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Gasoline Evaporative Losses from Retail Gasoline Outlets Across Canada, 2009

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Symbols

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- . not available for any reference period
- .. not available for a specific reference period
- ... not applicable
- 0 true zero or a value rounded to zero
- 0s value rounded to 0 (zero) where there is a meaningful distinction between true zero and the value that was rounded
- p preliminary
- r revised
- x suppressed to meet the confidentiality requirements of the *Statistics Act*
- E use with caution
- F too unreliable to be published
- * significantly different from reference category ($p < 0.05$)

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Gasoline Evaporative Losses from Retail Gasoline Outlets Across Canada, 2009

1 Introduction

The Survey of Industrial Processes (SIP) was conducted with one primary objective in mind. To test a methodology for collecting data on operational activities and industrial processes that would facilitate modelling/imputation of pollutant releases from small and medium-sized enterprises across Canada.

As a proof of concept, the SIP pilot focused on the operational activities and industrial processes used in retail gasoline outlets across Canada. Retail gasoline outlets and their associated gasoline vapour emissions were selected in cooperation with Environment Canada as an important data gap. The survey population included retail gas stations as well as marinas with gas docks. It comprised establishments primarily engaged in retailing gasoline fuel whether or not the outlet was operated in conjunction with a convenience store, repair garage, restaurant or other type of operation. Diesel-only outlets and card-locks were excluded from the population. The survey employed standard statistical methods in the collection of data including the design of the survey frame, sample selection, and statistical edits, imputations, and weighting methodologies.[1] Data collected include quantities of gasoline sold, gasoline truck delivery frequencies, number of gasoline storage tanks, number of fuel dispensers, age of site, and other related activities and processes that depict this particular sector of the Canadian economy.[2]

This report presents the modelling method used for the estimation of gasoline evaporative losses derived from the integration of the SIP survey data with a set of mathematical models[3,4,5]. The results presented here should be considered as a proof of concept only and are not intended as official statistical estimates.

The survey results can complement the area source (AS) component of Environment Canada's Air Pollutant Emissions Inventory while the National Pollutant Release Inventory (NPRI) accounts for point sources (PS). The NPRI collates data from a number of sources and presents estimates on the emissions of a number of air pollutants including volatile organic compounds that are the components of gasoline emitted to air. One part of the NPRI collects pollutant release data from establishments/facilities with emissions above given thresholds. The threshold applied to the NPRI limits its statistical coverage. It restricts the inventory to large emitters, leaving out medium and small emitters. These small and medium emitters together could add significantly to Canadian emissions of some pollutants. In light of the above, the SIP was conducted to address some of the data gaps present in the Canadian air emission inventories. Also, due to its bottom-up approach of collecting industry and process data though a survey, the SIP is potentially able to generate pollution estimates at levels of geography down to large cities.

This report is organized as follows. The following section describes gasoline evaporative losses in general and mentions some of the efforts to measure them elsewhere. The sources of evaporative losses from retail gasoline outlets are described next, with specific emphasis on Canadian outlets. The subsequent section presents the data

1. Statistics Canada, Definitions Data Sources and Methods, Survey of Industrial Processes (SIP), Record number *5163* (*www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5163&lang=en&db=imdb&adm=8&dis=2*).
2. Initial results of the survey were released in March, 2011. The release focused on descriptive statistics at the national level including the number of outlets, age distribution of storage tanks, number of storage tanks, and volume of throughputs along with a map allocating the distribution of retail gasoline outlets across Canada. Statistics Canada, March 23, 2011, *"Survey of Industrial Processes: Retail gasoline outlets", The Daily,* (*www.statcan.gc.ca/daily-quotidien/110323/dq110323a-eng.htm*) and Map 1.
3. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
4. US EPA, Document AP 42- Chapter 5, *Transportation and Marketing of Petroleum Liquids, 2006*.
5. Wongwises, S., Chanchlaona, S. and Rattanaprayura, I., *Displacement Losses from the Refuelling Operation of Passenger Cars*, Thammasat Int. J. Dc. Tech., Vol. 2, No. I, 1997.

sources used to generate the illustrative gasoline evaporative loss estimates from retail gasoline outlets across Canada including the initial survey results. The estimates themselves are presented in the ensuing section. An appendix outlines the mathematical models, uncertainties, and the assumptions used to generate the estimates.

2 Gasoline evaporative losses

Gasoline is a mixture of volatile organic compounds (VOC), mostly hydrocarbons that can freely evaporate at ambient temperatures. Retail gasoline outlets contribute to overall VOC emissions across Canada through fuel-related activities carried out on a daily basis. Gasoline contains compounds such as benzene, toluene, and ethylbenze, some of which have adverse impacts on human health. Benzene, for example is a carcinogen that is present in gasoline.[6] According to the United States Environmental Protection Agency (USEPA), the concentrations of benzene, ethylbenzene, toluene, and xylene around homes within 200 meters of retail gas stations are higher than urban background levels.[7] Gasoline vapour, once released to the atmosphere, combines with nitrogen oxides in the presence of sunlight and forms ozone. Ground-level ozone is a component of smog that aggravates respiratory illnesses.[8]

Estimation of evaporative losses from the gasoline distribution network, and in particular from retail gasoline outlets, has been the subject of several studies. For example, the California Energy Commission collects information on all retail fuelling stations located in California through the *California Annual Retail Fuel Establishment Form* which needs to be filled out by these facilities as a mandatory report.[9] Environment Australia estimates the aggregated emissions from service stations using information collected in the Australian *National Pollutant Inventory* (NPI).[10] According to the *European Emission Inventory Guidebook*, the contribution of the gasoline distribution sector to the total man-made non-methane volatile organic compounds emissions ranged from 1.5 % to 6.7%. The reported values apply to all 28 European countries that participate in the inventory.[11]

At the gas station/outlet level, some studies focused on empirical/experimental data while others used theoretical models based on established thermodynamic and gas-liquid equilibrium principles. Mathematical models to correlate the evaporation of gasoline and its components with other relevant factors have been developed and established.[12,13,14,15] The method used to estimate evaporative losses in this report builds upon these earlier studies.

3 Sources of gasoline evaporative losses

Evaporative losses from retail gasoline outlets can be classified into two categories. The first category includes those attributed to the processes and equipment used by the retail outlet to supply the gasoline. The second category includes losses attributed to vehicles being filled (vehicle tank refuelling loss). Following this classification, the sources of gasoline evaporative losses from retail outlets can be detailed as follows:

6. Environment Canada, *Benzene in Gasoline Regulations, Report SOR/97-493*, June 2011 (*http://laws-lois.justice.gc.ca/PDF/SOR-97-493.pdf*).
7. US EPA, Control of Hazardous Air Pollutants from Mobile Sources, Federal Register, Vol. 71, No. 60, March 2006.
8. Kirchstetter, T.W., Singer, B.-E. C. and Arley, R. A, Impact of California Reformulated Gasoline on Motor Vehicle Emissions, 2, Volatile Organic Compound Speciation and Reactivity, *Environ. Sci. Techno* 1999, Vol. 33, pp. 329-336.
9. California Energy Commission, California Annual Retail Fuel Establishment (Form CEC-A15), 2007 (*www.energy.ca.gov/2005publications/CEC-600-2005-032/CEC-600-2005-032-SF-RETAIL.PDF*).
10. Environment Australia, *Emissions Estimation Technique Manual for Aggregated Emissions from Service Stations*, November 1999.
11. *European Emission Inventory Guidebook, Gasoline Distribution* (Activities 050501– 050503), 1999.
12. Shine, B., *Methods for Estimating Volatile Organic Compound Emissions from Batch Processing Facilities*, J. Cleaner Prod., Vol. 4, No. 1, pp. 1-7, 1996.
13. Schifter, I., Daz, L., Vera, M., Castillo, M., Ramos, F., Avalos, S., and Lopez-Salinas, E., Impact of Engine Technology on the Vehicular Emissions in Mexico City, Environ. Sci. Technol., Vol. 34, No. 13, pp. 2663-2667, 2000.
14. Peress, J., *Estimate Storage Tank Emissions, Chemical Engineering Progress*; Vol. 97, No. 8, p. 44, August 2001.
15. Williams, G.P., and Gold, L.W., National Research Council Canada, 1976 (*www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/building-digest-180.html*).

3.1 Losses from standard operations of a retail gasoline outlet

3.1.1 Storage tank losses

Working loss in gasoline storage tanks is due to the combined effects of gasoline delivery to the storage tanks (the filling of storage tanks) and the emptying operation (the pumping of gasoline from storage tanks to the dispensers/gas pumps). During the filling of storage tanks, fuel vapours are released to the atmosphere due to the increased liquid level in the tank pushing up and reducing the vapour space in the tank. This space is also called outage space or headspace.

The vapour is consequently compressed in the tank, forcing the air-vapour mixture out through a vent pipe. If the tank is equipped with a pressure/vacuum valve on its vent pipe, vapours are released only when the pressure inside the tank exceeds the valve relief pressure. In the absence of such valves, as is the case in most of Canada,[16] any increase of tank pressure above atmospheric levels will release the vapours through the open vent pipe. The absence of such pressure/vacuum (P/V) valves on the storage tank vents of Canadian retail gasoline outlets was traditionally based on the consensus that P/V valves may freeze during the winter season, risking the implosion of storage tanks. This has freed retail gasoline outlets from the mandate of installing P/V valves and left the choice to do so to their own discretion.

In some parts of Canada, tanker truck drivers who deliver gasoline to retail gasoline outlets are required by law to attach a second hose to the storage tank while refilling it to capture part of the air-vapour mixture that would have otherwise escaped from the vent pipe. This is called vapour balancing. The effectiveness of this particular “second-hose” vapour recovery method (that is, vapour balancing) in the absence of a P/V valve on the vent pipe of a tank is uncertain. Although some reports claim 90% recovery, these reports have mostly assumed the presence of a P/V valve or some sort of an orifice restriction during gasoline tanker truck deliveries.[17,18]

Two methods are commonly used in filling storage tanks in retail gasoline outlets: splash filling and submerged filling. Significant liquid turbulence and vapour/liquid contact occur during a splash filling operation, resulting in high levels of vapour generation and subsequently high evaporative losses through the vent pipe. In submerged filling, the drop tube extends close to the base of the storage tank with fresh fuel being dispensed below the original liquid surface level. Liquid turbulence is thus controlled, resulting in much lower vapour generation and less evaporative losses than in the case of splash filling method.

According to the SIP results, there are some 29,000 retail gasoline storage tanks across Canada and it is reasonable to assume that not all of them are equipped with submerged fill pipes. How many are so equipped is unknown, since respondents to the SIP were not asked for this information. None of the outlet operators could answer this particular question during the testing of the draft questionnaire, so the question was not included on the final questionnaire. For this reason, an uncertainty algorithm that includes both submerged and splash filling was applied in calculation of the evaporative loss estimates.

Since dirt particles tend to settle at the bottom of storage tanks, the length of submerged tubes is such that they reach approximately 6 to 12 inches above the bottom of the tank in order to prevent settled particles from being agitated. It is assumed here that at the outset of any filling operation some splash filling occurs, while gradually the filling operation becomes fully submerged.

The estimation method used in this study uses a ratio to account for the application of such hybrid filling (splash and submerged). A ratio was estimated based on the assumption that the fill pipe is 12 inches above the bottom of the tank and the level of gasoline in an “empty” tank is always 6 inches from the base; that is, no storage tank is

16. Based on site visits, observations, P/V valve distributers and consultation with colleagues from Environment Canada.
17. Klimont, Z., *Emission Inventory Guidebook*, Gasoline Distribution Activities 050501 – 050503, IIASA, Austria, 1999.
18. Canadian Council of Ministers of the Environment, Environmental Code of Practice for vapour recovery in gasoline distribution networks, CCME-EPC-TRE-30E, 1991. Note: Section 5.3.1 of this code highlights the fact that the performance of the “second hose” of the tanker truck would result in 90% reduction of gasoline vapours normally emitted during underground tank refuelling (working loss). The same code indicates that achieving such a percentage recovery may be subject to the application of a P/V valve. The code then underlines a cautionary statement indicating that P/V valves may freeze in cold weather and may cause tank collapse during vehicle refuelling or may produce enough back pressure on the system to cause back flow and spills of gasoline. In the absence of empirical data on the vapour recovery efficiency of the second hose alone without a P/V valve, this study assumes, and in consultation with Environment Canada, 50% vapour recovery rather than the 90% recovery as outlined in CCME-EPC-TRE-30E without relevant supporting documents or data.

completely emptied before its next filling. This provides a 6-inch empty space that is always associated with splash filling.

Gasoline pumping activities during the refuelling of vehicles also contribute to the working loss in storage tanks. This occurs due to air being drawn through the vent pipe into the storage tanks as a result of the decrease in storage tank liquid level while pumping out gasoline. Once again this action is more pronounced in storage tanks that are not equipped with a pressure/vacuum valve on their vents as a control measure. Any additional entrained air becomes saturated with gasoline vapours and subsequently expands. The expanded air-vapour mixture exceeds the vapour holding capacity of the storage tank and is consequently expelled back to the atmosphere through the same vent pipe.

Gasoline evaporation due to working loss from retail gasoline outlets is estimated based on a USEPA model described in Appendix I.

Breathing loss (also known as standing loss) is due to the release of gasoline vapour to the ambient air due to the expansion and contraction of vapour inside storage tanks. The breathing loss results from changes in the temperature and pressure inside and outside of the storage tank. Breathing loss occurs irrespective of changes in the liquid level inside the tank.

Gasoline storage tanks are exposed to changes in temperature, pressure and, in the case of aboveground tanks, to solar radiation. As a result, the mixture of trapped air and gasoline vapour inside the tank undergoes passive heating and cooling cycles. This causes expansion and contraction of the vapour mixture, resulting in the release of vapour to the surrounding environment. In the absence of a control measure such as a P/V valve, this “breathing process” continues as long as there is some gasoline liquid inside an open-vent tank.

Since changes in temperature and pressure are less pronounced for underground tanks due to the protective and insulating effects of soil, the USEPA does not associate breathing loss with underground storage tanks. This is, in part, justifiable for several reasons. One reason is that most cities in the USA are in climates where the difference between the ambient air and the underground temperature is less pronounced than in most Canadian cities. Also underground tanks in the USA are generally equipped with vent pipes that have P/V valves with pre-set pressure and vacuum settings to control the breathing activity. As mentioned earlier, P/V valves are not common in Canada.[19] Instead, Canadian storage tanks generally employ valve-free vent pipes that are open to the atmosphere. In light of the above, unlike in the USA, breathing losses in Canadian underground gasoline tanks should be included in the evaporative loss estimates regardless of the partially insulating effects of being underground. Consequently, the estimates of evaporative losses reported here include breathing losses for both underground and aboveground storage tanks.

In the case of underground tanks, the effect of solar radiation was removed from the calculation and only the impact of temperature was included. The difference between air temperature inside an underground tank and that of the ambient air temperature outside was estimated to be 8 degrees Celsius during the cold season [20] and 12 degrees Celsius during the warm season.[21,22] These parameters were used in estimating breathing losses in underground gasoline storage tanks across Canada.

Gasoline evaporation from retail gasoline outlets due to the breathing loss is estimated based on a USEPA model described in Appendix I.

3.1.2 Residual losses

Operations and activities that involve opening the lids of gasoline storage tanks trigger the release of gasoline vapours to the atmosphere. Gasoline vapours accumulate in the headspace above the liquid gasoline level of tanks. This activity, though a minor contributor, is nonetheless an extra source of evaporative losses in retail gasoline outlets.

19. Canadian Council of Ministers of the Environment, *Environmental Code of Practice for vapour recovery in gasoline distribution networks*, CCME-EPC-TRE-30E, 1991.
20. In the evaporative loss estimates, cold season was assumed to be from October to March.
21. In the evaporative estimates, warms season was assumed to be from April to September.
22. Williams, G.P., and Gold, L.W., National Research Council Canada, 1976 (*www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/building-digest-180.html*).

Lids of gasoline tanks are regularly opened by the operators of the outlet to check the level of gasoline and for the presence of water in the tanks. Storage tank lids are also regularly opened by the gasoline delivery personnel during their filling operations. However, since Canadian gasoline storage tanks are generally open-vented tanks (that is, no P/V valves on the vents), any evaporative losses from opening the tank lids are minute. To that end, evaporative losses from this particular activity were considered negligible for the purposes here.

Monitoring also involves inserting a wooden dipstick into the storage tanks to measure the gasoline liquid levels and to check for the presence of water. The measurement of gasoline level and water monitoring in storage tanks is carried out on a regular basis. The measurement of gasoline level is conducted by both the operator of the retail outlet and the gasoline delivery personnel, independently. It involves the immersion of a graduated wooden stick into the liquid inside the tanks to determine the level of gasoline. In addition, operators use the wooden stick to check for the presence of water at the base of the tank by placing a special paste at the tip of the stick and observing any change in the colour of the paste.

Monitoring losses from dipsticks occur due to the evaporation of gasoline that has been adsorbed on the wooden surface of the dipsticks. These dipsticks are subsequently placed in the open air, causing the evaporation of adsorbed gasoline on the surfaces of these wooden sticks into the atmosphere. Fixed electronic level-monitoring devices are also available and are commonly used in many retail gasoline outlets across Canada, although the use of dipsticks remains common by gasoline delivery personnel verifying their deliveries.[23] Based on the activity data collected from the SIP and a laboratory experiment, the reported evaporative loss estimates have incorporated an empirical model to estimate losses from the use of dipsticks.

Gasoline evaporation from retail gasoline outlets due to monitoring losses related to the application of dipsticks are estimated based on an empirical model described in Appendix I.

A residual loss is any uncontrolled leak/spill that occurs from dispensers. Part of this residual loss is from nozzle spills. Since absorbents are mainly used by retail gasoline operators to clean up after this particular type of spill, it is assumed that the amount of such spills is correlated with the quantity of absorbents used. Note that at marinas with gas docks absorbent use is limited and as such any calculated residual loss at these facilities can be almost entirely attributed to leaks/spills at the dispenser.

Gasoline evaporation from retail gasoline outlets due to the residual loss is estimated based on USEPA emission factors and on an empirical model based on the capacity of absorbents to hold gasoline and the amount of absorbents used at the outlets as reported in the SIP. Both the emission factors and the empirical model are described in Appendix I.

3.2 Losses from the refuelling of vehicles

Refuelling emissions occur when vapour from the headspace of a vehicle fuel tank is displaced by the liquid gasoline that is dispensed into the fuel tank. The volume of displaced vapour during the refuelling operations is equal to the volume of gasoline dispensed into the vehicle fuel tank, plus the entrapped droplets of liquid fuel as a result of splashing and turbulence during filling which are subsequently released as vapour. The quantity of displaced vapours depends on the temperature of gasoline in the vehicle fuel tank, temperature of dispensed gasoline, gasoline Reid vapour pressure (RVP), and the dispensed volume of gasoline. The volume of vapour released during refuelling also depends on the vapour recovery method used. In the USA, many dispensers at retail gasoline outlets incorporate vacuum-based nozzles as a vapour recovery method. In the USA they also rely on the on-board vapour recovery (OBVR) system installed inside vehicles. In Canada, only the latter has been applied as the vapour recovery system during vehicle refuelling.[24] In fact, the combined use of the two methods could defeat the purpose since the former method counters the effectiveness of the latter.[25] In Canada, OBVRs have been installed in all newly manufactured

23. Based on an interview with a veteran gasoline truck delivery person working in Quebec and Ontario, site visits, and observations conducted by the SIP survey team; gasoline truck delivery personnel have a standard operating procedure to use the dipstick as a tool to confirm and record fuel deliveries.
24. Environment Canada, *Clean Air in Canada, Progress Report on Particulate Matter and Ozone, 2003*. Cat. no. En40-886/2003E (*www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&xml=93327F5F-59FF-3718-88E7-A338615E427E*).
25. US EPA, *Stage II Vapor Recovery Systems Issues Paper*, Office of Air Quality Planning and Standards Emissions Monitoring and Analysis Division Emissions Factors and Policy Applications Group (D243-02), August, 2004 (*www.epa.gov/ttnnaaqs/ozone/ozonetech/stage2/isspaper081204.pdf*).

vehicles since 1998. OBVRs are up to 98% efficient in capturing evaporative losses during a refuelling operation.[26] However, to account for operational and efficiency degradation of the OBVR systems, a recovery efficiency range of 90±5% was set for OBVRs for use in calculating the estimates reported here.

For evaporative loss estimates, a percentage of OBVR penetration based on the age of Canadian vehicles was used. Based on data from Environment Canada,[27] this percentage was estimated at 70±5% for the year 2009.

Evaporative losses due to the refuelling of vehicles are estimated based on a USEPA model described in Appendix I.

4 Data sources

4.1 Survey data

The SIP pilot was the main source of the data used in this study.[28] For the 2009 reference period, the SIP pilot survey covered all retail gasoline outlets, including marinas with gas docks, across Canada. All data referenced in this section are from the 2009 SIP pilot unless otherwise noted.

According to a National Retail Petroleum Site Census published by MJ Ervin and Associates, two decades ago there were over 21,000 retail gasoline outlets across Canada.[29] In 2009, there were fewer than 11,300 gasoline outlets in operation.

In 2009, approximately 40.7 billion litres of gasoline were sold at retail outlets across Canada (Table 1). Based on an average delivery of approximately 35,000 litres, it is estimated that over 1.1 million gasoline deliveries were needed to support the gasoline consumption of vehicles in Canada in 2009.

26. US EPA, *Stage II Vapour Recovery Systems*, Office of Air Quality Planning and Standards Emissions Monitoring and Analysis Division, Emissions Factors and Policy Applications Group (D243-02), August, 2004.
27. Environment Canada, *Special Request Estimate, 2009*.
28. Statistics Canada, March 23, 2011, "Survey of Industrial Processes: Retail gasoline outlets, 2009," *The Daily* (*www.statcan.gc.ca/daily-quotidien/110323/dq110323a-eng.htm*)
29. MJ Ervin and Associates, National Retail Petroleum Site Census, 2009.

Table 1
Survey of Industrial Processes – Retail Gasoline Outlets, 2009

	Estimates [2]
General Statistics [1]	
Outlets, deliveries, and volume	
Total number of retail gasoline outlets	11,262 A
Total number of gasoline truck deliveries	1,152,425 A
Average volume of gasoline sold per outlet (litres)	3,616,752 A
Above and underground storage tanks	
Total number of gasoline tanks	29,011 A
Average gasoline storage capacity per outlet (litres)	81,887 A
Dispensers (Pumps)	
Total number of dispensers	43,250 A
with mechanical display (percent)	13 A
with digital display (percent)	87 A
Service at the pump	
Self-service (percent)	54 A
Full service (percent)	30 A
Split service (percent)	16 A
Pay-at-the pump (percent)	46 A
Cleaning nozzle-spills at the pump	
Total amount of absorbent [3] used(kilogram)	286,366 B
Employment at the pump	
Total number of part-time employees	50,597 A
Total number of full-time employees	48,195 A

1. Outlets serving gasoline motor fuel including marinas with gas docks; excluding card locks/diesel-only outlets
2. Estimates contained in this table have been assigned a letter value to indicate the quality of the estimate. These quality indicators are represented by the coefficient of variation (expressed as a percentage). Class A = Excellent (0.0% to 4.9%); Class B = Very good (5.0% to 9.9%); Class C = Good (10.0% to 14.9%), Class D = Acceptable (15.0% to 24.9%); Class E = Use with caution (25.0% to 49.9%), Class F = Too unreliable to be published (more than 49.9% data are suppressed).
3. A granular substance typically used to absorb small accidental nozzle spills.

Source(s): Statistics Canada, Environment Accounts and Statistics Division, Survey of Industrial Processes, 2009, survey no. 5163.

4.2 Spatial data

A map representing the spatial distribution of gasoline outlets across Canada was created by using the postal code of each outlet to estimate its latitude and longitude. In major cities, this allocation method rendered a spatial distribution with a good accuracy. In less populated areas where postal codes cover larger areas, this method, though less accurate, was acceptable for the purposes here (See Map 1).

4.3 Meteorological data

Based on proximity to a meteorological station, retail outlet/site specific ambient temperatures (average, maximum, and minimum for warm and cold seasons, 2009, respectively) were obtained from Environment Canada.[30] Solar radiation values (average peak summer and winter) were extracted from the National Atlas of Canada[31] and digitized/mapped over the locations of gasoline retail outlets across Canada using geographical information system technology.

30. Environment Canada, Special Tabulation 2009, Weather and Environmental Monitoring, Meteorological Service of Canada, 2011 (*www.climate.weatheroffice.gc.ca*).
31. Natural Resources Canada, 1978–1995, *The Atlas of Canada, 5th edition* , "Solar Radiation: December and June (1956 to 1978)" (*http://atlas.nrcan.gc.ca/site/english/maps/archives/5thedition/environment/climate/mcr4077*).

4.4 Reid vapour pressure data

Reid vapour pressure for gasoline deliveries during cold and warm seasons were supplied by Environment Canada[32] and values were mapped and matched to respective retail gasoline outlet locations using geographical information system technology.

5 Results and estimates: evaporative losses

Data from the SIP were used along with the models described in the appendix I to calculate an estimate for gasoline evaporative losses for each retail gasoline outlet that reported to the SIP. The estimates addressed evaporative losses associated with on-site gasoline truck deliveries, storage tanks, vehicle refuelling, and other activities/processes and control measures related to retail gasoline outlets. Each individual evaporative loss estimate was weighted so that all of the individual estimates taken together represented the entire population of retail gasoline outlets across Canada. Sample weights were based on the statistical methodology employed in the SIP.[33]

5.1 Gasoline outlets across Canada

In 2009, approximately 58.3 million litres of gasoline (in liquid equivalents) was evaporated from some 11,200 retail gasoline outlets across Canada. This is equivalent to the contents of one full tanker truck evaporating approximately every 8 hours.

Table 2
Evaporative losses from retail gasoline outlets in Canada, 2009

	Evaporative losses
	litres
Total evaporative losses [1]	**58,300,000** [2]
Operational losses, outlets [3]	37,300,000 [4]
Refuelling losses, vehicles [5]	21,100,000 [6]

1. Including on-road gasoline outlets and marinas with gas docks (excluding card locks and diesel only outlets).
2. 57,000,000 to 59,700,000 litres (90% confidence interval).
3. Evaporation from gasoline storage tanks and related residual spills associated with the operation of an outlet.
4. 36,200,000 to 38,300,000 litres (90% confidence interval).
5. Evaporation from vehicles (cars and boats) and their gasoline tanks during gasoline fill ups.
6. 20,200,000 to 22,000,000 litres (90% confidence interval).

Source(s): Statistics Canada, Environment Accounts and Statistics Division, Survey of Industrial Processes, 2009, survey no. 5163.

5.1.1 On-road retail gasoline outlets

The following table presents a breakdown of gasoline evaporative losses from on-road gasoline outlets alone. Two-thirds of evaporative loss was due to the refilling of the 29,000 retail gasoline storage tanks that were in operation during 2009. The remaining third was from the refuelling of gasoline vehicles themselves.

32. Environment Canada, April 2007, *Study on Gasoline Vapour Recovery in Stage I Distribution Networks in Canada, Final Report 0514676*.
33. Statistics Canada, Definitions Data Sources and Methods, Survey of Industrial Processes (SIP), Record number *5163*, (*www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5163&lang=en&db=imdb&adm=8&dis=2*).

Table 3
Estimates of evaporative losses from on-road retail gasoline outlets in Canada, 2009

	Evaporative losses
Operational losses, outlets (litres)	**37,200,000** [1]
Evaporative losses from working [2] and breathing [3] of storage tanks (percent)	88
Residual losses [4] (percent)	12
Refuelling losses, vehicles [5] (litres)	**21,000,000** [6]

1. 36,600,000 to 37,700,000 litres (90% confidence interval).
2. Losses due to the regular filling up of storage tanks by gasoline tanker trucks.
3. Losses due to changes in temperature and pressure.
4. Losses due to typical daily leaks and spills.
5. Losses from vehicles' own gasoline tanks while refuelling.
6. 20,600,000 to 21,400,000 litres (90% confidence interval).

Source(s): Statistics Canada, Environment Accounts and Statistics Division, Survey of Industrial Processes, 2009, survey no. 5163.

5.1.2 Marinas with gas docks

In 2009, gasoline evaporative losses from all Canadian marinas with gas docks totalled 157,000 litres. This accounted for 0.3% of total national retail gasoline evaporative losses.

Table 4
Estimates of evaporative losses from marinas with gas docks in Canada, 2009

	Evaporative losses
Operational losses, outlets (litres)	**109,000** [1]
Evaporative losses from workingand breathing of storage tanks (percent)	96
Residual losses (percent)	4
Refuelling losses, boats (litres)	**48,000** [2]

1. 107,000 to 111,000 litres (90% confidence interval).
2. 47,300 to 48,600 litres (90% confidence interval).

Source(s): Statistics Canada, Environment Accounts and Statistics Division, Survey of Industrial Processes, 2009, survey no. 5163.

6 Concluding remarks

The SIP was designed as a pilot test of the use of economic and operational data collected through a statistical survey in the estimation of the release of certain criteria air contaminants (CACs) from small and medium-sized enterprises (SMEs) within a given sector of the Canadian economy.

As a proof of concept, the SIP pilot focused on the operational activities and industrial processes used in retail gasoline outlets across Canada. Retail gasoline outlets and their associated evaporative losses were selected in cooperation with Environment Canada as an important data gap.

The resulting estimates of gasoline evaporative losses compare well with Environment Canada's estimates once uncertainties are included. Environment Canada has estimated that the VOC emissions from the retail gasoline sector were approximately 68 million litres [34] in 2009 with a qualitative uncertainty of 25%.[35] This estimate overlaps statistically with that based on the SIP results (58 million litres with a quantitative uncertainty of 2.5% at 90% confidence level).

34. Environment Canada, Special Tabulation 2010, Pollution Data Division, Science & Risk Assessment, Science and Technology Branch (*www.ec.gc.ca/npri*).
35. Verbal communication with Environment Canada, 2011.

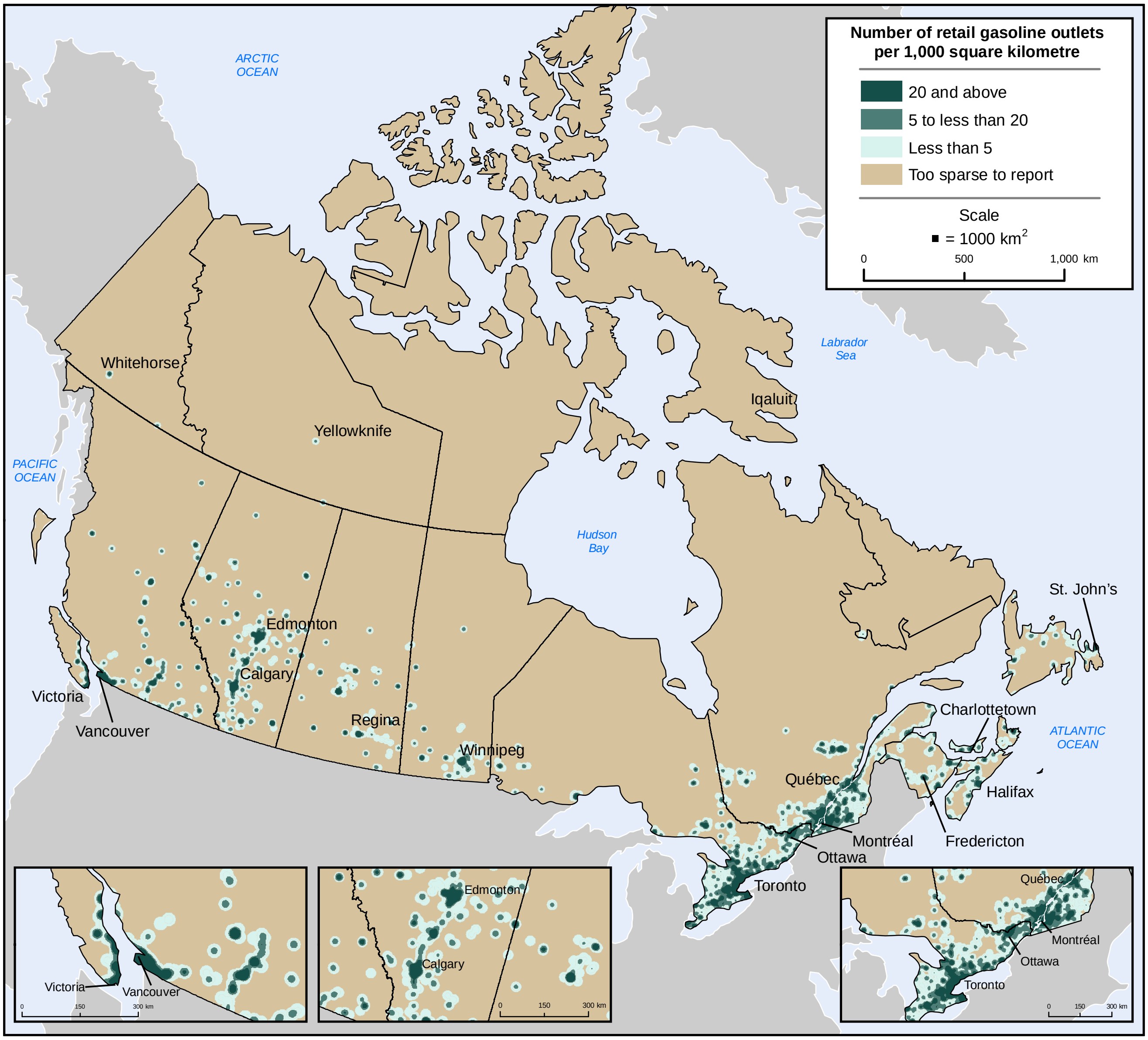
Although the two estimates were produced using different models in terms of scale and approach, the overlap in the two estimates is promising. The SIP, using a detailed bottom-up approach to estimate evaporative losses, has statistically validated the aggregated top-down approach of Environment Canada. The latter used total national gasoline sales with relevant emission factors and temporal adjustments.

The advantage of the SIP is in its statistical basis, with a broad population coverage, statistical weights, and quantifiable uncertainties. The SIP provides a rich pool of microdata from which pollution estimates can be generated at a much finer level of geography than is currently possible in the national pollutant inventory; for example, at the large city level. This in turn facilitates the generation of pollution concentration gradients across regions; that is, those with more stringent gasoline delivery regulations versus those with less stringent regulations to help compare the effects of regulations as they vary from location to location or province to province.

In addition, the detailed data collected by the SIP in terms of economic and operational activities, industrial processes and equipment offers the ability to generate different emission scenarios by changing assumptions around, for example, gasoline outlet operational practices or regulations.

It is an open question whether a similar outcome could be achieved for other industries and other pollutants. Further work would be required to identify existing emission models and/or develop new ones and additional industrial process surveys would be required to collect the necessary operational and process data. At the moment, this remains work for the future.

Map 1
Survey of Industrial Processes - Retail Gasoline Outlets, 2009



Source(s): Statistics Canada, Environment Accounts and Statistics Division, 2009, special tabulation.

Appendix I — Evaporative loss algorithm

The following presents the mathematical models used in estimating gasoline evaporative losses from retail gasoline outlets across Canada. Original units as reported in the literature were used in the evaporative loss algorithm (ELA) and converted as relevant using conversion factors.

A Monte Carlo simulation combining a number of uncertainties in the data has been applied in the generation of confidence intervals for the estimates reported. The uncertainties are described below.

The assumption for the efficiency of vapour recovery by the vapour balance (VB) system (the second hose connected to the storage tank by the truck operator during gasoline delivery) was set at 50% (±15%). This recovery efficiency is lower than the commonly reported value (greater than 90%) due to the absence of P/V valves on Canadian gasoline storage tanks. Based on site observations and expert opinions (including a discussion with an experienced gasoline truck delivery operator) and due to the absence of empirical data on the efficiency of VB systems while refilling storage tanks with no P/V valves, a recovery range from 35% to 65% was assumed reasonable.

In consultation with Environment Canada, the assumption for the penetration rate (use) of VB systems during gasoline deliveries was set at 90% (±10%) for gasoline outlets located in the Lower Fraser Valley, B.C.; Montreal, Que. and Southern Ontario and at 5% (±5%) for gasoline outlets located elsewhere across Canada.[1]

The assumption for the efficiency of vehicle on-board vapour recovery (OBVR) systems was set at 90% (±5%). This is slightly lower than the 98% recovery efficiency reported in the literature. The efficiency was lowered to account for the degradation of the recovery efficiency as vehicles age. A range between 85% and 95% was assumed reasonable.

In consultation with Environment Canada, the assumption for the OBVR system penetration rate was set at 70% (±5%).[2]

No data are available to support the assumption of submerged filling for all Canadian storage tanks. Therefore, two assumptions were made for the percent splash vs. non-splash (submerged) filling of gasoline storage tanks; a best-case scenario (95% submerged fill) and a worst-case scenario (5% submerged) in terms of evaporative losses. Both scenarios were applied in the ELA, to take into consideration the uncertainty on this particular activity.

The assumption for the percent variability in any reported gasoline throughputs by SIP respondents was set at ±25% of the reported values.

The assumption for the percent uncertainty in the volume and number of deliveries in warm season versus cold season was set at ±20% of the reported values.

1. Communications with colleagues at Environment Canada with expertise in this domain, 2011.
2. Communications with colleagues at Environment Canada with expertise in this domain, 2011.

Working loss

The following equation was used for the estimation of working loss from underground and aboveground gasoline storage tanks:[3]

(1) $WL = (0.0010)\ Q\ M_V\ P_{VA}\ K_N\ K_P$

Where:

WL	= storage tank working loss (lb/year)[4,5]
Q	= annual net gasoline throughput (bbl/year)
M_V	= gasoline vapour molecular weight (lb/lb-mole)
P_{VA}	= vapour pressure at daily average liquid surface temperature (psia)
K_N	= working loss turnover (saturation) factor, dimensionless;
K_P	= working loss product factor, dimensionless; see below
0.0010	= integrated conversion factor to yield the units of lb/year for the working loss
Q	The annual net gasoline throughput as reported by the respondents of the survey.[6]
M_V	The gasoline vapour molecular weight (M_V) was calculated by using equation (2)

(2) $M_V = 63 + 0.1053\ (T-15.55)$

Where:

T = site specific mean daily temperature during warm and cold season, respectively (°C); Site-specific ambient temperature data were supplied by Environment Canada.

P_{VA} The vapour pressure of gasoline at daily average liquid surface temperature was calculated using equation (3):[7]

(3) $P_{VA} = \mathrm{Exp}\ ((0.7553 - (413/(T+459.6)))\ S^{0.5})\ \log(RVP) - (1.854-(1042/(D29+459.6)))\ S^{0.5}) + ((2416/\ (T+459.6))-2.013)\ \log\ (RVP) - (8742/\ (T+459.6))\ +15.64)$

Where:

P_{VA}	= vapour pressure of gasoline at daily average liquid surface temperature (psia)
T	= temperature (°F)
RVP	= Reid vapour pressure (psia)
S	= slope of the ASTM distillation curve at 10 percent evaporation (% °F)
RVP	= Reid vapour pressure (RVP) for Canadian cities, obtained from Environment Canada.[8]

3. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
4. Several retail gasoline outlets across Canada sell bio-ethanol fuel. The use of bio-ethanol which consists of gasoline containing a certain percentage of ethanol has an impact on the magnitude of emissions. The percentage change in emissions from the use of bio-ethanol has been estimated from the following regression equation developed from the data presented in: Murrells, T. and Li, Y. AEA energy and Environment, UK Emissions Inventory Stakeholder Meeting, September 2008, Y = 0.0113x2 - 0.9698x + 102.54; where: Y = Percentage change in emissions, X = Percentage bio-ethanol in fuel (as reported in the SIP pilot survey).
5. The filling of storage tanks was assumed to consist of 5% splash filling and 95% submerged filling. A ratio of 11.5/7.3 was used in the ELA, representing the ratio of the US EPA emission factors for the two respective filling methods without the implementation of any vapour recovery systems. The value 11.3 is the emission factor in units of (lb VOC)/(1,000 gallon throughput) for splash filling of gasoline tanks without any vapour recovery, while the value 7.3 is the emission factor in units of (Ib VOC)/(1,000 gallon throughput) for submerged filling of gasoline tanks without any vapour recovery. The ratio 11.5/7.3 represents the increased percentage of emissions due to partial splash filling compared to full submerged filling.
6. The estimation of emissions has been made for the warm and cold seasons independently, using the physical properties of gasoline and the amount of gasoline deliveries during each season. In case of uncertainty in the gasoline delivery frequencies in the warm and cold seasons, the ratio of 1.2/0.8 was assumed for the frequency of warm season/cold season delivery. Accordingly, it is assumed that higher deliveries take place in the warm season compared to the cold season. This was found to be the more common trend across Canada, specified by the respondents of the survey.
7. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
8. Environment Canada, April 2007, *Study on Gasoline Vapour Recovery in Stage I Distribution Networks in Canada, Final Report 0514676*.

S = Distillation coefficient, the USEPA's average value of 3 for S was used.[9]
K_N The working loss turnover (saturation) factor (K_N) was estimated from the following USEPA model:[10]

For turnovers per year (N) > 36

(4) $K_N = (180 + N)/6N$

For turnovers per year (N) ≤ 36

(5) $K_N = 1$

N The turnover rate is estimated using equation (6):

(6) $N = 5.614\ Q_1/V_{LX}$

Where:

Q_1 = annual net gasoline throughput (bbl/year)
V_{LX} = storage tank working volume (gallon or litre, converted as appropriate); V_{LX} was estimated from equation (7);

(7) $V_{LX} = V_{total} – V_{Segment}$

Where:

V_{Total} = Volume of gasoline storage tank as reported by SIP survey respondents (litres)
$V_{Segment}$ = Volume of gasoline remaining at the base of the tanks,[11] estimated from equation (8) (litres):

(8) $V_{Segment} = L\ [r^2\ COS^{-1}\ (r-h)/r – (r-h)\ SQRT\ (2rh - h^2)]$

Where:

H = height of the remaining liquid at the bottom of tank (ft)
L = length of the tank (ft)
r = radius of the tank (ft); Tank radius and length were calculated from the volume of the tank reported by respondents using industry/manufacturers standard tank radiuses and volumes.[12]

K_P The working loss product factor (K_P) for gasoline was set to 1.[13]

9. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
10. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
11. The storage tank working volume (V_{LX}) is calculated by considering the use of only 95% of the tank volume since storage tanks are commonly not filled to the rim during the filling operation, and by further subtracting the volume of unused segment at the bottom of the tank ($V_{Segment}$). The unused segment of gasoline refers to a small amount of gasoline that is assumed to remain at the bottom of storage tanks on a permanent basis.
12. Modern Welding Co., Inc., STIP3. Underground Storage Tanks, 2011 (*www.modweldco.com/products/sti-p3-underground-storage-tanks/consolidated-stip3-info.pdf*).
13. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.

Breathing loss

Equation (9) was used for the estimation of breathing loss from underground and aboveground gasoline storage tanks:[14]

(9) $BL = 365\ K_E\ (3.1416\ /4\ D_E^2)\ H_{V0}\ K_S\ W_V$

Where:

BL	= storage tank breathing loss (lb/year)
365	= constant, the number of daily events[15] in a year
K_E	= vapour space expansion factor, dimensionless
3.1416	= mathematical constant; the standard ratio of 22/7 for circle circumference to its diameter
D_E	= effective tank diameter for horizontal tanks (ft)
H_{VO}	= vapour space outage (ft)
K_S	= vented vapour saturation factor, dimensionless
W_V	= gasoline vapour density (lb/ft^3)
K_E	The vapour space expansion factor (K_E) was calculated by using equation (10):

(10) $K_E = (\Delta T_V/T_{LA}) + (\Delta P_V\text{-}\Delta P_B)\ /\ (P_A\text{-}P_{VA})$

Where:

K_E	= vapour space expansion factor, dimensionless
ΔT_V	= daily vapour temperature range (°R, Degrees Rankin)
T_{LA}	= daily average liquid surface temperature (°R)
ΔP_V	= daily vapour pressure range (psia)
ΔP_B	= breather vent pressure setting range (psia)
P_A	= atmospheric pressure (psia)
P_{VA}	= vapour pressure at daily average liquid surface temperature (psia)
ΔT_V	The daily vapour temperature range (ΔT_V) was calculated by u sing equation (11):

(11) $\Delta T_V = 0.72\ \Delta T_A + 0.028\ \alpha\ I$

Where:

ΔT_V	= daily vapour temperature range (°R)
ΔT_A	= daily ambient temperature range (°R); the daily ambient temperature range (ΔT_A) is the difference between the average maximum and average minimum ambient temperatures during each season, as expressed by equation (12):

(12) $\Delta T_A = T_{AX} - T_{AN}$

Where:

T_{AX}	= daily average maximum ambient temperature (°R)

14. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
15. In the absence of response from the operators of a retail gasoline outlet, the location of storage tanks was assumed to be underground for on-road gasoline outlets and above ground for marinas with gas docks.

T_{AN} = daily average minimum ambient temperature (°R)
α = tank paint solar absorbance, dimensionless; the tank paint solar absorbance (α) data for aboveground tanks are provided by the USEPA.[16] For underground tanks, this parameter assumes the value of zero.
I = daily total solar insolation factor (Btu/ft^2 d); the daily total insolation factor (I) data for aboveground tanks are provided by the USEPA.[17] For underground storage tanks, this parameter assumes the value of zero.
T_{LA}[18] The daily average liquid surface temperature (T_{LA}) was calculated by using equation (13):

(13) $T_{LA} = 0.44\ T_{AA} + 0.56\ T_B + 0.0079\ \alpha\ I$

Where:

T_{LA} = daily average liquid surface temperature (°R)
T_{AA} = daily average ambient temperature (°R)
T_B = liquid bulk temperature (°R)
α = tank paint solar absorbance, dimensionless (see above)
I = daily total solar insolation factor (Btu/ft^2 d) (see above)
T_{AA} daily average ambient temperature (T_{AA}) was calculated by using equation (14):

(14) $T_{AA} = (T_{AX} + T_{AN})\ /2$

Where:

T_{AX} = daily average maximum ambient temperature (°R)
T_{AN} = daily average minimum ambient temperature (°R)
T_B[19] For aboveground tanks, the liquid bulk temperature (T_B) was calculated by using equation (15), while for underground tanks, it was assumed to be equal to the average underground temperature during the particular season:[20]

(15) $T_B = T_{AA} + 6\ \alpha - 1$

Where:

T_{AA} = daily average ambient temperature (°R)
α = tank paint solar absorbance, dimensionless
ΔP_V The daily vapour pressure range (ΔP_V) was calculated by using equation (16):

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16. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
17. US EPA, Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*.
18. For underground storage tanks, the annual liquid temperature range was assumed to be 5 to 15 degrees Celsius.
19. For underground storage tanks, this temperature was assumed to be equal to the daily average liquid surface temperature.
20. While Equation (15) was used for the calculation of liquid bulk temperature (T_B) for aboveground tanks, for underground tanks the liquid bulk temperature was assumed to be equal to the average underground temperature during the particular season. The temperature range of 5 to 15 ºC was assumed as the annual temperature range of liquid gasoline in underground storage tanks. This range was chosen since in addition to the temperature difference between underground (subsurface) and aboveground, there is a lag phase in the underground temperature profile compared to that of aboveground due to the insulating effect of the underground. Based on a report by the National Research Council of Canada on aboveground and underground temperature profiles for the city of Ottawa (1976), it has been assumed that the average annual range of underground temperature at a depth of 2 meters in Canada is 4 to 12 ºC. Gasoline is at a certain temperature when it leaves the refinery and is transported by tanker trucks for long distances. During the transportation, liquid gasoline temperature inside the tanker trucks changes in response to the ambient temperature. In the summer it heats up while getting cooler in the winter. Given the capacity of underground gasoline storage tanks in retail gasoline outlets and their corresponding turnover rate, it is plausible that liquid gasoline will often not reach the underground temperature during its residence time in the underground storage tanks. Accordingly, a temperature range of 5 to 15 ºC was assumed as an annual temperature range of liquid gasoline in underground storage tanks. During the calculation of breathing loss, if the mean ambient temperature during the warm season was higher than or equal to 15 ºC, then the underground temperature was assumed to be 15 ºC. However, if the mean ambient temperature during the warm season was lower than 15 ºC, then the underground temperature was assumed to be equal to the mean ambient temperature. Similarly, if the mean ambient temperature during the cold season was lower than or equal to 5 ºC, then the underground temperature was assumed to be 5 ºC. However, if the mean ambient temperature during the cold season was higher than 5 ºC, then the underground temperature was assumed to be equal to the mean ambient temperature.

(16) $\Delta P_V = P_{VX} - P_{VN}$

Where:

ΔP_V = daily vapour pressure range (psia)
P_{VX} = vapour pressure at the daily maximum liquid surface temperature (psia)
P_{VN} = vapour pressure at the daily minimum liquid surface temperature (psia)
ΔP_B[21] The breather vent pressure setting range (ΔP_B) was calculated by using equation (17):

(17) $\Delta P_B = P_{BP} - P_{BV}$

Where:

ΔP_B = breather vent pressure setting range (psig)
P_{BP} = breather vent pressure setting (psig)
P_{BV} = breather vent vacuum setting (psig)
P_{VA} The vapour pressure at daily average liquid surface temperature (P_{VA}) was calculated by using equation (3), above.
D_E[22] The effective tank diameter was calculated by using equation (18):

(18) $D_E = [L\ D / (3.1416/4)]^{-1/2}$

Where:

D_E = effective tank diameter (ft)
L = length of the horizontal tank (ft)
D = diameter of the horizontal tank (ft)
H_{VO}[23] The vapour space outage (H_{VO}) for horizontal tanks is equal to half of the effective tank height, calculated by using equation (19):

(19) $H_{VO} = H_E /2$

Where:

H_E = effective height of horizontal tanks (ft)[24]
H_E The effective height of a horizontal tank (H_E) corresponds to the height of a vertical tank having the same volume as the horizontal tank in question; it was calculated using equation (20):

21. In the absence of pressure and vacuum vents in Canadian retail gasoline outlets, ∆PB assumes the value of zero.
22. The effective tank diameter for horizontal tanks (D_E) is used in the estimation of breathing loss instead of the actual tank diameter since most Canadian retail gasoline outlets use horizontal storage tanks, while the breathing loss models have been originally developed for vertical tanks. This effective diameter corresponds to the effective surface area of liquid in the tank. Breathing loss is calculated assuming that the tank is always half full.
23. The effective height of a horizontal tank (H_E), used for the calculation of the vapour space outage (H_{VO}), corresponds to the height of a vertical tank having the same volume as the horizontal tank in question, and is estimated by assuming the volume of the tank to be approximately equal to the cross-sectional area of the tank times the length of the tank. It was calculated from the information provided by the US EPA (Document AP 42- Chapter 7, *Organic Liquid Storage Tanks, 2006*).
24. In case of no delivery to a retail gasoline outlet, for example, during the cold season for most Marinas across Canada, the vapour space outage (H_{VO}) increases since the tank is almost empty during this season. In this eventuality, the height of the outage space, hence the volume of vapour space outage was estimated by considering the entire effective height of the storage tank (rather than 50% of the height as applied in conventional scenarios) minus the height of the unused segment, $V_{Segment}$ at the bottom of tank. This was done since the lack of delivery increases the vapour space outage which will in turn increase the magnitude of breathing loss.

(20) $H_E = 3.1416\ D / 4$

Where:

D	is the diameter of the horizontal tank
K_S	The vented vapour saturation factor (K_S) was calculated by using equation (21):

(21) $K_S = 1/ (1+ 0.053\ P_{VA}\ H_{VO})$

Where:

P_{VA}	= vapour pressure at daily average liquid surface temperature (psia), the vapour pressure at daily average liquid surface temperature (P_{VA}) was calculated by using (3) above.
H_{VO}	= vapour space outage (ft), the vapour space outage (H_{VO}) was calculated by using equation (19) above.
W_V	The gasoline vapour density (W_V) was calculated by using equation (22):

(22) $W_V = M_V\ P_{VA} / (R\ T_{LA})$

Where:

M_V	= gasoline vapour molecular weight (lb/lb-mole), the gasoline vapour molecular weight (M_V) was calculated by using equation (2) above.
P_{VA}	= vapour pressure at daily average liquid surface temperature (psia), the vapour pressure at daily average liquid surface temperature (P_{VA}) was calculated by using equation (3).
R	= ideal gas constant (10.731 psia ft^3/lb-mole °R)
T_{LA}	= daily average liquid surface temperature (°R), the daily average liquid surface temperature (T_{LA}) was calculated by using equation (13).

Residual losses

Residual losses are the aggregates of

1. evaporation from wooden dip sticks used during standard monitoring operations;

2. spill losses due to nozzle spills from clients while refuelling own vehicles, and losses from common daily leaks based on an empirical emission factor supplied by the USEPA.

Monitoring loss

The monitoring loss was calculated by using equation (23):

(23) $DL = (N_{EV}\ AB_G\ A_I\ N_M)_{operator} + (N_{fil}\ AB_G\ A_I)_{trucker}$

Where:

DL	= dip stick loss (kg/year)
N_{EV}	= number of days the gasoline outlet is operating per year
AB_G	= absorbed gasoline on the immersed stick (kg/m^2)
A_I	= overall immersed area of stick (m^2)
N_M	= number of level measurements per day
N_{fil}	= number of gasoline deliveries to each tank in a year

N_{EV}	The number of operation days (events) in a year (N_{EV}) as reported by respondents of the survey.[25]
AB_G	The value of AB_G was estimated at 0.028 kg of gasoline per m^2 stick surface area, based on results from a laboratory experiment conducted for this particular project at Carleton University, Ottawa, Canada.
A_I	The overall immersed area of stick (A_I) is equal to the sum of cross sectional area of stick plus the area of four sides of stick.
N_M	The number of measurements per day (N_M) as reported by respondents of the survey.
N_{fil}	The number of gasoline deliveries to each tank in a given season was estimated by multiplying the number of turnovers per year (N) by the fraction of gasoline sold during the given season. The number of turnovers per year (N) was calculated by using equation (6) above.

Spill loss

A nozzle spill loss was calculated using equation (24):

(24) $AL = A_Y\, d / A_G$

Where:

AL	= adsorbent loss (kg /year)
A_Y	= absorbent use per year (kg/year); the amount of absorbent use per year as reported by respondents of the survey.[26]
d	= gasoline density at the average ambient temperature (kg/litre)
A_G	= absorbent capacity per one litre gasoline spill (kg/litre); the quantity of absorbent used per litre of spilled gasoline was estimated based on a field experiment conducted. An average value of 2.6 kg/L gasoline spill was applied.

The spill loss was estimated based on a USEPA emission factor and calculated by using equation (25)[27]

(25) $SL = Q\ EF$

Where:

SL	= spill loss (kg/year)
Q	= net gasoline throughput (litre/year); annual net gasoline throughput as reported by respondents of the survey.
EF	= corresponding emission factor (kg/ litre throughput); emission factor for common leaks and spills is reported by the USEPA as 80 mg/L gasoline throughput.[28]

25. In the absence of response from the operator of a retail gasoline outlet on the number of operating days, the average reported number of days from the survey population was 354 days for on-road gasoline outlets and 203 days for marinas with gas docks.
26. The amount of absorbent used was adjusted for gasoline spills; only based on the ratio between gasoline and diesel sales in each respective outlet.
27. US EPA, Document AP 42- Chapter 5, *Transportation and Marketing of Petroleum Liquids, 2006*.
28. US EPA, Document AP 42- Chapter 5, *Transportation and Marketing of Petroleum Liquids, 2006*.

Vehicle refuelling loss

The vehicle refuelling loss was calculated by using equation (26):

(26) $VL = 10^6 \times Q \times vl$

Where:

VL	= uncontrolled vehicle refuelling emissions (kg/year)
10^6	= conversion factor from mg to kg
Q	= volume of gasoline dispensed (litre/year), as reported to the SIP;
vl	= uncontrolled displacement losses from vehicle refuelling operations (mg/L) as per the empirical equation (27)[29]

(27) $vl = 264.2\ [(-5.909) - 0.0949\ (\Delta T) + 0.0884\ (T_D) + 0.485\ (RVP)]$

Where:

264.2	= conversion factor gram/gallon to mg/L (that is, 1,000/3.785)
5.909	= empirical coefficient
0.0949	= empirical coefficient
ΔT	= difference between temperature of gasoline in vehicle tank and temperature of dispensed gasoline (T_D); for the calculation of difference between temperature of gasoline in vehicle tank and the temperature of dispensed gasoline, the temperature of gasoline in the vehicle tank was assumed to be equal to the average daily ambient temperature during each season.
0.0884	= empirical coefficient
T_D	= temperature of dispensed gasoline (°F); the temperature of dispensed gasoline is the liquid bulk temperature in the storage tank. For aboveground tanks, this temperature was calculated by using equation (15) above, while for underground storage tanks, it was assumed to be equal to the daily average liquid surface temperature.
0.485	= empirical coefficient
RVP	= Reid vapour pressure (psia); values of Reid vapour pressure were obtained from Environment Canada.[30]

29. Rothman, D. and Johnson, R., *Refuelling Emissions from Uncontrolled Vehicles*, Technical Report, US EPA-AA-SDSB-85-6, 1985, as referenced in USEPA, Document AP 42- Chapter 5, *Transportation and Marketing of Petroleum Liquids, 2006*.
30. Environment Canada, April 2007, *Study on Gasoline Vapour Recovery in Stage I Distribution Networks in Canada, Final Report 0514676*.