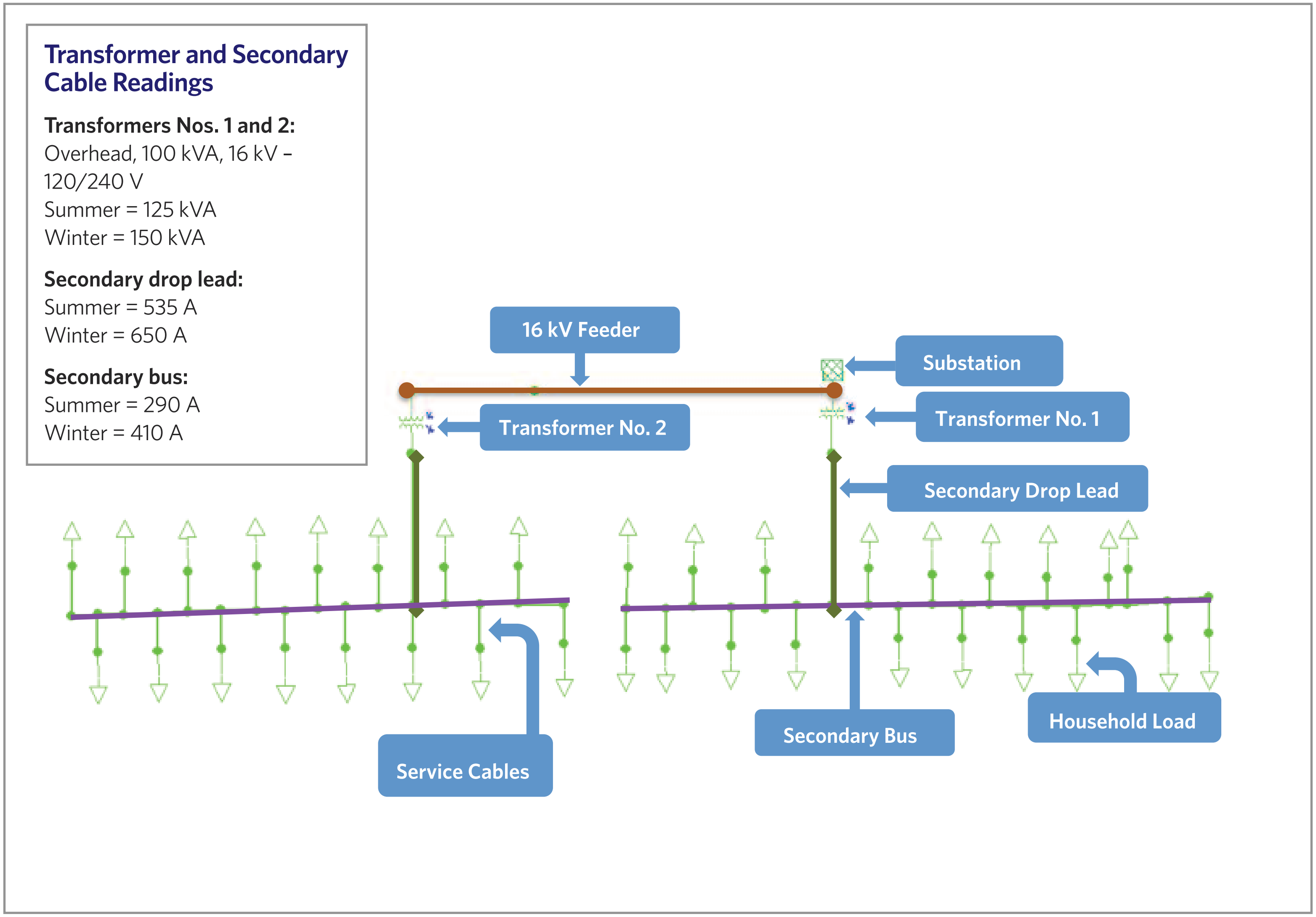
A postal code corresponding to an area with a high propensity for early adoption of EVs, based on responses to the market research survey, was selected as the test case for the investigation of the neighbourhood-level distribution system. Relevant feeder and transformer data for the postal code were used as inputs to CYME, an engineering software program, and a model was built that was capable of estimating the additional load on the transformer resulting from a number of different variables associated with EV charging.

The postal code area selected is supplied by a feeder with a rated voltage of 16 kV. The two most heavily loaded transformers on this feeder supply power to a total of 35 households, 19 on one transformer and 16 on the other. Both of the transformers are pole-mounted, 120/240 V, with a 100 kVA capacity. In other words, the transformers draw power at 16 kV and supply power at 120 V. This is a fairly common transformer size for the City of Toronto, but it should be noted that the distribution system is made up of a range of transformers with different capacities, each of which would experience the impacts related to EV penetration differently.

Contingencies are usually built into the distribution system to accommodate high-impact but low-probability events, such as heat waves, fires or equipment failures. The two transformers investigated have emergency capacities of 125 kVA in summer (temperatures of 30 °C or greater) and 150 kVA in winter (temperatures of 0 °C or below) to accommodate the loads typically associated with spikes or drops in temperature. Similarly, the rated current of the secondary drop lead is 535 A in summer and 650 A in winter, while the rated current on the secondary bus is 290 A in summer and 410 A in winter.

See Figure 16 for a representation of the CYME model of the distribution system at the neighbourhood level.

Figure 16: CYME Model of the Distribution System at the Neighbourhood Level



Transformer and Secondary Cable Readings

Transformers Nos. 1 and 2:
Overhead, 100 kVA, 16 kV – 120/240 V
Summer = 125 kVA
Winter = 150 kVA

Secondary drop lead:
Summer = 535 A
Winter = 650 A

Secondary bus:
Summer = 290 A
Winter = 410 A

SCENARIO DEVELOPMENT AND RESULTS

Scenario development and simulation offer a means of investigating possible situations and thus can inform the development of strategies to produce desired outcomes. A range of scenarios were investigated to better understand the extent to which a number of key variables could impact the capacity of the electricity distribution system at the neighbourhood level to accommodate EV charging at home. The scenario development consisted of

- establishing worst-case scenarios
- investigating key variables

In any given scenario, if the sum of the household load and the EV-related load is less than the available capacity of the transformer and of the secondary cables, the system is deemed to be equipped to accommodate the load. If the household load plus the additional EV-related load exceeds the available capacity, overloading may occur.

The results for each scenario are documented in the tables in this section of the report. Results highlighted in light purple in the tables indicate that loading exceeds the rated capacity of the transformer (i.e., 100 kVA). Results highlighted in light orange indicate that loading on the transformer or current on the secondary cables exceeds the emergency rated capacity for summer or winter, as applicable.

The following section outlines both the process and the key findings of the electricity distribution system assessment, beginning with the development of worst-case scenarios, followed by a discussion of the key variables predicted to have an effect on the capacity of the electricity distribution system to support additional loading as a result of EV charging.

Establishing Worst-Case Scenarios

The first set of scenarios tested the capacity of the electricity distribution system at the neighbourhood level based on a number of worst-case conditions or factors. These scenarios were developed based on predicted home charging patterns of early adopters of EV technology, two common on-board charger capacities and the assumption that ambient temperature can create additional stress for the neighbourhood-level distribution system. While the conditions associated with these worst-case scenarios are unlikely to occur, this investigation allows for further refinement of the variables considered in the remaining scenarios.

Peak Load in Summer or Winter

In summer there is an increase in the demand for electricity to power air conditioners to cool our houses. Similarly, the winter months are also a time of higher demand for power. People tend to be inside longer, with the lights on and furnace fans and heaters running, thus increasing the load on the transformer. The high demand for electricity to power these devices puts stress on the distribution system, increasing the potential for overloading or power disruption. This set of scenarios sought to establish the additional demand on the transformers resulting from ambient temperature.

Before any additional loading resulting from EV charging was considered, the days with the highest temperature in summer and the lowest temperature in winter from the previous year were investigated to establish the effects of extreme temperatures on the system. The warmest day from the previous year was July 21, 2011, with a high of 37.5 °C, and the coldest day was January 23, 2012, with a low of -19.9 °C. The following two scenarios assume that all households serviced by the transformers experience peak load – the maximum demand for electrical power – simultaneously.

The results show that, for the warmest day in summer, neither the transformer nor the secondary cables would have been close to approaching capacity, even with all households at peak load simultaneously. Similarly, on the coldest day, the system would have operated well below capacity and easily accommodated any additional loading related to winter conditions (e.g., people remaining indoors more, using more lights or electric heaters).

Table 1: All Households at Summer Peak Load

Transformer number	Transformer load (kVA)	Current on the secondary drop lead (A)	Current on the secondary bus (A)
1	42.1 kVA	170.2 A	104.7 A
2	37.9 kVA	153.2 A	99.7 A

Table 2: All Households at Winter Peak Load

Transformer number	Transformer load (kVA)	Current on the secondary drop lead (A)	Current on the secondary bus (A)
1	49.3 kVA	199.2 A	111.4 A
2	36.3 kVA	146.7 A	98.7 A

Electric Vehicle Charging in Summer and Winter

Many of the first wave of mass-produced EVs on the market (e.g., the 2011 Nissan LEAF) contain an on-board battery charger rated at 3.3 kW when charging at 240 V (Level 2 charging). Some of the newer EVs on the road today (e.g., Ford Focus Electric or Honda Fit EV) contain a 6.6 kW on-board charger, which significantly reduces the length of time required to charge the vehicle. However, compared to a 3.3 kW charger, a 6.6 kW charger doubles the demand for power on the electricity distribution system. While even more powerful on-board chargers exist, the 3.3 kW and 6.6 kW were used for the initial worst-case scenarios because they are currently the most common power ratings on the market.

The following scenarios test the worst possible outcome based on the following assumptions:

- All households have a single EV.
- All EVs are charging simultaneously (i.e., 100 per cent EV penetration).
- Peak load occurs at the same time for all households.

As with the previous set of investigations, both the warmest summer day and the coldest winter day were considered.

Electric Vehicle Charging with a 3.3 kW Charger

This set of scenarios estimated the capacity of the electricity distribution system at the neighbourhood level to accommodate EVs with an on-board 3.3 kW charger. The total load was calculated by adding together the load profile for each household serviced by the transformer and the incremental EV load (i.e., 3.3 kW per EV). The results show that if all households were charging an EV with a 3.3 kW charger simultaneously during summer or winter peak load conditions, one of the transformers (transformer No. 1) would be slightly overloaded (i.e., more than 100 kVA but less than the 125 kVA emergency rating).

Table 3: Summer Charging with a 3.3 kW Charger

Transformer number	Transformer load (kVA)	Current on the secondary drop lead (A)	Current on the secondary bus (A)
1	104.5 kVA	422.6 A	265.2 A
2	90.3 kVA	365.2 A	246.4 A

Table 4: Winter Charging with a 3.3 kW Charger Load

Transformer number	Transformer load (kVA)	Current on the secondary drop lead (A)	Current on the secondary bus (A)
1	111.7 kVA	451.4 A	272.0 A
2	88.8 kVA	358.9 A	245.7 A

Electric Vehicle Charging with a 6.6 kW Charger

This set of scenarios estimated the capacity of the electricity distribution system at the neighbourhood level to accommodate EVs with an on-board 6.6 kW charger. Table 5 shows that if all households were charging an EV simultaneously on the warmest day in summer at peak load, both transformers would be severely overloaded (more than 125% of the rated capacity), leading to potential power outages, and the secondary cables would be overcurrent.

Table 6 shows that if all households were charging simultaneously on the coldest day in winter, transformer No. 1 would be severely overloaded (more than 150% of the rated capacity), while transformer No. 2 would be slightly overloaded. Furthermore, all of the secondary cables for transformer No. 1 would be overcurrent.

Table 5: Summer Charging with a 6.6 kW Charger

Transformer number	Transformer load (kVA)	Current on the secondary drop lead (A)	Current on the secondary bus (A)
1	170.9 kVA	690.8 A	436.5 A
2	145.9 kVA	590.0 A	402.5 A

Table 6: Winter Charging with a 6.6 kW Charger Load

Transformer number	Transformer load (kVA)	Current on the secondary drop lead (A)	Current on the secondary bus (A)
1	178.1 kVA	720.0 A	443.7 A
2	144.4 kVA	583.8 A	401.9 A

Summary – Worst-Case Scenarios

The initial scenarios investigated the extent to which the electricity distribution system at the neighbourhood level may be constrained under worst-case conditions. The results of the analysis show that on the summer and winter days investigated, without the addition of an EV-related load, the transformers are able to easily accommodate loading resulting from temperature spikes or drops. However, both temperature and the size of the on-board charger are significant factors when the additional load from all EVs charging simultaneously at peak load is taken into consideration. While the likelihood of this combination of conditions occurring is highly improbable, particularly at the early adopter stage when the number of vehicles involved is small, planning and asset management should factor in the worst possible situations related to the uptake of EVs in the City of Toronto.

The analysis also shows that one of the two transformers (transformer No. 1) has the potential to overload before the other (transformer No. 2). As such, the remainder of the scenarios in the report focus only on transformer No. 1, the more constrained of the two transformers.

Investigating Key Variables

The findings from the worst-case scenarios informed further refinement of the electricity distribution system assessment. Additional scenarios were developed and tested based on a number of key variables predicted to have the greatest potential impacts on the capacity of the system to support EV-related loading.

The first two variables tested were

- electric vehicle charger capacity
- electric vehicle penetration rate

These two variables were also investigated in relation to two additional variables:

- time of charge
- ambient temperature

The key variables investigated are described in further detail below.

Electric Vehicle Charger Capacity

The results from the worst-case scenarios show that the greater the capacity of the on-board charger, the greater the impact EV charging will have on the electricity distribution system. For the remainder of the scenarios, a range of charger sizes is considered. This allows for more in-depth analysis of the extent to which conditions such as time of charge or ambient temperature could be factors when combined with the additional load from EVs across a range of on-board charger capacities.

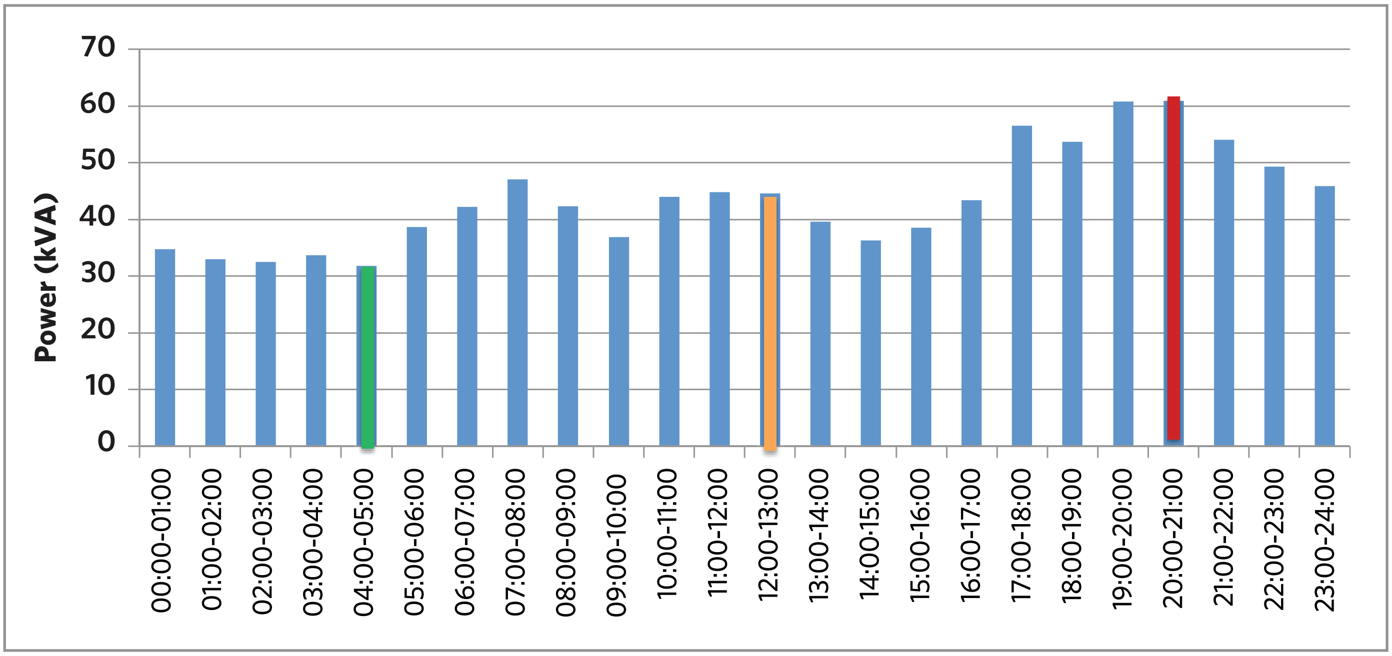
Electric Vehicle Penetration Rate

As the results of the market research have shown, the rate of EV penetration will be influenced by several factors, including demographics, consumer attitudes and the availability of charging infrastructure. At the same time, the total number of EVs that can be charged at one time is limited by the capacity of the transformer and secondary cables to meet the demand for power. The remainder of the scenarios in this report explore the impact on the transformer and secondary cables resulting from the incremental load from each additional EV charging. The EV penetration rate is calculated by using the load profile for each household and adding the load from one EV per household serviced by the most heavily loaded transformer (i.e., transformer No. 1).

Time of Charge

As the results from the worst-case scenarios show, the additional load from EV charging can alter the demand for electricity, possibly increasing it beyond the capacity of the neighbourhood-level electricity distribution system. Because the demand for electricity fluctuates over the course of a day, the time at which EVs are plugged in could have significant implications. To better understand the extent of the potential impact of time of charge, a load profile was generated for a randomly selected day with average temperatures (March 6, 2012).

Figure 17: Load Profile* by Hour for March 6, 2012



*This figure represents the total load profile for both transformers, No. 1 and No. 2.

Based on the load profile for the day in question, the following three time periods were selected for further analysis:

- minimum loading for the day (between 4 a.m. and 5 a.m.)
- medium loading (midday between 12 p.m. and 1 p.m.)
- maximum loading (between 8 p.m. and 9 p.m.)

The following scenarios investigated the effect of EV penetration and different types of on-board chargers on the electricity distribution system during these three times of day.

Minimum Load (4 a.m. to 5 a.m.)

Table 7 shows that the transformer could accommodate 100 per cent penetration of EVs with a 3.3 kW or lower rated on-board charger. If 13 vehicles with a 6.6 kW on-board charger were charging simultaneously, the transformer would be slightly overloaded. More significant overloading would occur for vehicles with a 10 kW, 16 kW or 20 kW charger at much lower penetration rates. For example, as few as five vehicles with a 20 kW charger could cause the transformer to overload slightly, while seven vehicles would cause significant overloading.

The results in Table 8 show the potential for overcurrent on the secondary drop lead for relatively high penetration levels of vehicles with a 10 kW, 16 kW or 20 kW on-board charger. Overcurrent conditions would occur on the secondary drop lead if 15 vehicles were charging with a 10 kW charger, 9 vehicles with a 16 kW charger or 8 vehicles with a 20 kW charger.

Table 7: Transformer Load at Minimum Load Time Based on Charger Capacity and EV Penetration

Number of EVs in addition to household load	Transformer load (kVA)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	17.2	17.6	18.9	22.0	25.3	31.1	35.0
2	18.5	19.4	22.0	28.4	35.0	46.8	54.7
3	19.8	21.2	25.2	34.8	44.8	62.7	74.6
4	21.1	23.0	28.4	41.3	54.7	78.6	94.6
5	22.4	24.8	31.6	47.8	64.7	94.6	114.5
6	23.8	26.6	34.8	54.4	74.6	110.5	134.5
7	25.1	28.5	38.0	60.9	84.6	126.5	154.5
8	26.4	30.3	41.3	67.5	94.6	142.5	174.4
9	27.8	32.2	44.6	74.0	104.5	158.5	194.4
10	29.2	34.0	47.8	80.6	114.5	174.4	214.4
11	30.5	35.9	51.1	87.2	124.5	190.4	234.4
12	31.9	37.8	54.4	93.8	134.5	206.4	254.4
13	33.2	39.6	57.6	100.3	144.5	222.4	274.4
14	34.6	41.5	60.9	106.9	154.5	238.4	294.4
15	36.0	43.4	64.2	113.5	164.4	254.4	314.4
16	37.4	45.2	67.5	120.1	174.4	270.4	334.4
17	38.7	47.1	70.7	126.7	184.4	286.4	354.4
18	40.1	49.0	74.0	133.3	194.4	302.4	374.4
19	41.5	50.9	77.3	139.9	204.4	318.4	394.4

Table 8: Current on the Secondary Drop Lead at Minimum Load Based on Charger Capacity and EV Penetration

Number of EVs in addition to household load	Current on secondary drop lead (A)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	70.23	72.32	78.15	91.90	106.07	131.07	147.73
2	76.06	80.24	91.90	119.40	147.74	197.74	231.06
3	81.89	88.16	105.65	146.90	189.41	264.41	314.39
4	87.72	96.08	119.40	174.40	231.08	331.08	397.72
5	93.55	104.00	133.15	201.90	272.75	397.75	481.05
6	99.38	111.92	146.90	229.40	314.42	464.42	564.38
7	105.21	119.84	160.65	256.90	356.09	531.09	647.71
8	111.04	127.76	174.40	284.40	397.76	597.76	731.04
9	116.87	135.68	188.15	311.90	439.43	664.43	814.37
10	122.70	143.60	201.90	339.40	481.10	731.10	897.70
11	128.53	151.52	215.65	366.90	522.77	797.77	981.03
12	134.36	159.44	229.40	394.40	564.44	864.44	1064.36
13	140.19	167.36	243.15	421.90	606.11	931.11	1147.69
14	146.02	175.28	256.90	449.40	647.78	997.78	1231.02
15	151.85	183.20	270.65	476.90	689.45	1064.45	1314.35
16	157.68	191.12	284.40	504.40	731.12	1131.12	1397.68
17	163.51	199.04	298.15	531.90	772.79	1197.79	1481.01
18	169.34	206.96	311.90	559.40	814.46	1264.46	1564.34
19	175.17	214.88	325.65	586.90	856.13	1331.13	1647.67

Medium Load (12 p.m. to 1 p.m.)

The results in Table 9 show that charging an EV at mid-peak on an average day would cause only a slight increase in the overall load on the transformer in comparison to charging at minimum load. Twelve vehicles with a 6.6 kW on-board charger would cause the transformer to overload slightly (by comparison, it would take 13 EVs with the same charger capacity to cause a slight overload at minimum load time – see Table 7). Just four EVs charging with a 20 kW charger would cause slight transformer overload while seven vehicles would cause a significant overload.

Table 10 indicates overcurrent on the secondary drop lead at high penetration rates of vehicles with a 10 kW, 16 kW or 20 kW charger.

Table 9: Transformer Load at Medium Load Based on Charger Capacity and EV Penetration

Number of EVs in addition to household load	Transformer load (kVA)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	26.6	27.1	28.3	31.4	34.6	40.3	44.2
2	27.9	28.8	31.4	37.6	44.2	55.9	63.7
3	29.2	30.6	34.5	44.0	53.9	71.6	83.5
4	30.5	32.3	37.6	50.4	63.7	87.4	103.3
5	31.8	34.1	40.8	56.8	73.6	103.3	123.2
6	33.1	35.9	44.0	63.3	83.5	119.2	143.1
7	34.4	37.7	47.2	69.8	93.4	135.2	163.1
8	35.7	39.5	50.4	76.3	103.3	151.1	183.0
9	37.1	41.4	53.6	82.9	113.3	167.1	203.0
10	38.4	43.2	56.8	89.4	123.2	183.0	223.0
11	39.7	45.0	60.1	96.0	133.2	199.0	243.0
12	41.1	46.9	63.3	102.5	143.1	215.0	262.9
13	42.4	48.7	66.6	109.1	153.1	231.0	282.9
14	43.8	50.6	69.8	115.7	163.1	247.0	302.9
15	45.1	52.4	73.1	122.2	173.1	262.9	322.9
16	46.5	54.3	76.3	128.8	183.0	278.9	342.9
17	47.9	56.1	79.6	135.4	193.0	294.9	362.9
18	49.2	58.0	82.9	142.0	203.0	310.9	382.9
19	50.6	59.9	86.1	148.5	213.0	326.9	402.9

Table 10: Current on Secondary Drop Lead at Medium Load Based on Charger Capacity and EV Penetration

Number of EVs in addition to household load	Current on secondary drop lead (A)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	108.43	110.52	116.35	130.10	144.27	169.27	185.93
2	114.26	118.44	130.10	157.60	185.94	235.94	269.26
3	120.09	126.36	143.85	185.10	227.61	302.61	352.59
4	125.92	134.28	157.60	212.60	269.28	369.28	435.92
5	131.75	142.20	171.35	240.10	310.95	435.95	519.25
6	137.58	150.12	185.10	267.60	352.62	502.62	602.58
7	143.41	158.04	198.85	295.10	394.29	569.29	685.91
8	149.24	165.96	212.60	322.60	435.96	635.96	769.24
9	155.07	173.88	226.35	350.10	477.63	702.63	852.57
10	160.90	181.80	240.10	377.60	519.30	769.30	935.90
11	166.73	189.72	253.85	405.10	560.97	835.97	1019.23
12	172.56	197.64	267.60	432.60	602.64	902.64	1102.56
13	178.39	205.56	281.35	460.10	644.31	969.31	1185.89
14	184.22	213.48	295.10	487.60	685.98	1035.98	1269.22
15	190.05	221.40	308.85	515.10	727.65	1102.65	1352.55
16	195.88	229.32	322.60	542.60	769.32	1169.32	1435.88
17	201.71	237.24	336.35	570.10	810.99	1235.99	1519.21
18	207.54	245.16	350.10	597.60	852.66	1302.66	1602.54
19	213.37	253.08	363.85	625.10	894.33	1369.33	1685.87

Maximum Load (8 p.m. to 9 p.m.)

Table 11 illustrates that if 11 EVs with a 6.6 kW on-board charger were plugged in simultaneously, it would cause the transformer to overload. Similar to the previous scenario for medium load, it would take only four vehicles charging with a 20 kW on-board charger to slightly exceed the capacity of the transformer. The transformer would be severely over capacity if six vehicles were charging with a 20 kW charger.

The secondary drop lead could be overcurrent for relatively high penetration rates of vehicles with a 6.6 kW or greater capacity on-board charger (see Table 12).

Table 11: Transformer Load at Maximum Load Based on Charger Capacity and EV Penetration

Number of EVs in addition to household load	Transformer load (kVA)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	37.2	37.6	38.9	41.9	45.1	50.8	54.6
2	38.4	39.4	41.9	48.1	54.6	66.2	74.0
3	39.7	41.1	45.0	54.4	64.2	81.8	93.6
4	41.0	42.9	48.1	60.8	74.0	97.6	113.4
5	42.3	44.6	51.3	67.2	83.8	113.4	133.2
6	43.6	46.4	54.4	73.6	93.6	129.3	153.1
7	44.9	48.2	57.6	80.1	103.5	145.2	173.0
8	46.2	50.0	60.8	86.5	113.4	161.1	192.9
9	47.6	51.8	64.0	93.0	123.3	177.0	212.9
10	48.9	53.6	67.2	99.5	133.2	192.9	232.8
11	50.2	55.5	70.4	106.1	143.2	208.9	252.8
12	51.5	57.3	73.6	112.6	153.1	224.9	272.8
13	52.9	59.1	76.8	119.1	163.1	240.8	292.7
14	54.2	61.0	80.1	125.7	173.0	256.8	312.7
15	55.6	62.8	83.3	132.2	183.0	272.8	332.7
16	56.9	64.6	86.5	138.8	192.9	288.7	352.7
17	58.3	66.5	89.8	145.4	202.9	304.7	372.6
18	59.6	68.3	93.0	151.9	212.9	320.7	392.6
19	61.0	70.2	96.3	158.5	222.9	336.7	412.6

Table 12: Current on Secondary Drop Lead at Maximum Load Based on Charger Capacity and EV Penetration

Number of EVs in addition to household load	Current on secondary drop lead (A)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	151.03	153.12	158.95	172.70	186.87	211.87	228.53
2	156.86	161.04	172.70	200.20	228.54	278.54	311.86
3	162.69	168.96	186.45	227.70	270.21	345.21	395.19
4	168.52	176.88	200.20	255.20	311.88	411.88	478.52
5	174.35	184.80	213.95	282.70	353.55	478.55	561.85
6	180.18	192.72	227.70	310.20	395.22	545.22	645.18
7	186.01	200.64	241.45	337.70	436.89	611.89	728.51
8	191.84	208.56	255.20	365.20	478.56	678.56	811.84
9	197.67	216.48	268.95	392.70	520.23	745.23	895.17
10	203.50	224.40	282.70	420.20	561.90	811.90	978.50
11	209.33	232.32	296.45	447.70	603.57	878.57	1061.83
12	215.16	240.24	310.20	475.20	645.24	945.24	1145.16
13	220.99	248.16	323.95	502.70	686.91	1011.91	1228.49
14	226.82	256.08	337.70	530.20	728.58	1078.58	1311.82
15	232.65	264.00	351.45	557.70	770.25	1145.25	1395.15
16	238.48	271.92	365.20	585.20	811.92	1211.92	1478.48
17	244.31	279.84	378.95	612.70	853.59	1278.59	1561.81
18	250.14	287.76	392.70	640.20	895.26	1345.26	1645.14
19	255.97	295.68	406.45	667.70	936.93	1411.93	1728.47

Summary – Time of Charge

Investigating the time of charge showed that all 19 households would be able to charge an EV at 1.4 kW, 1.9 kW or 3.3 kW without constraining the transformer or the secondary drop lead. Vehicles with a 6.6 kW on-board charger or greater capacity would have a more significant effect on the electricity distribution system, with as few as four vehicles with a 20 kW charger causing transformer overload at periods of both medium and maximum load, and as few as five at periods of minimum load.

EV charging during periods of peak electricity demand poses an increased risk of system overload and potential power outages compared to charging during off-peak times. The results of the market research showed that early adopters would most likely return home to charge their vehicles at periods of peak demand. As such, it is clear that the time of day EV owners decide to charge their vehicles is a factor requiring further consideration in electricity distribution system preparedness.

Ambient Temperature

As described earlier, in both summer and winter, there is an increase in the demand for electricity. The following scenarios provide a more detailed understanding of the number of vehicles, using a range of charger sizes, that could be charged on the warmest day in summer and the coldest day in winter. Previous scenarios have indicated that during periods of peak demand, the electricity distribution system could reach capacity at a much lower EV penetration rate than on a day with average temperatures. For this reason, the following set of scenarios determined the effect of ambient temperature only during the maximum load period.

Warmest Day in Summer (July 21, 2011)

Table 13 shows that the additional load on the electricity distribution system from the use of air conditioning during the summer months is a key factor in determining the number of EVs that can charge simultaneously across a variety of charger sizes. Whereas on an average day the capacity of the transformer could accommodate 100 per cent penetration of vehicles with a 3.3 kW charger, 16 vehicles charging simultaneously would cause the transformer to overload slightly on the warmest day in summer. As few as three vehicles with a 20 kW charger would cause similar overloading of the transformer, and four vehicles would cause a more significant overload. The same EV charger capacity would cause overcurrent on the secondary drop lead with four vehicles charging (see Table 14).

Table 13: Transformer Load on the Warmest Day

Number of EVs in addition to household load	Transformer load (kVA)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	54.0	54.4	55.7	58.7	61.9	67.5	71.2
2	55.2	56.1	58.7	64.8	71.2	82.7	90.4
3	56.5	57.9	61.8	71.0	80.8	98.2	109.9
4	57.8	59.6	64.8	77.3	90.4	113.8	129.5
5	59.1	61.4	67.9	83.6	100.1	129.5	149.2
6	60.4	63.2	71.0	90.0	109.9	145.3	169.0
7	61.7	64.9	74.2	96.4	119.7	161.1	188.8
8	63.0	66.7	77.3	102.8	129.5	176.9	208.7
9	64.3	68.5	80.5	109.3	139.3	192.8	228.6
10	65.6	70.3	83.6	115.7	149.2	208.7	248.5
11	66.9	72.1	86.8	122.2	159.1	224.6	268.4
12	68.2	73.9	90.0	128.7	169.0	240.5	288.3
13	69.5	75.7	93.2	135.2	178.9	256.5	308.3
14	70.9	77.5	96.4	141.7	188.8	272.4	328.2
15	72.2	79.3	99.6	148.2	198.8	288.3	348.2
16	73.5	81.2	102.8	154.7	208.7	304.3	368.1
17	74.8	83.0	106.0	161.3	218.6	320.3	388.1
18	76.2	84.8	109.3	167.8	228.6	336.2	408.1
19	77.5	86.6	112.5	174.4	238.5	352.2	428.0

Table 14: Current on the Secondary Drop Lead on the Warmest Day

Number of EVs in addition to household load	Current on secondary drop lead (A)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	218.73	220.82	226.65	240.40	254.57	279.57	296.23
2	224.56	228.74	240.40	267.90	296.24	346.24	379.56
3	230.39	236.66	254.15	295.40	337.91	412.91	462.89
4	236.22	244.58	267.90	322.90	379.58	479.58	546.22
5	242.05	252.50	281.65	350.40	421.25	546.25	629.55
6	247.88	260.42	295.40	377.90	462.92	612.92	712.88
7	253.71	268.34	309.15	405.40	504.59	679.59	796.21
8	259.54	276.26	322.90	432.90	546.26	746.26	879.54
9	265.37	284.18	336.65	460.40	587.93	812.93	962.87
10	271.20	292.10	350.40	487.90	629.60	879.60	1046.20
11	277.03	300.02	364.15	515.40	671.27	946.27	1129.53
12	282.86	307.94	377.90	542.90	712.94	1012.94	1212.86
13	288.69	315.86	391.65	570.40	754.61	1079.61	1296.19
14	294.52	323.78	405.40	597.90	796.28	1146.28	1379.52
15	300.35	331.70	419.15	625.40	837.95	1212.95	1462.85
16	306.18	339.62	432.90	652.90	879.62	1279.62	1546.18
17	312.01	347.54	446.65	680.40	921.29	1346.29	1629.51
18	317.84	355.46	460.40	707.90	962.96	1412.96	1712.84
19	323.67	363.38	474.15	735.40	1004.63	1479.63	1796.17

Coldest Day in Winter (January 23, 2012)

Table 15 shows that the additional winter load on the electricity distribution system is a key factor in determining the number of EVs that can charge simultaneously across a variety of charger sizes. The number of vehicles charging without causing the transformer to overload decreases proportionally as the size of the on-board charger increases. Just two EVs with a 20 kW charger could charge at the same time on the coldest day in winter without overloading the transformer. Seven EVs with the more common 6.6 kW on-board charger could charge simultaneously before the transformer load would exceed its rated capacity. Six vehicles charging at 20 kW and 17 charging at 6.6 kW would cause the secondary drop lead to be overcurrent (see Table 16).

Table 15: Transformer Load on the Coldest Day

Number of EVs in addition to household load	Transformer load (kVA)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	51.8	52.2	53.5	56.5	59.7	65.3	69.1
2	53.0	53.9	56.5	62.6	69.1	80.5	88.2
3	54.3	55.7	59.6	68.9	78.6	96.0	107.7
4	55.6	57.4	62.6	75.1	88.2	111.6	127.4
5	56.9	59.2	65.7	81.5	98.0	127.4	147.1
6	58.2	61.0	68.9	87.9	107.7	143.2	166.9
7	59.5	62.7	72.0	94.3	117.5	159.0	186.8
8	60.8	64.5	75.1	100.7	127.4	174.8	206.6
9	62.1	66.3	78.3	107.1	137.2	190.7	226.5
10	63.4	68.1	81.5	113.6	147.1	206.6	246.4
11	64.7	69.9	84.7	120.1	157.0	222.5	266.4
12	66.0	71.7	87.9	126.6	166.9	238.5	286.3
13	67.4	73.5	91.1	133.1	176.8	254.4	306.2
14	68.7	75.3	94.3	139.6	186.8	270.3	326.2
15	70.0	77.2	97.5	146.1	196.7	286.3	346.2
16	71.3	79.0	100.7	152.6	206.6	302.3	366.1
17	72.7	80.8	103.9	159.2	216.6	318.2	386.1
18	74.0	82.6	107.1	165.7	226.5	334.2	406.0
19	75.3	84.5	110.4	172.3	236.5	350.1	426.0

Table 16: Current on the Secondary Drop Lead on the Coldest Day

Number of EVs in addition to household load	Current on secondary drop lead (A)						
	EV charger capacity						
	1.4 kW	1.9 kW	3.3 kW	6.6 kW	10 kW	16 kW	20 kW
1	209.93	212.02	217.85	231.60	245.77	270.77	287.43
2	215.76	219.94	231.60	259.10	287.44	337.44	370.76
3	221.59	227.86	245.35	286.60	329.11	404.11	454.09
4	227.42	235.78	259.10	314.10	370.78	470.78	537.42
5	233.25	243.70	272.85	341.60	412.45	537.45	620.75
6	239.08	251.62	286.60	369.10	454.12	604.12	704.08
7	244.91	259.54	300.35	396.60	495.79	670.79	787.41
8	250.74	267.46	314.10	424.10	537.46	737.46	870.74
9	256.57	275.38	327.85	451.60	579.13	804.13	954.07
10	262.40	283.30	341.60	479.10	620.80	870.80	1037.40
11	268.23	291.22	355.35	506.60	662.47	937.47	1120.73
12	274.06	299.14	369.10	534.10	704.14	1004.14	1204.06
13	279.89	307.06	382.85	561.60	745.81	1070.81	1287.39
14	285.72	314.98	396.60	589.10	787.48	1137.48	1370.72
15	291.55	322.90	410.35	616.60	829.15	1204.15	1454.05
16	297.38	330.82	424.10	644.10	870.82	1270.82	1537.38
17	303.21	338.74	437.85	671.60	912.49	1337.49	1620.71
18	309.04	346.66	451.60	699.10	954.16	1404.16	1704.04
19	314.87	354.58	465.35	726.60	995.83	1470.83	1787.37

Electric Heating

The energy required to heat a home with electricity is much greater than the energy required to heat the same home with gas. The previous scenarios assumed that the households were heated with gas and showed that the transformer would be constrained at winter temperatures due to the additional EV load. It follows that adding the EV-related load to electrically heated households serviced by a single transformer could constrain the electricity distribution system even more severely.

In the absence of a neighbourhood known to contain a high proportion of electrically heated households, data from a single home with electric heating and from a gas-heated household of equivalent size located next door were used as proxies for investigating electric heating as a variable. In order to evaluate the number of electrically heated households that could be supplied by one transformer before causing it to overload, it was necessary to calculate how much greater the typical electric load would be for an electrically heated household as opposed to a gas-heated household. The peak load for the electrically heated household was divided by the peak load for the gas household for each of the winter months from the previous year, and the average quotient was used as a general multiplier representative of the additional load of an electrically heated home. In other words, the general multiplier was used to scale up, converting the load from each of the 19 gas-heated households on the transformer for the coldest day in winter to the load for an electrically heated household. At the same time, EV penetration levels were tested by adding the load representative of a vehicle with a standard 3.3 kW charger to each household load. This allowed for a better understanding of the point of intersection between the two variables and of the potential for overloading of the transformer and overcurrent on the secondary drop lead.

It is worth noting that this set of scenarios did not seek to predict what would occur if a household decided to switch to electric heating but rather to what extent a neighbourhood that may already contain a number of electrically heated households would be further constrained by the addition of EV-related loading.

The results in Table 17 show that if 35 per cent of the 19 households (i.e., seven houses) supplied by the transformer used electric heating without the additional EV-related load, the transformer would be slightly constrained. By comparison, the transformer has sufficient capacity to accommodate, without overloading, 14 gas-heated houses charging an EV simultaneously. The intersection point of seven electrically heated houses supplied by the transformer and seven EVs charging would cause the transformer to overload. Table 18 shows that seven electrically heated houses on the transformer and eight EVs charging would cause the secondary drop lead to be overcurrent.

Table 17: Transformer Load and Electric Heating Penetration

Number of EVs charging with household load	**Transformer load (kVA)**							
	Penetration of electric heating (19 houses in total)							
	0% **(0 houses)**	**5%** **(1 house)**	**10%** **(2 houses)**	**15%** **(3 houses)**	**20%** **(4 houses)**	**25%** **(5 houses)**	**30%** **(6 houses)**	**35%** **(7 houses)**
0	51.10	59.17	67.24	75.31	83.37	91.44	99.51	107.58
1	54.40	62.47	70.54	78.61	86.67	94.74	102.81	114.53
2	57.70	65.77	73.84	81.91	89.97	98.04	106.11	121.48
3	61.00	69.07	77.14	85.21	93.27	101.34	109.41	128.42
4	64.30	72.37	80.44	88.51	96.57	104.64	112.71	135.37
5	67.60	75.67	83.74	91.81	99.87	107.94	116.01	142.32
6	70.90	78.97	87.04	95.11	103.17	111.24	119.31	149.27
7	74.20	82.27	90.34	98.41	106.47	114.54	122.61	156.21
8	77.50	85.57	93.64	101.71	109.77	117.84	125.91	163.16
9	80.80	88.87	96.94	105.01	113.07	121.14	129.21	170.11
10	84.10	92.17	100.24	108.31	116.37	124.44	132.51	177.06
11	87.40	95.47	103.54	111.61	119.67	127.74	135.81	184.00
12	90.70	98.77	106.84	114.91	122.97	131.04	139.11	190.95
13	94.00	102.07	110.14	118.21	126.27	134.34	142.41	197.90
14	97.30	105.37	113.44	121.51	129.57	137.64	145.71	204.85
15	100.60	108.67	116.74	124.81	132.87	140.94	149.01	211.79

Table 18: Current on the Secondary Drop Lead and Electric Heating Penetration

Number of EVs charging with household load	Current on the secondary drop lead (A)							
	Penetration of electric heating (19 houses in total)							
	0% (0 houses)	5% (1 house)	10% (2 houses)	15% (3 houses)	20% (4 houses)	25% (5 houses)	30% (6 houses)	35% (7 houses)
0	206.6	239.22	271.84	304.47	337.09	369.71	402.33	434.95
1	220.35	252.97	285.59	318.22	350.84	383.46	416.08	463.90
2	234.10	266.72	299.34	331.97	364.59	397.21	429.83	492.85
3	247.85	280.47	313.09	345.72	378.34	410.96	443.58	521.80
4	261.60	294.22	326.84	359.47	392.09	424.71	457.33	550.75
5	275.35	307.97	340.59	373.22	405.84	438.46	471.08	579.69
6	289.10	321.72	354.34	386.97	419.59	452.21	484.83	608.64
7	302.85	335.47	368.09	400.72	433.34	465.96	498.58	637.59
8	316.60	349.22	381.84	414.47	447.09	479.71	512.33	666.54
9	330.35	362.97	395.59	428.22	460.84	493.46	526.08	695.49
10	344.10	376.72	409.34	441.97	474.59	507.21	539.83	724.43
11	357.85	390.47	423.09	455.72	488.34	520.96	553.58	753.38
12	371.60	404.22	436.84	469.47	502.09	534.71	567.33	782.33
13	385.35	417.97	450.59	483.22	515.84	548.46	581.08	811.28
14	399.10	431.72	464.34	496.97	529.59	562.21	594.83	840.23
15	412.85	445.47	478.09	510.72	543.34	575.96	608.58	869.17

Summary – Ambient Temperature

The results of the scenarios considering the effects of ambient temperature show that the electricity distribution system could support all 19 households on the transformer charging an EV at the same time at a rate of 1.4 kW or 1.9 kW. However, 15 vehicles with a 3.3 kW charger would cause the transformer to overload slightly on both the coldest and the warmest day. With 6.6 kW chargers, more than seven EVs would cause both transformer overload and overcurrent on the secondary drop lead. The electricity distribution system could support a much lower EV penetration rate for vehicles with chargers of a capacity greater than 6.6 kW (i.e., 10 kW, 16 kW, or 20 kW).

The greater the number of electrically heated households serviced by the transformer, the lower the number of EVs that could charge simultaneously without causing the transformer to exceed its rated capacity. Overloads would occur with approximately one-third of the homes electrically heated and with only one EV charging. It should be noted that the majority of areas within the City of Toronto with electrically heated homes tend to be high-density areas consisting primarily of apartments and condominiums, although this is not to say that there are no areas in Toronto with a higher number of single-family dwellings using electric heating.

Additional Considerations

While the scenarios developed by CUE provide a better understanding of the potential effects of EVs on the system at the transformer level, it is also important for the LDC to understand the impact of EV penetration across the entire distribution system. As Toronto is the most populous urban centre in Canada, the adoption of EV technology has the potential to be much greater in the city than in other areas.

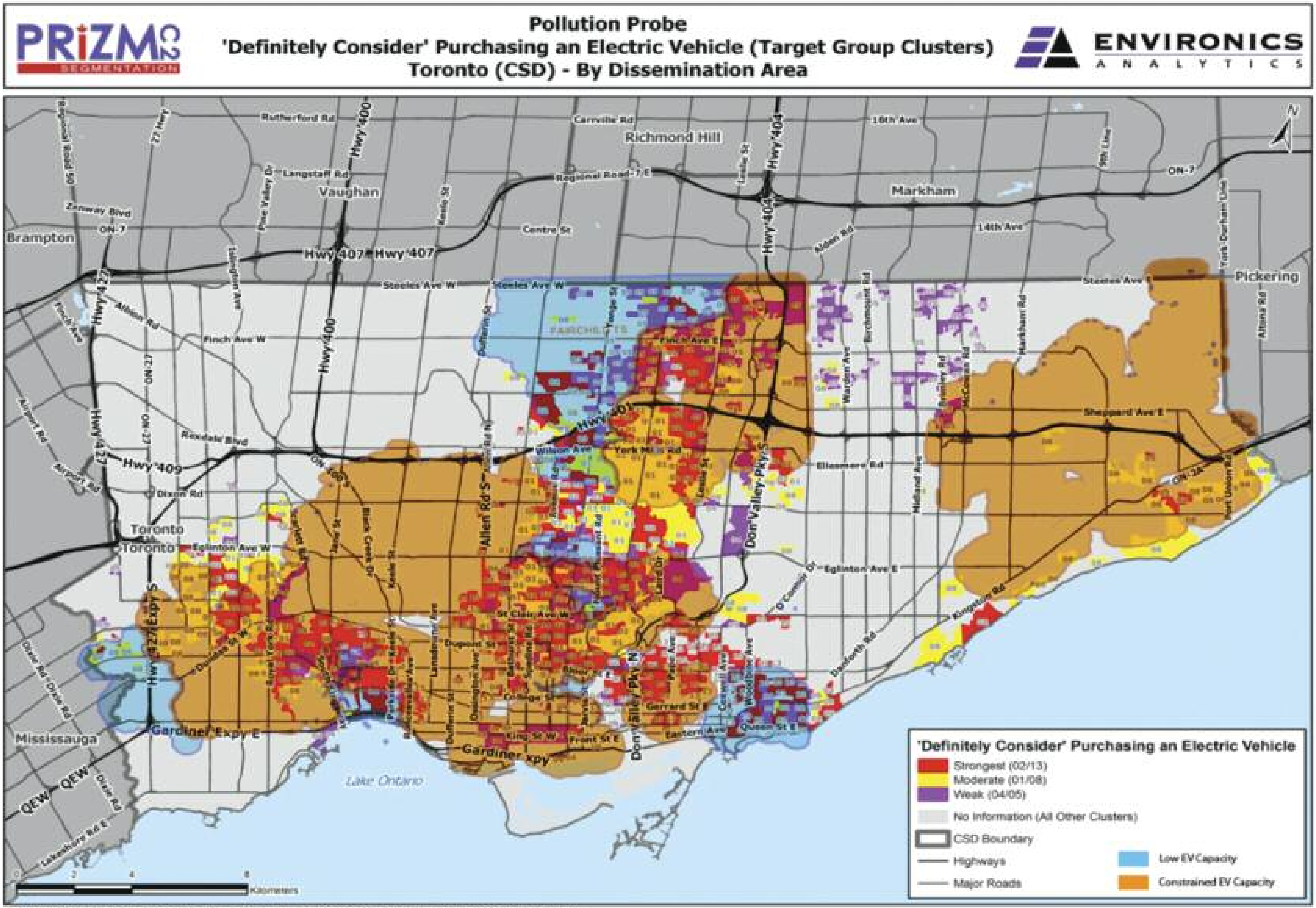
A system-wide examination of electricity distribution in the City of Toronto was undertaken by THESL, independent of the EMAP study. The impact of EVs on Toronto's distribution system as a whole was examined through analysis of distribution stations, feeders, transformers and secondary services, with a view to the further development of sustainable infrastructure for the increasing EV population. The THESL report (provided by THESL for inclusion as Appendix A of this EMAP report) underscores the need to address system-wide limitations of the electricity distribution system in relation to EV deployment.

THESL's system-wide analysis indicates that there are areas within Toronto's horseshoe and downtown core where distribution transformer stations are projected to be operating at low capacity (close to full capacity or slightly overloaded) or that will be more seriously constrained (operating at full capacity or severely overloaded) in accommodating the loads predicted as a result of EV uptake over the next ten years. When these low capacity and constrained areas of the electricity distribution system are overlaid on the heat map generated as part of the EMAP market research detailing neighbourhoods in which the likely adoption of EVs will take place, the need to prioritize infrastructure investment in specific geographic areas in order to mitigate potential EV-related risks is evident. An overwhelming majority of early adopter neighbourhoods are located in areas where the distribution system is predicted to be constrained or where there is little capacity to accommodate additional EV-related loading.

For more information on THESL's system-wide analysis, refer to Appendix A of this report.

Figure 17: Projected Early Adopter Neighbourhoods and Electricity Distribution System Areas of Low Capacity to Support EVs (10-Year Load Projection)

Note: This figure has been reproduced from Figure 5 of Appendix A.



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Summary

The results of the assessment of the electricity distribution system provide a better understanding of the key factors that will contribute to the capacity to accommodate anticipated EV-related loads at the neighbourhood level. Most of the scenarios investigated show that the system is currently able to support EV-related loading. However, future technological advances, the capacity of the on-board charger and ambient temperature all have the potential to significantly impact the system. While the likelihood that the worst-case conditions simulated will occur is not high, planning and asset management will nonetheless require consideration of these factors.

The potential reduction in the lifetime of distribution equipment as a result of EV charging is an important consideration not discussed at length in this report. If EVs are charging overnight, even at Level 1, they will be drawing continuous power at a time when the transformer would typically be cooling down (i.e., during its cooling cycle). This could result in degradation of and a reduced lifespan for the transformer and secondary cables.

In addition, the standard operating procedure for some LDCs is not to predict when transformers are about to fail, but rather to "run to failure" and then replace them. For example, because the downtown core of the City of Toronto is serviced by a network system, when one transformer fails, an adjacent one takes over and keeps the power flowing to customers' homes. Under these conditions, the backup transformer is potentially carrying twice its usual load and could be overloaded even with a much smaller number of EVs plugged in. In other words, while a small number of EVs charging might not impact the system under normal conditions, it could become a problem if a transformer fails because of age or for other reasons.

The implications of this assessment of the electricity distribution system at the neighbourhood level are of concern to LDCs. For example, should clusters of EV users choose to fast-charge at the same time, local transformers serving those neighbourhoods could overload, eroding the useful life of grid assets and possibly leading to disruptions in power supply. While the results of the assessment demonstrate that there are no immediate issues related to the capacity of the distribution system at the neighbourhood level to accommodate EV charging by early adopters, it is clear that LDCs could be faced with major challenges in the future if measures are not taken to address the demands of broader EV deployment.

Section Three of the EMAP report has outlined the process and results of the assessment of the capacity of the local electricity distribution system to accommodate the predicted loading resulting from EV charging.

Conclusion

The EMAP study described in this report is an important contribution to an in-depth analysis of the barriers and opportunities associated with EV deployment in the City of Toronto. The study integrated sophisticated market research with a neighbourhood-level analysis of the capacity of the electricity distribution system to accommodate EV charging. The outputs of this research build a comprehensive picture of a number of important considerations in planning and preparing for the increasing uptake of EVs. The implications of the findings are significant and point to the need for a fresh approach to EV technology and the infrastructure that supports it in the City of Toronto.

The EMAP methodology and findings provide a solid and objective foundation upon which to further explore the future for EVs as the market continues to evolve. The success of the technology depends on a deployment strategy that aligns with the needs of the local market, supports local grid asset management planning and increases the efficiency of capital investments in local infrastructure.

This report presents a three-point strategy for addressing the barriers to and opportunities for EV deployment identified through the EMAP process. The strategy focuses on the need to

- develop a business model specific to EVs
- build an effective policy framework that supports the EV business model
- explore the elements of a successful consumer engagement campaign

The implementation of this strategy hinges on continued and coordinated action on the part of those organizations and sectors with a direct stake in the success of EVs. Only through a collaborative effort will it be possible to develop an effective deployment strategy capable of mitigating potential barriers and fully realizing the real and tangible benefits associated with EV use.

Appendix A

Assessment of Electric Vehicle Impacts on THESL Distribution System

(Image courtesy BMW Canada)

Toronto Hydro Electric Systems Limited
Electric Vehicle Infrastructure Department

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Introduction

The purpose of this report is to review THESL distribution systems impact at Stations, Feeders, Transformers and Secondary levels from Electric Vehicle (EV) loads. In addition, it determines the depth of the impact and identifies the area that requires improvement or further engineering study through analyzing each area of the systems.

With the projected load growth of 1% in the horseshoe and 2% in the downtown area for the next 10 years, additional loads from EV creates additional constraint to existing aging Toronto Hydro's distribution system. This report will highlight the constraint and impact to the distribution system and will attempt to project the number of Electric Vehicles that can be connected to Toronto Hydro's distribution system.

System Overview

The characteristics and challenges for the four main configurations in THESL's distribution system are outlined below:

- 27.6 kV System: THESL's service territory is served by the 27.6 kV primary distribution system through 20 transformer stations ("TS") serviced from Hydro One transmission lines. A mix of overhead and underground, all 27.6 kV feeders are arranged to run radially from the TSs and keep feeder interconnection points normally open. These feeders serve a larger number of customers as compared to other systems, as well as 13.8 kV or 4.16 kV municipal substations ("MS"). The challenge of the 27.6 kV system is an aging infrastructure coupled with long feeders and a relatively large number of customers.

- 13.8 kV System: There are fifteen 115/13.8 kV transformer stations located in the pre-amalgamation city of Toronto. The dual radial system serves most of the commercial/industrial loads of the Toronto downtown core and 4 kV stations where each customer has two feeders connected in a normal/standby configuration. Customers with loads in excess of 10MVA are supplied with three or more dedicated feeders with pilot-wire protection. The key challenge with the 13.8 kV system is that municipal stations are typically older than 40 years with limited visibility and remote control capabilities. Feeder equipment is also largely unmonitored and lacks automation capabilities. Age, loss minimization, and equipment availability are drivers for system conversion, as well as requirements for future load growth.

- 4.16 kV System: The 4.16 kV overhead system is fed by 27.6 kV feeders outside of the pre-amalgamation city of Toronto and by 13.8 kV feeders and municipal stations within the Toronto area. Over the years, some areas of the 4 kV overhead system have been converted and are supplied from the 13.8 kV overhead or URD systems. The challenges with the 4.16 kV system are legacy equipment and higher system losses due to a lower voltage. The system is also largely unmonitored at the station and along the feeder.

- Secondary Network System: The secondary network is a system of interconnected secondary conductors, designed in grid or mesh configurations and supplied by a number of network units located in network vaults. The key challenges with network vaults are legacy and aging network units, harsh vault conditions and complexity of system design, thus leading to low probability high impact outages. Further, there are no remote monitoring and control capabilities in network vaults.

Maps of Distribution Systems (27.6 kV O/H, 13.8 kV UG/URD & Network and 4kV System)

The following figures (Fig. 1-4) are maps of the various systems in the THESL distribution system. The downtown[1] core is mostly network and underground installations, and the horseshoe[2] area is primarily overhead distribution.

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[1] Downtown core refers to the former city of Toronto

[2] Horseshoe refers to the former cities of Scarborough, North York, East York, York and Etobicoke.

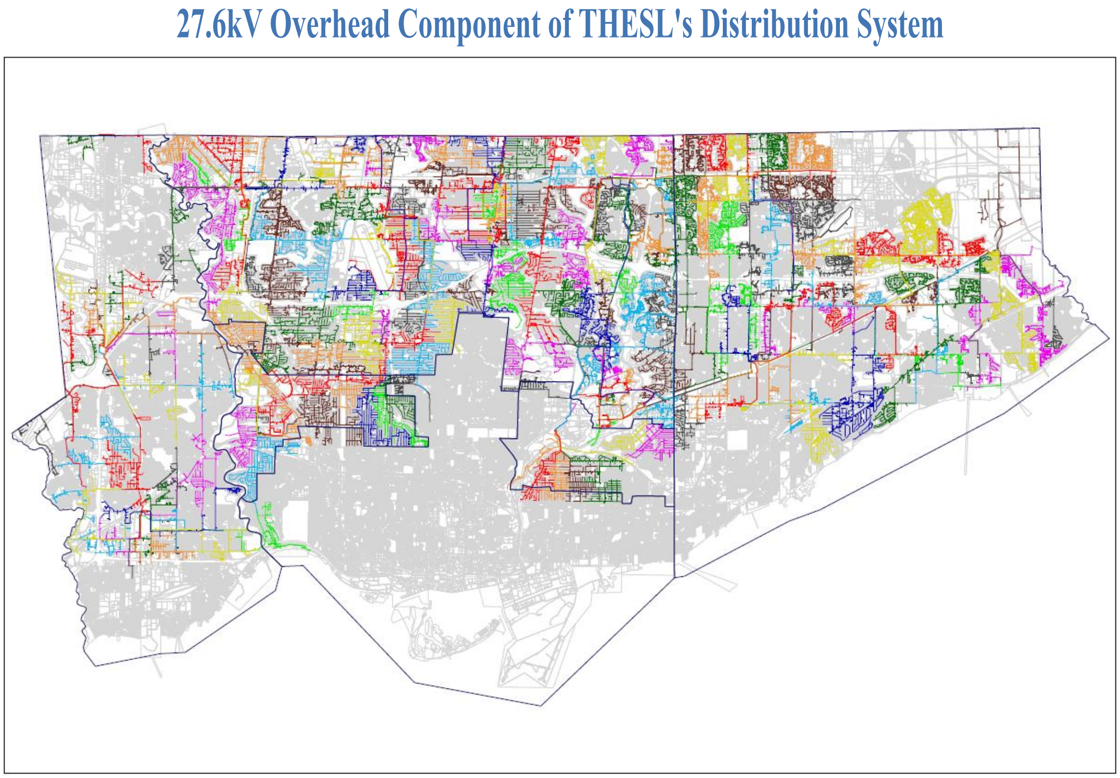

Figure 1: Map of the 27.6 kV overhead component of THESL’s distribution system

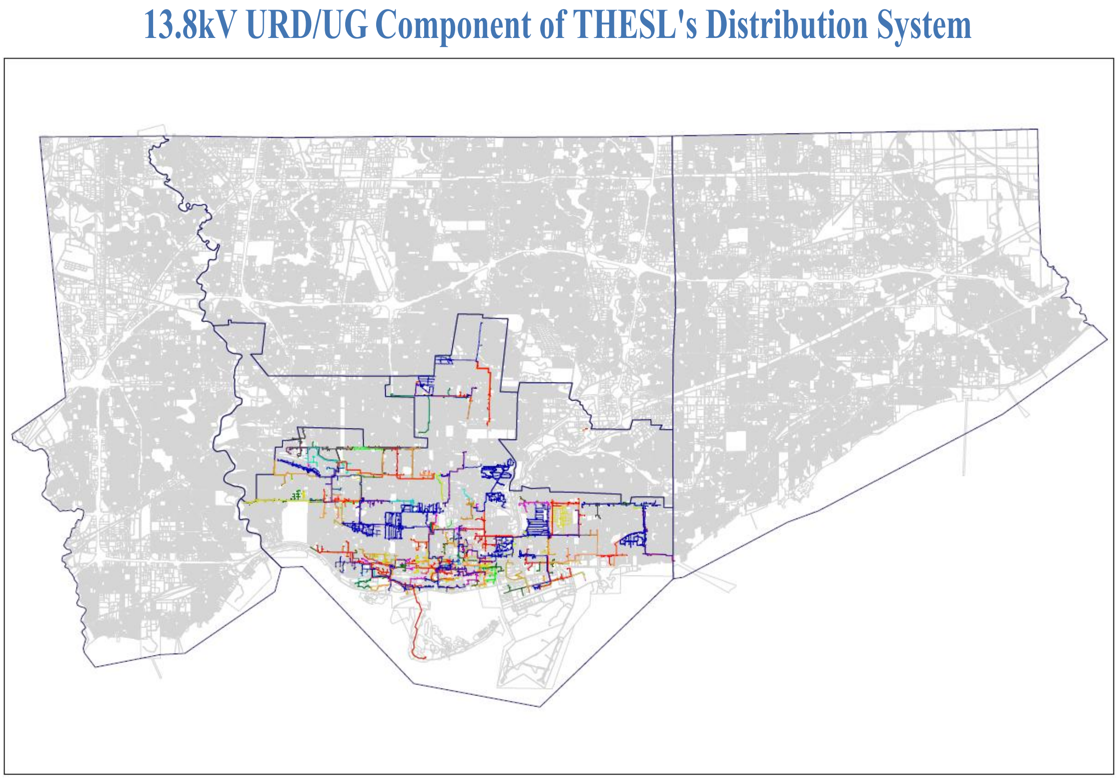

Figure 2: Map of the 13.8 kV URD/UG component of THESL’s distribution system

13.8kV Network Component of THESL's Distribution System

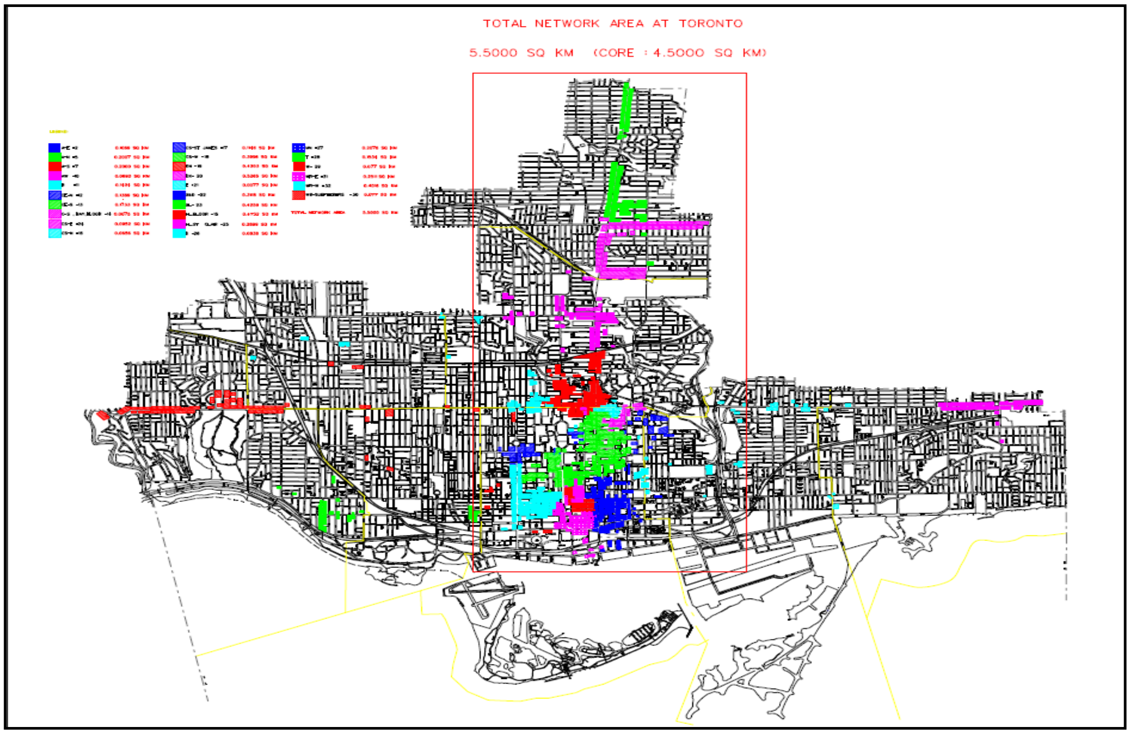

Figure 3: Map of the 13.8 kV NWK component of THESL's distribution system

4kV Component of THESL's Distribution System

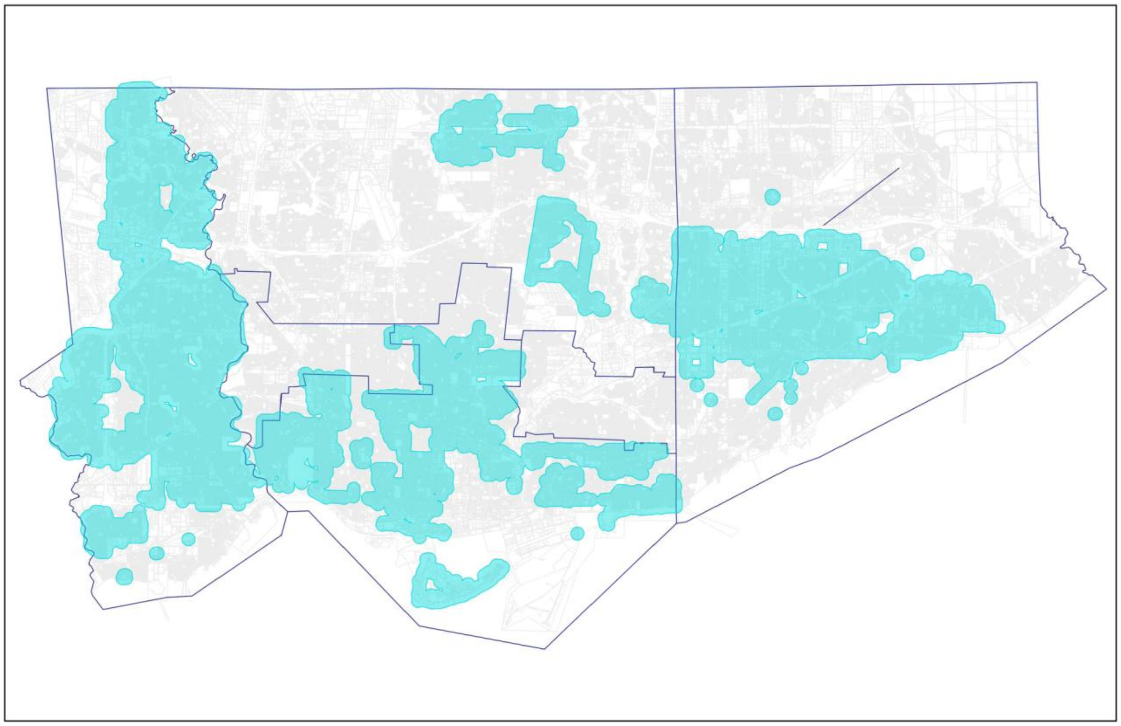

Figure 4: Map of the 4kV component of THESL's distribution system

EV Impacts Assessment

This document presents an assessment of the impacts of Electric Vehicles (EVs) on Toronto Hydro Electric Systems Limited's (THESL) electrical grid. A systematic approach was taken with examination of the distribution system from the station level to the individual neighbourhood transformers. Through such analysis of stations, feeders, transformers and secondary services, the impact from electrical vehicles can be identified and addressed. This enables Toronto Hydro to further develop sustainable infrastructure for the increasing EV population.

Before considering the impact of EVs, there is already a projected load growth of 1% in the horseshoe and 2% in the downtown area over the next 10 years. In addition, numerous reports suggest that the largest EV population growth will occur within the next 10 to 20 years in metropolitan areas. Toronto is one of the most populated cities in Canada and therefore, high EV adoption is expected.

THESL has played a leading role in the development of EV infrastructure development in Toronto. THESL has developed projects such as the Smart Experience and the EV Connections Program to study driving and charging patterns of EV owners in Toronto, helping to determine customer behaviour trends to better prepare for increased EV penetration.

THESL's distribution system has four main configurations, 27.6 kV, 13.8 kV, 4.16 kV, and the secondary network system. The current state of each of these systems is presented in this report, along with the potential capacity to handle electric vehicles.

For the next 10 years, we have an estimated capacity available for 303,081 EVs in the horseshoe area and 103,038 EVs in the downtown core of Toronto. The station level is the bottleneck for EV load growth. This capacity is based on the current 3.3kW (3.5 kVA) charging load of typical EVs. The table below lists the capacity of EV in the horseshoe and downtown area by distribution level.

Table 1: Summary of Available EV Capacity

System	**EV Capacity Available (based on forecast of 10 years)**			
	Station/ Bus Level	Feeder Level	Transformer Level	Secondary Service
Horseshoe Area (Scarborough, North York, East York, York and Etobicoke)	**303,081**	350,881	784,258	Minimal Impact
Downtown Toronto	**103,038**	174,948	212,539	
Total	**406,119**	525,829	996,797	

Station buses that are currently in the danger zone in the horseshoe area can accommodate an estimated 10,000 EV. While in the downtown core, buses in the danger zone have capacity for about 300 EVs over the next 10 years. The figure below illustrates the results from the EMAP study with the projected areas of low/constrained EV capacity within the THESL distribution system.

EMAP Prediction Results with Projected Low EV Capacity Zones
(10-Year Load Projection)

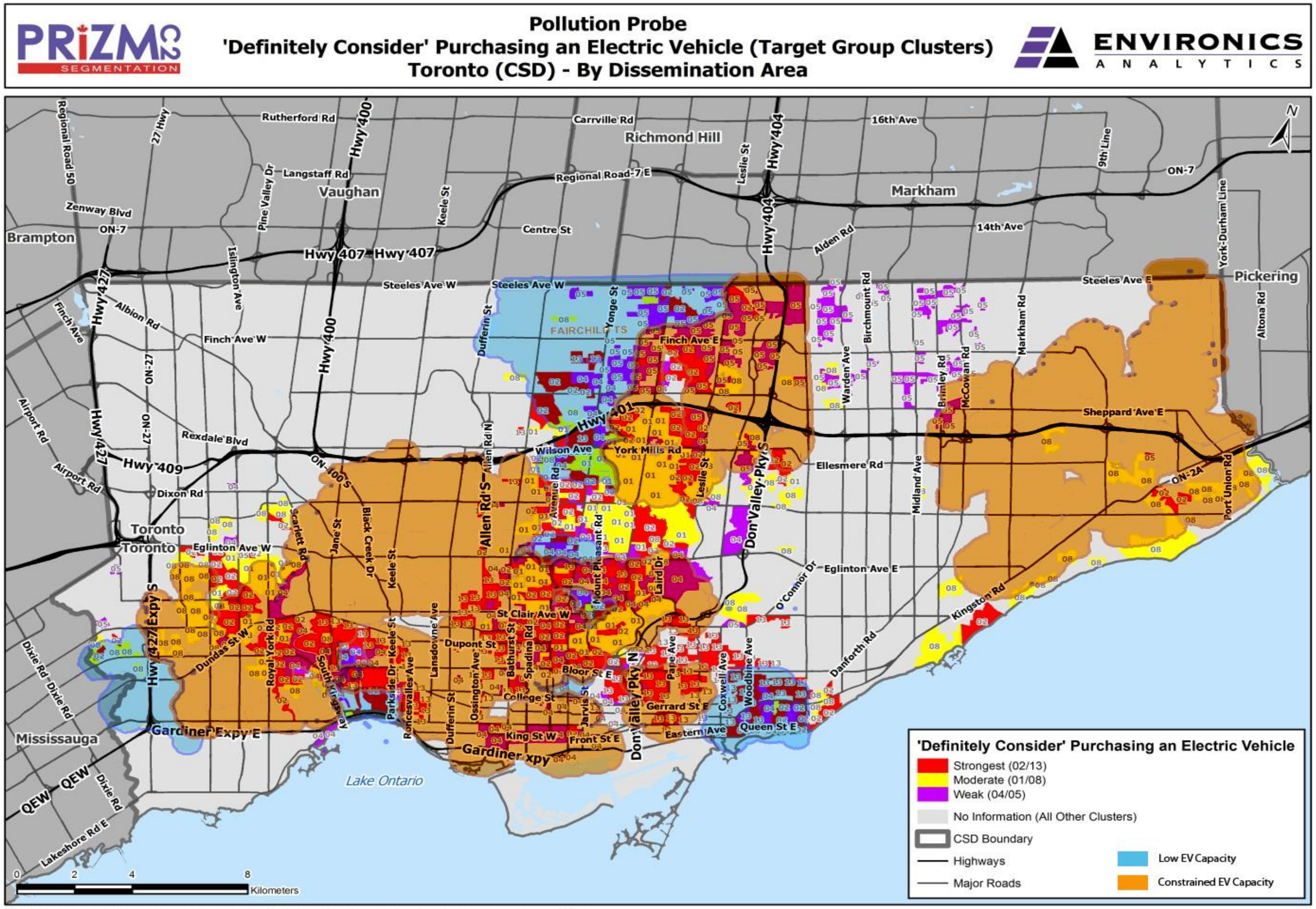

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Figure 5: EMAP Prediction Results with Projected Low EV Capacity Zones

On average 7.5 % of the feeders are overloaded under normal conditions and 26.5 % are overloaded under emergency conditions; and 10% of Pole/Pad/Vault transformers and 8.4% of network transformers under normal conditions are already overloaded. Secondary service cables will have minimal impact by the addition of EV load. Therefore, to handle larger penetration of EVs capital investments in stations, feeders and transformers may be required in certain geographic regions.

Future electric vehicles designs are anticipated to increase the battery size, charger size to deliver longer range. This increase in load will cause a significant reduction of EV capacity in the THESL distribution system. The figure below illustrates the estimated ramp down of EV capacity as charger size increases.

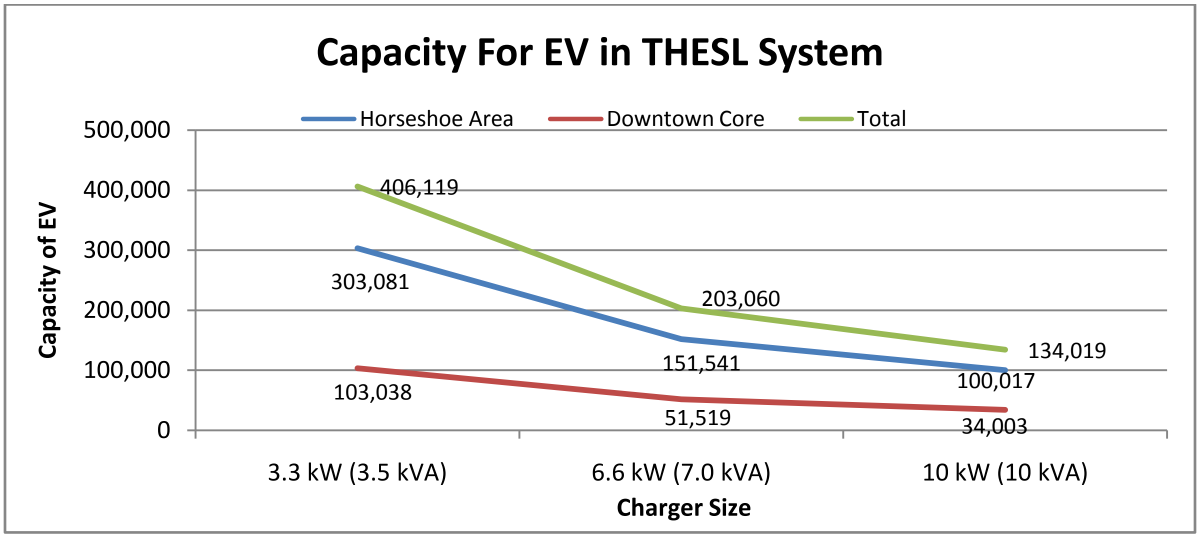

Figure 6: Capacity of EVs in the THESL System as charging rates increase

This report identifies the distribution transformer impact and reveals possible vulnerabilities on the feeder and stations levels as well. This study further improves our understanding of EV impact, and underlines the need to consider limitations of the system at all levels of the distribution grid.

This analysis will enhance THESL’s capital investment planning and mitigate emerging risks. It will also serve to communicate to external stakeholders the current assessment of the THESL distribution system EV impacts.

Figures 7 and 8 illustrate the projected areas with constrained EV capacity in the THESL distribution system.

Projected Stations/Buses with constrained EV Capacity in Horseshoe Area (Station loading >90%) (10 Year Load Projection)

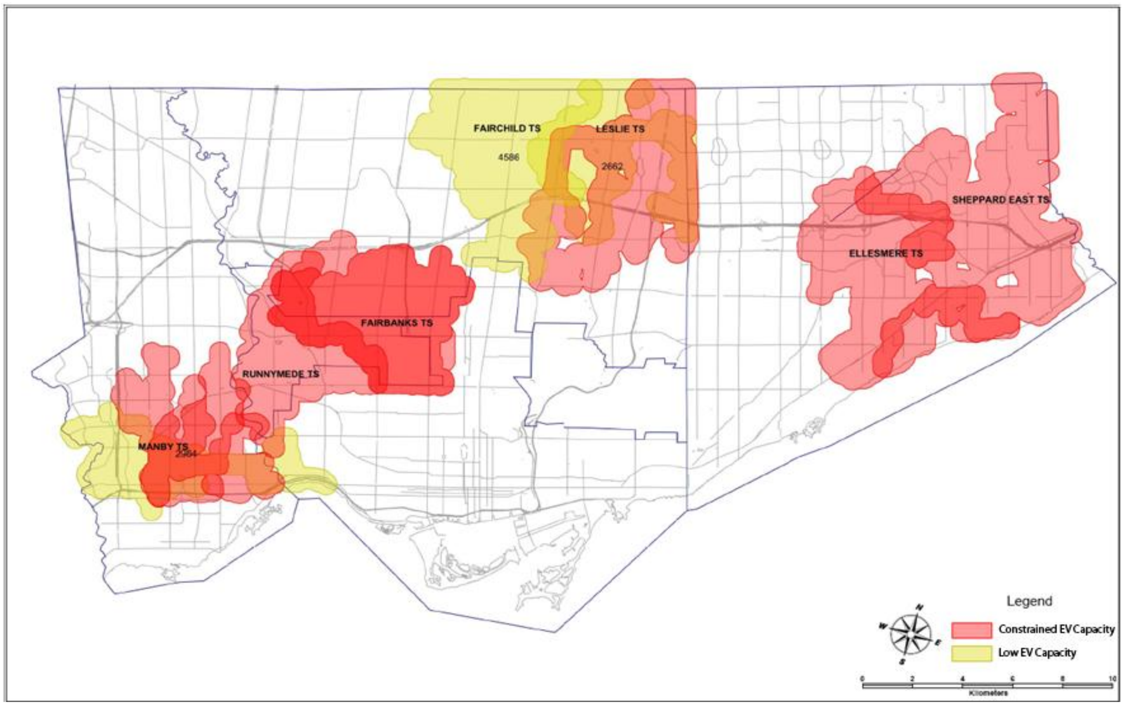

Figure 7: Projected Stations/Buses with constrained EV Capacity in Horseshoe Area (Station loading >90%)

Projected Stations/Buses with Constrained EV Capacity in Downtown Area (Station loading >90%) (10 Year Load Projection)

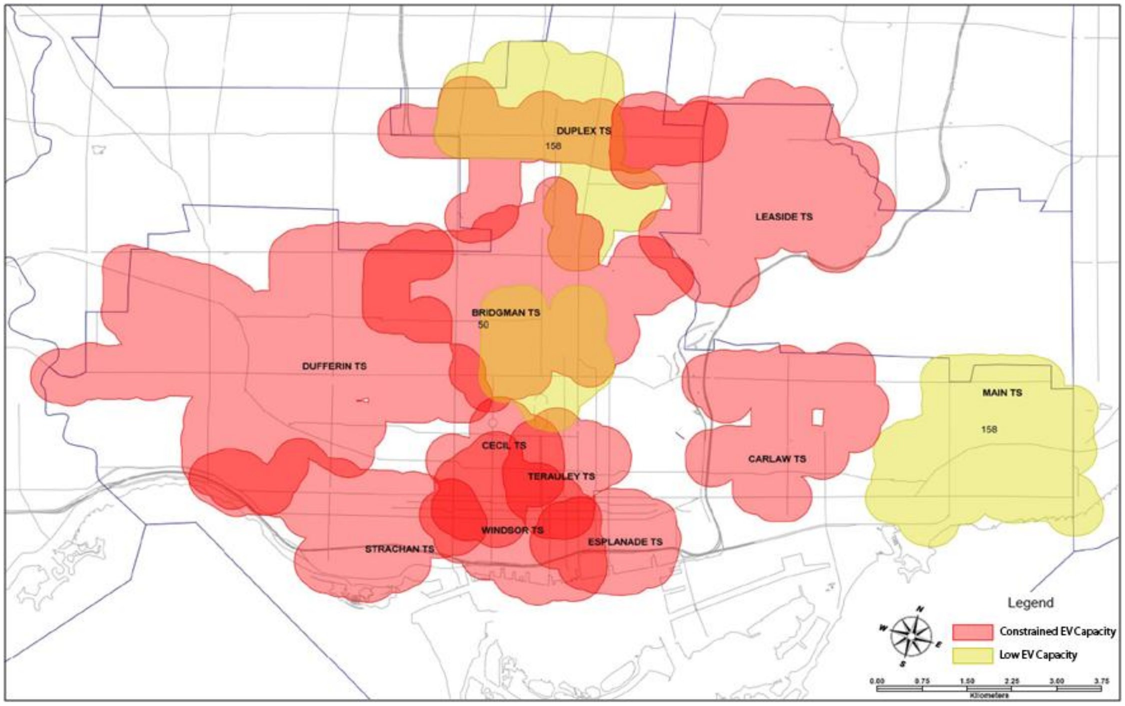

Figure 8: Projected Stations/Buses with constrained EV Capacity in Downtown Area (Station loading >90%)

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