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Benzene Releases from Gasoline Stations: Implications for Human Health

Health Canada

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Canada

Synopsis

Benzene is a recognized human carcinogen and, as such, a component of particular concern in gasoline. The objective of this assessment is to estimate the contribution of benzene emissions to inhalation exposures for communities residing in proximity to gasoline stations.

Two emission pathways are considered: long-term continuous benzene emissions via evaporative losses from gasoline station operations and short-term benzene emissions during tanker truck fuel unloading.

Air dispersion modelling was used to estimate annual average benzene concentrations attributable to gasoline station emissions for varying distances from the gasoline station fenceline. Specific scenarios assessed include gasoline stations with baseline, median, and high yearly gasoline throughputs. Air dispersion modelling was also used to estimate the average benzene concentrations at different distances from the gasoline station fenceline during the 1-hour time of average-sized tanker truck unloading, assuming the absence of vapour recovery and vent valves. For both types of releases, it is concluded that the inhalation exposures to benzene attributable to gasoline station emissions may pose unacceptable risks to human health for the general population living in the vicinity.

There are measures that can be taken to reduce benzene exposures and human health risks associated with benzene emissions from gasoline stations. These include the national implementation of vapour recovery at gasoline stations, the use of pressure/vacuum (p/v) valves on vent stacks, and the implementation of minimum setback distances for new construction. These measures could contribute to a decrease in benzene exposure for the general population in Canada, including potentially vulnerable populations such as pregnant people and children.

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1 Introduction

Benzene has been recognized as a human carcinogen by Health Canada (Canada 1993) and the International Agency for Research on Cancer (IARC) (IARC 2018). In Canada, the *Benzene in Gasoline Regulations* under the *Canadian Environmental Protection Act* 1999 (CEPA 1999) allow gasoline from a production facility to contain up to a maximum of 1.5% volume/volume (v/v) benzene, but require that the benzene content in gasoline from any production facility have an annual average of no more than 0.95% v/v (Canada 1999b; Canada 1997). Surveys of gasoline composition based on over 2500 samples annually (2013–2019) from 25 manufacturing, blending, and importing facilities determined that, over this time and over all regions of Canada, these targets were met, with the overall average benzene concentration in gasoline being 0.6% v/v, and only 3% of facilities reporting individual samples with benzene concentrations ranging between 1% and 1.5%(ECCC 2021).

Internationally, other jurisdictions have enacted similar regulations to limit the benzene concentration in gasoline. Refiners and importers in the United States are limited to a maximum annual average benzene content in gasoline of 0.62% v/v (US EPA 2012). European Union regulations permit up to 1% benzene in gasoline (European Commission 2000).

Gasoline stations are commonly located in close proximity to residential areas and the routine operations of gasoline stations can lead to the release of benzene in gasoline vapour resulting in potential exposures for the general public. Indoor and outdoor air levels of benzene are higher near sources of emissions such as filling stations (WHO 2000). These releases are from day-to-day evaporative losses during the operation of the gasoline station, as well as intermittent gasoline vapour releases during filling of underground storage tanks.

The mean concentration of benzene in ambient air in 16 Canadian cities surveyed between 1999 and 2009 was 0.3 to 2.9 µg/m^3 (Health Canada 2013). Measurements of outdoor benzene concentrations in Canada from 1999 to 2019 (with a minimum of 40 valid sampling points at each site) showed a downward trend (NAPS 2019). In 2019, annual average rural and urban benzene concentrations were 0.20 and 0.44 µg/m^3, respectively. Airborne concentrations of benzene at the perimeter of gasoline stations in five Canadian cities averaged 439 µg/m^3 in the summer of 1985 (PACE 1987) and 1383 µg/m^3 in the winter of 1986 (PACE 1989). No recent Canadian studies of benzene concentrations in the vicinity of gasoline stations have been identified.

A number of more recent studies reported benzene concentrations in the vicinity of gasoline stations in the United States and Europe (Palmgren 2000; Hilpert 2015, 2019; Barros et al. 2019; Hsieh 2021). These studies have raised concerns regarding potential elevated exposures to benzene for the general population living near gasoline stations. Specifically, concerns were expressed regarding the setback distances of residences with respect to gasoline stations, the effectiveness of vapour control measures, and the total volume of gasoline dispensed near residential areas (Hilpert 2015, 2019; Hsieh 2021).

There is a wide range of potential sources of benzene exposures for Canadians (e.g., consumer products, building materials, industrial releases, and smoking) in both indoor and outdoor air (WHO 2000). The objective of this assessment is to estimate the contribution of emissions from gasoline stations to benzene inhalation exposures for individuals residing in proximity to gasoline stations in Canada. Two emission pathways are considered: long-term continuous benzene emissions released via evaporative losses from gasoline stations, and short-term benzene emissions released during tanker truck fuel unloading.

While it is noted that some jurisdictions in Canada mandate vapour recovery during tanker truck fuel unloading at gasoline stations, (i.e., Stage 1 vapour recovery [CCME 1991], see Section 4 of this document), this report estimates potential benzene inhalation exposures from gasoline station emissions via air dispersion modelling in the absence of vapour recovery during fuel unloading to identify potential risks to human health following these exposures.

This assessment was undertaken to provide Canadian jurisdictions, regulators, and policy-makers with an evaluation of the potential magnitude of benzene vapour emissions from gasoline stations and the associated health risks. This report is intended to be used to inform decisions regarding mitigation of benzene vapour emissions from gasoline stations and health impacts associated with this benzene source in Canada.

2 Background

2.1 Health Effects of Benzene

Benzene has been classified as a Group 1 carcinogen ("Carcinogenic to humans") by the International Agency for Research on Cancer (IARC 2012, 2018), and as carcinogenic to humans by the Government of Canada (Canada 1993). Benzene was added to the List of Toxic Substances in Schedule 1 of CEPA 1999 (Canada 1999a). The adverse health effects of benzene have been reviewed and assessed in previous Canadian and International guideline documents (Canada 1993; ATSDR 2007; Health Canada 2009; Health Canada 2013).

Among the volatile components of liquid gasoline, benzene represents the highest health concern. Additionally, gasoline has been classified by the European Commission as a Category 1B carcinogen ("presumed to have carcinogenic potential for humans") when the concentration of benzene in liquid gasoline is ≥ 0.1% by weight (w/w) (European Union 2008, 2009; UN 2013, IMAP 2018).

The Government of Canada's Priority Substances List (PSL) Assessment Report on Benzene (Canada 1993) developed estimates of carcinogenic potency associated with inhalation exposure to benzene. A 5% tumourigenic concentration (TC_{05}) for benzene was calculated to be 14,700 µg/m^3 from the epidemiological investigation of Rinsky et al. (1987), based on acute myelogenous leukemia in Pliofilm workers. The TC_{05} value is the air concentration of a substance associated with a 5% increase in incidence or mortality due to tumours. Linear extrapolation from the TC_{05} results to benzene concentrations associated with risk levels of 1 in 1,000,000 and 1 in 100,000 equal to 0.29 µg/m^3 and 2.9 µg/m^3, respectively. Accordingly, the risk level associated with a benzene concentration of 1 µg/m^3 is 1 in 290,000.

The Health Canada cancer potency estimate can be compared with those determined by other organizations. The US EPA has derived reference values for benzene (US EPA 1998) using similar epidemiological datasets. The US EPA (1998) derived a range of cancer potencies for benzene, and it was estimated that exposure concentrations of 0.13–0.45 µg/m^3 are associated with a risk level of 1 in 1,000,000, and 1.3–4.5 µg/m^3 are associated with a risk level of 1 in 100,000. Linear extrapolation from the Health Canada TC_{05} concentration values gives risks within the range of the US EPA risk levels.

The PSL Assessment Report (Canada 1993) also identified non-cancer effects from short-term benzene exposure. The most sensitive endpoint was developmental hematotoxicity in fetal and neonatal mice exposed to 5 ppm (16 mg/m^3) benzene in utero (Keller and Snyder 1986; Canada 1993). In the US, the California Office of Environmental Health Hazard Assessment (OEHHA) derived an Acute Reference Exposure Level (AREL) of 0.008 ppm or 27 µg/m^3 for benzene based on this effect in mice by applying an uncertainty factor of 600 to the 5 ppm value (5 ppm / 600 =

0.008 ppm); the uncertainty factor was based on use of a lowest observed adverse effect level as the point of departure, interspecies differences, and intraspecies differences. This AREL was considered protective for the general population exposed to infrequent 1-hr exposures to benzene (OEHHA 2014).

2.2 Gasoline station and gasoline delivery tanker truck statistics in Canada

Gasoline stations are ubiquitous in urban and rural settings. Gasoline stations vary in size as characterized by physical footprint and yearly average gasoline throughput. Market survey data indicates that as of December 31, 2020, there were 11,908 retail gasoline stations operating in Canada (Kalibrate 2021). A survey of 411 regions, covering all major and many minor markets across 10 provinces in Canada, identified a total of 7,138 gasoline stations accounting for approximately 70% of total gasoline gross sales in Canada. Of these, detailed information including station name, address, and throughput were collected for 6,565 gasoline stations identified as having annual gasoline throughputs greater than 1 million L (Kent Group 2020). The total annual gasoline throughput for these stations was 32 billion L, with a median and 95th percentile station throughput (the latter called “high throughput” from here onwards) of 4 and 10.6 million L/year, respectively. These values were used to model potential gasoline vapour releases from gasoline stations and resulting benzene exposures of Canadians residing within the vicinity. It was noted that there are gasoline stations in Canada with annual throughputs significantly higher than the 95th percentile throughput however, the 95th percentile was statistically more appropriate for the purposes of this assessment.

Gasoline storage tank filling schedules depend on the tank capacity and throughput of each individual gasoline station. Individual gasoline station storage tanks range from 45,000 to 91,000 L (Transcourt 2018). Typical gasoline delivery tanker trucks have holding capacities of between 11,400 and 43,900 L (USDT 2012). For this report, a typical gasoline delivery tanker truck was assumed to have a capacity of 35,000 L (Statistics Canada 2012) and a large tanker truck was assumed to have a capacity of 43,900 L. For median- and high-throughput gasoline stations, this corresponds to approximately two to six fuel deliveries per week.

Gasoline vapour forms in the gasoline station storage tank due to partial evaporation of liquid gasoline under operating temperatures. To prevent pressure imbalances in storage tanks due to the expansion and contraction of the gasoline vapour, stacks of vent pipes are installed on the tanks; they connect the vapour phase in the tank to the external atmosphere. In Canada, the vent pipes open directly to the atmosphere at elevated heights of approximately 3 m or more. These vent stacks are usually positioned in groups at the edges of gasoline stations (Figure 2-1(a)). For some gasoline stations, the vent stacks may be located close to residential buildings (Hilpert 2019).

In the absence of any vapour recovery on the gasoline delivery tanker truck, liquid gasoline delivered to a gasoline station storage tank pushes the gasoline–air mixture in the empty tank into the atmosphere via the storage tank vent pipes (Figure 2-1(b)). This gasoline loss during refilling of the storage tank is called the working loss.

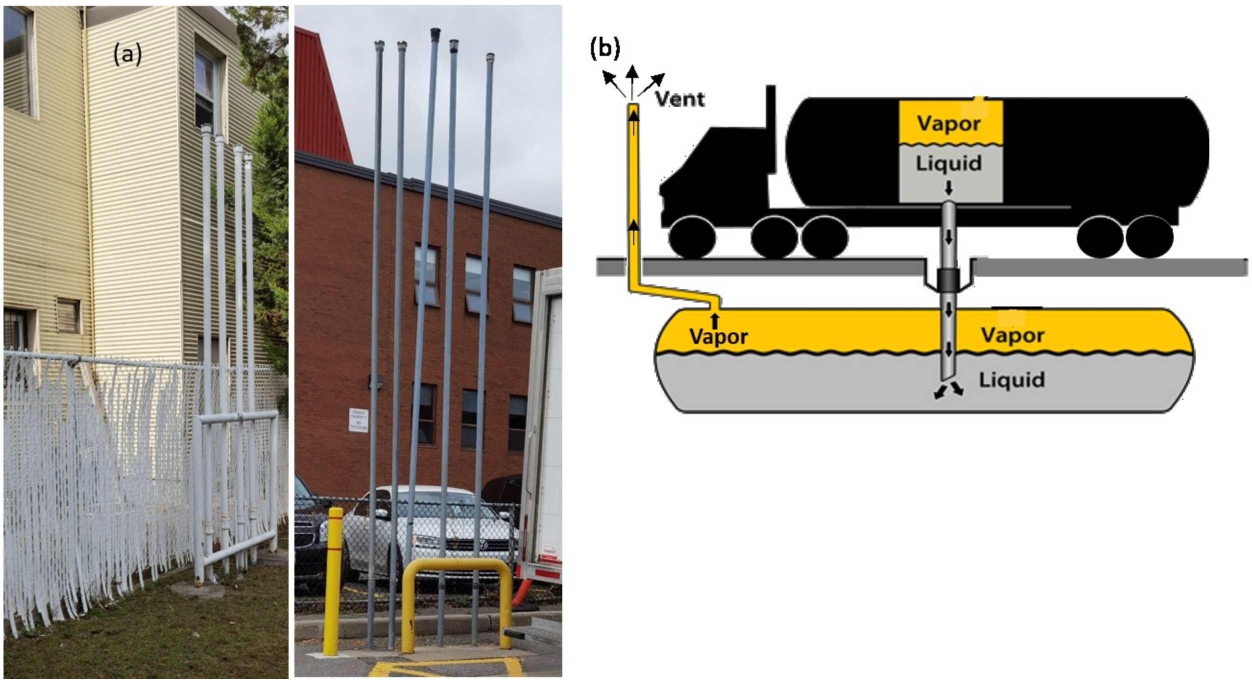

Figure 2-1. (a) Two examples of gasoline station vent stacks connected to the underground storage tanks in close proximity to residential areas (photos taken by Health Canada, Existing Substances Risk Assessment Bureau in Ottawa ON, September 2021). (b) A schematic representation of gasoline delivery by a tanker truck in the absence of vapour recovery where the gasoline vapour in the storage tank is driven out of the vent pipe into the atmosphere to balance the pressure inside the storage tank. Graphic credit for part (b): Washington State JLARC Report on Gas Vapor Regulations.

In the absence of vapour recovery, average total evaporative losses of 0.15% of the gasoline station throughput were estimated by the Statistics Canada Survey of Industrial Processes (SIP) using models and exposure factors from the US EPA AP 42 (Statistics Canada 2012; Yerushlami and Rastan 2014).

Cross referencing station location information (Kent Group 2020) with satellite imagery has identified residential areas as close as 10 m to the gasoline station fencelines. A typical gasoline station set-up is schematically shown in Figure 2-2.

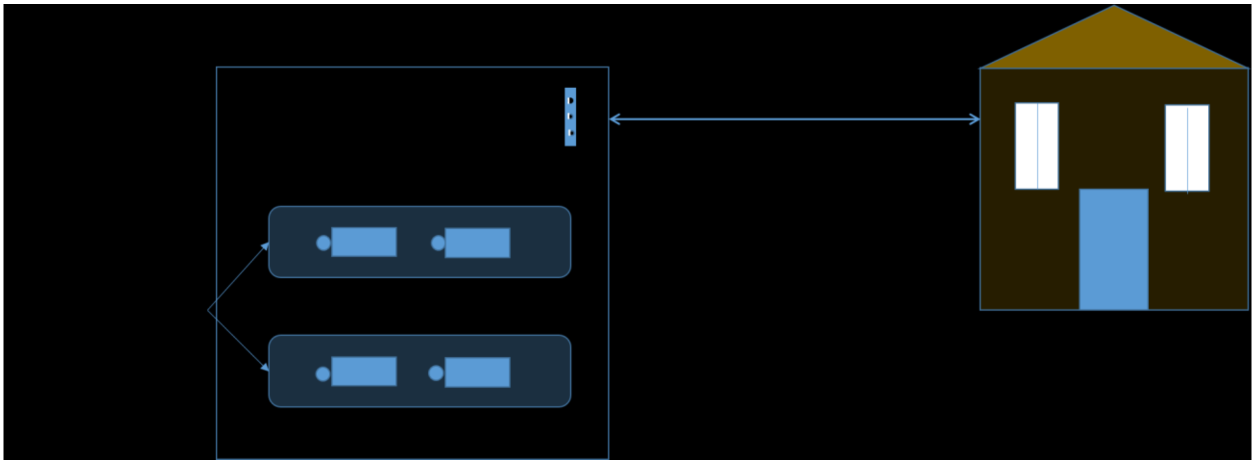

Figure 2-2. Schematic representation of a typical gasoline station layout with respect to residential areas. The vapour release areas associated with the entire gasoline station and vent stack are shown separately in this figure.

2.3 Benzene concentrations in ambient air in Canada

Numerous studies have reported on the concentration of benzene in ambient air in Canada and trends indicate a decrease in the average outdoor benzene air concentration across Canada over time (Dann 2015; Stroud 2016; Galarneau 2016). Outdoor benzene concentrations in Canada from 1999 to 2019 from the National Air Pollution Surveillance (NAPS) program are shown in Figure 2-3, confirming a downward trend in ambient benzene concentrations during this period (NAPS 2019). In 2019, annual average rural and urban benzene concentrations were 0.20 and 0.44 µg/m^3, respectively. These benzene concentrations represent averages from data collected from 51 urban and 16 rural areas.

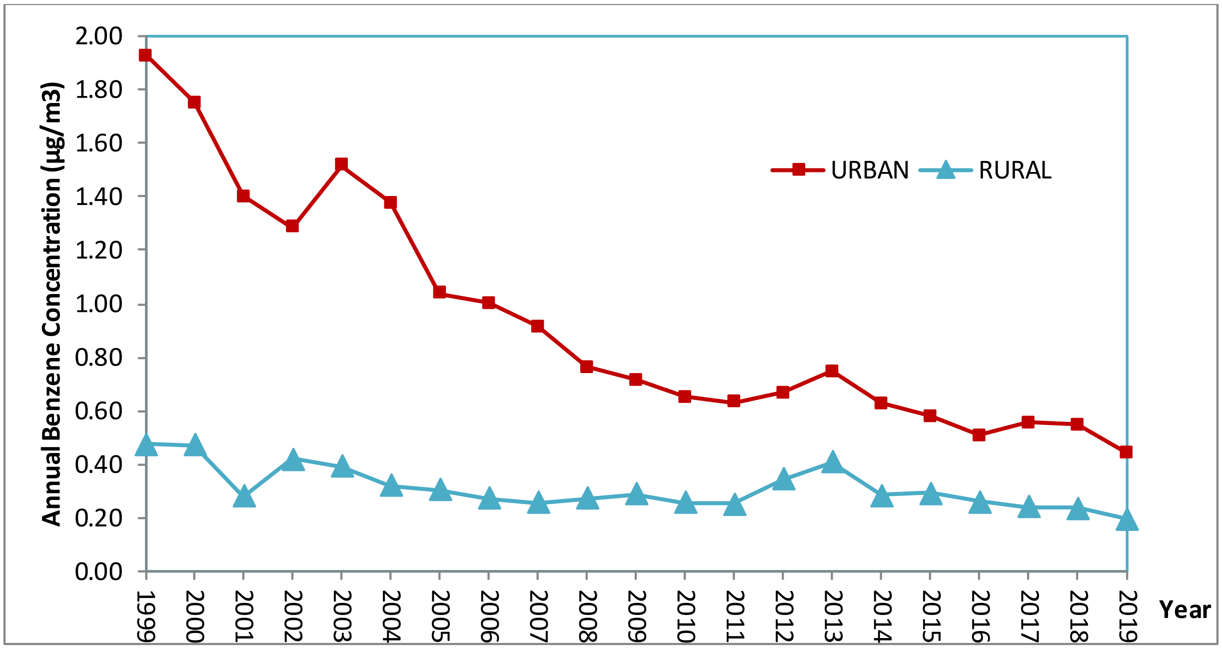

Figure 2-3. Average annual urban and rural benzene concentrations in ambient air in Canada from 1999 to 2019 (NAPS 2018, 2019; Figure prepared from data provided in personal communication from ECCC, Air Quality Research Division).

The trends in Figure 2-3 show that, over time, the concentration of benzene in outdoor air has decreased, but these average concentrations do not give an indication of the direct impact of individual gasoline stations on local benzene concentrations in nearby residential areas. Gasoline stations have the potential to increase the near-field concentration of benzene above the general background values. Short-term (1-hr) increases in benzene concentration in residential areas adjacent to gasoline stations due to activities such as storage tank refilling are also not specifically reflected in these overall outdoor trends. The gasoline station releases can lead to additional benzene exposures and health effects for the general population in Canada living within the vicinity of gasoline stations.

3 Risks to human health from benzene concentrations in the vicinity of gasoline stations

3.1 Long-term benzene exposures: Evaporative emissions from gasoline stations

In this section, benzene emissions from gasoline stations are modelled based on estimates of total evaporative loss. Air dispersion modelling is used to estimate how benzene concentration changes with distance from the gasoline station fenceline.

Estimates of cancer potency are then used to estimate the risk of this benzene exposure to residents living in the vicinity of gasoline stations.

Evaporative emission scenarios were developed to estimate benzene exposure in the vicinity of gasoline stations. A baseline throughput of 1.0 million L/year was selected along with the median and high throughput values of 4.0 and 10.6 million L/year described previously in section 2.2.

A total gasoline evaporative loss rate of 0.15% of the throughput of the gasoline station is assumed in this report (Statistics Canada 2012). The scenarios consider 0.6% v/v benzene in liquid gasoline in Canada (ECCC 2021) and a gasoline liquid density of 0.755 g/cm^3. The resulting benzene emission rates for the baseline, median, and high-throughput gasoline stations are estimated to be 0.25, 1.0, and 2.65 mg/s, respectively. Input factors for the air dispersion modelling calculations are given in Table B-1 of Appendix B.

The benzene emission rates for the baseline, median, and high throughput gasoline stations were used in SCREEN3 (1996) to estimate the dispersion of benzene in air at various distances from the gasoline stations. SCREEN3 is a screening-level Gaussian air dispersion model which uses wind as the driver for air dispersion of vapours. A maximum exposure concentration was estimated based on a combination of meteorological conditions, including wind speed, air turbulence, and humidity. In this work, the model was used to estimate benzene concentrations released into the air from an area source at the gasoline station, and provides the maximum concentrations of the released vapour at a chosen receptor height and at various distances from the source, in the direction downwind of the prevalent wind one hour after a given release event. For exposures from area sources over the span of a year, it can be expected that changing wind directions may vary the location which receives the maximum vapour concentrations from the source. The annual concentration received at a fixed location calculated from an area source was determined by multiplying the maximum 1-hr concentration by a factor of 0.2 (SCREEN3 1999; ECCC, HC 2016, 2017). SCREEN3 has been used by Health Canada in air dispersion modelling in a number of screening assessments of petroleum group substances, including those for the Petroleum and Refinery Gases (ECCC, HC 2017) and Natural Gas Condensates (ECCC, HC 2016), which indicated that the concentrations of dispersed vapours at different distances from the release source predicted by SCREEN3 are comparable to measured values and other screening-level air dispersion models.

An exposure scenario was developed for the general population in Canada living in the vicinity of the fenceline of a 20 m × 20 m gasoline station (Figure 2-2). The combination of the gasoline station refuelling bay and vent stacks was considered an area emission source and a receptor height corresponding to the average height of Canadians (1.74 m) was used in the air dispersion calculations. The gasoline station and vent stacks are not single point sources of vapour emission. Additionally, the gasoline station cannot be considered a uniform volume source for vapour release as sources of benzene emissions are localized at multiple locations near the ground or at the top of the vent stacks.

The parameters used in air dispersion modelling of gasoline station benzene releases are provided in Table B-1 of Appendix B. The incremental benzene concentration attributable to gasoline station emissions for the baseline, median, and high throughput scenarios is presented for varying distances from the fenceline (1.74 m receptor height) in Figure 3-1 (see also Table B-2 [Appendix B]).

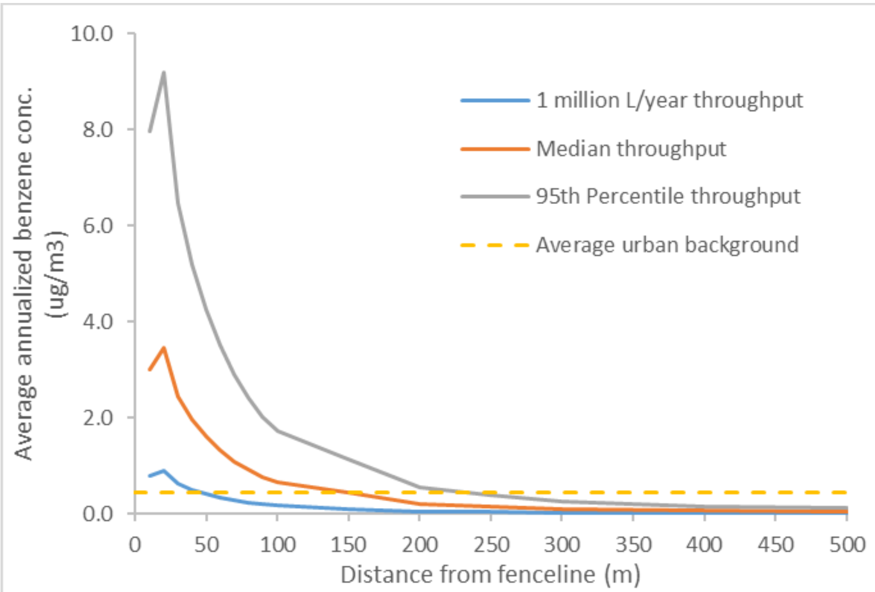

Figure 3-1. Average annualized benzene concentration attributable to evaporative losses from baseline, median, and high throughput gasoline stations.

The highest average annualized increases in modelled benzene concentrations occur at a distance of 20 m from the station fenceline, and were estimated to be 0.88, 3.5, and 9.2 µg/m^3, respectively, for the baseline, median throughput, and high throughput, and gasoline station scenarios. As residential areas have been identified at distances starting at 10 m from the fenceline of gasoline stations with these throughputs in Canadian locations, there is the potential for residential areas to be situated in areas with the highest estimated benzene levels.

To characterize the potential incremental maximum risks to health from these three scenarios, the highest predicted annual concentrations of benzene were compared with the TC_{05} of benzene (Canada 1993). One approach that can inform the health risks of ambient concentrations is to calculate the margin of exposure (MOE). In this assessment, the MOE is the ratio of the TC_{05} effect level benzene concentration (identified in section 2.1) to the observed benzene concentrations. As a reference for the risk associated with the urban background benzene concentration of 0.44 µg/m^3, comparing it with the TC_{05} results in a MOE of 14,700/0.44 = 33,400 which approximates a risk level of 1.5 per million [1,000,000/(33,400/0.05)] population exposed to this concentration of benzene.

Error! Not a valid bookmark self-reference. provides the MOE and relative risk per million for each exposure scenario.

Table 3-1. MOEs for incremental benzene concentration from gasoline evaporative loss from gasoline stations at 20 metres from the fenceline

Scenario	Maximum incremental annual benzene conc. (µg/m³)	Benzene TC_{05} (µg/m³)	MOE	Risk per million population
Baseline throughput gasoline station (1,000,000 L/yr)[a]	0.88	14,700	16,700	3
Median throughput gasoline station (4,000,000 L/yr)[a]	3.5	14,700	4,200	12
High throughput gasoline station (10,600,000 L/yr)[a]	9.2	14,700	1600	32
Average urban background (NAPS 2019)	0.44	14,700	33,400	1.5

[a] Derived using SCREEN3 air dispersion modelling

The MOEs of 1,600, 4,200, and 16,700 correspond to increases in incremental risk of cancer of 32, 12, and 3 per million for the high-throughput, median-throughput, and baseline-throughput gasoline stations, respectively. These results indicate that estimated exposures to benzene for those who live in close proximity to gasoline stations with annual throughputs greater than 1 million litres may pose an elevated risk to human health compared with general population exposures in urban environments. Of particular concern are those living near the median- and high-throughput gas stations, as the maximum incremental increase in risk exceeds 10 per million. The distances from the gasoline station fenceline at which the incremental benzene concentrations from gasoline stations correspond to the 1 in 1 million risk level of 0.29 µg/m³ are estimated as 70 m for the baseline-, 160 m for the median-, and 300 m for the high-throughput gasoline station scenarios (Table B-2 and Figure 3-1).

3.2 Short-term benzene exposures: Vapour release from underground storage tanks during tanker truck unloading

In this section, the short-term (1hr) release of benzene from a gasoline station during fuel unloading by tanker truck is determined. Using air-dispersion modelling, the variation of concentration of benzene at distances away from the gasoline station is calculated. These 1hr air concentrations are compared with short-term health endpoints. The relative contribution of these short-term releases is qualitatively compared with the total evaporative loss from the station.

It was assumed that the unloading of gasoline from 35,000 L to 43,900 L tanker trucks into the gas station storage tank requires a period of 1 hr and the release of the vapour from the unloading event was averaged over this same period. One hour was also the shortest averaging time of emissions in the dispersion model. As liquid gasoline enters the storage tank from the truck, to maintain the storage tank pressure, an equivalent amount of the air and gasoline vapour mixture in the storage tank headspace is released into the atmosphere from the storage tank vent stack. A vent release height of 3.66 m (12 ft) (CAPCOA 1997) for the gas station storage tank was assumed (Figure 2-1[a]). A 0.3 m × 3 m area corresponding to the approximate release area of the vent stack was assumed, as depicted in Figure 2-2.

Due to the physical–chemical properties of gasoline components, its liquid composition differs significantly from that of the headspace vapour which equilibrates on top of the liquid phase in a closed vessel. The California Air Pollution Control Officers Association (CAPCOA) estimates the vapour space above liquid gasoline in underground gasoline station storage tanks to be a 70:30 (volume %) air–gasoline mixture (CAPCOA 1997) with a density of 1.682 kg/m^3. For gasoline with a 0.6% v/v composition of benzene in the liquid phase, the air–gasoline vapour mixture released into the atmosphere will contain 0.18% w/w benzene (CAPCOA 1997; Hilpert et al. 2019).

Based on these values, a benzene release rate of 32.7 mg/(m^2·s) from the area of the vent stacks is estimated for the average 1 hr of vapour release time associated with the unloading of a 35,000 L capacity truck.

Based on the benzene release rate and the exposure factors given in Table B-3 of Appendix B, the maximum incremental benzene concentrations for 1 hr of exposure at different distances from the vent pipe array without vapour recovery from the unloading of a 35,000 L delivery tanker truck, as calculated by SCREEN3, are shown in Figure 3-2 and provided in

Table B-4 of Appendix B.

The maximum 1hr increase in modelled benzene concentrations occur at a distance of 10 m from the station fenceline, and were predicted for unloading of 35,000 and 43,900 L tanker trucks to be 805 and 1,010 µg/m³, respectively (see Figure 3-2). Residential areas have been identified at this distance from gasoline stations, indicating the potential for residences to be situated in areas with the highest benzene levels.

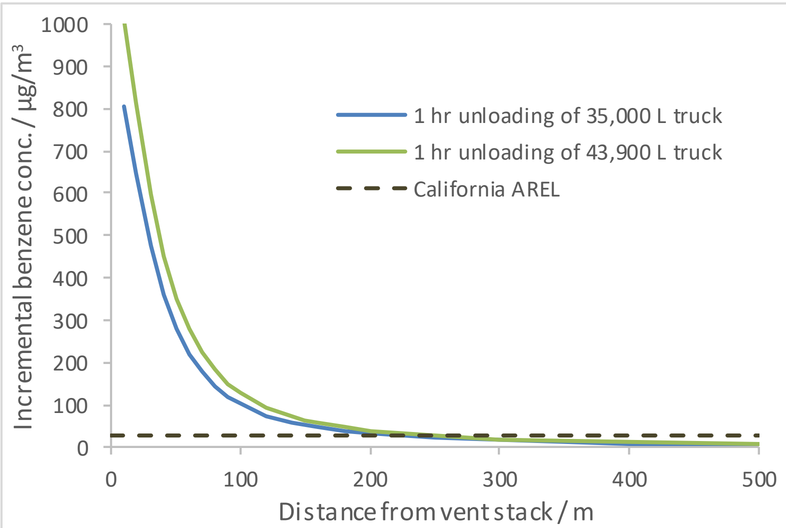

Figure 3-2. Predicted maximum 1-hr incremental benzene concentration as a function of distance from vent stacks resulting from 35,000 and 43,900 L gasoline tanker truck deliveries.

Comparing this estimate of 805 µg/m³ with the effect level of 16 mg/m³ based on developmental hematotoxicity in mice (Keller and Snyder 1986) results in an MOE of 20 (see Table 3-2, indicating a possible short-term risk to human health). For a large delivery truck, the MOE is even smaller at 16. Typically, an acceptable MOE to an effect level determined from laboratory animals is in the range of 300 to 1000.

The California EPA considered a safety factor of 600 with the above effect level to determine their 1 hr benzene AREL of 27 µg/m³ (OEHHA 2014). The modelled incremental benzene releases from the vent stacks become smaller than this AREL at distances between 210 and 240 m (for the 35,000 and 43,900 L tanker trucks, respectively) from the gasoline station fenceline.

Table 3-2. MOEs at 10 metres from the vent stack for benzene releases during the unloading of gasoline from tanker trucks

Scenario	Maximum hourly benzene concentration from truck release[a] (µg/m³)	Benzene developmental hemotoxicity effect level (mg/m³)	MOE

Unloading from 35,000 L tanker truck	805	16	20
Unloading from 43,900 L tanker truck	1010	16	16

[a] Derived using SCREEN3 air dispersion modelling

These results indicate that estimated exposures to benzene during truck unloading may pose an elevated risk to pregnant people and their developing fetuses who live in close proximity to gasoline stations or may be within the vicinity of a tanker truck unloading event. The frequency of these elevated short term exposure events occurring is dependent on station throughput and volume of fuel per delivery. For example, assuming all deliveries are 35,000 L, it is estimated that there would be 29, 114, and 303 such events per year for the baseline-, median-, and high-throughput gas stations, respectively.

The transient benzene concentrations released during the 1-hr period of gasoline tanker truck unloading are considerably higher than the 24-hr average concentrations of benzene from continuous releases from the gasoline station. At a distance of 20 m from the fenceline (

Table B-4, Appendix B), averaging the benzene release concentration from the 35,000 L tanker truck unloading event over 24 hrs, with two deliveries per week, and accounting for changes in wind direction during tanker truck unloading events on different days [650 μg/m^3×(1/24)×(2/7)×0.2], the benzene concentrations from tanker truck unloading are estimated to contribute up to approximately 40% of the total benzene concentration that results from all gasoline station evaporative losses.

4 Mitigating measures for reducing benzene exposure from gasoline station evaporative releases

There are a number of mitigating measures for vapour releases at gasoline stations based on the Environmental Code of Practice issued by the Canadian Council of Ministers of the Environment (CCME 1991). These measures, which include Stage 1 vapour recovery (Figure 4-1), were designed to reduce the release of gasoline vapours from gasoline stations, thus lowering concentrations of volatile organic compounds (VOCs) and ozone in the lower atmosphere. Certain provinces and municipalities have enacted requirements for Stage 1 vapour recovery at gasoline stations; however, the majority of provinces and territories do not currently have any such requirements.

Another potential vapour mitigation measure at gasoline stations is the installation of pressure/vacuum (p/v) valves on the top of vent pipes. These valves maintain the underground storage tank over-pressure or under-pressure within set limits. In addition to reducing emissions during gasoline unloading, these valves also reduce evaporative losses from the storage tanks during daily gasoline station operations. The presence of p/v valves is not currently regulated in Canada, but their use in gasoline station storage tank vent pipes is mandated in the United States (USCFR 2021).

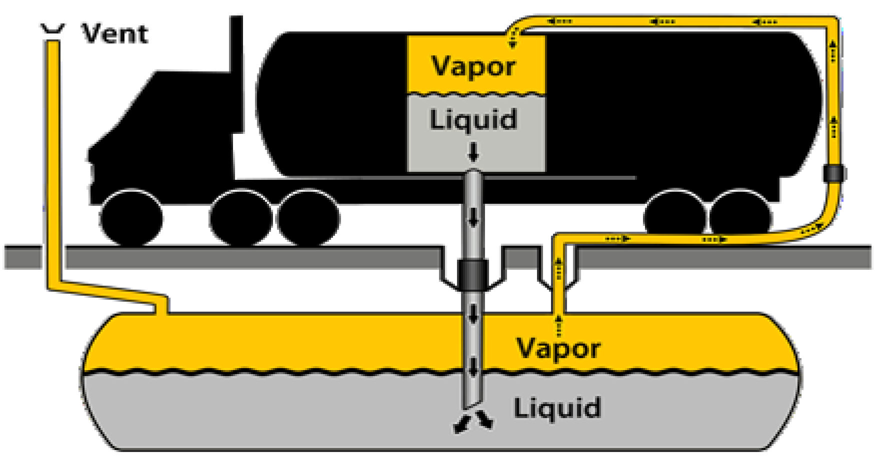

Figure 4-1. In the presence of Stage 1 vapour recovery in the tanker truck, as liquid gasoline is deposited into the storage tank, the vapour in the storage tank is

predominantly drawn back into the delivery truck. Graphic credit: Washington State JLARC Report on Gas Vapor Regulations.

It is estimated that the use of Stage 1 vapour recovery on a tanker truck during gasoline unloading, as shown in Figure 4-1, could capture 50%–90% of the vapour released during the truck unloading event (CCME 1991; Statistics Canada 2012) and up to 99% if p/v valves are present on vent stacks (Statistics Canada 2012). The recovered vapours in the tanker truck are returned to the loading facility (i.e., bulk plant or refinery) for processing/recovery.

In some urban locations, gasoline stations and their vent stacks may be located near residential areas. There are no Canadian federal or provincial regulations regarding minimum setback distances for either gasoline stations or vent stacks from residential areas. Some international jurisdictions, such as California, mandate that gasoline stations with throughput of 13.6 million L/year or greater must be 91 m (300 ft) from schools, daycares, and other sensitive land uses (CalEPA/CARB 2005; Hilpert et al. 2019).

5 Uncertainties in Evaluating the Risk to Human Health

Recent Canadian benzene concentrations based on monitoring data at or near gasoline station operations were not available. Estimates of benzene release from gasoline stations were based on modelled values of total evaporative losses, which were then used with air dispersion models to estimate the benzene exposures of residents living within the vicinity of gasoline stations. Modelling inherently includes uncertainties relating to the assumptions, input data, and modelling tools used. Model validation with monitoring of benzene concentrations in air near gasoline stations under a variety of conditions would further advance the understanding of potential exposures to benzene near gasoline stations.

The assumption is made that an individual is continuously exposed and that the indoor air concentration of benzene resulting from gasoline station emissions is equal to the modelled outdoor air concentration.

This assessment only considers exposures to benzene from a single gasoline station. There are other potential contributors to both indoor and outdoor benzene levels. The presence of smokers in the home and of an attached garage can influence indoor benzene concentrations (Health Canada 2013). At busy urban intersections, it is not unusual to find multiple gas stations within close proximity of one another. In these cases, the emissions from these multiple gas stations may reach the same residential areas, which would increase the exposures of members of the population living there (Hsieh et al. 2021).

The TC_{05} for benzene was based on a lifetime of exposure estimated using adult breathing rates and body masses. Infants and children may be more affected by the benzene concentrations estimated in this analysis due to differences in breathing rates and body weights.

In June 2021, the Government of Canada announced that it is setting a mandatory target for all new light-duty cars and passenger trucks sales to be zero-emission by 2035, to help put Canada on a path to achieving its long-term goal of net zero emissions by 2050 (Transport Canada 2021). The reduction of gasoline powered vehicles in the marketplace would be expected to result in a corresponding reduction in gasoline station benzene emissions and corresponding risks to health.

6 Conclusion

In this report, the short-term benzene releases occurring due to tanker truck unloading of gasoline into storage tanks at gasoline stations and long-term releases of benzene from gasoline station total evaporative losses are estimated. For long-term inhalation exposure to evaporative emissions of benzene from gasoline in the vicinity of gasoline stations, the incremental risks for tumourogenicity for those living in the vicinity of the gasoline station ranged from 3 to 32 per million population at a distance of 20 m from the gasoline station fenceline. Risk levels of 10 per million and above are of particular concern. The contributions from gasoline station benzene emissions influences exposures up to distances of 70 to 300 m from the station fenceline, depending on the fuel throughput. The short-term inhalation exposures to emissions of benzene from gasoline unloading by tanker trucks results in MOEs for developmental hemotoxicity effects in pregnant people at 10 m from the gasoline station fenceline that are well below 300, and considered inadequate. At distances up to 210 to 240 m from the fenceline, the exposure concentrations are still greater than the California EPA AREL for short-term benzene inhalation (OEHHA 2014). There is the potential for these short-term exceedances to occur more than 300 times over a year for a high throughput station.

There are measures that can be taken to further reduce benzene exposures and human health risks associated with benzene emissions from gasoline stations. These include the national implementation of vapour recovery at gasoline stations, the use of pressure/vacuum (p/v) valves on vent stacks, and the implementation of minimum setback distances from gasoline stations for new construction. These measures could also contribute to a decrease in benzene exposure for the general population in Canada.

The Government of Canada will collect comments and information to refine the risk assessment and further explore possible risk management options to reduce the release of benzene vapours from gasoline stations. Information on potential risk management measures will be provided at the time of the final assessment, and consultation on the possible implementation of risk management measures will take place subsequent to that point.

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Appendix A: Gasoline Substance Identity and Compositions

Table A-1. Physical and chemical property values of gasoline

Property	Value	Reference
Melting point (°C)	-40	ChemInfo 2009
Boiling point (°C)	39–204 25–220	ATSDR 1995 CONCAWE 1992
Vapour pressure (Pa at 37.8 °C)	35,000–90,000 240 000	CONCAWE 1992 ECHA 2018a, b
Henry's law constant (Pa·m^3/mol)[a]	48.6–3.3 × 10^5	Air Force 1989
Log K_{ow} [b]	2.13–4.87	Air Force 1989
Water solubility (mg/L) [c]	0.1–1790	EPI Suite 2008
Density (kg/L at 15 °C)	0.72–0.79 0.6–0.88	CONCAWE 1992 ECHA 2018a, b

Abbreviations: K_{ow}, octanol–water partition coefficient.
[a]Based on benzene–trimethylpentane range.
[b]Based on naphthalene–trimethylpentane range.
[c]Range of solubilities of components.

Appendix B: Exposure Characterization for Benzene Evaporative Release from Gasoline Stations

Table B-1. Inputs to SCREEN3 for benzene exposure in the vicinity of gasoline stations resulting from total evaporative loss

Variables	Input variables
Source type	Area
Effective emission area[a]	20 m × 20 m
Effective emission height	2.3 m (average of vent [at 3.66 m] and gas pump [1 m] release heights)
Gasoline density (g/mL)	0.755
Benzene content in gasoline (percent v/v)	0.6
Gasoline station throughput, median (baseline; high) (million L/year)	4.0 (1;10.6)
Total gasoline evaporative loss (percent)	0.15
Emission rate of benzene, median (baseline;high) (mg/s)	1.0 (0.25; 2.65)
Receptor height[a]	1.74 m (average adult height)
Source release height[b]	2.3 m
Adjustment factor[c]	0.4 (variable wind direction during 24-hour period) 0.2 (average wind direction during 1-year period)
Urban–rural option	Urban
Meteorology[d]	1 (full meteorology)
Minimum and maximum distance	10–1000 m

[a] Curry et al. (1993).
[b] Average of vent pipe and gas pump height
[c] US EPA (1992).
[d] Default value in SCREEN3.

Table B-2. Average annual concentrations of benzene in the vicinity of gasoline stations resulting from total evaporative emissions for baseline, median, and high throughput gasoline stations

Distance (m)	Benzene concentration from baseline (1 million L/year) throughput gasoline stations (µg/m³)	Benzene concentration from median (4 million L/year) throughput gasoline stations (µg/m³)	Benzene concentration from high (10.6 million L/year) throughput gasoline stations (µg/m³)
10	0.783	3.01	7.97
20	0.885	3.47	9.21
30	0.616	2.45	6.48
40	0.493	1.96	5.20
50	0.404	1.61	4.27
60	0.331	1.32	3.50
70	0.273	1.09	2.89
80	0.227	0.91	2.41
90	0.191	0.76	2.03
100	0.163	0.65	1.72
150	0.083	0.43	1.13
200	0.051	0.20	0.54
250	0.034	0.15	0.40
300	0.025	0.10	0.26
400	0.015	0.06	0.16
500	0.010	0.04	0.11
600	0.008	0.03	0.08
700	0.006	0.02	0.06
800	0.005	0.02	0.05
900	0.004	0.02	0.04
1000	0.003	0.01	0.04

Table B-3. Inputs to SCREEN3 calculation of benzene emissions from gasoline tanks as a result of unloading from tanker trucks

Variables	Input variables
Source type	Area
Effective emission area[a]	0.3 m × 3 m
Average (upper bound) volume of gasoline tanker truck	35,000 L (43,900 L)
Gasoline unloading time from truck	1 hr
Ratio of air to gasoline vapour in storage tank	70:30 (v/v %)
Density of air + gasoline vapour mixture	1.682 kg/m^3
Percent benzene (wt%) in air+gasoline mixture in gasoline storage tank	0.18%
Release rate of benzene for average (upper bound) tanker truck	0.029 g/s (0.037 g/s)
Emission rate of benzene for average (upper bound) tanker truck	3.27×10^{-5} $g/(s \cdot m^2)$ (4.1×10^{-5} $g/(s \cdot m^2)$)
Receptor height	1.74 m (average adult height)
Source release height[a]	3.66 m
Urban–rural option	Urban
Meteorology	1 (full meteorology)
Minimum and maximum distance	10–1000 m

[a] CAPCOA (1997)

Table B-4. The maximum 1 hr air concentrations of benzene in the vicinity of a gasoline station for 35,000 and 43,900-L tanker truck unloading

Distance (m)	Maximum 1 hr conc. of benzene (µg/m^3) for 35,000 L tanker truck	Maximum 1 hr conc. of benzene (µg/m^3) for 43,900 L tanker truck
10	805.20	1009.95
20	647.40	812.02
30	477.66	599.12
40	360.84	452.60
50	280.08	351.30
60	221.04	277.25
70	177.36	222.46
80	144.72	181.52
90	119.94	150.44
100	100.86	126.51
120	74.10	92.94
140	56.69	71.11
150	50.23	63.01
160	44.83	56.23
180	36.40	45.66
200	30.19	37.87
210	27.69	34.73
220	25.63	30.72
230	23.56	29.55
240	21.84	27.39
250	20.32	25.49
270	17.74	22.25
300	14.73	18.48
400	8.93	11.20
500	6.10	7.65
600	4.50	5.64
700	3.49	4.38
800	2.82	3.53
900	2.34	2.93
1000	1.98	2.48