Gouvernement du Canada Government of Canada

Screening Assessment
Petroleum Sector Stream Approach

Natural Gas Condensates

Environment Canada
Health Canada

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Canada

Synopsis

Pursuant to sections 68 and 74 of the *Canadian Environmental Protection Act, 1999* (CEPA), the Ministers of the Environment and of Health have conducted a screening assessment of natural gas condensates (NGCs), a class of substances that share similar sources, properties, and use. In this screening assessment, NGCs are defined as complex combinations of hydrocarbons that condense or are separated from the gaseous phase into the liquid phase: during production at wellheads; in natural gas processing plants; in gas pipelines for production, gathering, transmission and distribution; and/or in straddle plants along the main gas pipelines. NGCs consist of hydrocarbons mostly falling within, but not necessarily spanning, a carbon range of C_2 to C_{30}, with predominant hydrocarbons typically falling between C_5 and C_{15}. In addition, this definition encompasses all liquids derived from natural gas distillates, except those with predominant hydrocarbon fractions below C_5. The largest use of condensates in Canada is as a diluent for bitumen or heavy crude oils. About 23% of the NGCs used for this purpose can be recovered from the diluted materials in petroleum refineries and/or upgraders for reuse; this recovered NGC is also considered within the context of this assessment. Other uses are as industrial feedstocks and as gasoline blending stocks. NGCs were included in the Petroleum Sector Stream Approach (PSSA) because they are related to the petroleum sector and are considered to be of Unknown or Variable composition, Complex reaction products or Biological materials (UVCBs).

Following the categorization of the *Domestic Substances List*, three NGCs (CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1) were identified as priorities for assessment as they met the categorization criteria under subsection 73(1) of CEPA and were identified as priorities based on other human health concerns. Due to their similarity of sources, properties, hazard, and the compositional variability within, and overlap between NGCs that can lead to interchangeable use of CAS RNs, this screening assessment encompasses all NGCs as described in the Substance Identity and Uses sections.

Spill data for NGCs for the years 2002-2011 from the province of Alberta were analyzed to provide an indication of the frequency and magnitude of spills to land and freshwater. Spill data for this same period from the Nova Scotia and Newfoundland and Labrador offshore petroleum boards were used for the analyses of spills to marine water. The risk analysis conducted with these data indicates that NGCs may cause harm to soil organisms given the frequency and volume of spills to land (i.e., approximately 50 reported spills per year with a median volume of 500 L). In addition, there are, on average, two reported spills/year of NGCs to freshwater that may cause harm to aquatic organisms. Given the low reported frequency and magnitude of release of NGCs to marine water, there is a low risk of harm to marine organisms.

Considering all available lines of evidence presented in this screening assessment, there is risk of harm to organisms, but not to the broader integrity of the environment from NGCs. It is concluded that NGCs meet the criteria under paragraph 64(*a*) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. However, it is concluded that NGCs do not meet the criteria under paragraph 64(*b*) of CEPA as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

Exposure and hazard information on the three high-priority NGCs (CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1), as well as information on NGCs in general, were used for the human health portion of this assessment.

Due to the absence of relevant toxicological studies on NGCs, health effects information on benzene and low boiling point naphthas (LBPNs) (that are similar to NGCs from a physical-chemical perspective) were considered. Benzene, a component of NGCs, has been identified by Health Canada and several international regulatory agencies as a carcinogen, and was added to the *List of Toxic Substances* in Schedule 1 of CEPA. Based on an analysis of the major hydrocarbon constituents of NGCs, benzene was selected as a high-hazard component to characterize potential exposure and risk to the general population from evaporative emissions of NGCs.

The potential for general population exposure to NGCs was evaluated by considering data on the handling/transportation of CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1 and on evaporative emissions from NGC storage facilities. For non-cancer endpoints, margins of exposure (MOEs) for short-term inhalation exposures to evaporative emissions of NGCs in the vicinity of rail loading/unloading sites are considered potentially inadequate to address uncertainties related to health effects and exposure. For cancer endpoints, MOEs based on upper-bounding estimates of long-term inhalation exposures to evaporative emissions of NGCs in the vicinity of high-volume rail or truck loading/unloading sites, as well as in the vicinity of NGC storage facilities, are considered potentially inadequate to address uncertainties related to health effects and exposure.

Based on the information presented in this screening assessment, it is concluded that NGCs meet the criteria under paragraph 64(*c*) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.

It is concluded that natural gas condensates meet one or more of the criteria set out in section 64 of CEPA.

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1. Introduction

Pursuant to s. 68 and 74 of the *Canadian Environmental Protection Act, 1999* (CEPA) (Canada 1999), the Minister of the Environment and the Minister of Health conduct screening assessments of substances to determine whether these substances present or may present a risk to the environment or to human health.

A key element of the Government of Canada’s Chemicals Management Plan is the Petroleum Sector Stream Approach (PSSA), which involves the assessment of approximately 160 petroleum substances that are considered high priorities for action. These substances are primarily related to the petroleum sector and are considered to be of Unknown or Variable composition, Complex reaction products or Biological materials (UVCBs).

High priority petroleum substances fall into nine groups of substances based on similarities in production, toxicity and physical-chemical properties (Table A-1 in Appendix A). In order to conduct the screening assessments, each high priority petroleum substance was placed into one of five categories (“Streams”) depending on its production and uses in Canada:

> Stream 0: substances not produced by the petroleum sector and/or not in commerce;
> Stream 1: site-restricted substances, which are substances that are not expected to be transported off refinery, upgrader or natural gas processing facility sites[1];
> Stream 2: industry-restricted substances, which are substances that may leave a petroleum-sector facility and may be transported to other industrial facilities (for example, for use as a feedstock, fuel or blending component), but that do not reach the public market in the form originally acquired;
> Stream 3: substances that are primarily used by industries and consumers as fuels;
> Stream 4: substances that may be present in products available to the consumer.

An analysis of the available data determined that 67 high-priority petroleum substances may be present in consumer products under Stream 4, as described above. These 67 substances were further sub-grouped as follows, based on their physical and chemical properties and potential uses: aromatic extracts, gas oils, heavy fuel oils (HFOs), low boiling point naphthas (LBPNs), natural gas

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[1] For the purposes of the screening assessment of PSSA substances, a “site” is defined as the boundaries of the property where a facility is located.

condensates (NGCs), solvents, petroleum and refinery gases, base oils, petrolatum and waxes, and asphalt.

This screening assessment addresses natural gas condensates. During the categorization of the Domestic Substances List, three NGCs under Chemical Abstracts Service Registry Numbers (CAS RNs) 64741-47-5, 64741-48-6 and 68919-39-1 were identified as priorities for assessment, as they met the categorization criteria under s. 73 of CEPA and were identified as priorities based on other human health concerns. Other NGCs were also identified as priorities based on other human health concerns. Due to their similarity of sources, properties, hazard, and the substantial compositional variability within, and overlap between NGCs that can lead to interchangeable use of CAS RNs, this screening assessment encompasses all NGCs as described in the Substance Identity and Uses sections. These substances were included in the PSSA because they are related to the petroleum sector and are complex mixtures.

According to information submitted under s. 71 of CEPA (Environment Canada 2008, 2012) an in-depth literature review, and a search of material safety data sheets (MSDS), these substances are used as viscosity adjustors/diluents for heavy crude oil and bitumen, as industrial feedstocks, and as gasoline blending stocks.

Screening assessments focus on information critical to determining whether substances within a grouping meet the criteria set out in s. 64 of CEPA. Screening assessments examine scientific information to develop conclusions by incorporating a weight-of-evidence approach and precaution[2].

This screening assessment includes consideration of information on chemical properties, environmental fate, hazards, uses and exposure for NGCs, including information submitted by stakeholders for CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1. Relevant ecological data were identified up to August 2015 and health-related data to September 2015. Empirical data from key studies as well as some results from models were used to reach conclusions. When available

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[2] A determination of whether one or more of the criteria of s. 64 are met is based upon an assessment of potential risks to the environment and/or to human health associated with exposures in the general environment. For humans, this includes, but is not limited to, exposures from ambient and indoor air, drinking water, foodstuffs and the use of consumer products. A conclusion under CEPA on the substances in the Chemicals Management Plan is not relevant to, nor does it preclude, an assessment against the hazard criteria specified in the *Hazardous Products Regulations* which is part of the regulatory framework for the Workplace Hazardous Materials Information System (2015) for products intended for workplace use. Similarly, a conclusion based on the criteria contained in s. 64 of CEPA does not preclude actions being undertaken under other sections of CEPA or other Acts.

and relevant, information presented in assessments from other jurisdictions was considered.

This screening assessment does not represent an exhaustive or critical review of all available data. Rather, it presents the most critical studies and lines of evidence pertinent to the conclusion.

This screening assessment was prepared by staff in the Existing Substances Programs at Health Canada and Environment Canada and incorporates input from other programs within these departments. The human health and ecological portions of this assessment have undergone external review. Comments on the technical portions relevant to the environment were received from Mr. Gordon Dinwoodie (Alberta Energy and Utilities Board), Mr. Geoff Granville (GCGranville Consulting Corp.), and Dr. Ken Trudel (SL Ross Environmental Research Ltd.). Comments on the technical portions relevant to human health were received from scientists selected by Toxicology Excellence for Risk Assessment (TERA), including Dr. Brian Endlich (California Department of Toxic Substances Control), Mr. Robert Lee (Neptune and Company Inc.), Dr. Donna Vorhees (The Science Collaborative-North Shore) and Dr. Calvin Willhite (Risk Sciences International). Additionally, the draft of this screening assessment was subject to a 60-day public comment period. While external comments were taken into consideration, the final content and outcome of the screening assessment remain the responsibility of Health Canada and Environment Canada.

The critical information and considerations upon which the screening assessment is based are given below.

2. Substance Identity

In this screening assessment report, natural gas condensates are defined as complex combinations of hydrocarbons that condense or are separated from the gaseous phase into the liquid phase during production at wellheads; in natural gas processing plants; in gas pipelines for production, gathering, transmission and distribution; and/or in straddle plants along the main gas pipelines. They consist of hydrocarbons mostly falling within, but not necessarily spanning, a carbon range of C_2 to C_{30}, with predominant hydrocarbons typically falling between C_5 to C_{15}. In addition, this definition encompasses all liquids derived from natural gas distillates, except those with predominant hydrocarbon fractions below C_5. NGCs used as a diluent for bitumen or heavy crude oils can be recovered from the diluted materials in petroleum refineries and/or upgraders for reuse; this recovered NGC is also considered within the context of this assessment.

The above definition encompasses the terms used by different organizations to describe NGCs and other substances associated with natural gas production, such as “pentanes plus” (i.e., C_5^+), and “natural gas liquids” (NEB 2005; Statistics

Canada 2011a; Canadian Centre for Energy 2011). Definitions of these terms by different organizations are presented in Appendix B. These terms are defined similarly to or used interchangeably with NGCs. In addition, the term “condensates” or “gas condensates” is used in some literature (SL Ross 1982; Jokuty et al. 1999; McMillen et al. 2001; Rixey 2001) and is used interchangeably with NGCs within the context of this screening assessment. It is noted that C_5^+ can also be referred to as “natural gasoline” (Mokhatab et al 2006). NGCs have been identified under the CAS RN for natural gasoline (i.e., CAS RN 8006-61-9) (Plains Midstream Canada 2010). However, this CAS RN has also been used to describe fuel gasoline. Gasoline fuel is not considered as an NGC.

NGCs are UVCB substances that are complex combinations of hydrocarbon molecules that originate in nature or are the result of chemical reactions and processes that take place during processing, transport, blending, etc. Given their complex and variable compositions, they could not practicably be formed by simply combining individual constituents.

Information on the composition of NGCs has been compiled, but this information is dependent on the definition of NGCs which is not always consistent between sources. NGCs have been described as containing alkanes, isoalkanes, cycloalkanes and aromatics that mainly fall in the C_5–C_{30} carbon range, and with API gravities generally greater than 45° (McMillen et al. 2001; Hawthorne and Miller 1998, Canadian Centre for Energy 2011), though lower molecular weight substances may be present. NGCs can be subdivided into “light” (mainly C_5–C_{10}) or “heavy” (mainly C_5–C_{15}) (Favennec 2001). Condensates from Alberta have hydrocarbons primarily in the range of C_5–C_{16} (Hawthorne and Miller 1998), while other parts of Canada could give rise to NGCs with a narrower or broader carbon range, depending on properties of the underground formation/well, etc. NGCs coming directly from conventional oil wells tend to have a tail of heavier hydrocarbons, while those coming from natural gas wells, natural gas processing plants or from condensation in pipelines have a much narrower range of hydrocarbons (McMillen et al. 2001).There is no clear demarcation between some NGCs and light petroleum, as some NGCs are similar to a very light and volatile crude oil, but differ from most crude oils in that the heavier asphaltenes are absent (S. L. Ross 1982). The carbon ranges, major components and aromatic to aliphatic ratios of the three high-priority NGCs identified during the categorization of the Domestic Substances List are given in Appendix Table C-1.

Several studies are available that describe the compositions of some NGCs, including the levels of aromatic compounds. Adler et al. (1992) identified 115 different hydrocarbons in an NGC from a well in northern California, with cyclic hydrocarbons being predominant. In a condensate sample from the North Sea, hydrocarbons from C_4 to C_9 accounted for more than 70% by weight (% w/w), including approximately 2% w/w of benzene and 0.5% w/w of ethylbenzene (Riaz et al. 2011). Rixey (2001) reported benzene concentrations in 14 NGC samples ranging from 0.15% w/w (1500 mg/kg) to 3.6% w/w (36 000 mg/kg) with a mean concentration of 1.0% w/w (10 300 mg/kg). Hawthorne and Miller (1998) found that condensates from various locations in North America had significant concentrations of benzene (0.15 to 3.6% w/w), toluene (1.1 to 5.8% w/w), ethylbenzene (up to 5.5% w/w), xylenes (*m*, *p*-xylenes: 0.33 to 5.5% w/w), and other alkyl-benzenes, with the Alberta sample containing the highest concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX). Kerr et al. (2001) reported that three polycyclic aromatic hydrocarbons (PAHs), benzo[*a*]anthracene, benzo[*b*]fluoranthene and chrysene, were detected in 10 condensate samples (origin unspecified) with mean concentrations of 0.3 mg/kg, 0.64 mg/kg, and 1.9 mg/kg, and the detection frequency of 10%, 30% and 40%, respectively. Manzano et al. (1997) found the aromatic fraction of several gas condensate samples from the Brazeau River area in central-west Alberta were dominated by dibenzothiophenes and benzothiophenes.

The Sable Offshore Energy Project (SOEP) off the coast of Nova Scotia near Sable Island primarily extracts natural gas, and in the process produces NGCs. Hydrocarbon analyses of condensates from the SOEP, as well as condensate samples from the Brazeau River area in central-west Alberta, are given in Table 2-1.

Table 2-1 Percentage of hydrocarbon classes (% w/w) for Canadian condensate samples (Jokuty et al. 1999, Manzano et al. 1997)

Hydrocarbon Group	**SOEP**	**Brazeau River, AB**[a]
Saturates	88, 81[b]	81.7
Aromatics	11	16.9
Resins	0	1.16
Asphaltenes	1	0.22
Waxes	2	0.00

[a] Average of 11 samples (Manzano et al. 1997)
[b] by Mackay and Zagorski (1982) and SL Ross (1982).

The Sable Island condensate is approximately 85% saturates (based on two measurements) and 11% aromatics, with very low concentrations of asphaltenes and waxes (Table 2-1). The Brazeau River, AB samples are similarly high in saturates, do not contain any waxes, and also have very low amounts of resins and asphaltenes (Table 2-1).

In addition to petroleum hydrocarbons, NGCs may also contain significant quantities of sulphur-containing compounds, such as hydrogen sulphide, various organosulphur compounds such as thiols, organic sulphides, dimethyl sulphide, and thiophenes (Manzano et al., 1997). Hydrogen sulphide is being assessed separately by the Government of Canada.

3. Physical and Chemical Properties

Physical and chemical properties determine the overall characteristics of a substance and are used to determine the suitability of different substances for different types of applications. Such properties also play a critical role in determining the environmental fate of substances (including their potential for long-range transport), as well as their toxicity to humans and non-human organisms.

The composition and physical-chemical properties of NGCs vary with the source of crude oil or natural gas and the processing steps involved. Data on physical-chemical properties of Canadian NGC samples are presented in Table 3-1.

Table 3-1 Physical and chemical properties[a] of various Canadian NGCs

Sample Name/Origin	Density (kg/m^3)	API Gravity	Specific Gravity	Viscosity	Water Solubility (mg/L)	References
SOEP Condensate	704	-	0.70	0.411 cP	12–14, 76 (20° C)	MacLean (1989), S.L. Ross (1995), S.L. Ross (1982), Jokuty et al. (1999)
Panuke, SOEP	775	-	0.77	1.90 cP	-	S.L. Ross (1995)
Cohasset, SOEP	790	-	0.79	2.6 cP	-	S.L. Ross (1995)
Venture B-43, SOEP	823 (15° C)	39.9	0.83	2.7 cP (5° C) 2.0 cP (15° C)	58.1, 74.7[b]	S.L. Ross (1995, 1982)
Condensate blend, AB[c]	719	65.2	0.72	0.86 cSt (7.5° C)	-	Crude Quality Inc. (2011)
Natural Gas Condensates, AB (CAS RN 64741-47-5)	600–750	-	0.60-0.75	<1 cSt (0 ° C)	Insoluble	Gibson Energy ULC (2013)
Gibsons Heavy Sweet Condensate, (CAS RN 64741-47-5)	769.4 (15° C)	-	0.77	-	Insoluble	Gibson Energy ULC (2014)
Rangeland	745.2	58.3	0.74	1.13 cSt	-	Crude

Sample Name/Origin	Density (kg/m^3)	API Gravity	Specific Gravity	Viscosity	Water Solubility (mg/L)	References
Condensate[d]				(7.5° C)		Quality Inc. (2015a)
Fort Sask. Condensate[e]	674.4	78.1	0.67	0.54 cSt (7.5° C)	-	Crude Quality Inc. (2015b)
Pembina Condensate[f]	760.4	54.5	0.76	0.54 cSt (7.5° C)	-	Crude Quality Inc. (2015c)
Peace Condensate[g]	744.4	58.4	0.74	1.17 cSt (7.5° C)	-	Crude Quality Inc. (2015d)
Condensate – High Prairie	654.4 (15° C)	-	0.65	0.458 cSt (10° C)	Insoluble	Plains Midstream Canada (2014a)
Condensate - COED to Enbridge	722.2 (15° C)	64.2(15° C)	0.65	0.763 cSt (10° C)	Insoluble	Plains Midstream Canada (2014b)
Gas condensate, Brazeau River area , AB[h]	-	48.40	0.79	-	-	Manzano et al. (1997)

cP – centipoise (dynamic viscosity)

cSt – centistokes (kinematic viscosity)

[a] The temperature at which the property was determined is given in parentheses, if it was available. For conversion of density to specific gravity, 15° C assumed if temperature not given.

[b] Temperature of measurement unknown, 0% weathered sample, 58.1 mg/L in synthetic seawater, 74.7 mg/L in distilled water.

[c] Condensate Blend (CRW) is “a fully blended aggregate of many light sweet feeder streams and begins its existence in blend tanks in Edmonton, AB. The CRW blend is nearly completely consumed within Alberta as a diluent in heavy crude blending” (Crude Quality Inc. 2011). Enbridge Pipelines has developed specifications for the component streams of CRW blend, including density between 600–775 kg/m^3, a maximum viscosity of 2.0 cSt, etc. (Crude Quality Inc. 2011).

[d] Rangeland Condensate (CRL) is gathered from gas plant operations in the foothills to the southwest of Edmonton, and batch delivered to Edmonton on the Plains Midstram Marketing Rangeland pipeline. CRL is blended into CRW at the Enbridge Edmonton Terminal. One year average values are reported.

[e] Fort Saskatchewan condensate (CFT) is a fractionated stream produced by Keyera at their Fort Saskatchewan operations. CFT is delivered into CRW at the Enbridge Edmonton Terminal on a continuous, rateable basis. One year average values are reported.

[f] Pembina condensate is gathered from gas plant operations in the foothills to the west of Edmonton, and batch delivered to Edmonton on the Pembina Drayton Valley pipeline. It is blended into CRW at the Enbridge Edmonton Terminal on an intermittent basis dependent on batch arrivals.

[g] Peace condensate is gathered from gas plant operations in the foothills to the northwest of Edmonton, and batch delivered to Edmonton on the Pembina Peace pipeline. It is blended into CRW at the Enbridge Edmonton Terminal on an intermittent basis dependent on batch arrivals.

[h] Data has been averaged for 11 samples taken within about a 30 km^2 area near the Brazeau River of west-central Alberta, in the Nisku Formation.

The NGCs described in Table 3-1 from Canadian sources have densities that mainly fall within the range of light crude oil (i.e., less than 820 kg/m^3 (CONCAWE 2001)). Only the NGC from the Venture well of the SOEP is slightly above this value and thus is considered to be a medium petroleum oil. The specific gravity of NGCs typically ranges from 0.5–0.8 (EnCana 2011, JP Morgan 2013; SourceGas 2007); specific gravity values reported for condensate blend (CRW) from Western Canada range from around 0.64 to 0.67 (Crude Quality Inc., 2011; Cenovus Energy 2014). C_2–C_8 NGCs can have specific gravities as low as 0.3 (Marathon Oil Company 20011). Based on their densities and specific gravities, NGCs will float on water. Viscosities of NGCs from Western Canada range from 0.54 to 1.17 cSt at 7.5° C (Table 3-1), which is less than that of water (i.e., approximately 1.4 cSt at 7.5° C) (The Engineering Toolbox, undated).

Data on the physical-chemical properties of some NGC CAS RNs are provided in Table 3-2 based on empirical and read-across data found in the European Chemicals Bureau's (ECB) IUCLID (International Uniform Chemical Information Database) dossiers for the NGC CAS RNs in Table 3-2 (ECB 2000a,b,c) and from other sources (Enerchem 2009; Source Gas 2007; Spectra Energy 2013; Gibson Energy ULC 2013). The ECB dossiers provide physical and chemical properties for CAS RN 64741-47-5 and 68919-39-1 primarily based on read-across from unleaded gasoline (CAS RN 86290-81-5) (ECB 2000a,c,d). No specific physical-chemical property data are provided in the ECB dossier for CAS RN 64741-48-6.

Table 3-2 Physical and chemical properties of three NGCs

Property	**CAS RN 64741-48-6**	**CAS RN 68919-39-1**	**CAS RN 64741-47-5**
Melting point (°C)	-	< -60[a]	< -60[a] < -54
Normal boiling point range (°C)	-96 to 170	25–200[a] 30–300	25–200[a] 30–300
Vapour pressure (kPa)	82.7–179.3 (12–26 psi[b]) (37.8°C)	35–90 (37.5°C)[a] 106 (20°C)	35–90 (37.5°C)[a] 35–75 (20°C)
Vapour density (air = 1)	>1	>1	2.5 (30°C)
log K_{ow}[c](dimensionless)	-	2.1–6[a]	2.1–6[a]
Water solubility (mg/L)	negligible	30–100 (20°C) [a]	30–100 (20°C) [a]
Relative density (dimensionless)	0.5–0.75	0.68–0.79 (15°C) [4] 0.7	0.68–0.79 (15°C) [4] 0.6–0.75
References	Enerchem 2009; Source Gas 2007	ECB 2000c; Spectra Energy Transmission 2013	ECB 2000a; Gibson Energy ULC 2013

[a] Based on unleaded gasoline CAS RN 86290-81-5
[b] psi = pounds per square inch (absolute)
[c] K_{ow}, octanol–water partition coefficient
[d] Represents a typical range for Group 3G products (Group 3G includes a series of refinery streams used in blending gasoline, as feedstock for further refinery processes, or as industrial solvents)

To predict the physical/chemical properties and ecological fate of a complex petroleum substance such as an NGC, representative structures were chosen from each chemical class contained within the substance (Table C-2 in Appendix C). As the composition of NGCs is variable and not well defined, representative structures could not be chosen based on their proportion in the mixture. This lack of general compositional data resulted in the selection of 54 representative structures for alkanes, isoalkanes, alkenes, cycloalkanes, mono- and di-aromatics, polyaromatics and alkyl-aromatics ranging from C_2 to C_{20}, based solely on carbon numbers for each hydrocarbon class. Physical–chemical data were taken from scientific literature (as listed in EPI Suite (2008)), or, in the absence of empirical data, were modelled using EPI Suite (2008). A summary of empirical and modelled physical and chemical properties for the representative hydrocarbon structures of NGCs is given in Table C-2 (Appendix C).

It should be noted that the physical and chemical behaviour of the representative substances differ when substances are present in a mixture, such as NGCs. The vapour pressures of components of a mixture will be lower than their individual vapour pressures due to Raoult’s law (the total vapour pressure of an ideal mixture is proportional to the sum of the vapour pressures of the mole fractions of each individual component). Similar to Raoult’s law, the water solubilities of components in a mixture are lower than when they are present individually (Banerjee 1984). Concurrently, however, when part of a mixture, components that are normally solid under environmental conditions may have lower melting points (and therefore be in a liquid state), as well as increased vapour pressure and water solubility (Banerjee 1984). This is not reflected in Table C-2, Appendix C. However, the physical and chemical properties of the individual representative structures (Table C-2, Appendix C) give an indication of how these individual components of the petroleum mixture may behave in the environment.

Water solubilities range from very low (0.004 mg/L) for the longest chain alkanes to high (1790 mg/L) for the simplest mono-aromatic structure (benzene). S.L Ross (1982) notes that most of the solubility of the Venture condensate can be attributed to the combined solubilities of the BTEX substances (benzene, toluene, ethylbenzene and xylenes), contributing to about 91% of the solubility in both distilled and synthetic seawater.

Experimental and modelled vapour pressure data for representative structures are moderate to very high, with the exception of structures with 20 carbon atoms, and a four-ringed PAH, which have low vapour pressure. Vapour pressure decreases with increasing molecular size.

Based on the data in Tables 3-1 and 3-2, NGCs are highly volatile and moderately soluble in water. Log K_{OW} values range from low to high (more than 4.5), meaning that partitioning to organic matter in sediments or soil will vary, depending upon the composition of the NGCs. For example, NGCs having more high molecular weight components such as PAHs, which have high K_{OW} values, will partition to organic carbon to a greater extent than NGCs with less of these components.

4. Sources

As NGCs are typically (but not exclusively) associated with natural gas (Schlumberger 2011), the potential locations for producing NGCs are primarily the same sites where natural gas is produced. In Canada, natural gas is produced in several regions, most notably the Western Canada Sedimentary Basin, which includes Alberta, as well as parts of north-eastern British Columbia and western Saskatchewan. Other natural gas production fields are found in Southern Ontario, Quebec, a small region of New Brunswick, southeast Yukon and the Northwest Territories. Off-shore natural gas production is located off the east coast of Nova Scotia. NGCs may also be associated with oil production, which occurs primarily in Alberta, Saskatchewan, and offshore Newfoundland and Labrador, and also in British Columbia, Manitoba, Ontario and New Brunswick (CAPP 2015). NGCs may also be produced from unconventional shale gas or tight gas development (CAPP 2012).

NGCs can also be generated at the wellheads of gas, condensate or oil wells, where natural gas, petroleum hydrocarbon (PHC) liquids, and/or water are preliminarily separated. Raw natural gas from the wellheads is delivered through gathering lines to processing plants, where NGCs can potentially develop in the gathering lines during pipeline transportation (NEB 2005; Natural Gas Supply Association 2011). A significant amount of NGCs can be produced as by-products from raw natural gas processing plants where natural gas is purified before entering into product distribution pipelines (NEB 2005; Hammer et al., 2012). Most of the Canadian condensate supply is derived from the processing of raw natural gas (NEB 2004). In addition to gas processing at wellheads or at centralized gas processing plants, NGCs can be separated from raw natural gas in straddle plants located on the main pipeline networks. The straddle plants remove additional amounts of ethane and heavier liquids from the gas stream (NEB 2004).

Production data for NGCs and related substances (e.g., C_5^+) in Canada were collected from various sources. Recent estimates of production of NGCs in Canada range from eight million (for C_5+ from gas plants (NEB 2011)) to ten million m^3/year (condensate from the field plus C_5^+ (Statistics Canada 2011b)) Approximately 89% of the 2010 condensate production originated from Alberta, 6% from BC, 4.9% from Nova Scotia, and 0.45% from Saskatchewan (NEB 2011). In Canada, most of the off-shore natural gas production originates from facilities off the coast of Nova Scotia (the SOEP). The SOEP has a production of approximately 800 000 m^3/year of liquid (termed natural gas liquids) consisting of ethane, propane, butane and C_5^+ (ExxonMobil 2011a); this liquid is considered to be an NGC within this assessment. In addition, data were also collected for three NGCs identified under CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1 through a notice published under s. 71 of CEPA (Environment Canada 2012). In 2010, the total manufactured quantity of these three NGCs was between 100 million and one billion metric tonnes, the import quantity was between 100 000 and one million tonnes, and the total transported quantity was between 100 million and one billion tonnes (Environment Canada 2012).

The United States Environmental Protection Agency (U.S. EPA) Inventory Update Reporting System documents that the annual production volumes for each of CAS RNs 64741-47-5 and 64741-48-6 in the U.S.A in 2006 were above one million m^3 (about 750 000 metric tonnes). Although CAS RN 68919-39-1 was not reported in 2006, the production volume was above one million m^3 (about 750 000 metric tonnes) in 2002 (U.S.EPA IUR 2012).

Globally, NGCs identified under CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1 have been identified as high production volume (HPV) substances (i.e., with production or import quantities of 1000 tonnes/year or above) by the Organization for Economic Co-operation and Development (OECD). In addition, CAS RN 68919-39-1 has been identified as an HPV chemical by Australia (defined as a combined manufacturing and import quantity of 1000 tonnes/year or more). World production of NGCs in 2013 was 6.9 million barrels per day (1.1 million m^3/day or 825 000 metric tonnes/day) and is expected to increase to 8.8 million barrels per day (1.4 million m^3/day or 1.1 million metric tonnes/day) in 2019, a 3.3% increase (IEA 2014).

5. Uses

Viscosity adjustors/diluents are blended into heavy crude oil or bitumen to reduce their density and viscosity in order to meet pipeline specifications. Various substances may be used for this purpose including NGCs, and the largest use of NGCs in Canada is as a diluent (NEB 2004, NEB 2013). Potential exposures to NGCs that have been used to adjust the viscosity of petroleum substances are more suitably considered in the context of the petroleum substance(s) that has been diluted and are not considered in this assessment. However, once the diluted petroleum substance is delivered to its destination, about 23% of the NGCs can be recovered from the heavy crude oil or bitumen and shipped back to the extraction site to be used once more as a diluent (NEB 2013). Releases during shipment of this recirculated NGC are considered in this assessment.

Additional use information identified for NGCs under s. 71 of CEPA, an in-depth literature review and a search of material safety datasheets indicates that NGCs can also be used as gasoline blending stocks and industrial feedstocks. Although

NGCs were initially thought to be present in consumer products, an in-depth review identified only industrial uses. It is therefore expected that the general population would not have access to these substances.

CAS RN 64741-47-5 has been reported to be used in oilfield applications such as well servicing and in hydraulic fracturing operations (Devon 2010; Gibson Energy ULC 2010; Keyera 2011).

6. Release to the Environment

Releases of NGCs from upstream petroleum facilities and transportation are considered to be the major sources of releases of NGCs to the environment. Information on releases of NGCs was primarily obtained from data collected through the *Notice with respect to certain high priority petroleum substances on the* Domestic Substances List, published under s. 71 of CEPA (Environment Canada 2012), the Alberta Energy Resources Conservation Board (ERCB 2012) (now called the Alberta Energy Regulator), the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB 2002-2012), and the Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOPB 2015). NGCs are not reportable under the Canadian National Pollutant Release Inventory (NPRI 2012), or under the U.S. Toxics Release Inventory Program (US EPA 2012).

6.1 Releases from Petroleum Facilities

In general, petroleum facilities (onshore and offshore) and chemical facilities in Canada are highly regulated, and regulatory requirements are established under various jurisdictions. As well, the petroleum industry has implemented voluntary measures to manage releases (CAPP 2005, 2006, 2007; SENES 2009).

Releases of NGCs from petroleum facilities can be characterized as either controlled or unintentional releases. Controlled releases are planned releases of produced water, or releases from pressure relief valves, venting valves and drain systems for safety purposes or maintenance. Unintentional releases are typically characterized as spills or leaks from various equipment, valves, piping or flanges.

S. 71 data reported by industry (Environment Canada 2012) included total releases by CAS RNs to air, water and land, as well as quantities of waste transferred to off-site waste management facilities. Any companies producing or importing over 100 kg of any of the three NGC CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1 were required to report. Total reported releases of the three NGCs to land in 2010 were between 100 000 and one million kg. Total reported releases to water were between 100 and 1000 kg. Reported releases to air totalled between 1000 and 10 000 kg.

6.1.1 Controlled Releases from Petroleum Facilities

Controlled releases of NGCs originate primarily from upstream oil and gas facilities (onshore or offshore). The potential locations for the controlled release of NGCs from such facilities include relief valves, venting valves or drain valves on the piping or equipment (e.g., tanks) where NGCs are generated or stored in the vicinity of wellheads or processing sites.

Under typical operating conditions, almost all controlled releases of NGCs at natural gas or petroleum processing facilities are captured in a closed system, according to defined procedures, and returned to the processing facility or to the wastewater treatment plant. Therefore, exposure of the general population or the environment to NGCs is not expected from such types of releases.

Controlled releases to the environment include the permitted release of produced water into the surrounding marine environment by offshore facilities (NEB et al. 2010). Produced water may contain oil with a 24-hour average concentration up to 44 mg/L, and a 30-day volume weighted average concentration of 30 mg/L (NEB et al. 2010). Produced water includes formation water, injection water and process water that is extracted along with oil and gas during petroleum production. In addition, a portion of the chemicals added during processing of reservoir fluids may partition to the produced water. This water is separated from the petroleum process stream and, after treatment, is discharged to the marine environment (NEB et al. 2010).

Table 6-1 presents estimates of petroleum hydrocarbons released in produced water from the SOEP. It is assumed that most of the petroleum hydrocarbons in the produced water originate from NGCs in the formation water. Produced water discharges from the SOEP show an increasing trend over 2009-2011, which is to be expected in a mature reservoir with decreasing yields.

Table 6-1 Estimated releases of petroleum hydrocarbons in produced water (PW) from the SOEP

Year	Average PW discharge (L/month)[a]	Estimated mass of oil discharged in PW (kg/month)[b]	Estimated volume of oil discharged in PW (L/month)[c]
2009	15 304 000	460	595
2010	19 604 000	590	763
2011	24 058 000	720	931

[a] From CNSOPB 2012

[b] Litres water/month × 0.00003 kg oil/L = kg/day oil (Note: concentration meets the monthly Performance Target of 30 mg oil/L)

[c] Kilograms oil/month ÷ (0.773 kg/L density) = litres oil/month. Average density (0.7734 kg/L) calculated from densities of SOEP condensates in Table 3-2.

Niu et al. 2010 reported the concentration of BTEX, PAHs and alkanes in produced water from the Venture and Thebaud wells of the SOEP, from sampling events that took place in July and August 2009 and from the Thebaud well in August 2007. Naphthalene and its alkylated homologues made up approximately

85 and 97% of the total PAHs of the produced water sampled from the Venture and Thebaud platforms, respectively (Niu et al. 2010). In comparison to the other organic components, long-chain alkanes, having low water-solubility, were detected at the lowest concentrations (Table 6-2). The profiles of alkanes were slightly different between the two wells, with Thebaud having the highest concentrations in the C_{13}–C_{18} range, while for Venture, concentrations were highest in the C_{10}–C_{15} range, with decreasing concentrations with increasing carbon number for both wells (Niu et al. 2010).

Table 6-2 Composition of hydrocarbons in produced water from the Venture and Thebaud wells of the SOEP (Niu et al. 2010)

Compound	Concentration (mg/L)
Benzene	4.2–18
Toluene	5.2–24
Ethylbenzene	0.14–1.1
Xylenes	1.1–8.0
Total BTEX	13–51
Total phenols	11–25
Naphthalene	0.19–1.5
Total PAHs	0.53–2.1
Total alkanes (C_{10}-C_{35})	0.13–0.36

During land-based production, produced water is typically disposed of by re-injection into a deep disposal well (Pembina Institute 2007). Produced water is mostly saline and contains a variety of chemicals, so the soil may become contaminated if there are leaks from the disposal well or from the underground formation into which the produced water is being disposed (Pembina Institute 2007). There are laws and regulations governing the disposal of produced water and drilling wastes from land-based oil and gas production. For example, in Alberta, disposal requirements are given in the *Alberta Oil and Gas Conservation Regulations* (Alberta Regulation 151/71) of the *Oil and Gas Conservation Act* (Alberta 2011). These Regulations and related Directives describe requirements for waste storage tanks and excavations, and require clean-ups of any spills.

6.1.2 Unintentional Releases from Petroleum Facilities

Unintentional releases of NGCs may occur at production facilities. Legislation includes requirements at the provincial/territorial level to prevent or manage the unintentional releases of petroleum substances and streams within a facility through the use of operating permits (SENES 2009). Such control measures include appropriate material selection during the design and setup processes, regular inspection and maintenance of storage tanks, pipelines and other process equipment, the implementation of leak detection and repair or other equivalent programs, the use of floating roofs in above-ground storage tanks to reduce the internal gaseous zone; and the minimal use of underground tanks, which can lead to undetected leaks or spills (SENES 2009). Existing occupational health and safety legislation specifies measures to reduce occupational exposures of employees, and some of these measures also serve to reduce unintentional releases (CanLII 2001). Non-regulatory measures (e.g., guidelines, and best practices) are also in place at petroleum sector facilities to reduce unintentional releases.

Fugitive releases of NGCs may occur during all stages of NGC production, processing, transportation, and storage. Though a buried pipeline is not itself a significant source of VOC emissions, the surface facilities that are associated with petroleum pipelines can be significant sources of VOC emissions, as described by Durrenberger et al. (2006). Armendariz (2009) describes fugitive emission sources from natural gas in detail, from well drilling and gas processing to gas delivery systems. Various equipment (e.g., pumps, and vessels) and fittings (e.g., flanges, gauges, pipe connectors, and valves) involved in these systems are potentially significant sources of fugitive emissions of volatile hydrocarbons into the atmosphere. Fugitive emissions are caused by leaks from the above-mentioned equipment, as well as by wear, rust and corrosion, improper installation or maintenance, or overpressure of the gases or liquids in the piping (Armendariz 2009). However, unlike a point-source spill to soil or water, fugitive atmospheric releases are often wide-spread.

Evaporative emissions from condensate storage tanks may also be a substantial source of VOC emissions, as storage of NGCs is often required at gas or oil extraction sites, gas processing plants or transportation terminal sites (Chambers 2004; Hendler et al., 2009; Armendariz 2009). Hendler et al. (2009) measured the emission rates of vent gas from various “condensate tank batteries” in East Texas in the summer of 2006, including benzene emissions, and also presented the speciation profile of venting gas from condensate storage tanks. The average vent gas emission rate was approximately 19 ± 28 kg per barrel of condensate produced, with benzene levels ranging from 0.13 to 1.4% w/w in the vent gases. EC/R (2011) also reported benzene levels of 0.03 to 5.7% w/w (0.54 ± 0.88% w/w) in the venting emissions from 46 storage tanks in the USA. These storage tanks contained condensate substances with API gravities equal to or greater than 40 and, therefore, it was considered that all were representative of condensate storage vessels. In Canada, benzene emissions from “condensate tanks” in two Canadian gas processing facilities in Alberta were similarly investigated, using the differential absorption light detection and ranging (DIAL) technique. The benzene emissions from condensate tank areas were measured to be 0.03 kg/hour (Chambers 2004). A VOC venting rate of 0.02–0.2 kg per barrel of condensate produced is estimated based on the modelled annual releases from the storage tanks and the total condensate produced in Canada, assuming a vapour control unit is in place for large-volume tanks in western Canada. A detailed estimation of potential exposure of the general population to NGC vapours and benzene emissions from storage tanks is presented in the subsequent human exposure section, based on measured emission data from Hendler et al. (2009) and Chambers (2004) by assuming that the condensate tanks in the studies are representative of storage scenario for NGCs defined in this assessment.

6.2 Unintentional Releases – Spills to the Environment

Unintentional releases to the environment also occur when NGCs are spilled. Releases of NGCs (under the general substance description “condensate”) were assessed through an analysis of historical spill data (2002–2011) from Alberta.

Spills of NGCs from the upstream energy sector within the province of Alberta are reported to the Alberta Energy Regulator (AER) (formerly Alberta’s Energy Resources Conservation Board (ERCB)). The AERrequires reporting for spills greater than or equal to two m^3 (2000 L) on land leased for the purpose of resource extraction, or any amount spilled if it’s from a pipeline, or that goes off of the leased land or any release, on or off lease, of any size that may cause, is causing or has caused an adverse effect (AER 2015). During the ten year period 2002–2011, a total of 531 spills of condensate, with a total volume of approximately 2.2 million litres, were reported in Alberta (ERCB 2012)[3].

There were no upward or downward trends in the number of condensate spills reported per year in Alberta from 2002–2011. Between 40 and 72 spills were reported per year. Condensate spills data reported in Alberta from 2002–2011 are summarized in Tables 6-3 and 6-4.

Table 6-3 Summary of spill data for Alberta over ten years (2002-2011) by compartment of release (ERCB 2012).

Compartment	No. of spills	Average no. spills per year	Total volume spills (L)	Percent of total volume	Average Spill Volume (L)	Median Spill Volume (L)
Air/Land	503	50	1 883 900	86	3 745	500
Muskeg/ Stagnant Water	16	1.6	225 900	10	14 119	2500
Flowing	7	0.7	83 400	3.8	11 914	1000

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[3] Spills that occurred at large gas plant facilities (sweet gas plants and sulphur recovery gas plants) where the spills were not reported to go off-site were not included in the total, as spills at these sites are expected to undergo immediate remediation that minimizes their entry into the environment. Spills caused by vandalism were also not included in the total, as these spills are not considered to be preventable.

water[a]						
Unknown	5	0.5	10 600	0.48	2 120	3000
Total	531		2 203 800	100		

[a] includes spills to lakes

Spills to air/land comprise the majority of the spills reported in Alberta from 2002-2011. There were approximately 25 spills/year with volumes above the median, nine spills/year with volumes above the average, and five spills/year with volumes above the 90th percentile (9000 L).

Table 6-4 Sources of condensate spills in Alberta (2002-2011) (ERCB 2012)

Source	**No. spills**	**Vol. spills (L)**	**% No. Spills**	**%Vol. spills**
Pipelines	164	815 400	31	37
Gas & oil wells	162	373 700	31	17
Oil/Gas/Bitumen Batteries	73	420 900	14	19
Compressor and Pump Stations	53	65 700	10	3.0
Gas plants	47	233 800	8.9	11
Unknown	29	216 300	5.5	9.8
Injection/Disposal	2	8 000	0.38	0.36
Oil Sands plant	1	70 000	0.19	3.2
Total	531	2 203 800	100	100

The Alberta spill database records the size of the area affected by the spills (in ranges). About 64% of the condensate spills were reported to have an area of “100 m^2 or less”, 20.2% had an area of “over 100 m^2 but less than 1000 m^2”, 4.5% had an area of “over 1000 m^2”, and for 12% of the spills, the area affected was not reported. The database also records the volume of free product recovered for each spill. However, as concern is with acute (short-term) risk (Section 8.1), and there is no information about the time period between the release and the remediation (recovery of product), only the total volume spilled was considered in the determination of ecological risk (Sections 8.2, 8.3).

Spills of NGCs to the marine environment appear to be minimal, based on reports from offshore developments off the coasts of Nova Scotia and Newfoundland and Labrador for the years 2002–2011 (CNSOPB 2002-2011; CNLOPB 2015) and information about releases obtained from ExxonMobil, the operator of the SOEP.

According to ExxonMobil, there have been no hydrocarbon spills/releases from the SOEP’s pipelines, and there have been no blowouts associated with the

SOEP since start-up in December 1999 (e-mail communication, 2011, ExxonMobil Halifax office to Ecological Assessment Division, Environment Canada, unreferenced). As well, since no spills to water were reported to the s. 71 survey (Environment Canada 2012), there do not appear to have been spills from marine vessels in 2010.

Spills data for condensate for the years 2002–2011 were examined for Nova Scotia’s and for Newfoundland and Labrador’s offshore gas and petroleum production projects (C-NSOPB 2002–2012, C-NLOPB 2015). . These reports do not include produced water, or spills from tanker ships once they are no longer docked/involved in offloading materials from the offshore platform (C-NSOPB and C-NLOPB 2012). For offshore Nova Scotia, there were seven spills of condensate reported during the period 2002–2011, with the largest spill being 128 L. For offshore Newfoundland and Labrador, there were three small spills of 10 L or less reported in the years 2002–2004, with no condensate spills reported from 2005–2011. The total volume spilled from the offshore east coast, based on these sources, during this period was 207 L. The average and median spill sizes were approximately 21 L and 3.1 L, respectively (C-NSOPB 2002-2011).

Estimated releases to marine water are discussed in Section 8.1.1.

6.3 Releases from Transportation

With the transport of NGCs by ship, rail, pipeline or truck, unintentional releases of NGCs will generally enter the air, water or soil depending on the mode of transportation involved. Unintentional spills or leaks during the handling and transit processes were considered in this screening assessment for the potential to cause ecological harm. Due to their high volatility (see Table 3-2), evaporative emissions into the air from unintentional spills will account for a high proportion compared to the proportions entering water and/or soil.

The handling of NGCs at petroleum facilities for the purpose of transportation is regulated at both the federal and provincial levels, with measures covering loading and unloading (SENES 2009). Collectively, these measures establish requirements for safe handling of petroleum substances, and are intended to minimize or prevent potential releases during loading, transportation and unloading operations (SENES 2009).

Releases from washing or cleaning transportation vessels are not considered in this screening assessment because tanks or containers for transferring petroleum substances are typically dedicated vessels and therefore washing or cleaning is not required on a routine basis (U.S. EPA 2008).

Two types of releases that may occur during handling and transportation of NGCs are considered in this screening assessment. These are evaporative emissions and unintentional releases (e.g., spills or leaks). The quantity of evaporative emissions to the ambient air depends on the volatility of a substance, temperature or pressure changes occurring during storage or transportation, and tightness of storage/transport vessels and valve settings. Assessment of potential exposure of the general population from transportation of NGCs focuses on evaporative emissions, which occur during regular operating activities.

Based on the information submitted (under s. 71 of CEPA) and additional literature review, pipeline, ship, truck and rail were identified as being involved in the transportation of NGCs. Information on transportation quantity was collected under s. 71 of CEPA specific to CAS RNs 64741-47-5, 64741-48-6, and 68919-39-1. The majority of these NGCs are transported by pipeline (approximately 99%), followed by rail (approximately 0.2%), truck (approximately 0.1%) and ship (approximately 0.07%). Between 100 million and one billion tonnes of these NGCs were transported by pipeline in 2010 (Environment Canada 2012), with more than 90% of the total being CAS RN 64741-47-5. Between 100 000 and one million tonnes of these NGCs were transported by rail, with the highest reported quantity of approximately 700 million kg per site. Between 100 000 and 1 million tonnes of theses NGCs were transported by truck, with CAS RN 68919-39-1 representing 68% of this total. Between 100 000 and one million tonnes of CAS RN 64741-47-5 were transported by ship in 2010.

The quantities of evaporative emissions to ambient air from the transportation of NGCs were estimated based on transportation data for three NGCs (i.e., CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1) (Table F-1 in Appendix F). Such estimates were used for determining the potential inhalation exposure of the general population to evaporative emissions from the transportation of NGCs (Section 9.1). The estimated evaporative emission quantities for loading and unloading are considered in the human health exposure assessment for NGCs insofar as the focus is on potential for releases outside the facility, where there is a potential for exposure of the general population. Occupational exposures to NGCs are not evaluated in this assessment.

7. Environmental Fate and Behaviour

7.1 Environmental Distribution

When petroleum substances are released into the environment, four major fate processes will take place: dissolution in water, volatilization, biodegradation and adsorption. These processes will cause changes in the composition of these UVCB substances. In the case of spills on land or water surfaces, photodegradation —another fate process— can also be significant.

As noted previously, the solubility and vapour pressure of components within a mixture will differ from those of the component alone. These interactions are complicated for complex UVCBs such as petroleum hydrocarbons.

Each of the fate processes affects hydrocarbon families differently. Aromatics tend to be more water-soluble than aliphatics of the same carbon number, whereas aliphatics tend to be more volatile (Potter and Simmons 1998). Thus, when a petroleum mixture is released into the environment, the principal water contaminants are likely to be aromatics, while aliphatics will be the principal air contaminants (Potter and Simmons 1998). The volatilities of alkenes and alkanes are similar and they are more volatile than aromatics and cycloalkanes. Aromatics and cycloalkanes have similar volatility. The most soluble and volatile components have the lowest molecular weight; thus, there is a general shift to higher-molecular-weight components in residual materials. Following an initial loss due to volatilization and solubilization, the remaining degradative pathway is biodegradation, usually by bacteria.

Biodegradation almost always occurs when petroleum mixtures are released into the environment. It has been widely demonstrated that nearly all soils and sediments have populations of bacteria and other organisms that are capable of degrading petroleum hydrocarbons (Pancirov and Brown 1975). Degradation occurs both in the presence and absence of oxygen. Two key factors that determine degradation rates are oxygen supply and molecular structure. In general, degradation is more rapid under aerobic conditions. Decreasing trends in degradation rates according to structure are as follows (Potter and Simmons 1998):

(1) *n*-alkanes, especially in the C_{10}–C_{25} range, which are degraded readily;
(2) isoalkanes;
(3) alkenes;
(4) benzene, toluene, ethylbenzene and xylenes (BTEX) (when present in concentrations that are not toxic to the microorganisms);
(5) monoaromatics;
(6) polynuclear (polycyclic) aromatic hydrocarbons (PAHs); and
(7) higher molecular weight cycloalkanes (which may degrade very slowly (Pancirov and Brown 1975)).

Three weathering processes — dissolution in water, volatilization and biodegradation — typically result in the depletion of the more readily soluble, volatile and degradable compounds and the accumulation of those most resistant to these processes in residues. Due to the complex interaction of components within a mixture that impacts their physical-chemical properties and behaviour, it is difficult to predict the fate of a complex mixture. Therefore, as a general indication of the fate of NGCs, the physical-chemical properties of representative structures of NGCs (Table C-2 in Appendix C) were examined.

7.1.1 Fate in Water

7.1.1.1 Volatilization

Experimental and modelled vapour pressure data for representative structures are moderate to very high, with the exception of structures with 20 carbon atoms, and a four-ringed PAH, which have low vapour pressure. This indicates that most components of NGCs will partition to air.

The degree of volatilization is primarily dependent on the volatilities of the components of the petroleum mixture, along with other environmental conditions such as the temperature, wind and water conditions if spilled into water (CONCAWE 1983). Virtually all components less than C_{12}, such as BTEX, have been found to volatilize from water within 24 hours (RMRI 2007; NRC 2003).

7.1.1.2 Dissolution

Water solubility ranges from very low (0.004 mg/L) for the longest chained alkanes to high (1790 mg/L) for the simplest mono-aromatic structure (benzene). In general, aromatic compounds are more soluble than alkanes, isoalkanes and cycloalkanes with the same carbon numbers. Data in Table C-2 (Appendix C) indicate that the components likely to remain in water are the smallest representative structures from each group (monoaromatics, C_2–C_5 alkanes and isoalkanes, mono- and di-cycloalkanes), based on their relatively high water solubility and low log K_{OW} and log K_{OC} values. The C_9 and higher alkanes, isoalkanes, cycloalkanes and two or more ring aromatics are likely to sorb to sediments based on their lower water solubility and moderate to high log K_{ow} and log K_{oc} values.

BTEX compounds do not sorb strongly to suspended or deposited marine sediments. Their concentrations in sediments, even near produced water discharges nearly always are very low (Armstrong et al. 1979; Neff et al 1989). However, higher molecular weight aromatic and aliphatic hydrocarbons may accumulate in sediments near produced water discharges (Armstrong et al. 1979, Neff et al., 1989, Means et al., 1990; Rabalais et al.199la,b), particularly if water depths are shallow.

While low molecular weight aromatics are relatively water soluble, they are also often the most volatile. It is expected that these most soluble components will still be lost primarily by volatilization because it occurs 10 to 1000 times faster than dissolution (Lee et al. 1990). Harrison et al. (1975) determined that the dissolution rate may be as low as 1% of the volatilization rate. Thus, only a small proportion of the soluble components will be dissolved in the water (CONCAWE 1983; API2010; Lee et al. 1990). Once the lighter weight components are removed via volatilization, the dissolution rate can be considered negligible (NRC 1985).

Neff et al. (2000) hypothesized that about 11% of Australian Campbell condensate and 23% of Wonnich light crude oil would persist on the sea surface for a day under calm sea conditions (no wind or waves). After about a week or less, Campbell condensate and Wonnich crude oil would dissipate completely from the sea surface. Under windier conditions, evaporative weathering of the crude and refined oils would be more rapid than measured in the laboratory.

Danion et al. (2011) mainly detected light PAH compounds in the water soluble fraction (WSF) of Arabian crude oil and the weathered oil product. The concentration of each PAH in the soluble fraction did not appear to be connected to an abundance of PAHs in the crude oil but rather to the molecular weight and solubility of compounds. Two and three-ring PAHs and alkylated analogues formed a high proportion of the WSF while the heaviest PAHs with five and six benzene rings (more than and/or equal to 276 g mol/L) were not found in the water despite their presence in the oil. The absence of anthracene in the WSF was unexpected (Danion et al. 2011). This was hypothesized to be due to its molecular configuration, which is a linear tricyclic aromatic isomer compared to the angular form of phenanthrene, which lowers its solubility (Danion et al. 2011). Based on this research, it can be anticipated that WSFs from light and heavy crude oils (and hence also NGCs) will be similar, since they will both contain the lighter and more soluble compounds.

According to modelling done for the Deep Panuke offshore gas project (EnCana Corp. 2006), ten barrels (approximately 1590 L) of condensate spilled into the sea from an offshore platform will travel about 400 m, and will completely dissipate from the sea surface in about 20 minutes, with a maximum dispersed oil concentration of 28 ppm, or about 21 mg/L, assuming ppm given in wt/wt., and using an average density for NGCs of 0.740 kg/L (derived from Table 3-2). This concentration will drop to 0.1 ppm (or 0.074 mg/L) within about 15 hours, assuming a 10 m mixing depth (EnCana Corp. 2006).

7.1.2 Fate in Soil

The movement of PHCs such as NGCs through soil is much more complicated than the spread of oil slicks on water. Unless the geology of an area is well known, the horizontal and vertical movement of oil from a spill site is difficult to predict (Fingas et al. 1979).

Oil spilled on land will spread over the surface and sink into any permeable rocks or soils. The degree of penetration will depend on the nature of the rocks/soil, and the type and volume of oil. Low viscosity oil, such as NGCs, will rapidly penetrate into a dry porous soil such as coarse sand, which will reduce its rate of spread over the surface. Conversely, a wet or clay-like soil will tend to resist penetration by spilled oil. In this case, the spilled oil will continue to spread horizontally. In typical agricultural soils, spilled oil will usually saturate the upper

10–20 cm of the soil, irrespective of the oil viscosity. However, if depressions in the soil contain water, the oil will not penetrate at all. Light oils such as NGCs, which spread rapidly over the soil surface, will tend to volatilize quickly (Fingas et al. 1979).

Spilled oil has a tendency to migrate along artificial fills, such as pipeline trenches and utility ducts, as these excavations are often backfilled with material which is more permeable than the original soil. Oil in the subsoil will be pulled downward by gravity. When the oil at the surface is depleted, the oil will continue moving downward, leaving behind a funnel of soil which is partially saturated with oil. The lighter and more mobile components of the oil will migrate downward, leaving behind heavier residual components. Subsequent rainfall percolating through the soil may contribute to further downward movement of the oil. Migration of the oil will continue until it is completely absorbed by the soil, stopped by an impermeable layer, or reaches the groundwater. Then the oil may be carried along by the groundwater, which may result in eventual contamination of surface water (Fingas et al. 1979).

Petroleum oil has been shown to have high sorption to soil (Sexstone et al. 1978). It is considerably higher in drier soils with high organic content (Sexstone et al. 1978). In wet and poorly drained soils, hydrocarbon concentrations do not penetrate as deep, with the highest concentrations found in the upper four cm (Sexstone et al. 1978). Volatilization of low molecular weight aliphatic and aromatic fractions from moist soil surfaces is an important fate process, although it is not as rapid as volatilization following oil release on water. The higher molecular weight components will likely sorb to soil more than lower molecular weight compounds and therefore will persist at the site of release.

In situations where large quantities of petroleum hydrocarbons enter the soil, soil organic matter and other soil sorption sites become fully saturated and the petroleum hydrocarbons form a separate phase (a non-aqueous phase liquid or NAPL) in the soil. At concentrations below the retention capacity for the hydrocarbon in the soil, the NAPL will be immobile (Arthurs et al. 1995); this is referred to as residual NAPL (Brost and DeVaull 2000). Above the retention capacity, the NAPL becomes mobile and will move within the soil due to gravity (Arthurs et al. 1995; Brost and DeVaull 2000). According to Arthurs et al. (1995), gasoline reaches retention capacity at 68 000 mg gasoline/kg dry weight (dw) soil in sand, 170 000 mg/kg dw in loamy sand and 238 000 mg/kg dw in silt loam.

The low molecular weight aliphatic and aromatic fractions that are more soluble and volatile (e.g., benzene, and naphthalene) may leach into the groundwater if released at depth within the soil matrix, as in the case of leaks from underground storage tanks (O’Reilly et al. 2001). The C_9 and higher alkanes, isoalkanes, cycloalkanes and two- or more-ring aromatics are likely to sorb to soils based on their lower water solubility and moderate to high log K_{ow} and log K_{oc} values.

In summary, NGCs will volatilize from soil, but not likely as rapidly as they do from water, as they will quickly penetrate a dry soil due to their low viscosity.

7.2 Persistence and Bioaccumulation Potential

Due to the complex nature of petroleum substances such as NGCs, the persistence and bioaccumulation potential of components of these substances is characterized based on empirical and/or modelled data for a suite of 54 petroleum hydrocarbon structures. These representative petroleum hydrocarbon structures do not represent all possible structures in petroleum substances, nor do they necessarily represent the full range of persistence or bioaccumulation potential present in any given chemical class of structures (e.g., alkanes, monoaromatics, etc.) or carbon number (e.g., C_{10}). Thus, the modelling results do not indicate the persistence and bioaccumulation potential of all substances in a specific class and carbon range but instead give a more general indication of these properties.

7.2.1 Environmental Persistence

The persistence of a suite of petroleum hydrocarbons expected to occur in NGCs was characterized based on empirical and/or modelled data.

Model results and the weighing of information are reported in the petroleum substances persistence and bioaccumulation supporting documentation (Environment Canada 2014). These data are summarized in Table D-1 (Appendix D).

For NGCs, a read-across approach with gasoline, diesel, and crude oil was used, as they contain many of the same components as NGCs.

Barker et al. (1995) investigated the biodegradation of condensate liquids present in the soil and groundwater at two gas production sites in the Denver-Julesburg Basin, USA. Groundwater and soil analysis/monitoring at these sites provided evidence that intrinsic bioremediation was occurring by multiple pathways, including aerobic oxidation, as well as anaerobically by Fe(III) and sulphate reduction (Barker et al. 1995). It was not possible to determine a rate constant or half-life from the data presented in this paper.

Experimental aerobic primary and ultimate biodegradation values for a formulated gasoline (Prince et al. 2007, Table D-2 in Appendix D) and gasoline (Solano-Serena et al. 1999; Table D D-3 in Appendix D) indicate that the mean and median half-lives of most of the hydrocarbon components and classes of gasoline measured in these studies are less than 182 days in water. All detectable components of gasoline had undergone primary degradation within 57 days at 21 °C in unacclimated sea and fresh water, although different components degraded at different rates (Prince et al. 2007). A whole gasoline was 94% mineralized within 25 days at 30 °C with an activated sludge culture (Solano-Serena et al. 1999). The residual components were mainly branched alkanes with a quaternary carbon and/or alkyl chains on consecutive carbons (Solano-Serena et al. 1999). The hydrocarbon components of gasoline are also considered to be inherently biodegradable (CONCAWE 2014).

Marchal et al. (2003) studied the primary biodegradation of gasoline (C_4–C_{10}) and various types of diesel oils (C_{11}–C_{25}) in closed flask tests using activated sludge microflorae, as well as microflorae taken from various soils, including spruce forest soil, garden soil, and soils polluted with petroleum hydrocarbons. The mineralization of diesel fuels was also studied in addition to the primary degradation. The tests were run for 28 days in conditions optimal for biodegradation concerning pH, temperature, substrate concentration, nutrient and oxygen supply. Primary degradation ranged from 85–100% for gasoline and from 60–91% for commercial diesel fuel, depending on the type of bacteria they were incubated with (as described above). Mineralization of commercial diesel fuel ranged from 55–67% indicating that intermediary metabolites could accumulate. The recalcitrant hydrocarbons of these fuels were cycloalkanes and branched alkanes, in particular those having quaternary carbon atoms or consecutive substituting groups on the main carbon chain.

Many organisms can metabolize a broad array of hydrocarbons, although they may not be able to grow when exposed to individual compounds. For example, only ten of the 25 individual gasoline components run in the OECD Ready Biodegradability 301C (MITI) protocol (OECD 1993) showed significant ready biodegradation (mineralization) (Sakuratani et al. 2005). Prince et al. (2007) hypothesized that primary biodegradation half-lives were shorter for hydrocarbons in a gasoline mix than for individual components because indigenous microorganisms degrade hydrocarbons most effectively when they are presented as a mixed suite of hydrocarbon substrates that allow microbes to use intermediates from different pathways to balance their overall metabolism.

Empirical and modelled half-lives in the atmosphere for many components of NGCs are less than two days. However, some components, such as C_2–C_6 alkanes, C_4–C_6 isoalkanes, C_6–C_8 monoaromatics, and C_{13} cycloalkane diaromatics, can have half-lives greater than two days and thus they may undergo long-range atmospheric transport. In addition, some three- to six-ring PAHs may also undergo long-range atmospheric transport to remote regions due to sorption to particulate matter (Environment Canada 2014).

Considering biodegradation in water, soil and sediment, the following components are expected to have half-lives greater than six months in water and soils and greater than a year in sediments: C_{15}–C_{30} dicycloalkanes, C_{18}–C_{22} polycycloalkanes, C_{12} monoaromatics, C_9–C_{20} cycloalkane monoaromatics, C_{10}–C_{30} diaromatics, C_{12} cycloalkane diaromatics, and C_{14} and C_{30} three-ring PAHs,

C_{18}–C_{20} four-ring PAHs, C_{20}–C_{30} five-ring PAHs and C_{22} six-ring PAHs. The C_9–C_{12} dicycloalkanes, C_{14} and higher polycycloalkanes, and C_9 and higher monoaromatics also have half-lives greater than a year in sediments (Table D-1 in Appendix D).

7.2.2 Potential for Bioaccumulation

Because of the limited empirical data for NGCs, bioaccumulation potential was characterized based on empirical and/or modelled data for a suite of petroleum hydrocarbons expected to occur in petroleum substances. Bioaccumulation factors (BAFs) are the preferred metric for assessing the bioaccumulation potential of substances, as the bioconcentration factor (BCF) may not adequately account for the bioaccumulation potential of substances via the diet, which predominates for substances with log K_{ow} greater than approximately 4.5 (Arnot and Gobas 2003).

In addition to fish BCF and BAF data, bioaccumulation data for aquatic invertebrate species were also considered. Biota-sediment/soil accumulation factors (BSAF), trophic magnification factors, and biomagnification factors were also considered in characterizing bioaccumulation potential.

Empirical and modelled bioaccumulation data for petroleum hydrocarbons, as well as the weighing of information, are reported in the supporting document (Environment Canada 2014). A summary of the results for bioaccumulation potential is presented in Table D-4 in Appendix D.There is consistent empirical and predicted evidence to suggest that the following components have the potential for high bioaccumulation with BAF/BCF values greater than 5000: C_{13}–C_{15} isoalkanes, C_{12}–C_{15} monocycloalkanes, C_{12} and C_{15} dicycloalkanes, C_{14} and C_{22} polycycloalkanes, C_{15} monoaromatics, C_{15}–C_{20} cycloalkane monoaromatics, C_{12}–C_{13} diaromatics, C_{20} cycloalkane diaromatics, C_{14} and C_{20} three-ring aromatics, C_{16}–C_{20} four-ring PAHs, C_{20}–C_{22} five-ring PAHs, and C_{22} six-ring PAHs (Table D-4, Appendix D). These components are highly lipophilic and are associated with a slow rate of metabolism in certain organisms such that the rate of uptake greatly exceeds the total elimination rate. However, most of these components are not expected to biomagnify (relative to their concentration in the diet) in aquatic or terrestrial foodwebs, largely because the combination of metabolism (albeit slow), low dietary assimilation efficiency and growth dilution allows the elimination rate to exceed the uptake rate when exposure occurs from the diet only (Environment Canada 2014). In addition, fish and other vertebrates have a higher capacity to metabolize aromatic components than invertebrates, which decreases the potential for trophic transfer of these components. However, one study (Harris et al. 2011) suggests that some alkyl-PAHs may biomagnify. While only BSAFs were found for some PAHs, it is possible that BSAFs will be greater than one for invertebrates, given that they do not have the same metabolic competency as fish. BSAFs will likely decrease beyond C_{22} due to reduced bioavailability of the higher boiling point fractions (Muijs and Jonker 2010).

Monitoring of aliphatic hydrocarbons in mussels is performed annually as part of the Environmental Effects Monitoring (EEM) program for the Sable Offshore Energy Project near Nova Scotia (see Sources section). While mussels sampled from the legs of the Thebaud platform in 2010 had somewhat elevated concentrations of C_{10}–C_{24} aliphatic hydrocarbons as compared to those from the control site, they were likely of biogenic origin as the hydrocarbon profile was typical of that produced by naturally occurring phytoplankton (ExxonMobil 2011b). In addition, PAH and total petroleum hydrocarbons (C_{11}–C_{32}) concentrations were below detectable levels (less than 0.05 mg/kg dw and less than 15 mg/kg dw, respectively) in both the control and Thebaud mussels. Therefore, it does not appear that petroleum hydrocarbons or PAHs found in NGCs are bioaccumulating in mussels in the vicinity of the SOEP.

8. Potential to Cause Ecological Harm

8.1 Ecological Effects Assessment

While some studies on the toxicity of NGCs were identified, studies with similar petroleum substances were also considered in a read-across approach. Light NGCs generally fall within the petroleum group “Low Boiling Point Naphthas” (LBPNs) (Table A-1 in Appendix A). LBPNs are petroleum substances with a carbon range primarily C_4–C_{12}. Gasoline also belongs within this petroleum group and therefore, data from both gasoline and LBPNs are considered as read-across for light NGCs.

Heavy NGCs contain larger components than the lighter NGCs (predominantly up to C_{15}) but can be higher as some NGCs range up to C_{30}. This carbon range spans the kerosene (C_9–C_{16}) carbon range, and also includes part of the diesel (C_9–C_{30}) and Fuel Oil No. 2 (C_{11}–C_{20}) range. Therefore, kerosene, diesel, and Fuel Oil No. 2 are used in a read-across approach for heavy NGCs. WSF from crude oils will also be used for read-across. A study by Danion et al. (2011) determined that the WSF of Arabian crude oil contains mainly light PAH compounds; it is therefore anticipated that WSFs from light and heavy crude oils (and hence, to some extent, also NGCs) will be similar, since they will mainly contain the lighter and more soluble compounds.

The condensates from offshore Nova Scotia are considered to be heavy NGCs, as distillation data for Sable Island Condensate (Jokuty et al. 1999) indicates that only 30% of its volume has distilled at a temperature of 123 °C (i.e., approximately 70% of the volume is comprised of substances with carbon chains greater than eight carbons), and more than 30% of the volume distills at a temperature greater than 220 °C (i.e., approximately 30% of the volume is in the range of 12 carbons and greater).

8.1.1 Aquatic Compartment

Chronic toxicity of NGCs in the aquatic environment is not expected, as NGCs are expected to rapidly volatilize from water (Environmental Fate, Section 7.1.2). Therefore, only acute toxicity data is considered here.

8.1.1.1 Studies with NGCs

A suite of toxicity tests were conducted with condensate from the Venture field of the SOEP (Mobil Oil Canada Ltd. 1983). Toxicity tests with rainbow trout (*Salmo gairdneri*) in static or static-renewal systems that were open to the air and gently agitated resulted in a 48 h LC_{50}[4] of 5 ppm (initial concentration of condensate); however, there was 75% loss of condensate within 24 hours in the test (Atlantic Oceanics 1982). For sea urchins (*Strongylocentrotus droebachiensis*), a 96h LC_{50} between 10 and 40 ppm was reported (Atlantic Oceanics 1982). *Daphnia magna* tests were conducted in closed, non-aerated systems resulting in a 48 h LC_{50} of 9 ppm (or 7.4 mg/L using the density of Venture condensate from Table 3-2) for WSF of fresh condensate, 30 ppm for condensate weathered to 29% of initial concentration, and 2 ppm for condensate weathered to 58% of initial concentration (Bobra 1982).

Bobra et al. (1983) studied the toxicity of saturated solutions of an NGC with different degrees of weathering (0, 42 and 71 % evaporated) to *D. magna* in closed systems. Test solutions were prepared by adding an excess quantity of the gas condensate to distilled water in 250 mL cylindrical separatory funnels. The solution was gently shaken on a wrist-action shaker for 12 hours and allowed to settle at room temperature for at least 48 hours before removing a water sample for the bioassay and analysis. Acute 48 h LC_{50}s ranged from 0.03 mg/L for the 71% weathered sample to 9 mg/L for fresh NGC.

MacLean and Doe (1989) performed static acute 48 h toxicity tests with no headspace with *D. magna* in freshwater and the brine shrimp *Artemia spp.* in seawater with a WSF of Venture condensate from the SOEP and a Sable Island condensate. *Artemia* tests were conducted with instar II while the daphnid tests were conducted with neonates less than or equal to 24 h old. Nominal EC50/LC50 values expressed as a percentage of the WSF were converted to

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[4] The LC_{50} (median lethal concentration) is the concentration of the substance in water, soil, or sediment that is is estimated to be lethal to 50% of the test organisms.

estimated EC50[5]/LC50 values using the initial measured concentration of the 100% WSF. Estimated EC_{50}s for immobilization with Sable Island condensate were 0.41 and 3.4 mg/L with *Daphnia* and were 1.94 and 2.58 mg/L with *Artemia*. EC_{50}s with Venture condensate were 0.83 mg/L with *Daphnia* and were 3.7 mg/L with *Artemia*.

Mahon et al. (1987) studied the toxicity of the water-accommodated fraction (WAF) of NGC from the Sable Island, NS area to mummichog (*Fundulus heteroclitus*), a fish native to this area, in static open systems. Tests were conducted with both “fresh” (seven day old) and “stored” (four year old) condensate. Ninety-six hour LC_{50}s for stored and fresh condensate were between 3.8 and 5.2 mg/L naphthalene equivalents (initial concentrations), respectively, though all deaths except one occurred within the first 24 hours. Hydrocarbon concentrations in the water, however, declined by 80–90% during the 96 hour exposure period, likely due to volatilization, as oxygen was bubbled into all the experimental containers at 100 mL/min.

Neff et al. (2000) studied the acute toxicity of the WAF of Campbell condensate, an NGC (density 754 kg/m^3) to six species of marine animals, in static tests. The species tested included the temperate species silverside minnows, *Menidia beryllina*; mysids, *Americamysis (Mysidopsis) bahia*; and sea urchin larvae, *Strongylocentrotus purpuratus*, or sand dollar larvae, *Dendraster excentricus*. The tropical/subtropical species studied were clownfish, *Amphiprion clarkii*; tropical penaeid shrimp, *Penaeus vannamei*; and sea urchin larvae, *Arbacia punctulata*. Fresh Campbell condensate had LC_{50}/EC_{50} values for most species between 30–39% WAF, with the exception of *A. punctulata* larvae, which was less sensitive. This WAF range contained 11.2–14.5 mg/L total MAHs, 0.05–0.07 mg/L total PAHs and 0.03–0.29 mg/L total phenols. Measured concentrations of PHCs during/after the tests were not provided, so it is not known if concentrations of the test substances remained constant throughout the tests.

8.1.1.2 Read-across data for light NGCs

As discussed above, toxicity data for LBPNs, including gasoline, are considered as suitable surrogates for light NGCs.

LBPNs and gasoline have aromatic contents similar to that reported for a Sable Island condensate (11% aromatics, Table 2-1). LBPNs have variable aromatic content, in the range 4–26% (Environment Canada, Health Canada 2012), while

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[5] The EC_{50} (median effective concentration) is the concentration of the substance in water, soil or sediment that is estimated to cause a specified toxic effect to 50% of the test organisms.

gasoline has 5–55% aromatics (CONCAWE 1992). Acute aquatic toxicity studies with fish, invertebrates and algae on samples of gasoline and low boiling point naphtha streams show acute toxicity LC_{50}/EC_{50} values in the range 1–18 mg/L (CONCAWE 1996).

Measured acute toxicity values for unleaded gasoline from tests using WSF or WAF were all within two orders of magnitude, ranging from 2.7-16 mg/L for fish (48-96 hr LC/LL_{50})[6], 0.3–25 mg/L for invertebrates (48-96 hr EC/EL_{50}[7]) and 1.4–4.2 mg/L for algae (96 hr IL_{50}). The exposure scenarios used in this report (see Section 8.0) are based on spills, with calculated exposure concentrations that are essentially loading rates to water. Therefore, loading rates (i.e., WAF studies) are more applicable and preferred for these scenarios than the measured fraction of gasoline dissolved in water. However, most studies used measured concentrations and these data are also considered.

The lowest gasoline toxicity values (0.3, 1.2, and 3 mg/L for invertebrates, and 2.7 mg/L for fish) were flow through, closed test systems using a WSF as cited by CONCAWE (1992); however, the original reports are not available and the reliability of these studies can not be determined.

CONservation of Clean Air and Water in Europe (CONCAWE) (1996a) summarized the results of a series of studies conducted on gasoline blend WAFs in closed test systems. All studies were conducted following acceptable protocols; however, some studies experienced high (>20%) loss of substance during the test duration. Only those studies with <20% loss were considered as reliable. In these studies algae were the most sensitive, with a 96-hr IL_{50}[8] of 1.4 mg/L (CONCAWE 1995a), followed by rainbow trout (*Oncorynchus mykiss*) with a 96-hr LL_{50} of 11 mg/L (CONCAWE 1995b) and *Daphnia* with a 48-hr EL_{50} of 12 mg/L (CONCAWE 1995c). Though algae appear to be more sensitive to gasoline, the confidence interval was very large, suggesting uncertainty in the IL_{50} value. Tighter confidence intervals were obtained with fish and *Daphnia*, and thus the LL_{50} of 11 mg/L for fish and EL_{50} of 12 mg/L for *Daphnia* are considered to be more reliable. Measured concentrations of benzene, toluene, ethylbenzenes, and naphthalene (BTEXN) in the prepared WAFs (31 to 34% of gasoline in the WAF, *Daphnia* study; 32 to 57% of gasoline in the WAF, fish study) indicate that the LC_{50} for rainbow trout occurs within the range of

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[6] The LL_{50} (median lethal loading) is the amount (i.e., loading rate) of petroleum product needed to generate a water-accommodated fraction (WAF) that is estimated to be lethal to 50% of the test organisms.

[7] The EL_{50} (median effective loading) is the amount (i.e., loading rate) of petroleum product needed to generate a WAF that is estimated to cause a specific toxic effect (e.g. immobilization) to 50% of the test organisms.

[8] The IL_{50} (median inhibiting loading rate) is the amount (i.e., loading rate)of petroleum product needed to generate a WAF that is estimated to cause a 50% impairment in a quantitative biological function (e.g., growth rate) relative to a control.

approximately 3.5–6.3 mg BTEXN/L and the EC_{50} for *Daphnia* occurs within the range of approximately 3.7–4 mg BTEXN/L.

A reliable study with unleaded gasoline that controlled for loss of test substance was also conducted by MacLean and Doe (1989) with *Daphnia*, resulting in an EC_{50} of 4.9 mg/L. Similarly, a reliable fish toxicity test was conducted by Lockart et al. (1987), resulting in an LC_{50} of 6.8 mg/L. These studies provide similar results on a measured water concentration basis as those calculated for fish and Daphnia from CONCAWE (1995a,c). However, the MacLean and Doe (1989) and Lockart et al. (1987) values are based on a test concentrations made by diluting a saturated stock solution and not individually prepared test concentrations. In addition, these are measured water concentrations, not loading rates.

8.1.1.3 Read-across data for heavy NGCs

Petroleum substances similar to heavy NGCs used as analogue data include crude oil, as well as kerosenes (not including cracked kerosene; C_9–C_{16}, less than and/or equal to 25% aromatics (API 2010), diesel fuels (C_9–C_{30}, 28% aromatics (CONCAWE 2001), andFuel Oil No. 2 (C_{11}–C_{20}, 20–25% aromatics (NRC 1985)), though the aromatic content of Fuel Oil No. 2 is higher than that reported for two Canadian condensates (11–17%, Table 2-1).

Acute toxicity data for read-across substances are tabulated and discussed in Environment Canada (2015). Acceptable acute aquatic toxicity data for heavy NGCs, including read-across and modelled data are summarized in Table 8-1 below. All the endpoints are lethality or immobilization with the exception of the algae data.

Table 8-1 Aquatic toxicity data used in the determination of toxicity of heavy NGCs

Substance	Species	Test type	Test Length	Endpoint	Value (mg/L) (C.I.)	Reference
NGCs, fresh	*Daphnia magna*	WSF	48 h	LC_{50}	9 (4-30)	Bobra et al. 1983
NGCs, 42% weathered	*D. magna*	WSF	48 h	LC_{50}	2 (0.6-5.6)	Bobra et al. 1983
Sable Island condensate	*D.magna*	WSF	48 h	EC_{50}	0.41 (0.33-0.49)	Maclean and Doe 1989
NGCs from SOEP, Venture well	*D. magna*	WSF	48 h	EC_{50}	0.83 (0.63-1.1)	Maclean and Doe 1989
Sable Island	Brine shrimp,	WSF	48 h	EC_{50}	1.94 (1.55-	Maclean and Doe

Substance	**Species**	**Test type**	**Test Length**	**Endpoint**	**Value (mg/L) (C.I.)**	**Reference**
condensate	*Artemia sp.*				2.31)	1989
NGCs from SOEP, Venture well	Brine shrimp, *Artemia sp.*	WSF	48 h	EC_{50}	3.72 (2.96-5.26)	Maclean and Doe 1989
13 types of crude oil (individually tested)	*D. magna*	WSF	48 h	EC_{50}	0.23-3.47	Maclean and Doe 1989
13 types of crude oil (individually tested)	Brine shrimp, *Artemia sp.*	WSF	48 h	EC_{50}	1.4-8.68	Maclean and Doe 1989
C_2-C_{20} NGCs, modelled data	Marine amphipod *Rhepoxynius abronius*		Acute	LL_{50}	0.40	PETROTOX (2009)
Kerosene, hydro-desulfurized CAS RN 64741-81-0	Rainbow Trout *(Oncorhynchus mykiss)*	WAF	72 h	EL_{50}	20 (6.8-34)	Exxon Biomedical Sciences Inc. 1995c
Diesel	Rainbow trout (*O. mykiss*)	WSF	48 h	LC_{50}	2.4	Lockhart et al. 1987
Norman Wells crude	*Rainbow trout*	WSF	48 h	LC_{50}	10.4	Lockhart et al. 1987
Furnace Fuel (Fuel Oil No. 2)	*D. magna*	WSF	48 h	EC_{50}	1.9 (1.6-2.2)	MacLean and Doe 1989
Diesel, type not specified	*D.magna*	WSF	48 h	EC_{50}	4.1 (3.3-4.8)	Maclean and Doe 1989
Kerosene, hydro-desulfurized CAS RN 64741-81-0	*D.magna*	WAF	48 h	EC_{50}	1.4 (Conf Interval 1.0-2.0)	Exxon Biomedical Sciences Inc. 1995e
Kerosene, hydro-desulfurized	Algae *Selanastrum*	WAF	72 h	EL_{50} (AUGC)	15 (0-52)	Exxon Biomedical Sciences

Substance	Species	Test type	Test Length	Endpoint	Value (mg/L) (C.I.)	Reference
CAS RN 64741-81-0	*capricornutum*					Inc. 1995h

AUGC = Area under growth curve

8.1.1.4 Modelled data

CONCAWE developed an aquatic toxicity model specifically for petroleum hydrocarbon mixtures, called PETROTOX (2009). This model assumes that chemical action is via narcosis and therefore accounts for additive effects according to the toxic unit approach. It can model petroleum hydrocarbon toxicity for C_4–C_{41} compounds dissolved in the water fraction. Components smaller than C_4 are considered too volatile to impart any significant toxicity, and those larger than C_{41} too hydrophobic and immobile to impart any significant aquatic toxicity. PETROTOX (2009) generates estimates of toxicity with a median lethal loading concentration (LL_{50}) rather than an LC_{50} due to the insolubility of petroleum products in water. The LL_{50} value is the amount of petroleum substance needed to generate a WAF that is toxic to 50% of the test organisms. It is not a direct measure of the concentration of the petroleum components in the WAF.

Toxicity was modelled in “low resolution mode” using only one hydrocarbon block (boiling point ranges described below). The percent weight of aliphatic and aromatic substances was set at 90:10, based on analyses of Sable Island condensate as described in Jokuty et al. (1999).

Toxicity was modelled for light NGCs (C_2–C_8, based on the carbon range of CAS RNs 64741-48-6 and 68919-39-1) using the boiling point range 0.1-140°C (the boiling point of butene is -1.3 °C and that of *m*-xylene is 139 °C (EPI Suite 2011)). The toxicity of heavy NGCs (C_2–C_{20}, based on CAS RN 64741-47-5) was modelled using the boiling point range 0.1–495 °C (the boiling point of the C_{20} substance benzo[*a*]pyrene was measured as 495°C (EPI Suite 2011)). The toxicity estimates of these two ranges of substances to a suite of aquatic organisms are included in Table 8-2 below. The toxicities were calculated using a 10% headspace scenario, as headspace is commonly kept to a minimum in toxicity tests of volatile substances, as well as a more environmentally relevant 90% headspace scenario.

Table 8-2 PETROTOX acute toxicity (LL50s) estimates for aquatic organisms (mg/L)

Species Type	Species	C_2–C_8, 10% head-space	C_2–C_8, 90% head-space	C_2–C_{20}, 10% head-space	C_2–C_{20}, 90% head-space

Fresh-water	*S.capricornutum* (green algae)	21.7	1551	13.1	851
Fresh-water	*D. magna* (water flea)	6.16	337	3.28	158
Fresh-water	*O.mykiss* (rainbow trout)	3.53	154	1.35	36.7
Marine	*Palaemonetes pugio* (Grass shrimp)	3.06	134	1.07	22.6
Marine	*R. abronius* (Amphipod)	1.67	72.7	0.40	2.07
Marine	*M. beryllina* (Inland silverside)	21.7	1551	13.1	851

The modelled data indicate that C_2–C_{20} NGCs have moderate (1–100 mg/L) to high (less than1 mg/L) acute toxicity to aquatic organisms in tests with minimal headspace, and low to moderate acute toxicity with a 90% headspace that would allow for volatilization. C_2–C_8 NGCs have moderate toxicity with 10% headspace, and mainly low toxicity with 90% headspace, with the exception of the marine amphipod result, which shows moderate toxicity.

The modelled *Daphnia* LL_{50} data with 10% headspace are in the same range as that observed with condensate from the SOEP in laboratory tests conducted using methods to limit loss of NGCs, where closed system 48 h EC_{50}/LC_{50}s for *D. magna* with fresh condensate are 0.41 to 6.9 mg/L (MacLean and Doe 1989, Bobra et al. 1983). The modelled data for most of the other species are in the same range as the empirical and modelled *Daphnia* data, while NGCs appear less toxic to the green algae *S. capricornutum* (Table 8-1).

8.1.1.5 Discharges from the SOEP

Discharges from the SOEP, which include spills and produced water, and discharges to air, may expose organisms around the drilling platforms. Produced water contains NGCs as well as other compounds such as iron and ammonia, and thus it may be difficult to determine the produced water components responsible for any effects. It is thought, however, that the high concentrations of iron and ammonia in produced water are the main contributors to toxicity in tests of produced water from the SOEP (ExxonMobil 2011b). Niu et al. (2010) also indicate that the released produced water is hypoxic, which also contributes to toxicity.

Monitoring studies can indicate if discharges from the SOEP are impacting the area around offshore platforms. An EEM program which includes toxicity testing (water and sediment), body burden analysis, sediment chemistry and seabird monitoring, is carried out off the coast of Nova Scotia in the vicinity of offshore oil and gas operations (CNSOPB 2011). In general, environmental effects from offshore oil and gas in Nova Scotia have been found to be mild, and less than predictions made in the SOEP 1996 Environmental Impact Statement (CNSOPB 2011). No toxic results have been observed in water column samples collected adjacent to the platform to date, and no effects on the health of Atlantic cod have been noted (CNSOPB 2011).

Sediment quality monitoring and toxicity testing, as part of the EEM program from 1998 to 2007, focused on a set of 24 metal chemical parameters, total petroleum hydrocarbon (TPH), and barium. Monitoring has consistently found most parameters unchanged from the 1998 baseline surveys, with the exceptions of TPH and barium concentrations found to be elevated above background levels due mainly to drill waste and cuttings piles. Concentrations have decreased to background level over time. No toxic responses have been observed in amphipod lethality tests at any site since 2003 (CNSOPB 2011).

Throughout monitoring for tainting for the SOEP from 1998-2008, no tainting effects were observed in the far- (greater than 1000m), mid- (500m), and near-field (250m) sampling sites (CNSOPB 2011). Tainting was only encountered once in Jonah crabs collected directly from the platform structure at Venture (year not given) (CNSOPB 2011).

Environment Canada air quality surveys conducted on Sable Island, NS, to date have not demonstrated an effect related to SOEP activities (CNSOPB 2011).

8.1.1.6 Selection of Critical Toxicity Value (CTV) for aquatic organisms

Petroleum hydrocarbons such as NGCs, crude oil, etc. are expected to have similar toxicities to freshwater and marine species, as they are non-polar narcotics, and therefore will not be affected by the dissolved salts present in greater quantities in the seawater. Therefore, both freshwater and marine aquatic toxicity data were considered for the choice of the aquatic CTV.

There are no empirical data for light NGCs; the only empirical data were for unprocessed heavy NGCs, as described above. Therefore, for light NGCs read-across data from gasoline were used. While a lower toxicity value was obtained with algae, the 96-hr LL_{50} of 11 mg/L for rainbow trout with gasoline (CONCAWE 1995b) is selected as the CTV for light NGCs as it is considered more reliable, though similar to, that for algae (i.e., within one order of magnitude) as discussed above. This CTV is supported by similar results based on measured water concentrations (MacLean and Doe 1989; Lockhart et al. 1987) and are similar to the modelled PETROTOX results for light NGCs with 10% headspace (Section 8.1.1.4).

The data in Tables 8-1 and 8-2 demonstrate that empirical toxicity values for heavy NGCs and similar petroleum substances, as well as modelled toxicity data for C_2-C_{20} NGCs, are all generally within the same order of magnitude (0.2-10 mg/L). Preference is given to the toxicity data for NGCs that are of acceptable quality. The lowest empirical data point was 0.41 mg/L for NGCs with *Daphnia magna*, which is very similar to the lowest modelled toxicity value for the marine amphipod *R. abronius* (LL_{50} of 0.40 mg/L with C_2-C_{20} NGCs and 10% headspace). This study (MacLean and Doe 1989) is considered to be of good quality. Therefore, for heavy NGCs, the aquatic CTV will be the *D. magna* 48 hour EC_{50} of 0.41 mg/L, the lowest acceptable empirical value.

8.1.2 Terrestrial Compartment

8.1.2.1 Soil Organisms (Plants, Invertebrates)

Lucas and Freedman (1989) examined the effects of an experimental oiling with NGC on three plant communities on Sable Island: (i) a dune grassland dominated by marram-grass *Ammophila breviligulata*, (ii) a herbaceous beach community dominated by the sandwort *Honckenya peploides*; and (iii) a heath dominated by *Empetrum nigrum, Myrica pensylvanica, Rosa virginiana, and Vaccinium angustifolium*. The experimental treatments were: (i) control; (ii) sprayed with 6.3 litres of condensate/25 m^2; and (iii) sprayed with 12.5 litres/25 m^2. The application rates of NGC were chosen to exceed the estimated worst-case scenarios for hydrocarbon deposition by an offshore blowout in the vicinity of Sable Island. Both of the condensate treatments were sufficient to contaminate most above-ground plant surfaces and the upper several centimetres of the sandy soil.

Initially, in all three communities there was a severe herbicidal effect on most above-ground plant tissues that were directly impacted by the condensate. However, below-ground tissues were little affected by the hydrocarbon treatment, and the vigorous regeneration that issued from these tissues allowed an essentially complete recovery of most species after one or two post-spill growing seasons. This pattern of initial damage followed by vigorous re-growth is similar to the findings of Baker (1971a,b, 1973) who studied effects of experimental treatments with crude oil and diesel fuel on temperate salt marshes dominated by various grass species. The perennial herbaceous dicots sustained damage to their above-ground tissues, but regenerated from their below-ground perennating tissues. However, the annual species studied by Baker (1971a,b, 1973) showed little ability to survive or regenerate after treatment with liquid hydrocarbons.

Chronic toxicity of light NGCs is not anticipated; in shallow soil the majority of light components are expected to evaporate within ten days, as shown by Arthurs et al. (1995) in a gasoline study.

Hutchinson (1984) studied the short- and long-term effects of experimental crude oil and diesel fuel spills on the vegetation in the spruce taiga and of crude oil spills on the arctic tundra in the Northwest Territories. Diesel and oil spills caused defoliation and reduced ground cover. After 6–9 years, the experimental oil spill sites had generally very poor recovery of the lichens and mosses which constituted a high percentage of the vegetation in the areas studied. Diesel spills appeared to have as severe an effect on vegetation in the short term as crude oil spills (Hutchinson 1984). However, the long-term survival of vegetation species was better in the diesel sites, probably due tothe quicker volatilization of toxic oil components in the absence of tarry compounds, causing less residual toxicity (Hutchinson et al. 1984). An effect of both types of spills was a 59 to 67 % decrease in species diversity, as compared to the control plots. However, there were differences in the species affected in the oil and the diesel plots. Hutchinson (1984) hypothesized that the diesel may have penetrated the soil to a greater extent than did the crude oil, thus killing the underground rhizomes of the horsetails (*Equisetum pratense* and *E. scorpoides*), unlike at the crude oil sites. Other researchers studying the effects of crude oil spills in the north found similar effects to this study, such as heavy mortality of lichens and mosses (Johnson et al. 1980), as well as delayed damage to the black spruce trees (Jenkins et al. 1978).

Szymura et al. (2010) studied the growth of mature Scots pine (*Pinus sylvestris*) (53-57 years in age) in a gasoline contaminated area in Poland. The contaminated site was a stand of pine trees planted for wood production in a sandy soil into which 70 tonnes of unleaded gasoline had been spilled due to a malfunction at an adjacent fuel storage station, which had also penetrated the water table. Two uncontaminated locations in the pine stand were used as control sites. The trees growing in contaminated sites showed strong depletion of radial growth starting immediately after pollution. Such depletion lasted two to three years before the ring widths stabilised at a low level. After a few years the radial increment increased, and ten years later did not differ from the increment of trees in the unpolluted sites.

No data on the toxicity of NGCs to soil organisms were found, but data exists for gasoline as well as various distillate fractions of petroleum hydrocarbons, as described below.

The Canada-Wide Standard for Petroleum Hydrocarbons in Soil (CCME 2008) were used as a data source for quantification of effects of NGCs on terrestrial ecosystems. This system uses four fractions of total petroleum hydrocarbons (TPH): Fraction 1 (F1) (C_6 to C_{10}); Fraction 2 (F2) (more than C_{10} to C_{16}); Fraction 3 (F3) (more than C_{16} to C_{34}); and Fraction 4 (F4) (more than C_{34}), and assumes a 20:80 ratio of aromatics to aliphatics. This system uses four land-use classes (agricultural, residential, commercial and industrial) and two soil types (coarse-grained and fine-grained) for the determination of remedial standards.

The lowest Canada-wide Standard criteria for soil contact are those for coarse-grained agricultural/residential soil. Fraction 1 is most like light NGCs and Fractions 1 and 2 are most like heavy NGCs. The F1 standard for direct soil contact by soil organisms in coarse-grained agricultural/residential soil is 210 mg/kg dw and that for F2 is 150 mg/kg dw.

8.1.2.2 Mammals

Only one study of the toxicity of NGCs to terrestrial mammals was found, and is summarized as follows. Thirty of approximately 200 mature ewes on a ranch in northern California died or were euthanized during a 21-day period following a one day accidental exposure to surface water heavily contaminated with NGC (10–100% hydrocarbon content by volume), as reported by Adler et al. (1992). The ewes were grazing on pasture that contained a fenced-off natural gas well and a storage tank holding NGCs. The source of the condensate was traced to a valve leak on the storage tank that had contaminated the surrounding soil. No information was available about the volume of the condensate released from the tank, nor about its physical/chemical properties.

Preceding the deaths, heavy rains apparently had saturated the soil, and the high water table brought the condensate to the top of surface water pools outside the fenced area. Eight ewes died the first day without clinical signs, and although the surface water was immediately fenced off thereafter, ewes continued to succumb over a 21-day period, with the majority of deaths occurring between days 10 and 17 (Adler et al. 1992).

A potent gasoline-like odor was detected in the gastrointestinal tract in all but two of the sheep. Following pathologic evaluation of the dead/euthanized ewes, the principal cause of mortality was determined to be aspiration pneumonia, but myocardial degeneration and necrosis, renal tubular damage, gastritis, enteritis and meningeal edema and hyperemia were also observed (Adler et al. 1992). Gas chromatographic analysis identified chemical traces of the hydrocarbons in the tissues, and “fingerprinting”, the process of matching chromatographic tracings, provided forensic proof of the contamination source. This incident indicates that acute exposure from accidental leaks of NGCs from pipelines/storage tanks could be harmful to surrounding wildlife or farm animals.

No other mammalian toxicity data for NGCs were found. Mammalian toxicity data for analogue substances are described in the Health Effects Assessment section.

The CCME (2008) standards for PHCs in soil include guidelines on levels in soil to protect livestock from PHCs in drinking water derived from a groundwater source, where PHC leachate migrated from the soil to the groundwater. Standards for the protection of livestock watering are 4200 mg/kg for F1 and 10 000 mg/kg for F2 (CCME 2008).

8.1.2.3 Selection of CTVs for Terrestrial Organisms

Given that soil invertebrates in direct contact with soil are much more sensitive to the effects of PHCs than mammals exposed through drinking water, the Canada-Wide Standards for direct soil contact by soil organisms in agricultural/residential soil are selected as the CTVs. Therefore, the CTV for effects in terrestrial organisms (plants, invertebrates) for light NGCs is 210 mg/kg dw, and that for heavy NGCs is 150 mg/kg dw, the lowest Canada-Wide Standard for F1 and F2, respectively.

8.2 Ecological Exposure Assessment

The main sources of exposure to NGCs in the environment are expected to be releases to marine water from oil and gas production, and spills to land and freshwater from transport and upstream production. For each scenario and medium of concern, predicted environmental concentrations (PECs) were determined as estimates of concentrations of NGCs that would be expected in the environment. Estimations of releases of NGCs (as reported as condensates) were based on data from the Alberta spills database (ERCB 2012).

The Alberta spills database reported both the volume released as well as the volume of free product recovered. When using this data, however, the volume recovered was not considered in the exposure estimates as there is no indication as to the timeframe for the recovery process. Acute impacts are expected to occur quickly following release of NGCs. Therefore, the volume spilled rather than the volume remaining after recovery was used in the exposure estimates.

8.2.1 Aquatic Compartment

8.2.1.1 Releases to Freshwater

Given the low number of releases to flowing freshwater reported to Alberta's spill database (less than one spill/year reported) and to freshwater in the s. 71 survey, an exposure scenario for releases to flowing freshwater[9] was not developed.

However, there were 16 spills to muskeg/stagnant water reported in Alberta from 2002-2011 with total reported volume of 225 900 L, with average and median spill volumes of 14 119 L and 2500 L, respectively. Given that muskeg/stagnant water is relatively shallow and not very well mixed, a simple dilution exposure scenario was considered to calculate the dilution factor necessary for the median

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[9] The term flowing freshwater as used by the Alberta Energy Regulator (formerly the ERCB) includes lakes.

spill volume to be below a level expected to cause harm (see Characterization of Ecological Risk section).

8.2.1.2 Releases to Marine Water

The total reported volume spilled from the offshore east coast oil and gas operations during the 10-year period 2002-2011 was 207 L, with a total of 10 spills. The average and median spill sizes were 21 L and 3.1 L, respectively (see Section 6.2).

Modelling of small batch condensate spills from offshore platforms was done as part of the Environmental Assessment Report of the Development Plan Application for the Deep Panuke offshore gas project, which is also located in the vicinity of Sable Island, NS (EnCana Corp. 2006). The smallest spill that was modelled was a ten barrel (approx. 1590 L) spill. The report (EnCana Corp. 2006) states that this spill is likely to persist on the water surface for about 20 minutes and travel about 400 m from the release point prior to dissipation under average wind conditions. The maximum condensate concentration is estimated to be 28 ppm, or about 20.7 mg/L, assuming that ppm is given in vol/vol., and using an average density for NGCs of 0.74 kg/L (derived from Table 3-1). The dispersed oil concentration will drop to 0.1 ppm (or 0.074 mg/L) within about 15 hours, assuming a 10 m mixing depth. The average concentration during the first 15 hours is calculated as 10.4 mg/L, which is the average of 20.7 and 0.074 mg/L.

Between 100 000 and 1 million tonnes of NGCs (CAS RN 64741-74-5) were transported by ship in 2010 (Environment Canada 2012); however, no releases to water were reported (see Releases from Transportation, Section 6.3). Therefore, the ecological exposure assessment for releases to marine water from ships was not further developed.

A scenario for the potential impacts of produced water on aquatic organisms (fish, invertebrates, algae, phytoplankton) was not developed. There is a regulatory requirement for offshore platforms and floating production storage and offloading (FPSO) vessels to undergo an environmental assessment to directly determine the effect on these aquatic organisms. Specifically, the Canada-Nova Scotia and Canada- Newfoundland and Labrador Offshore Petroleum Boards (CNSOPB, CNLOPB) mandate an environmental effects monitoring (EEM) program as a condition of operation. The EEM program determines and quantifies changes that the project may cause in the surrounding environment. Typically, specific environmental conditions and endpoints are established, which involve regulatory departments and agencies. Environment Canada officials have participated in the design of the program and the review of EEM reports.

Results from the EEM program for the SOEP indicate minimal to no effects on the marine environment (CNSOPB 2011).

8.2.2 Terrestrial Compartment

There was an average of about 50 spills/year to air/land reported in Alberta from 2002-2011, with an average spill volume of 3745 L (Table 6-3) and a median spill volume of 500 L. The largest single release of NGCs to land for the years 2002-2011 was a pipeline leak of 190 000 L in 2002 (ERCB 2012).

Due to the paucity of data available on the size of NGC spills to the soil surface and on the area affected, the terrestrial scenario does not provide an expected concentration of NGC in soil. Any spill will saturate a certain volume of soil, thus the retention capacity for three soil types (as described below), based on gasoline, will be used as PECs. Gasoline is considered to be an appropriate surrogate for NGCs due to its similar properties. From this, the total potential volume of soil affected by an NGC spill can be calculated to estimate the magnitude of the impact.

Arthurs et al. (1995) studied the volatilization of gasoline from three Canadian soils: Ottawa sand, Delhi loamy sand and Elora silt loam. The authors provide the retention capacity of gasoline in dry soil, thus enabling the determination of the approximate volume of soil that could reasonably be expected to be contaminated by an average gasoline spill. Information used to calculate the total potential soil volume affected, as well as the expected soil volume saturated with gasoline can be found in Table E-1 (Appendix E). According to Arthurs et al. (1995), gasoline reaches retention capacity at 68 000 mg gasoline/kg dw soil in moist sand, 170 000 mg/kg dw in moist loamy sand and 238 000 mg/kg dw in moist silt loam. The PECs for soil are taken as the above retention capacities of gasoline in soil.

The average and median spill volumes of NGCs to land from 2002-2011 were 3745 L (2771 kg) and 500 L (370 kg), respectively (Table 6-3). Based on the above information, if these amounts of NGCs were released directly onto soil, between 6.8 and 24 m^3 of soil would be contaminated for an average spill or 0.91-3.2 m^3 of soil for a median spill, depending on the soil type (Table E-1 in Appendix E). These volumes of soil are only those which would be saturated with NGCs (i.e., at the retention capacity, above which a mobile NAPL forms) and do not include any potential unsaturated areas or the movement of NGCs through soil after the spill.

8.3 Characterization of Ecological Risk

The approach taken in this ecological screening assessment was to examine available scientific information and develop conclusions based on a weight-of-evidence approach as required under CEPA. For each environmental compartment, an estimate of the predicted no effect concentration (PNEC) was determined by dividing the CTV by an appropriate assessment factor. PECs were determined for the aquatic and terrestrial exposure scenarios (Section 8.0). A risk quotient (RQ = PEC/PNEC) was calculated for each environmental compartment and is an important line of evidence in evaluating the potential risk to the environment. A minimum spill volume required to obtain the risk quotient was also estimated to evaluate the number of spills that might exceed that threshold in a given year.

The models used for the release scenarios to a large water body take into consideration the dispersion of the petroleum substance spilled, and therefore the calculated spill volume relating to an RQ of one is not for the acute, initial exposure to the spilled material. It is recognized that local, acute effects may occur during the initial phase of a spill before significant dispersion and weathering occurs.

The CTV for heavy NGCs for aquatic scenarios is the empirical 48 hour daphnid LC_{50} value of 0.41 mg/L obtained with fresh Sable Island condensate (Maclean and Doe 1989). For light NGCs, the CTV for aquatic scenarios is based on a 96 h LC_{50} for rainbow trout of 11 mg/L with gasoline (CONCAWE 1995a). An assessment factor of 10 was chosen to account for interspecies variations in sensitivity to baseline narcosis. This results in aquatic (marine and freshwater) PNECs of 0.041 mg/L for heavy NGCs and 1.1 mg/L for light NGCs (Table 8-3).

The spill volume required to obtain an RQ of one (i.e., the PEC equals the PNEC), referred to as the critical spill volume (CSV), was calculated for both the heavy and light NGCs and are given in Table 8-3. For this analysis, it was assumed that all of the condensate spilled was either light NGCs or heavy NGCs. To scale down the PECs to equal the PNECs, the scaling factor was based on the ratio of 10.4 mg/L concentration in water for a 1590 L spill, which was used to develop the PEC for marine water (see Ecological Exposure Assessment, Aquatic Compartment section). Using this ratio, a water concentration of 0.041 mg/L for heavy NGCs would result from a 6.3 L spill, and a water concentration of 1.1mg/L for light NGCs would result from a 168 L spill. Comparing these critical spill volumes to the 2002-2011 spill data for Nova Scotia and Newfoundland and Labrador shows that, of the 11 spills of condensate to marine water during this 10 year period, five spills exceeded 6.3 L and no spills exceeded 168 L. Therefore, on average, less than one spill per year during this ten year period exceeded the CSV for heavy NGCs and no spills exceeded the CSV for light NGCs. Given the small size of most spills, and the low frequency of spills to marine water (approximately one spill/year on average) (Section 6.2), this analysis indicates that releases of NGCs have low potential to cause harm to marine species.

Table 8-3: PNECs and critical spill volumes calculated for NGCs in the marine compartment

NGC type/ scenario	Organism	PNEC (mg/L)	Critical Spill Volume	No. spills more than and/or	No. spills more than

			(CSV) (L)[a]	**equal to CSV from 2002-2011[b]**	**and/or equal to CSV per year[b]**
heavy, marine spill	*D. magna*	0.041	6.3 L	5	0.5
light, marine spill	*O. mykiss*	1.1	168 L	none	none

[a] Critical spill volume is the volume required to obtain an RQ = one

[b] Based on CNSOPB (2001-2012) and CNLOPB (2015)

For the risk characterization for the scenario of spills into muskeg/stagnant water, the dilution factor needed to achieve a risk quotient of one with the median spill volume of NGCs reported in Alberta from 2002–2011 (ERCB 2012), which was 2500 L (1850 kg) (Table 6-3), was determined. The aquatic PNECs in Table 8-3 are used. The dilution needed for a 2500 L spill of NGCs to achieve a risk quotient of one is 1.7 x 10^9 L for light NGCs and 4.5 x 10^{10} L for heavy NGCs. The volume of a body of muskeg/stagnant water is expected to be less than that and, therefore, these very high dilution factors are unlikely to occur when NGCs are spilled into such waters. Muskeg depths in Alberta typically vary from 0.6-2 m (Christian 2012), and a significant part of their volume is taken up by vegetation/decomposed vegetation (peat). Since the median reported spill needs such high dilution factors to achieve a risk quotient of one, it is therefore considered that at least half of all the reported spills of NGCs to muskeg/stagnant water in Alberta (or about one spill per year on average) have the potential to harm aquatic organisms. However, even water bodies with sufficient volume to dilute a spill to the PNEC (e.g., that have a volume of 4.5 x 10^{10} L and greater) might be impacted as this scenario assumes complete and instantaneous mixing of the entire volume of NGCs spilled into the water body. It is recognized that local, acute effects may occur in the vicinity of any spill until weathering and dispersion decreases the concentration to that below which impacts occur.

This analysis only considers spill data for Alberta, where the majority of terrestrial oil and gas extraction in Canada occurs. However, spills to muskeg and/or other freshwater may occur in other NGC-producing provinces, such as British Columbia, Saskatchewan and Nova Scotia, and it is considered that a high proportion of these spills would also have the potential to harm aquatic organisms. It is therefore considered that releases of both light and heavy NGCs into muskeg/stagnant freshwater have the potential to harm aquatic organisms.

For terrestrial soil scenarios, the Canada-Wide standard for ecological direct soil contact with PHC F1 is used as the PNEC for light NGC and that for F2 is used as the PNEC for heavy NGC. The PECs are the retention capacities of gasoline in various soil types, as described in Section 8.2.2. A summary of the risk quotients for the terrestrial compartment is given in Table 8-4.

Table 8-3 Risk quotients for NGCs in the soil compartment

NGCs type	Soil type	PEC (mg/kg dw)	PNEC (mg/kg dw)	Risk Quotient
Heavy	Sand	68 000	150[a]	453
Light	Sand	68 000	210[b]	324
Heavy	Loamy sand	170 000	150[a]	1133
Light	Loamy sand	170 000	210[b]	810
Heavy	Silt loam	238 000	150[a]	1587
Light	Silt loam	238 000	210[b]	1133

[a] CCME Canada-wide Standard for ecological direct soil contact with PHC F2 in a residential/agricultural soil.
[b] CCME Canada-wide Standard for ecological direct soil contact with PHC F1 in a residential/agricultural soil.

The minimum spill to terrestrial environments that would generate a risk quotient of one could not be determined given the information available. There are on average approximately 50 spills per year to air/land reported in Alberta, where most of the oil and gas drilling in Canada occurs, with average and median spill volumes of 3754 L and 500 L, respectively. About 25% of the reported Alberta spills that occurred from 2002–2011 affected an area greater than 100 m^2 (ERCB 2012).

Based on a NAPL forming in the range of 68 000–238 000 mg/kg (Arthurs et al. 1995), the volume of soil that a volume of NGCs would completely saturate was calculated using the bulk density of the soil (Table E-1, Appendix E). This saturated soil volume is considered the minimum volume of soil that is negatively impacted (i.e., would result in harm to soil organisms) by the NGCs spilled. Based on spill data from Alberta, an average spill of NGCs (3754 L) would saturate an area between 6.85 m^3 and 24 m^3, a median spill would saturate 0.9–3.2 m^3 of soil and a 90th percentile spill of 9000 L would saturate 16 to 58 m^3 of soil ((Table E-1, Appendix E). There are approximately 25 spills/year greater than the median value, nine spills/year above the average value and five spills/year greater than the 90th percentile spill in Alberta. All spills had associated reported volumes.

Half of these spills are at volumes that would result in the saturation of more than 0.9 to 3.2 m^3 soil, based on soil retention capacities from Arthurs et al. (1995), with NGCs at a level that would cause severe harm (RQs = 394 to more than 1000). The volumes of soil impacted by these spills that would have an RQ more than one will be much larger than the volumes of saturated soil. Spills of NGC to soil will also occur in other provinces, though these numbers are unknown. Thus, spills to soil are of sufficient frequency and volume to demonstrate the likelihood of harm to terrestrial organisms. Because NGCs are not quickly diluted in soil (unlike in water), it takes very little to create harmful conditions for soil organisms. Site remediation is not considered in this analysis, as the concern is for the acute effects of NGCs, which would occur before site remediation takes place.

NGCs have the potential to cause harm to soil organisms, as indicated by the low effects levels for hydrocarbon fractions F1 and F2 in the Canada-Wide Standards for petroleum hydrocarbons in soil (210 and 150 mg/kg dry weight, respectively). This indicates that soil organisms may be adversely impacted by exposure to low concentrations of these hydrocarbons from NGCs.

NGCs have the potential to cause harm to aquatic freshwater organisms, based on the very large (10^9 or 10^{10} L) dilution that would be needed to achieve low-risk conditions in a scenario of a spill to muskeg/stagnant water.

A key consideration in characterizing the ecological risks of NGCs is the nature, extent and frequency of spills. Based on the available information, NGCs are of concern to terrestrial organisms (invertebrates, plants) due to the frequency and size of spills to soils (on average approximately 50 spills/year in Alberta of which half would result in harm to soil-dwelling organisms). NGCs may also cause harm to aquatic organisms based on the frequency of spills into freshwater (approximately two spills per year to muskeg/stagnant water in Alberta). The frequency of releases to land and muskeg/stagnant water is based on spills data from one province only; therefore, the number of releases across Canada is likely greater. However, the risk analyses indicate that the average and median size spills of NGCs to marine water are below the volume that would be expected to have a harmful impact on aquatic organisms.

Based on the available information, NGCs contain components that may persist in air and undergo long-range atmospheric transport. They also contain components that may persist in soil, water and/or sediment for long periods of time, thus increasing the duration of exposure to organisms. NGCs are also expected to contain components that are highly bioaccumulative. Studies suggest that most components will not likely biomagnify in food webs; however, there is some indication that alkylated PAHs might.

In general, fish can efficiently metabolize aromatic compounds. There is some evidence that alkylation increases the bioaccumulation of naphthalene (Neff et al. 1976; Lampi et al. 2010), but it is not known if this can be generalized to larger PAHs.

Some lower trophic level organisms (i.e., invertebrates) appear to lack the capacity to efficiently metabolize aromatic compounds, resulting in high bioaccumulation potential for some aromatic components as compared to fish. This is the case for some three-, four-, five-, and six-ring PAHs, which were bioconcentrated to high levels by invertebrates (e.g., *Daphnia*, molluscs) but not by fish. There is potential for such bioaccumulative components to reach toxic levels in organisms if exposure is continuous and of sufficient magnitude, though this is unlikely in the water column following a spill scenario due to relatively rapid dispersal. However, some of these components can also persist in sediments for long periods of time, which can increase the exposure duration of benthic invertebrates to these components.

In contrast with aquatic systems, in terrestrial systems NGCs will not significantly disperse in soil, and the higher molecular weight components with high K_{OC} and low volatility will tend to remain in soil, leading to longer exposure. Consumption of plants/soil invertebrates exposed to NGCs by higher trophic level organisms may result in biomagnification in the food chain of bioaccumulative components that are not easily metabolized.

8.3.1 Conclusion

Based on the information presented in this screening assessment, NGCs may cause harm to organisms in areas close to points of release to soil and freshwater; however, these releases do not compromise the broader integrity of the environment. It is concluded that NGCs meet the criteria under paragraph 64(*a*) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. However, NGCs do not meet the criteria under paragraph 64(*b*) of CEPA as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

8.3.2 Uncertainties in Evaluation of Ecological Risk

All modelling of physical-chemical properties and persistence, bioaccumulation and toxicity characteristics of NGCs is based on molecular structures and physical and chemical properties data. As NGCs are UVCBs, they cannot be represented by a single, discrete chemical structure. The specific chemical composition of NGCs is not well defined. Therefore, for the purposes of modelling, a suite of representative structures was chosen to represent the range of components likely present. Specifically, these structures were used to assess the fate and hazard properties of NGCs. Given that more than one representative structure may be used for the same carbon range and type of component, it is recognized that structure-related uncertainties exist for this substance. Given the large number of potential permutations of the type and percentages of these structures in NGCs, there is uncertainty in the results associated with modelling. In addition, the behaviour of individual representative structures may differ when they are present as components in a mixture, such as NGCs. However, the empirical data for NGCs and empirical read-across data available for other similar substances (e.g., gasoline, LBPNs, gas oils, and crude oil), reduce the overall uncertainty in using the modelled data.

The release and spill information reported to the Alberta spills database from 2002 to 2011 contains uncertainties in the reported quantities. A volume was reported for every spill in the Alberta database, though the compartment of release and source of the spill was not always reported.
There is uncertainty about how many spills occurred across Canada during the years 2002-2011. The spills data for Alberta, Nova Scotia and Newfoundland and Labrador, however, can be considered to account for a large fraction of spills of NGCs in Canada, given that these provinces are the predominant producers of NGCs in Canada.

NGCs are expected to remain in water for relatively short periods of time due to their high volatility. However, many acute aquatic toxicity studies use closed systems to prevent the volatile components from escaping the experimental chambers. As such, toxicity of NGCs in aquatic systems is likely less than reported here.

There is uncertainty about the concentration of NGCs that would saturate the soil and produce a mobile NAPL. The work of Arthurs et al. (1995), who found that the retention capacity of gasoline in various soils was between 68 000-238 000 mg/kg dw, was used in this report. However, other studies have reported different soil retention capacities for petroleum hydrocarbons (e.g., Brost and DeVaull (2000) found that the NAPLs of fuel products in the density range of gasoline, such as NGCs, will become mobile in the range of 3400–80 000 mg/kg dw soil in various soils). If lower soil retention capacities had been used in the risk characterization section, it would have led to greater volumes of soil estimated as being saturated by NGCs and even higher risk quotients.

There is also uncertainty about the combined risks posed by NGCs together with other PHCs following spills from upstream petroleum facilities. This risk assessment looks solely at the risks posed by NGCs but does not consider their combined exposure with other PHCs as would occur in the environment, following releases of PHCs from wells and other petroleum facilities.

9. Potential to Cause Harm to Human Health

9.1 Exposure Assessment

9.1.1 Environmental Media

Analysis of potential exposure of the general population to NGCs via environmental media focuses on evaporative emissions of NGCs during transportation (loading/unloading) and storage. For the purpose of assessing the potential to cause harm to human health, the unintentional leaks or spills data in the ecological portion of this risk assessment are considered to occur on a non-routine or unpredictable basis at distinct locations, and emergency and contingency plans are in place at federal or provincial levels. Therefore, unintentional leaks or spills are not considered within the context of assessment on the potential exposure to NGCs by the general population in Canada.

Evaporative emissions from petroleum substances can enter ambient air and may result in exposure to the general population. As NGCs are mainly used as feedstocks, diluents or blending components, and may be transported between industrial facilities, evaporative emissions of NGCs could enter the air during production, transportation, and/or storage.

Inhalation is considered to be the primary route of exposure for the general population to evaporative emissions of NGCs. The exposure assessment focuses on inhalation exposure of the general population residing adjacent to areas of NGC loading/unloading or storage. Dermal and oral exposures are not expected, as the general population has limited or no direct access to NGCs during transportation or to locations where NGCs are produced or stored (e.g., gas and oil extraction wellheads, and gas processing and fractionation facilities).

Among the chemical compounds present in NGCs, benzene is the highest hazard component for long-term inhalation health concerns from exposures to NGC evaporative emissions. The use of the highest hazard component accounts for any other less hazardous NGC volatile components that may be associated with either short- or long-term inhalation health effects (see Section 9.2).

Monitoring data on benzene in the local environment near petroleum facilities have been reported in several studies. Dann and Wang (1995) summarized the benzene concentrations in ambient air in Canada from 1989 to 1993 based on the samples collected from over 30 different urban and rural monitoring sites. In the vicinity of 3 km to a Canadian refinery, the 24-hour benzene levels were reported as 1.8 ± 1.1 µg/m^3 with a maximum level of 6.1µg/m^3 based on 108 samples collected for all 4 years. The highest 24-hour benzene concentration was observed as 126 µg/m^3 in 1993, at a distance of no more than 2.5 km to a petroleum facility. Burstyn et al. (2007) and You et al. (2008) described a study on monitoring the airborne benzene concentrations over 1200 sites across the primary oil and gas industry in Alberta, north-eastern British Columbia and central and southern Saskatchewan from April 2001 to December 2002. Based on more than 11 300 samples taken, the monthly-based concentration of airborne benzene ranged from less than 0.5 ng/m^3 to up to 9 µg/m^3 with a geometric mean of 0.16 µg/m^3. You et al. (2008) concluded that tank batteries located within 2 km are the most influential contributor to benzene concentrations in the local ambient air. As reported by NAPS (2012), the annual benzene concentrations in the vicinity of an industry area in Alberta were estimated to be 1.54 ± 0.85 µg/m^3, based on over 60 samples collected throughout the year 2009 for a period of 24-hr and at a frequency of once every 6 days. At a downwind distance of 50 m from a sweet gas plant, Chambers (2004) reported a single 1-hour snapshot of the benzene concentration in air of 12.85 µg/m^3. In comparison, at a refinery fenceline, Gariazzo et al. (2005) reported daily average of benzene levels ranging from 0.9 to 6.8 µg/m^3 and daily maximum levels ranging from 5.9 to 72.7 µg/m^3 based on 7-day monitoring measurements. Simpson et al. (2013) reported benzene levels ranging from 0.19 to 21.01 µg/m^3 at 500 m or more downwind of an emission source based on 48-hour samples. These studies demonstrate the potential variations in measurements taken over a short time scale. Zielinska et al. (2014) measured the concentrations of benzene in ambient air surrounding unconventional natural gas production facilities in Texas. At a distance of 70 m downwind from two condensate tanks, the benzene level approached the upwind background level. Such data are limited in their representativeness of larger scale operations and/or storage tanks. Additionally, due to a lack of detailed information on both the sample sizes and activities occurring at the site during sampling, as well as what appears to be an unrepresentative background measurement, such data are not considered to be applicable to a wider range of NGC facilities and thus are not used as the primary information in this assessment report.

9.1.2 Evaporative Releases from Transportation

Evaporative releases from the transportation of NGCs include potential releases during transit, and loading and unloading processes. Such releases are estimated based on the transportation data for CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1. Based on the information submitted under section 71 of CEPA for these CAS RNs and an additional literature search, NGCs are transported by pipeline, truck, rail and ship (Environment Canada 2012a; ExxonMobil 1996). However, evaporative emissions from liquid substances by pipeline transport are generally not expected under routine operating conditions (U.S. EPA 2008); therefore, potential inhalation exposure of the general population to evaporative emissions of NGCs during transportation focuses on transport by rail, truck and ship, and includes loading, transit and unloading processes.

It is considered that there is a higher likelihood of exposure associated with an idling vehicle as compared to a moving vehicle. The concentration of a substance of interest in the local air near a stationary release source (e.g., an idling vehicle) is higher than that from a moving release source (e.g., a truck along a roadway, or a ship moving out of a port), as the moving release source disperses emissions across a larger geographical area than the stationary release source. Therefore, for a transit process, the maximum exposure likelihood is estimated based on truck transportation in a scenario in which a tanker truck (carrying NGCs) idles for a 1-hour rest period. Potential bystanders are considered to be located a minimum of 200 metres away. Compared to rail or ship transportation, tanker truck idling locations are commonly shared with the general population along highways and in urban settings, thereby, idling via rail or ship transportation (excluding vehicle exhaust emissions from an idling vehicle) is considered to be covered by the tanker truck scenario.

Loading and unloading operations involved in truck, rail and ship transportation are also considered in identifying any potential impact on the general population residing in the vicinity of a loading/unloading area. Ship transportation occurs less frequently than the other modes of transportation, assuming transport and loading/unloading events occur once every 6 weeks throughout the year (ExxonMobil 1996). For truck or rail transportation, the number of loading/unloading events per year is estimated based on the reported annual transportation volumes (Environment Canada 2012a) , and an assumption of a capacity of 30 m^3 per tanker truck or 2800 m^3 per train (40 rail cars in total). Based on the information submitted under section 71 for CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1, it is estimated that the average and the maximum values of handling quantities per site by rail or truck were approximately 20 million kg and 700 million kg in 2010, respectively. As a conservative estimate, it is considered that a vapour control system (i.e., a vapour recovery or combustion unit) is not in place in loading/unloading facilities involving the transport of NGCs. Additional sensitivity analyses on the impacts of transportation volume and vapour recovery efficiency are provided in Section 9. 1. 4.

Based on the transportation data specific to CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1, the estimated quantities of evaporative emissions to ambient air resulting from transportation are given in Table F-1 of Appendix F. The average or upper-bounding estimates for evaporative releases were calculated based on their average or maximum annual transported quantities by each mode, multiplied by the emission loss percentage of total organic substances derived from handling of gasoline, i.e., 0.084% w/w for loading or unloading and 0.0013% w/w for transit loss by trucks or rails, and 0.031% w/w for loading/unloading and 0.046% w/w for transit by marine transport (U.S.EPA 2008). The average and the maximum evaporative emissions are used for deriving the contributions of NGCs and benzene arising from transport of NGCs to the local ambient air in an average and an upper-bounding exposure scenario, respectively.

For the truck and train transportation scenarios, bystanders are considered to be potentially located at a minimum distance of 200 metres. This is a realistic distance for the potential exposure of the general population based on map analysis and also the assumption of commonly shared locations with the general population for trucks (e.g., idling trucks). For the ship transportation scenario, the general population is not expected to reside closer than 1500 m to marine loading/unloading ports. This was also confirmed by photomap analysis.

In the absence of long-term air monitoring data in the vicinity (i.e., 0, 200, 500 and 1000 m) of NGC loading/unloading facilities, the contributions of NGCs and benzene to the local ambient air were estimated using an air dispersion model based on the estimated evaporative emissions from loading/unloading events for various transportation modes and for 1-hour truck idling.

SCREEN3 (1996), a screening-level Gaussian air dispersion model, was used to determine the dispersion profiles of NGC concentrations or benzene levels in the ambient air attributable to the evaporative emissions from transportation. The SCREEN3 model was developed based on the Industrial Source Complex (ISC) model (for assessing pollutant concentrations from various sources in an industry complex). SCREEN3 is designed to estimate maximum concentrations of chemicals at chosen receptor heights and at various distances from a release source for a given continuous emission event. The maximum calculated exposure concentration is selected based on a built-in meteorological data matrix of different combinations of meteorological conditions, including wind speed, turbulence and humidity. The driver for air dispersion in the SCREEN3 model is wind. This model directly predicts concentrations resulting from point, area and volume source releases. SCREEN3 provides the maximum exposure concentration in the direction downwind from the prevalent wind 1 hour after the release event. With an assumption of a continuous release occurring over a 24-hour period and considering the changing wind direction over this period, a maximum concentration during a 24-hour exposure period is estimated by multiplying a factor of 0.4, for fugitive area emission sources, with the maximum 1-hour exposure as assessed by the ISC Version 3 (U.S. EPA 1992). For exposures over the span of a year, it can be expected that with changing wind directions the substance air concentrations within an area release source may not vary to the same extent as those of point release sources; the meteorological conditions giving rise to a maximum 1-hour exposure can persist for a longer duration; thus, the maximum concentration for one year is determined by multiplying the maximum 1-hour concentration by a factor of 0.2. Under certain circumstances, it is recognized that such an adjustment factor can be reduced by using a refined model with site-specific meteorological conditions (e.g., AERMOD). However, a screening level assessment does not incorporate information about a specific site, but rather gives a conservative estimate of exposure that is protective of the general population. The adjustment factor of 0.2 has been consistently applied in eight published final screening assessment reports under the PSSA (Environment Canada, Health Canada 2013a-d, 2014b-e), of which some substances were concluded to meet one or more of the criteria set out in section 64 of CEPA. Others have concluded the substances do not to meet any of the criteria set out in section 64 of CEPA. For intermittent events (e.g., loading/unloading) occurring over a year, the amortized exposure annual estimates are calculated by multiplying the maximum SCREEN3 estimate adjusted for 1-year average wind direction, with the projected event hours (less than 10 hours up to greater than 1500 hours per year for different modes of transportation) out of total 8760 hours in a year.

The results of the modelled dispersion profiles of the NGC vapour and benzene in ambient air by SCREEN3, associated with transportation events, are presented in Tables 9-1 and 9-2, including the maximum concentrations within 1-hour, 24-hour, and annual estimates accounting for both changing wind directions and intermittent nature of the events, for average and upper-bounding exposure scenarios. The average exposure scenarios were based on the average transportation quantities among the 3 CAS RNs (CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1) submitted under section 71 of CEPA, except that the rail loading/unloading average scenario was based on the median value of reported transportation quantities. The upper-bounding exposure scenarios were based on the highest transportation quantities among the 3 CAS RNs (CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1) submitted under section 71 of CEPA. For example, the upperbounding scenario for rail transport was derived using the highest reported rail transport quantity of approximately 700 million kilograms in 2010. All input parameters (e.g., emission rates, emission areas) and underlying assumptions are presented in Table F-2 in Appendix F. The benzene concentrations were estimated based on 0.5% w/w benzene in NGC vapours (Hendler et al. 2009).

Table 9-1 Maximum NGC exposure estimates from handling and transport of NGCs[a].

Scenario	1-hour (μg/m^3)	24-h with averaged wind direction (μg/m^3)	Amortized annual concentration (μg/m^3)
Truck idling for 1-hr (at 200 m)	9 - 20	-	0.07 - 0.16
Truck loading/ unloading (at 200 m)	9800	3900	97 - 440
Train loading/ unloading (at 200 m)	178000	71000	6.5 – 3700[b]
Ship loading/ unloading/ idling (at 1500 m)	4100	1600	19

[a] For numbers presented in a range, the low-end estimates were based on average exposure scenarios, and the high-end estimates were based on upper-bounding exposure scenarios.
[b] For the high-end estimate of 3700 µg/m^3 was derived from the highest reported value of approximately 700 million kg in 2010.

Table 9-2 Maximum benzene exposure estimates from handling and transport of NGCs[a]

Scenario	1-hour (µg/m^3)	24-h with averaged wind direction (µg/m^3)	Amortized annual concentration (µg/m^3)
Truck idling for 1-hr (at 200 m)	0.045 - 0.1	-	0.00035 - 0.0008
Truck loading/ unloading (at 200 m)	49	20	0.48 - 2.2
Train loading/ unloading (at 200 m)	890	360	0.032 – 19[b]
Ship loading/ unloading/ idling (at 1500 m)	20	8	0.096

[a] For numbers presented in a range, the low-end estimates were based on the average exposure scenarios, and the high-end estimates were based on upper-bounding exposure scenarios.
[b] For the high-end estimate of 19 µg/m^3 was derived from the highest reported value of approximately 700 million kg in 2010 and 0.5% w/w of benzene in NGC vapours.

The potential contribution of NGCs and benzene to ambient air during transportation events are presented in Tables 9-1 and 9-2, at 200 m or 1500 m away from the release sources. The highest estimates are observed from loading/unloading events by rail transportation. For maximum concentrations within 1-hour, the modelled NGC and benzene levels are 178 mg/m^3 and 890 µg/m^3 at 200 m away from the release source. The maximum estimates within 24-hr at 200 m are 71 mg/m^3 for NGCs and 360 µg/m^3 for benzene. The upper-bounding amortized annual estimates are 3700 µg/m^3 for NGCs and 19 µg/m^3 for benzene, at 200 metres away from the railcar loading/unloading areas, based on the highest reported quantity of approximately 700 million kg in 2010. Similarly, for truck transportation, the upper-bounding estimate for annual benzene contribution is 2.2 µg/m^3 at 200 m away from a truck loading/unloading dock. Both upper-bounding estimates for annual benzene contribution to the local ambient air, at 200 m away from truck and rail loading/unloading areas, are substantially higher than the average annual air benzene level of 0.32-0.84 µg/m^3 in rural and urban areas across Canada (NAPS 2012). For the other transportation scenarios, at a distance of 200 m or 1500 m away from the release sources, the estimates for the annual contribution of benzene to ambient air are lower than the average annual Canadian ambient air concentration of 0.32-0.84 µg/m^3 reported by NAPS (2012). The modelled air levels for benzene or NGCs decrease with an increasing distance from a release source. At a distance of 1500 m, the estimated annual contributions of benzene to ambient air from upper-bounding scenarios are lower than the average annual Canadian ambient air benzene level.

9.1.3 Exposure to Evaporative Emissions from Storage Tanks

Storage of NGCs occurs in tank batteries at or near the wellheads and gathering sites, or gas processing plants, often in fixed-roof tanks (CAPP 2002; Mokhatab et al. 2006; Hendler et al. 2009), as well as at storage terminals where large volumes of NGCs can be stored in floating-roof tanks. A tank battery normally consists of gas-liquid separator(s), as well as liquid storage tank(s). After preliminary separation from gas and water, condensate substances can be temporarily stored in the storage tanks, prior to delivery for further treatment. In a gas processing plant, condensates may be stored before being delivered to a stand alone fractionation plant for producing final individual end-products including propane, butane, pentane and C_5^+. A vessel for occasionally holding up NGCs is sometimes used at a facility in case of a temporary process upset or excessive incoming flow of the condensate substances from an upstream facility which uses pipelines for product transport (Mokhatab et al. 2006; ExxonMobil 2011c). Thus, condensate storage tanks commonly exist in gas gathering and processing facilities.

Evaporative emissions from storage tanks include breathing loss caused by any changes in ambient temperature and/or pressure (i.e., expulsion of vapour from the tank), working loss during filling and/or emptying a tank, and flashing loss associated with an occurrence of pressure drops in an operating system (CAPP 2002; European Commission 2006; U.S. EPA 2008). As pressurized condensates are transferred into an atmospheric storage vessel, a pressure drop occurs and some gases originally dissolved in the liquid are thereby released, through storage tank vents, into the atmosphere (Ross 2004). Compared to breathing loss and working loss, flashing gas loss tends to be relatively more significant and is a dominant contribution to the total evaporative emission (CAPP 2002).

In this screening assessment, the total emissions from condensate storage tanks, including breathing loss, working loss and flashing loss, were used for determining the air concentration to which the general population residing in the vicinity of storage tank areas may be exposed. Using different measuring techniques, Hendler et al. (2009) and Chambers (2004) studied the evaporative emissions from condensate storage tanks at different facilities in the U.S.A. and Canada, respectively. Such measured emission data represent the total evaporative emissions from the tanks, and are used as a basis for assessing the exposure of the general population to the evaporative emissions from storage tanks.

Hendler et al. (2009) measured emission rates and analyzed the composition of vent gas from 21 condensate storage tank batteries at different wellheads and gathering sites in East Texas areas from May to July 2006. The condensate storage tanks aged from 2 to 10 years old and were maintained under good conditions. The flow rates of total vent gas were measured by a thermal mass flow meter connected to a storage tank vent, or as in the case of multiple storage tanks operated in parallel, connected to a vent gas gathering pipe located at the tops of the tanks. The flow rates of vent gas from condensate storage tanks were measured, over a 24-hour period, as 383.7 ± 1007.9 kg/day, and 199.6 kg/day as 75th percentile value (8.3 kg/hour). By normalizing the condensate production rates at different sites, the vent gas rate was estimated to be 18.9 ± 28.4 kg/bbl of condensate produced with 21.8 kg/bbl of condensate as the 75th percentile. Results from the speciation of vent gas show that average VOCs in the vent gas could amount to over 70% w/w, with nitrogen, carbon dioxide, methane and ethane as the remaining portion. Benzene levels in the vent gas ranged from 0.13% w/w to 1.35% w/w (0.42 ± 0.31% w/w), with 0.52% w/w as the 75th percentile. Thus, the emission rate of benzene from the condensate tanks was calculated as 0.07 ± 0.18 kg/hr (varying from 0.0002 to 0.85 kg/hr), with 0.04 kg/hr at the 75th percentile.

Evaporative emission rates of benzene from condensate tanks and different processing areas, as part of evaporative emissions of total VOCs, were also examined by the Alberta Research Council in two upstream oil and gas facilities in Alberta from July to August of 2004, one sweet gas processing plant and one sour gas processing plant (Chambers 2004). The evaporative emissions were measured by DIAL. Compared to the other processing areas, the condensate storage tanks are considered as a significant source for benzene emissions. Both plants had fixed-roof condensate storage tanks on site. In the sweet gas processing plant, one condensate tank and two fracturing oil tanks were located in the tank area. The benzene emission rate from the tank area (3 tanks in total) was 0.03 kg/hour (as time weighted mean, TWM, calculated based on a series of individual scans over a 4-hour period), accounting for 50% of the total benzene emission from the whole plant. After adding a cooler to decrease the temperature of incoming flow to the condensate tank below 30°C, the benzene emission from the tank area was reduced by 100% to below detection limit. In the sour gas processing plant, two fixed-roof condensate storage tanks were located in the tank area. Total benzene emission rate from the tank area was measured as 0.03 kg/hour (TWM of a series of individual scans over a 2-hour period). The reported benzene emission rates from condensate tank areas by Chambers (2004) (i.e., 0.03 kg/hour) are of the same order of magnitude as the data by Hendler et al. (2009) (i.e., 0.04 kg/hour as the 75th percentile). Nevertheless, it should be noted that both studies were conducted during the summer and the measured emission rates may represent a peak value and could be higher than the average of the year (Armendariz 2009). On the other hand, photo-degradation of airborne benzene in the summer tends to be higher than that in the winter due to a greater abundance of OH radicals (Burstyn et al. 2007).

In addition, Chambers (2004) compared the DIAL measurement data with the estimates using CAPP Level 2 detailed method for VOC emissions. The author concluded that DIAL measurement data were in line with or higher than the CAPP estimates. The CAPP Level 2 detailed method is mainly based on equipment installed and emissions factor for each piece of equipment, to estimate the evaporative emissions of VOCs (CAPP 2014). For benzene evaporative emission from the tank area in the sweet gas processing plant, CAPP Level 2 method provides an estimation of 0.27 tonnes/year (operating hours of 8760 hours/year) whereas DIAL approach provides an estimation of 0.26 tonnes/year before the cooler is installed (0.03 kg/hour x 8760 hour/year = 0.26 tonnes/year). For the sour gas processing plant, the CAPP Level 2 method only reported the benzene evaporative emission from the whole plant to be 0.392 tonnes/year but no data were specific to the emissions from the tank area. In contrast, 0.26 tonnes/year is estimated for the annual benzene emission from the tank area by using the DIAL approach and 2.1 tonnes/year as the total annual evaporative benzene losses from the whole facility. When using DIAL emission rates to project total annual emissions from condensate storage tanks, consideration must be given to the fact that they are based on relatively short-term DIAL measurements (i.e., a series of individual scans within a short-time frame), and actual emissions can vary significantly over time as a result of operational and meteorological changes.

In the current screening assessment, the exposure estimates for airborne NGC levels were based on 8.3 kg/hour of NGC vapour emissions from the storage tanks in condensate batteries located in Texas, as the 75th percentile in the measurement data reported by Hendler et al. (2009). The exposure estimates for airborne benzene levels were based on 0.03 kg/hour of benzene emissions from the condensate tanks measured by DIAL technique from Canadian natural gas plants (Chambers 2004). This value is also in line with the 75th percentile of benzene emission measurement by Hendler et al. (2009), i.e., 0.04 kg/hr.

In the absence of air monitoring data associated with operational practices in the vicinity (i.e. 0, 200, 500 and 1000 m) of NGC storage sites, SCREEN3 (1996) was used to determine the dispersion profiles of NGC and benzene concentrations in the ambient air resulting from the evaporative emissions from condensate storage tanks. As evaporative emissions from storage tanks are considered as a continuous event, the SCREEN3 estimates adjusted for 1-year average wind direction are considered to represent the annual estimates for NGC and benzene contributions to the ambient air. The derived concentrations of NGCs and benzene in the local ambient air serve as a basis for assessing health effects on the general population living in the vicinity of condensate storage tanks.

Input parameters for SCREEN 3 modelling are provided in Table F-2 in Appendix F. The release area of the storage tank was assumed to be 20 m × 20 m, with releases occurring over the course of 365 working days per year (8760 operating hours per year) and exposure concentrations accounting for variable wind conditions over 24-hour and annual periods for urban and rural locations. Based on the definitions of rural and urban provided by U.S. EPA (1992, 2005) and Lakes Environmental Consultants (2003), rural terrain is chosen in SCREEN3 for a tank battery located in an open remote area with less obstruction for wind flow (e.g., buildings or other structures). In contrast, for those condensate storage tanks located in a gas processing plant, urban site is chosen where a rougher surface is created for wind flow, giving rise to a more localized and turbulent atmosphere with lower air dispersion further down the wind, as compared to that in rural area. Based on photomap analysis, minimal distances of bystanders from the storage tanks in urban and rural sites are 200 m and 1500 m, respectively. The modelled concentration profiles of NGCs and benzene in ambient air are presented in Table 9-3.

Table 9-3 Maximum contribution of NGCs and benzene (μg/m^3) from condensate storage tanks to ambient air

Substance	**Scenario**	**1-hr**	**24-hr with averaged wind direction**	**Annual concentration**
NGCs	200 m (urban)	2300	920	460
NGCs	1500 (rural)	800	320	160
Benzene	200 m (urban)	8.3	3.3	1.7
Benzene	1500 (rural)	2.9	1.2	0.58

The air dispersion modelling indicates that the maximum one-hour concentration of benzene at 200 m from storage tanks containing NGCs is 8.3 μg/m^3. The 24-hour maximum benzene levels at 200 m and 1500 m are 3.3 μg/m^3 and 1.2 μg/m^3, respectively. These concentrations are similar to the reported values of 1.8 ± 1.1 μg/m^3 within 3 km from a petroleum facility (Dann and Wang 1995). The modelled annual maximum benzene concentration in ambient air at 200 m is 1.7 μg/m^3. At 300 m, the benzene contributed to ambient air is 0.82 μg/m^3, a concentration that is equivalent to the recent ambient background level of benzene in rural and urban areas across Canada (0.32-0.84 μg/m^3) (NAPS 2012). These estimates indicate that the concentration of benzene in ambient air declines quickly with increasing distance from the release source.

Setback distances from industrial facilities to permanent dwellings are established at the provincial level. Based on the magnitude of potential releases of H_2S, the Energy Resources Conservation Board (ERCB) of Alberta (now called the Alberta Energy Regulator (AER)) established a guideline for a minimum separation distance between a petroleum facility (e.g., a well, pipeline, tank battery or other facility) and a permanent dwelling (AER 2011). A minimum setback distance of 100 m is required for any permanent dwelling and at least 500 m is required for public facilities (AEUB 1998; AER 2011). Consultation and notification are provided to the general population in the vicinity of petroleum facilities. Similarly, in British Columbia, residents are generally located at least 200-300 metres from a facility and additional operational safety and equipment requirements are often imposed (personal communication with British Columbia Oil & Gas Commission, Feb. 2012). From a perspective of permissible noise level and noise control, a distance of 1.5 km from the facility fence line to a receptor (e.g., permanent dwelling) is recommended in British Columbia (OGC 2009).

9.1.4 Sensitivity Analysis

Additional analysis was conducted to investigate the influence of loading/unloading volumes by truck or rail, different vapour recovery efficiency values, and alternative air dispersion modelling on changes in benzene contribution to ambient air. Based on the upper-bound ambient benzene background level of 0.84 $\mu g/m^3$ (NAPS 2012), it is estimated that a loading/unloading volume of approximately 30, 120, and 600 million kg/year per site of NGCs by rail or truck results in a benzene contribution comparable to the ambient background level at 200 m, assuming a vapour recovery efficiency of 0%, 75%, and 95%, respectively. In addition, an alternative air dispersion screening model AERSCREEN (U.S. EPA 2011) was used to modelling selected exposure scenarios (storage tanks, upper-bounding transportation by rail or truck). The results from this model were consistent with those from SCREEN3 (Table F-6, Appendix F)

9.1.5 Consumer Products

NGCs are not expected to be in marketplace products and therefore exposures to the general population are not expected.

9.2 Health Effects Assessment

Information on the potential health effects of NGCs was not available. Therefore, toxicology studies on petroleum substances that share similar physical-chemical properties with NGCs (e.g., LBPNs, unleaded gasoline) were considered. The aromatic solvent CAS RN 64742-95-6 and reformed naphthas (CAS RNs 64741-63-5, 64741-68-0 and 68955-35-1) were excluded as they are not considered to be appropriate read-across substances for NGCs due to their high aromatic content (20-100%). Appendix G contains a general overview of health effects information on surrogate substances considered representative of NGCs. A summary of key studies in laboratory animals is given below.

LBPNs exhibit low acute toxicity by the oral, inhalation and dermal routes of exposure as indicated by median lethal doses (LD_{50s}) that were not established (Rausina 1984; Stubblefield et al. 1989; CONCAWE 1992; API 2008b; RTECS 2008a, b, c, f). Mild to moderate eye and skin irritation has been observed in rabbits, and these substances do not appear to be skin sensitizers (API 1980b, 1986a-d, g, 2008b; CONCAWE 1992).

Short-term and subchronic inhalation LOEC/LOAECs were identified for various LBPN substances that were used for read-across to the NGCs. These values vary over 100 fold (214 mg/m^3 to 23 400 mg/m^3), and many of the health effects observed at these levels of exposure are limited and/or reversible.

A lowest LOAEC of 1327 mg/m^3 was identified after inhalation exposure of male and female SD rats to gasoline for 4 weeks. After a 4-week recovery period, females exhibited increased relative heart weights and serum glucose, and males elevated serum inorganic phosphate. Brain sections of the frontal cortex showed that dopamine and dopamine metabolites were increased in males but decreased in females, and entorhinal serotonin was increased in females (Chu et al. 2005). The biological basis behind the gender differences is unknown.

Effect levels lower than 1327 mg/m^3 were also identified but were not considered suitable upon which to base a LOAEC. A single dose (214 mg/m^3), 4-day study was conducted in rats exposed to white spirits (Riley et al. 1984). The tested white spirits were a mixture of aliphatic hydrocarbons predominantly C_9-C_{12}, and therefore may be limited in their representativeness of NGCs from a physical-chemical perspective. The study showed minor respiratory effects and the reversibility of the cellular changes was not examined (Riley et al. 1984). Furthermore, the respiratory physiology was not affected until higher exposure concentrations (i.e., at 1271 and 1353 mg/m^3 where bronchitis and mixed inflammatory cell infiltration in the lungs were observed (Rector et al. 1966). All these respiratory effects are considered to be localized rather than systemic effects as observed at 1327 mg/m^3 by Chu et al. (2005). A 4-17 week inhalation study of white spirits exposure in rats indicated a virtual no effect level of 575 mg/m^3 as no significant effects were seen at the first observation time point of 4 weeks (Savolainen and Pfaffli 1982). A 90-day continuous exposure study to mineral spirits in 5 species showed an apparent guinea pig-specific effect of increased mortality at 363 mg/m^3 (Rector et al. 1966). There were no adverse effects in rats, rabbits, dogs and monkeys at this level of exposure, and no mortality of these species at 1271 mg/m^3. Additionally, there was no guinea pig mortality at 1353 mg/m^3 for exposures of 8 hours per day, 5 days per week for 6 weeks (Rector et al. 1966). Collectively, the effect levels from 214 to 575 mg/m^3 are not used as a LOAEC for characterizing the risk of short-term exposure, as no or limited short-term effects were reported in the studies above, and a significant difference exists in the physical-chemical properties (e.g., carbon range, boiling point range) of white spirits/mineral spirits and the NGCs identified in this screening assessment. Therefore, the evidence supports the selection of 1327 mg/m^3 (with 120 hours of total exposure) as a suitable and conservative LOAEC upon which to base the characterization of risk of short-term exposures.

At effect levels higher than 1327 mg/m^3, there were significant changes in serum creatine kinase, cerebellar succinate dehydrogenase, creatine kinase and glutathione, as well as reductions in rat muscle uronic and sialic acids at 2875 mg/m^3 (Savolainen and Pfaffli 1982), oxidative stress in the brain, kidney and liver of rats at 4679 mg/m^3 (Lam et al. 1994), hepatocyte hypertrophy and increased liver weights in rats at 13 650 mg/m^3 (API 2008b) and decreased haemoglobin and hematocrit, and hypertrophy and hyperplasia of nasal goblet cells in rats 23 400 mg/m^3 (Lapin et al. 2001) (Appendix G for further details).

A chronic inhalation LOAEC of 200 mg/m^3 was identified based on ocular irritation and discharge in rats exposed to unleaded gasoline (containing 2% benzene) at concentrations of 0, 200, 870 or 6170 mg/m^3 (MacFarland et al. 1984). Dermal application of petroleum naphtha (CAS RN not assigned) for 105 weeks to mice resulted in a lowest LOAEL of 694 mg/kg-bw based on local inflammation and degenerative skin changes beginning at 6 months post-exposure (Clark et al. 1988).

Oral and inhalation toxicity studies of LBPNs or gasoline that exhibit certain renal effects in male rats are not considered relevant for human health risk assessment (Carpenter et al. 1975; Phillips and Egan 1984; Research and Environmental Division 1984; Halder et al. 1984, 1985; Gerin et al. 1988; Short et al. 1989; U.S.EPA 1991; Rodgers and Baetcke 1993; Schreiner et al. 1998, 1999, 2000; McKee et al. 2000; API 2005a, 2008b, c).

The European Commission and International Agency for Research on Cancer (IARC) have classified some NGCs and LBPNs as carcinogenic. The European Commission previously classified the three NGCs identified by CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1 as Category 2 carcinogens, i.e., “*Substances which should be regarded as if they are carcinogenic to man*” (R45: *may cause cancer*) (benzene content more than and/or equal to 0.1% by weight) (ESIS 2008; European Commission 2008a), and re-classified these substances as Category 1B carcinogens as “*presumed to have carcinogenic potential for humans, largely based on animal evidence*” (H350: *may cause cancer*) in 2009, due to modifications in re-naming each classification group (European Commission 2008b, 2009). Although NGCs are not classified by IARC, several LBPN substances similar to NGCs, including CAS RNs 64741-41-9, 64741-46-4, 64741-54-4, 64741-55-5, 64741-64-6, 64741-69-1, 64741-74-8, 64742-82-1, and 68410-05-9, were listed under “principle refinery process streams” and classified as Group 2A carcinogens (IARC 1989a,b).

Only studies examining unleaded gasoline for inhalation carcinogenicity and the ability to promote or initiate tumour formation were found (MacFarland et al. 1984; Short et al. 1989; Standeven and Goldsworthy 1993; Standeven et al. 1994, 1995). There is evidence of carcinogenicity for gasoline in rats and mice when exposed via inhalation. For long-term dermal exposures to LBPNs in mice, there is limited evidence of carcinogenicity (Appendix G for more details).

The volatile constituent benzene is found in all LBPNs, including NGCs assessed in this report. Measured benzene concentrations range from non-detectable in isomerized naphthas to 20% in reformates (UN 2009). Benzene levels in liquid NGC are generally less than 4% w/w (Hawthorne and Miller 1998; Riaz et al. 2011). Benzene level in NGC vapours ranged from 0.1 to 1.4% w/w (Hendler et al. 2009). Benzene was classified as a Group 1 carcinogen (*carcinogenic to humans*) by the IARC (IARC 2011), and as carcinogenic to humans by the Government of Canada (Canada 1993), and was added to the List of Toxic Substances in Schedule 1 of CEPA 1988. The European Commission classified benzene as a Group 1A carcinogen (*known to have carcinogenic potential for humans*) and recommends that all LBPNs and NGCs containing more than and/or equal to 0.1% benzene by weight be classified as Category 1B carcinogens, even in the absence of stream-specific animal data (ESIS 2008; European Commission 2008a, 2008b, 2009).

Other volatile NGC components that have health endpoints of potential concern include *n*-hexane (neurotoxicity), toluene (ototoxicity), ethylbenzene (Group 2B carcinogen as "*possibly carcinogenic to humans*"), xylene (Group 3 carcinogen as "*not classifiable as to its carcinogenicity to humans*"), and *n*-pentane (Group 3 carcinogen as "*not classifiable as to its carcinogenicity to humans*") (IARC 1989c, 1999, 2000; Cappaert et al. 1999; Gagnaire and Langlais 2005; Environment Canada, Health Canada 2009; Hendler et al. 2009).

Given the absence of LBPN or NGC-specific studies assessing carcinogenicity via inhalation, and the limited data on gasoline, the potential for carcinogenicity can be assessed by considering the cancer risk associated with potential exposure to the high-hazard component benzene. The Government of Canada has previously developed estimates of carcinogenic potency associated with inhalation exposure to benzene. A tumourigenic concentration ($TC_{0.05}$) was calculated as 14.7×10^3 µg/m^3 from the epidemiological investigation of Rinsky et al. (1987) based on acute myelogenous leukemia and a linear-quadratic exposure–response model (Canada 1993). The U.S. EPA (U.S. EPA 2000) quantified the cancer potency from inhalation exposure to benzene using low-dose linearity maximum likelihood estimates, based on the same epidemiological study of Pliofilm workers (Rinsky et al. 1981, 1987) that was the basis for the $TC_{0.05}$ reported by the Government of Canada.

A number of epidemiological studies, especially some early studies, have reported increases in the incidence and/or mortality of leukemia, skin cancer, kidney cancer and lung cancer among worker in petroleum refineries and other operating segments (e.g., marketing and distribution, pipeline, production) in the U.S.A, Canada or other countries (Hendricks et al. 1959; Lione and Denholm 1959; McCraw et al. 1985; Divine and Barron 1986; Nelson et al. 1987; Wong and Raabe 1989; Schnatter et al. 1993, 2012; Rushton and Romaniuk 1997; Raabe et al. 1998; Divine and Hartman 2000; Gamble et al. 2000; Lewis et al. 2000a, 2000b and 2003). However, most studies lack information on the levels of exposure to petroleum substances and there are other potential confounding factors; as such it is difficult to assign causation between any increased rate or risk for cancer and exposure to any given petroleum substance. Though IARC (1989b) lists occupational exposures in petroleum refining as Group 2A (*probably carcinogenic to humans*), it also concluded that there is limited evidence to support the view that working in petroleum refineries entails a risk of skin cancer and leukaemia. Additionally, there is a lack of direct link between the reported health effects and exposure solely to the NGCs or the LBPNs considered in this report. Therefore, the evidence gathered from these epidemiological studies is considered to be inadequate to inform the human health risk characterization for the NGCs.

LBPNs have demonstrated limited evidence of genotoxicity in *in vivo* and *in vitro* assays including for micronuclei induction, sister chromatid exchange and chromosomal aberrations *in vivo*, and *in vitro* in the Ames, UDS, mouse lymphoma and sister chromatid exchange assays, and for mutagenicity in CHO cells (Appendix G for more details). However, the overall test battery is incomplete for each substance.

Data from the LBPNs show that reproductive or developmental toxicity was not observed for the majority of the LBPNs. NOAEC values for reproductive toxicity following inhalation exposure to the LBPNs ranged from 1701 mg/m^3 (Stoddard solvent) to 27 059 mg/m^3 (light catalytic cracked naphtha CAS RN 64741-55-5) (Phillips and Egan 1981; Schreiner 1984; Dalbey et al 1996; Bui et al. 1998; Schreiner et al. 1999; McKee et al. 2000; API 2008b,c). Reproductive toxicity NOAELs have also been determined for the dermal and oral routes of exposure (Appendix G for more details).

Development toxicity was reported for rats with inhalation exposure to 4679 mg/m^3 de-aromatized white spirit (CAS RN 64742-48-9; “hydrotreated heavy naphtha” based on Health Canada’s DSL naming convention) for 6 hours/day from gestation days 7 to 20 (Hass et al. 2001). A decreased number of pups per litter and a higher frequency of post-implantation loss were observed. Additionally, increased birth weights and cognitive and memory impairments were observed in the offspring.

9.3 Characterization of Risk to Human Health

Based on its established carcinogenicity and known presence in NGCs, benzene is considered to be the component representing the highest health concern for long-term inhalation exposure to NGCs. In the absence of air monitoring data associated with operational practices in the vicinity (i.e., 0, 200, 500 and 1000 m) of NGC storage sites and truck/rail loading/unloading sites, risk associated with long-term inhalation exposure of the general population to evaporative emissions of NGCs from storage tanks or transportation was characterized by comparing the estimated annual benzene contribution to ambient air with the carcinogenic potency of benzene. Characterizing the risk associated with short-term exposure to evaporative emissions of NGCs from storage tanks or transportation involves a comparison of 24-hour exposure estimates of NGCs or benzene with the health effects data for benzene and surrogate LBPN substances considered for read-across to NGCs.

For long-term inhalation exposure, the estimates of carcinogenic potency for benzene previously developed by the Government of Canada (Canada 1993) were used to calculate a margin of exposure (MOE) associated with long-term exposure to evaporative emissions containing benzene from NGC transportation and condensate storage tanks. The MOE estimates are determined by comparing potential exposures in the vicinity of loading/unloading facility areas or condensate storage tanks (i.e., at 200 m or 1500 m from these release sources), with the tumourigenic concentration ($TC_{0.05}$) of 14.7×10^3 µg/m^3 for benzene. The $TC_{0.05}$ value is the concentration of a substance in air associated with a 5% increase in incidence or mortality from tumours (Health Canada 1996).

The MOE estimates for long-term inhalation exposures are presented in Table 9-4, including the MOE estimates for different transportation scenarios and for condensate storage tanks. Long-term inhalation exposure in the vicinity of a vehicle idling area or a loading/unloading dock for marine transport, or an average-volume loading/unloading dock for truck or rail transport, or 1 500 m away from storage tanks in an open remoted area (i.e. rural) results in MOE estimates of 25 300 to greater than 18 000 000, which are considered to be adequate to address uncertainties related to health effects and exposure. However, for long-term inhalation exposure in the vicinity of a high-volume loading/unloading area for rail or truck transportation (i.e., upper-bounding exposure scenario), as well as in the vicinity of condensate storage tanks, the MOEs at 200 m range from 770 to 6700 for rail or truck handling and 8600 for the storage scenario, respectively. Such MOEs are considered potentially inadequate to address uncertainties related to health effects and exposure.

Table 9-4 MOE estimates for long-term benzene exposure from NGC transportation and storage

Scenario	Distance (m)	Inhalation exposure estimate (µg/m^3)	Health effect endpoint (µg/m^3)	MOE

Truck idling for 1-hr	200	≤0.0008	14 700	>1.8 x 10^7
Truck loading/unloading[a]	200	0.48 - 2.2	14 700	30 600 – 6 700
Rail loading/unloading[a]	200	0.032 - 19	14 700	459 300 - 770
Ship loading/unloading /idling	1500	0.096	14 700	153 000
Storage tanks	200 (urban)	1.7	14 700	8600
Storage tanks	1500 (rural)	0.58	14 700	25 300

[a] Estimates for inhalation exposure and MOEs are presented in a range, with the first numbers (e.g., 0.48 µg/m^3) based on the average exposure scenarios and the second numbers (e.g., 2.2 µg/m^3) based on the upper-bounding exposure scenarios.

For the characterization of risk of potential short-term inhalation exposure to NGCs, MOE estimates were based on the estimated maximum 24-hr contribution of NGCs or of benzene to ambient air. These estimates were compared with the conservative short-term inhalation LOAEC of 1327 mg/m^3 (as based on neurotransmitter changes in rats) (Chu et al. 2005), or the critical non-neoplastic effect level for benzene of 32 mg/m^3 (as based on immunological effects in male mice) (Canada 1993). The MOEs for the various exposure scenarios are presented in Tables 9-5 and 9-6, and range from 18 to 66 000 for NGCs, and from 90 to 320 000 for benzene. For the rail loading/unloading scenario, the estimates for short-term MOEs range from 18 to 66, based on LOAECs of 1327 - 4679 mg/m^3 for NGCs (Table 9-5), and for benzene the MOE is 90 based on the benzene non-neoplastic effect level of 32 mg/m^3 (Table 9-6). These MOEs are considered to be potentially inadequate to address uncertainties related to health effects and exposure. For the other exposure scenarios listed in Tables 9-5 and 9-6, given the nature of these critical short-term effects and the conservative approaches within the assessment, the MOEs are considered adequate to address uncertainties related to health effects and exposure.

Table 9-5 MOE estimates for short-term NGC exposure

Scenario	Distance (m)	Max. 24-hr inhalation exposure estimate (µg/m^3)	Health effect endpoint (mg/m^3)	MOE
Truck idling for 1-hr	200	≤20[a]	1327	≥66 000
Truck loading/ unloading	200	3900	1327	340
Rail loading/ unloading	200	71 000	1327	18[b]
Ship loading/	1500	1600	1327	830

unloading/idling				
Storage tanks	200 (urban)	920	1327	1400
Storage tanks	1500 (rural)	320	1327	4 100

[a] Based on a maximum 1-hr estimate.
[b] MOE of 66 if LOAEC of 4679 mg/m^3 is chosen, based on the induction of oxidative stress in brain (Lam et al. 1994).

Table 9-6 MOE estimates for short-term benzene exposure

Scenario	Distance (m)	Max. 24-hr inhalation exposure estimate (μg/m^3)	Health effect endpoint (mg/m^3)	MOE
Truck idling for 1-hr	200	0.1[a]	32	≥320 000
Truck loading/ unloading	200	20	32	1 600
Rail loading/ unloading	200	360	32	90
Ship loading/ unloading/idling	1500	8	32	4 000
Storage tanks	200 (urban)	3.3	32	9 700
Storage tanks	1500 (rural)	1.2	32	26 600

[a] Based on a maximum 1-hr estimate

9.4 Uncertainties in Evaluation of Risk to Human Health

The composition of NGCs can vary depending on the source of natural gas or crude oil, operating conditions, seasonal process issues and economic cycles. Therefore, the hazard properties of NGCs may change based on the levels of component substances.

There is uncertainty regarding determining evaporative emission rates of NGCs from loading/unloading operations and transit processes. These were estimated based on the transportation volumes and modes that were submitted under s. 71 of CEPA for CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1, as well as empirical emission factors developed by U.S. EPA (2008) for transportation of petroleum liquids. The actual quantities of the releases also vary with operating conditions, modes of loading (e.g., submerged vs. splash loading), physical-chemical properties of the substances and maintenance conditions of tank containers, etc.

Reliable Canadian monitoring data for benzene in the vicinity of petroleum facilities were not identified. Therefore, general population exposures were estimated in part using screening level computer models. There is inherent uncertainty in estimates derived with models, including the long-term concentrations using max. 1-hr estimates from SCREEN3 (assumptions made in the modeling are listed in Appendix E).

10 Conclusion

Considering all available lines of evidence presented in this screening assessment, there is risk of harm to organisms, but not to the broader integrity of the environment from NGCs. It is concluded that NGCs meet the criteria under paragraph 64(*a*) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that may have an immediate or long-term harmful effect on the environment or its biological diversity. However, it is concluded that NGCs do not meet the criteria under paragraph 64(*b*) of CEPA as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

Based on the information presented in this screening assessment, it is concluded that NGCs meet the criteria under paragraph 64(*c*) of CEPA as they are entering or may enter the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.

It is concluded that NGCs meet one or more of the criteria set out in s. 64 of CEPA.

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APPENDICES

Appendix A: Petroleum substance grouping

Table A-1: Description of the nine groups of petroleum substances[a]

Group[a]	Description	Example
Crude oils	Complex combinations of aliphatic and aromatic hydrocarbons and small amounts of inorganic compounds, naturally occurring under the earth's surface or under the sea floor	Crude oil
Petroleum and refinery gases	Complex combinations of light hydrocarbons, primarily from C_1–C_5	Propane
Low boiling point naphthas	Complex combinations of hydrocarbons, primarily from C_4–C_{12}	Gasoline
Gas oils	Complex combinations of hydrocarbons, primarily from C_9–C_{25}	Diesel fuel
Heavy fuel oils	Complex combinations of heavy hydrocarbons, primarily from C_{11}–C_{50}	Fuel oil No. 6
Base oils	Complex combinations of hydrocarbons, primarily from C_{15}–C_{50}	Lubricating oils
Aromatic extracts	Complex combinations of primarily aromatic hydrocarbons from C_{15}–C_{50}	Feedstock for benzene production
Waxes, slack waxes and petrolatum	Complex combinations of primarily aliphatic hydrocarbons from C_{12}–C_{85}	Petrolatum
Bitumen or vacuum residues	Complex combinations of heavy hydrocarbons having carbon numbers greater than C_{25}	Asphalt

[a] These groups were based on classifications developed by CONCAWE and a contractor's report presented to the Canadian Petroleum Products Institute (CPPI) (Simpson 2005).

Appendix B: Other terms relevant to NGCs

There is a wide range of terms used to describe NGCs and other substances associated with natural gas production. Terms such as “pentanes plus”, “natural gas liquids” and “natural gasoline”, are sometimes defined similarly to or used interchangeably with NGCs.

Table B-1: Other terms relevant to NGCs.

Reference	Natural gas liquid	Pentanes plus	Condensates
Statistics Canada (2011a)	Defined as gas plant NGLs, including propane, butane and ethane.	“A mixture of mainly pentanes and heavier hydrocarbons which ordinarily may contain some butanes and which is obtained from the processing of raw gas, condensate or crude oil.”	“A mixture of mainly pentanes and heavier hydrocarbons that may be contaminated with sulphur compounds, that is recoverable at a well from an underground reservoir and that is gaseous in its virgin reservoir state but is liquid at the conditions under which its volume is measured or estimated.”
NEB (2005)	“The hydrocarbon components recovered from processing natural gas. This generally includes ethane,propane, butane, pentanes and heavier hydrocarbons.”	“A mixture mainly of pentanes and heavier hydrocarbons obtained from the processing of raw gas, condensate or crude oil”.	“The light liquid hydrocarbons separated from crude oil after production, and the mixture of pentanes and heavier hydrocarbons separated from natural gas production.”
Canadian Centre for Energy (2011)	“Liquids obtained during production of natural gas, comprising ethane, propane, butane and condensate.”		“Liquids recovered during the production of natural gas, consisting primarily of pentane and heavier hydrocarbons.”

Appendix C: Physical and chemical data tables for NGCs

Table C-1: Substance identity of three NGCs (NCI 2009).

CAS RN and DSL Name	Chemical group	Major components	Carbon range	Approximate ratio of aromatics to non-aromatics
64741-47-5 Natural gas condensates (petroleum)	Petroleum – NGCs	Aliphatic and aromatic hydrocarbons	C_2–C_{20}	11: 88 (See Table 2-1)
64741-48-6 Natural gas (petroleum), raw liquid mix	Petroleum – NGCs	Aliphatic and aromatic hydrocarbons	C_2–C_8	11: 88 (See Table 2-1)
68919-39-1 Natural gas condensates	Petroleum – NGCs	Aliphatic and aromatic hydrocarbons	C_2–C_8	11: 88 (See Table 2-1)

Table C-2: Physical and chemical properties for representative structures contained in NGCs (experimental (expt.) and modelled values, EPISuite 2008)[1]

***n*-Alkanes**

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_2 Ethane (74-84-0)	-88.6 (expt.)	-182.8 (expt.)	4.20×10^{6} (expt.)	5.07×10^{4} (expt.)
C_4 Butane (106-97-8)	-0.5 (expt.)	-138.2 (expt.)	2.4×10^{5} (expt.)	9.6×10^{4} (expt.)
C_6 Hexane (110-54-3)	68.7	−95.3 (expt.)	2.0×10^{4} (expt.)	1.82×10^{5} (expt.)
C_9 Nonane (111-84-2)	150.8 (expt.)	-53.5 (expt.)	593.0 (expt.)	3.5×10^{5} (expt.)
C_{12} Dodecane (112-40-3)	216 (expt.)	-9.6 (expt.)	32 (expt.)	8×10^{5} (expt.)
C_{15} Pentadecane (629-62-9)	270.6 (expt.)	9.9 (expt.)	0.5 (expt.)	1.3×10^{6} (expt.)
C_{20} Eicosane (112-95-8)	343.0 (expt.)	36.8 (expt.)	6.2×10^{-4} (expt.)	5.3×10^{6}

Isoalkanes

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_4 Isobutane (75-28-5)	-11.7	-138.3 (expt.)	3.5×10^{5} (expt.)	1.2×10^{5} (expt.)
C_6 2-methylpentane (107-83-5)	60.2 (expt.)	-153.7 (expt.)	2.8×10^{4} (expt.)	1.7×10^{5} (expt.)
C_9 2,3-dimethylheptane (3074-71-3)	133.0(expt.)	-113.0 (expt.)	1.4×10^{3}	6.4×10^{4}

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{12} 2,3-dimethyldecane (17312-44-6)	181.4	-43.0	165.3	2.5×10^5
C_{15} 2-methyltetradecane (1560-95-8)	250.2	1.5	5.8	3.7×10^5
C_{20} 3-methyl nonadecane (1560-86-7)	326	39.5	0.092	9.1×10^6

Monocycloalkanes

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_6 Cyclohexane (110-82-7)	144.0 (expt.)	6.6 (expt.)	1.3×10^4 (expt.)	1.5×10^4 (expt.)
C_9 1,2,3-trimethylcyclohexane (1678-97-3)	224.0 (expt.)	-66.9 (expt.)	650.0	1.7×10^4
C_{12} *n*-hexylcyclohexane (4292-75-5)	224.0 (expt.)	−43 (expt.)	15.2 (expt.)	2.9×10^4
C_{15} nonyl cyclohexane (2883-02-5)	282 (expt.)	−10 (expt.)	1.2 (expt.)	5.8×10^4
C_{20} Tetradecylcyclohexane (1795-18-2)	360 (expt.)	24 (expt.)	0.022	$3.5 \text{ x } 10^5$

Dicycloalkanes

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_9 *cis*-bicyclo nonane (4551-51-3)	167.0 (expt.)	-53.0 (expt.)	320.0	2×10^3
C_{12} Dicyclohexyl (alt name: 1,1'-bicyclohexyl) (92-51-3)	256.0 (expt.)	69.0 (expt.)	12.0 (expt.)	31.0 (expt.)
C_{15} pentamethyl decalin (91-17-8)	248	8.6	6.6	2.8 ×10^4
C_{20} 2,4-dimethyl octyl-2-decalin	329	78	0.04	8.2 ×10^4

Polycycloalkanes

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{14} hydro-phenanthrene	255	20.8	4.53	8.6 ×10^3
C_{18} hydro-chrysene	316	66.4	0.0041	5.7 ×10^3

Monoaromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_6 Benzene (71-43-2)	80.0 (expt.)	5.5 (expt.)	12 600 (expt.)	562 (expt.)
C_7 Toluene (108-88-3)	110.6 (expt.)	-94.9 (expt.)	3790 (expt.)	673 (expt.)
C_8 Ethylbenzene (100-41-4)	136.1 (expt.)	-94.9 (expt.)	1280 (expt.)	7.98×10^2 (expt.)

C_8 *m*-xylene (108-38-3)	139.1 (expt.)	-47.8 (expt.)	1110.0 (expt.)	7.2×10^{-3} (expt.)
C_8 *o*-xylene (95-47-6)	144.5 (expt.)	-25.2 (expt.)	881 (expt.)	525 (expt.)
C_8 *p*-xylene (106-42-3)	138.3 (expt.)	13.2 (expt.)	1180 (expt.)	699 (expt.)
C_9 Ethylmethyl-benzene (25550-14-5)	229.6	-80.8 (expt.)	348.0	560.0
C_{12} 1,2,4-triethylbenzene (877-44-1)	169.3 (expt.)	-43.8 (expt.)	280.0 (expt.)	6.0×10^{2} (expt.)
C_{15} *n*-nonyl benzene (1081-77-2)	281 (expt.)	−24 (expt.)	0.76 (expt.)	4200
C_{20} Tetradecyl-benzene	359 (expt.)	16 (expt.)	$3.17x10^{-3}$ (expt.)	$7.2\ x10^{3}$

Cycloalkane monoaromatics

Chemical Class, Name and CAS RN	**Boiling Point (°C)**	**Melting Point (°C)**	**Vapour pressure (Pa)**	**Henry's Law Constant (Pa·m³/mol)**
C_9 Indane (56573-11-6)	177.9 (expt.)	-51.4 (expt.)	142.0 (expt.)	20.0 (expt.)
C_{10} Tetralin (119-64-2)	207.6 (expt.)	-35.7 (expt.)	49.0 (expt.)	1.4×10^{2} (expt.)
C_{12} ethyl tetralin (32367-54-7)	235 (expt.)	-42.8 (expt.)	8.0	$2.4\ \times10^{2}$
C_{15} methyl-octahydro-phenanthrene	285	50.9	0.34	939
C_{20}	351	115.7	0.003	1710

ethyl-dodecahydro-chyrsene				

Diaromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{10} Naphthalene (91-20-3)	217.9 (expt.)	80.2 (expt.)	11.3 (expt.)	45.0 (expt.)
C_{12} 1,1'-biphenyl (92-52-4)	256 (expt.)	69 (expt.)	12 (expt.)	31 (expt.)
C_{15} 4-isopropyl biphenyl	309.0	43.7	0.1	23.8
C_{20} iso-decyl naphthalene (91-20-3)	366.4	99.5	1.35×10^{-3}	7.4×10^{-3}

Cycloalkane diaromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{12} acenaphthene (83-32-9)	279 (expt.)	93.4 (expt.)	0.3 (expt.)	18.6
C_{15} ethylfluorene (65319-49-5)	321	89.5	0.02	8.6
C_{20} *iso*-Heptylfluorene	374	119	5.6×10^{-4}	2.2×10^{2}

Three-ring aromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{14} anthracene (120-12-7)	339.9 (expt.)	215.0 (expt.)	8.71×10^{-4} (expt.)	5.63 (expt.)
C_{15} 2-methyl-phenanthrene (2531-84-2)	350 (expt.)	65 (expt.)	0.01	1.2

C_{20} 2-isohexyl phenanthrene	391	129	0.00017	23.7

Four-ring aromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{16} Fluoranthene (206-44-0)	348.0 (expt.)	107.8 (expt.)	1.2×10^{-3} (expt.)	0.90
C_{18} chrysene (218-01-9)	448 (expt.)	258.2 (expt.)	8.31×10^{-7} (expt.)	0.53 (expt.)
C_{20} Benzo(*k*)-fluoranthene (207-08-9)	480.0 (expt.)	217.0 (expt.)	1.3×10^{-7} (expt.)	0.0592 (expt.)

Five-ring aromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{20} Benzo[*a*] Pyrene (50-32-8)	495 (expt.)	177.0 (expt.)	7.32×10^{-7} (expt.)	4.63×10^{-2} (expt.)

Table C-2 continued: Physical and chemical properties for representative structures of NGCs[1]

***n*-Alkanes**

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_2 Ethane (74-84-0)	1.81 (expt.)	1.12	60.2 (expt.)
C_4 Butane (106-97-8)	2.89 (expt.)	3.0	61.0
C_6 Hexane (110-54-3)	3.9 (expt.)	2.2	Fresh water: 9.5–13 (20°C); Salt water: 75.5 (20°C)

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_9 *n*-nonane (111-84-2)	5.7 (expt.)	4.9	0.2 (expt.)
C_{12} *n*-dodecane (112-40-3)	6.1	5.3	0.004 (expt.)
C_{15} pentadecane (629-62-9)	7.7	6.7	7.6×10^{-5} (expt.)
C_{20} eicosane (112-95-8)	10.2	5.8	0.002 (expt.)

Isoalkanes

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_4 Isobutane (75-28-5)	2.8[a]	1.6	49.0
C_6 2-methylpentane (107-83-5)	3.2	2.1	14 (expt.)
C_9 2,3-dimethylheptane (3074-71-3)	4.6	2.9	0.7
C_{12} 2,3-dimethyldecane (17312-44-6)	6.1	3.6	0.1
C_{15} 2-methyltetra-decane (1560-95-8)	7.6	6.6	0.003
C_{20} 2-methyl nonadecane (1560-86-7)	10	8.8	1.1×10^{-5}

Monocycloalkanes

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_6 Cyclohexane (110-82-7)	3.4	2.2	55.0 (expt.)
C_9 *n*-propylcyclohexane (1678-92-8)	4.6	4.0	3.7
C_9 1,2,3-trimethylcyclohexane (1678-97-3)	4.4	2.9	4.6
C_{12} *n*-hexylcyclohexane (4292-75-5)	6.05	3.8	0.1
C_{15} nonyl cyclohexane (2883-02-5)	7.5	4.6	0.004 (expt.)
C_{20} Tetradecylcyclohexane (1795-18-2)	10.0	5.9	1×10^{-5}

Dicycloalkanes

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_9 *cis*-bicyclo nonane	3.7	3.2	19.3
C_{12} Dicyclohexyl (alt name: 1,1'-bicyclohexyl) (92-51-3)	4.0 (expt.)	3.5	6.9 (expt.)
C_{15} Pentamethyldecalin (91-17-8)	6.3	5.5	0.05
C_{20} 2,4-dimethyl octyl-	8.9	7.7	1.1×10^{-4}

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
2-decalin			

Polycycloalkanes

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_{14} Hydro-phenanthrene	5.2	4.5	0.5
C_{18} Hydro-chrysene	6.2	5.4	0.034

Monoaromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_6 Benzene (71-43-2)	2.1 (expt.)	2.2	1 790.0 (expt.)
C_7 Toluene (108-88-3)	2.73 (expt.)	2.07 (expt.)	526 (expt.)
C_8 Ethylbenzene (100-41-4)	3.15 (expt.)	2.23 (expt.)	169 (expt.)
C_8 *m*-xylene (108-38-3)	3.20 (expt.)	2.25 (expt.)	161 (expt.)
C_8 *o*-xylene (95-47-6)	3.12 (expt.)	2.25 (expt.)	178 (expt.)
C_8 *p*-xylene (106-42-3)	3.15 (expt.)	2.41 (expt.)	162 (expt.)
C_9 Ethylmethyl-	3.5(expt.)	2.9	74.6 (expt.)

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
benzene			
C_{12} 1,2,3-triethylbenzene (42205-08-3)	5.1	3.7	1.8
C_{12} 1,2,4-triethylbenzene (877-44-1)	3.6 (expt.)	3.2	57.0 (expt.)
C_{15} *n*-nonyl benzene (1081-77-2)	7.1 (expt.)	4.4	0.04
C_{20} Tetradecyl-benzene	8.9	7.7	4.1×10^{-4}

Cycloalkane monoaromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_9 Indane (56573-11-6)	3.2 (expt.)	2.8	109.0 (expt.)
C_{10} Tetralin (119-64-2)	3.5 (expt.)	3.0	47.0 (expt.)
C_{12} Ethyl tetralin (32367-54-7)	4.9	4.22	5.29
C_{15} Methyl-octahydro-phenanthrene	5.4	4.4	0.37
C_{20} Ethyl-dodecahydro-chyrsene	6.9	5.7	5.6×10^{-4}

Diaromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_{10} Naphthalene (91-20-3)	3.3 (expt.)	3.0 (expt.)	31.0 (expt.)
C_{12} 1,1'-biphenyl (92-52-4)	4 (expt.)	3.5	6.9 (expt.)
C_{15} 4-isopropyl biphenyl	5.5 (expt.)	4.6	0.9
C_{20} iso-Decyl naphthalene (91-20-3)	8.06	7.00	2.4×10^{-3}

Table C2-21: Cycloalkane diaromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_{12} Acenaphthene (83-32-9)	3.9 (expt.)	3.7	2.5
C_{15} Ethylfluorene (65319-49-5)	5.1	4.5	0.2
C_{20} *iso*-Heptylfluorene	7.4	6.5	1.9×10^{-3}

Three-ring aromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_{14} Anthracene (120-12-7)	4.45 (expt.)	4.31 (expt.)	0.0434 (expt.)
C_{15} 2-methyl-phenanthrene (2531-84-2)	4.9 (expt.)	4.5	0.3 (expt.)
C_{20} 2-isohexyl phenanthrene	7.4	5.9	0.001

Four-ring Aromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_{16} Fluoranthene (206-44-0)	5. (expt.)	4.5	0.26 (expt.)
C_{18} Chrysene (218-01-9)	5.81 (expt.)	5.26	0.002 (expt.)
C_{20} Benzo(*k*)-fluoranthene (207-08-9)	6.1 (expt.)	5.3	0.0008 (expt.)

Five-ring Aromatics

Chemical Class, Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C unless otherwise stated)
C_{20} Benzo[*a*] pyrene (50-32-8)	6.13 (expt.)	6.7	0.0016 (expt.)

[1] All values are modelled unless denoted with an (expt.) for experimental data. Models used were: MPBPWIN (Version 1.43) for melting point, boiling point and vapour pressure, HenryWin (Version 3.20) for Henry's Law constants, KOWWIN (Version 1.67a) for log K_{ow}, KOCWIN (Version2.0) for log K_{oc}, WSKOW (Version 1.41) for water solubility.

Appendix D: Persistence, Bioaccumulation and Toxicity Information

Table D-1: An analysis of persistence data for petroleum hydrocarbons representative of NGCs based on Environment Canada (2014)

Number of carbons	C_2	C_3	C_4	C_5	C_6	C_8	C_9	C_{10}	C_{11}
***n*-alkane**	A	A	A	A	A	n/a	-	-	n/a
***i*-alkane**	n/a	n/a	A	A	A	-	-	-	n/a
Mono-cyclo-alkane	n/a	n/a	n/a	n/a	-	-	-	-	n/a
Dicyclo-alkane	n/a	n/a	n/a	n/a	n/a	n/a	Sd	n/a	n/a
Poly-cyclo-alkane	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mono-aromatic	n/a	n/a	n/a	n/a	A	A	Sd	n/a	Sd
Cycloalkane mono-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	S,W, Sd	S,W ,Sd	n/a
di-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	S,W ,Sd	n/a
cyclo-alkane di-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table D-1 continued: An analysis of persistence data for petroleum hydrocarbons representative of NGCs based on Environment Canada (2014).

# of carbons	C_{12}	C_{13}	C_{14}	C_{15}	C_{18}	C_{20}	C_{22}	C_{25}	C_{30}
n-alkane	-	n/a	n/a	-	-	-	n/a	n/a	-
i-alkane	-	-	n/a	-	n/a	-	n/a	n/a	W,S, Sd
Mono-cyclo-alkane	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Sd
Dicyclo-alkane	Sd	n/a	n/a	W,S, Sd	W,S, Sd	W,S, Sd	n/a	W,S, Sd	W,S, Sd
Polycyclo-alkane	n/a	n/a	Sd	n/a	W,S, Sd	n/a	W,S, Sd	n/a	n/a

# of carbons	**C_{12}**	**C_{13}**	**C_{14}**	**C_{15}**	**C_{18}**	**C_{20}**	**C_{22}**	**C_{25}**	**C_{30}**
Mono-aromatic	W,S, Sd	n/a	n/a	Sd	n/a	-	n/a	n/a	W,S, Sd
Cyclo-alkane mono-aromatic	W,S, Sd	n/a	n/a	W,S, Sd	n/a	W,S, Sd	n/a	n/a	n/a
Di-aromatic	W,S, Sd	n/a	n/a	W,S, Sd	n/a	W,S, Sd	n/a	n/a	W,S, Sd
Cyclo-alkane di-aromatic	W,S, Sd	A	n/a	-	n/a	-	n/a	n/a	n/a
3-ring poly-aromatic	A	n/a	A,W,S, Sd	-	n/a	-	n/a	n/a	W,S, Sd
4-ring poly-aromatic	n/a	n/a	n/a	n/a	A,W,S, Sd	W,S, Sd	n/a	n/a	n/a
5-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	A,W,S, Sd	n/a	n/a	W,S, Sd
6-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	A,W,S, Sd	n/a	n/a

A – Predicted half-life in air of two days or greater
S – Predicted half-life in soil of six months or greater
W – Predicted half-life in water of six months or greater
Sd – Predicted half-life in sediment of one year or greater
- Indicates that these structures are not considered to persist for long periods of time in air, soil, water, or sediment.
n/a – not-applicable. Indicates that no such carbon number exists within the group or it was not modelled

Table Series D-2: Primary aerobic biodegradation half-lives of hydrocarbons from a formulated gasoline in water (Prince et al. 2007)

Aromatics

Class and compound	**Median half-life (days)**	**Mean half-life (days)**
benzene	3.2	4.6
1-methylethylbenzene	3.2	5.2
2-ethyl-1,3-dimethylbenzene	3.2	4.9

Diaromatics

Class and compound	Median half-life (days)	Mean half-life (days)
naphthalene	3.2	4.4

***n*-Alkanes**

Class and compound	Median half-life (days)	Mean half-life (days)
butane	15	32
hexane	6.5	10.
nonane	3.2	4.4
dodecane	2.8	3.8

Iso-alkanes

Class and compound	Median half-life (days)	Mean half-life (days)
2-methylpropane (iso-butane)	17	42
2-methylpentane	10	17
3-methylpentane	10	21
2-methylheptane	4.8	6.0
4-methylnonane	3.2	4.8

Cycloalkanes

Class and compound	Median half-life (days)	Mean half-life (days)
1,1,3-trimethylcyclohexane	8.5	14

Table D-3: Ultimate biodegradation of hydrocarbons from a formulated gasoline in water (Solano-Serena et al. 1999)

Component	Test Duration (days)	% Biodegraded
Whole Gasoline	25	94
Aromatics	25	99 ± 1
Branched Alkanes	25	74 ± 5
Linear Alkanes	25	92 ± 1

Table D-4: An analysis of experimental and modelled bioaccumulation data for petroleum hydrocarbons representative of NGCs based on Environment Canada (2014)

# of carbons	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
***n*-alkane**	-	-	-	-	-	n/a	n/a	*B*	n/a	-
***i*-alkane**	n/a	n/a	-	-	-	n/a	-	-	-	n/a
mono-cycloalkane	n/a	n/a	n/a	n/a	-	-	-	-	-	n/a
dicycloalkane	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	-	n/a
poly-cycloalkane	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
monoaromatic	n/a	n/a	n/a	n/a	-	-	-	-	-	n/a
Cycloalkane monoaromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	-	n/a
Diaromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	b	b
Cycloalkane diaromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3-ring polyaromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
4-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table D-4 continued: An analysis of experimental and modelled bioaccumulation data for petroleum hydrocarbons representative of NGCs based on Environment Canada (2014)

# of carbons	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{18}	C_{20}	C_{22}	C_{25}	C_{30}
n-alkane	-	-	-	-	-	-	-	-	n/a	n/a
i-alkane	-	B	n/a	B	n/a	n/a	n/a	n/a	n/a	n/a
mono-cycloalkane	B	n/a	n/a	B	n/a	n/a	n/a	n/a	n/a	n/a
Dicyclo-alkane	B	-	n/a	B	n/a	n/a	n/a	n/a	n/a	n/a
poly-cycloalkane	n/a	n/a	B	n/a	n/a	-	n/a	B	n/a	n/a
Mono-aromatic	-	n/a	n/a	B	n/a	n/a	n/a	n/a	n/a	n/a
Cycloalkane mono-aromatic	-	n/a	n/a	B	n/a	n/a	B	n/a	n/a	n/a
Diaromatic	B,b	B,b	-	-	n/a	n/a	n/a	n/a	n/a	n/a
Cycloalkane	b	b	-	b	-	n/a	B	n/a	n/a	n/a

diaromatic										
3-ring polyaromatic	-	n/a	B	*B*,b	*B*,b	n/a	B	n/a	n/a	n/a
4-ring poly-aromatic	n/a	n/a	n/a	n/a	B	B	B	n/a	n/a	n/a
5-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	B	B	n/a	n/a
6-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	B	n/a	n/a

B – Highly bioaccumulative with a BCF/BAF greater than 5000 based on modelled and/or empirical data
B – BCFs/BAFs are close to, but less than 5000 L/kg ww.
b – Empirical BMF or TMF greater than one
n/a – not-applicable. Indicates that no such carbon number exists within the group or it was not modelled
- Indicates that these structures are not considered highly bioaccumulative

Appendix E: Ecological Exposure Scenario Information

Table E-1. Total volume of soil expected to be saturated after spills of NGCs to soil, based on Alberta data for 2002-2011

Volume of NGCs spilled (L)	**Spill type**	**Soil type**	**Retention capacity[a,b] ($mg_{gasoline}/kg_{soil}$)**	**Bulk density of soil[b] (g/cm^3)**	**Volume of soil saturated by NGCs (m^3)**
3754	average	Ottawa sand	68 000	1.7	24
3754	average	Delhi loamy sand	170 000	1.5	9.6
3754	average	Elora silt loam	238 000	1.5	6.8
500	median	Ottawa sand	68 000	1.7	3.2
500	median	Delhi loamy sand	170 000	1.5	1.3
500	median	Elora silt loam	238 000	1.5	0.9
9000	90th percentile	Ottawa sand	68 000	1.7	58
9000	90th percentile	Delhi loamy sand	170 000	1.5	23
9000	90th percentile	Elora silt loam	238 000	1.5	16

[a] After 24 hours of free drainage.

bFrom Arthurs et al. (1995). Based on dry soil bulk density.

Appendix F: Modelling results for human exposure to NGCs

Table F-1: Estimated regular evaporative emissions of NGCs (kg/year/site) to ambient air during transportation process by rails, trucks and ships[a]

Transportation Scenario	Average [b]	Upper-bounding [c]
Loading	Less than 20 000	Less than 90 000
Transport	Less than 100	Less than 200 000
Unloading	Less than 10 000	Less than 600 000

[a] Assuming that a vapour control unit (recovery or combustion) is not in place in all modes of transportation

[b] Based on the average handling quantities among 3 NGCs (CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1)

[c] Based on the maximum handling quantities among 3 NGCs (CAS RNs 64741-47-5, 64741-48-6 and 68919-39-1)

Table F-2: Variable inputs to SCREEN3

Variables	Input
Source type	Area
Effective emission area[a]	10 x 2 m (truck idling), 20 x 20 m^2 (truck or storage tanks), 40 x 10 m^2 (rail), 50 x 10 m^2 (ship)
Emission rate (g/s.m^2)	Transportation: Less than 5 x 10^{-3} (truck idling); Less than 0.1(truck loading/unloading) [b]; Less than 1 (train loading/unloading)[b]; Less than 1 (ship loading/unloading)[b] Storage: 0.0058 (NGCs); 2.1 x 10^{-5} (benzene)[c]
Source release height[a]	Transportation: 3 m Storage: 3.5 m
Receptor height[d]	1.74 m (humans)
Variable wind adjustment factor[e]	0.4 (from maximum 1 h to 24 h) 0.2 (from maximum 1 h to annual)
Urban–rural option	Transportation: urban Storage: urban or rural
Meteorology[f]	1 (Full meteorology)
Minimum and maximum distance to use	50–5000 m

[a] Professional judgement based on photo presented in Hendler et al. (2009).

[b] Emission rate is calculated from emission loss quantity (kg/year) (Table G.1), the estimated number of events per year, the estimated time per event, and effective emission areas. Only the upper bounds are presented.

[c] Based on the emission rates of 8.3 kg/hr of NGC by Hendler et al. (2009) and 0.03 kg/hr of benzene by Chambers (2004), divided by the effective emission area

[d] Curry et al. (1993)

[e] U.S. EPA (1992).

[f] Default value in SCREEN3 (1996)

Table F-3: Estimates for benzene contribution (µg/m^3) to ambient air in the vicinity of NGC loading/unloading sites (rail)

Distance (m)	Max. 1-hour conc.	Max. 24-hr conc.	Annual concentration (average)	Annual concentration (Upper-bounding)
50	8350	3340	0.30	174
100	3032	1213	0.11	63
200	890	356	0.032	19
300	432	173	0.016	9.0
400	261	104	0.0095	5.4
500	178	71	0.0065	3.7
600	131	52	0.0047	2.7
700	102	41	0.0037	2.1
800	82	33	0.0030	1.7
900	68	27	0.0025	1.4
1000	58	23	0.0021	1.2
1500	31	12	0.0011	0.63
2000	21	8.4	0.00077	0.44
2500	15	6	0.00055	0.31
3000	12	4.8	0.00044	0.25
3500	9.8	3.9	0.00036	0.20
4000	8.2	3.3	0.00030	0.17
4500	7.1	2.8	0.00026	0.15
5000	6.2	2.5	0.00022	0.13

Table F-4: Estimates for benzene contribution to ambient air in the vicinity of NGC loading/unloading sites (truck)

Distance (m)	Max. 1-hour conc.	Max. 24-hr conc.	Annual concentration (average)	Annual concentration (Upper-bounding)
50	356	142	3.5	16
100	154	62	1.5	6.8
200	49	20	0.48	2.2
300	24	9.6	0.24	1.1
400	15	6.0	0.15	0.66
500	10	4.0	0.098	0.44
600	7.5	3.0	0.074	0.33
700	5.8	2.3	0.056	0.25
800	4.7	1.9	0.047	0.21
900	3.9	1.6	0.039	0.18
1000	3.3	1.3	0.032	0.14
1500	1.8	0.72	0.018	0.080
2000	1.2	0.48	0.012	0.053
2500	0.87	0.35	0.0086	0.039
3000	0.68	0.27	0.0066	0.030
3500	0.56	0.22	0.0054	0.024
4000	0.47	0.19	0.0047	0.021
4500	0.41	0.16	0.0039	0.018
5000	0.36	0.14	0.0034	0.015

Table F-5: SCREEN3 estimates for benzene contribution (µg/m^3) to ambient air in the vicinity of NGC storage tanks (emission rate = 0.03 kg/hr)[a]

Distance (m)	Max. 1-hour conc.	Max. 24-hr conc.	Max. conc. with 1-year average wind conditions
50	55.24	22.10	11.05
100	25.53	10.21	5.11
200	8.30	3.32	1.66
300	4.12	1.65	0.82
400	2.51	1.00	0.50
500	1.72	0.69	0.34
600	1.27	0.51	0.25
700	0.99	0.40	0.20
800	0.80	0.32	0.16
900	0.66	0.26	0.13
1000	0.56	0.22	0.11
1500	2.91	1.16	0.58
2000	1.89	0.76	0.38
2500	1.37	0.55	0.27
3000	1.06	0.42	0.21
3500	0.86	0.34	0.17
4000	0.71	0.28	0.14
4500	0.61	0.24	0.12
5000	0.53	0.21	0.11

[a] Estimates from 50-1000 m are based on urban setting and the estimates from 1500 – 5000 m are based on rural setting in SCREEN3.

Table F-6: Aerscreen estimates for benzene contribution (µg/m^3) to ambient air in the vicinity of NGC tanks and rail and truck loading.

Distance (m)	Annual concentration (Upper-bounding) Storage Tanks	Annual concentration (Upper-bounding) Truck Loading/Unloading	Annual concentration (Upper-bounding) Train Loading/Unloading
50	7.2	10.33	90.06
100	2.8	3.97	32.17
200	1.1	1.82	12.02
300	0.6	0.86	6.82
400	0.4	0.58	4.58
500	0.3	0.43	3.37
600	0.2	0.33	2.52
700	0.2	0.27	2.12
800	0.2	0.23	1.76
900	0.1	0.19	1.50
1000	0.1	0.17	1.30
1500	0.1	0.10	0.79
2000	0.1	0.08	0.60
2500	0.0	0.06	0.50
3000	0.0	0.06	0.44
3500	0.0	0.05	0.39
4000	0.0	0.05	0.36
4500	0.0	0.04	0.33
5000	0.0	0.04	0.31

Assumptions made in the Aerscreen modelling:
Average Min/Max Temperature (ºK)= 270.6 / 283.5 (Calgary); Minimum Distance to Ambient Air (m) =1; Select Chemistry = No chemistry; Source Elevation (m) = 0; Minimum Wind Speed (m/s) = 0.5; Anemometer Height (m) = 10; Meteorology (Tanks) =AERMET Seasonal Tables Dominant Surface Profile /Rural-Grassland/ Average Moisture; Meteorology (Rail and Trucks) = AERMET Seasonal Tables Dominant Surface Profile /Urban-Urban (population 100 000) / Average Moisture.

Appendix G: Summary of Health Effects Information for NGCs (toxicological data of pooled LBPNs)

Table G-1: Critical information on health effects of pooled LBPNs for NGCs

Acute Toxicity

Exposure	CAS RN (or specific substance)	Effect levels[a]/results
Oral	64741-55-5, 64741-54-4, 64741-66-8, 64741-87-3, 8030-30-6	**LD_{50}:** more than 5000 mg/kg (rat) (API 1982, API 1986a, b; RTECS 2008e, f, g).
Oral	8052-41-3, 64742-48-9	Lethal dose more than 5000 mg/kg in rats (RTECS 2008a; Rausina 1984)
Inhalation	64741-55-5, 64741-54-4, 64741-66-8, 64741-87-3, 8032-32-4, 8052-41-3	**LC_{50}:** more than 5 mg/L (more than 5000 mg/m^3)[b] (rat) (CONCAWE 1992; API 1987c, d, e, f; API 2008a; RTECS 2008a, b, d, f, g)
Inhalation	Untreated naphtha, coker naphtha	Lethal dose = 10.6 mg/l (Stubblefield et al. 1989) 10.6 mg/l as an aerosol, 6-hr exposure, Sprague-Dawley rats (5/sex), Swiss-Webster mice (5/sex) Mortality: 10 out of 10 (mice), 2 out of 10 rats. Discoloration of liver, kidney and lungs in dead animals, increased liver/body and kidney/body weight ratios in mice, lung/body weight ratio in male rats and liver/body weight ratio in female rats.
Dermal	64741-55-5 64741-66-8, 64741-87-3, 8030-30-6	**LD_{50}:** more than 2000 mg/kg-bw (rabbit) (API 1986a, c; CONCAWE 1992; API 2008b; RTECS 2008c, g).
Dermal	64741-54-4, 8052-41-3	**Lethal dose** more than 2000 mg/kg-bw in rabbits (RTECS 2008a, f)
Dermal	Untreated naphtha from a fluid coker	**LD_{50}: more than** 3160 mg/kg-bw (rabbit) (Stubblefield et al. 1989)
Ocular	Untreated naphtha from a fluid coker	**LOEL:** more than 0.1 mL (Stubblefield et al. 1989) A single 0.1-mL dose was placed into the lower conjunctival sacs of the left eyes of New Zealand white rabbits (9 in total, 12-week old). The unexposed eye of each rabbit served as a concurrent control.

Exposure	CAS RN (or specific substance)	Effect levels[a]/results
		Observations were on 1, 4 and 24-hr after the treatment and on days 2,3,4,7 and 10. Ocular irritation was assessed by Draize method. Conjunctival redness, no iridal or corneal involvement. Complete recovery on day 10.

Short-term and Subchronic Toxicity

Exposure	CAS RN (or specific substance)	Effect levels[a]/results
Inhalation	64741-55-5	**LOAEC:** 23400 mg/ m^3 for increased relative liver weight, nasal mucosa hyperplasia and hyperplasia/hypertrophy of goblet cells, decreased haemoglobin and hematocrit (Lapin et al. 2001). Male and female Sprague-Dawley rats were exposed to 0, 750, 2500 or 7500 ppm (0, 2340, 7700 or 23400 mg/ m^3)[c,f] test substance for 6 h/day, 5 d/week for 15 weeks. **Subchronic NOAEC:** 7700 mg/ m^3. CASRN 64741-55-5 consists of C_4-C_9 with boiling range of -20 to 190ºC, 8-30 % w/w aromatics with benzene Less than 2 % w/w
Inhalation	64741-41-9	**LOAEC:** 13650 mg/m^3 for systemic toxicity (API 2008b). Sprague-Dawley rats (12/sex/dose) were continuously exposed to 0, 100, 500 or 3000 ppm (0, 455, 2275 or 13650 mg/m^3) test substance for 30 days (males) or 31 days (females). Satellite groups of non-pregnant female rats (12/dose) were exposed to 0, 100, 500 or 3000 ppm from 2 weeks before mating for 7 consecutive weeks (until gestational day 19) or for up to 8 consecutive weeks (if no evidence of mating). 13650 mg/m^3 – increased incidence of stained and wet fur (all groups); decreased body weight, weight gain and food efficiency (short-term females); increased liver weight and hepatocellular hypertrophy (males, short-term females); increased kidney weight (short-term females) (not associated with functional or microscopic change); minimal hypertrophy of thyroid follicular epithelium (males, short-term females). **NOAEC:** 2275 mg/ m^3. CASRN 64741-41-9 consists of ~30 % w/w naphthenics.
Inhalation	White spirit (CAS RN is not assigned in the original study)	**NOAEC:** 575 mg/m^3 indicated by the authors to be a virtual no effect level (Savolainen and Pfaffli 1982). Male Wistar rats (20 per dose) were exposed to 0, 575, 2875 or 5750 mg/m^3 test substance for 6 h/day,

		5 days/week, for 4, 8, 12 or 17 weeks. Reduced creatine kinase activity in cerebellar homogenate was observed at 4 but not at 17 weeks. Decreased serum creatine kinase was seen at 17 weeks. Dose-dependent decreased cerebellar succinate dehydrogenase activity was seen from weeks 8 to 17. *more than and/or equal to 2875 mg/m^3*: Changes in cerebellar glutathione levels and creatine kinase activity. Significantly reduced muscle cell plasma membrane uronic and sialic acids at weeks 12 and 17. Test substance “white spirit” has a boiling range of 152-182 ºC, and 12 % w/w aromatics (benzene Less than 4.6 % w/w)
Inhalation	Mineral spirits (CAS RN is not assigned in the original study)	**LOAEC:** 363 mg/m^3 for guinea pig-specific increased mortality (Rector et al. 1966). Long-Evans rats (*n* = 133), Sprague-Dawley rats (*n* = 18), guinea pigs (*n* = 262), albino New Zealand rabbits (*n* = 29), male squirrel monkeys (*n* = 27) and male Beagle dogs (*n* = 18), were exposed continuously for 90 days to various concentrations (114–1271 mg/m^3) of test substance. A parallel short-term repeated exposure study of 8 h/day, 5 d/week for 6 weeks was also conducted at 593, 596 and 1353 mg/m^3. Guinea pigs exhibited increased mortality (4/15) at 363 mg/m^3 or greater levels in the continuous study, but not at any dose (593-1353 mg/m^3) in the repeated short-term exposure study. No mortality was observed for rats, rabbits, dogs and monkeys in the continuous or repeated short-term studies. At 1271 mg/m^3, congested lungs, bronchitis and mixed inflammatory cell infiltration in the lungs was observed in all species in the continuous study. At 1353 mg/m^3, congestion and emphysema in 7/8 guinea pig lungs in the short-term repeated study. Test substance had a boiling range of 140 - 190ºC and 13-19 % w/w aromatics.
Inhalation	White spirit (CAS RN is not assigned in the study)	**Lowest LOEC:** 214 mg/m^3 for upper respiratory tract irritation (Riley et al. 1984). Female CD-1 rats (six per dose) were head-only exposed to 0 or 214 mg/m^3 test substance for 4 h/day for 4 days. At 214 mg/m^3 histopathology showed inflammatory cell infiltrate in the nasal cavity, trachea and larynx; loss of cilia, hyperplasia of basal cells and squamous metaplasia in the trachea and nasal cavity. Test substance was mainly C_9 - C_{12}, with a boiling range of 150-195 ºC, and 19 % w/w aromatics.
Inhalation	Gasoline[g]	**Lowest LOAEC:** 1327 mg/m^3 for changes in brain neurotransmitter levels and serum biochemistry (Chu et al. 2005). Male and female Sprague-Dawley rats (15 per sex per dose) were exposed to 0 or 500 ppm (0 or 1327 mg/m^3)[c,h] test substance for 6 h/day,

		5 days/week, for 4 weeks. In males, reversible increased kidney weight, hepatic ethoxyresorufin *O*-deethylase activity and elevated lymphocyte counts were seen. Serum inorganic phosphate was significantly elevated in the male recovery group. Increased heart weight and glucose levels (females). Decreased hemoglobin levels (females). Altered brain biogenic amine levels (dependent on brain region and sex). Increased urinary ascorbic and hippuric acid levels. Most effects returned to control levels after recovery. Test substance had 30 % w/w aromatics.
Inhalation	64742-48-9	**LOAEC:** 4679 mg/m^3 for oxidative stress in the brain, kidney and liver (Lam et al. 1994). Male Wistar rats (28 per dose) were exposed to 0, 400 or 800 ppm (0, 2339 or 4679 mg/m^3) test substance for 6 hours/day, 7 days/week, for 3 weeks. At all concentrations increased glutathione levels in the hemisphere (brain) was observed as well as mucous membrane irritation. Dose-dependent increased relative kidney weight and body weight were observed. At 4679 mg/m^3, there was an induction of oxidative stress in the brain, kidney and liver. Reactive oxygen species increased in the liver and hippocampus, but decreased in the kidney. Decreased feed consumption, increased water consumption and decreased hepatic glutamine synthetase activity were observed. Test substance (dearomatized white spirit) had a boiling range of 145-200 ºC and Less than 0.4 % w/w aromatics.
Dermal	64741-54-4	**LOAEL:** 200 mg/kg-bw for decreased growth rate (API 1986g). Doses of 200, 1000 or 2000 mg/kg-bw were applied to the shaven skin of male and female rabbits, 3 times/week for 28 days (12 applications total). *200 mg/kg-bw*: Slight to moderate and slight skin irritation in males and females, respectively; reduced growth rate (males). *1000 mg/kg-bw*: Moderate skin irritation; reduced growth rate (male and female). *2000 mg/kg-bw*: Moderate skin irritation; weight loss (females), before reduced growth weight (males).
Dermal	64742-48-9	**LOAEL:** 500 mg/kg-bw per day for hematological changes (males) and 1500 mg/kg-bw per day for biochemical changes (males and females) (Zellers 1985). Doses of 0, 500, 1000 or 1500 mg/kg-bw per day were administered to male and female F344 rats (10 of each sex per group), 6 h/day, 5 days/week, for 4 weeks. *500 mg/kg-bw per day*: Dose-dependent increase in white blood cells (due to increase in neutrophils and

		lymphocytes) in males. *1000 mg/kg-bw per day*: Significant decrease in feed consumption (females). *1500 mg/kg-bw per day*: Severe erythema, moderate eschar formation, dose-dependent increase in white blood cells (due to increase in neutrophils and lymphocytes) in females, significant decrease in feed consumption (males), mild anemia, decreased serum albumin (9–25%), total serum protein (10–13%) and blood urea nitrogen (9–25%) and increased platelet counts (10–20%).
Dermal	64741-55-5	**Lowest LOAEL:** 30 mg/kg-bw per day for skin irritation (Mobil 1988a). Doses of 0, 30, 125 or 3000 mg/kg-bw per day were applied to the clipped backs of male and female Sprague-Dawley rats (15 of each sex per dose), 5 days/week for 90 days. *All doses*: Dose-related increase in skin irritation, erythema and edema at treated sites and histopathological correlates of hyperplasia, inflammation and ulceration. No other effects reported.

Chronic Toxicity (non-cancer)

Exposure	CAS RN (or specific substance)	Effect levels[a]/results
Inhalation	8006-61-9 unleaded gasoline	**LOAEC:** 67 ppm (200 mg/m^3) for ocular discharge and irritation (MacFarland et al. 1984). Male and female B6C3F1 mice and Fischer 344 albino rats (approximately 6 weeks of age; 100 mice or rats of each sex per group) exposed to 0, 67, 292 or 2056 ppm (0, 200, 870 or 6170 mg/m^3) of the test substance (containing 2% benzene) via inhalation, 6 h/day, 5 days/week, for 103–113 weeks. *All doses*: Ocular discharge and irritation (rats). 67 ppm (200 mg/m^3) and 292 ppm (870 mg/m^3): decreased survival rates (male mice). However, highest dose group had a higher survival rate compared to the controls. *870 mg/m^3*: Increased relative kidney weight (male rats). 292 (870 mg/m^3) and 2056 ppm (6170 mg/m^3): dose-related increase in testes and ovary weights (rats).2056 *ppm (6170 mg/m^3)*: Increased absolute and relative kidney weights (male rats) and increased relative kidney weight (female rats). Decreased body weight (rats and male mice). Decreased absolute heart weight (rats).
Dermal	Petroleum naphtha (CAS RN is not assigned in the original study)	**Lowest LOAEL:** 25 mg (neat) (694 mg/kg-bw) (Clark et al. 1988) Male and female C3H/HeN mice (25 of each sex) exposed to 25 mg (694 mg/kg-bw)[i,j] of the test substance (neat), applied to the shaved skin of the dorsal thoracic region, 3 times/week for 105 weeks. Dermal irritation after 10–15 days. Inflammatory and

		degenerative skin changes after 6 months.

Reproductive and Developmental Toxicity

Exposure	CAS RN (or specific substance)	Effect levels[a]/results
Inhalation	64741-55-5	**Highest NOAEC:** 7518 ppm (27059 mg/m^3) for reproductive and developmental toxicity (Schreiner et al. 1999). 0, 752, 2512 or 7518 ppm (0, 2707, 9041 or 27059 mg/m^3) administered to male and female Sprague-Dawley rats (10/sex/dose), 6 hours/day, 7 days/week from 2 weeks prior to mating through to gestational day 19, and to male Sprague-Dawley rats (10/dose), 6 hours/day, 7 days/week from 2 weeks prior to mating for 51 consecutive days for unmated females and parental males and for 35-41 consecutive days (up to GD 19) for parental females. Parental females sacrificed on post-natal day 4; unmated and male rats sacrificed after last litters reached post-natal day 4. All doses – No effect on reproductive organs (testes, epididymides, ovaries), reproductive performance or foetal development.
Inhalation	64742-48-9 (de-aromatized white spirit)	**LOAEC:** 800 ppm (4679 mg/m^3) for reproductive and developmental toxicity and developmental neurotoxicity (Hass et al. 2001). Pregnant Wistar rats exposed to 800 ppm (4679 mg/m^3)[c,k] of the test substance, via inhalation, 6 h/day from GD 7 to GD 20. *4679 mg/m^3*: Decreased number of pups per litter and higher frequency of post-implantation loss. Increased birth weight of pups. *4679 mg/m^3*: Decreased motor activity (non-significant). No effect observed for neuromotor activity. For learning ability, exposed rats showed behaviour comparable to that of controls at 1 month of age. At 2 months of age, impaired cognitive function (females) and impaired memory (males) were observed. At 5 months of age, learning and memory deficits were observed in both sexes.
Oral	64741-55-5	**NOAEL:** 2000 mg/kg-bw for reproductive toxicity and teratogenicity (Stonybrook Laboratories 1995). Pregnant Sprague-Dawley rats exposed to 2000 mg/kg-bw of the test substance, via oral exposure, on GD 13to identify and compare any potential direct teratogenic effects that might be obscured by maternal or fetal toxicity resulting from repetitive exposure. Caesarean sections performed on GD 20.
Dermal	68513-02-0, full range coker naphtha	**Highest NOAEL:** 1000 mg/kg-bw per day for reproductive and developmental toxicity (ARCO 1994). Pregnant Sprague-Dawley rats (12 per dose, 15 for control) exposed to 0, 100, 500 or 1000 mg/kg-bw per day of the test substance (neat), applied to the shaved skin of the back (not occluded), from GD 0 to

		GD 20. Observation until lactation day 4. No effects observed with respect to number of females delivering live litters, gestation length, number of implantation sites, number of litters with live pups, offspring survival at lactation days 0–4, pup sex ratio and pup body weight
Dermal	Petroleum naphtha (CAS RN is not assigned in the original study)	**NOAEL:** 25 mg (694 mg/kg-bw per day) for reproductive toxicity (Clark et al. 1988). Male and female C3H/HeN mice (25 of each sex) exposed to 25 mg (694 mg/kg-bw per day)[i,j] of the test substance (neat), applied to the shaved skin of the dorsal thoracic region, 3 times/week for 105 weeks. No effects observed in gonads.

Carcinogenicity

Exposure	CAS RN (or specific substance)	Effect levels[a]/results
Inhalation (chronic)	Gasoline[g]	Concentrations of 0, 67, 292 or 2056 ppm (0, 200, 870 or 6170 mg/m^3) of the test substance (containing 2% benzene content) administered to male and female B6C3F1 mice and Fischer 344 albino rats (approximately 6 weeks of age, 100 mice or rats of each sex per group), via inhalation, 6 h/day, 5 days/week, for 103–113 weeks. 2056 ppm (6170 mg/m^3) - Increased incidence of hepatocellular tumours (adenomas and carcinomas) in female mice (14%, 19%, 21% and 48%, respectively; final group was statistically significantly different from controls). Increased incidence of renal tumours in female mice (2/100 at the highest concentration). Concentration-related increased incidence of primary renal neoplasms in male rats (*n* = 0, 1, 5 and 7, respectively). Appearance of tumours not considered statistically significant in male mice and female rats, and renal tumours in male rats are not considered relevant to humans (MacFarland et al.1984).
Inhalation (initiation/promotion)	Gasoline[g]	**Negative in sequence reversal study (initiation):** Male F344 rats (8–9 weeks of age, 30 rats per group) exposed to 10, 69 or 298 ppm (27, 183 or 791 mg/m^3)[c,h] of the test substance (PS-6 blend) or to a positive control (50 ppm TMP), via inhalation, 6 hours/day, 5 days/week, for 24 weeks. After a 4-week rest period, the promoter EHEN was administered at 170 mg/L in drinking water for 2 weeks. Rats were sacrificed at 65–67 weeks. Appropriate controls present. Insignificant renal cell tumour incidence observed in all exposure groups (0, 1, 0 and 0 developed tumours, respectively) (Short et al. 1989). **Positive for promotion** in male rats **but Negative for promotion** in female rats**:** Male and female F344 rats (8–9 weeks of age, 30 rats of each sex per group) administered EHEN at 170 mg/L in the drinking water for 2 weeks. After a 4-

		week rest period, 10, 69 or 298 ppm (27, 183 or 791 mg/ m^3)^{c,h} of the test substance (PS-6 blend) or a positive control (50 ppm TMP) was administered, via inhalation, 6 hours/day, 5 days/week, until sacrifice at 65–67 weeks. Increased incidence of renal cell tumours observed in males (1, 0, 1 and 2 developed tumours, respectively), although not statistically significant. Insignificant tumour incidence observed in any exposure group in females (1, 0, 2 and 2 developed tumours, respectively) (Short et al. 1989). **Positive for promotion** in mice: 16 female B6C3F1 mice (12 days of age, 8 mice per concentration) administered DEN at 5 mg/kg-bw, via intraperitoneal injection. At 5–7 weeks of age, mice then exposed to the test substance (PS-6 blend), via inhalation, at concentrations of 0 or 2039 ppm (0 or 5412 mg/m^3)^{c,h}, 6 hours/day, 5 days/week, for 13 weeks. Significant increase in the incidence of gross hepatic masses observed (7/8 in test group developed tumours versus 2/8 in control group) (Standeven and Goldsworthy 1993). 36 female B6C3F1 mice (12 days of age, 12 mice per concentration) administered DEN at 5 mg/kg-bw, via intraperitoneal injection. At 5–7 weeks of age, mice then exposed to the test substance (PS-6 blend), via inhalation, at concentrations of 0, 283 or 2038 ppm (0, 751 or 5410 mg/m^3)^{c,h}, 6 hours/day, 5 days/week, for 16 weeks. Alternatively, the test substance was administered to initiated mice at 2038 ppm (5410 mg/m^3) in addition to 1 mg/kg of EE2 in the diet. Significant increase in the incidence of macroscopic hepatic neoplasms observed in mice exposed to 2038 ppm of the test substance alone, and also with co-exposure to EE2 (10.3-fold and 60-fold increases, respectively, over the proper controls) (Standeven et al. 1994). 24 male B6C3F1 mice (12 days of age, 12 mice per concentration) administered DEN at 5 mg/kg-bw, via intraperitoneal injection. At 5–7 weeks of age, mice then exposed to the test substance (PS-6 blend), via inhalation, at concentrations of 0 or 2046 ppm (0 or 5431 mg/ m^3)^{c,h}, 6 hours/day, 5 days/week, for 16 weeks. Significant increase in the incidence of macroscopic hepatic neoplasms observed (2.3-fold over the proper controls) (Standeven et al. 1995).
Dermal exposure (chronic)	64741-46-4	**Highest dermal effect level: 1351 mg/kg-bw per day** (Blackburn et al. 1986). 50 mg (1351 mg/kg-bw per day). 50 male C3H/HeJ mice (6–8 weeks of age) were exposed to 50 mg (1351 mg/kg-bw per day)^{i,j} of the test substance (neat) applied to the shaved skin of the interscapular region of the back, 2 times/week, until a papilloma

		more than 1 mm^3 appeared. Increased incidence of skin tumours. Tumour incidence: 11/44 in the test group; 0/50 in the negative control group; 46/48 in the positive control group. Tumours appeared after 85 weeks in the test group and after 46 weeks in the positive control group.
Dermal exposure (chronic)	Petroleum naphtha (CAS RN is not assigned in the original naphtha)	**Lowest dermal effect level: 25 mg (694 mg/kg-bw per day)** (Clark et al. 1988) Male and female C3H/HeN mice (42–50 days of age, 25 of each sex) were exposed to 25 mg (694 mg/kg-bw per day)[i,j] of the test substance (neat) applied to the shaved skin of the dorsal thoracic region, 3 times/week for up to 105 weeks. Increased incidence of skin tumours (21%). Tumour incidence: 10/47 in test group (3 squamous cell carcinomas and 7 fibrosarcomas); 0/46 in the negative control group; 49/49 in the positive control group (49 squamous cell carcinomas). Tumours appeared after 94 weeks in the test group and 28 weeks in the positive control group.
Dermal (initiation/promotion)	64741-87-3	**Negative for initiation** in male mice (Skisak et al. 1994). 30 male CD-1 mice (7–9 weeks of age) administered 50 µL (917 mg/kg-bw per day)[j,l,n] of the test substance (neat) for 5 consecutive days. After a 2-week rest period, 50 µL of the promoter PMA was administered 2 times/week for 25 weeks. Both substances applied to the shaved dorsal intrascapular skin. Insignificant increase in skin tumours, as shown by 3/29 in the test group (squamous cell papillomas); 3/30 in the negative control group; 30/30 in the positive control group. Tumours appeared after 20 weeks in the test group and 16 weeks in the negative control group. **Negative for promotion** in male mice (Skisak et al. 1994). 30 male CD-1 mice (7–9 weeks of age) administered 50 µL of DMBA as a single dose. After a 2-week rest period, 50 µL (917 mg/kg-bw per day)[j,l,n] of the test substance was administered, 2 times/week for 25 weeks. Both substances applied to the shaved dorsal intrascapular skin. No increase in skin tumours: 0% in the test and negative control groups; 30/30 in the positive control group.

Genotoxicity

in vivo	64741-55-5, 64741-87-3, 64741-66-8	**Chromosomal Aberrations (Bone Marrow Cytogenesis)** **Negative** in rats, via inhalation of the test substance up to 2050 ppm, 6 hours/day for 5 days. NOAEC = 2050 ppm (5442 mg/m^3) (API 1985d, 1986i). **Negative**: Male and female Sprague-Dawley rats (15/sex/group) were administered 0.3, 1.0 or 3.0 g/kg (300, 1000 or 3000 mg/kg-bw) of the test substance (*API 81-04*), as a single dose via *i.p.* injection

		(5/sex/dose were sacrificed at 6, 24 and 48 hours after exposure). NOAEL = 3000 mg/kg-bw (API 1985f, e and 2003b). **Sister Chromatid Exchange** **Positive**: Male and female B6C3F1 mice (5/sex/group) were administered 200, 1200, 2400 mg/kg-bw of the test substance (*API 81-03*), as a single dose, via *i.p.* injection. Pairwise comparisons, by sex, of SCE in bone marrow cells of mice from each treatment group with its vehicle control were significantly different. Reviewers note that although interaction between the test substance and DNA was demonstrated, it was not considered definitive for clastogenic activity since no genetic material was unbalanced or lost. (API 1988a).
in vivo	White spirit (CAS RN is not assigned in the original study)	**Micronuclei Induction** (Gochet et al. 1984) **Highest inhalation NOAEC = 50 g/m^3** **Negative:** Four male BALB/c mice exposed to 50 g/m^3 (50 000 mg/m^3) of white spirit, via inhalation, for five periods of 5 min, spaced by 5 min intervals. NOAEC: 50 g/m^3 (50 000 mg/m^3). **Highest intraperitoneal injection NOAEL = 0.1 mL (3710 mg/kg-bw)** **Negative:** Male and female BALB/c mice (five of each sex per group) administered 0.01, 0.05 or 0.1 mL (371, 1855 or 3710 mg/kg-bw)[j,l,o] of white spirit, as a single dose, via intraperitoneal injection (sacrificed after 30 h). NOAEL: 0.1 mL (3710 mg/kg-bw).
in vivo	Baseline gasoline vapour condensate	**Micronuclei Induction** (API 2005a). **Negative**: Sprague Dawley rats (5/sex/group) (satellite study to 13 week subchronic study) exposed to 0, 2050, 10153 or 20324 mg/m^3 of the test substance, via inhalation, 6 hours/day, 5 days/week for 4 weeks. No significant increases in micronucleated immature or mature erythrocytes; no cytotoxicity; no decrease in proportion of immature erythrocytes. **Sister Chromatid Exchange** (API 2005b). **Positive**: Sprague Dawley rats (5/sex/group) (satellite study to 13 week subchronic study) exposed to 0, 2050, 10153 or 20324 mg/m^3 of the test substance, via inhalation, 6 hours/day, 5 days/week for 4 weeks. Statistically significant increases in SCE frequency at all doses for females and at mid- and high-doses for males. Increases in average generation time but no difference in mitotic indices. No genetic material lost or unbalanced but considered as exposure biomarker.
in vivo	64742-89-8 64741-84-0	Substance was a blend of any or all the listed CAS numbers **Chromosomal Aberrations** **Positive**: 30 male Long-Evans rats (age and cell

		type not specified) exposed to 1.5mL/kg of *Rubber Solvent*, as a single dose, via *i.p.* injection for a maximum of 7 days. Type I and II aberrations observed within 1 day (API 1977a).**Negative**: Bone marrow cells derived from male Sprague-Dawley rats exposed to *Rubber Solvent* (dose unspecified) (API 1977a). **Dominant Lethal Assay** **Negative**: Rats exposed to *Rubber Solvent* (dose unspecified) (API 1977a).
in vivo	64742-48-9	**Micronuclei Induction** **Negative:** Male and female Crl:CD-1 (ICR) BR Swiss mice (10-15/sex/group) exposed to 0, 625, 1250 or 2500 mg/kg bw/day (daily for 2 days) or 2500 mg/kg/day (for 1 day) of the test substance, via oral gavage. NOAEL = 2500 mg/kg per day (Khan and Goode 1984).
in vitro[p]	64741-46-4	**Reverse Mutations, modified Ames Assay** **Positive**: *Salmonella typhimurium* (strains not identified) exposed to extracts of the test substance (doses not identified), with and without exogenous metabolic activation, using the Ames assay. Data analysis conducted using non-linear regression (Blackburn et al. 1988). **Negative:** *S. typhimurium* (strains not identified) exposed to the test substance (doses not identified), with and without exogenous metabolic activation (rat liver S9) (Ames Assay) (Blackburn et al. 1988). **Negative:** *S. typhimurium* TA98 exposed to DMSO extracts of the test substance at doses of 0-50 µl/plate, with and without exogenous metabolic activation (modified Ames Assay) (Blackburn et al. 1986).
in vitro[p]	64741-55-5	**Mouse Lymphoma TK gene Mutation Assay** **Negative:** L5178Y TK+/- mouse lymphoma cells exposed to the test substance (API 83-20), for 4 hours, at concentrations of 50-150 ηl/mL and 200-300 ηl/mL, without and with exogenous metabolic activation (rat liver S9), respectively, in the second assay. The range in the first assay of 50-800 ηl/mL and 25-500 ηl/mL, without and with activation, respectively, saw a wide range of toxicity (API 1987a). **Negative:** L5178Y TK+/- mouse lymphoma cells exposed to the test substance (API 81-03), with and without exogenous metabolic activation (details of study not provided) (API 1985d). **Negative/Equivocal:** L5178Y TK+/- mouse lymphoma cells exposed to the test substance (API 81-04), with/without exogenous metabolic activation (details of study not provided) (API 1985c). **Negative/Equivocal:** L5178Y TK+/- mouse

		lymphoma cells exposed to the test substance (API 81-04), without exogenous metabolic activation (details of study not provided); Equivocal for L5178Y TK+/- mouse lymphoma cells exposed to test substance (API 81-04), with exogenous metabolic activation (details of study not provided). One or more doses exhibited a 2-fold increase in mutant frequency over background levels, but no dose-response was observed (API 1986k). **Sister Chromatid Exchange Assay** (API 1988b). **Negative:** Chinese hamster ovary cells exposed to the test substance (API 81-03) at doses of 0.05, 0.1, 0.2 or 0.3 µl/mL, without exogenous metabolic activation (rat liver S9). **Equivocal:** Chinese hamster ovary cells exposed to the test substance (API 81-03) at doses of 0.03, 0.05, 0.1 or 0.2 µl/mL, with exogenous metabolic activation. 2 intermediate doses induced small but statistically significant increases in SCE.
in vitro[p]	64741-54-4	**Forward Mutations (Mouse Lymphoma Assay)** (API 1986l). **Positive:** Cells exposed to the test substance (API 83-18) (details of study not provided).
in vitro[p]	64741-87-3, 64741-66-8	**Forward Mutations (Mouse Lymphoma TK Gene Mutation Assay) (**API 1985a, k). **Negative:** L5178Y TK+/- mouse lymphoma cells exposed to test substances API 81-08 and API 83-19, for 4 hours, at concentrations of 0.005-0.08 µL/mL and 0.00004-0.8 µL/mL, without and with exogenous metabolic activation (rat liver S9), respectively. Several trials performed to verify absence of genotoxicity
in vitro[p]	64741-74-8	**Mouse Lymphoma Forward Mutations Assay** (Kirby et al. 1979). ***Positive*****:** L5178Y TK+/− mouse lymphoma cells exposed to the test substance at concentrations of 0, 0.013, 0.018, 0.024, 0.032, 0.042, 0.056, 0.075 or 0.10 µL/mL, without exogenous metabolic activation (rat liver S9), using the mouse lymphoma assay. Weak induction of forward mutations observed at the two highest doses. No dose–response trend was observed at the six lower doses. ***Negative*****:** L5178Y TK+/− mouse lymphoma cells exposed to the test substance at concentrations of 0, 0.013, 0.018, 0.024, 0.032, 0.042, 0.056, 0.075 or 0.10 µL/mL, with exogenous metabolic activation (rat liver S9), using the mouse lymphoma assay. No induction of forward mutations observed at any dose. **Reverse Mutations Ames Assay** (Blackburn 1981). **Negative:** S. typhimurium TA98, TA100, TA1535, TA1537 and TA1538 exposed to the test substance at doses of 0, 0.094, 0.30, 0.97 and 3.1 µL/plate or 0, 0.029, 0.094, 0.30 or 0.97 µL/plate, with and without exogenous metabolic activation (rat liver S9),

		respectively. **Cell Transformation Assay** **Negative:** BALB-c/3T3 mouse embryo cells exposed to the test substance at doses of 0, 0.8, 4.0, 20.0 or 100 µg/mL, for 2-3 days. Cloning efficiencies (CE) inhibited from 4.0µg/mL (89% CE) to 100 µg/mL (65%CE, 40% viability) (Tu and Sivak 1981 and Roy 1981). **Negative:** Mouse C3H embryo cells exposed to the test substance at doses of 0, 0.625, 1.25, 2.5 and 5.0 µl/mL, without exogenous metabolic activation (Jensen and Thilager 1978).
in vitro^{p}	64742-89-8 64741-84-0	Substance was a blend of any or all listed CAS numbers **Mouse Lymphoma Forward Mutations Assay** (API 1977a) **Negative**: L5178Y mouse lymphoma cells exposed to *Rubber Solvent* (doses unspecified). **Reverse Mutations (Ames Assay)** (API 1977a) **Negative**: *S. typhimurium* (5 strains, not identified) and *Saccharomyces cerevisiae* strain D4 exposed to *Rubber Solvent* (doses unspecified), with and without S9 metabolic activation.
in vitro^{p}	White spirit (CAS RN not assigned in the original study)	**Sister Chromatid Exchange Assay** (Gochet et al. 1984**)** **Negative:** Lymphocytes derived from 1 male human (2 cultures/dose) exposed to *white spirit* (diluted in ethanol using 20 and 50µL) at 1:1, 1:2, 1:4 and 1:8 ratios for 1 and 24 hour exposures. **Reverse Mutations (standard and modified Ames Assay)** (Gochet et al. 1984) ***Negative*****:** *S. typhimurium* TA98, TA100, TA1530, TA1535, TA1537 and TA1538 exposed to *white spirit* at doses of 0.0010-1 µL/plate (standard and pre-incubation methods) and 10µL (gas-phase method), with and without exogenous metabolic activation (Aroclor 1254-induced rat liver S9)
in vitro^{p}	64742-48-9	**Cell Transformation Assay** (Brecher and Goode 1984b). **Negative:** BALB/3T3-C1-1-1 mouse embryo cells exposed to the test substance at doses of 16, 32, 64 or 200 µg/mL (15 cultures per dose) for 2 days, without exogenous metabolic activation (S9). Toxicity seen at more than and/or equal to 32 µg/mL. **UDS Assay** (Brecher and Goode 1984a): **Negative**: male rat hepatocyte cells exposed to the test substance, without exogenous metabolic activation.

		Mammalian Cell Forward Mutation (Papciak and Goode 1984): **Negative**: Chinese hamster ovary cells exposed to the test substance, with and without exogenous metabolic activation.

Various

Skin irritation	64741-55-5	Primary irritation index: 1.7/8.0 (Draize 24 h occluded patch test in rabbit skin); moderate skin irritant in rabbits (API 1986b).
Skin irritation	64741-54-4	Primary irritation index: 6.9/8.0 (Draize 24 h occluded patch test in rabbit skin) (API 1986d).
Skin irritation	64741-87-3	Primary irritation index: 1.2/8.0 (Draize 24 h occluded patch test in rabbit skin); mild skin irritant in rabbits (API 1986c).
Skin irritation	64741-66-8	Primary irritation index: 3.9/8.0 (Draize 24 h occluded patch test in rabbit skin); moderate skin irritant in rabbits (API 1986a).
Eye irritation Draize test (rabbit)	64741-55-5	Slight (API 1986b); non-irritant (API 1986g).
Eye irritation Draize test (rabbit)	64741-54-4	Slight (API 1986d).
Eye irritation Draize test (rabbit)	64741-87-3	Slight (CONCAWE 1992); non-irritant (API 1986c, 2008a).
Eye irritation Draize test (rabbit)	64741-66-8	Non-irritant (API 1986a).
Sensitization[q] Closed patch technique (guinea pigs)	64741-55-5	Negative (API 1986b).
Sensitization[q] Closed patch technique (guinea pigs)	64741-54-4	Negative (API 1986d).
Sensitization[q] Closed patch technique (guinea pigs)	64741-87-3	Negative (API 1986c).
Sensitization[q] Closed patch technique (guinea pigs)	64741-66-8	Negative (API 1986a).

Abbreviations: bw, body weight; DEN, *N*-nitrosodiethylamine; DMBA, 7,12-dimethylbenzanthracene; DNA, deoxyribonucleic acid; EE2, ethinyl estradiol; EHEN, *N*-ethyl-*N*-hydroxyethylnitrosamine; GD, gestation day; PMA, phorbol-12-myristate-13-acetate; RDS, replicative DNA synthesis; TMP, 2,2,4-trimethylpentane; UDS, unscheduled DNA synthesis.

[a] LC_{50}, median lethal concentration; LD_{50}, median lethal dose; LOAEC, lowest-observed-adverse-effect concentration; LOAEL, lowest-observed-adverse-effect level; NOAEC, no-observed-adverse-effect concentration; NOAEL, no-observed-adverse-effect level.

[b] 1 m^3 = 1000 L.

[c] The following formula was used for conversion of provided values into mg/m^3 in air: (*x* ppm × MM)/24.45, assuming at 1atm and 25°C.

[d] Molar mass (MM) of CAS RN 8052-41-3 reported to be 138.6 g/mol (Carpenter et al. 1975).

[e] The MM of CAS RN 8032-32-4 was not available; therefore, a MM of 64.9 g/mol (gasoline) was used (Roberts et al. 2001).

[f] The MM of CAS RN 64742-95-6 was not available; therefore, a MM of 64.9 g/mol (gasoline) was used (Roberts et al. 2001).

[g] Gasoline captures the following CAS RNs: 8006-61-9 and 86290-81-5.

[h] MM of gasoline reported to be 64.9 g/mol (Roberts et al. 2001).

[i] The following formula was used for conversion of provided values into mg/kg bw: *x* mg/kg bw.

[j] Body weight not provided; thus, laboratory standards from Salem and Katz (2006) were used.

[k] MM of CAS RN 64742-48-9 reported to be 143 g/mol (Hass et al. 2001).

[l] The following formula was used for conversion of provided values into mg/kg bw: *x* mL/kg bw × ρ.

[m] Density (ρ) of gasoline reported to be 720 mg/mL (CONCAWE 1992).

[n] Density (ρ) of CAS RN 64741-87-3 reported to be 678.2 mg/mL (API 2003b).

[o] Density (ρ) of CAS RN 8052-41-3 reported to be 779 mg/mL (Gochet et al. 1984).

[p] Negative result studies described in table correspond to studies with the highest dose used.

[q] Poor response in positive control noted.