Screening Assessment
Petroleum Sector Stream Approach

Heavy Fuel Oils
[Site-Restricted]

Chemical Abstracts Service Registry Numbers
64741-45-3
64741-61-3
64741-80-6
68333-22-2
68333-27-7
68476-32-4
68478-17-1

Environment Canada
Health Canada

September 2011

Synopsis

The Ministers of the Environment and of Health have conducted a screening assessment of the following site-restricted heavy fuel oils (HFOs):

CAS RN[a]	DL[b] Name
64741-45-3	Residues (petroleum), atmospheric tower
64741-61-3	Distillates (petroleum), heavy catalytic cracked
64741-80-6	Residues (petroleum), thermal cracked
68333-22-2	Residues (petroleum), atmospheric
68333-27-7	Distillates (petroleum), hydrodesulfurized intermediate catalytic cracked
68476-32-4	Fuel oil, residues-straight-run gas oils, high-sulfur
68478-17-1	Residues (petroleum), heavy coker gas oil and vacuum gas oil

[a] The Chemical Abstracts Service Registry Number (CAS RN) is the property of the American Chemical Society and any use or redistribution, except as required in supporting regulatory requirements and/or for reports to the government when the information and the reports are required by law or administrative policy, is not permitted without the prior, written permission of the American Chemical Society.
[b] DSL = Domestic Substances List

These substances were identified as high priorities for action during the categorization of the Domestic List, as they were determined to present the greatest potential or intermediate potential for exposure of individuals in Canada and were considered to present a high hazard to human health. Most of these substances were identified by categorization as ecological priorities as some of their components met criteria for persistence or bioaccumulation and inherent toxicity to non-human organisms, but no components met all three criteria. These substances were all included in the Petroleum Sector Stream Approach (PSSA) because they are related to the petroleum sector and are all complex mixtures.

Heavy fuel oils (HFOs) are a group of complex petroleum mixtures that serve as blending stocks in final heavy fuel products or as intermediate products of distillate or residue derived from refinery distillation or cracking units. The final fuel product usually consists of a mixture of HFOs as well as higher-quality hydrocarbons as diluents. HFOs are composed of aromatic, aliphatic and cycloalkane hydrocarbons, primarily in the carbon range of C_{20} to C_{50} (C_{11} is the smallest hydrocarbon found in the group) and have a typical boiling point range from 160–650°C. As such, HFOs are considered to be of Unknown or Variable composition, Complex reaction products or Biological materials (UVCBs). In order to predict the overall behaviour of these complex substances for the purposes of assessing the potential for ecological effects, representative structures have been selected from each chemical class in the mixture.

Based on the combined evidence of empirical and modeled bioconcentration/ bioaccumulation potential, the HFOs assessed in this report likely contain large

proportions of C_{15}-C_{20} components that are highly bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations* of CEPA 1999. All of the HFOs considered here may be comprised of significant proportions of components (mostly $\geq C_{30}$) that persist in soil, water and sediments based on criteria in the *Persistence and Bioaccumulation Regulations.* No components of these HFOs were found to be both persistent and bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations*.

The modelled ecotoxicological data suggest that these HFOs, as complex mixtures, are potentially hazardous to aquatic organisms. However, the HFOs considered in this report have been identified as site-restricted (i.e., they are a subset of HFOs that are not expected to be transported off of the petroleum refinery or upgrader facility sites). Accordingly, exposure is expected to be negligible and so the potential for ecological harm is considered to be low.

Site-restricted HFOs were identified as a high priority for action because they were considered to present a high hazard to human health. A critical effect for the initial categorization of site-restricted HFO substances was carcinogenicity, based primarily on classifications by international agencies. Several studies reported skin tumour development in mice, rabbits and monkeys following repeated dermal application of HFO substances. HFOs demonstrated genotoxicity in *in vivo* and *in vitro* assays, although results varied between HFOs with different CAS RNs. Studies on laboratory animals indicate that HFOs may also adversely affect reproduction and development. Information on additional HFO substances in the PSSA that are similar from a processing and physical-chemical perspective were considered for characterization of human health effects.

The HFOs considered in this screening assessment have been identified as site-restricted. According to information submitted under section 71 of CEPA 1999 and other sources of information, these HFOs are consumed on site or blended into substances leaving the site under different CAS RNs. In addition, a number of regulatory and non-regulatory measures are already in place in Canada, which minimize releases of site-restricted petroleum sector substances, including provincial/territorial operating permit requirements, and best practices and guidelines put in place by the petroleum industry at refinery and upgrader facilities. Accordingly, environmental and general population exposure to these substances is not expected, and therefore harm to the environment or human health is not expected.

Therefore, it is concluded that these site-restricted HFO substances are not entering 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 biodiversity, or that constitute or may constitute a danger to the environment on which life depends, or that constitute a danger in Canada to human life or health.

Based on the information available, it is concluded that the seven site-restricted HFOs listed under CAS RNs 64741-45-3, 64741-61-3, 64741-80-6, 68333-22-2, 68333-27-7,

68476-32-4 and 68478-17-1 do not meet any of the criteria set out in section 64 of CEPA 1999.

Because these substances are listed on the Substances List, their import and manufacture in Canada are not subject to notification under subsection 81(1) of CEPA 1999. Given the potential hazardous properties of these substances, there is concern that new activities that have not been identified or assessed could lead to these substances meeting the criteria set out in section 64 of the Act. Therefore, application of the Significant New Activity provisions of the Act to these substances is being considered, so that any proposed new manufacture, import or use of this substance outside a petroleum refinery or upgrader facility is subject to further assessment, to determine if the new activity requires further risk management consideration.

Introduction

The *Canadian Environmental Protection Act, 1999* (CEPA 1999) (Canada 1999) requires the Minister of the Environment and the Minister of Health to conduct screening assessments of substances that have met the categorization criteria set out in the Act to determine whether these substances present or may present a risk to the environment or to human health.

Based on the information obtained through the categorization process, the Ministers identified a number of substances as high priorities for action. These include substances that:

- met all of the ecological categorization criteria, including persistence (P), bioaccumulation potential (B) and inherent toxicity to aquatic organisms (iT), and were believed to be in commerce in Canada; and/or
- met the categorization criteria for greatest potential for exposure (GPE) or presented an intermediate potential for exposure (IPE) and had been identified as posing a high hazard to human health based on classifications by other national or international agencies for carcinogenicity, genotoxicity, developmental toxicity or reproductive toxicity.

A key element of the Government of Canada's Chemicals Management Plan (CMP) 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).

Screening assessments focus on information critical to determining whether a substance meets the criteria as set out in section 64 of CEPA 1999. Screening assessments examine scientific information and develop conclusions by incorporating a weight-of-evidence approach and precaution.[1]

Grouping of Petroleum Substances

The high priority petroleum substances fall into nine groups of substances based on similarities in production, toxicity and physical-chemical properties (Table A1.1 in

[1] A determination of whether one or more of the criteria of section 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 1999 on the petroleum substances in the Chemicals Management Plan (CMP) is not relevant to, nor does it preclude, an assessment against the hazard criteria specified in the Controlled Products Regulations, which is part of the regulatory framework for the Workplace Hazardous Materials Information System (WHMIS) for products intended for workplace use. Similarly, a conclusion based on the criteria contained in section 64 of CEPA 1999 does not preclude actions being undertaken in other sections of CEPA 1999 or other Acts.

Appendix 1). In order to conduct screening assessments, each high priority petroleum substance was placed into one of five categories ("streams") based on its production and use in Canada:

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

An analysis of the available data determined that approximately 70 high priority petroleum substances are site-restricted under stream 1, as described above. These occur within four of the nine substance groups: heavy fuel oils, gas oils, petroleum and refinery gases, and low boiling point naphthas.

These site-restricted substances were identified as GPE or IPE during the categorization exercise based on their production volumes reported in the Domestic Substances List (DSL). However, according to information submitted under section 71 of CEPA 1999, voluntary industry submissions, an in-depth literature review, and a search of material safety data sheets, these substances are consumed on-site or are blended into substances leaving the site under different Chemical Abstract Services Registry Numbers (CAS RNs) (which will also be addressed under the CMP).

This screening assessment addresses seven site-restricted heavy fuel oils (HFOs) described under CAS RNs 64741-45-3, 64741-61-3, 64741-80-6, 68333-22-2, 68333-27-7, 68476-32-4 and 68478-17-1. The remaining high priority HFOs (under 14 different CAS RNs) will be assessed separately as they belong to streams 2, 3 or 4 (as described above). Health effects were assessed using toxicological data pooled across all 21 HFO CAS RNs.

Included in this screening assessment is the consideration of information on chemical properties, hazards, uses and exposure, including the additional information submitted under section 71 of CEPA 1999. Data relevant to the screening assessment of these substances were identified in original literature, review and assessment documents, stakeholder research reports and from recent literature searches, up to July 2010 for the environmental components of the document and up to October 2009 for the health

[2] 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. In these cases, facilities are either petroleum refineries or upgraders.

components. Key studies were critically evaluated; modelling results were used to reach conclusions.

Characterizing risk to the environment involves the consideration of data relevant to environmental behaviour, persistence, bioaccumulation and toxicity, combined with an estimation of exposure to potentially affected non-human organisms from the major sources of release to the environment. Conclusions regarding risk to the environment are based in part on an estimation of environmental concentrations resulting from releases and the potential for these concentrations to have a negative impact on non-human organisms. As well, other lines of evidence of environmental hazard are taken into account. The ecological portion of the screening assessment summarizes the most pertinent data on environmental behaviour and effects, and does not represent an exhaustive or critical review of all available data. Environmental models and comparisons with similar petroleum mixtures may assist in the assessment.

Evaluation of risk to human health involves consideration of data relevant to estimation of exposure (non-occupational) of the general population, as well as information on health hazards (based principally on the weight of evidence assessments of other agencies that were used for prioritization of the substance). Decisions for human health are based on the nature of the critical effect and/or margins between conservative effect levels and estimates of exposure, taking into account confidence in the completeness of the identified databases on both exposure and effects, within a screening context. The screening assessment does not represent an exhaustive or critical review of all available data. Rather, it presents a summary of the critical information upon which the conclusion is based.

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 written peer review/consultation. Comments on the technical portions relevant to human health were received from scientific experts selected and directed by Equilibrium Environmental Inc., including Anthony Knafla (Equilibrium Environmental Inc) and Ross Wilson (Wilson Scientific Consulting Inc.).

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 summarized below.

Substance Identity

Heavy fuel oils (HFOs) are a group of complex petroleum mixtures that serve as blending constituents in final fuel products or as intermediate products of distillate or residue derived from refinery distillation or cracking units (Table A3.1 in Appendix 3) (CONCAWE 1998). The final fuel product usually consists of a blend of HFOs and high-quality hydrocarbons that have been produced in the refinery or in upgrader facilities.

Physical and Chemical Properties

The composition and physical-chemical properties of HFOs vary based on the source of crude oil or bitumen, and the processing steps involved. A summary of data on the physical and chemical properties of site-restricted HFOs is presented in Table 1.

HFOs are composed of aromatic, aliphatic and cycloalkane hydrocarbons, primarily in the carbon range of C_{11} to C_{50} (Table A3.1 in Appendix 3) (CONCAWE 1998) and have a general boiling-point range of 160–650°C (API 2004).

Table 1: General physical and chemical properties for site-restricted HFOs

Property	Type	Value	Temperature (°C)	Reference
Pour point (°C)	Experimental	<30	-	ECB 2000a; API 2004
Boiling point (°C)	Experimental	160–650*	-	API 2004
Density (kg/m^3)	Experimental	900–1 100	20	ECB 2000a; API 2004; NOVA Chemicals 2007a, b
Vapour pressure (Pa)	Experimental	282.6–3 519.6	21	ATSDR 1995
Henry's Law constant (Pa·m^3/mol)	Experimental	33–4 900 (aliphatic)	20	Gustafson et al. 1997
	Experimental	0.0067–0.23 (aromatic)		
Log K_{oc} (dimensionless)	Experimental	3.0–6.7	-	ATSDR 1995
Log K_{ow} (dimensionless)	Experimental	2.7–6.0	20	ECB 2000a
Water solubility	Experimental	<100	20	ECB 2000a

(mg/L)		0.4–6.3	-	Anderson et al. 1974; Suntio et al. 1986; MacLean and Doe 1989

Abbreviations: K_{oc}, organic carbon–water partition coefficient; K_{ow}, octanol-water partition coefficient.
* Boiling-point ranges are not known for all CAS RNs in this report; this is a general range for HFOs.

The theoretical vapour pressures of individual substances comprising HFOs are low to moderate due to their high molecular weights. However, the actual vapour pressures will be influenced by the substance composition of the HFO mixture in which they occur. Water solubilities of all HFOs are low and octanol-water partition coefficient estimations vary considerably, probably due to the complex nature of these mixtures.

In order to predict the overall properties and behaviour of a complex petroleum substance, representative structures were selected from each chemical class within the mixture. Thirty structures were chosen based on boiling-point ranges for each HFO (Table A3.2 in Appendix 3), the amount of data on each structure, and the median of the boiling-point range of similar structures. The database in PetroTox (2009) was used to select representative structures. As the precise substance compositions of HFOs are not well defined and are indeed variable, representative structures are not considered to be proportionally representative. This resulted in the selection of representative structures for alkanes, isoalkanes, 1- and 2-ring cycloalkanes, and one-, two-, three- and five-ring aromatics ranging from C_{15} to C_{50} (Table A3.3 in Appendix 3). Physical-chemical data for each representative structure were assembled from the scientific literature or from the EPIsuite (2008) group of environmental models. No information was found on the boiling point or carbon range of CAS RN 68476-32-4; therefore, it is unclear what structures would be representative. However, its properties likely reflect the properties of the other site-restricted HFOs, and this is assumed throughout.

Sources

Site-restricted HFOs are produced in Canadian refineries and upgraders. The CAS RN descriptions (NCI 2006), typical process flow diagrams (Figures A2.1 to A2.7b in Appendix 2) (Hopkinson 2008), and information collected under section 71 of CEPA 1999 (Environment Canada 2008, 2009), indicate that these substances are intermediate streams within both refineries and upgraders or are blended to make other products under a new CAS RN. As such, these HFOs are not expected to be transported off of facility sites. Consequently, the quantities produced are not critical to this screening assessment since the potential for release to the environment is negligible.

CAS RN 64741-45-3 represents a residual fraction from atmospheric distillation of crude oils (Figure A2.1 in Appendix 2).

CAS RN 64741-61-3 represents a distillate derived from a fractionation column treated with the effluent from a catalytic cracking process (Figure A2.2 in Appendix 2).

CAS RN 64741-80-6 refers to a residual fraction derived from fractionating a mixture produced from a thermal cracking process (e.g., coking or visbreaking) (Figure A2.3 in Appendix 2).

CAS RN 68333-22-2 refers to a residual fraction from atmospheric distillation of crude oils (Figure A2.4 in Appendix 2).

CAS RN 68333-27-7 represents a residual fraction from the bottom of a distillation column fed with hydrogen-treated intermediate distillate from a catalytic cracking unit (Figure A2.5 in Appendix 2).

CAS RN 68476-32-4 represents several streams direct from the atmospheric distillation tower to kerosene/diesel blending (Figure A2.6 in Appendix 2).

CAS RN 68478-17-1 refers to a residual fraction from a distillation column treated with heavy coker gas oil and/or vacuum gas oil derived from a coking unit and/or a vacuum distillation unit in a refinery or an upgrader (Figures A2.7a and A2.7b in Appendix 2).

Uses

According to the information collected through the *Notice with respect to certain high priority petroleum substances* (Environment Canada 2008) and the *Notice with respect to potentially industry-limited high priority petroleum substances* (Environment Canada 2009), published under section 71 of CEPA 1999, the substances listed in this screening assessment were identified as either being consumed at the facility or blended into substances leaving the site under different CAS RNs. Although these substances were identified by multiple use-codes established during the development of the DSL, it has been determined from information submitted under section 71 of CEPA 1999 (Environment Canada 2008, 2009), voluntary submissions from industry, an in-depth literature review and a search of material safety data sheets that these site-restricted HFOs are not expected to be transported off refinery or upgrader facility sites.

Releases to the Environment

Potential releases of HFO substances from refineries and upgraders can be characterized as either controlled or unintentional releases. Controlled releases are planned releases from pressure relief valves, venting valves and drain systems that occur for safety purposes or maintenance, considered part of routine operations, and occur under controlled conditions. Unintentional releases are typically characterized as unplanned releases due to spills or leaks from various equipment, seals, valves, pipelines, flanges, etc., resulting from equipment failure, poor maintenance, lack of proper operating practices, adverse weather conditions or other unforeseen factors. Refinery and upgrader operations are highly regulated and regulatory requirements are established under various

jurisdictions. As well, voluntary non-regulatory measures implemented by the petroleum industry are in place to manage these releases (SENES 2009).

Controlled Releases

The site-restricted HFO CAS RNs in this screening assessment originate from distillation columns in a refinery or an upgrader, either as a residue (bottom product) or a distillate. Thus, the potential locations for the controlled release of HFOs include relief valves and venting valves or drain valves on the piping or (e.g., vessels) in the vicinity of this equipment.

Under typical operating conditions, controlled releases of site-restricted HFOs would be captured in a closed system[3], according to defined procedures, and returned to the processing facility or to the facility wastewater treatment plant. In both cases, exposure of the general population or the environment is not expected from the site-restricted HFO substances under the CAS RNs identified in this screening assessment as they are not expected to be transported off refinery or upgrader facility sites.

Unintentional Releases

Unintentional releases (including fugitive releases) occur from equipment (e.g., pumps, storage tanks), seals, valves, piping, flanges, etc., during processing and handling of petroleum substances and can be greater in situations of poor maintenance or operating practice. Regulatory and non-regulatory measures are in place to reduce these events at petroleum refineries and upgraders (SENES 2009). Rather than being specific to one substance, these measures are developed in a more generic way in order to reduce unintentional releases of all substances in the petroleum sector.

For the Canadian petroleum industry, requirements at the provincial or territorial level typically prevent or manage the unintentional releases of petroleum substances and streams within a facility (through the use of operating permits) (SENES 2009).

At the federal level, unintentional releases of some petroleum substances are addressed under the *Fisheries Act*; the *Petroleum Refinery Liquid Effluent Regulations and Guidelines* set the discharge limits of oil and grease, phenol, sulphides, ammonia nitrogen and total suspended matter, as well as testing requirements for acute toxicity in the final petroleum effluents entering Canadian waters.

Additionally, 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 2009).

[3] For the purposes of the screening assessment of PSSA substances, a closed system is defined as a system within a facility which does not have any releases to the environment, and in which losses are collected and either recirculated or destroyed.

Non-regulatory measures (e.g., guidelines, best practices) to reduce unintentional releases at petroleum-sector facilities 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 aboveground storage tanks to reduce the internal gaseous zone and the minimal use of underground tanks, which can lead to undetected leaks (SENES 2009).

Environmental Fate

Since all of the available information indicates that these site-restricted HFOs are not transported or released from refinery or upgrader sites into the environment, only general data on the environmental behaviour of these substances is presented in the screening assessment.

Persistence and Bioaccumulation

Environmental Persistence

No empirical data are available on the degradation of these site-restricted HFOs as complex mixtures. A quantitative structure-activity relationship (QSAR)-based weight of evidence approach (Environment Canada 2007) was therefore applied using the BioHCwin (2008), BIOWIN (2008) and AOPWIN (2008) degradation models. Modelling was based on the various representative structures of the HFOs.

AOPWIN (2008) is a model that calculates atmospheric oxidation half-lives of compounds in contact with hydroxyl radicals in the troposphere under the influence of sunlight. Atmospheric oxidation rates were calculated for all of the representative structures. Although the low vapour pressures of these representative structures indicate that volatilization may not be a very significant fate process, oxidation half-lives less than 1 day (Table A3.11 in Appendix 3) indicate this would be a relatively rapid removal process if these substances were introduced into the atmosphere (Atkinson 1990; API 2004).

Based on the analysis of ultimate biodegradation in water from the BIOWIN (2008) model, and primary biodegradation in water from the BioHCwin (2008) model, the C_{31} to C_{50} alkanes, C_{30} to C_{50} isoalkanes, C_{35} to C_{50} one-ring cycloalkanes, C_{20} to C_{50} two-ring cycloalkanes, C_{30} to C_{50} one-ring aromatics, C_{42} to C_{50} two-ring aromatics, C_{30} to C_{50} three-ring aromatics, and C_{20} to C_{30} five-ring PAHs in these HFOs all have half-lives in water $\geq$ 182 days (Table A3.4 in Appendix 3). Using an extrapolation ratio of 1:1:4 for water:soil:sediment biodegradation half-lives (Boethling et al. 1995), the half-lives in soil and sediment can be extrapolated from the half-life estimations in water. This extrapolation indicates that many of the mid and all of the high molecular weight components would have half-lives of $\geq$ 182 days in soil and $\geq$ 365 days in sediment.

All of the HFOs considered in this report contain significant proportions of components (mostly ≥C_{30}; see Table A3.5 in Appendix 3) that are persistent based on criteria in the *Persistence and Bioaccumulation Regulations* (Canada 2000).

Potential for Bioaccumulation

Since no experimental bioaccumulation or bioconcentration data for these HFOs as a mixture were available, empirical data on representative structures found in HFOs and other hydrocarbon mixtures in a read-across approach, and a predictive approach using a bioconcentration factor (BCF) model, were applied (BCFBAF 2008a). The BCFBAF model incorporates the generic QSAR model of Arnot and Gobas (2003).

Uptake and depuration of various petroleum hydrocarbons by mollusks and fishes has been shown in numerous studies (Stegeman and Teal 1973; Hardy et al. 1974; Fong 1976; Roubal et al. 1978; McCain et al. 1978; Nunes and Benville 1978; Cravedi and Tulliez 1983; Niimi and Palazzo 1986; Niimi and Dookhran 1989; Hellou et al. 1994; Burkhard and Lukasewycz 2000; Wetzel and van Vleet 2004; Colombo et al. 2007; Zhou et al. 1997). Aromatic and aliphatic components are readily taken up, primarily in adipose tissue. Moderate concentrations have been found in muscle, gall bladder, gill and brain of exposed fish, but once these fish were removed to a clean environment, depuration occurs. However, tissue levels can remain relatively constant for a period of time. It may take weeks to months to reach undetectable levels. After a spill, the pollution load may remain for some time in the natural environment; therefore, the time for depuration in fish will be longer than that reported in laboratory-controlled studies.

Due to the lack of a rapid detoxification system, mollusks are unable to metabolize aromatic hydrocarbons readily. Moderate accumulation of petroleum hydrocarbons can occur in stable tissue compartments with low hydrocarbon turnover (Stegeman and Teal 1973; Neff et al. 1976).

It is reported that bioaccumulation of petroleum hydrocarbons in higher-chain organisms such as fish is found to be low due to their metabolic elimination and detoxification mechanisms (Southworth et al. 1978; Jonsson et al. 2004). There is no evidence that petroleum hydrocarbons biomagnify up the food chain (Broman et al. 1990; Wan et al. 2007; Takeuchi et al. 2009).

Only three studies on bioaccumulation factors (BAFs) of PAHs in aquatic organisms (fish and clams) were found (Neff et al. 1976; Zhou et al. 1997; Burkhard and Lukasewyez 2000). The PAHs studied were one-ring C_6 to C_9, two-ring C_{10} to C_{13} and three-ring C_{14} to C_{18}. As reflected by the findings of Niimi and Dookhran (1989) and Niimi and Palazzo (1986), PAHs were not accumulated by fish through dietary exposure because of the combined effects of poor absorption efficiencies and rapid elimination rates. Hence,

none of the measured BAFs for one-ring aromatics and PAHs in the carbon range C_6 to C_{18} were considered to be high.

For bioaccumulation, the derivation of a bioaccumulation factor (BAF) is preferred over a bioconcentration factor (BCF), because the latter does not include chemical exposure through diet (Barron 1990). However, due to the scarcity of measured BAFs available, BCFs from various published works were compiled to provide further evidence for bioaccumulation and BAFs were predicted using kinetic mass-balance modeling (Arnot and Gobas 2003).

A suite of BCFs for components of heavy fuel oils (C_6 to C_{18}) were found (Table A3.7 in Appendix 3), namely for: alkanes, isoalkanes, two-ring cycloalkanes, two-ring cycloalkanes, one-ring aromatics, cycloalkane monoaromatics, cycloalkane diaromatic, and polyaromatics (Carlson et al. 1979; CITI 1992; Tolls and van Dijk 2002; Jonsson et al. 2004; Yakata et al. 2006; EMBSI 2004, 2005a, b, 2006, 2007, 2008f, 2009; JNITE 2010). Of the 31 components studied, only a C_{13} two-ring aromatic, 2-isopropyl naphthalene had a BCF > 5000. However, this isopropyl functional group was considered to be atypical of petroleum hydrocarbons (Lampi et al. 2010). The remaining measured BCF show that this fraction is not expected to highly bioconcentrate in fish via water-borne exposures (Table A3.7 Appendix 3).

The BCF and BAF model estimates for the 11 C_{15} to C_{20} linear and cyclic representative structures range from 219–470 000 (Table A3.6 in Appendix 3). There are no measured BCF or BAF data for this particular carbon fraction. Only the C_{15} two ring cycloalkanes were predicted to have a BCF greater than 5000 suggesting a lower potential for uptake from the water for this carbon range in general. However, the carbon range around C_{15} appear to be highly bioaccumulative via the diet as most of the BAFs predicted for the cycloalkane and aromatic components in this carbon fraction exceed 5000 (Tables A3.6 in Appendix 3). The BCF and BAF predictions for the C_{15} fraction are within the parametric, mechanistic and metabolic domains of the model and so are considered reliable.

Most components > C_{20} have an estimated log K_{ow} > 8 and were excluded from the modeling, as predictions may be highly uncertain due to limitations of the model (Arnot and Gobas 2003). In Arnot and Gobas (2006a), at a log K_{ow} of 8.0, the empirical distribution of "acceptable" fish BCF data shows that there are very few chemicals with fish BCFs exceeding 5000. Examination of Environment Canada's empirical BCF/BAF database for DSL and non-DSL chemicals developed by Arnot and Gobas (2003b) and further by Arnot (2005, 2006b) shows that these are only highly chlorinated substances (i.e., decachlorobiphenyl, nonachlorobiphenyl, heptachlorobiphenyl), which have BCFs in the 10^5 range noting that octachloronaphthalene has a measured BCF of <1000 (Fox et al. 1994, Gobas et al. 1989, Oliver and Niimi 1988) and all have log K_{ow} values less than 9.0. The log K_{ow} of the C_{20} cyclo alkane fraction and >C_{20} fractions is ~9.0 or greater than 9.0. At this log K_{ow} there are no empirically observed BCF (laboratory) or BAF values recorded for any species of invertebrates or vertebrates. This is most likely a result of very low bioavailability (and thus poor dietary assimilation

efficiency). Therefore the predicted BCF and BAF values for the $>C_{20}$ fraction are considered to be out of the parametric domain of the Arnot-Gobas model (2003) and considered as being highly uncertain and not reliable values. The bioaccumulation potential of the $>C_{20}$ fraction is thus expected to be very low which means the BCFs and BAFs for these fractions is also very likely < 5000.

Based on reported data, aquatic organisms readily take up petroleum hydrocarbons, primarily into lipids. Moderate concentrations can be found in some muscle and internal organs of fish based on chronic concentration of petroleum hydrocarbons and the distribution of fatty tissues. When fish are no longer exposed to these substances, depuration occurs quickly. Observed reductions in tissue burdens of hydrocarbons with increasing exposure time indicate biotransformation in fish. The tendency for specific types of petroleum hydrocarbons (PHC) to bioaccumulate in tissues suggests that these compounds could be transferred at low concentrations into the food chain, although they do not bioaccumulate to high levels or biomagnify in food chains. This pattern of uptake and depuration also indicates that pulsed exposures likely would not result in bioaccumulation over the long term.

Based on the combined evidence of empirical and modeled BCFs and BAFs, the HFOs assessed in this report contain large proportions of components that are highly bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations* (Canada 2000).

No components of these HFOs were found to be both persistent and bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations.*

Potential to Cause Ecological Harm

Ecological Effects Assessment

Limited experimental aquatic toxicity data were obtained for several of the HFO CAS RNs considered here (EMBSI 2008a, b, c).

The experimental toxicity data for CAS RN 64741-80-6 (Table A3.8 in Appendix 3) indicate that at moderate concentrations, this HFO does not have a harmful effect on rainbow trout, green algae or water flea. However, the HFO tested was a relatively heavy fraction and therefore did not contain many of the C_{15} to C_{20} hydrocarbons that would likely contribute to aquatic toxicity.

CONservation of Clean Air and Water in Europe (CONCAWE) developed an aquatic toxicity model specific to petroleum hydrocarbon mixtures called PetroTox (2009). PetroTox assumes toxicological action via narcosis and therefore accounts for additive effects according to the toxic unit approach (PetroTox 2009). It models the toxicity of petroleum hydrocarbons dissolved in the water fraction for C_5-C_{41} compounds;

compounds smaller than C_5 are considered by the model to be too volatile to remain in water long enough to impart any significant aquatic toxicity, and compounds greater than C_{41} are assumed too hydrophobic and immobile to impart any toxicity. PetroTox generates estimates of toxicity with a median lethal loading concentration (LL_{50}) rather than a median lethal concentration (LC_{50}) due to the insolubility of petroleum substances in water. The LL_{50} value is the amount of petroleum substances needed to generate a water-accommodated fraction (WAF) that is toxic to 50% of the test organisms. It is not a measure of the concentration of the petroleum components in the WAF.

A range of aquatic toxicity predictions were obtained using the PetroTox (2009) model (Table A3.9 in Appendix 3). These results indicate that all of these HFOs are potentially hazardous to many aquatic organisms (acute $LL_{50} \leq 1.0$ mg/L), although some CAS RNs are not hazardous to some marine organisms. The estimated toxicity values are much lower than the experimental data from EMBSI (2008a, b, c). PetroTox (2009) estimates that the bulk of the toxicity of these CAS RNs is due to the C_{15}-C_{25} di- and polyaromatic fractions; those CAS RNs that are not hazardous to some marine organisms tend to have higher boiling-point ranges.

To determine whether the PetroTox modelled data are appropriate, a read-across approach was used to compare HFO-modelled toxicity to Fuel Oil No. 6 (Bunker C fuel oil) toxicity. Fuel Oil No. 6 is a dense viscous oil with a wide boiling-point range of 160–700ºC (Environment Canada 2010). Table A3.10 in Appendix 3 presents Fuel Oil No. 6 acute toxicity data to aquatic organisms.

Aquatic LC_{50} values for Fuel Oil No. 6 range from 0.9 to 4.6 mg/L. These values fall within the range of 0.1 to 18.6 mg/L for many of the modelled LL_{50}s for HFOs from PetroTox (Table A3.10 in Appendix 3). Therefore, the modelled data are considered to reflect the toxicity of a similar, commercially available, heavy fuel oil. An average toxicity value to *Rhepoxynius abronius* of 0.1 mg/L is the lowest LL_{50} generated by PetroTox under an acute exposure to a marine amphipod. This will be the critical toxicity value (CTV) for marine exposures because no other ecotoxicity data were identified.

Terrestrial Compartment

Acute toxicity tests were not identified for any of the CAS RNs considered in this report, but identified for other PSSA HFOs. In an acute oral study conducted in rats, clear indications of intoxication were evident up to 24 hours post-treatment after a single dose of 2000 milligram/kilogram-body weight (mg/kg-bw) of CAS RN 64742-90-1 (steam-cracked residue) (ECB 2000b). An oral LD_{50} of 5500 mg/kg-bw was established (after 14 days of observation) in rats after a single oral exposure to Fuel Oil No. 6 (Bunker C oils from various European manufacturers). Total (100%) mortality was observed at 10 000 and 25 000 mg/kg-bw in the same study (ECB 2000b). Catalytically cracked clarified oil (CAS RN 64741-62-4) exhibited an oral LD_{50} of 4320 mg/kg-bw (after 14 days of observation) after a single exposure to rats. A dermal LD_{50} of >3 160 mg/kg-bw in rabbits for CAS RN 64742-90-1 was identified (ECB 2000a).

Ecological Exposure Assessment

The subset of HFOs considered in this report have been identified as site-restricted, indicating that they are not expected to be transported off or released from refinery or upgrader facility sites. Release to the ecosystem is therefore expected to be negligible and exposure is not expected.

Characterization of Ecological Risk

All of these HFOs contain high proportions of components (mostly $\geq C_{30}$) that are persistent based on criteria in the *Persistence and Bioaccumulation Regulations* (Canada 2000).

Based on the combined evidence of empirical and modeled data on bioconcentration and/or bioaccumulation, the HFOs assessed in this report likely contain a large proportion of C_{15}-C_{20} components that are highly bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations* (Canada 2000).

No components of these HFOs were found to be both persistent and bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations.*

Based on information obtained from a variety of sources (voluntary industry submissions, an in-depth literature review, and a search of material safety data sheets), the HFOs considered in this screening assessment have been identified as site-restricted - i.e., they are not expected to be transported off refinery or upgrader facility sites. These HFOs are consumed on-site or are blended into other substances leaving the site under different CAS RNs. Measures (including provincial/territorial operating permit requirements, and best practices and guidelines put in place by the petroleum industry) are in place to minimize releases from refineries and upgrader facilities. As a result of these factors, the likelihood of exposure, and potential for risk, of organisms in the environment to HFOs under these CAS RNs is considered to be low.

Uncertainties in Evaluation of Ecological Risk

The site-restricted HFOs are UVCBs and therefore their specific chemical compositions are not well defined. HFO streams under the same CAS RN can vary significantly in the number, identity and proportion of constituent compounds, depending on operating conditions, feedstocks and processing units.

All modelling of a substance's physical and chemical properties and persistence, bioaccumulation and toxicity characteristics is based on chemical structures. Since these substances are UVCBs, they cannot be represented by a single, discrete chemical structure. Therefore, for the purposes of modelling, representative structures that would provide conservative estimates were identified. Given that more than one representative structure may be derived for the same UVCB, it is recognized that structure-related uncertainties exist for these substances. The physical-chemical properties of 30

representative structures were used to estimate the overall behaviour of the HFOs. The reliance on this method generates additional uncertainties in persistence and bioaccumulation predictions. CAS RN 68476-32-4 did not have an identified carbon range or boiling-point range. As such, it was assumed to behave in a similar fashion to the other site-restricted HFOs identified in this report. However, a lack of information on this CAS RN adds considerable uncertainty if its chemical structures differ significantly from that of the other HFOs in this assessment.

As these substances are classified as site-restricted, environmental releases and exposures are expected to be negligible. However, monitoring data for specific CAS RN were not identified to verify this assumption.

Potential to Cause Harm to Human Health

Health Effects Assessment

There are only a limited number of studies evaluating the health effects of site-restricted HFOs available. Therefore, in order to characterize the toxicity of these substances, additional HFOs in the PSSA— similar from both a process and physical-chemical perspective—were evaluated for their toxicological effects. Since both the site-restricted and the additional PSSA high priority HFO substances have similar physical-chemical and toxicological properties, the toxicological data were pooled across CAS RNs to construct a toxicological profile representative of all HFOs. This approach was taken in order to represent the toxicity of HFOs as a group. Appendix 4 contains a summary of available information on health effects for site-restricted HFO substances and the lowest-observed-adverse-effect-levels/concentrations (LOAELs/LOAECs) observed from the pooled toxicological data.

The HFO category of petroleum mixtures represented in Appendix 4 includes both residual fuels from distillation or cracking units and blended products, and consists of aromatic, aliphatic and cycloalkane hydrocarbons; heavy fuels may also contain hydrogen sulphide.

The acute toxicity of HFOs generally appears to be low. Oral median lethal dose (LD_{50}) values were found to range from >2000 to >25 000 mg/kg-bw in rats. Dermal LD_{50} values ranged from >2000 to >5350 mg/kg-bw in rabbits and >2000 mg/kg-bw in rats. One inhalation study noted a median lethal concentration (LC_{50}) value of >3700 mg/m^3 in rats (CONCAWE 1998; ECB 2000a; API 2004; US EPA 2005). Minimal to moderate skin irritation was observed in all cases of acute dermal exposure. Available data indicate that the HFOs or components tested are generally minimally irritating to the eye (CONCAWE 1998).

Short-term and subchronic dermal toxicity studies conducted over periods of 3 days to 13 weeks are available for HFO substances. Minimal to severe skin irritation was observed in all rat studies; the lowest dose examined for skin irritation was 8 mg/kg-bw per day

(Mobil 1994a, b). Selected systemic effects observed in these studies include: mortality, reduced body weight gain and body weight, changes in specific organ weights (i.e., liver and thymus), reduced haematology parameters (e.g., haemoglobin, erythrocytes and platelets) and aberrant serum chemistry (UBTL 1990, 1994; API 1983; Mobil 1988, 1990, 1992, 1994a, b; Feuston et al. 1994, 1997). For short-term exposure, a LOAEL of 1 mg/kg-bw per day was determined for maternal toxicity following dermal exposure of pregnant CD rats to catalytically cracked clarified oil (CAS RN 64741-62-4) at doses of 0.05, 1.0, 10, 50 or 250 mg/kg-bw per day from gestational days 0 to 19. Effects noted at the LOAEL include: significantly decreased maternal body weight, decreased body weight gain and feed consumption, as well as decreased gravid uterine weight and the occurrence of red vaginal exudates (Hoberman et al. 1995). For subchronic exposure, a LOAEL of 8 mg/kg-bw per day was established following dermal exposure of male and female rats to CAS RNs 64741-62-4 or 64741-81-7 at doses of 8, 30, 125, 500 or 2000 mg/kg-bw per day for 13 weeks. Effects noted at the LOAEL include: decreased platelet counts and increased liver weight, as well as dose-related skin irritation (Feuston et al. 1994, 1997; Mobil 1988, 1992, 1994b).

One short-term inhalation study was conducted using CAS RN 64742-90-1. A LOAEC of 540 mg/m^3 for decreased body weight and increased liver weight was observed in Fisher 344 rats following administration of 540 or 2000 mg/m^3, 6 hours per day for 9 days (Gordon 1983).

In a short-term oral toxicity study conducted for CAS RN 64741-62-4, a single dose of 2000 mg/kg or single doses of 125, 500 or 2000 mg/kg were administered to pregnant Sprague-Dawley rats on one of gestational days 11–15 or on gestational day 12, respectively. Decreased maternal body weight gain and thymus weights were reported, regardless of treatment day, for the gestational-day segment of the study. Dose-related decreased maternal body weight gain and thymus weights were reported for the dose-response segment of the study (Feuston and Mackerer 1996). There were no subchronic or chronic oral toxicity studies available in the HFO literature.

The genotoxicity of HFOs has been evaluated with *in vivo* and *in vitro* assays. Results of *in vivo* genotoxicity testing with HFO substances were mixed; three HFO substances were assessed. Positive results were observed for micronuclei induction, unscheduled deoxyribonucleic acid (DNA) synthesis (UDS) and sister chromatid exchange assays conducted in rats and mice (Khan and Goode 1984; API 1985a, b). Negative results were observed for micronuclei induction and bone marrow chromosomal aberrations in two studies assessing a heavy-vacuum gas oil and a catalytically cracked clarified oil, respectively, in rats (API 1985c; Mobil 1987a).

In vitro assays evaluating the genotoxicity of HFOs also produced mixed results. Positive results were obtained in the Ames, modified Ames and mouse lymphoma assays, as well as for unscheduled DNA synthesis and cell transformation (API 1985c, d, 1986a; Blackburn et al. 1984, 1986; Mobil 1985; Feuston et al. 1994, Brecher and Goode 1983, 1984). Regarding Fuel Oil No. 6, negative results were obtained in the mouse lymphoma and Ames assays (for forward and reverse mutations), as well as for sister chromatid

exchange. Negative results for other HFOs were limited and observed only in one forward mutation assay and one cell-aberration assay (Farrow et al. 1983; API 1985e; Vandermeulen et al. 1985; Vandermeulen and Lee 1986; Mobil 1987b). Equivocal results were observed in a mouse embryo transformation assay, in a forward mutation assay and in one sister chromatid exchange assay (Papciak and Goode 1984; API 1985f, 1986b). The overall genotoxicity database indicates that while the results varied depending on the substance tested and the assay used, HFOs display genotoxic potential.

HFOs have been classified by the European Commission as Category 2 carcinogens (*may cause cancer*) (European Commission 1994; ESIS 2008) and by the International Agency for Research on Cancer (IARC) as Group 2B carcinogens (*possibly carcinogenic to humans*) for residual (heavy) fuel oils (IARC 1989a).

A number of skin painting studies were conducted in mice, rabbits and monkeys to investigate the dermal carcinogenic potential of HFOs using both chronic and initiation/promotion methodologies. Skin tumours, including both malignant carcinomas and benign papillomas, were observed in all studies (Smith et al. 1951; Shapiro and Getmanets 1962; Getmanets 1967; Shubik and Saffiotti 1955; Saffiotti and Shubik 1963; API 1989a, b; McKee et al. 1990; Blackburn et al. 1984, 1986; Bingham and Barkley 1979; Bingham et al. 1980; Lewis 1983; Weil and Condra 1977; Sun Petroleum Products Co. 1979). Exposure durations for the chronic studies ranged from 25 weeks to the animals' lifetimes, with reported tumour latency periods ranging from 8 to 113 weeks. In several studies, however, the durations of exposures and latencies were not specified (IARC 1984, 1989a, b; CONCAWE 1998). In a chronic study, male mice were dermally treated with CAS RN 64741-62-4 at doses of 8.4, 16.8, 42, 83.8 or 167.6 mg/kg-bw, three times per week for a lifetime. Significant skin tumour formation was observed at all doses in a dose-response fashion (McKee et al. 1990). In the one initiation study that was identified, male mice were dermally treated with CAS RN 64741-62-4 at a dose of 16.8 mg/kg-bw for five consecutive days. Significant skin tumour formation was observed at this dose. In the corresponding promotion study, no increase in histologically confirmed tumour incidence was observed. A statistically significant increase in the number of mice with gross masses (and shortened latency periods) was observed, however, indicating possible weak promoting activity (API 1989a).

Regarding tumorigenicity of HFOs, it is recognized that they may contain appreciable concentrations of minor constituents such as PAHs, and the quantity of this fraction can vary depending on the nature and amount of diluent fractions and whether the residue component is cracked or uncracked. The Government of Canada has completed a human health risk assessment of five PAHs, consisting of a critical review of relevant data under the Priority Substances Program. Based primarily on the results of carcinogenicity bioassays in animal models, these PAHs were classified as "probably carcinogenic to humans:" substances for which there is believed to be some chance of adverse effects at any level of exposure (Environment Canada 1994). Further assessment of minor constituents is beyond the scope of the current assessment.

HFOs have also been investigated for their reproductive and developmental effects. A LOAEL of 1.0 mg/kg-bw per day was identified for reproductive and developmental toxicity after dermal exposure of pregnant rat dams to catalytically cracked clarified oil (CAS RN 64741-62-4) during gestational days 0 to 19 (the no-observed-adverse-effect-level (NOAEL) was 0.05 mg/kg-bw per day). Reproductive effects included decreased number of live foetuses and increased incidences of resorptions, early resorptions and percent of dead or resorbed conceptuses per litter. Foetal developmental variations were also observed in this study but were determined not to be treatment-related (Hoberman et al. 1995). In another short-term dermal study, a LOAEL of 8 mg/kg-bw per day was established for treatment-related developmental toxicity after exposing pregnant Sprague-Dawley rats to CAS RN 64741-62-4 during gestation (Feuston et al. 1989; Mobil 1987c). Developmental effects included a low incidence of foetal external abnormalities including cleft palate, micrognathia (shortened lower jaw) and kinked tail.

Only one oral reproductive and developmental study was identified for any HFO substance. A LOAEL of ≥125 mg/kg was established based on a dose-related increase in resorptions (concomitant decrease in litter size), decreased foetal body weight and increased incidences of skeletal malformations in this acute study that exposed pregnant Sprague-Dawley rats to CAS RN 64741-62-4 during gestation (Feuston and Mackerer 1996). No reproductive or developmental toxicity studies were identified for any HFO substance via the inhalation route of exposure.

Although results varied depending on the substance tested, the overall weight-of-evidence suggests that HFOs exhibit reproductive and developmental toxicity in laboratory animals.

Epidemiological data were not available for consideration in the human health effects evaluation of HFO substances.

Characterization of Risks to Human Health

Site-restricted HFOs were identified as a high priority for action because they were considered to present a high hazard to human health. A critical effect for the initial categorization of site-restricted HFO substances was carcinogenicity, based primarily on the classifications of HFOs by international agencies. These substances are classified by the European Commission as Category 2 carcinogens (European Commission 1994; ESIS 2008) and by IARC as Group 2B carcinogens (IARC 1989a). However, the HFOs considered in this report have been identified as site-restricted (i.e., indicating that they are not expected to be transported off refinery or upgrader facility sites), and therefore general population exposure is expected to be negligible. Accordingly, the likelihood of exposure to Canadians is considered to be low; hence, the risk to human health is likewise considered to be low.

Uncertainties in Evaluation of Human Health Risk

The site-restricted HFOs are considered to be UVCBs and their specific chemical compositions are not well defined. HFO streams under the same CAS RN can vary significantly in the number, identity and proportion of constituent compounds, depending on operating conditions, feedstocks and processing units. Consequently, it is difficult to obtain a truly representative toxicological data set for individual CAS RNs. For this reason all available toxicological data for substances with similar petroleum processing and physical-chemical properties were pooled across multiple CAS RNs to develop a comprehensive toxicity profile by including the available data for all HFOs. Specific physical-chemical properties of some HFOs were not available, therefore, properties of representative HFOs were used as needed.

The scope of this screening assessment does not involve full investigation of the mode of induction of effects.

The PSSA screening assessments evaluate substances that are complex mixtures (UVCBs) composed of a number of substances in various proportions due to the source of the crude oil and its subsequent processing. Monitoring information or provincial release limits from petroleum facilities target broad releases such as oils and greases to water or air. These widely encompassing release categories do not allow for detection of individual complex mixtures or production streams. As such, the monitoring of broad releases cannot provide sufficient data to associate a detected release with a specific substance identified by a CAS RN, nor can the proportion of releases attributed to individual CAS RNs be defined.

Conclusion

All of the HFOs considered in this assessment may be comprised of significant proportions of components (mostly $\geq C_{30}$) that persist in soil, water and sediments based on criteria in the *Persistence and Bioaccumulation Regulations* (Canada 2000).

Based on the combined evidence of empirical and modeled bioconcentration/ bioaccumulation potential, the HFOs assessed in this report likely contain a large proportion of C_{15}-C_{20} components that are highly bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations*.

No components of these HFOs were found to be both persistent and bioaccumulative based on criteria in the *Persistence and Bioaccumulation Regulations.*

Based on the information presented in this screening assessment, the basis for categorization for human health hazard was carcinogenicity. HFOs also exhibit properties of genetic toxicity and appear to adversely affect reproduction and development.

The HFOs listed in this screening assessment (CAS RNs 64741-45-3, 64741-61-3, 64741-80-6, 68333-22-2, 68333-27-7, 68476-32-4 and 68478-17-1) are restricted to petroleum refineries and upgrader facilities; therefore, exposure of the general population

and the environment is not expected. It is concluded that these site-restricted HFOs are not entering 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; that constitute or may constitute a danger to the environment on which life depends; or that constitute or may constitute a danger in Canada to human life or health.

It is therefore concluded that these site-restricted HFOs do not meet any of the criteria set out in section 64 of CEPA 1999.

Because these substances are listed on the Domestic Substances List, their import and manufacture in Canada are not subject to notification under subsection 81(1) of CEPA 1999. Given the potential hazardous properties of these substances, there is concern that new activities that have not been identified or assessed could lead to these substances meeting the criteria set out in section 64 of the Act. Therefore, application of the Significant New Activity provisions of the Act to these substances is being considered, so that any proposed new manufacture, import or use of these substances outside a petroleum refinery or upgrader facility is subject to further assessment, to determine if the new activity requires further risk management consideration.

References

[ATSDR] Agency for Toxic Substances and Disease Registry. 1995. Toxicological profile for fuel oils. Atlanta (GA): US Department of Health and Human Services, Public Health Service. [cited 2009 Aug 1]. Available from: http://www.atsdr.cdc.gov/toxprofiles/tp75.pdf.

[API] American Petroleum Institute. 1983. A 28-day dermal toxicity study of catalytic cracked clarified oil, API sample 81-15. Study conducted by Borriston Laboratories Inc. Washington (DC): American Petroleum Institute. API Medical Research Publication 30-32854. [cited in CONCAWE 1998; ECB 2000a, b].

[API] American Petroleum Institute. 1985a. An evaluation of the potential of RO-1, 81-15 and PS8-76D5-SAT to induce unscheduled DNA synthesis (UDS) in the *in-vivo/in-vitro* hepatocyte DNA repair assay. Study conducted by SRI International. Washington (DC): American Petroleum Institute. API Medical Research Publication 32-32406. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1985b. *In-vivo* sister chromatid exchange (SCE) assay. API sample 81-15 catalytically cracked clarified oil (CAS 64741-62-4). Study conducted by Microbiological Associates Inc. Washington (DC): American Petroleum Institute. API Health and Environmental Sciences Department Report 32-32254. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1985c. Mutagenicity evaluation studies of catalytically cracked clarified oil. API sample 81-15 in the rat bone marrow cytogenetic assay and in the mouse lymphoma forward mutation assay. Study conducted by Litton Bionetics Inc. Washington (DC): American Petroleum Institute. API Medical Research Publication 32-30534. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1985d. An evaluation of the potential of RO-1, 81-15 and PS8-76D5-SAT to induce unscheduled DNA synthesis (UDS) in primary rat hepatocyte cultures. Study conducted by SRI International. Washington (DC): American Petroleum Institute. API Medical Research Publication 32-32407. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1985e. CHO/HGPRT (Chinese hamster ovary/hypoxanthine-guanine phosphoribosyl transferase) mammalian cell forward gene mutation assay of API sample 81-15 catalytic cracked clarified oil (CAS 64741-62-4). Study conducted by Pharmakon Research International Inc. Washington (DC): American Petroleum Institute. API Medical Research Publication 32-32118. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1985f. Sister chromatid exchange (SCE) assay in Chinese hamster ovary (CHO) cells. API sample 81-15 catalytically cracked clarified oil (CAS 64741-62-4). Study conducted by Microbiological Associates Inc. Washington (DC): American Petroleum Institute. API Health and Environmental Sciences Department Report 32-32750. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1986a. *Salmonella*/mammalian-microsome plate incorporation mutagenicity assay (Ames test). Study conducted by Microbiological Associates Inc. Washington (DC): American Petroleum Institute. API Medical Research Publication 33-30599. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1986b. Morphological transformation of BALB/3T3 mouse embryo cells. API sample 81-15 catalytically cracked clarified oil (CAS 64741-62-4). Study conducted by Microbiological Associates Inc. Washington (DC): American Petroleum Institute. API Health and Environmental Sciences Department Report 33-32638. [cited in CONCAWE 1998; ECB 2000a; API 2004].

[API] American Petroleum Institute. 1989a. Short-term dermal tumorigenesis study of selected petroleum hydrocarbons in male CD-1 mice. Initiation and promotion phases. Study conducted by IIT Research

Institute. Washington (DC): American Petroleum Institute. API Health and Environmental Sciences Department Report 36-32643. [cited in CONCAWE 1998].

[API] American Petroleum Institute. 1989b. Lifetime dermal carcinogenesis/chronic toxicity screening bioassay of refinery streams in C3H/HeJ mice (AP-135r). Study conducted by Primate Research Institute, New Mexico State University. Washington (DC): American Petroleum Institute. API Health Environmental Sciences Department Report 36-31364. [cited in CONCAWE 1998; cited in ECB 2000a].

[API] American Petroleum Institute. 2004. High Production Volume (HPV) Challenge Program. Robust summary of information on heavy fuel oils. Summary prepared by the American Petroleum Institute. Available from: http://www.epa.gov/hpv/pubs/summaries/heavyfos/c15368rs.pdf

Anderson JW, Neff JM, Cox BA, Tatem HE, Hightower GM. 1974. Characteristics of dispersions and water-soluble extracts of crude oil and refined oils and their toxicity to estuarine crustaceans and fish. Mar Biol 27:75-88.

Arnot J, Gobas F. 2003. A generic QSAR for assessing the bioaccumulation potential of organic chemicals in aquatic food webs. QSAR and Combinatorial Science 22:337-345.

Arnot JA. 2005. Bioconcentration factor and bioaccumulation factor assessments for organic chemicals on the Canadian domestic substances list: Task 1: Supplementation of Environment Canada's BCF database. Report to Environment Canada, New Substances Branch. March.

Arnot, JA, Gobas F. 2006a. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. Environ. Rev. 14:257-297.

Arnot JA 2006b. Bioconcentration factor and bioaccumulation factor assessments for organic chemicals on the Canadian domestic substances list: Database update. Report to Environment Canada, New Substances Branch. March.

[AOPWIN] Atmospheric Oxidation Program for Windows [Estimation Model]. 2008. Version 1.92a. Washington (DC): US Environmental Protection Agency, Office of Pollution Prevention and Toxics; Syracuse (NY): Syracuse Research Corporation. Available from: http://www.epa.gov/oppt/exposure/pubs/episuite.htm.

Banerjee S. 1984. Solubility of organic mixtures in water. Environ Sci Technol 18:587-591.

Barron MG. 1990. Bioconcentration. Environ. Sci. Technol. 24:1612-1618.

Bingham E, Barkley W. 1979. Bioassay of complex mixtures derived from fossil fuels. Environ Health Perspect 30:157-163 [cited in IARC 1984].

Bingham E, Trosset RP, Warshawsky D. 1980. Carcinogenic potential of petroleum hydrocarbons: a critical review of the literature. J Environ Pathol Toxicol 3:483–563. [cited in IARC 1989a].

[BCFBAF] BioConcentration Factor Program for Windows [Estimation Model]. 2008a. Version 3.00. Washington (DC): US Environmental Protection Agency, Office of Pollution Prevention and Toxics; Syracuse (NY): Syracuse Research Corporation. Available from: http://www.epa.gov/oppt/exposure/pubs/episuite.htm

[BCFBAF] BioConcentration Factor Program for Windows [Estimation Model]. 2008b. Version 3.00. User Guidance Manual. Washington (DC): US Environmental Protection Agency, Office of Pollution Prevention and Toxics; Syracuse (NY): Syracuse Research Corporation. Available from: http://www.epa.gov/oppt/exposure/pubs/episuite.htm

[BioHCwin] Biodegradation of Petroleum Hydrocarbons Program for Windows [Estimation Model]. 2008. Version 1.01a. Washington (DC): US Environmental Protection Agency, Office of Pollution Prevention and Toxics; Syracuse (NY): Syracuse Research Corporation. Available from: http://www.epa.gov/oppt/exposure/pubs/episuite.htm.

[BIOWIN] Biodegradation Probability Program for Windows [Estimation Model]. 2008. Version 4.10. Washington (DC): US Environmental Protection Agency, Office of Pollution Prevention and Toxics; Syracuse (NY): Syracuse Research Corporation. Available from: http://www.epa.gov/oppt/exposure/pubs/episuite.htm.

Blackburn GR, Deitch RA, Schreiner CA, Mehlman MA, Mackerer CR. 1984. Estimation of the dermal carcinogenic activity of petroleum fractions using a modified Ames assay. Cell Biol Toxicol 1:67-80. [cited as original article and in IARC 1989b].

Blackburn GR, Deitch RA, Schreiner CA, Mackerer CR. 1986. Predicting carcinogenicity of petroleum distillation fractions using a modified *Salmonella* mutagenicity assay. Cell Biol Toxicol 2:63-84. [cited as original article and in IARC 1989b].

Boethling RS, Howard PH, Beauman JA, Larosche ME. 1995. Factors for intermedia extrapolations in biodegradability assessment. Chemosphere 30(4):741-752.

Brecher S, Goode JW. 1983. BALB/3T3 transformation test. Aromatic pyrolysis oil. Project No. 2084. Prepared by Gulf Life Sciences Center, Pittsburgh, Pennsylvania, for Gulf Oil Chemicals Co., Houston, Texas. [cited in US EPA 2005].

Brecher S, Goode JW. 1984. Hepatocyte primary culture/DNA repair test of aromatic pyrolysis oil. Project No. 2083. Prepared by Gulf Life Sciences Center, Pittsburgh, Pennsylvania, for Gulf Oil Chemicals Co., Houston, Texas. [cited in US EPA 2005].

Broman DC, Lindberg NC, Zwbuhr Y. 1990. An in-situ study on the distribution, biotransformation and flux of polycyclic aromatic hydrocarbons (PAHs) in an aquatic food chain (seston-*Mytilus edulis L.*-*Somateria mollissima*) from the Baltic: an ecotoxicological perspective. Environ Toxicol Chem 9:429-442.

Burkhard L, Lukasewycz M. 2000. Some bioaccumulation factors and biota-sediment accumulation factors for polycyclic aromatic hydrocarbons in lake trout. Environ Toxicol Chem 19(5):1427-1429.

Canada. 1999. Canadian Environmental Protection Act, 1999. S.C., 1999, c. 33. Available from: http://www.gazette.gc.ca/archives/p3/1999/g3-02203.pdf.

Canada. 2000. *Canadian Environmental Protection Act, 1999: Persistence and Bioaccumulation Regulations*, P.C. 2000-348, 23 March 2000, SOR/2000-107. Available from: http://www.gazette.gc.ca/archives/p2/2000/2000-03-29/pdf/g2-13407.pdf.

[CanLII] Canadian Legal Information Institute [databases on the Internet]. 2001–. Ottawa (ON): Canadian Legal Information Institute. [cited 2009]. Available from: http://www.canlii.org/en/index.php.

Carlson RM, Oyler AR, Gerhart EH, Caple R, Welch KJ, Kopperman HL, Bodenner D, Swanson D. 1979. Implications to the aquatic environment of polynuclear aromatic hydrocarbons liberated from northern great plans coal. US EPA Environmental Research Laboratory (EPA 600/3-79-093).

[CITI] Chemicals Inspection and Testing Institute. 1992. Bioaccumulation and biodegradation data on existing chemicals based on the CSCL Japan. Tokyo, Japan.

Colombo J, Cappelletti N, Migoya M, Speranza E. 2007. Bioaccumulation of anthropogenic contaminants by detritivorous fish in the Río de la Plata estuary: 1-Aliphatic hydrocarbons. Chemosphere 68:2128-2135.

[CONCAWE] CONservation of Clean Air and Water in Europe. 1998. Heavy fuel oils. Prepared by CONCAWE's Petroleum Products and Health Management Groups. Brussels (BE): CONCAWE. Product Dossier No. 98/109.

Cravedi J, Tulliez J. 1983. Hydrocarbon disposition, lipid content, and fatty acid composition in trout after long-term dietary exposure to *n*-alkanes. Environ Res 32(2):398-413.

[EETD] Environmental Emergencies Technology Division, *experimental data,* Environment Canada, Ottawa, ON, 1989 [cited in Environment Canada 2010].

Environment Canada. 1994. Polycyclic Aromatic Hydrocarbons. ISBN 0-662-22209-1, Cat. No. En40-215/42E. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl1-lsp1/hydrocarb_aromat_polycycl/index-eng.php.

Environment Canada. 2007. Guidance for conducting ecological assessments under CEPA, 1999: science resource technical series, draft module on QSARs. Unpublished information. Environment Canada, Existing Substances Division.

Environment Canada. 2008. Data for petroleum sector stream substances collected under the *Canadian Environmental Protection Act, 1999*, Section 71: Notice with respect to certain high priority petroleum substances. Data prepared by: Environment Canada, Oil, Gas, and Alternative Energy Division.

Environment Canada. 2009. Data for petroleum sector stream substances collected under the *Canadian Environmental Protection Act, 1999*, Section 71: Notice with respect to potentially industry-limited high priority petroleum substances. Data prepared by: Environment Canada, Oil, Gas, and Alternative Energy Division.

Environment Canada. 2010. Oil properties database. Available online from: http://www.etc-cte.ec.gc.ca

[EPIsuite] Estimation Programs Interface Suite for Microsoft Windows [Estimation Model]. 2008. Version 3.4. Washington (DC): US Environmental Protection Agency, Office of Pollution Prevention and Toxics; Syracuse (NY): Syracuse Research Corporation. Available from: http://www.epa.gov/oppt/exposure/pubs/episuite.htm.

[ECB] European Chemicals Bureau. 2000a. IUCLID dataset for clarified oils (petroleum), catalytic cracked (CAS No. 64741-62-4). Available from: http://ecb.jrc.ec.europa.eu/iuclid-datasheet/64741624.pdf.

[ECB] European Chemicals Bureau. 2000b. IUCLID dataset for fuel oil, No. 6. (CAS No. 68553-00-4). Available from: http://ecb.jrc.ec.europa.eu/iuclid-datasheet/68553004.pdf.

[ECB] European Chemicals Bureau. 2000c. IUCLID dataset for distillates (petroleum), hydrodesulfurized intermediate catalytic cracked (CAS No. 68333-27-7). Available from: http://ecb.jrc.ec.europa.eu/iuclid-datasheet/68333277.pdf.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2004 (unpublished). Fish, aqueous bioaccumulation study. Study No. 0409544. Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2005a (unpublished). Fish, dietary bioaccumulation study. Study No. 0409547. Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2005b (unpublished). Fish, aqueous bioaccumulation test. Study No. 0523644. Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2006 (unpublished). Fish, dietary bioaccumulation test. Study No. 0681647. Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2007 (unpublished). Fish, dietary bioaccumulation study. Study No. 0796347T. Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2008a (unpublished). Alga, growth inhibition test, final report. Study No. 0791367. Test substance: Heavy Fuel Oil #9 (MRD-07-915). Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2008b (unpublished). *Daphnia* sp., acute immobilization test, final report. Study No. 0791342. Test substance: Heavy Fuel Oil #9 (MRD-07-915). Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2008c (unpublished). Fish, acute toxicity test, final report. Study No. 0791358. Test substance: Heavy Fuel Oil #7 (MRD-07-913), Heavy Fuel Oil #9 (MRD-07-915). Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2008d (unpublished). Alga, growth inhibition test, final report. Study No. 0790967. Test substance: Heavy Fuel Oil #3 (MRD-07-909). Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2008e (unpublished). *Daphnia* sp., acute immobilization test, final report. Study No. 0790942. Test substance: Heavy Fuel Oil #3 (MRD-07-909). Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2008f (unpublished). Fish, dietary bioaccumulation study. Study No. 0818447. Annandale (NJ): EMSBI.

[EMBSI] ExxonMobil Biomedical Sciences Inc. 2009 (unpublished). Fish, dietary bioaccumulation study. Study No. 0818447. Annandale (NJ): EMSBI.

[ESIS] European Chemical Substances Information System [database on the Internet]. 2008. Database developed by the European Chemicals Bureau (ECB). [cited 2008 Nov 27]. Available from: http://ecb.jrc.it/esis

European Commission. 1994. Commission Directive 94/69/EC of 19 December 1994. Annex II. Official Journal of the European Communities. 31.12.94. L 381, Vol. 37. European Commission. 21st ATP.

Farrow MG, McCarroll N, Cortina T, Draus M, Munson A, Steinberg M, Kirwin C, Thomas W. 1983. *In vitro* mutagenicity and genotoxicity of fuels and paraffinic hydrocarbons in the Ames, sister chromatid exchange, and mouse lymphoma assays [Abstract No. 144]. Toxicologist 3:36. [cited in IARC 1989a].

Feuston MH, Kerstetter SL, Singer EJ, Mehlman MA. 1989. Developmental toxicity of clarified slurry oil applied dermally to rats. Toxicol Ind Health 5(3):587-599.

Feuston MH, Low LK, Hamilton CE, Mackerer CR. 1994. Correlation of systemic and developmental toxicities with chemical component classes of refinery streams. Fundam Appl Toxicol 22:622-630.

Feuston MH, Mackerer CR. 1996. Developmental toxicity of clarified slurry oil, syntower bottoms, and distillate aromatic extract administered as a single oral dose to pregnant rats. J. Toxicol Environ Health 49(1) 45-66.

Feuston MH, Hamilton CE, Mackerer CR. 1997. Systemic and developmental toxicity of dermally applied syntower bottoms in rats. Fundam Appl Toxicol 35:166-176.

Fong WC. 1976. Uptake and retention of Kuwait crude oil and its effects on oxygen uptake by the soft-shell clam *Mya arenaria*. J Fish Res Board Can 33(12):2774-2780.

Fox K, Zauke G, Butte W. 1994. Kinetics of Bioconcentration and Clearance of 28 Polychlorinated Biphenyl Congeners in Zebrafish (Brachydanio rerio). Ecotoxicol. Environ. Saf. 28(1):99-109.

Getmanets, IY. 1967. Comparative evaluation of the carcinogenic properties of cracking residues of high- and low-paraffin petroleum. Gig Tr prof Zabol 11:53-55 [cited in IARC 1989b].

Gobas F, Clark K, Shiu W, Mackay D. 1989. Bioconcentration of polybrominated benzenes and biphenyls and related superhydrophobic chemicals in fish: role of bioavailability and elimination into the feces. Environ. Toxicol. Chem 8:231-245.

Gordon T. 1983. Nine-day repeated dose inhalation toxicity study in rats. Aromatic pyrolysis oil. Project No. 2035. Prepared by Gulf Life Sciences Center, Pittsburgh, Pennsylvania, for Gulf Oil Chemicals Co., Houston, Texas. [cited in US EPA 2005].

Gustafson JB, Griffith Tell J, Orem D. 1997. Selection of representative TPH fractions based on fate and transport considerations. Total Petroleum Hydrocarbon Criteria Working Group Series, Vol. 3. Amherst (MA): Amherst Scientific Publishers. 109 p.

Hardy R, Mackie P, Whittle K, McIntyre A. 1974. Discrimination in the assimilation of *n*-alkanes in fish. Nature 252:577-578.

Hellou J, Payne J, Upshall C, Fancey L, Hamilton C. 1994. Bioaccumulation of aromatic hydrocarbons from sediments: a dose–response study with flounder (*Pseudopleuronectes americanus*). Arch Environ Contam Toxicol 27:477-485.

Hoberman AM, Christian MS, Lovre S, Roth R, Koschier F. 1995. Developmental toxicity study of clarified slurry oil (CSO) in the rat. Fundam Appl Toxicol 28:34-40.

Hopkinson R. 2008. Priority substances under Environment Canada's Chemicals Management Plan for the petroleum sector. Richmond (BC): Levelton Consultants Ltd.

[IARC] IARC Working Group on the Evaluation of Carcinogenic Risks in Humans. 1984. Mineral oils. In: Polynuclear aromatic compounds. Part 2. Carbon blacks, mineral oils and some nitroarenes. IARC Monogr Eval Carcinog Risks Hum 33:87-168.

[IARC] IARC Working Group on the Evaluation of Carcinogenic Risks in Humans. 1989a. Fuel oils. In: Occupational exposures in petroleum refining; crude oil and major petroleum fuels. IARC Monogr Eval Carcinog Risks Hum 45:239-270.

[IARC] IARC Working Group on the Evaluation of Carcinogenic Risks in Humans. 1989b. Occupational exposures in petroleum refining. In: Occupational exposures in petroleum refining; crude oil and major petroleum fuels. IARC Monogr Eval Carcinog Risks Hum 45:39-117.

[JNITE]. 2010. Japanese National Institute of Technology and Evaluation. Official Bulletin of Economy, Trade and Industry. Database accessed Sept 1010. Available from: http://www.safe.nite.go.jp/data/hazkizon/pk_e_kizon_data_input.home_list

Jonsson G, Bechmann RK, Bamber SD, Baussant T. 2004. Bioconcentration, biotransformation, and elimination of polycyclic aromatic hydrocarbons in Sheepshead minnows (Cyprinodon variegates) exposed to contaminated seawater. Environ Toxicol Chem 23: 1538-1548. Cited in the Golder Associates Ltd. 2006 report: Lakewater and aquatic long-term monitoring 2005-2006 interpretive report, Wabamum Lake derailment site.

Khan SH, Goode JW. 1984. Micronucleus test: aromatic pyrolysis oil orally for 2 days. Project No. 2082. Prepared by Gulf Life Sciences Center, Pittsburgh, Pennsylvania, for Gulf Oil Chemicals Co., Houston, Texas. [cited in US EPA 2005].

Lampi M, Paumen M, Parkerton T. 2010. An evaluation of the persistence, bioaccumulation and toxicity of petroleum hydrocarbons. ExxonMobil Biomedical Sciences Inc. for CONCAWE, Brussels, Belgium.

Lewis SC. 1983. Crude petroleum and selected fractions. Skin cancer bioassays. Prog Exp Tumor Res 26:68-84. [cited in IARC 1989b].

MacLean MM, Doe KG. 1989. The comparative toxicity of crude and refined oils to *Daphnia magna* and *Artemia*. Ottawa (ON): Environment Canada. 72 p. Manuscript Report EE-111.

McCain BB, Hodgins HO, Gronlund WD, Hawkes JW, Brown DW, Myers MS. 1978. Bioavailability of crude oil from experimentally oiled sediment to English sole *Parophrys vetulus*. J Fish Res Board Can 35(5):657-664.

McKee RH, Nicolich MJ, Scala RA, Lewis SC. 1990. Estimation of epidermal carcinogenic potency. Fundam Appl Toxicol 15:320-328.

[Mobil] Mobil Oil Corporation. 1985. A modified Ames pre-incubation mutagenesis assay for determination of specific mutagenicity of the DMSO extract of heavy vacuum gas oil. Study No. 52261. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in API 2004].

[Mobil] Mobil Oil Corporation. 1987a. Micronucleus assay of bone marrow red blood cells from rats treated via dermal administration of heavy vacuum gas oil. Study No. 61591. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in API 2004].

[Mobil] Mobil Oil Corporation. 1987b. Metaphase analysis of Chinese hamster ovary (CHO) cells treated *in vitro* with a DMSO extract of heavy vacuum gas oil. Study No. 52262. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in API 2004].

[Mobil] Mobil Oil Corporation. 1987c. Clarified slurry oil: developmental toxicity study in rats. Study No. 50541. Mobil Environmental and Health Science Laboratory, Princeton, NJ. [cited in ECB 2000b].

[Mobil] Mobil Oil Corporation. 1988. Thirteen-week dermal administration of syntower bottoms to rats. Study No. 62710. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in ECB 2000b].

[Mobil] Mobil Oil Corporation. 1990. Developmental toxicity study in rats exposed dermally to Ferndale syntower bottoms. Study No. 62934. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in ECB 2000b].

[Mobil] Mobil Oil Corporation. 1992. Thirteen-week dermal administration of heavy atmospheric gas oil to rats. Study No. 63456. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in API 2004].

[Mobil] Mobil Oil Corporation. 1994a. Developmental toxicity study in rats exposed dermally to heavy coker gas oil (HCGO). Study No. 64168. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in ECB 2000b].

[Mobil]. Mobil Oil Corporation. 1994b. Thirteen-week dermal administration of Joliet heavy coker gas oil to rats. Study No. 64165. Princeton (NJ): Mobil Oil Corporation, Environmental and Health Sciences Laboratory. [cited in ECB 2000b].

[NCI] National Chemical Inventories [database on a CD-ROM]. 2006. Columbus (OH): American Chemical Society, Chemical Abstracts Service. Available from: http://www.cas.org/products/cd/nci/require.html

Neff JM, Cox BA, Anderson JW. 1976. Accumulation and release of petroleum derived aromatic hydrocarbons by four species of marine animals. Mar Biol 38(3):279-289.

Niimi A, Dookhran G. 1989. Dietary absorption efficiencies and elimination rates of polycyclic aromatic hydrocarbons (PAHs) in rainbow trout (*Salmo gairdneri*). Environ Toxicol Chem 8:719-722.

Niimi A, Palazzo V. 1986. Biological half-lives of eight polycyclic aromatic hydrocarbons (PAHs) in rainbow trout (*Salmo gairdneri*). Water Res 20(4):503-507.

NOVA Chemicals. 2007a. Material Safety Data Sheet: HAGO (Heavy Atmospheric Gas Oil). Calgary (AB): NOVA Chemicals. Available from: http://www.novachem.com/productservices/docs/HeavyAtmosphericGasOil_MSDS_EN.pdf.

NOVA Chemicals. 2007b. Material Safety Data Sheet: VGO (Vacuum Gas Oil). Calgary (AB): NOVA Chemicals. Available from: http://www.novachem.com/productservices/docs/VacuumGasOil_MSDS_EN.pdf.

Nunes P, Benville Jr. E. 1978. Acute toxicity of the water soluble fraction of Cook Inlet crude oil to the Manila clam. Mar. Pollut. Bull. 9:324-331.

Oliver B, Niimi A. 1988. Trophodynamic Analysis of Polychlorinated Biphenyl Congeners and Other Chlorinated Hydrocarbons in the Lake Ontario Ecosystem. Environ. Sci. Technol. 22:388-397

Papciak MS, Goode JW. 1984. CHO/HGPRT test using aromatic pyrolysis oil. Project No. 2081. Prepared by Gulf Life Sciences Center, Pittsburgh, Pennsylvania, for Gulf Oil Chemicals Co., Houston, Texas. [cited in US EPA 2005].

[PetroTox] A tool for the hazard assessment of petroleum substances. 2009. Version 3.01. HydroQual, Inc., for CONservation of Clean Air and Water in Europe (CONCAWE). Available from: http://www.concawe.be/Content/Default.asp?PageID=241 [Restricted Access].

Rossi SS, Anderson JW, Ward GS. 1976. Toxicity of water-soluble fractions of four test oils for the polychaetous annelids, *Neanthes arenaceodentata* and *Capitella capitata*. Environ Pollut 10:9-18.

Roubal WT, Stranahan SF, Malins DC. 1978. The accumulation of low molecular weight aromatic hydrocarbons of crude oil by coho salmon (*Oncorhynchus kisutch*) and starry flounder (*Platichthys stellatus*). Archive Environ Contam Toxicol 7:237-244.

Saffiotti U, Shubik P. 1963. Studies on promoting action in skin carcinogenesis. Natl Cancer Inst Monogr 10:489-507 [cited in IARC 1984].

Salem H, Katz SA, editors. 2006. Inhalation toxicology. 2nd ed. Boca Raton (FL): CRC Press, Taylor & Francis Group.

[SENES] SENES Consultants Limited. 2009. Review of current and proposed regulatory and non-regulatory management tools pertaining to selected petroleum substances under the Chemicals Management Plan. Report to Health Canada. Richmond Hill (ON): SENES Consultants Limited.

Shapiro DD, Getmanets IY. 1962. Blastomogenic properties of petroleum of different sources. Gig Sanit 27: 38-42 [cited in IARC 1989b].

Shubik P, Saffiotti U. 1955. The carcinogenic and promoting action of low boiling catalytically cracked oils. Acta Unio Int. Contra Cancrum 11:707-711 [cited in IARC 1984].

Simpson BJ. 2005. Analysis of petroleum hydrocarbon streams on the Health Canada CEPA/DSL draft maximal list. Contractor's report prepared for the Canadian Petroleum Products Institute, Ottawa, Ontario.

Smith WE, Sunderland DA, Sugiura K. 1951. Experimental analysis of the carcinogenic activity of certain petroleum products. Arch Ind Hyg Occup Med 4:299-314 [cited in IARC 1984].

Southworth GR, Beauchamp JJ, Schmieden PK. 1978. Bioaccumulation potential of polycyclic aromatic hydrocarbons in *Daphnia pulex.* Wat Res. 12:973-977.

[SPARC]. 2009. Sparc performs automated reasoning in chemistry. [Internet]. US Environmental Protection Agency. Ecosystems Research Division. Available from: http://www.epa.gov/athens/research/projects/sparc/.

Stegeman JJ, Teal JM. 1973. Accumulation, release and retention of petroleum hydrocarbons by the oyster *Crassostrea virginica*. Mar Biol 22:37-44.

Sun Petroleum Products Co. 1979. EPA/OTS No. 8EHQ-0379-0140. NTIS/OTS0200438. [Abstract]. [cited in TOXLINE 2009].

Suntio I, Shiu WY, Mackay D. 1986. Analyses of water soluble fractions of crude oils and refined products: a study of solubility of selected oils in water. Contract No. 164. Ottawa (ON): Environment Canada.

Takeuchi I, Miyoshi N, Mizukawa K, Takada H, Ikemoto T, Omori K, Tsuchiya K. 2009. Biomagnification profiles of polycyclic aromatic hydrocarbons, alkylphenols and polychlorinated biphenyls in Tokyo Bay elucidated by $\delta^{13}C$ and $\delta^{15}N$ isotope ratios as guides to trophic web structure. Mar Pollut Bull 58:663-671.

Tolls J, van Dijk J. 2002. Bioconcentration of n-dodecane and its highly branched isomer 2,2,4,6,6-pentamethylheptane in fathead minnows Chemosphere 47:1049-1057.

[TOXLINE] Toxicology Literature Online [database on the Internet]. 1974–. Bethesda (MD): National Library of Medicine (US). [revised 2009 Apr 18; cited 2009 Apr 21]. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?toxadv.htm.

[US EPA] US Environmental Protection Agency. 2005. Appendix II. Robust summaries of studies used to characterize the fuel oils category. Washington (DC): US Environmental Protection Agency, High Production Volume Chemical Program. Available from: http://www.epa.gov/hpv/pubs/summaries/fueloils/c13435rr3.pdf.

[UBTL] Utah Biomedical Testing Laboratory Inc. 1990. 28-day dermal toxicity study in rats. Salt Lake City (UT): UBTL Inc. Report No.: ATX-90-0066. [cited in API 2004].

[UBTL] Utah Biomedical Testing Laboratory Inc. 1994. A developmental toxicity screen in female rats administered F-228 dermally during gestation days 0 to 20. Study No. 66479. Salt Lake City (UT): UBTL Inc. Report No.: ATX-91-0267. [cited in API 2004].

Vandermeulen HH, Lee RW. 1986. Lack of mutagenic activity of crude and refined oils in the unicellular alga *Chlamydomonas reinhardtii*. Bull Environ Contam Toxicol 36:250-253. [cited in IARC 1989a].

Vandermeulen HH, Foda A, Stuttard C. 1985. Toxicity vs. mutagenicity of some crude oils, distillates, and their water soluble fractions. Water Res 19:1283-1289. [cited in IARC 1989a].

Wan Y, Jin X, Hu J, Jin F. 2007. Trophic dilution of polycyclic aromatic hydrocarbons (PAHs) in a marine food web from Bohai Bay, North China. Environ Sci Technol 41:3109-3114.

Weil CS, Condra NI. 1977. Experimental carcinogenesis of pyrolysis fuel oil. Am Ind Hyg Assoc J 38:730-733. [cited in IARC 1989b].

Wetzel D, Van Vleet E. 2004. Accumulation and distribution of petroleum hydrocarbons found in mussels (*Mytilus galloprovincialis*) in the canals of Venice, Italy. Mar Pollut Bull 48:928-936.

Yakata N, Sudo Y, Tadokoro H. 2006. Influence of dispersants on bioconcentration factors of seven organic compounds with different lipophilicities and structures Chemosphere 64:1885-1891.

Zhou S, Heras H, Ackman RG. 1997. Role of adipocytes in the muscle tissue of Atlantic salmon (Salmo salar) in the uptake, release and retention of water-soluble fraction of crude oil hydrocarbons. Mar Biol 127:545-553.

Appendix 1: Description of the Nine Groups of Petroleum Substances

Table A1.1: Description of the nine groups of petroleum substances

Group[1]	Description	Example
Crude oil	Mixture of aliphatic and aromatic hydrocarbons and small amounts of inorganic compounds occurring naturally under the earth's surface or under the sea floor	Crude oil
Petroleum and refinery gases	Mixture of light hydrocarbons, primarily from C_1 to C_5	Propane
Low boiling point naphthas	Mixture of hydrocarbons, primarily from C_4 to C_{12}	Gasoline
Gas oils	Mixture of hydrocarbons, primarily from C_9 to C_{25}	Diesel
Heavy fuel oils	Mixture of heavy hydrocarbons, primarily from C_{11} to C_{50}	Fuel Oil No. 6
Base oils	Mixture of hydrocarbons primarily, from C_{15} to C_{50}	Lubricating oils
Aromatic extracts	Mixture of primarily aromatic hydrocarbons from C_{15} to C_{50}	Feedstock for benzene production
Waxes, slack waxes and petrolatum	Mixture of primarily aliphatic hydrocarbons from C_{12} to C_{85}	Petrolatum
Bitumen or vacuum residues	Mixture of heavy hydrocarbons having carbon numbers greater than C_{25}	Asphalt

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

Appendix 2: Engineering Process Flow Diagrams for Heavy Fuel Oils

Red dotted line indicates the process relevant to the particular CAS RN.
FCCU: Fluid Catalytic Cracking Unit; LPG: Liquified Petroleum Gas

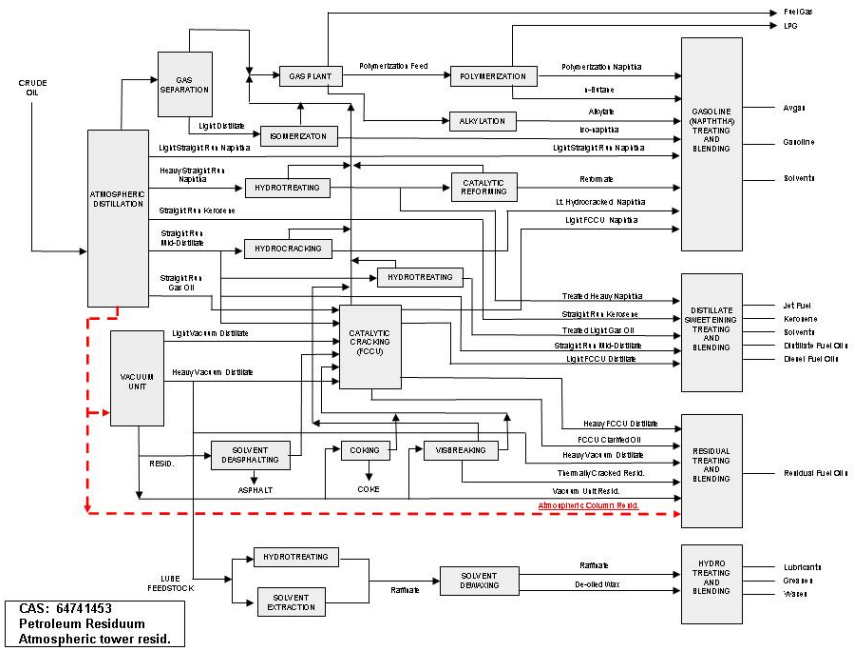

Figure A2.1 Process flow diagram for CAS RN 64741-45-3 in a refinery (Hopkinson 2008).

CAS RN 64741-45-3 is a processing intermediate formed after atmospheric distillation of crude oil in a refinery.

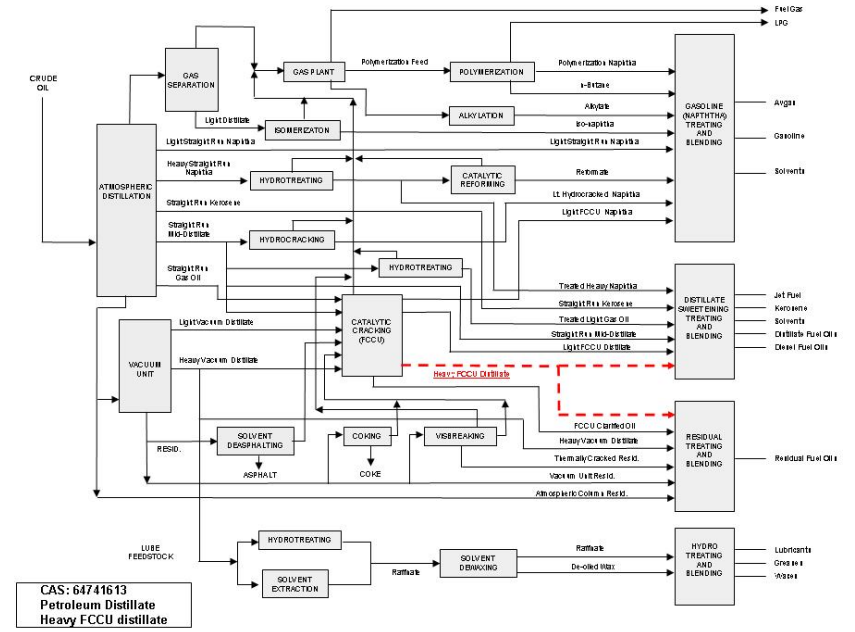

Figure A2.2 Process flow diagram for CAS RN 64741-61-3 in a refinery (Hopkinson 2008).

CAS RN 64741-61-3 is a processing intermediate formed after catalytic cracking in an upgrader.

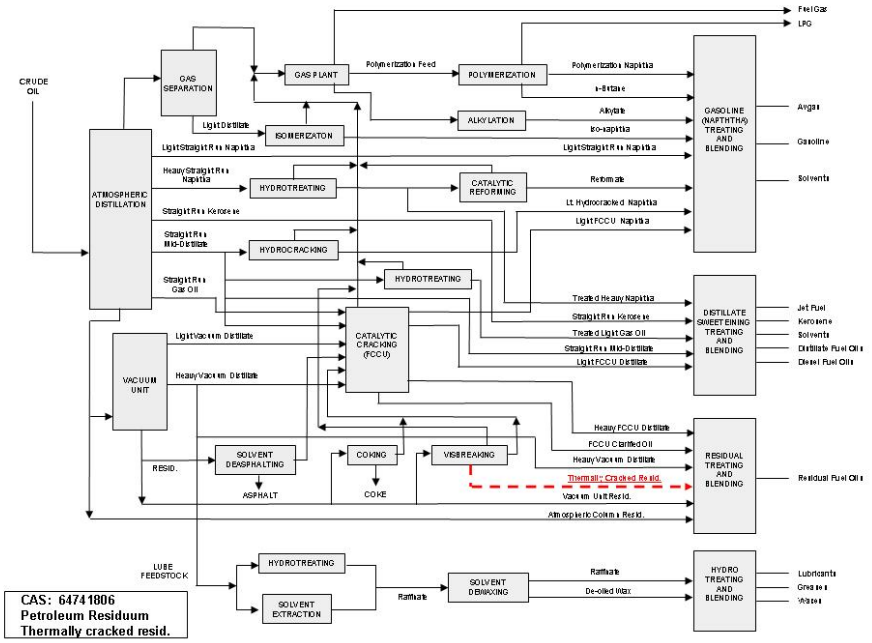

Figure A2.3. Process flow diagram for CAS RN 64741-80-6 in a refinery (Hopkinson 2008).

CAS RN 64741-80-6 is shown to be a processing intermediate formed after visbreaking in a refinery.

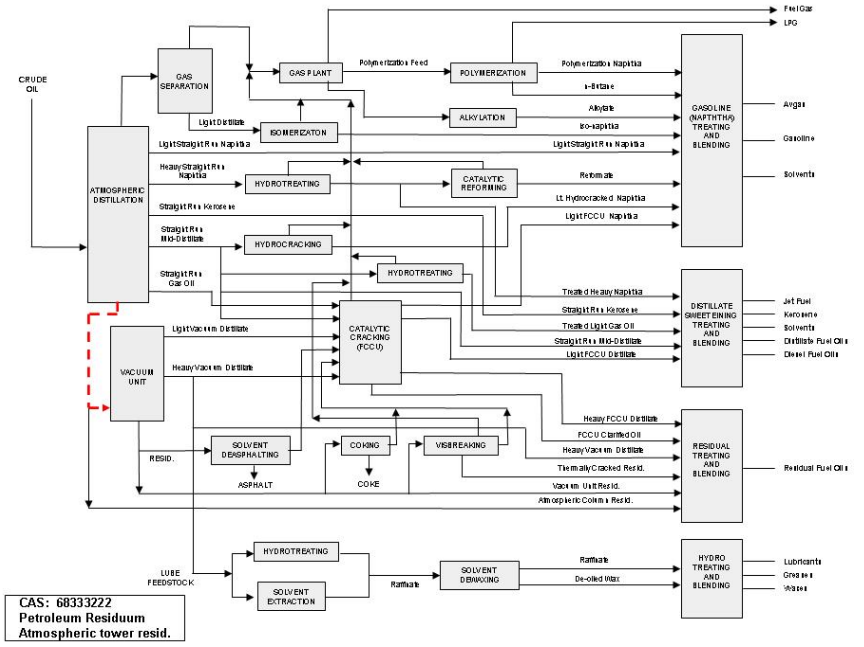

Figure A2.4. Process flow diagram for CAS RN 68333-22-2 in a refinery (Hopkinson 2008).

CAS RN 68333-22-2 is shown to be a processing intermediate formed after atmospheric distillation in a refinery.

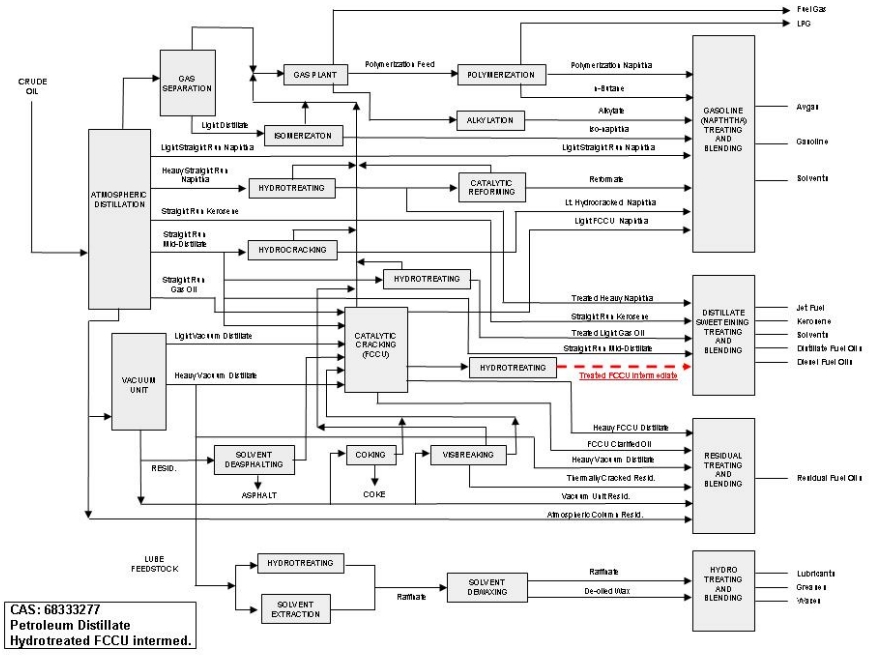

Figure A2.5. Process flow diagram for CAS RN 68333-27-7 in a refinery (Hopkinson 2008).

CAS RN 68333-27-7 is a processing intermediate shown to be formed after hydrotreating in a refinery.

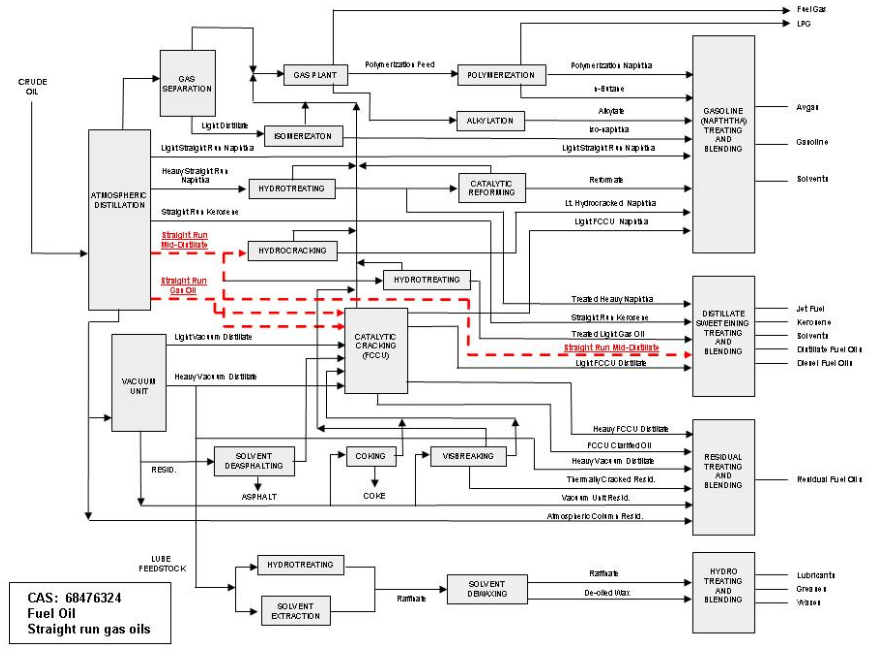

Figure A2.6. Process flow diagram for CAS RN 68476-32-4 in a refinery (Hopkinson 2008).

CAS RN 68476-32-4 is a processing intermediate shown to be formed after atmospheric distillation in a refinery.

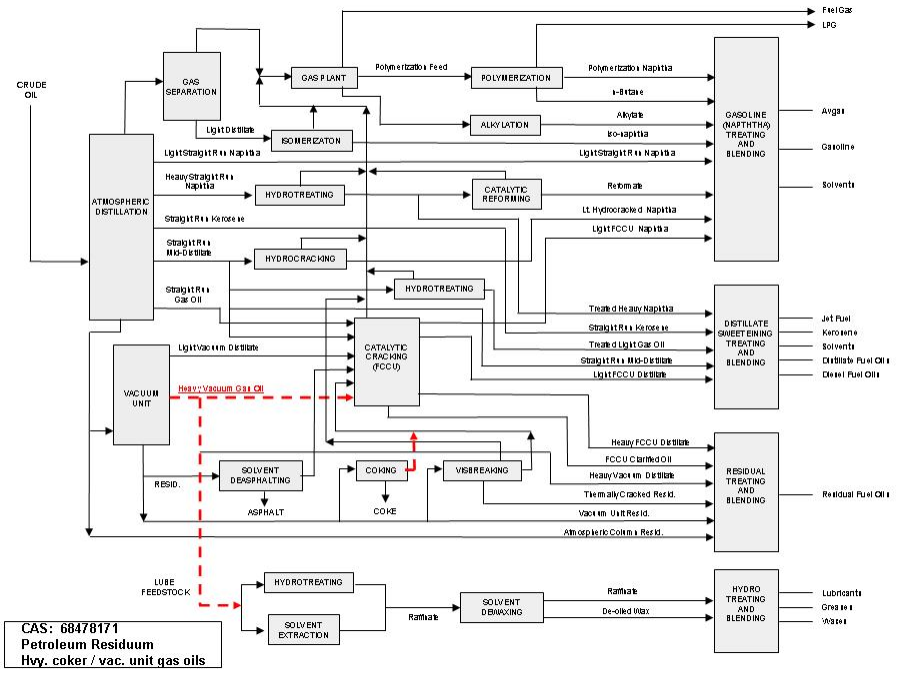

Figure A2.7a. Process flow diagram for CAS RN 68478-17-1 in a refinery (Hopkinson 2008).

CAS RN 68478-17-1 is a processing intermediate shown to be formed after vacuum distillation in a refinery.

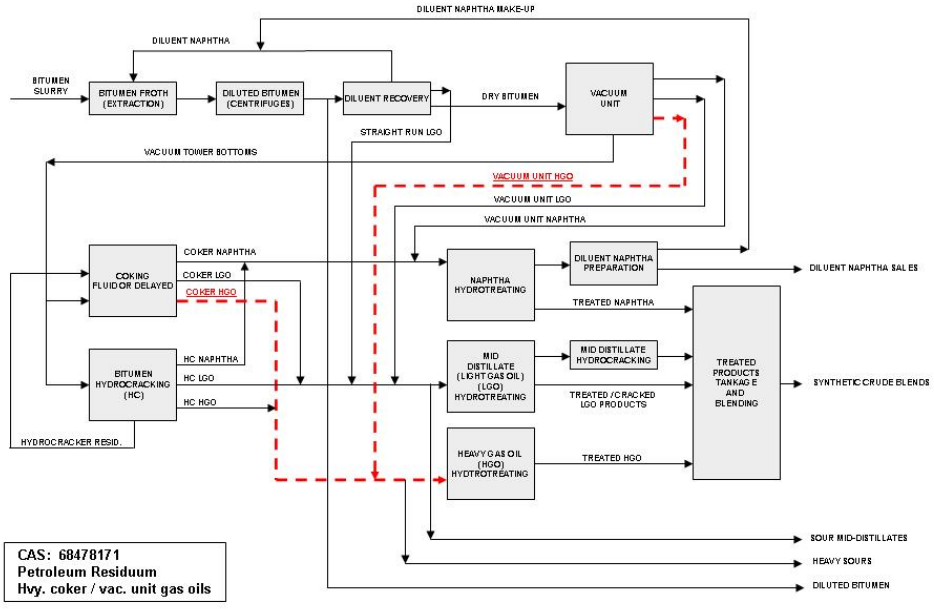

Figure A2.7b. Process flow diagram for CAS RN 68478-17-1 in an upgrader (Hopkinson 2008).

CAS RN 68478-17-1 is a processing intermediate shown to be formed after coking in an upgrader.

Appendix 3: Data Tables for Site-restricted HFOs

Table A3.1a. Substance identity for site-restricted HFOs

CAS RN; DSL name (NCI 2006)[1]	64741-45-3: Residues (petroleum), atmospheric tower		
	64741-61-3: Distillates (petroleum), heavy catalytic cracked		
	64741-80-6: Residues (petroleum), thermal cracked		
	68333-22-2: Residues (petroleum), atmospheric		
	68333-27-7: Distillates (petroleum), hydrodesulphurized intermediate catalytic cracked		
	68476-32-4: Fuel oil, residues—straight-run gas oils, high-sulphur		
	68478-17-1: Residues (petroleum), heavy coker gas oil and vacuum gas oil		
Chemical group	Petroleum—heavy fuel oils		
Major components	Aromatic, aliphatic and cycloalkane hydrocarbons		CONCAWE 1998
Carbon range	CAS RN 64741-45-3	>C_{20}	CONCAWE 1998
	CAS RN 64741-61-3	C_{15}-C_{35}	CONCAWE 1998
	CAS RN 64741-80-6	>C_{20}-C_{50}	CONCAWE 1998
	CAS RN 68333-22-2	>C_{11}	CONCAWE 1998
	CAS RN 68333-27-7	C_{11}-C_{30}	CONCAWE 1998
	CAS RN 68476-32-4	Unknown	
	CAS RN 68478-17-1	>C_{13}	CONCAWE 1998
Approximate ratio of aromatics to non-aromatics	50:50		API 2004
Three- to seven-ring PAHs (wt %)	≥5%		CONCAWE 1998

Abbreviations: CAS RN, Chemical Abstracts Service Registry Number; DSL, Domestic Substances List; wt, weight.
[1]All DSL names were identical to those in NCI (2006).

Table A3.1b. Physical and chemical properties for representative structures of HFOs[a]

Chemical class, name (CAS RN)	HFO represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)[b]	Sub-cooled liquid vapour pressure (Pa)[c]
Alkanes					
C_9 n-Nonane (111-84-2)	68783-08-4	151 (e)	−54(e)	593(e)	
C_{15} Pentadecane (629-62-9)	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	271 (e)	12	0.03	
C_{20} Eicosane (112-95-8)	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	343 (e)	37 (e)	6E−4	8E−4
C_{30} Triacontane	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	450 (e)	65.8 (e)	4E−9	9E−9
C_{50}	64741-75-9, 68333-22-2, 68478-17-1, 70592-78-8	548 (e)	88 (e)	2E−7	8E−7
Isoalkanes					
C_9 2,3-dimethylheptane (3074-71-3)	68783-08-4	141 (e)	−116 (e)	1E3	
C_{15} 2-methyltetradecane (1560-95-8)	68783-08-4, 70592-76-6, 70592-77-7	250	1.5	5.8	
C_{20} 3-methyl nonadecane (6418-45-7)	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	326	40	0.1	0.1
C_{30} Hexamethyl tetracosane (111-01-3)	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	350 (e)	−38 (e)	0.04	
C_{50}	64741-75-9, 70592-78-8	548	289	1E−13	1E−9

Chemical class, name (CAS RN)	HFO represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)[b]	Sub-cooled liquid vapour pressure (Pa)[c]
One-ring cycloalkanes					
C_9 1,2,3-trimethylcyclohexane (1678-97-3)	68783-08-4	144 (e)	−66.9 (e)	649	
C_{15} Nonylcyclohexane (2883-02-5)	68783-08-4, 70592-76-6, 70592-77-7	282 (e)	−10 (e)	1.2 (e)	
C_{20} Tetradecylcyclohexane (1795-18-2)	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	360 (e)	24 (e)	0.02	0.02
C_{30} 1,5-dimethyl-1-(3,7,11,15-tetramethyloctadecyl) cyclohexane	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	421	103	2E−4	9E−4
C_{50}	64741-75-9, 68333-22-2, 68478-17-1	699	300	1E-13	3E-10
Two-ring cycloalkanes					
C_9 *cis*-bicyclononane (4551-51-3)	68783-08-4	167 (e)	−53 (e)	320.0	
C_{15} 2-isopentadecylin	68783-08-4	244	23	2.4	
C_{20} 2,4-dimethyloctyl-2-decalin	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	339	41	0.02	0.1
C_{30} 2,4,6,10,14 pentamethyldodecyl-2-decalin	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	420	106	0.0001	0.0009
C_{50}	64741-75-9	687	300	1E−13	3E−10
One-ring aromatics					
C_9 Ethylmethylbenzene (25550-14-5)	68783-08-4	165.2 (e)	−80.8 (e)	384.0 (e)	

Chemical class, name (CAS RN)	HFO represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)[b]	Sub-cooled liquid vapour pressure (Pa)[c]
C_{15} 2-nonyl benzene (1081-77-2)	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	281 (e)	−24 (e)	0.7 (e)	
C_{20} Tetradecyl benzene	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	359 (e)	16 (e)	0.008 (e)	0.003
C_{30} 1-benzyl 4,8,12,16 tetramethyleicosane	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	437	131	1E−5	1E−4
C_{50}	64741-75-9	697	304	1E−13	3E−11
Two-ring aromatics					
C_{15} 4-isopropylbiphenyl	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	308	44	0.06	
C_{20} 2-iso-decyl naphthalene	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	373	99	0.0007	0.007
C_{30} 2-(4,8,14,18-tetramethylhexadecyl) naphthalene	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	469	171	7E−7	2E−5
C_{50}	64741-75-9	722	316	1E−13	6E−12
Three-ring aromatics					
C_{15} 2-methylphenanthrene (2531-84-2)	68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	350 (e)	65 (e)	0.009	
C_{20} 2-isohexyl phenanthrene	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	398	129	0.0001	0.002
C_{30} 2-(2,4,10-	64741-75-9, 68783-08-4,	493	191.6	10E−8	6E−6

Chemical class, name (CAS RN)	HFO represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)[b]	Sub-cooled liquid vapour pressure (Pa)[c]
trimethyltridecyl) phenanthrene	70592-76-6, 70592-77-7, 70592-78-8				
C_{50}	64741-75-9	746	349	1E−13	1E−12
Five-ring PAHs					
C_{20} Benzo(a)pyrene (50-32-8)	64741-75-9, 68783-08-4, 70592-76-6, 70592-77-7, 70592-78-8	495 (e)	177 (e)	7E−7	2E−5
C_{30} Dimethyloctyl-benzo(a)pyrene	64741-75-9 70592-76-6, 70592-77-7, 70592-78-8	545	231	2E−9	3E−7

Table A3.1b cont. Physical and chemical properties for representative structures of HFOs[a]

Chemical class, name (CAS RN)	Henry's Law Constant ($Pa \cdot m^3/mol$)[d]	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L)[e]	Sub-cooled liquid solubility (mg/L)[f]
Alkanes					
C_9 n-Nonane (111-84-2)	3E5(e)	5.7 (e)	3.0	0.2(e)	
C_{15} Pentadecane (629-62-9)	1E6 (e)	7.7	4.6	8E−5 (e)	
C_{20} Eicosane (112-95-8)	113	10	5.9	0.002 (e)	0.002 (e)
C_{30} Triacontane	3E4	15	13	5E−11	2E−10
C_{50}		25	14	5E−21	
Isoalkanes					
C_9	4.3E4	4.6	2.8	3.1	

Chemical class, name (CAS RN)	Henry's Law Constant ($Pa \cdot m^3/mol$)[d]	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L)[e]	Sub-cooled liquid solubility (mg/L)[f]
2,3-dimethylheptane (3074-71-3)					
C_{15} 2-methyltetradecane (1560-95-8)	4E5	7.6	4.5	0.003	
C_{20} 3-methyl nonadecane (6418-45-7)	276	10	5.8	1E−5	0.13
C_{30} Hexamethyl tetracosane (111-01-3)	2E9	15	13	2E−10	5E−11
C_{50}		25	13.8	6E−21	3E−18
One-ring cycloalkanes					
C_9 1,2,3-trimethylcyclohexane (1678-97-3)	2E4	4.4	2.9	4.6	
C_{15} Nonylcyclohexane (2883-02-5)	6E4	7.5	4.6	0.004 (e)	
C_{20} Tetradecylcyclohexane (1795-18-2)	63	9.9	5.9	1E−5	0.1
C_{30} 1,5-dimethyl-1-(3,7,11,15-tetramethyloctadecyl) cyclohexane	2E8	14.5	13	3E−10	2E−9
C_{50}		25	14	2E-21	
Two-ring cycloalkanes					
C_9 *cis*-bicyclononane (4551-51-3)	2E3	3.7	3.0	19.3	
C_{15} 2-isopentadecylin	2E4	6.6	4.6	0.03	
C_{20}	1935	9.0	5.9	9E−15	0.02

Chemical class, name (CAS RN)	Henry's Law Constant ($Pa \cdot m^3/mol$)[d]	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L)[e]	Sub-cooled liquid solubility (mg/L)[f]
2,4-dimethyloctyl-2-decalin					
C_{30} 2,4,6,10,14 pentamethyldodecyl-2-decalin	4E7	13.6	12	2E−9	1E−8
C_{50}		24	14	5E−20	
One-ring aromatics					
C_9 Ethylmethylbenzene (25550-14-5)	324	3.6 (e)	3	74.6 (e)	
C_{15} 2-nonyl benzene (1081-77-2)	4225	7.1 (e)	4.6	0.04	
C_{20} Tetradecyl benzene	49	8.9	5.9	4E−4	0.02
C_{30} 1-benzyl 4,8,12,16 tetramethyleicosane	7.0E5	13.5	12	7E−9	8E−8
C_{50}		24	14	2E−19	
Two-ring aromatics					
C_{15} 4-isopropylbiphenyl	24	5.5	4.6	0.7	
C_{20} 2-iso-decyl naphthalene	420	8.1	5.9	0.002	0.005
C_{30} 2-(4,8,14,18-tetramethylhexadecyl) naphthalene	10E3	12.8	11	3E−8	8E−7
C_{50}		23	13.9	1E−18	
Three-ring aromatics					
C_{15} 2-methylphenanthrene	6.5	4.9 (e)	4.5	0.3 (e)	

Chemical class, name (CAS RN)	Henry's Law Constant ($Pa \cdot m^3/mol$)[d]	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L)[e]	Sub-cooled liquid solubility (mg/L)[f]
(2531-84-2)					
C_{20} 2-isohexyl phenanthrene	10	7.4	5.9	8E−4	0.05
C_{30} 2-(2,4,10-trimethyltridecyl) phenanthrene	3E3	12	10	1E−8	5E−7
C_{50}		22	14	5E−19	8E−16
Five-ring PAHs					
C_{20} Benzo(a)pyrene (50-32-8)	5E−5	6(e)	6.7	0.002	0.1
C_{30} Dimethyloctyl-benzo(a)pyrene	5.1	10.9	9.5	1E−7	1E−5

[a] All values are modelled unless denoted with an (e) for experimental data.

[b] This is the maximum vapour pressure of the surrogate; the actual vapour pressure as a component of a mixture will be lower 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). The lightest C_9 and heaviest C_{50} representative structures were chosen to estimate a range of vapour pressures from the minimum to maximum values.

[c] Estimated sub-cooled liquid vapour pressures were obtained from AEROWIN (Version 1.01) in EPIsuite (2008). Sub-cooled liquid vapour pressures were only estimated for components determined to be solid at 25°C (i.e., $\geq C_{20}$).

[d] Henry's Law constants for C_{20}–C_{30} representative structures were calculated with HENRYWIN Version 3.10 from EPIsuite (2008), using both sub-cooled liquid solubility and sub-cooled liquid vapour pressure. Henry's Law constants for C_{50} representative structures were not calculated as sub-cooled liquid solubility data were not available. Solubility data gave anomalously high values for substances that have negligible solubility and volatility.

[e] Maximum water solubility was estimated for each surrogate based on its individual physical-chemical properties. The actual water solubility of a component in a mixture will be lower, as the total water solubility of an ideal mixture (Table 2 in text) is proportional to the sum of the water solubilities of the mole fractions of each individual component (Banerjee 1984).

[f] Estimated sub-cooled liquid solubilities were obtained from the CONCAWE1462 database within PetroTox (2009). The estimates contained within the database were calculated using the SPARC Performs Automated Reasoning in Chemistry (SPARC 2009). Sub-cooled liquid solubility values were only estimated for components determined to be solid at 25°C (i.e., $\geq C_{20}$). Sub-cooled liquid solubility data were not available for the C_{50} components.

Table A3.2. Boiling point ranges for HFOs

CAS RN	Boiling point range (°C)	Carbon range	Reference
64741-45-3	277-561	$>C_{20}$	API 2004
64741-61-3	260-500	C_{15}-C_{35}	CONCAWE 1998
64741-80-6	>350	$>C_{20}$-C_{50}	CONCAWE 1998
68333-22-2	>200	$>C_{11}$	CONCAWE 1998
68333-27-7	205-450	C_{11}-C_{30}	CONCAWE 1998
68476-32-4	Unknown		
68478-17-1	>230	$>C_{13}$	CONCAWE 1998

Table A3.3. Representative structures that would be included for each CAS RN*

	Boiling point (°C)	64741-45-3	64741-61-3	64741-80-6	68333-22-2	68333-27-7	68478-17-1
Alkanes							
C_{15}	271		Yes		Yes	Yes	Yes
C_{20}	343	Yes	Yes		Yes	Yes	Yes
C_{30}	450	Yes	Yes	Yes	Yes	Yes	Yes
C_{50}	548	Yes		Yes	Yes		Yes
Isoalkanes							
C_{15}	250				Yes	Yes	Yes
C_{20}	326	Yes	Yes		Yes	Yes	Yes
C_{30}	350	Yes	Yes		Yes	Yes	Yes
C_{50}	548	Yes		Yes			Yes
One-ring cycloalkanes							
C_{15}	282	Yes	Yes		Yes	Yes	Yes
C_{20}	360	Yes	Yes	Yes	Yes	Yes	Yes
C_{30}	421	Yes	Yes	Yes	Yes	Yes	Yes
C_{50}	699	Yes		Yes			Yes
Two-ring cycloalkanes							
C_{15}	244				Yes	Yes	Yes
C_{20}	339	Yes	Yes		Yes	Yes	Yes
C_{30}	420	Yes	Yes	Yes	Yes	Yes	Yes
C_{50}	687	Yes		Yes			Yes
One-ring							

	Boiling point (°C)	64741-45-3	64741-61-3	64741-80-6	68333-22-2	68333-27-7	68478-17-1
aromatics							
C_{15}	281	Yes	Yes		Yes	Yes	Yes
C_{20}	359	Yes	Yes	Yes	Yes	Yes	Yes
C_{30}	437	Yes	Yes	Yes	Yes	Yes	Yes
C_{50}	697	Yes		Yes			Yes
Two-ring aromatics							
C_{15}	308	Yes	Yes		Yes	Yes	Yes
C_{20}	373	Yes	Yes	Yes	Yes	Yes	Yes
C_{30}	468.5	Yes	Yes	Yes	Yes		Yes
C_{50}	722			Yes			Yes
Three-ring aromatics							
C_{15}	350	Yes	Yes	Yes	Yes	Yes	Yes
C_{20}	398	Yes	Yes	Yes	Yes	Yes	Yes
C_{30}	493	Yes	Yes	Yes	Yes		Yes
C_{50}	746			Yes			Yes
Five-ring aromatics							
C_{20}	495	Yes	Yes	Yes	Yes		Yes
C_{30}	545	Yes		Yes			Yes

* No information was found on the boiling point or carbon range of CAS RN 68476-32-4 and therefore it is unclear what structures would be representative.

Table A3.4. Modelled data for primary (BioHCwin 2008) and ultimate (BIOWIN 2008) biodegradation of representative structures of HFOs in water

	Primary half-life (days)[1] (BioHCwin)	Ultimate biodegradation result (BIOWIN)	Half-life compared to criteria (days)
Alkanes			
C_{15}	19	Days/weeks	≤182
C_{20}	40	Weeks	≤182
C_{30}	143	Weeks	≤182
C_{31}	250	Weeks/months	≥182
C_{50}	4 581	Months	≥182
Isoalkanes			
C_{15}	17	Weeks	≤182

	Primary half-life (days)[1] (BioHCwin)	Ultimate biodegradation result (BIOWIN)	Half-life compared to criteria (days)
C_{20}	36	Weeks	≤182
C_{30}	333	Weeks/months	≥182
C_{50}	3 504	Months	≥182
One-ring cycloalkanes			
C_{15}	25	Weeks	≤182
C_{20}	53	Weeks	≤182
C_{30}	154	Weeks/months	≤182
C_{35}	187	Weeks/months	≥182
C_{50}	660	Weeks	≥182
Two-ring cycloalkanes			
C_{15}	88	Weeks/months	≤182
C_{20}	250	Weeks/months	≥182
C_{30}	1 761	Weeks/months	≥182
C_{50}	494	Days	≥182
One-ring aromatics			
C_{15}	14	Weeks	≤182
C_{20}	31	Weeks	≤182
C_{30}	252	Weeks/months	≥182
C_{50}	1 594	Weeks/months	≥182
Two-ring aromatics			
C_{15}	8	Weeks/months	≤182
C_{20}	24	Weeks	≤182
C_{30}	145	Weeks/months	≤182
C_{42}	201	Weeks/months	≥182
C_{50}	444	Days/weeks	≥182
Three-ring PAHs			
C_{15}	24	Weeks/months	≤182
C_{20}	35	Weeks/months	≤182
C_{30}	212	Months	≥182
C_{50}	12 690	Weeks/months	≥182
Five-ring PAHs			
C_{20}	422	Months	≥182
C_{30}	2 076	Recalcitrant	≥182

[1]Half-life estimations are for water.

Table A3.5. Potential presence of representative structures likely to be persistent in water, soil, and sediment[1]

	64741-45-3	64741-61-3	64741-80-6	68333-22-2	68333-27-7	68478-17-1
Alkanes						
C_{31}	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
C_{50}	**Yes**		**Yes**			**Yes**
Isoalkanes						
C_{30}	**Yes**	**Yes**		**Yes**	**Yes**	**Yes**
C_{50}	**Yes**		**Yes**			**Yes**
One-ring cycloalkanes						
C_{35}	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
C_{50}	**Yes**		**Yes**			**Yes**
Two-ring cycloalkanes						
C_{20}	**Yes**	**Yes**		**Yes**	**Yes**	**Yes**
C_{30}	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
C_{50}	**Yes**		**Yes**			**Yes**
One-ring aromatics						
C_{30}	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
C_{50}	**Yes**		**Yes**			**Yes**
Two-ring aromatics						
C_{42}	**Yes**		**Yes**			**Yes**
C_{50}			**Yes**			**Yes**
Three-ring aromatics						
C_{30}	**Yes**	**Yes**	**Yes**			**Yes**
C_{50}			**Yes**			**Yes**
Five-ring aromatics						
C_{20}	**Yes**	**Yes**	**Yes**	**Yes**		**Yes**
C_{30}	**Yes**		**Yes**			**Yes**

[1] CAS RN 68476-32-4 is not included due to a lack of data on its boiling point.

Table A3.6. Fish BAF and BCF predictions for representative structures of HFOs using BCFBAF (2009) with metabolism

Representative Structures*	Log K_{ow}	k_M[a] (/day)	BCF[1] (L/kg)	BAF[2] (L/kg)
Alkanes				
C15	7.7	0.34-0.45[b]	37-48[b]	456-753[b]

Representative Structures*	Log K_{ow}	k_M[a] (/day)	BCF[1] (L/kg)	BAF[2] (L/kg)
Isoalkanes				
C_{15}	7.6	0.05	680	100 000
1-ring cycloalkanes				
C_{15}	7.5	0.04	1 032	160 000
2-ring cycloalkanes				
C_{15}	6.3	0.002	9 649	470 000
1-ring aromatics				
C_{15}	7.1 (e)	0.13	345	1830
2-ring aromatics				
C_{15}	5.5 (e)	0.05	3569	6961
3-ring PAHs				
C_{15}	4.9–5.2 (e)	0.54	788	851
C_{20}	7.4	0.09	829	49 000
5-ring PAHs				
C_{20}	6.13 (e)	0.77	500	984

[a] Biotransformation rate constant for 10 g fish.
[b] Representative structures that were remodelled using BAF-QSAR v1.5 based on similar structures with experimental data.
* Any representative structures with estimated log Kow values > 8 were excluded from this analysis due to model limitations.
(e): Experimental data.
[1] EpiSuite 2008.
[2] Arnot and Gobas 2003.

Table A3.7. Comparisons of experimental BCFs and modeled BCFs (BCFBAF 2008) on some representative structures of HFOs.

	Reference; Species tested	Log K_{ow}	BCF[a] Measured (L/kg)	BCF[b] Modeled (L/kg)
Alkanes*				
C_8 n-parafins Octane	JNITE; Carp	5.18 (e)	530	1480
C_{12} n-parafins n-dodecane	Tolls and v Dijk, 2002 cited Lampi et al. (2010) – unpublished; fathead minnow	6.10 (e)	400	901
C_{15} n-parafins n-pentadecane	CITI 1992; Carp	7.71	20	723
C_{15} n-parafins n-pentadecane	JNITE; Carp	7.71	26	723
C_{16} n-parafins n-hexadecane	CITI 1992; Carp	8.20	46	494
C_{16} n-parafins n-hexadecane	JNITE; Carp	3.15 (e)	20.2	494
Isoalkanes*				
C_{15} 2,6,10-trimethyl dodecane	EMBSI 2004b; 2005c; rainbow trout	7.49	291/817	1 646
One-ring cycloalkanes*				
C_6 Cyclohexane	CITI 1992; Carp	3.44 (e)	77	76
C_7 1-methylcyclohexane	CITI 1992; Carp	3.61 (e)	240	220
C_8 ethylcyclohexane	CITI 1992; Carp	4.56 (e)	2 529	839
Two-ring cycloalkanes*				
C_{10} Trans-decalin	CITI 1992; Carp	4.20	2 200	884
C_{10} Cis-decalin	CITI 1992; Carp	4.20	2 500	884
One-ring aromatics*				
C_9 1,2,3-trimethylbenzene	CITI 1992; Carp	3.66 (e)	125/141	159
C_{10} 1,2-diethylbenzene	CITI 1992; Carp	3.72 (e)	478/556	221
C_{11} 1-methul-4-tert-butylbenzene	JNITE; Carp	3.66 (e)	<1.0	890
Cycloalkanes monoaromatic*				
C_{10} Tetralin	CITI 1992; Carp	3.49 (e)	230	176
C_{18} dodecahydrochyrsene	EMBSI 2008c; rainbow trout	6.00	4 588	2 234
Two-ring aromatics*				
C_{10}	JNITE; Carp	3.30 (e)	94	112

Naphthalene				
	CITI 1992; Carp	3.30 (e)	95/91	112
C_{11} 2-methylnaphthalene	Jonsson et al. 2004 (cited in Lampi et al. 2010); sheepshead minnow	3.86 (e)	1 871	405
C_{12} 1,3-dimethylnaphthalene	Jonsson et al. 2004 (cited in Lampi et al. 2010); sheepshead minnow	4.42 (e)	2 051	1 021
C_{13} 2-iso-Propylnaphthalene	Jonsson et al. 2004 (cited in Lampi et al. 2010); sheepshead minnow	4.63	12 298[c]	1 745
C_{14} 4-ethylbiphenyl	Yakata et al. 2006 (cited in Lampi et al. 2010); carp	4.80	1 039	611
Cycloalkanes diaromatic*				
C_{12} acenaphthene	CITI 1992; Carp	3.92 (e)	979/1 003	122
C_{18} hexahydro terphenyl	EMBSI 2008c, 2009c; rainbow trout	6.44	1 646	713
Four-ring aromatics*				
C_{12} acenaphthylene	Yankata 2006; Carp	3.94 (e)	579/596	415
C_{13} fluorene	CITI 1992; Carp	4.18 (e)	672/780	698
C_{14} phenanthrene	Carlson et al. 1979; fathead minnow	4.46 (e)	2 927/3 546	1 096
C_{16} fluoranthene	EMBSI 2007b, 2009c; rainbow trout	5.16 (e)	435	560
C_{18} chrysene	EMBSI 2006b, 2009c; rainbow trout	5.81 (e)	153	2 010
C_{18} Triphenylene	JNITE; Carp	5.49 (e)	61	489

[a] Experimental BCFs from various sources.
[b] Modeled BCFs using BCFBAF (2008); BCF of a lower trophic fish were chosen to match the lipid content of fish in the Japanese database.
[c] C_{13} 2-iso-Propylnaphthalene: The only measured BCF found >5000 out of the thirty-one data points; it is greater than the modeled value by an order of magnitude.

Table A3.8. Empirical data for aquatic toxicity of CAS RN 64741-80-6 (EMBSI 2008a, b, c)

Species	**Test**	**Concentration (mg/L) 68471-80-6**
Pseudokirchneriella subcapitata (green alga)	EL_{50} 72-hour reduction in growth rate	>107

Daphnia magna (water flea)	EL_{50} 48-hour immobilization	>95
Oncorhynchus mykiss (rainbow trout)	LL_{50} 96-hour lethality	>98

EL_{50}: The loading concentration of a substance that is estimated to cause some toxic sublethal effect on 50% of test organisms.

LL_{50}: The loading concentration of a substance that is estimated to be lethal to 50% of test organisms.

Table A3.9. Modelled acute LL_{50} data for aquatic toxicity (PetroTox 2009)

Test organism	Common name	LL_{50} (mg/L)			
		64741-45-3 >C_{20}	68333-22-2 >C_{11}	68478-17-1 >C_{13}	64741-80-6 C_{21}-C_{50}
Daphnia magna	Water flea	1.0	0.8	0.8	18.6
Oncorhynchus mykiss	Rainbow trout	0.5	0.4	0.4	0.6
Pseudokirchneriella capricornutum	Green alga	>1000	7.4	7.8	2.3
Rhepoxynius abronius	Marine amphipod	0.2	0.2	0.1	0.1
Palaemonetes pugio	Grass shrimp	0.5	0.3	0.3	0.4
Menidia beryllina	Inland silverside	3.1	3.0	2.72	>1000
Neanthes arenaceodentata	Marine worm	1.7	1.5	1.41	>1000
		68333-27-7 C_{11}–C_{30}	64741-61-3 C_{15}–C_{35}	68476-32-4 No data	
Daphnia magna	Water flea	0.7	1		
Oncorhynchus mykiss	Rainbow trout	0.2	0.2		
Pseudokirchneriella capricornutum	Green alga	0.5	0.6		
Rhepoxynius	Marine	0.1	0.1		

		LL_{50} (mg/L)			
abronius	amphipod				
Palaemonetes pugio	Grass shrimp	0.1	0.2		
Menidia beryllina	Inland silverside	>1000	>1000		
Neanthes arenaceodentata	Marine worm	4.1	7.6		

Table A3.10. Aquatic toxicity of Fuel Oil No. 6 (Bunker C)

Test organism	Common name	Type of test	Endpoint	Type	Value (mg/L)	Reference
Fish						
Cyprinodon varieganus	Sheepshead minnow	Acute (48 hours)	LC_{50}	Water soluble fraction (WSF)	4.4	Anderson et al. 1974
Menidia beryllina	Inland silverside	Acute (48 hours)	LC_{50}	WSF	2.7	Anderson et al. 1974
Menidia beryllina	Inland silverside	Acute (96 hours)	LC_{50}	Dispersion sea water	130	ECB 2000c
Fundulus similus	Longnose killifish	Acute (48 hours)	LC_{50}	WSF	2.27	Anderson et al. 1974
Invertebrates						
Daphnia magna	Water flea	Acute (48 hours)	LC_{50}	WSF	>4.45	MacLean and Doe 1989
		Acute (48 hours)	LC_{50}	WSF	>0.4	EETD 1989
Artemia spp.	Brine shrimp	Acute (48 hours)	LC_{50}	WSF	>2.29	MacLean and Doe 1989
		Acute (48 hours)	LC_{50}	WSF	>0.32	EETD 1989
Palaemonetes pugio	Grass shrimp	Acute (48 hours)	LC_{50}	WSF	2.8	Anderson et al. 1974
Mysidopsis almyra	Mysid shrimp	Acute (48 hours)	LC_{50}	WSF	0.9	Anderson et al. 1974
Neanthes arenaceodentata	Marine worm	Acute (48 hours)	LC_{50}	WSF	4.6	Rossi et al. 1976
		Acute (48 hours)	LC_{50}	WSF	1.1	Rossi et al. 1976

Table A3.11. Atmospheric degradation of representative structures via reaction with hydroxyl radicals (AOPWin 2008).

	Half-life (days)
	OH•
Alkanes	
C_9	1.1
C_{15}	1
C_{20}	0.4
C_{30}	0.3
C_{50}	0.2
Isoalkanes	
C_9	1.1
C_{15}	0.6
C_{20}	0.4
C_{30}	0.3
C_{50}	0.2
One-ring cycloalkanes	
C_9	0.8
C_{15}	0.5
C_{20}	0.4
C_{30}	0.2
C_{50}	0.2
Two-ring cycloalkanes	
C_9	0.8
C_{15}	0.4
C_{20}	0.3
C_{30}	0.2
C_{50}	0.1
Polycycloalkanes	
C_{14}	0.4
C_{18}	0.3
C_{22}	0.2
One-ring aromatics	
C_9	1.4
C_{15}	0.7
C_{20}	0.5
C_{30}	0.3
C_{50}	0.2
Cycloalkanes monoaromatic	
C_{10}	0.3
C_{15}	0.5
C_{20}	0.3

	Half-life (days)
	OH•
Two-ring aromatics	
C_{15}	0.2
C_{20}	0.2
C_{30}	0.1
C_{50}	0.1
Cycloalkanes diaromatic	
C_{12}	0.2
C_{15}	0.6
C_{20}	0.5
Three-ring PAHs	
C_{15}	0.3
C_{20}	0.3
C_{30}	0.2
C_{50}	0.1
Four-ring PAHs	
C_{16}	0.4
C_{20}	0.2
Five-ring PAHs	
C_{20}	0.2
C_{30}	0.1
Six-ring PAHs	
C_{22}	0.1

Appendix 4. Summary of Health Effects Information from Pooled Toxicological Data for HFO Substances

Endpoint	CAS RN[1]	Effect level[2]/Result
Acute toxicity	**64741-45-3**	**Oral LD_{50}** (rat): >5000 mg/kg-bw (both sexes) for sample F-132 (API 2004).
	64741-62-4 68553-00-4	**Lowest Oral LD_{50}** (rat): 4320 mg/kg-bw (females) for sample API 81-15 and 5130 mg/kg-bw (both sexes) for sample API 79-2 (CONCAWE 1998; API 2004; ECB 2000a). **Other Oral LD_{50}s** (rat): >2000 mg/kg-bw to >25 000 mg/kg-bw (both sexes) for six CAS RNs tested (CONCAWE 1998; ECB 2000a; API 2004; US EPA 2005).
	64741-45-3	**Dermal LD_{50}** (rabbit): >2000 mg/kg-bw (both sexes) for sample F-132 (API 2004). **Other Dermal LD_{50}s** (rabbit): >2000 to >5350 mg/kg-bw (both sexes) for five CAS RNs tested (CONCAWE 1998; ECB 2000a; API 2004).
	64741-62-4	**Other Dermal LD_{50}** (rat): >2000 mg/kg-bw (both sexes) (ECB 2000a).
	64741-90-1	**Inhalation LC_{50}** (rat): >3700 mg/m^3 (both sexes) (US EPA 2005).
Short-term repeated-dose toxicity	**64741-45-3**	**Dermal LOAEL** = 1000 mg/kg-bw per day for decreased maternal body weight. Doses of 50, 333 or 1000 mg/kg-bw per day were applied to the shorn dorsal skin of pregnant Sprague-Dawley rats (12 per dose) from gestational days 0 to 20 (UBTL 1994). **Other Dermal Study**: Male and female Sprague-Dawley rats (10 per sex per dose) were treated with 0.01, 0.25 or 1.0 mL/kg-bw per day (9 231 or 928 mg/kg-bw per day), 5 times per week for 4 weeks. Trace to mild acanthosis and trace to moderate hyperkeratosis was observed at 928 mg/kg-bw per day. No systemic effects were observed (UBTL 1990).
	64741-62-4	**Lowest Dermal LOAEL** = 1 mg/kg-bw per day for dose-related decreases in gravid uterine weight, maternal body weight, body weight gain and feed consumption, as well as the occurrence of red vaginal exudates. Doses of 0.05, 1.0, 10, 50 or 250 mg/kg-bw per day were applied to the clipped skin of pregnant CD rats from gestational days 0 to 19 (Hoberman et al. 1995). **Other Dermal LOAELs:** 8 mg/kg-bw (every other day) for aberrant serum chemistry. Doses of 8, 30, 125 or 500 mg/kg-bw per day or 4, 30, 125 or 500 mg/kg-bw per day were applied to the shaved backs of pregnant Sprague-Dawley rats (15 per dose) from gestational days 0 to 19 (the 4 mg/kg-bw per day dose was given as 8 mg/kg-bw every other day). Decreased body weight gain and food consumption were also observed at 8 mg/kg-bw per day (every other day) (Mobil 1990; Feuston et al. 1997). 200 mg/kg-bw per day for liver enlargement (females), and 2000 mg/kg-bw per day for liver enlargement and pathological changes in the liver (males), changes in the lymphoid organs, and slight to severe hypocellularity in the bone marrow. Doses of 200, 1000 or 2000 mg/kg-bw per day were applied to the skin of male and female Fischer 344 rats (5 per sex per dose), 3 times per week for 28 days. One treatment-related death was observed at 1000 mg/kg-bw per day and two treatment-related deaths were observed at 2000 mg/kg-bw per day (API 1983).

	64741-81-7	8 mg/kg-bw per day for decreased thymus weight (relative and absolute), increased liver weight (relative) and skin irritation. Doses of 8, 30, 125 or 250 mg/kg-bw per day were applied to the shaved backs of pregnant Sprague-Dawley rats (15 per dose) from gestational days 0 to 19. Altered haematology parameters and aberrant serum chemistry at an unspecified dose, as well as dose-related skin irritation were observed. Red vaginal discharge, paleness and emaciation were observed at 30 mg/kg-bw per day. Moribundity was observed at 250 mg/kg-bw per day (Mobil 1994a).
	64742-90-1	**Inhalation LOAEC** = 540 mg/m^3 for a concentration-related decrease in body weight (more severe in males) and an increase in liver weight (females). Concentrations of 540 or 2000 mg/m^3 were administered to male and female Fischer 344 rats (5 per sex per dose), 6 hours per day for 9 days. A concentration-related increase in hair loss, nasal discharge, discharge from the eyes, eyes closed and perianal soiling was observed. Yellow discolouration of the lungs and hyperplasia of the pulmonary alveolar macrophages were also observed at all concentrations. Increased liver (male and female) and lung weights (female) and decreased spleen (male and female) and heart weights (male) were observed at 2000 mg/m^3 (Gordon 1983).
	64741-62-4	**Oral LOAEL:** ≥125 mg/kg for maternal toxicity. A single dose of 2000 mg/kg or single doses of 125, 500 or 2000 mg/kg were administered to pregnant Sprague-Dawley rats (presumably via gavage) on one of gestational days 11–15 (profile of teratogenic effects as a function of gestation day) or gestational day 12 (profile of teratogenic effects as a function of dose), respectively. Two separate studies used two different samples for each study. (1) General observations (≥500 mg/kg): Red vaginal discharge, perineal staining and decreased stool. (2) Teratogenic effects versus gestation day (2000 mg/kg): Decreased body weight gain and thymus weight (regardless of exposure day). (3) Teratogenic effects versus dose (125, 500, 2000 mg/kg): Dose-related decrease in body weight gain and thymus weight (Feuston and Mackerer 1996).
Subchronic toxicity	64741-62-4	**Lowest Dermal LOAELs:** 8 mg/kg-bw per day for a significant reduction in platelet count, and 30 mg/kg-bw per day (male) and 125 mg/kg-bw per day (female) for dose-related reductions in red blood cell, haemoglobin and haematocrit counts, dose-related decrease in thymus weight, as well as increased mortality (20% males and 80% females). Doses of 8, 30, 125 or 500 mg/kg-bw per day were applied to the shaved backs of male and female Sprague-Dawley rats (10/sex/dose), 5 times per week for 13 weeks. Dose-related increases in liver weight and decreases in platelet count were also observed at 30 mg/kg-bw per day (male) and 125 mg/kg-bw per day (female). Decreased body weight gain was observed for both sexes at 125 mg/kg-bw per day. All male and female rats died at 125 mg/kg-bw per day and 500 mg/kg-bw per day, respectively (Feuston et al. 1997; Mobil 1988). 8 mg/kg-bw per day for increased relative liver weight (male and female) and increased absolute liver weight (female). Doses of 8, 30, 125, 500, or 2000 mg/kg-bw per day were applied to the shorn backs of male and female Sprague-Dawley rats, 5 times per week for 13 weeks. Increased mortality, decreased body weights, decreased thymus weight and aberrant serum chemistry and haematology were also observed at unspecified doses (Feuston et al. 1994).
	64741-81-7	8 mg/kg-bw per day for moderate skin irritation (dose-related) and 30 mg/kg-bw per day for altered serum chemistry. Doses of 8, 30 or 125 mg/kg-bw per day were applied to the shaved backs of male and female Sprague-Dawley rats (10/sex/dose), 5

		times per week for 13 weeks. Altered haematology parameters and decreased thymus weight (relative and absolute) were also observed at 30 mg/kg-bw per day. Decreased body weight gain (males), as well as increased liver weight (relative and absolute) and a decreased number of lymphoid cells in the thymus were observed at 125 mg/kg-bw per day (Mobil 1994b).
	68783-08-4	**Other Dermal LOAEL** = 125 mg/kg-bw per day for enlarged and reddened lymph nodes and thickening of the limiting ridge between the non-glandular and glandular sections of the stomach. Changes in a number of serum chemistry and haematological parameters, as well as increased liver and decreased thymus sizes, were also observed at 125 mg/kg-bw per day. At 500 mg/kg-bw per day observed effects included decreased body weight gain (males), a reduction in haematopoiesis in the bone marrow and in the number of lymphocytes in the thymus glands, liver hypertrophy and connective tissue formation, and increased areas of haematopoiesis, focal necrosis and individual cell death in the liver. Doses of 30, 125 or 500 mg/kg-bw per day were applied to male and female Sprague-Dawley rats (10/group), 5 times per week for 13 weeks. Slight skin irritation was observed at all doses (Mobil 1992).
Carcinogenicity	**64741-61-3**	**Dermal Study:** Groups of CD1 mice (25/sex) were treated with 714 mg/kg-bw (20mg)[3,4] of the test substance, 3 times per week for 18 months. Observed increase in tumour incidence (87% of observable masses were skin tumours, 86% of which were benign papillomas; squamous cell carcinomas were also present) (Sun Petroleum Products Co. 1979). A group of female Swiss mice (100 mice) were treated with 800 mg/kg-bw (20mg)[3,4] of the test substance, 3 times per week for 18 months. A significant increase in tumour incidence was observed in exposed mice (43 squamous cell carcinomas), as well as numerous less severe lesions (Sun Petroleum Products Co. 1979).
	64741-80-6	**Dermal Study:** Groups of male C3H mice (10-30/group) were treated with 1563 or 3125 mg/kg-bw (50 or 100mg)[3,4] of the higher-boiling fractions of [31], 1, 2 or 3 times per week for 18 months or until cancer was grossly observed (exact details not provided). High numbers of skin tumours were observed (exact results not provided). No correlation between distillation range, benzo(a)pyrene content, tumour incidence or time to first tumour appearance could be demonstrated (Lewis 1983).
	64741-45-3 and **64741-80-6**	**Dermal Study:** Groups of C3H mice (19-40/group) were treated with 714 or 1876 mg/kg-bw (20 or 50mg)[3,4] of the test substance, twice per week (duration not specified). Exposure to 20 mg of Mixture 1 (100% atm. tower residue/0% cracked residue) resulted in 1/19 and 1/19 mice developing malignant and benign skin tumours, respectively (final effective number[5] was 17 mice). Exposure to 50 mg of Mixture 1 resulted in 3/20 and 7/20 mice developing malignant and benign skin tumours, respectively with a latency period of 58.8 weeks (final effective number was 17 mice). Exposure to 20 mg of Mixture 2 (95% atm. tower residue/5% cracked residue) resulted in 15/30 and 8/30 mice developing malignant and benign skin tumours, respectively with a latency period of 41.5 weeks (final effective number was 27 mice). Exposure to 50 mg of Mixture 2 resulted in 13/30 and 8/30 mice developing malignant and benign skin tumours, respectively with a latency period of 28.3 weeks (final effective number was 27 mice). Exposure to 20 mg of Mixture 3 (90% atm. tower residue/10% cracked residue) resulted in 19/30 and 7/30 mice developing malignant and benign skin tumours, respectively with a latency period of 40.4 weeks (final effective number was 26 mice). Exposure to 50 mg of Mixture 3 resulted in 22/30 and 3/30 mice developing malignant and benign skin tumours, respectively with a latency period of 32.2 weeks (final effective number was 25 mice). Exposure to 20 mg of Mixture 4 (80% atm. tower residue / 20% cracked residue) resulted in 12/25 and 9/25 mice developing malignant and benign skin tumours, respectively with a latency period of 25.2 weeks (final effective number was 23 mice) (Bingham et al.

		1980).
	64741-62-4	**Lowest dermal effect level** = 8.4 mg/kg-bw (25µl of *CCCO* at 1%). Groups of male C3H mice (50/dose) were treated with 25µl of *CCCO* at 1, 2, 5, 10 and 20% (8.4, 16.8, 42, 83.8, 167.6 mg/kg-bw)[4,6,7,8] in mineral oil, 3 times per week for a lifetime. At 1%, 9/50 exposed mice developed tumours (4 carcinomas, 5 papillomas). At 2%, 34/50 exposed mice developed tumours (30 carcinomas, 4 papillomas with a latency period of 92 weeks). At 5%, 46/50 exposed mice developed tumours (46 carcinomas with a latency period of 61 weeks). At 10%, 48/50 exposed mice developed tumours (47 carcinomas, 1 papilloma with a latency period of 45 weeks). At 20%, 50/50 exposed mice developed tumours (50 carcinomas with a latency period of 36 weeks). Of the 610 mice tested with the negative control (highly refined mineral oil) only two mice developed benign papillomas (none developed carcinomas) (McKee et al. 1990). **Initiation/Promotion Dermal Study**: *Initiation*: Groups of male CD mice (30/group) were treated with 16.8 mg/kg-bw (50µl of *CCCO* at 1%)[4,6,8] in toluene, once/day for 5 consecutive days. After a 2-week rest period, the promoter phorbol-12-myristate-13-acetate (PMA) was applied twice per week, for 25 weeks. Observed significant increase in skin tumours incidence (26/30 exposed mice developed tumours after 16 days). Promotion: Details of study design not provided. Observed no increase in histologically confirmed tumour incidence. However, observed statistically significant increase in the number of mice with grossly observed masses and shortened latency time. Suggests possible weak promoting activity (API 1989a).
Developmental and reproductive toxicity	**64741-45-3**	**Dermal Reproductive NOAEL (male)** = 928 mg/kg-bw per day for testicular parameters. Doses of 0.01, 0.25 or 1 mL/kg per day (9, 231 or 928 mg/kg-bw per day) were applied to male Sprague-Dawley rats, 5 times per week for 4 weeks (UBTL 1990). **Dermal Developmental LOAEL** = 1000 mg/kg-bw per day for increased gestation length and decreased pup body weight. Doses of 50, 333 or 1000 mg/kg-bw per day were applied to the shorn dorsal skin of pregnant Sprague-Dawley rats for gestational days 0-20 (UBTL 1994).
	64741-62-4	**Dermal reproductive LOAEL (female) =** 1 mg/kg-bw per day for decreased number of live foetuses, increased incidence of resorptions, early resorptions and the percentage of dead or resorbed conceptuses per litter (these effects were all dose-related and were observed at doses that were maternally toxic). At 1 mg/kg-bw per day an increased incidence in foetal variations associated with a decrease in foetal body weight was observed, including slight dilation of the lateral ventricles of the brain, moderate dilation of the renal pelvis, bifid thoracic vertebral centrum and decreased average number of ossified caudal vertebrae, metacarpals and hindpaw phalanges (these effects were noted to be reversible delays in development). Doses of 0.05, 1.0, 10, 50 or 250 mg/kg-bw per day were applied to the clipped skin of pregnant CD rats from gestational days 0–19 (Hoberman et al. 1995). **Lowest dermal developmental LOAEL =** 8 mg/kg-bw for foetal external abnormalities. Doses of 4, 8, 30, 125 or 250 mg/kg-bw per day were applied to the shaved backs of pregnant Sprague-Dawley rats (10 per dose) for gestational days 0–19 (4 mg/kg-bw dose given as 8 mg/kg-bw every other day). At 8 mg/kg-bw per day external abnormalities in living and dead foetuses, including cleft palate, micrognathia (shortened lower jaw) and kinked tail, were observed (these effects were noted to occur at low incidences). An increased incidence of resorptions, decreased number of viable offspring, reduced fetal size, visceral anomalies and skeletal variations were observed at 30 mg/kg-bw per day. There were no viable foetuses at 250 mg/ kg-bw per day (Feuston et al. 1989; Mobil 1987c).

		Other dermal studies: Doses of 4, 8, 30, 125 or 500 mg/kg-bw per day were applied to the shaved backs of pregnant Sprague-Dawley rats (15 per dose) from gestational days 0–19 (4 mg/kg-bw per day dose was administered as 8 mg/kg-bw every other day). At 8 mg/kg-bw per day an increased incidence of resorptions and a decreased number of viable foetuses was observed (biologically significant). At 30 mg/kg-bw per day a statistically significant increased incidence of resorptions was observed, as well as decreased foetal body weight. An increased incidence of foetal external, skeletal and visceral anomalies (primarily rib malformations and cleft palate) was observed at 500 mg/kg-bw per day (Mobil 1990; Feuston et al. 1997). **Other dermal studies:** Doses of 8, 30, 125 or 500 mg/kg-bw per day were applied to the shaved backs of male Sprague-Dawley rats (10 per dose), 5 times per week for 13 weeks. Decreased sperm count after 9 weeks of exposure was observed at 500 mg/kg-bw per day (Mobil 1988; Feuston et al. 1997). **Oral reproductive and developmental LOAEL =** ≥125 mg/kg for increased resorptions, decreased foetal body weight and increased incidence of skeletal malformations. Pregnant Sprague-Dawley rats were administered 2000 mg/kg on one of gestational days (GD) 11–14 (profile of teratogenic effects as a function of gestation day). Additionally, 125, 500 or 2000 mg/kg was administered to pregnant Sprague-Dawley rats on gestational day 12 (profile of teratogenic effects as a function of dose). Two separate studies using two different samples (clarified slurry oil and syntower bottoms) for each study. (1) Teratogenic effects versus gestation day (2000 mg/kg): The greatest incidence of resorptions/decreased litter size occurred on GDs 11-12. Foetal body weights were reduced on all GDs. The greatest incidence of foetal external anomalies and visceral malformations occurred on GDs 12-14 and 12-13, respectively. Various foetal skeletal malformations occurred on all GDs. (2) Teratogenic effects versus dose (125, 500, 2000 mg/kg): Dose-related response for increased resorptions, decreased litter size, decreased foetal body weight and increased incidence of foetal skeletal malformations. A variety of foetal external anomalies were also observed at 2000 mg/kg (Feuston and Mackerer 1996).
Genotoxicity – *in vivo*	64741-90-1	**Positive for Micronuclei Induction (Oral LOAEL)** = 1250 mg/kg-bw (males) and 5000 mg/kg-bw (females). Groups of male and female CD Swiss mice (10/sex/dose) were administered 1250, 2500 or 5000 mg/kg-bw of aromatic pyrolysis oil, via oral gavage, for 2 days. One group of mice (15/sex/dose) was administered 5000 mg/kg-bw, via oral gavage, as a single dose. A significant increase in micronucleated polychromatic erythrocytes was observed (Khan and Goode 1984).
	64741-62-4	**Positive for Sister Chromatid Exchange (i.p. injection LOAEL)** = 2000 mg/kg-bw (males) and 4000 mg/kg-bw (females). Groups of male and female B6C3F1 mice (5/sex/dose) were administered a single dose of 400, 2000 or 4000 mg/kg-bw of API 81-15, via intraperitoneal injection. A small but significant increase in SCEs/metaphase was observed in bone marrow cells. The response was also dose-related (API 1985b). **Positive for Unscheduled DNA Synthesis (Oral LOAEL)** = 200 mg/kg-bw (after 12 hours) and 1000 mg/kg-bw (after 2 hours). Groups of male Fischer 344 rats (3/dose) were administered 50, 200 or 1000 mg/kg-bw of API 81-15, via oral gavage, at 2 and 12 hours. A significant increase in UDS was observed in primary hepatocyte cultures (API 1985a). **Negative for Chromosomal Aberrations (i.p. injection NOAEL)** = 1000 mg/kg-bw

		per day. Groups of male and female Sprague-Dawley rats (11/sex/dose) were administered 100, 300 or 1000 mg/kg-bw per day of API 81-15, via intraperitoneal injection, for 5 days. No increase in the frequency of aberrations in bone marrow cells and no increase in the mitotic index were observed (API 1985c).
	64741-57-7	**Negative for Micronuclei Induction (Dermal NOAEL)** = 2000 mg/kg-bw. Groups of male and female rats (10/sex/dose) were exposed dermally to 30, 125, 500 or 2000 mg/kg-bw per day, 5 days per week for 13 weeks. No increase in the frequency of micronuclei induction in bone marrow cells was observed (Mobil 1987a).
Genotoxicity – *in vitro*	**64741-61-3** and 64741-62-4	**Positive for Mutagenicity (reverse mutations)**: *S. typhimurium* TA98 was exposed to DMSO extracts at doses of 0.5, 1, 2.5, 5 or 10 µL/plate, with S9 metabolic activation (Aroclor 1254-induced rat liver). A dose-related increase in mutagenic potency was observed and a mutagenicity index of 130 was determined (Blackburn et al. 1984). Additionally, *S. typhimurium* TA98 was exposed to DMSO extracts (dissolved in cyclohexane) at doses of 0.5, 1, 1.5, 2 or 5 µL/plate, with S9 metabolic activation (Aroclor 1254-induced Syrian golden hamster liver). A dose-related increase in mutagenic potency was observed and a mutagenic index of ~58 was determined (Blackburn et al. 1986).
	64742-90-1	**Positive for Unscheduled DNA Synthesis**: Primary rat hepatocyte cultures derived from F-344 male rat liver were exposed to ethanol dilutions of aromatic pyrolysis oil at doses of 0.5, 2, 10 or 60 µg/mL for 18-20 hours (without S9 metabolic activation). Dose-response observed for UDS at ≥2 µg/mL (Brecher and Goode 1984). **Positive for Cell Transformation**: BALB/3T3-A31-1-1 mouse embryo cells exposed to ethanol dilutions of aromatic pyrolysis oil at doses of 8, 16, 32, 64, 128 or 256 µg/mL for 2 days (without S9 metabolic activation). Borderline positive response observed at ≥128 µg/mL and inconsistent responses observed at ≥8 µg/mL (Brecher and Goode 1983). **Ambiguous for Mutagenicity (forward mutations)**: Chinese hamster ovary cells exposed to ethanol dilutions of aromatic pyrolysis oil at doses of 32, 64, 96, 128, 175 or 256 µg/mL, without S9 metabolic activation and 128, 175, 256, 375, 512 or 750 µg/mL, with S9 metabolic activation. A repeat experiment was conducted at doses of 500, 600 or 750 µg/mL, with S9 metabolic activation. S9 was prepared from Aroclor-1254 induced rat liver. Reduced cell count was observed at all doses (±S9) and significant toxicity was observed at all doses (+S9). An increase in mutant frequency was observed at 750 µg/mL, with S9 metabolic activation, accompanied by a relatively linear dose-related response from the lower doses. No mutagenic effects were observed without S9 metabolic activation. In the repeat experiment, an increase in mutant frequency was observed at 500 µg/mL (higher doses were toxic) (Papciak and Goode 1984).
	64741-62-4	**Positive for Mutagenicity (Mouse Lymphoma assay)**: L5178Y cells exposed to API 81-15 at doses ranging from 1.95 to 31.3 nL/mL, for 4 hours, with and without S9 metabolic activation (rat liver). Toxicity was noted at all levels and survival was <10% at doses above 3.9 nL/mL. Without activation, the test substance was weakly positive at the highest concentration only. With activation, the test substance induced a dose-related increase in mutant frequency at doses >0.977 nL/mL (API 1985c). **Ambiguous for Sister Chromatid Exchange**: Chinese hamster ovary cells were exposed to the test substance at doses of 5-100 µg/mL, without S9 metabolic activation and 100-5000 µg/mL, with S9 metabolic activation. An increase in SCEs was observed with activation. No increase in SCEs observed without activation (API 1985f).

	64741-57-7	**Ambiguous for Cell Transformation**: BALB/3T3 mouse embryo cells exposed to the test substance at doses of 1, 3, 6 and 9 µg/mL, without S9 metabolic activation (for 3 days) and 10, 30, 100 and 300 µg/mL, with S9 metabolic activation (for 4 days). S9 was prepared from Aroclor-induced male rat liver. An increase in cellular transformation frequency was observed at 100 µg/mL after 4 hours, with activation. Low survival rates were observed at doses >100 µg/mL, with activation. No increase in morphological transformation without activation (API 1986b). **Negative for Cellular Aberrations (cytogenetic assay)**: Chinese hamster ovary cells exposed to the test substance at doses of 5, 8, 10, 12 or 15 µL/mL, with and without S9 metabolic activation (Mobil 1987b).
Human Studies		No studies were identified.

[1] Site-restricted HFO substances are indicated in bold.
[2] Abbreviations: 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.
[3] The following formula was used for conversion of provided values into mg/kg-bw*: x* ml/kg-bw × ρ.
[4] Body weight (bw) not provided, thus laboratory standards from Salem and Katz, Inhalation Toxicology, 2006 were used.
[5] Effective number = number of mice given adequate exposure minus number that died without a tumour (IARC 1989b).
[6] The following formula was used for conversion of provided values into mg/kg-bw: (% of dilution x *x* mL x ρ)/bw.
[7] Density not provided, thus a density from CONCAWE 1998 was used.
[8] A volume/volume dilution was assumed.